THE DEVELOPMENT OF A SAMPLING PROTOCOL FOR MONITORING FINE GRAINED SEDIMENTATION AT FOREST ROAD STREAM CROSSINGS

By

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Abstract

Forest harvesting activities, particularly road construction, are known to increase fine sediment (< 3.35mm) transport and storage in forest streams. Although increased levels of fine sediment storage are known to detrimentally affect all stream trophic levels, forest management is prescriptive in nature with limited field monitoring. This project involved the design and evaluation of a sampling protocol to assess fine sedimentation around stream crossing construction sites. The protocol includes the application of three fish habitat sampling techniques, namely the McNeil corer, gravel bucket, and infiltration bag. The McNeil core gathers information on bulk streambed composition, while gravel buckets capture sediment depositing on the streambed, and infiltration bags capture fine sediment that deposits on and flows through streambed interstices. These techniques are not compared but rather the sampling protocol is assessed through a review of the results from eight case studies. All case studies are within the Prince George Forest District and each was experiencing road construction activities. The protocol was effective in identifying significant increases in fine sediment storage downstream. A follow-up statistical evaluation to estimate sample numbers returned values that ranged between 4 and 1900 depending upon the ability to detect set levels of difference (i.e. 5 to 20%) 90% of the time. The protocol detected differences at the case study sites with six or less replicates per technique because their site differences far exceeded the 20% estimate used in the sample number calculation. This protocol is an effective monitoring tool and should be used to monitor forest road stream crossing construction and maintenance.

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Chapter 1 Introduction

1.0 Rationale

Over the last century anadromous salmon stocks of the Pacific Northwest have deteriorated from a pristine state to one experiencing extinction and uncertainty (Slaney *et al.,* 1996). This decrease in stocks is believed to have resulted from the continued degradation of habitat quality due to urbanization, industrial development, forest harvesting, and intensive fishing pressure from commercial and recreational angling.

Considerable resources have been invested in developing better methods for estimating the size of remaining fish stocks and restoring fish habitat previously damaged by forest development. In contrast, habitat quality assessment programs receive a comparatively small amount of resources. Specifically, there has been little monitoring of pristine areas or of the effects of forest harvesting on pristine fish habitat as *activities proceed.* Instead, long-term research studies are conducted that focus on determining the post-hoc effects of forestry on a basin's geomorphology, and hydrology. Although valuable, these studies differ from monitoring programs because they are retrospective and do not provide the information necessary to determine possible biological consequences before they happen.

Although forestry is one of the largest industries in British Columbia, there is little monitoring of its effect on watersheds. Rather, it is assumed that adherence to the British Columbia Forest Practices Code (FPC) will ensure that water quality, water quantity, and fish populations are protected. However, FPC effectiveness has not been assessed through environmental monitoring. Instead, monitoring efforts are concentrated on post-event environmental assessment studies, which are applied retroactively to assess environmental degradation caused by extreme events such as forestry induced debris torrents, road washouts, or landslides. Although the results of these studies may be used to modify management guidelines in regions similar to the area studied, the overall improvement of forest management activities is not a primary objective. Instead, these studies are applied to determine environmental damage so that an appropriate fine can be levied. Consequently, industry is often reluctant to participate in conducting these studies unless legislated to do so as part of their development plan.

Present legislation does not require forest companies to submit environmental impact statements (EIS) on how water quality and quantity levels will be altered in their development plans. EIS requires the developer to intensively monitor the environment prior to, during, and sometimes after development has occurred to show that they have maintained the environmental quality levels that were agreed upon with the regulatory agency and included in their development permits. In the absence of this type of monitoring, efforts have been focussed on post-event assessment studies but these do not ensure that the forest resource is managed sustainably.

Forest harvesting activities can alter stream temperature, nutrient, metal, pesticide, pH, and dissolved oxygen levels, as well as channel morphology (MacDonald *et al.*, 1991). Of these, channel morphology changes are the most readily observed and they may have the most severe biological consequences. The alteration of channel morphology includes changes in pool size, riffle stability, woody debris levels, and the sediment transport regime.

Forestry and fishery interaction research programs have been implemented in several areas of British Columbia including Carnation Creek, Takla Lake, and the Queen Charlotte Islands. These studies as well as others nationally and internationally have shown that forest harvesting can negatively affect stream hydrology, morphology, and all levels of a stream's trophic structure (Waters 1995, Hogan *et al.* 1998, Culp *et al.* 1986, Anderson *et al.* 1996, Nakamoto 1998). Although there are many similarities among watershed response to forestry, there are differences. For example, Tripp (1998) found that poor harvesting practices on coastal British Columbia affected 7.5 times more stream area than poor road practices. Huntington (1996) demonstrated that in the Clearwater River watershed of Idaho, roads were the cause of increased fine sediment accumulation within the streambed, which reduced salmonid production. The diversity in response to harvesting activities emphasizes the need for increased monitoring, however the number of active monitoring programs is far exceeded by the number of watersheds opened to forest development.

1.1 Sediment Transport and Forestry Effects

Streams transport organic and inorganic material and although each plays an important role in streambed morphology this thesis focuses on sediment, the inorganic fraction.

Sediment is a general term referring to all inorganic material within the stream ranging from silt to boulders, it is:

> The insoluble products of rock weathering, when moved by water are generally called sediment. The source of sediment is, of course, the rocks that occur on the continental surface. Denudation, or lowering of the land surface by erosion, results from a number of processes, including solution, erosion, and transport by water... (Leopold 1994, 183)

A stream's sediment load is composed of two fractions, namely suspended load and bedload. Suspended load refers to material that remains in suspension within the water column (Leopold, 1997). Typically, this includes finer material such as silt, clay, and fine sand. In contrast, bedload is composed of heavier grains that cannot remain in suspension but are periodically lifted and dropped in the downstream direction (Leopold, 1994). This mode of transport is often referred to as saltation. Particles that are too large to saltate may instead be pushed in the downstream direction so that they slide along the immobile bed surface (Leopold, 1997). Sediment transport levels vary between watersheds because of differences in basin geology, soil infiltration capacity, vegetative cover, stream power, and climate (Brooks *et al.*, 1991).

The sediment load, which is that amount of sediment passing one point within a watershed, is not equal to the rate of upstream erosion. Approximately 25% of sediment entering a stream escapes the watershed, indicating that 75% is stored throughout the basin in transitional storage areas or depositional zones including the floodplain (Leopold, 1997). For example, sediment eroded from the inside bend of one streambank is often stored a short distance downstream on the outside bend of another (Leopold, 1994). Although streambed composition is dynamic, forest harvesting activities can alter the fine sediment concentration, where fine sediment is defined as having an intermediate axis less than 3.35mm, beyond natural levels. Significant increases in fine sediment can deteriorate fish habitat, particularly in spawning areas (Bjornn and Reiser. 1991).

Forest harvesting activities can increase stream sediment loads by initiating debris torrents, (Tripp and Poulin, 1986 and 1992), increasing the number of landslides and stream bank erosion (Roberts, 1987), and increasing surface erosion and delivery to the channel (Lewis 1998 and Corner *et al.* 1996) (Fig. 1.1). Although harvesting activities and harvested areas can act as sediment sources and at times initiate mass movement, the majority of studies have focussed on road construction and use.

Beschta (1978) found a 150% increase in sediment load following road construction in Oregon's Alsea watershed. Bilby *et al.* (1989) determined that sediment generation was dependent upon traffic. Further, they found that of 2000 surveyed road drainage points within four watersheds, 34% drained directly into streams that were predominantly first and second order systems. In the Clearwater River watershed, roads were found to contribute as much sediment as landslides (Cederholm *et al.*, 1981). Burns (1970) indicated that sediment loads in a harvested California basin were greatest during the road construction period although they were sustained for several years with continued harvesting.

Forest road generated sediment can be transported along the road's surface in rivulets or along its ditches. While there is a storage and transport regime within these systems, the focus of this thesis is sediment delivery to the stream and this is most obvious where streams and roads meet, at crossings. Stream crossings were selected because of their consistent reference in the literature and the ease in designating them as a point source for increased sediment levels downstream.

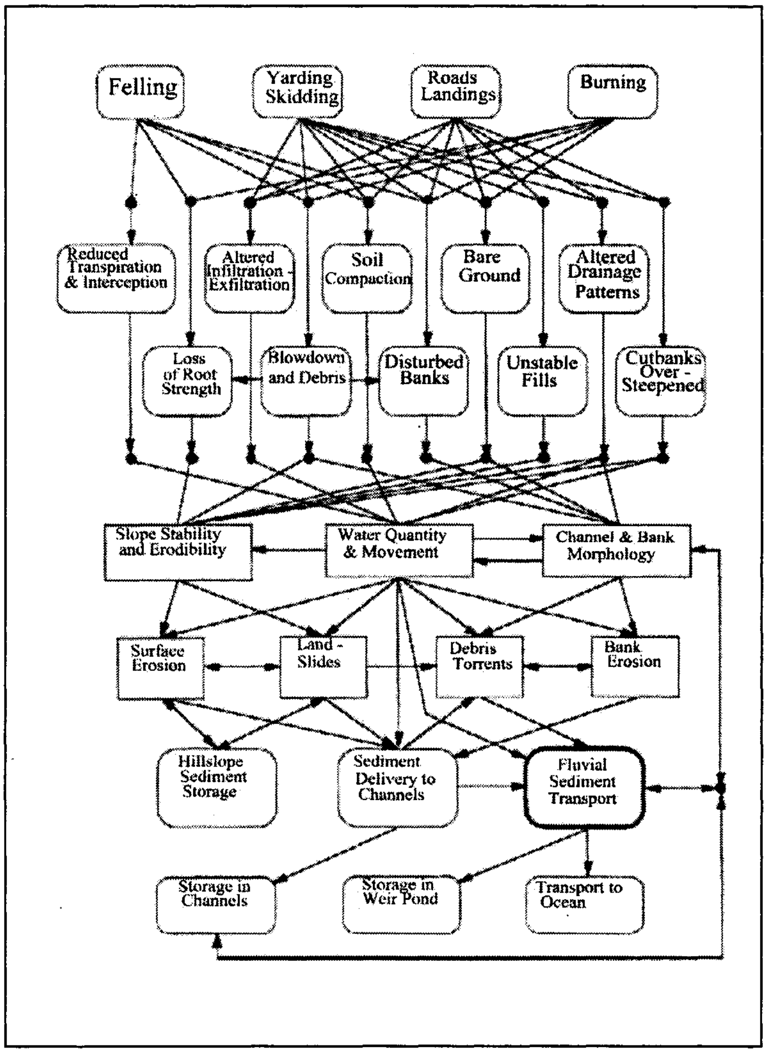

Figure 1.1: Forest harvesting activities and their potential effects on increased erosion and sediment delivery to streams (From Lewis, 1998).

1.2 Sediment Effects on Biological Communities

Sediment yield information is important for resource managers because of the detrimental effect that increased storage can have on all levels of stream biology. An increase in sedimentation levels above typical background concentrations can negatively effect primary producers, invertebrates, and fish (Waters, 1995).

1.2.1 Primary Producers

Aquatic primary producers range in size from the easily visible macrophytes such as Canadian pond weed, *Elodea canadensis,* to the barely visible periphyton such as the diatom *Navicula.* While macrophytes often adhere to the streambed via roots, periphyton may attach to rocks, sand, or plants with gelatinous stalks (South and Whittick, 1987).

Regardless of their size, all aquatic plants can be affected by increases in fluvial sediment loads. Sediment can affect plants by reducing light penetration through light reflection and absorption in the water column or by settling atop benthic forms. This decrease in light lowers the photosynthetic capability and organic content of plant cells. Further, sediment can damage plants through direct contact and if it deposits in high concentrations it can prevent attachment or may smother them (Wood and Armitage 1997, Waters 1995, Newcombe and MacDonald 1991).

Davies-Colley *et al.* (1992) noted that clay additions downstream of placer mining operations reduced the photosynthetic active radiation (PAR) depth in streams, which in turn reduced periphyton productivity. Further, they found that periphyton biomass decreased upon exposure to placer runoff and that remaining biomass had a high clay content, which made it a poor food source for stream invertebrates. King and Ball (1967) noted that road construction activities and sediment additions resulted in a 68% decrease in the streams periphyton community. Brookes (1988) found that stands of the macrophyte *Ranunculus sp.* were smothered downstream of a channelization project during low flow because these species could not alter their rooting depth.

1.2.2 Benthic Invertebrates

Benthic invertebrates form the next few trophic levels above primary producers, their functional feeding groups range from the herbivorous scrapers to the carnivorous piercers (Peckarsky *et al.*, 1990). While herbivorous invertebrates are affected by the reduced food quality of clay laden periphyton, the following discussion focuses on the direct effects experienced by all invertebrates. These include the alteration of substrate composition, instigation of drift due to deposition or saltation, decreased respiratory rates due to sediments depositing on respiratory structures, feeding behaviour alterations, and direct mortality of immobile life stages (Rutherford and MacKay 1986, Wood and Armitage, 1997).

A stream's benthic invertebrate community structure and density is strongly associated with the streambed substrate. Initially, it was believed that invertebrate diversity increased with increasing substrate size. This has been shown to be only true for the surface dwelling Ephemeroptera, Plecoptera, and Trichoptera (EPT) groups (Waters, 1995). Invertebrate community structure is positively affected by increased concentrations of stream detritus, which can increase oxygen exchange and act as a food source (Culp *et al.*, 1983). So, attempts to define community structure must consider streambed substrate composition as well as hydrology.

Fine sediment deposition on the streambed can clog interstitial streambed spaces, which may reduce interstitial oxygen levels. Further, it can restrict the size of depositing detritus (Culp *et al.*, 1986). This alteration of the benthic environment can induce an escape or drift response from those organisms unable to cope with the change. Saltating sediments can also increase drift upon contact with surface dwelling invertebrates (Quinn *et al.*, 1992). Culp *et al.* (1986) noted that during their controlled addition of sands to a surveyed stream channel, the invertebrate population was reduced by more than 50% within 24 hours of sand exposure as a result of catastrophic drift.

Eriksen (1966) noted physiological differences between two mayfly species that defined their habitat preference. One species had inefficient gills at low oxygen levels and preferred large substrate where water flow was unrestricted. The other had highly efficient gills at low oxygen levels and was commonly found in silt deposits. Presumably then, an increase in fine sedimentation in an area dominated by the species with inefficient gills could result in a shift from that species to the one capable of inhabiting depositional areas. Further, expanding this to an order level, it is possible that sustained concentrations of increased sedimentation could cause shifts from surface dwelling EPT groups to depositional zone species such as chironomids.

Finally, invertebrate feeding behaviour alteration and direct mortalities can occur if sediment concentrations are sufficiently high. Filter feeders will not be able to effectively capture prey items in high concentrations of sediment (Waters, 1995). Immobile life stages such as pupae obviously cannot drift yet they require flowing water for oxygen exchange, so where sediment deposits are thick exposed pupae may suffocate (Rutherford and MacKay, 1986).

Although invertebrate communities can be affected in several manners, it is important to recognize that exposure duration is equally important to the concentration of fine sediment (Rosenberg and Wiens, 1978). Most of the aforementioned studies determined that community structure and density often returned to pre-disturbance levels once the sediment wave had passed through the sample area. So, extreme but temporally short events such as a road washout may be less damaging than chronic sediment sources that are not as visibly extreme such as increased erosion from riparian or fire areas (Minshall *et al.*, 2001).

1.2.3 Fish

Although there have been studies of sediment effects on several fish species, the vast majority of them have focused on the salmonids. Generally, fish can be affected at the behavioural and physiological levels (Waters, 1995). Behavioural responses are the first observable reactions to increased sediment and are also the most transitory. They are often a response to increased suspended sediments and include avoidance and increased cough frequency (Anderson *et al.*, 1996). Physiological responses are dependent upon life stage and the type of sediment encountered, suspended or depositing. This thesis focuses on sedimentation so only those potential effects are discussed.

Excess sedimentation can affect fish populations by reducing habitat and directly affect individuals through increased egg mortalities and reduced fry emergence. Habitat alteration through increased sedimentation can result in a reduction of fish food resource and over-wintering sites due to in-filling of pools, as well as the alteration of spawning gravels (Waters 1995, Anderson *et al.* 1996, Wood and Armitage 1997). Further, increased bedload transport may result in deep scour or fill which can remove or bury eggs and fry (Montgomery *et al.*, 1996).

Scrivner and Brownlee (1989) documented a 50% decrease in coho (*Oncorhynchus kisutch)* and chum salmon (*O. keta)* populations of Carnation Creek following harvesting. They attribute this to high levels of fine gravel and sand transport resulting from increased streambank erosion and removal of large organic debris dams. Specifically, they noted that sands formed an impermeable layer within the streambed at varying depths depending upon previous storm flows. They postulated that these layers of sand isolated salmon redds and prevented efficient oxygen exchange or fry emergence.

Excess sedimentation has been consistently shown to affect fish communities but the biologically active grain size varies between studies. McNeil and Ahnell (1964) determined that spawning success of pink salmon (*O. gorbuscha)* was inversely proportional to streambed permeability and the concentration of medium to fine sands and smaller (less than 0.833mm). Others have reported similar findings but focussed on grain sizes ranging between 0.25 and 6.4mm (Chapman 1988. Lisle 1989, Platts *et al.* 1989, Reiser and White 1988, Phillips *et al.* 1975).

The findings of these studies have been incorporated into environmental protection legislation at the provincial level. A search of sediment criteria in Canada determined that there were none proposed for Manitoba, Ontario, Nova Scotia, or federally. When this project was initiated, the British Columbia criterion for fine sediment was 3.35 mm. That is, no streamside activities were to increase background concentration of sediments below this diameter within the streambed (Singleton, 1985). In 1999, these criteria were amended and now state that streambeds should not contain more than 10% of < 2 mm, 19% of < 3 mm, and 25% of <6.35 mm at salmonid spawning sites (Caux *et al.*, 1997). For example, road construction activities that increased baseline concentrations of the < 2mm fraction from 9% to 12% would be deemed to have degraded the site to unacceptable levels by the provincial authority.

1.3 Study Objective and Hypothesis

The objective of this thesis was to develop and evaluate a sampling protocol for the assessment of fine-grained sedimentation around forest road stream crossing construction and maintenance sites. It presents a sampling protocol that includes the application of three fish habitat sampling techniques, namely the McNeil corer, gravel bucket, and infiltration bag. These techniques are not compared but rather the sampling protocol is assessed through a review of the results from eight case studies. Further, sample size requirements were estimated in a follow-up program. Sample size estimates were determined using standard statistical formulas and by determining the effective sample size, which is that number of samples at which precision reaches a plateau. The protocol developed has a general form. It does not provide a set of explicit instructions but rather an outline of procedures that can be adapted to address the objectives of any sampling program ranging from simple trend monitoring to a more complex impact assessment study. Procedures described include application of the impact-control sampling design, the collection of biophysical information during site establishment, and data analysis.

The project's null hypothesis is that forest road construction and maintenance activities do not increase fine sediment storage in central interior streams. It is also postulated that increased sediment concentrations can be found with three fish habitat assessment techniques, namely the McNeil corer, gravel buckets, and infiltration bags.

Chapter 2: Sampling Design, Techniques, and Analysis

2.0 Introduction

The objective of this project is to develop and evaluate a sampling protocol that will quantify increases in the short-term storage of fine sediments downstream of forest road stream crossings. The goal of this protocol is to increase the application of monitoring/assessment studies in forest management. This chapter presents the sampling protocol, a description of the study sites, the sampling design, sampling techniques, grain size and statistical analysis procedures.

2.1 Case Studies

The eight sites chosen in the Prince George Forest Region were experiencing some road construction activities (Fig. 2.1). Also, they were all designated S2 streams under the FPC, that is fish bearing streams with active channel widths between 5 and 20 m. These sites were selected based on information gathered during telephone interviews with government and industry staff. Staff members from the Ministries of Environment and Forests were consulted, as were those from Canadian Forest Products Ltd., Slocan, Lakeland Mills, and Finlay Forest Industries. Summary information is provided in table 2.1 and a more detailed site description is provided in Appendix 1.

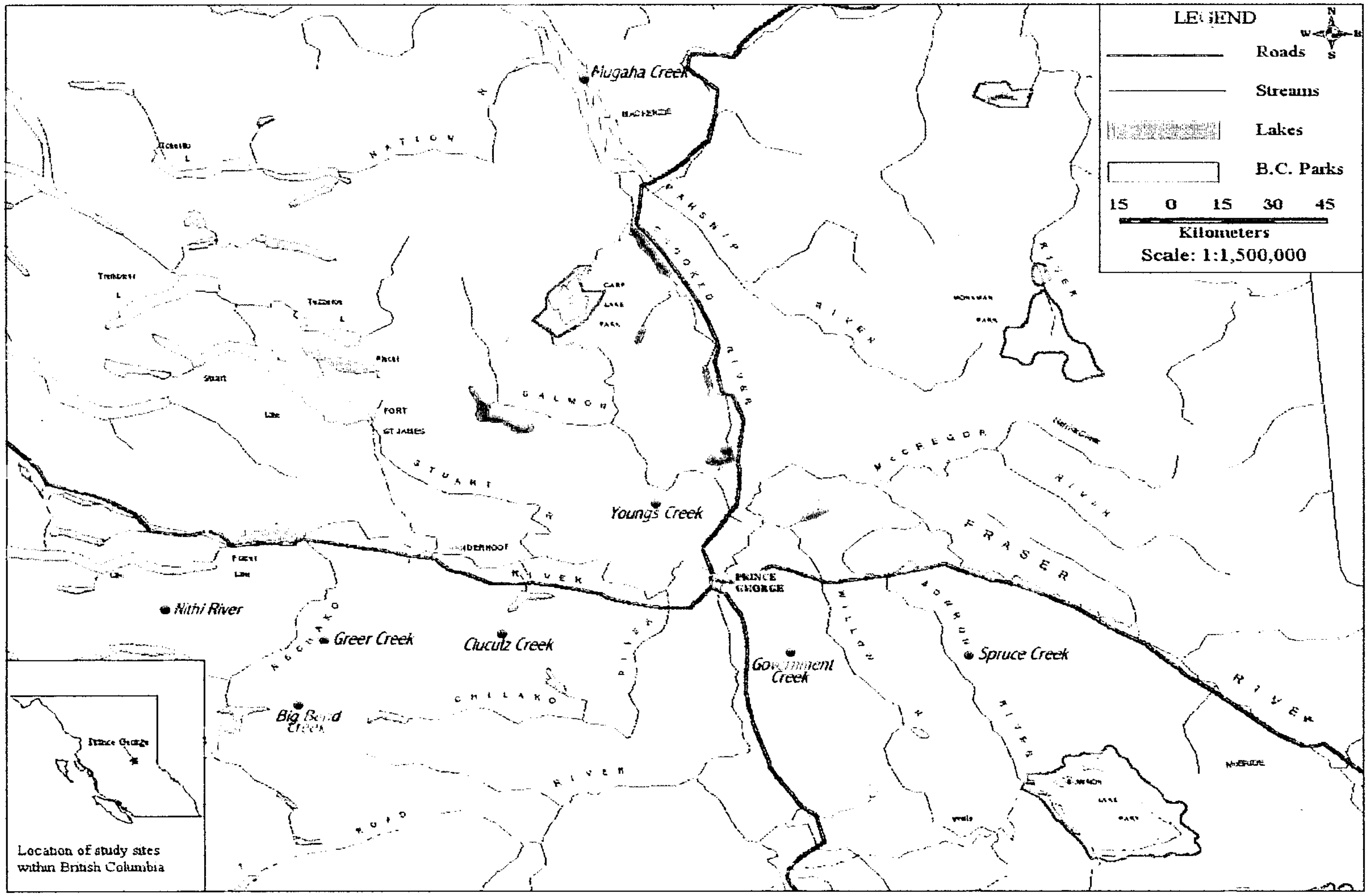

Figure 2.1 Prince George area map showing the approximate location of the eight case study streams (highlighted in red).

Table 2.1: Summary information of the eight case studies.

Stream	Channel Width (m)	Study Design	Activity
Spruce Creek	5.0	Impact-Control[1]	Ditch Erosion
Government Creek	8.0	Impact-Control	Bridge Construction
Youngs Creek	12.6	Impact-Control	Historical Crossing
Nithi River	4.5	Impact-Control	Bridge Construction
Big Bend Creek	7.0	Impact-Control	Bridge Construction
Cluculz Creek	6.0	Impact-Control[2]	Culvert Replacement
Greer Creek	7.0	Impact-Control	Bridge Construction
Mugaha Creek	10.0	Impact-Control	Bridge Washout

[1]Impact-control studies are performed after the activity. An upstream 'control' and downstream 'impact' site are sampled to determine the investigated activity's effects.
[2]Dataset includes baseline information before activity was initiated.

2.2 Sampling Design

The impact-control design consists of comparing one or more potentially affected sites with similar control sites. A shortfall of this design is the lack of comparative site information before the investigated activity. To counteract this shortfall, it is necessary to collect site information that will account for data variability caused by site differences (Manly, 2001). The Cluculz Creek study differed from the others because baseline samples that ensured control and impact site similarity were collected prior to road construction activities.

2.3 Site Establishment Procedures

Where possible, study sites were established within the same stream reach to reduce environmental variability. A reach was defined as two repeating units where a unit is composed of two habitat features such as riffle and run or pool and riffle. Site establishment data was collected at all sites and included measurements of active and bankfull channel width, discharge, mean depth, habitat units, gradient, pebble count, and technique placement depth and overlying velocity (at time of sampling).

The active channel width of a stream is the horizontal distance over the stream channel between stream banks that is covered by water. Bankfull width is the channel width where water would just begin to spill into the active floodplain (Platts *et al.*, 1983). Bankfull indicators include changes in streamside vegetation, slope, bank material, undercuts and stain lines (Harrelson *et al.*, 1994).

Discharge data was collected at each site by measuring velocity at 10-20 evenly spaced locations along a channel cross section selected downstream from the sample area that was relatively flat and free of obstruction that would interfere with flow measurement. When water depths were less than 1m, a single velocity reading was taken at 60% of the depth but when depth exceeded 1m, two readings were taken, one at 20% and 80% (Harrelson *et al.*, 1994). Velocity data were gathered over a period of 40 seconds. Discharge was calculated for each location and then summed for the channel. The mean stream depth value was determined as the average of the depths collected during the velocity readings.

The sample area was sketched in field notes with specific attention to habitat features and the location of sample replicates. This sketch could be referred to at a later date to determine if the sample area consisted of one or more reaches and to note the similarity of sample replicate locations between sites. Channel gradient information was collected while gathering habitat data. Gradient was measured with a clinometer as follows; field staff positioned themselves at a distance greater than the channel width apart at the stream's edge. Gradient was measured by sighting the clinometer from one staff to the other at the same distance from the ground. For example, when sighting to a taller individual, the staff member taking the reading may measure to the other's shoulder whereas if the individual was shorter the measurement may be to the top of the other's head. Three to five measures were taken and the average gradient was calculated and presented as the channel gradient.

The streambed was characterized by conducting a pebble count (Leopold *et al.*, 1992). These counts were conducted at several cross-sections near the sample area so that representative portions of each habitat unit were sampled. Starting at bankfull elevation, the sampler would blindly reach to their left or right foot. The first particle that was touched was removed and the intermediate axis, or width, of the particle was measured and recorded by the second staff member on a tally sheet that was divided into grain classes as defined by the Wentworth Scale (Appendix 3). The sampler then moved a standard step distance and selected another pebble at the top of the same foot used in selecting the first pebble. This continued until a minimum of 100 pebbles was counted.

The final site establishment parameter collected was the overlying water depth and velocity above each sample for each technique. This information was gathered to ensure selected sample replicate sites were comparable within and between locations and it was gathered during each sample visit. Example field sheets are provided in Appendix 4.

2.4 Sedimentation Assessment Techniques

The two forms of sampling techniques used here were the streambed corer and sediment traps. Streambed corers gather data on streambed grain size composition. While several designs exist, the McNeil core was selected for this program because of its availability and inexpensive sampling costs when compared to others such as freeze coring. Sediment traps collect sediment that deposits on or infiltrates through the streambed. The two types used here were gravel buckets, which collect sediment that deposits on the streambed, and infiltration bags, which collect sediment that moves vertically and horizontally through the streambed.

2.4.1 McNeil Corer

Since its development in 1964, the McNeil corer has become a commonly applied technique for assessing spawning gravel composition in streams because it was a significant improvement over the previously applied techniques of visual observation or shovel sampling (McNeil and Ahnell 1964, Schuett-Hames *et al.* 1994). The McNeil core provided a quantitative and repeatable sampling method (McNeil and Ahnell, 1964).

McNeil core samples are measures of bulk streambed composition that are collected by inserting the core tube into the streambed and removing all sediments within the tube. The tube is inserted into the streambed by torquing the corer while keeping it level using the handle on top of the basin (Fig 2.2) or on the sides of the basin (Fig 2.3). These handles also help staff to keep the corer from rocking during the sampling process, which would disturb the fine sediments. Once the core tube has been fully inserted, the sample is removed from the tube by hand and transferred to a sample bucket until the end of the core tube is reached. Although originally designed to assess fish habitat quality, the McNeil core has been used to quantify increased fine sediment loading downstream from industrial activities such as coal mining operations (MacDonald and McDonald, 1987).

The corer used for this study differs slightly from the original design shown in Figure 2.2. The original design was modified because it was heavy and expensive to construct. The modified version was made with heavy gauge aluminum rather than stainless steel, which made it considerably lighter and cheaper to make. In addition, it is larger than the original, standing 0.9m (vs. 0.45-0.6m) tall with an outer basin diameter of 0.6m, and the coring tube which is equipped with a replaceable ring of steel teeth, is 0.2m in diameter and can penetrate the streambed to a depth of 0.25m (Fig. 2.3). Finally, the core handles were placed on the sides of the outer basin and not along the top as shown in Figure 2.2.

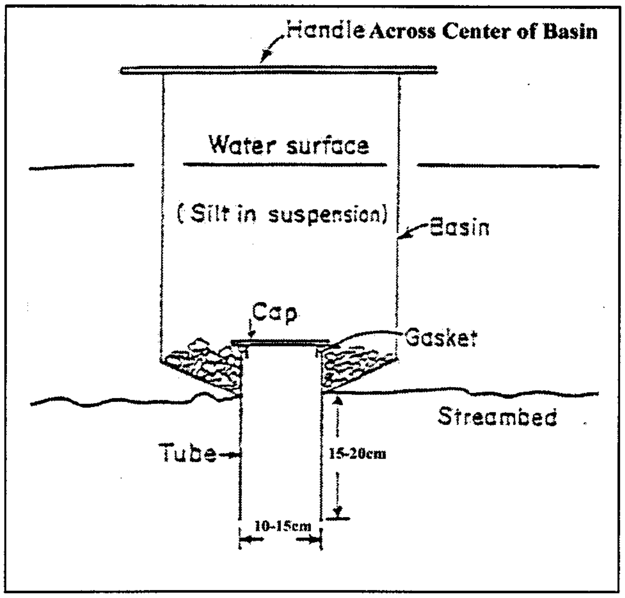

Figure 2.2. The original McNeil-Ahnell corer design (McNeil and Ahnell, 1964).

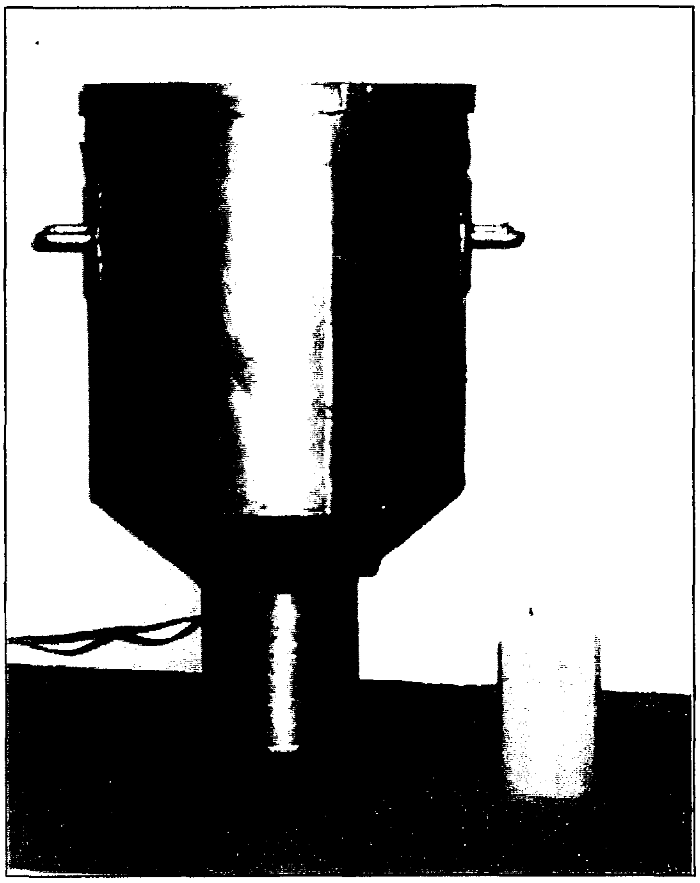

Figure 2.3. Modified McNeil core design with a 1-liter bottle for scale.

The sample procedure was also altered from the original. The old technique required sampled sediments to be brought up through the core tube and placed in the basin. Remaining fine sediments in the tube that were kept in suspension by infiltrating water were removed by a single valve pump or the tube was capped which created a vacuum that allowed trapped water to be lifted from the stream and placed in a bucket. For this program, sampled sediment was transferred directly to a clean 4 L bucket. Also, rather than pumping out sediment laden water, the water level within the tube was measured, it was then mixed to suspend settling fine sediment and a 1 liter water sample was taken. This 1 liter sample was analyzed for suspended solids as described in Appendix 2. The mass of suspended solids (SS) was calculated using the concentration of SS and the volume of water in the tube. This data was then added to silt/clay fraction.

McNeil core samples were collected from riffle areas near pool tail-outs (Fig. 2.4) as follows:

1. Sample locations were approached from an upstream direction so as to not step over the sample area prior to coring,
2. Field staff faced upstream and positioned their body over the corer and placed their hands on the handles (Fig. 2.5).
3. The corer was kept perpendicular to the streambed as field staff turned the corer into the streambed being careful not to use a rocking motion.
4. Once the corer was fully driven into the streambed staff checked to ensure the basin was flush to the streambed.

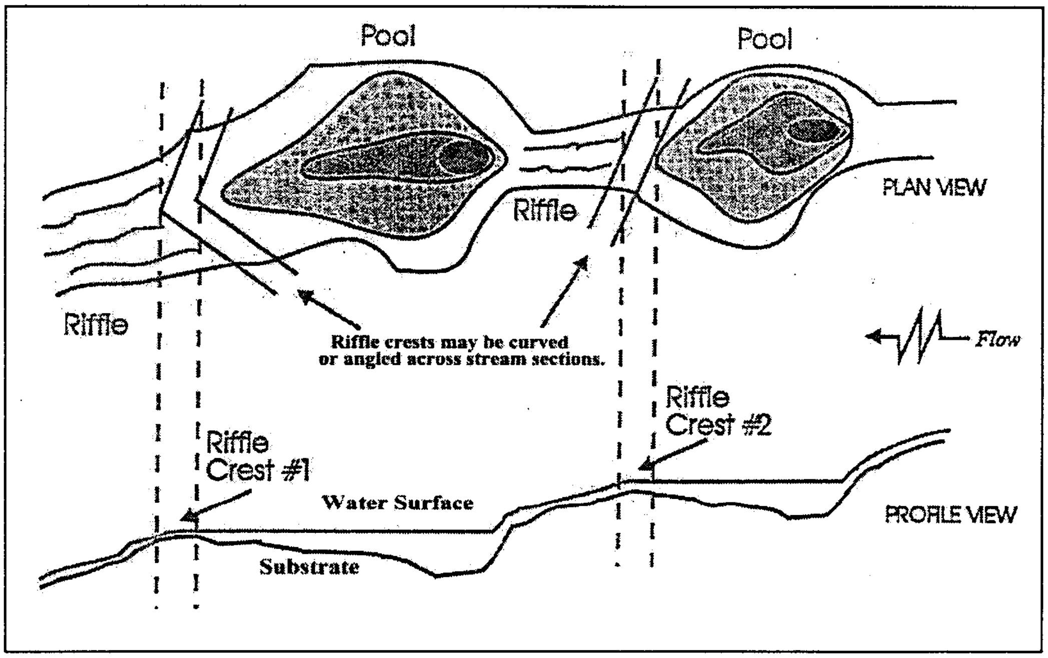

Figure 2.4: A schematic of the typical McNeil core sampling locations in riffle areas near pool tail-outs, with darker areas representing increased depth (from Schuett-Hames et al., 1994).

Figure 2.5: McNeil core sampling site approached from the downstream direction and the sample is taken by leaning over the core and forcing it into the streambed until it is flush.

5. The core sample was removed by a hand to a standard depth, the top of the ring of teeth.
6. Sediment was rinsed off the sampler's hand into the bucket and a core tube 1 L water sample was collected to determine the mass of fine sediments.

2.4.2 Gravel Buckets

Gravel buckets are sediment traps used to measure deposition onto and infiltration into the streambed (Fig. 2.6). These samplers consisted of a four liter hard plastic bucket filled with a washed angular gravel that had an average intermediate axis of 1.8cm. Although not commonly referred to in the literature, this bucket size was consistent with that of Lisle and Eads (1991) as well as Larkin *et al.* (1998). The gravel size and shape was selected with reference to Meehan and Swanston (1977), who determined that angular gravel with a 1.8 cm intermediate axis trapped more fine sediment than circular gravels at velocities greater than 0.4 m/s.

Gravel buckets were typically placed in McNeil core sample locations once the core had been extracted or in runs with a stream depth less than 30cm. Once the sites were chosen gravel bucket samples were collected as follows:

1. A hole was dug to the approximate depth of the gravel bucket (~20 cm for 4 liter buckets). Larger material was placed to the side to refill vacant areas around the bucket once installed.
2. The sealed bucket was placed level and flush to the streambed (Fig. 2.7).
3. The velocity and depth were re-measured to ensure replicate site similarity.

Figure 2.6: A gravel bucket sampler. This particular sample could not be included in the data set because the bucket was overfilled so the effective sample period was not known.

4. Once upstream sampling was completed and suspended sediment that was generated from this sampling had appeared to move downstream or settle out, the gravel bucket lids were removed as staff moved in a downstream direction. Once the final lid was removed field staff exited the channel below the last bucket.

5. During the retrieval visit, staff entered the stream below the last bucket and replaced lids in an upstream direction. Following lid replacement the overlying depth and velocity were again measured to determine changes since installation.

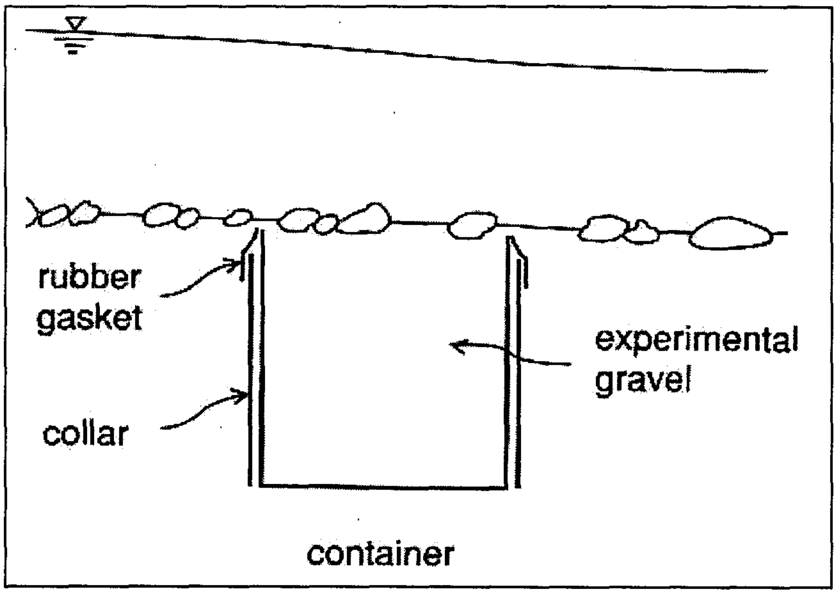

Figure 2.7: Gravel bucket schematic showing flush placement with streambed (Lisle and Eads, 1991). Note that a rubber gasket was not used for this study.

2.4.3 Infiltration Bags

Infiltration bags measure the amount of sediment moving vertically and horizontally through a streambed. The bags are a modified form of the wire basket retrieval system presented by Sear (1993). To prevent the loss of fine sediments when removing openwork wire baskets, Sear placed them in a collapsed polyethylene bag that was forced open with a foam collar. The bag was lifted up over the basket prior to basket removal and it prevented the loss of 26 to 40% of the collected sample. The infiltration bag is essentially a stronger version of the polyethylene bag (Lisle and Eads, 1991).

The infiltration bag is a waterproof fabric bag that is approximately 20cm in diameter and 35 cm long. It is attached with a hose clamp to a brightly coloured steel ring that is also 20 cm in diameter. The bag is collapsed into the ring and is buried to a depth of 30cm in the streambed (Fig. 2.8). The bag is removed from the streambed by a winch or pulley that hooks onto lines extending from the buried steel ring (Fig. 2.9).

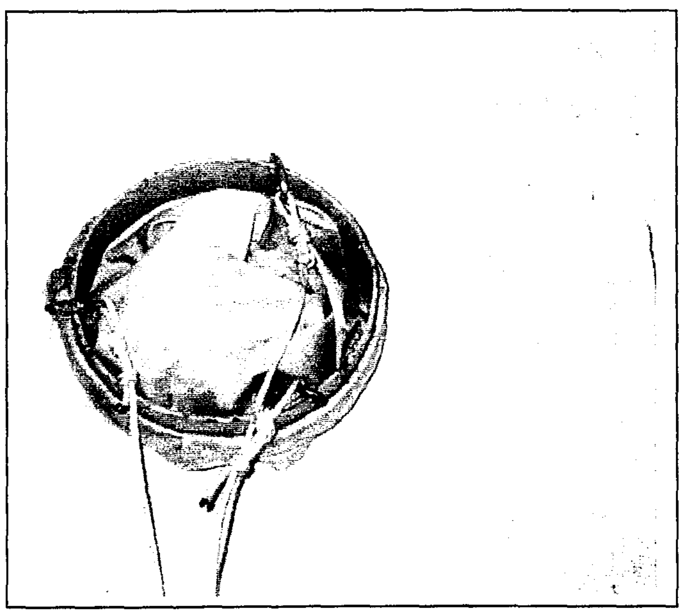

Figure 2.8: Infiltration bag collapsed within the steel ring, a 1 liter bottle is shown for scale.

Infiltration bags were placed in shallow runs that were less than 30cm deep. Following the site selection process, infiltration bag samples were deployed and collected as follows:

1. Infiltration bag sites were excavated as staff moved in a downstream direction so that any suspended sediment generated by this disturbance would move downstream of the sample area.

2. Holes were dug to a depth of 35 cm and a width of 30 cm. This provided ample room for the steel ring and incorporates the 30 cm depth typically referred to in the literature for salmonid redds.
3. The collapsed bag was placed into the bottom of the hole and the reference gravel was poured into the hole until it was level with the surrounding streambed. When backfilling was a problem, a sheet metal sleeve was used to support the streambed walls during placement of the bag and reference gravel.

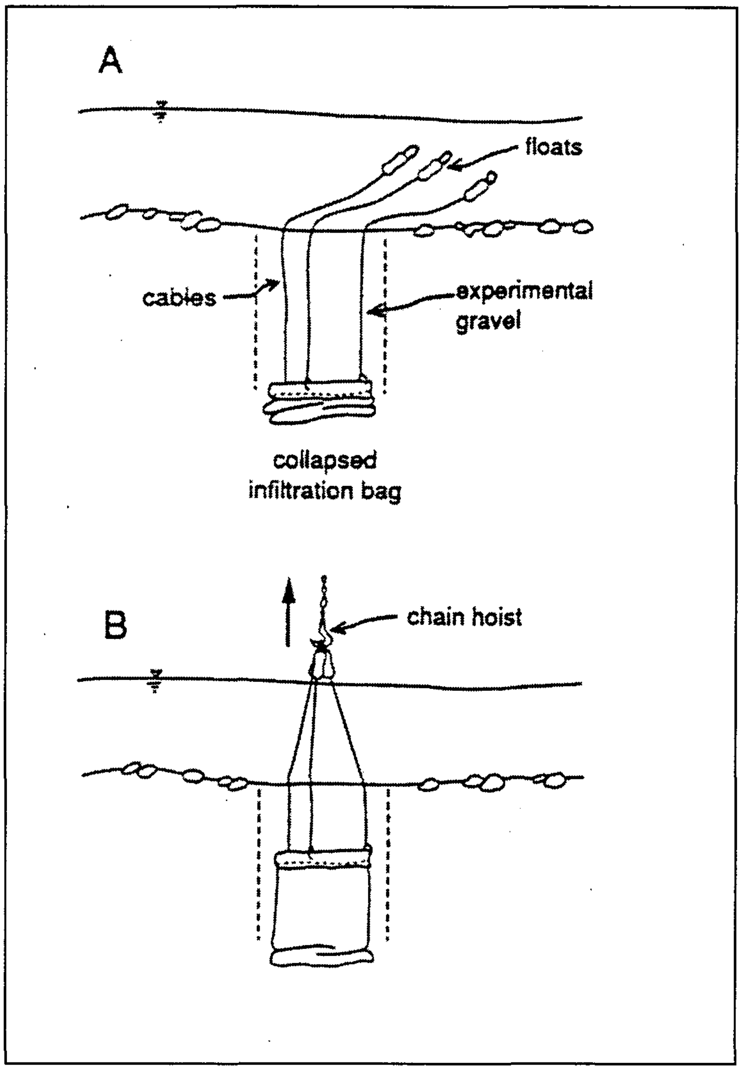

Figure 2.9: Infiltration bag deployment (A) and retrieval (B) showing the application of pulley or winch to remove it from the streambed. (Figure from Lisle and Eads, 1991)

4. The recovery lines were held by hand so they remained on the surface after the reference gravel was poured.
5. Staff then moved downstream to the next bag.
6. To retrieve bags the sites were approached from downstream. The lines were located and attached to the winch/pulley system (Fig. 2.9).
7. The bag was brought to the streambed surface and then capped with a 4 liter gravel bucket lid so that upon removing it from the stream bed the overlying water was not sampled.
8. The sample was transferred to a 4-liter bucket for transport. The bag was rinsed and re-deployed.

2.5 Sample Numbers

The sampling techniques presented here were developed for research purposes so there was limited sampling guideline information, particularly for their application in environmental assessments as proposed in this thesis. Although the literature does provide some information for the McNeil core, there were no similar numbers provided for gravel buckets or infiltration bags. Further, there were no historical sediment sampling data from any of the case study creeks that could be used to determine possible sample numbers using statistical methods. As such, the sample number varied between sites and over time as experience was gained and data was received back from the laboratory. Sample numbers ranged between three and six and reflect the availability of appropriate sampling sites within each creek and the creek width (Table 2.2).

To address the lack of sampling guidelines another sampling program was undertaken in 1998. To assess the effective sample number, defined here as being that number of samples after which there is limited gain in precision, three creeks were selected for over-sampling. Cluculz, Youngs, and Spruce Creek were chosen for the collection of 12 McNeil core and gravel bucket samples as well as 10 infiltration bags. These sample numbers, 12 and 10, were selected because they exceeded the numbers collected during the eight case studies and also exceeded those numbers observed in the literature for McNeil Coring (MacDonald and McDonald 1987, Schuett-Hames *et al.* 1994). Further, sample requirements greater than these would hamper the application of this protocol in an assessment program because sample weights would be too heavy. These creeks were chosen because of the range in their active channel widths (5-11m). The data were subdivided into clusters ranging from 4 to 12 samples based upon similar site depth and overlying velocity. Coefficients of variation (CV) were then calculated for each cluster.

Table 2.2 Sample site channel width, sampling technique, and sample numbers.

Stream	**Channel Width (m)**	**Sampling Technique**	**Number of Samples (each site per visit)**[1]
Spruce Creek	9.0	McNeil Core Gravel Bucket	6, 6 6, 6
Government Creek	8.0	McNeil Core	3
Youngs Creek	12.6	McNeil Core Gravel Bucket Infiltration Bag	3, 6, 6 4, 6 3, 4
Nithi River	4.5	McNeil Core Gravel Bucket	3, 3 3, 3
Big Bend Creek	7.0	McNeil Core Gravel Bucket	6, 6 6, 6
Cluculz Creek	6.0	McNeil Core Gravel Bucket Infiltration Bag	3, 4, 6, 6 4, 6, 6 4, 4
Greer Creek	7.0	McNeil Core Gravel Bucket	4, 6 4, 4
Mugaha Creek	10.0	McNeil Core Gravel Bucket Infiltration Bag	6, 6 6, 6 4, 4

[1]Each number represents the sample number taken that trip, i.e. 6,6, indicates six samples were taken during the first and second trip.

Another approach to determine sample size was used for comparison to the sample estimates from CV alone. Sample number estimates were calculated using the following formula from Sokal and Rohlf (1969):

$N \geq 2 (\sigma/\delta)^2 \{t_{\alpha [v]} + t_{2(1-\rho) [v]}\}^2$ (Equation 1)

Where: N= sample number
σ = true standard deviation (approximated)
δ = smallest true difference desired to detect
t = t-distribution
v = degrees of freedom of the sample $\sigma_{approx.}$
α =significance level
ρ = desired power (i.e. probability a difference is found if it exists)

Example Calculation:
Gravel Buckets
CV = 7.6% for 9 replicates
We want to detect a 20% difference 90% of the time.

$V = 2(9\text{-}1) = 16$, $\sigma_{approx} = 7.6\ Y/100$, 20% difference is $\delta = 20Y/100$

$N \geq 2 (7.6Y/100 / 20Y/100)^2 \{t_{.05\ 16} + t_{.2\ 16}\}^2$
$N \geq 2 (7.6/20)^2 \{1.746+1.34\}^2$
$N \geq 2.74 \sim 3$ Samples
To confirm 3 is correct, re-calculate using 3 rather than 9 replicates, which gives an answer of 5.35. When 5 is used the answer is 4, so 4 is a good approximation.

2.6 Grain Size Analysis

Samples were submitted to Soilcon Laboratories of Vancouver after they were pre-screened with a 16 and 9mm sieve. The 16 and 9mm data were not included in further analysis because we were interested in the finer fractions, particularly the very fine gravels and smaller as defined by the Wentworth Scale (Appendix 3). Soilcon Laboratories applied a gravimetric method to sieving the remaining sample and used sample sieves with mesh sizes of 6.3, 4.0, 2.8, 2.0 mm and 500, 250, 125, 63 μm.

Gravimetric analysis is a common procedure for materials testing and soils analysis and is typically observed in the literature because it is more precise than volumetric analysis. The Soilcon Laboratories procedure is as follows:

1. Sediment was removed from the sample container by inverting it onto a drying tray lined with a pre-weighed plastic sheet. A wash bottle was used to rinse fine sediments at the bottom of the pail and wash them onto the tray. The sample was spread in a thin layer to promote drying.
2. After the sample was air-dried to a constant weight, the weight of the air-dried sample was taken. It was corrected for the weight of the plastic sheet.
3. The sample was placed in portions in the top sieve of a stack consisting of 6.3, 4.0, 2.8 and 2.0 mm pre-weighed sieves and a bottom pan. Dry sieves were shaken by hand until particles no longer pass through to the next sieve. Each sieve was then removed and weights were recorded (corrected for sieve weight).
4. The sample collected in the bottom pan from step 3 (the 'minus 2mm fraction') was then moved in portions to a stack containing a 500, 250, 125 and 63 μm cleaned sieves. These samples were wet sieved. The portions were not limited to a maximum of 50 g because any larger may have caused the sieves to become overloaded or clogged. Sieves were often checked to ensure they were not being clogged.
5. Once the wash water ran clear the sieves were removed one at a time (i.e. from coarse to fine) and the captured sample was transferred to a pre-weighed aluminum dish. The contents were then oven-dried at 105°C. The sample weight was corrected for aluminum tray weight and recorded.
6. Because the < 63 μm (silt/clay) fraction is lost during washing it was determined by subtraction of the larger fraction weights from the total "minus 2 mm" sample weight.

The data generated were tabulated as percent less than, percent retained on sieve, and sample weight retained on each sieve. The percent retained and sample weights on each sieve were used in the analysis. Percent retained on sieve data was renamed percent composition and was used for the analysis of McNeil core data because it provides a measure of streambed composition. Weight data was used for the traps because it provides a measure of sediment loading.

2.7 Data Analysis

Generally, there are two approaches for interpreting sediment data, the first is to use the raw data and the second is to generate central tendency measures. Raw data measures incorporate each grain size's weight or percent composition while central tendency measures attempt to reduce all grain size information to one number that best describes the entire particle size range. Central tendency measures include the Fredle Index, geometric mean diameter, and median particle size D_{50} (Waters 1995, Platts *et al.* 1983). This thesis focussed on the application of raw data because the goal was to quantify inputs of fine sediment from activities of interest and not to describe the general streambed condition.

Prior to conducting a statistical analysis, the data were viewed graphically to become familiar with them and to allow for the determination of normality, designation of outliers, and to assess the potential for significant differences. Normality is a standard assumption of the parametric statistics applied and required confirmation. Data outliers were viewed in light of site establishment data to see if environmental variables could explain them. For example, did an outlying sample have higher overlying water velocity than the other samples? Finally, by plotting sample means and their 95% confidence intervals the potential for significant differences was assessed.

The percent composition data were arc-sin transformed in accordance to Sokal and Rohlf (1969) because they are proportions and therefore not normally distributed. Weight data were not transformed. To determine the presence of significant differences between sites a two-way analysis of variance (ANOVA) was applied using site and grain size as factors. Here site has two categories, namely up and downstream while grain size has seven categories ranging from fine gravel to silt/clay. Tukey's post-hoc comparison or *honestly significant difference* (HSD) procedure was used to identify grain sizes that were significantly different between sites when a main effect (site difference) was observed (Sokal and Rohlf, 1969). For presentation purposes in this thesis, the differences are quantified by individual student t-tests results. When the main effect (site difference) was not significant but an interaction effect was, the graph was once again viewed to see if there appeared to be a grain size difference between sites. A significant interaction effect indicates that there is a relationship between the two factors, i.e. grain size composition is influenced by site. Where a significant difference appeared to occur, as noted by a lack of overlapping confidence intervals and means between sites for a specific grain size, a t-test was completed. However, only one or two t-tests were run because the potential for type 1 error, the rejection of a true null hypothesis, increases with the number of t-tests applied.

During the data analysis process it was thought that this data may be influenced by pseudoreplication (Hurlbert, 1984). That is, each set of McNeil core, gravel bucket, and infiltration bags replicates can be seen to be correlated and therefore not independent or true replicates. This increases the potential for type 1 error. To address this concern, an

ANOVA of means was conducted for each site where more than one data set was collected for a given technique. For example, mean values for each grain size collected with McNeil Cores during each of two trips were computed. The mean values for each grain size over the two trips were grouped by site, yielding two sets of values for each grain size and location. An ANOVA of these values provides results free of pseudoreplication effects (Manly, 2001). However, this analysis could not be applied across all case studies because some did not have more than one sample set.

Chapter 3: Sedimentation Survey Results

3.0 Introduction

To determine the presence of forest road construction and maintenance effects on downstream fine sedimentation, eight sites were selected and an impact-control study was conducted. Summary results for each study are provided in the following section and two of them, Cluculz and Spruce Creek are presented in more detail. These were selected because they have more extensive databases than most of the other studies and they demonstrate that the protocol worked in different situations. In the Cluculz Creek study the sediment source was less than 100 m from the study area while on Spruce Creek the source was approximately 3 km from the study area. Site establishment data and statistical analysis information for each station is presented in Appendix 1. In addition to the discussion of Cluculz and Spruce Creek, data from an ancillary program designed to determine sample size requirements per given stream width is presented.

3.1 Case Study Results

Seven of the eight case studies had significantly higher levels of fine sediment depositing downstream of the selected forest harvesting activity for one or all of the techniques used (Table 3.1). The Greer Creek study did not show a significant increase in fine sediment downstream of bridge construction. This is likely the result of a decrease in discharge during our study period and the application of sediment control measures by the construction crew, which consisted of hay bales and geo-textile.

Table 3.1: Sampling technique, sample number per visit, and a result summary for each of the eight case studies.

Site	Technique	Sample Number per Visit	Results
Big Bend Creek	McNeil Core Gravel Buckets	4 and 6 4 and 6	Higher sand downstream Higher sand and clay downstream
Cluculz Creek	McNeil Core Gravel Bucket Infiltration Bag	3, 4, 6, and 6 4, 6, and 6 4 and 4	Higher sand and clay downstream Higher sand and clay downstream Higher very fine gravel upstream
Government Creek	McNeil Core	3	Higher sand downstream
Greer Creek	McNeil Core Gravel Bucket	4 and 6 4	No site differences No site differences
Mugaha Creek	McNeil Core Gravel Bucket Infiltration Bags	6, 6, and 6 6 and 6 4 and 4	Higher sand downstream Higher sand downstream Higher sand downstream
Nithi River	McNeil Core Gravel Bucket	3 and 4 4	Higher sand downstream No site differences
Spruce Creek	McNeil Core Gravel Bucket	6, 6, and 6 6 and 6	No site differences Higher sand downstream
Young's Creek	McNeil Core Gravel Bucket Infiltration Bag	3, 4, and 6 4 and 6 3	Higher sand downstream Higher sand downstream No site differences

3.1.1 Cluculz Creek

Cluculz Creek is an S2 stream, which is a fish bearing stream between 5 and 20 m wide, in the Vanderhoof forest district. Its fisheries population includes the Kokanee salmon (*Oncorhynchus nerka)* and rainbow trout (*O. mykiss*). The selected crossing was chosen because its two culverts were being replaced with a pipe arch. These culverts had repeatedly failed to accommodate spring flows often resulting in a road washout. So, the culverts were being replaced and the channel bank was being reinforced with boulders to direct flow through the new pipe arch (Photos 3.1 & 3.2).

Photo 3.1 Upstream view of Cluculz Creek from the road showing the two culverts prior to their replacement with pipe arch and revetment of the streambank.

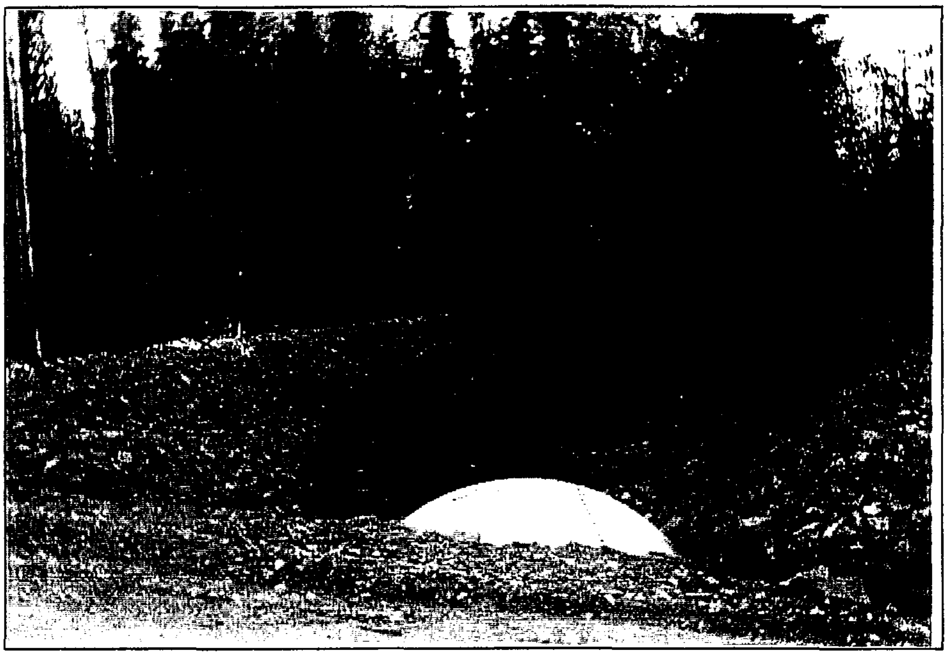

Photo 3.2: Upstream view of Cluculz Creek from the same location as Photo 3.1 showing the new pipe arch and the streambank revetment.

The culvert replacement represents a large scale disturbance within the chosen reach of Cluculz Creek. Baseline samples were collected on July 25, 1997 and the construction activities occurred between August 15-21. The creek was redirected through a temporary channel for several hours on August 18 or 19 while the culverts were pulled and the pipe arch was installed. Construction period samples were collected with gravel buckets. Post-construction samples were collected with some or all techniques on September 23, October 22, and November 16, 1997. Construction activities were found to cause a significant increase in fine sediment depositing downstream of the area up to the final sample date (Table 3.2).

The most dramatic increase at the downstream site was observed for the construction period bucket samples, which were retrieved on August 21 two-three days after the creek was redirected. These samplers collected weights for each grain size that were up to threefold greater at the downstream site (Fig. 3.1). Although this signal response is clearly shown in the gravel bucket samples, it is interesting to note that a similar response was not identified for the McNeil core samples. An important aspect of the sampling protocol is identified in these results because the lack of correspondence between techniques may have nothing to do with their sensitivity but instead be a function of operator bias. That is, the first gravel buckets were installed in McNeil core sampling locations during the July 25 visit. Upon our return on August 21, the streambed in this area had changed from its original charcoal grey colour to tan as a result of the high amount of sediment deposited in the area. Despite this obvious increase in deposited sediment, McNeil core samples were not collected there because that area was sampled during the previous visit. Instead, samples were collected downstream of the buckets, outside of the high deposition area.

Table 3.2: Summary statistics of the Cluculz Creek assessment program.

Sampler	Date	N[1]	F-value	p-value	Interaction[2]	Significant Differences
McNeil Core	07/25/97	3	0.09	0.77	0.98	No Differences
	08/21/97	4	0.002	0.97	0.99	No Differences
	09/23/97	6	1.7	0.19	0.03	Med. Sand Down ($p = 5.04 * 10^{-5}$) Fine Sand Down ($p = 9.98 * 10^{-5}$) V. Fine Sand Down ($p = 0.03$) Silt/Clay Down ($p = 0.0002$)
	11/06/97	6	5.06	0.03	$4.92 * 10^{-17}$	Tukey's HSD indicates Fine Gravel higher Up ($p = 0.007$), Coarse Sand Down ($p = 0.0002$), and Med. Sand Down ($p = 5.04 * 10^{-5}$)
Gravel Buckets	08/21/97	4	42.71	$1.4*10^{-7}$	0.09	Tukey's HSD – Higher Weights Down for all grain sizes
	10/22/97	6	0.0	0.99	0.98	No Differences
	11/06/97	6	133.9	$6.4*10^{-17}$	$1.7*10^{-20}$	Tukey's HSD – Higher Weights Down for all grain sizes
Infiltration Bags	10/22/97	4	2.72	0.11	0.23	No Difference
	11/06/97	4	6.95	0.01	0.04	Tukey's HSD indicates higher gravel upstream ($p=0.049$)

[1]N stands for sample number

[2]Interaction p-value refers to the significance of the interaction between the two factors site and grain size. A significant interaction indicates that grain size composition is influenced by site.

McNeil core data showed a significant difference in the sand and silt/clay fractions between the up and downstream locations four and ten weeks after the culvert replacement (Fig. 3.2 and 3.3). This is likely the result of deposited sands moving downstream from the originally effected area as fall flows increased.

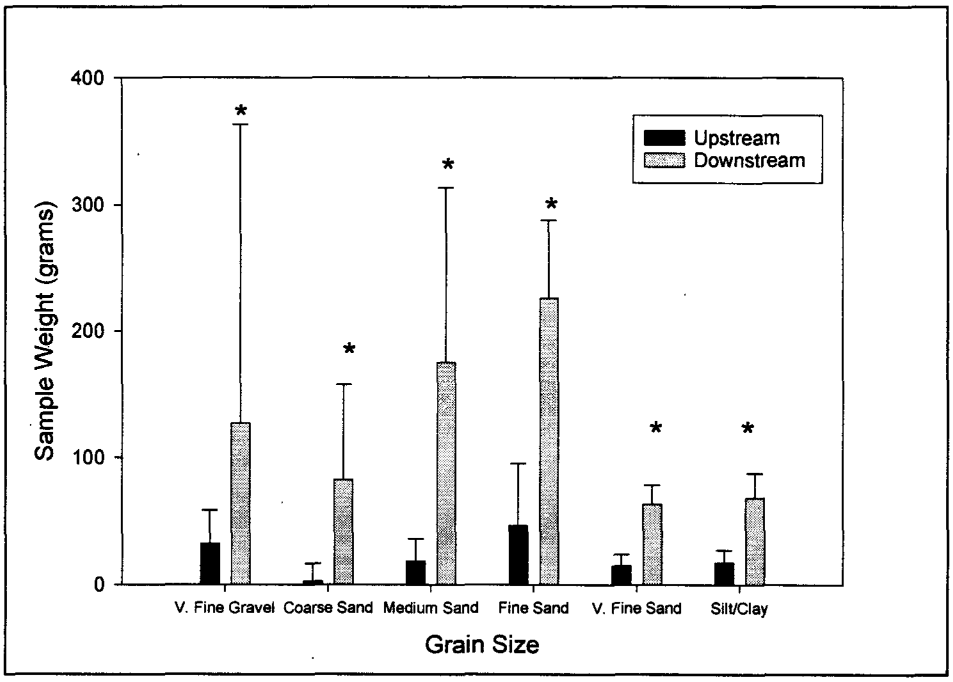

Figure 3.1: Gravel bucket mean weights and their upper 95% confidence limits from samples collected at Cluculz Creek on August 21 during the construction period. An asterisk highlights those grain sizes where there is a significant difference between sites.

Some of the gravel bucket and infiltration bag samplers were lost at the downstream location during the October placement as a result of high flows. Neither the buckets nor bags show a significant difference between sites, possibly due to the low number of samples at the downstream station. Ten weeks following construction, buckets show that the crossing was still acting as a sediment source for the sand and silt/clay fractions (Fig. 3.4). The infiltration bags captured significantly more very fine gravel at the upstream locations (Fig. 3.5).

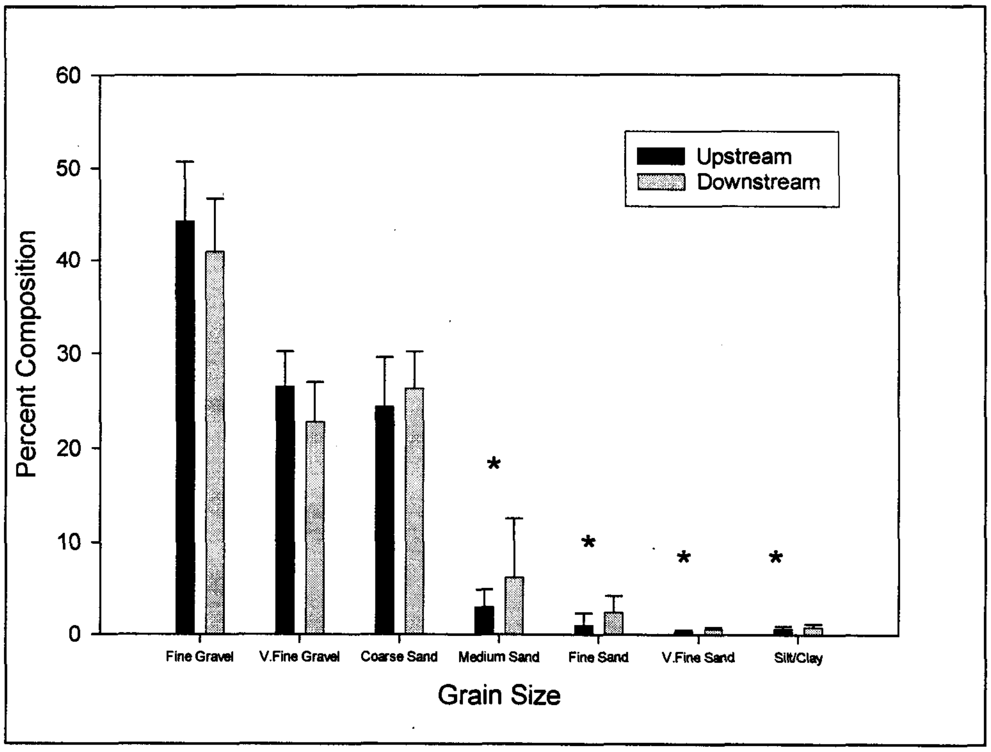

Figure 3.2: Cluculz Creek McNeil core means and upper 95% confidence limits for the September23 samples. Asterisks highlight a significant difference between sites.

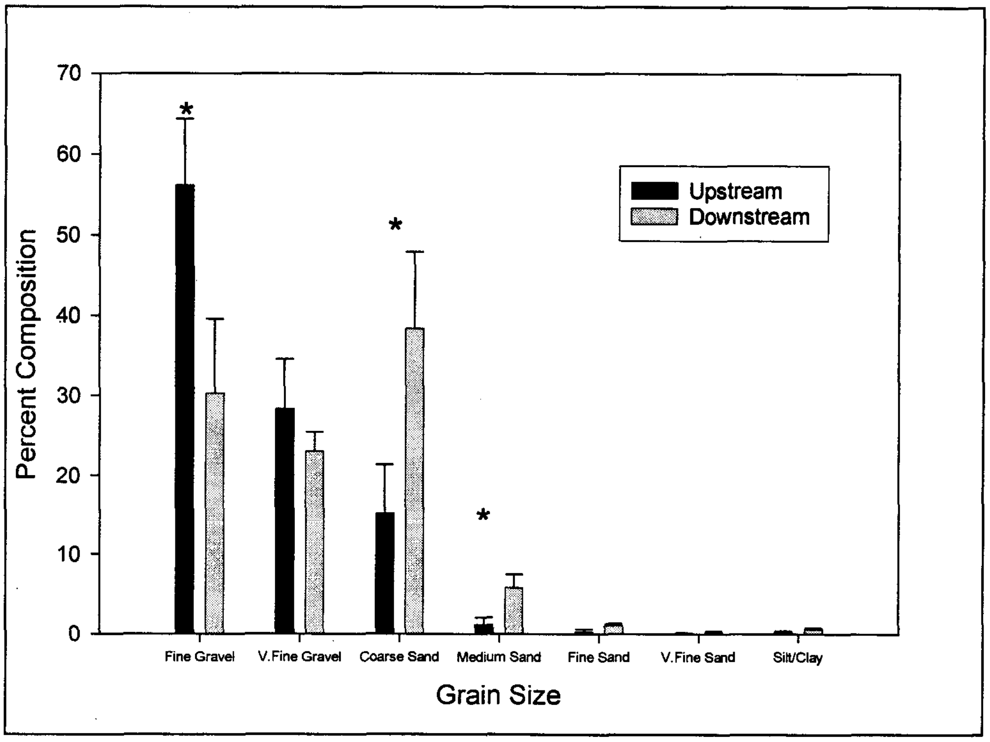

Figure 3.3: Cluculz Creek McNeil core sample means and upper 95% confidence limits for the November 6 samples. Asterisks highlight a significant difference between sites.

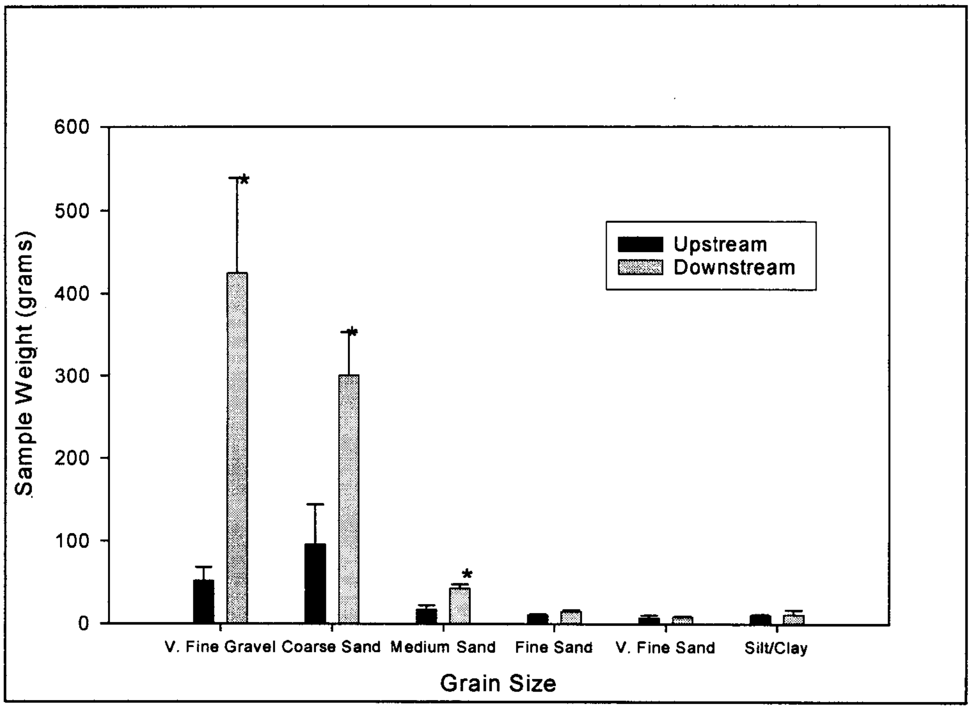

Figure 3.4: Cluculz Creek gravel bucket sample means and upper 95% confidence limits for the November 6 samples. Asterisks highlight a significant difference between sites.

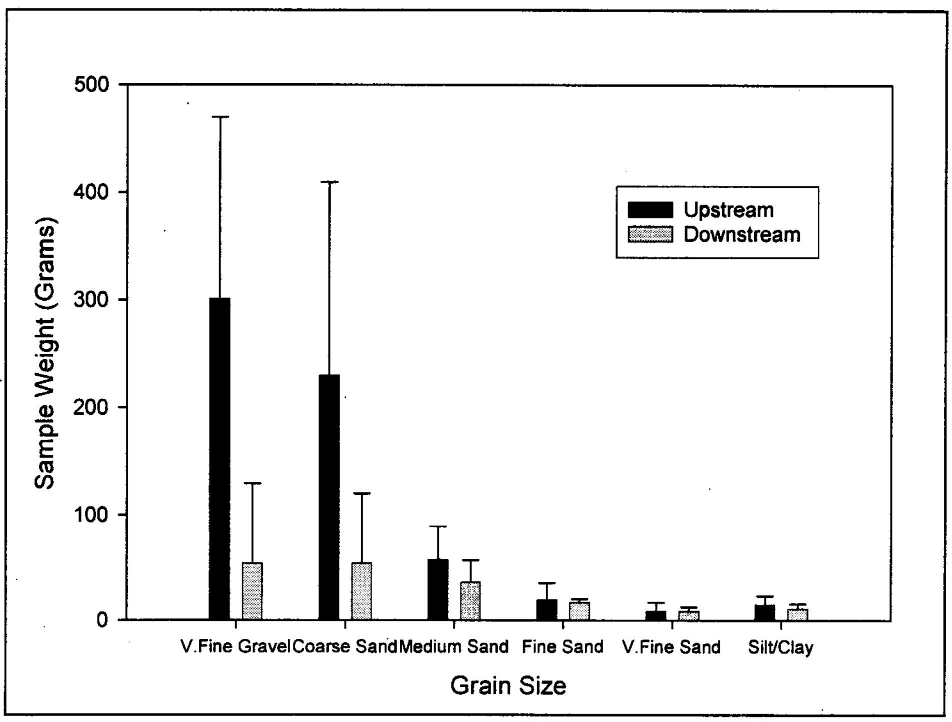

Figure 3.5: Cluculz Creek infiltration bag sample means and upper 95% confidence limits for samples collected on November 6. Very fine gravel was higher upstream.

3.1.2 Spruce Creek

Spruce Creek is an S2 stream, which is a fish bearing stream between 5 and 20 m wide, in the Prince George forest district. Its fisheries populations include the rainbow trout (*Oncorhynchus mykiss)* and bull trout (*Salvelinus confluentus*). It was selected for sampling based upon reports from Ministry of Forests (MoF) staff of high main-stem turbidity levels resulting from road construction near the headwaters of one of its tributaries. Prior to site establishment, the road construction area near the tributary's headwaters was visited. This new road, the 283 road, had some erosion along it ditch walls and at one of the switchbacks. The ditch wall had deteriorated enough to allow road runoff to enter the tributary (Photo 3.3).

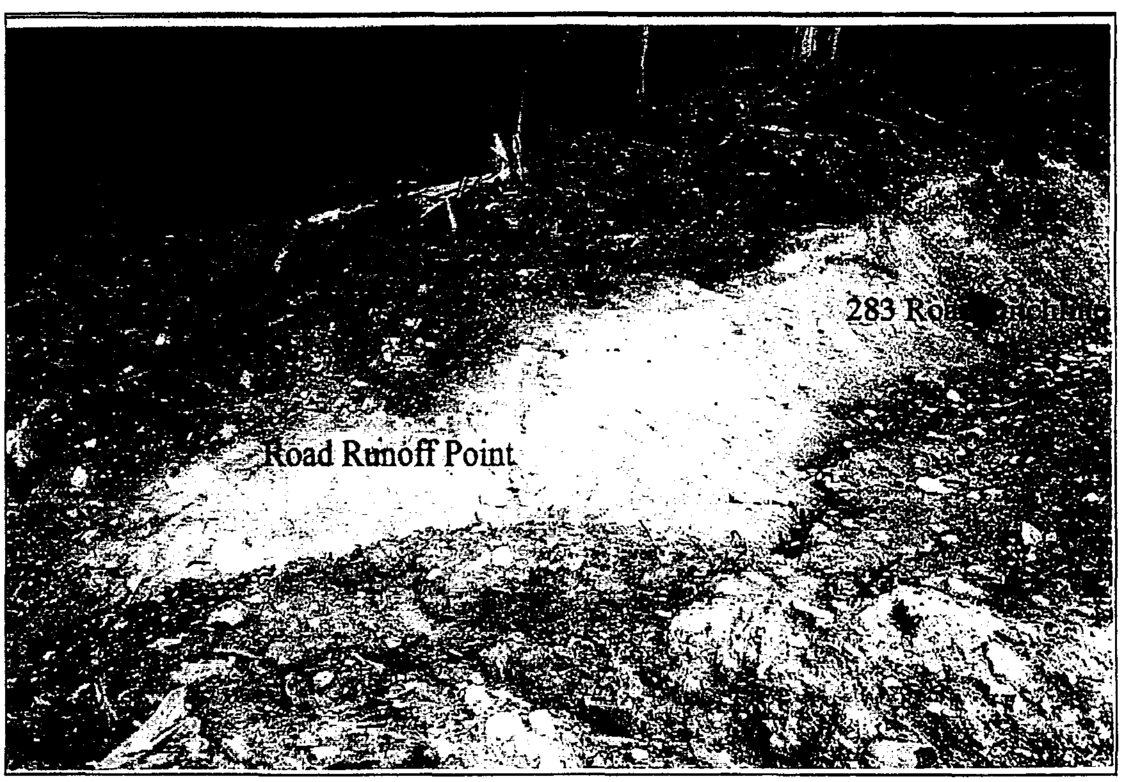

Photo 3.3: Ditch wall erosion at the 283 road approximately three to five kilometers from the sampling area.

During the site establishment visit on September 11, the tributary and Spruce Creek mainstem near their confluence were sampled. Two stations were selected in the tributary above its confluence with Spruce Creek to determine if the gradient change between them affected sedimentation within the tributary. Two stations were also established on Spruce Creek above and below the confluence to determine the tributary's effect on depositing sediment downstream (Fig. 3.6). McNeil core samples did not indicate a difference between the tributary or mainstem stations (Table 3.3 and Fig. 3.7).

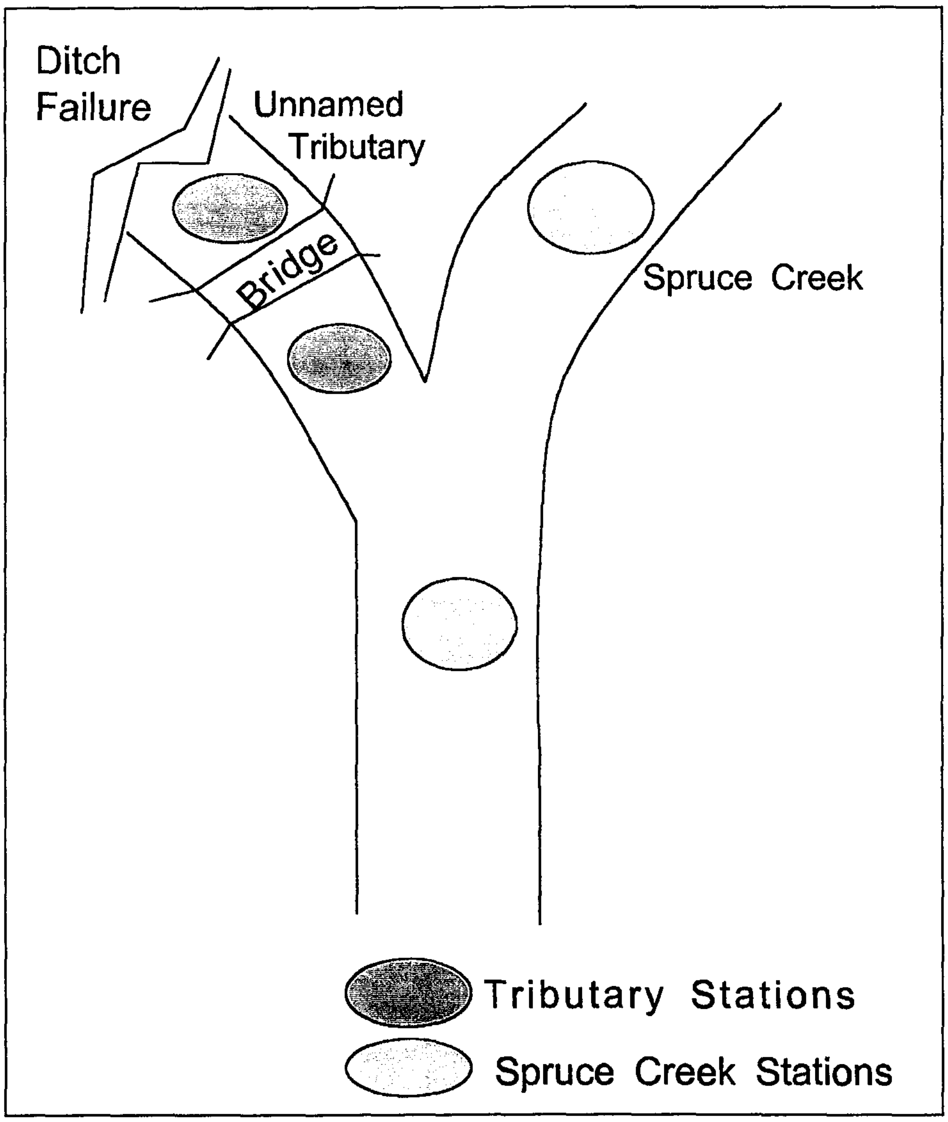

Fig. 3.6: Schematic of the Spruce Creek and unnamed tributary sampling stations.

Table 3.3: Summary statistics for the Spruce Creek assessment program.

Sampler	Date	N[1]	F-Value	p-value	Interaction[2]	Significant Differences
McNeil Core	09/11/97	6	0.02 0.003	0.9 0.96	0.8 0.1	No Differences (Spruce) No Differences (Trib.)
	10/16/97	6	0.61	0.44	0.004	Coarse Sand Up ($p = 0.03$)
	11/23/97	6	0.72	0.4	0.05	No Differences
Gravel Buckets	10/16/97	6	16.06	0.0001	0.4	Higher Weights Down
	11/20/97	6	24.6	$6.1*10^{-6}$	0.01	Tukey's HSD- Higher Weights for all sands and silt clay Down

[1]N stands for sample number.

[2]Interaction p-value refers to the significance of the interaction between the two factors site and grain size. A significant interaction indicates that grain size composition is influenced by site.

The McNeil core samples showed higher amounts of coarse sand upstream on Spruce Creek in October but not November (Figs. 3.8 and 3.9). In contrast, gravel buckets showed there to be higher depositing sediments at the downstream Spruce Creek site in October and November (Table 3.2, Figs. 3.10 and 3.11). This discrepancy in results may be due to the fact that fine sediment input from the tributary was not sufficiently high to alter natural streambed composition or that the fine sediments captured and retained by the gravel buckets were not retained by the natural streambed. That is, the fine sediment load sampled by the gravel buckets may have moved downstream from the sample area during the bucket sampling period. If so, the McNeil cores would not be expected to return data similar to that of the buckets.

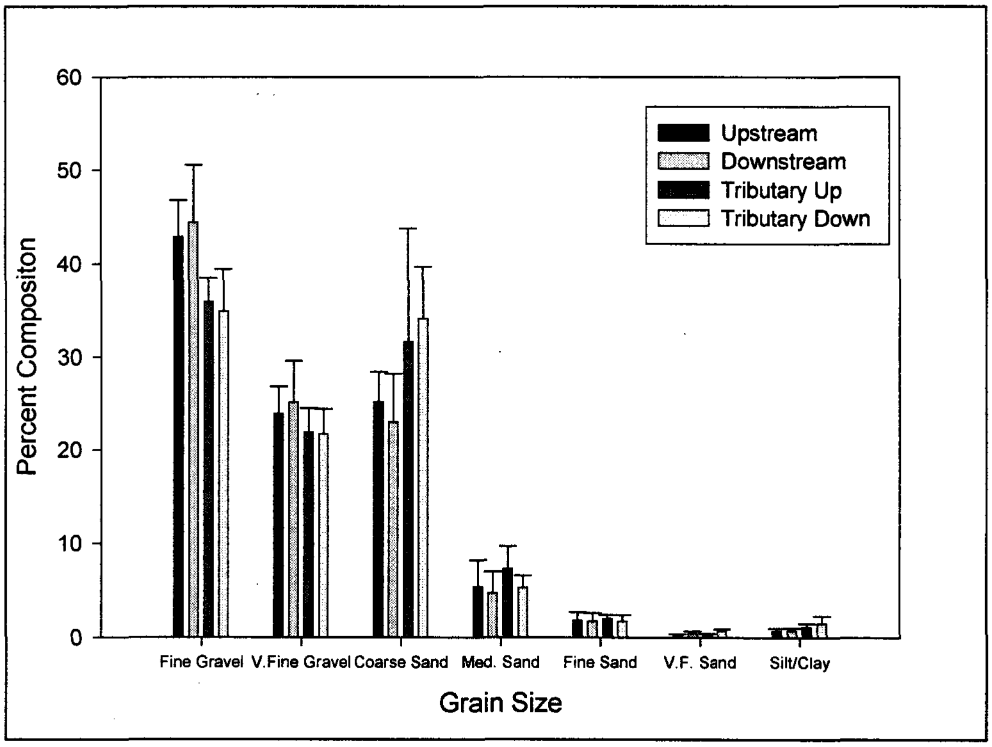

Figure 3.7: McNeil core sample means and their upper 95% confidence intervals for Spruce Creek and the tributary on September 11, 1997.

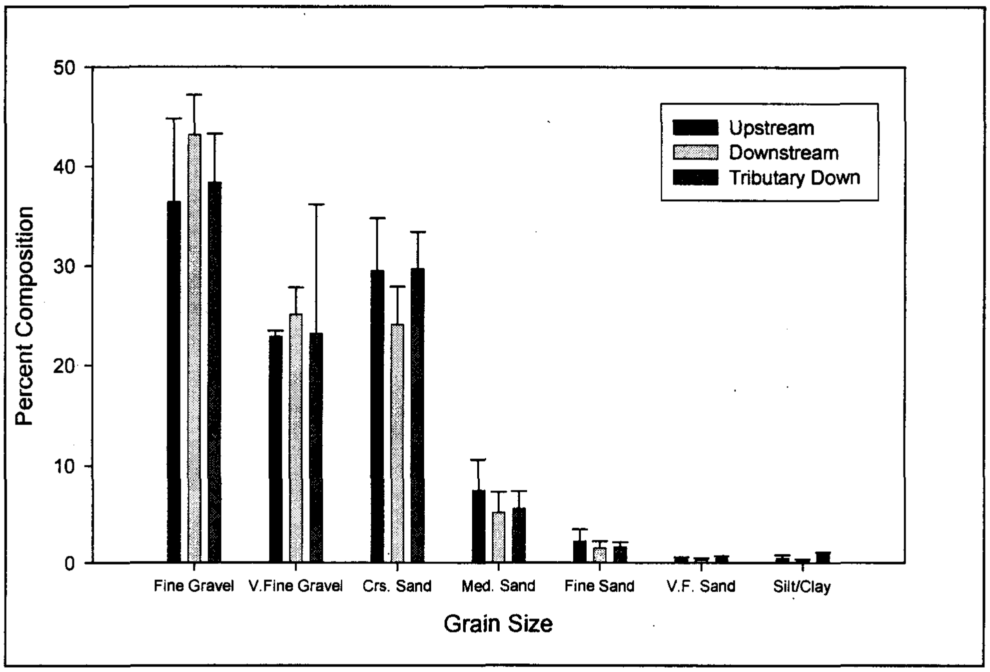

Figure 3.8: McNeil core sample means and their upper 95% confidence intervals for Spruce Creek and the lower tributary station on October 16, 1997.

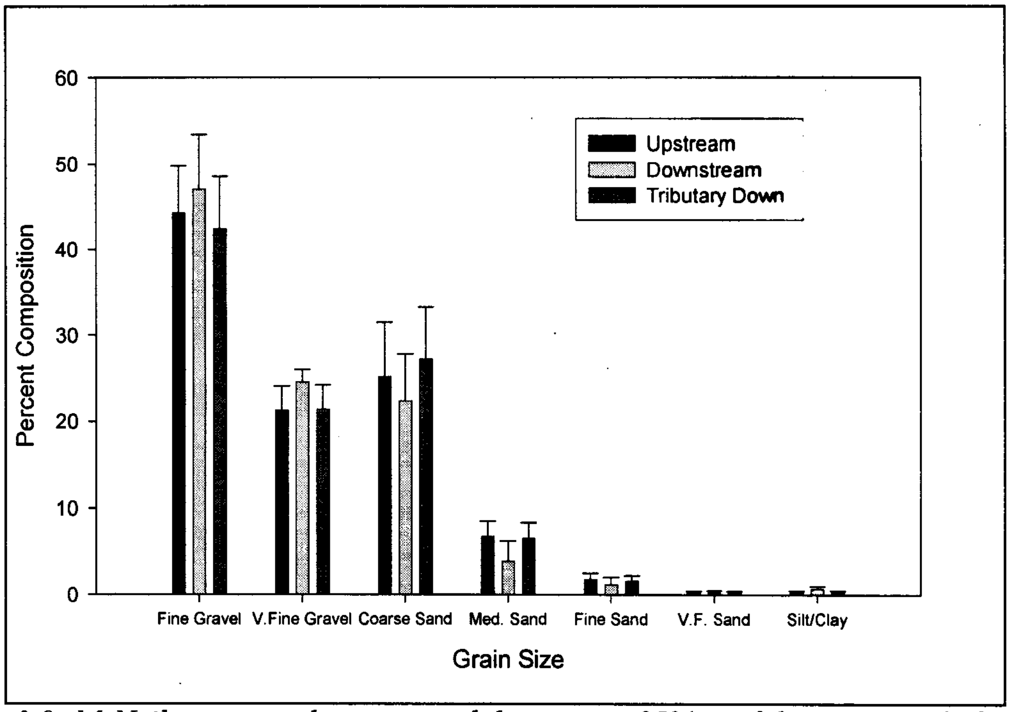

Figure 3.9: McNeil core sample means and their upper 95% confidence intervals for Spruce Creek and tributary for November 23, 1997.

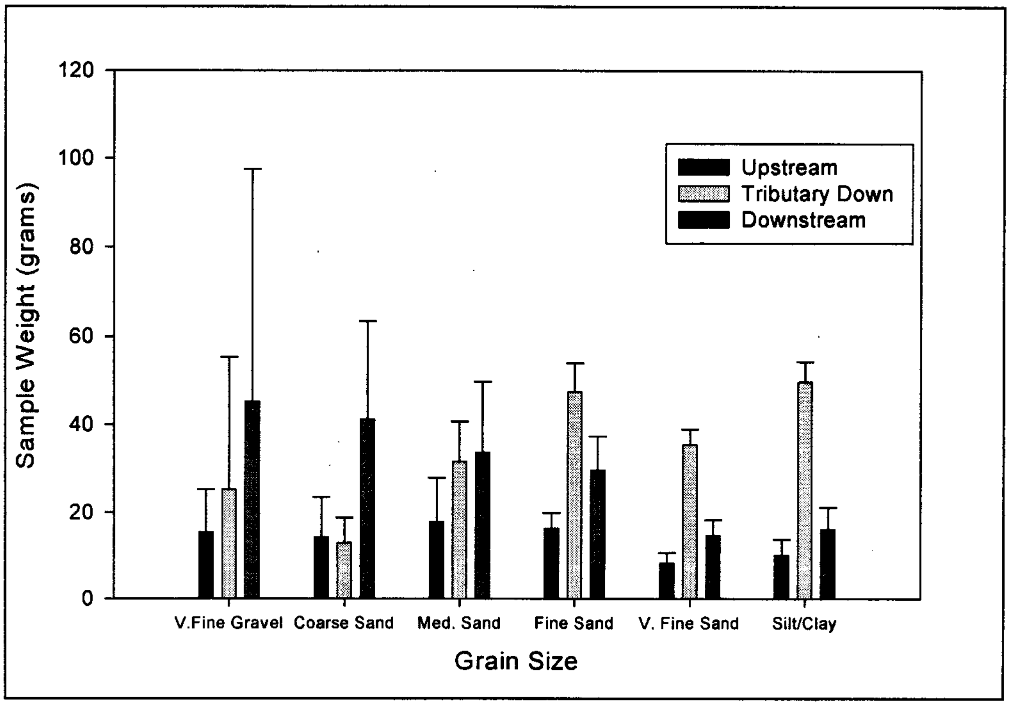

Figure 3.10: Gravel bucket sample means and their upper 95% confidence intervals for samples collected on October 16, 1997. All Spruce Creek downstream samples are significantly different from those upstream.

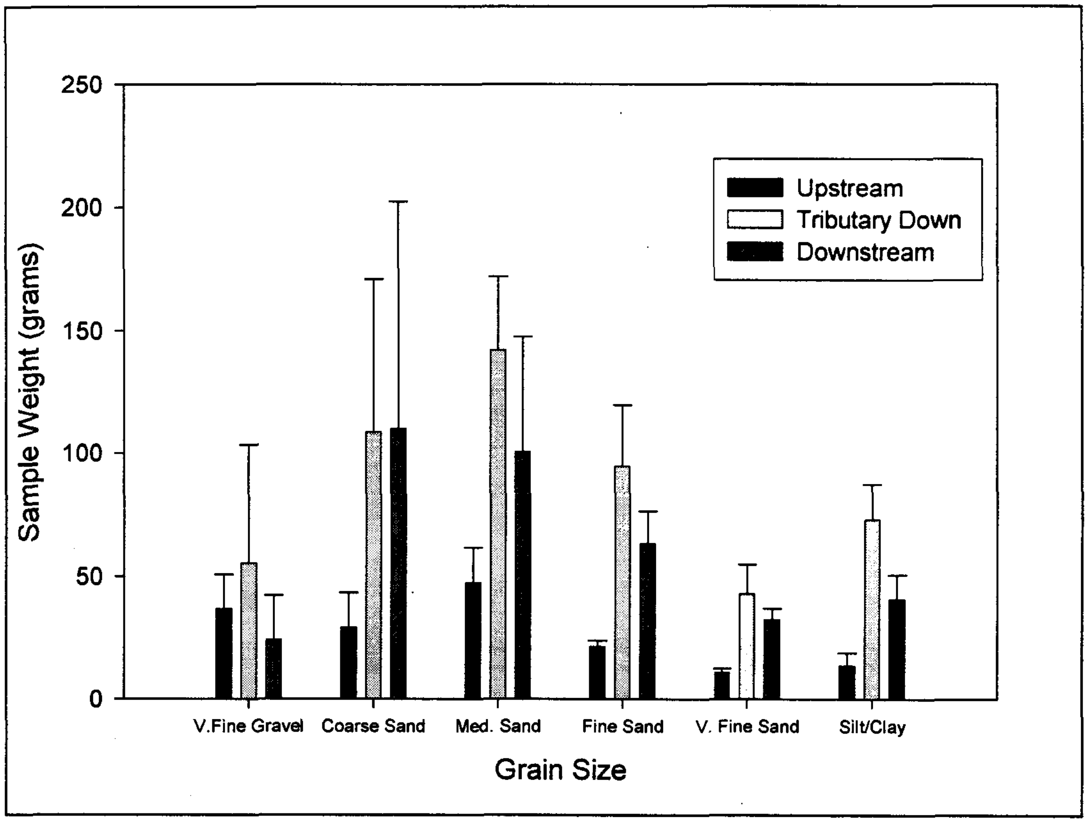

Figure 3.11: Gravel bucket sample means and their upper 95% confidence intervals for samples collected on November 23, 1997. The Spruce Creek downstream site has higher sands and silt/clay.

3.2 Pseudoreplication

Pseudoreplication is the use of inferential statistics to test for treatment effects with data drawn from studies where the treatments are not replicated or sample replicates are not statistically independent (Hurlbert, 1984). If data are not independent the sample size used by the statistic is larger than the effective number of independent observations. This can lead to false significant results from tests of significance and the generation of confidence intervals that are narrower than appropriate (Manly, 2001).

Although not originally considered in the study design, pseudoreplication effects are investigated here *a posteori* for those case studies where multiple sample sets were collected (Sec. 2.7). There were some differences from the findings presented in Table 3.1 but the general trend is similar (i.e. one or all of the techniques show increased sedimentation downstream) indicating that the sampling protocol is effective (Table 3.4).

Table 3.4: Summary results from the re-analysis of data when considering the effects of pseudoreplication (differences from Table 3.1 are highlighted).

Site	Technique	Sample Number per Visit	Results
Big Bend Creek	McNeil Core Gravel Buckets	4 and 6 4 and 6	Higher Sand Downstream **No Site Difference**
Cluculz Creek	McNeil Core Gravel Bucket	3, 4, 6, and 6 4, 6, and 6	**No Site Difference** Higher Sample Weight Downstream
Greer Creek	McNeil Core	4 and 6	No Site Differences
Mugaha Creek	McNeil Core Gravel Bucket Infiltration Bags	6, 6, and 6 6 and 6 4 and 4	Higher Sand Downstream **No Site Difference** **No Site Difference**
Nithi River	McNeil Core	3 and 4	Higher Sand Downstream
Spruce Creek	McNeil Core Gravel Bucket	6, 6, and 6 6 and 6	No Site Difference Higher Sand Downstream
Young's Creek	McNeil Core Gravel Bucket	3, 4, and 6 4 and 6	**No Site Difference** Higher Sand Downstream

3.3 Sample Number Estimates

Sample numbers varied between study streams and sample periods. Sample numbers increased with creek size and where several sets were collected, the latter sets had higher sample numbers. This increase in sample number is attributable to increased field experience and the ability to review sample data as they were returned from the lab. With this gained knowledge, it was clear that data quality would be improved by increased sampling for the remainder of the program. Although the quality and quantity of data from the original design was suitable for hypothesis testing, there was still a need to determine optimal sample numbers. Two approaches were taken, namely the determination of effective sample size using the coefficient of variation (CV) and a formula based estimate.

The CV is calculated as the standard deviation divided by the mean and multiplied by one hundred. As sample numbers increase, the mean and standard deviation change as does the CV. The CV is used here to represent changes in precision. Specifically, this exercise focuses on finding the sample number where the CV stabilizes. The effective sample number, defined here as that number of samples after which precision gains are small (i.e. < 5%), was determined for three stream classes as defined by their wetted width, namely 5m (Cluculz Creek), 9m (Spruce Creek), and 11m (Young's Creek).

All available data for a site were ranked in two ways, first in order of increasing water depth and second by increasing velocity. Depth and velocity were chosen for identifying sample replicate locations because of their hydraulic relevance and they are two variables that are easily measured in the field. Further, these flow characteristics will influence the local depositing environment and so should be relatively standardized (Petticrew *et al.*, in progress).

The weight of sediment deposited at each site as measured by the given technique was then included in these ranked tables (e.g. Table 3.5) and clusters were formed starting with the largest number of similar values. For example, in Table 3.5 six samples have a water depth of 8cm to represent the first cluster (CV=18.9%). The second cluster is identified by including the maximum number of samples of the depth that is most similar to the original cluster. In this case the two samples with depths of 9cm were included (CV=16.3%). The third cluster now incorporates the single sample at 7cm because it is more similar to the original cluster than the samples at 10cm (CV=17.1%). The final cluster includes all samples and it has a CV of 18.4%. Note that the change in CV from six to twelve samples is less than 3%. Very little precision appears to be gained by increasing sample numbers but eight is chosen as the effective sample number because it has the lowest CV.

Table 3.5: Cluculz Creek gravel bucket data grouped by sample depth.

Sample Identifier	Sample Depth (cm)	Depositing Sediment Sample Weight (grams)	Clusters of Samples
10	7	70.6	
9	8	74.4	
4	8	124.8	
11	8	89.7	6
3	8	81.3	8
5	8	85.2	9
1	8	78.1	12
2	9	90.4	
6	9	92.8	
12	10	76.9	
7	10	94.7	
8	10	122	
		Cluster CV	18.9(6) 16.3(8) 17.1(9) 18.4 (12)

Generally, most sample sets returned data with low variability with the exception of the Youngs Creek gravel bucket and infiltration bags. The majority of sample replicate combinations returned coefficients of variation (CV) in the range of 5 to 30%, often showing a minimal decrease in CV with increasing the sample number above six. As such, data collected for the eight case studies, which ranged between 4 and 6, are considered sufficient to adequately describe those sample areas.

3.3.1 Gravel Buckets

Gravel bucket sample sets exhibited a low degree of variability regardless of sample number in Cluculz and Spruce Creek but were quite variable for Youngs Creek. The effective sample number for 5, 9, and 11m wide creeks is estimated to be 8, 9, and 10 (Tables 3.6 and 3.7). However, 10 replicates is the suggested minimum for the selected 11m wide creek because of the high variability at that site (Tables 3.6 and 3.7).

Table 3.6: Effective sample numbers (highlighted cells) for gravel buckets based upon the lowest CV for groupings by depth.

	Cluculz Creek (5m)		Spruce Creek (9m)		Youngs Creek (11m)	
	Number	C.V.	Number	C.V.	Number	C.V.
Set # 1	6	18.9	6	16.8	6	90.6
	8	16.3	8	17.0	8	88.7
	9	17.1	10	16.6	10	68.5
	12	18.4	12	16.5	12	81.2
Set # 2	6	9.1	6	20.0		
	8	8.0	9	18.2		
	10	8.5	12	30.4		
	12	8.3				

Table 3.7: Effective sample numbers (highlighted cells) for gravel buckets based on the lowest CV for groupings by velocity.

	Cluculz Creek (5m)		Spruce Creek (9m)		Youngs Creek (11m)	
	Number	C.V.	Number	C.V.	Number	C.V.
Set # 1	6	20.7	6	17.0	6	86.5
	8	18.1	8	17.0	8	93.8
	12	19.0	10	16.1	10	80.2
			12	16.5	12	81.2
Set # 2	7	7.7	6	12.1		
	9	7.6	8	37.2		
	12	8.3	10	31.4		
			12	30.4		

3.3.2 Infiltration Bags

The infiltration bag samples show an increasing degree of variability as the wetted width increases. Eight of the ten samples collected in Young's Creek samples were deployed in a depth of 10cm so there was no analysis of grouping based on depth for that creek. The effective sample number for 5, 9, and 11m wide creeks is estimated to be 4, 8, and 10 (Table 3.8).

Table 3.8: Effective sample numbers (highlighted cells) for infiltration bags based on the lowest CV for groupings by depth and velocity.

	Cluculz Creek (5m)		Spruce Creek (9m)		Youngs Creek (11m)	
	Number	C.V.	Number	C.V.	Number	C.V.
Depth	4	23.2	4	31.9		
	7	37.5	6	28.7		
	10	31.4	8	28.8		
			10	44.3		
Velocity	4	24.7	4	52.6	4	54.7
	7	38.1	5	49.1	6	44.1
	10	31.4	7	51.2	8	41.3
			10	44.3	10	38.2

3.3.3 McNeil Core

The McNeil core data set differs from the gravel buckets and infiltration bags because it shows a decrease in the required sample number as the channel width increases. In accordance with the data in Tables 3.9 and 3.10, the required sample number for 5m wide streams is 10, for 9m it is 7 and for 11m it is 9. This contradicts the trend observed for gravel buckets and infiltration bags as well as general intuition. We would expect that as the sample area increases the number of samples required to characterize it should also increase.

This observation may be attributed to a high variability in sample site depth and velocity amongst all of the creeks (Table 3.11). Given this variability and the low increase in precision with increased sample number from 6 to 12 at Cluculz Creek (average decrease in CV is 2.6%) the effective sample number for streams 5, 9, and 11m wide is estimated to be 6, 8, and 10 samples.

Table 3.9: Effective sample numbers (highlighted cells) for McNeil Cores based on the lowest CV for groupings by depth.

	Cluculz Creek (5m)		Spruce Creek (9m)		Youngs Creek (11m)	
	Number	C.V.	Number	C.V.	Number	C.V.
Set #1	6	23.2	6	34.5	6	35.4
	8	21.3	8	35.7	8	30.9
	10	22.8	10	37.4	10	34.5
	12	21.1	12	34.9	12	33.9
Set #2	6	14.8	6	13.0	6	9.8
	8	14.7	8	15.1	8	16.9
	10	13.3	10	22.3	10	14.9
	12	13.2	12	21.6	12	22.4

Table 3.10: Effective sample numbers (highlighted cells) for McNeil Cores based on the lowest CV for groupings by velocity.

	Cluculz Creek (5m)		Spruce Creek (9m)		Youngs Creek (11m)	
	Number	C.V.	Number	C.V.	Number	C.V.
Set #1	6	20.7	6	32.8	6	39.9
	8	24.9	8	36.3	8	38.3
	10	22	10	35.7	10	34.7
	12	21.1	12	34.9	12	33.9
Set #2	6	14.8	6	24.6	6	31.5
	8	15.7	8	23.6	8	26.7
	10	13.9	10	22.5	10	27.4
	12	13.2	12	21.6	12	22.4

Table 3.11 McNeil core sample depth and velocity summary statistics for both McNeil core sample periods.

Site	Mean Velocity	Standard Deviation	Mean Depth	Standard Deviation
Cluculz Creek	0.29 0.52	0.05 0.04	9.33 8.80	0.98 1.53
Spruce Creek	0.64 0.70	0.07 0.14	9.50 9.80	1.00 1.07
Young's Creek	0.32 0.67	0.04 0.11	7.10 8.70	0.50 0.90

The results of the clustering CV analysis show the importance of maintaining similarity in site selection. Increased sample numbers are expected to improve the accuracy of the mean and the variation around the mean. However, in some cases the smallest CV was found with the lower sample sizes. This potentially reflects the magnitude of the change of controlling variable used for clustering (i.e. 6 samples from the same water depth versus 9 samples that incorporate 3 depths). As depth and velocity are important controlling variables for sediment deposition it is best to maintain equivalent conditions for all replicates. This is clearly not always the possible and therefore results in 'natural variability'. The range sampled here was not expected to generate large differences but may be affecting the variation.

3.3.4 Formula Based Sample Size Estimates

The formula based sample number requirements were typically much larger than those generated using CV alone (Table 3.12). As with most equation based sample estimates, these numbers ensure statistical requirements are met, i.e. in our example the ability to detect a 5,10, or 20% difference 90% of the time (Equation 1). Note that with the statistically based formula there is no consideration of the environmental limitations of the sample area, whereas the availability of similar sampling sites is implicit within the CV analysis.

Table 3.12 Calculated sample numbers for each technique assuming 90% chance of finding 20%, 10%, or 5% differences between sample sites.

	5 meter			9 meter			11 meter		
Detectable Difference	*20 %*	*10%*	*5%*	*20 %*	*10%*	*5%*	*20 %*	*10%*	*5%*
Gravel Bucket	4	14	56	9	40	75	250	986	1972
Infiltration Bag	30	115	450	46	176	684	83	306	1227
McNeil Core	12	43	146	11	39	143	28	108	421

The difference between the CV and formula based sample estimates can be explained. First, the CV analysis looks at the decrease in variability with increased sample numbers (based on clusters) with an upper limit of 12 samples. So, if the lowest CV is 25% at 8 replicates, this is the best sample number within the possible sample size of 12 replicates despite the high variability. Although this seems a shortfall, seven of the eight case studies saw a significant difference between stations with even less samples than suggested by the CV analysis because the difference in mean sediment levels exceeded the suggested differences from above. Of those included in the table, the 20% is most detectable and relevant as other studies have focussed on quantifying this level of difference between locations (Rood and Church, 1994).

Chapter 4: Discussion

4.0 Introduction

The objective of this study was to design and evaluate a sampling protocol to quantify increases in the storage of fine sediments downstream of forest road construction and maintenance activities. Study results confirm that the protocol described here is capable of detecting these increases. One or all the techniques used were able to detect significant increases in the fine sediment concentration for seven of the eight case studies presented.

These observations agree with the literature, which often highlights forest roads, particularly stream crossings, as a major contributor of sediment to streams. Sediment delivery pathways include road and ditch runoff as well as mass wasting during road construction or following significant road bed deterioration (Cafferata and Spittler 1998). Beschta (1978) demonstrated that road construction activities increased sediment load to a magnitude similar that of mass wasting in coastal Oregon streams. Bilby *et al.* (1989) found that 34% of surveyed road drainage points in a southwestern Washington watershed directly entered streams. Further, in most cases fine sand (<0.2 mm) was delivered to the streams by these roads but as gradient increased there was a shift to the larger grain sizes of sand.

Many published studies from British Columbia have not emphasized roads as a significant contributor of sediment because they were conducted in coastal environments where landslides or debris torrents are the dominant sediment sources. Scrivner and Brownlee (1989) found that forest roads were not a significant contributor of sediment within the Carnation Creek watershed because they were constructed with blasted rock so they could not generate fine sediment from their surface as observed in many other basins. Tripp and Poulin (1986) suggest that in Queen Charlotte Island watersheds, the collective influence of forest harvesting activities on sediment transport and storage may be as significant as a single landslide. Interior streams may have greater potential to show significant road effects because mass wasting events are often less prominent and soil structures differ from the coastal systems. Slaney (1975) demonstrated significant delivery of sediment to streams from skid-trails and landings in the Slim Creek watershed, near Prince George, because trails were constructed in silty-loam deposits. Beaudry (1999) noted a significant increase in suspended sediments due to road runoff in the Baptiste watershed, near Fort St. James.

During the data analysis process and subsequent presentation of results, three issues surfaced that require more detailed discussion. These include technique sensitivity, sediment monitoring and cumulative effects, as well as error analysis.

4.1 Technique Sensitivity

Technique sensitivity as defined here refers to the ability of a sampling technique to detect a difference in sediment storage between sites and for it to provide repeatable results. Prior to assessing sensitivity it is necessary to review the sampling protocol for each technique to highlight external influences on sample collection and to clarify each technique's strength and weakness.

4.1.1 McNeil Core

The McNeil core is a sediment corer that penetrates the streambed and provides a bulk sample of the bed to the depth that the core is driven. It is the most environmentally representative sampling technique presented here because the natural streambed is sampled directly. Further, Young *et al.* (1991) determined in laboratory trials with known sediment mixtures that the McNeil core provided more accurate and precise samples than the single or tri-probe freeze corer and shovels.

A potential problem with the McNeil core is the under sampling of fine sediments due to the disturbance of interstitial fines during the coring process. Similar to other coring techniques, this disturbance of interstitial fines may bias the sampler to larger grain sizes. Further, the coarser fine sediments (e.g. sands) that have settled out at the bottom of the core may not be adequately suspended or they can settle out again just prior to collection of the one-liter core water sample. However, by ensuring the consistency of sampling personnel and procedure it is appropriate to compare sediment concentrations between sites using this technique.

The McNeil core has distinct advantages over other corers and the trap techniques including its ease of use, portability, and adaptability. The core tube can be exchanged for narrower or broader tubes to best suit the range of particle sizes the researcher wants to collect. It collects natural streambed material making it a better measure of streambed conditions than sediment traps. Further, it is the only technique presented where sample volumes can be collected to fit accepted bulk sample standards such as the ISO standards adopted from de Vries (1970) and the truncated sample volumes proposed by Church *et al.* (1987). Both of these sampling standard volumes exceed those presented in this paper and may be best employed for longer term programs where slight differences need to be determined or larger areas are sampled.

Both bulk standards use the sample's large grain sizes to determine the required total sample volume. The de Vries model assumes that the particle at the 84th percentile (D_{84}) is suitably large whereas the Church *et al.* (1987) model allows the sampler to determine the upper grain size included in the analysis, which is defined as the truncated grain size. The de Vries sample volumes are set with reference to three precision levels, namely high, medium, and low (Fig. 4.1). Using a D_{84} of 30 mm (located on x-axis of Fig 4.1) the low precision sample weight required is 60 kg (read the corresponding y-value from the intercept of 30 mm with line 'ISO 4364-1977:low precision'), the medium is 600 kg, and the high is 6000 kg. Church *et al.* (1987) standards require the sampler to select that portion of the streambed grain size range to which they will compare the fine sediment composition. This upper limit must contain a minimum of 100 grains (Fig. 4.2). Using a truncated limit of 30 mm 40 kg of sample is required (read the 30mm intercept with the '0.1%' precision line of fig 4.2).

Although the de Vries sample weights were too onerous for this program, some of the McNeil core samples that were collected did fall within Church *et al.* (1987) guidelines. However, neither standard was met using the trapping techniques. Adherence to these standards was not a requirement because the goal of this thesis was to develop an easily

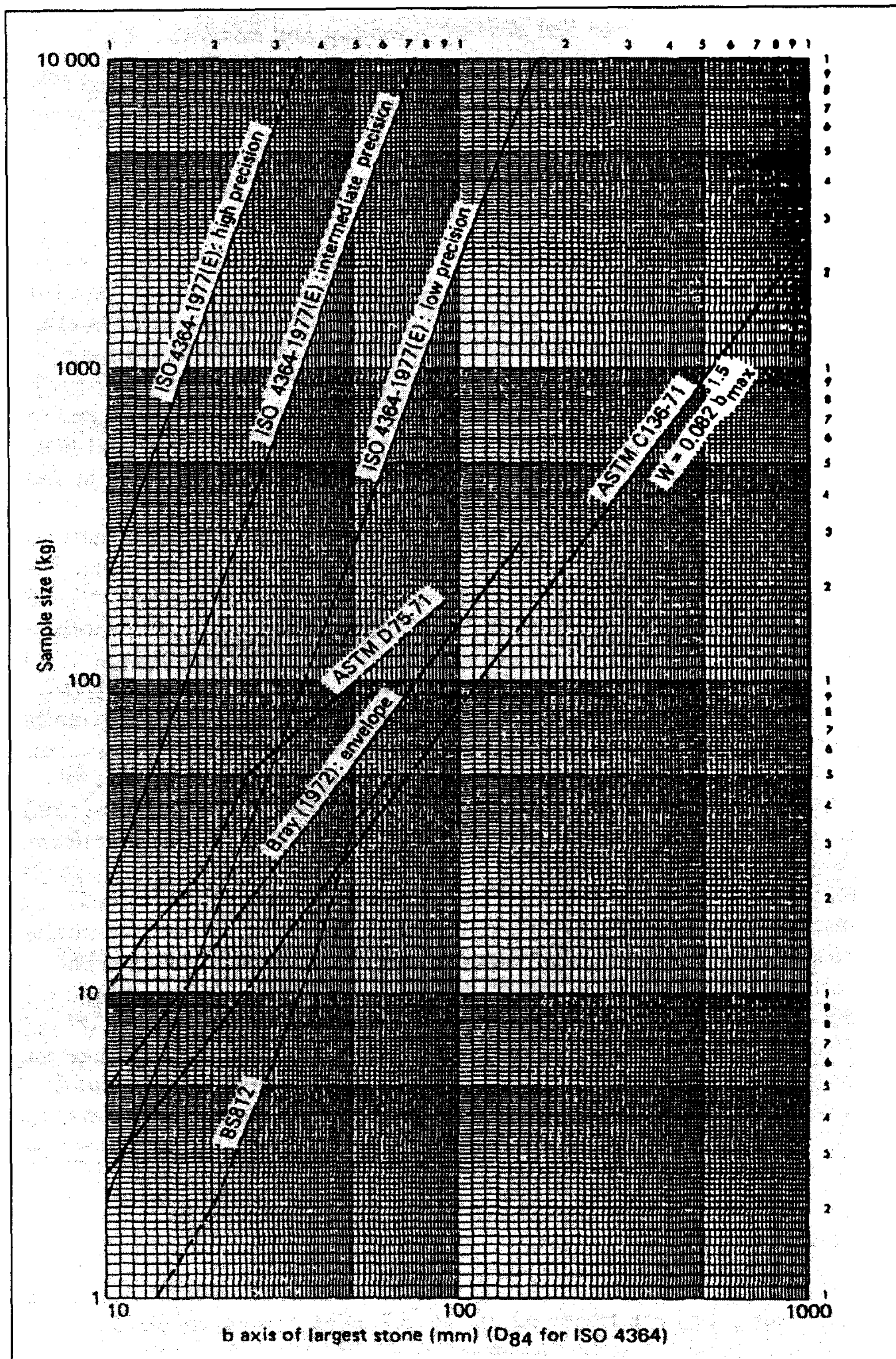

Figure 4.1. Several bulk sample standards including that based on the intermediate axis of the D_{84} stone proposed by DeVries (1970). (From Church et al., 1987).

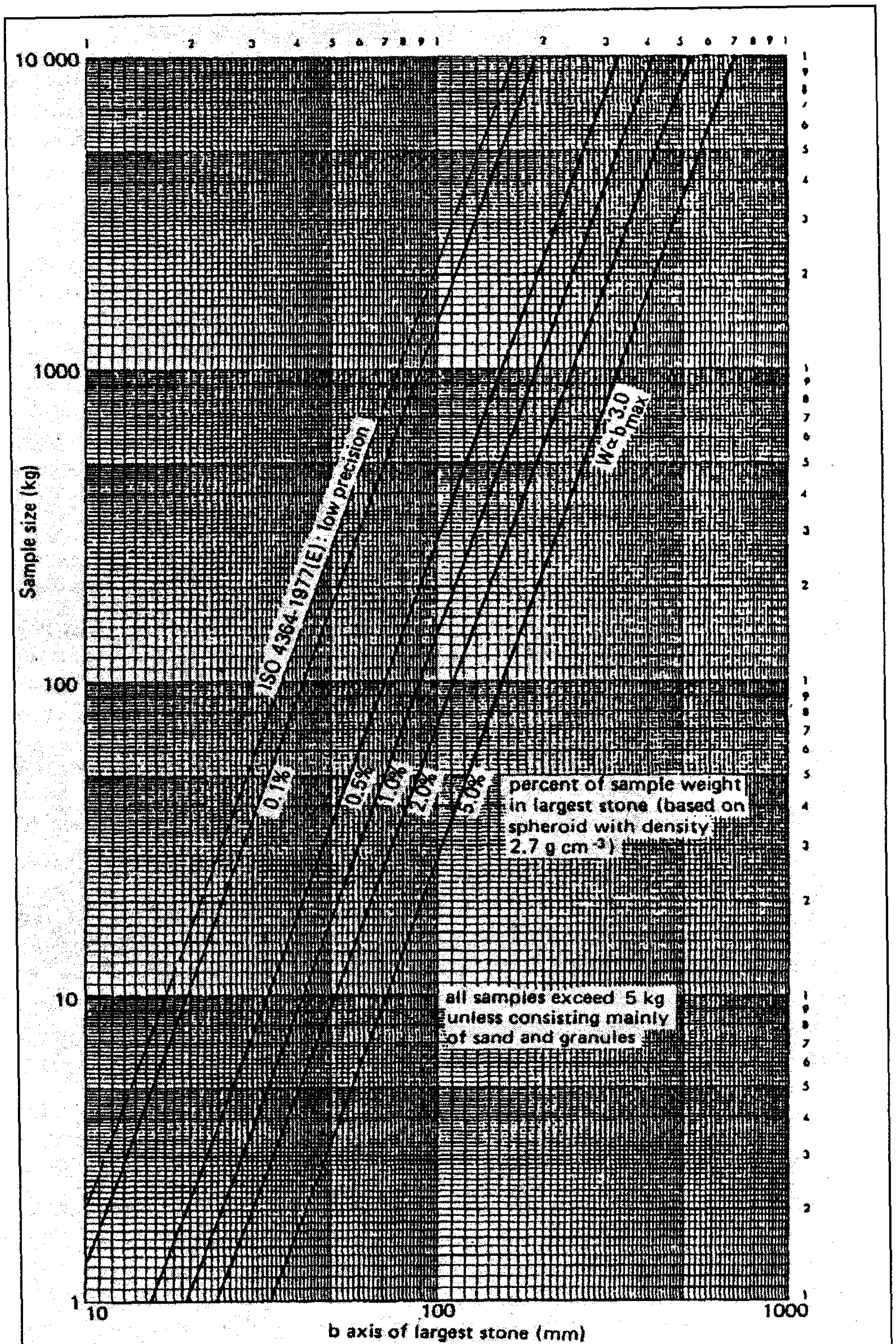

Figure 4.2: Bulk sample standards based on the intermediate axis of the largest stone included in the analysis (Church et al., 1987).

applied but defensible and repeatable protocol that could be used in remote areas. That is, a relatively simple assessment protocol yielding samples that can be physically carried was required.

4.1.2 Gravel Buckets

Gravel buckets are impermeable walled containers that trap depositing and/or saltating sediment that settles on the reference gravel's surface. They provide a standardized measure of sedimentation within a known grain size matrix as related to a specific monitored activity. The gravel bucket is a trap and so it may not be representative of the natural environment because the bucket walls prevent exchange with the surrounding streambed. Further, if the reference gravel has a different grain size composition than the natural substrate, their trapping efficiencies will differ so bucket results may not be indicative of the retained portion of settled solids in the sample area. However, it is important to recognize that the gravel bucket is not meant to simulate the streambed. Instead, its purpose is to measure the contribution of a specific activity to the sediment loading of a stream. It quantifies the addition of sediment to the streambed and not streambed alteration. To assess streambed alteration the bucket should be deployed with another sampler that samples the streambed directly such as the McNeil corer.

4.1.3 Infiltration Bags

Infiltration bags are also traps but unlike the buckets they are collapsed and buried at the bottom of a column of reference gravel within the streambed. They have an advantage over gravel buckets because the column of reference gravel is open to exchange with the surrounding streambed and samples depositing sediment and sediment that is vertically or horizontally infiltrating through the streambed. The reference gravel is clean and its size and shape ensure that pore spaces are numerous and capable of retaining settled fines by reducing interstitial flow, all of which make it an effective sampler. Assuming that the sample collected when the bag is removed from the streambed represents the fine sediment burden at that location and time, this technique may be best applied over short periods before and after an event. When it is left for longer periods the reference gravel may come to equilibrium with the fine sediment composition of the bed but the time for this cannot be measured.

4.1.4 Summary

Each technique focuses on sampling a different portion of the depositing sediment load and as such it can be expected that they may provide different results for the same site as shown in Table 4.1. As previously stated, the McNeil core may be biased toward sampling of the larger grain size (>1mm) and so may not show increases in finer sediments while the traps do detect a difference. This was observed at Big Bend, Cluculz, and Spruce Creek. Infiltration bags incorporate subsurface and surface sediment movement and can therefore differ from gravel buckets as shown in Young's Creek. Further, McNeil core samples and gravel buckets can show significant increase in fine sediments due to surface loading but if these concentrations are not consistent with depth in the streambed they may not be observed by infiltration bags. Infiltration bags do not have the shelter provided by bucket walls nor do they have the potential settling areas available on natural substrate so their surface fines may be more easily disturbed. This was observed at Young's Creek where both buckets and cores showed higher fine sediment burden than the bags.

Insufficient sample numbers may also explain the apparent discrepancy between the data collected by different samplers. Many of the case studies did not have sufficient sample numbers collected as was later determined by the sample number estimate program initiated in Cluculz, Spruce, and Youngs Creek. For example, four McNeil cores and three buckets were originally collected at Nithi River but according to our sample size estimates from the CV analysis, six cores and eight buckets would have been more representative for that stream width. Although neither the McNeil nor gravel bucket data set has the appropriate number of replicates, the McNeil core sample number was closer to the suggested number than the buckets. This may explain why cores determined there to be higher sand concentrations downstream and the gravel buckets did not (Table 4.1).

The sample size requirement information indicates that the infiltration bag will return the least variable data with the fewest number of samples for the 5 m wide stream while sample numbers are similar for all techniques in the 9 and 11 m wide creek (Table 4.2). Generally, the sample numbers are comparable across techniques indicating that each is capable of returning acceptable data with relatively few replicates. Further, the data gathered by these different techniques is often comparable. Where it is not possible to collect the suggested number of replicates due to site restrictions, the sample size should be no less than three samples, which was shown in the Big Bend, Nithi River, and Government Creek site to be sufficient to determine a difference between sites.

Table 4.1: Summary results for the seven case studies where differences were observed between sites. Differences between employed samplers are bolded and italicized.

Site	Techniques	Results
Big Bend Creek	McNeil Core Gravel Buckets	Higher sand downstream Higher sand and ***clay downstream***
Cluculz Creek	McNeil Core Gravel Bucket Infiltration Bag	Higher sand and clay downstream Higher sand and clay downstream Higher very fine gravel upstream
Greer Creek	McNeil Core Gravel Bucket	No site differences No site differences
Mugaha Creek	McNeil Core Gravel Bucket Infiltration Bags	Higher sand downstream Higher sand downstream Higher sand downstream
Nithi River	McNeil Core Gravel Bucket	***Higher sand downstream*** ***No site differences***
Spruce Creek	McNeil Core Gravel Bucket	***No site differences*** ***Higher sand downstream***
Young's Creek	McNeil Core Gravel Bucket Infiltration Bag	***Higher sand downstream*** ***Higher sand downstream*** ***No site differences***

Table 4.2. Sample size estimates for each sampling technique in 5, 9, and 11m wide creeks.

Stream Widths	McNeil Core	Gravel Bucket	Infiltration Bag
5	6	8	4
9	8	9	8
11	10	10	10

To summarize, technique sensitivity is subjective because each technique was found to return acceptable data with similar sample numbers per given stream width (Table 4.2). Further, there was general agreement between sample results for deployed techniques in each of the eight case studies. Sensitivity then is a consideration best decided upon by the sampler and the monitoring requirements of the project. For example, it is likely that the trapping techniques will be more sensitive to subtle increases in the depositing sediment load when the source is constant because their reference gravels have been cleaned and are of a size that optimizes trapping of fine sediments (Meehan and Swanston, 1977). However, while they may be more sensitive to increased fine sediments the data collected by them may not represent a similar change to the streambed and so the information gathered may be more relevant if partnered with the McNeil corer. Finally, the McNeil core and infiltration bag may be a more sensitive measure of compositional changes with depth if the sediment supply stops and sediment has already been deposited on the streambed.

4.2 Cumulative Effects and Forestry

Forest harvesting activities can increase point source loading of sediment to streams within a watershed. The routing and downstream accumulation of sediment from these point sources is of concern because it will affect stream biota and streambed composition at each of its temporary storage areas. This sedimentary cumulative watershed effect (CWE) is one of the most detrimental consequences of forest harvesting activities on a watershed. However, the CWE is difficult to assess because its effect is dependent upon the grain size being introduced, the sequence of streams that transport it, and the original sedimentary state of the streambed it encounters (Bunte and MacDonald, 1999). Further, while it may be possible to determine the change in fine sediment levels at a single point in the stream, it is difficult to determine which upstream land use activities instigated the change.

Bunte and MacDonald (1999) suggest that to manage a watershed for cumulative sediment effects it is necessary to monitor for a minimum of 5 - 10 years pre-and-post harvesting because sediment transport is highly variable. However, this type of program is cost prohibitive and exceeds the time frame required under most resource management programs. The sampling protocol presented here may bridge the gap between the long-term study and the need for immediate information to address management needs.

Applying the monitoring protocol presented here, short-term spatial monitoring around selected activities, will make it possible to designate sediment load increases on an activity and site specific basis. That is, by monitoring a representative number of sites for specific forest harvesting activities the sediment contribution from forest harvesting practices within an affected watershed can be estimated. For example, monitoring 20% of all stream crossings, riparian harvest areas, and landing sites near streams within a harvested watershed will allows for estimation of the contribution from these point sources. Further, these data can be used to justify the modification of those practices found to contribute significant amounts of fine sediment.

4.3 Potential Errors

Three sources of error have the potential to affect project results, namely sampling error, measurement error, and interpretation error. Sampling error refers to errors in the sampling method, which is the selection of sites and techniques. Measurement error refers to error in sampling extraction and analysis. Interpretation error refers to error in data interpretation, which results in an erroneous conclusion.

Sampling error was addressed in two manners, site establishment data ensured consistency in sample site conditions between sampling stations within a stream and techniques were deployed in accordance with available standards (McNeil and Ahnell 1964, Lisle and Eads 1991). The site establishment data assured maximum sample site similarity given available field conditions. Although it may have been possible to find more comparable sites further up or downstream of the selected stations, there was a spatial sampling constraint. Specifically, if similar sites were chosen that were more than a couple of reach lengths from each other data interpretation is made more complex because we would have to account for the influence of tributaries, springs, or any sites of increased streambank erosion and sedimentation between the stations. Finally, where the number of sample sites within a station were limited and a sample had to be collected in a location having depth and velocity levels well outside the mean for that station, its data could be excluded from future analysis should it be shown to be an outlier.

There was limited information to draw from when developing this sampling protocol. Specifically, there was no sampling guidebook that discussed the theoretical and practical considerations necessary to design an effective sampling program. As such, the design and sampling process provided educational opportunities to improve the protocol. Starting with basic information available from the literature on how to use these sampling techniques, we were able to modify the technique to suit our specific needs and the assumptions behind these modifications were verified in the field. For example, the McNeil core has steel teeth that must be driven into the streambed by exerting pressure from above. It appears that the best approach is to torque the handles forcing the teeth to to cut the streambed. When sampling in the field, it is immediately obvious that when you torque the handles the core can rock, particularly on coarse substrate. This rocking results in the formation of fine sediment plumes behind the corer due to bed disturbance. To counteract this condition two adjustments were needed. First sampling was conducted in an upstream manner to minimize contamination of sample sites downstream with excess fines caused by streambed disturbance during the sampling process. Secondly, to maximize capture of fines the coring process the sampler had to be tall enough to rest their body on top of the core and also had to be sufficiently heavy to force a good seal between the core tube and the streambed.

Measurement error refers specifically to sample analysis procedures and field instruments. A commercial laboratory analyzed sediment samples in accordance to ASTM standards for gravimetric sieving. In addition to the adherence of this sampling protocol, 5-10% of the samples sent were re-sieved and the values compared. If the original and re-sieved values were more than 5% different from each other the sample was again re-sieved and if the difference held true, the samples from that batch were excluded. Fortunately, no re-sieved samples lay outside the acceptable level of difference.

Field instruments included a measuring tape, velocity meter, clinometer, and ruler. The same field equipment was used throughout the study to ensure consistency between sample stations within and between streams. The velocity meter was calibrated prior to the field season and its maintenance procedures were adhered to throughout the study period. The combination of these activities ensured that collected data were of good quality.

Interpretation error is theoretically more complex to address because it refers to our reliance on numerical information gathered by these techniques to reconstruct what happened at our sampling stations. It is a result of the cumulative error generated by program design and statistical analysis. These issues exceed the scope of this thesis. It is assumed here that the sampling design employed at each site was suitable for assessment purposes and that the resulting statistical interpretation led to the appropriate result.

Chapter 5: Conclusion and Recommendations

The results of this thesis confirm that forest road construction and maintenance activities at stream crossings can increase the downstream level of fine grain sedimentation. As such, the null hypothesis, that these activities do not increase fine grain sedimentation, is rejected. Equally important to this finding is the achievement of the thesis objective, which was to develop a sampling protocol that could determine increases in fine grain sedimentation. The protocol presented here included:

- The application of one or more fish habitat evaluation techniques (McNeil Core, gravel bucket, infiltration bag).
- The use of an impact-control sampling design.
- The collection of site establishment data to ensure that sites were biophysically similar.
- The use of a two-way ANOVA and Tukey's HSD test to detect significant differences.

The case study findings remained consistent when the effect of pseudoreplication was considered. Further, despite the low number of samples collected at case study sites, when compared to those determined by the sample number estimate program, significant differences were found because the sites exhibited a greater magnitude of difference than that set when using the sample number formula.

Each sampling technique has environmental limitations and sampling situations to which they are best applied. Although each technique can detect increases in sedimentation, they are best used in combination because they measure different things. The McNeil core samples the streambed directly, the gravel bucket captures and retains depositing or saltating sediment, and the infiltration bag measures sediment that deposits on and moves horizontally through the streambed.

In conclusion, the protocol presented in this thesis is an effective tool for monitoring sedimentation at stream crossings. However, there is no reason for it to be confined to this land use concern. Instead, it should be applied to monitor other forest harvesting activities as well as other land use activities that have the potential to increase a stream's sediment load. Other recommendations include the application of geochemical fingerprinting, biological monitoring, and the application of these techniques to collect sediment bound contaminants.

Incorporating a geochemical analysis of captured sediments would enhance the sampling protocol. Geochemical fingerprinting could increase the reliability of sampling results and may broaden sampling possibilities. Fletcher and Christie (1999) used inductively coupled plasma mass-spectrophotometry (ICP-MS) to identify tracer elements for several newly formed sediment sources in six small streams (<5 m wide) in the Baptiste Watershed near Fort St. James, BC. They defined an element as being a useful sediment when:

> … the greater the compositional difference between stream sediments a new source *(sediment source)*, the greater the potential value of an element as a tracer. Compositional differences between sediment and sources were therefore evaluated from: (i) the geochemical contrast (ratio) between concentration of the element within a sediment source and stream sediment above the source and (ii) by testing mean values of the sediment and source for significant differences. (p. 4)

Several elements were found to be acceptable tracers for the studied basins including calcium, chromium, iron, manganese, nickel, phosphorous, strontium, and titanium. Although not originally identified as a tracer, zinc was also found to be useful because it gave very high concentrations downstream of new stream crossings. They concluded this to be a result of sediment abrading the new galvanized culverts. Once identified, tracer elements were used to determine mixing or dilution of the new sediment into the streambed downstream. They found that within 200m of the new sediment source the added sediment concentrations had fallen to less than 10% on these small streams. This technique would benefit assessment sampling around specified forest harvesting activities because it would be possible to designate the source material of the increased sediment. Further, by sampling at distances downstream from the investigated activity it would be possible to determine the total streambed area effected and the period of effect. Finally, the application of this protocol in a Before-After-Control-Impact study design will make study findings more definitive because the temporal change in impact and control sites can be assessed as a function of the investigated activity.

Once increases in fine sediment are documented it is possible to hypothesize biological effects with reference to provincial water quality criteria (Nagpal, 2000) and the available literature (Culp *et al.* 1986, Waters 1995, Shaw and Richardson 2001). If used in this manner the protocol described here holds good potential as a surrogate for determining biological effects:

Because it is difficult to reliably assess the relationship between essential in-stream habitat and the eventual survival to adulthood of anadromous salmonids, monitoring the physical attributes of habitats that support aquatic organisms is a fundamental first step in evaluating the link between the effects of timber harvesting and anadromous fishes. (Conquest *et al.*, 1994 p. 76).

As with most biological systems, the rules do not always hold true so instead of relying solely on sediment information it is recommended that these studies be conducted in conjunction with biological monitoring programs to determine the susceptibility of monitored populations to observed increases in fine sediment deposition. Candidate populations include periphyton and invertebrates but if fish are the resource concern it is suggested that redds, eggs, or survival-to emergence of fry be used because unlike the more transient adults these forms reside in the streambed and will be more greatly effected by temporally constrained sediment pulses. Periphyton and invertebrate populations can be collected relatively quickly and interpreted with reference to accepted techniques including the rapid bio-assessment protocols of the U.S. EPA (Plafkin *et al.*, 1989) or other biologic indices such as the index of biological integrity (Karr and Chu, 1998). When used in combination, the results of the sedimentation and biological community assessment will be more conclusive.

Finally, this protocol should not be limited to assessing forest road construction and harvesting effects alone. Instead, it can be applied to the management of all land use activities that have the potential to increase fine sediment deposition in streambeds. Another potential application of the sampling techniques is to capture sediment for the analysis of sediment bound contaminants. This includes those programs focussing on the quantification of pesticides, hydrocarbons, heavy metals, organo-chlorines and others that may be released from industrial activities such as agricultural activities, mining, and pulp mills.

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Appendix 1

Transcribed Field Forms

BIG BEND CREEK

General Site Identification

Forest District:	Vanderhoof
Location:	Bridge is at 77 km on the Kluskus Forest Forest Service Road
Biogeoclimatic Zone:	Sub-boreal Spruce moist cold climate (Babine variant) - SBSMC2
Ecoregion:	Nechako Lowland
Site Referral:	Norm Fallows, Vanderhoof
Forest Operator:	Plateau Forest Products
Investigated Activity:	Bridge built to replace pre-existing culverts
Dates Visited:	September 16, October 22, November 10 1997

General Physical Observations

Big Bend Creek is an S2 stream (fish bearing and between 5 and 15 m wide) located on the Kluskus Forest Service Road. The creek crosses this Forest Service Road at two locations, one at 77.5 km, and the other at 84 km. It is at the 77.5 location where the new bridge was installed. Two stations were established in the creek with the downstream (d/s) station located approximately 15 m d/s of the new bridge, and the upstream (u/s) station located approximately 5 m u/s of the road crossing at the 84 km location. Beaver activity immediately u/s of the new bridge prevented installing the u/s site at that location. However, given the high density of beaver dams it seems logical to assume sediment additions between sites would be retained behind the dams.

During the initial visit, the d/s site was approximately 7.0 m wide with the u/s site between 3 – 4 m wide. Because of the distance between the sites it was necessary to complete site establishment procedures at both stations.

Visually, the creek appeared to be carrying little or no fine sediment. However, the d/s station had considerable amount of fine sediment on the creek bed as compared to the u/s site. It was expected that both the McNeil Ahnell cores and the trapping method installed, gravel buckets, would show a difference in the amount of material transported d/s versus u/s.

Upstream Site (U/S):

This site was located approximately 5 m u/s of the road crossing at the 84 km location. Sampling was conducted in a riffle/run area.

Downstream Site (D/S):

This site was located 20 m d/s of the new bridge constructed at the 77.5 km location. Sampling was conducted in a riffle/run area.

Site Location and Description

	UPSTREAM	DOWNSTREAM
GPS Coordinates	North 53° 29'178" West 124° 31'582" Altitude 941 m	North 53° 31'860" West 124° 35'166" Altitude 975 m
Channel Width (m)	3.5	7.0
Bankfull Width (m)	5.0	8.0
Bankfull Height (m)	0.5	0.5
Floodplain	Extends 10m on either side of channel. Predominant vegetation around creek is willow.	Extends 10 m on right bank. Follows channel on left bank. Riparian vegetation is mostly wetland species.
Pebble Count Data		
% < 2mm	18	44
% 2 - 4mm	2	3
% 4 - 8mm	9	1
% 8 - 16mm	15	8
% 16 - 32mm	26	16
% 32 - 64mm	16	17
% 64 – 90mm	6	3
% 90 – 128mm	2	5
% 128 – 180mm	3	2
% 180 – 256mm	2	1
% 256 – 512mm	1	0
Streambed Composition	18% sand, 68% gravel, 13% cobble, 1% boulder	44% sand, 45% gravel, 11% cobble
Gradient (%)	3.0	2.0
1st Installation – Sep 16		
Discharge (m^3/s)	0.353	0.229
Weather	4/10 cloud cover, 15.9°C	same as upstream
Water Temp. (°C)	10.0	10.7
Dissolved O_2 (mg/L)	12.4	11.8
Turbidity (NTU)	n/a	n/a
Methods Deployed	McNeil Cores, Gravel Buckets	McNeil Cores, Gravel Buckets
1st Removal/ 2nd installation – Oct. 23		
Discharge (m^3/s)	0.58	0.60
Channel Width (m)	3.8	7.15
Weather	7/10 cloud cover	as u/s
Water Temp. (°C)	2.8	3.6
Dissolved O_2 (mg/L)	13.3	13.2
Turbidity (NTU)	1.73, 1.40, 1.34, 1.11	1.12, 0.94, 0.94
Methods Deployed	McNeil cores and Gravel Buckets	as u/s
2nd Removal- Nov. 10		
Discharge (m^3/s)	0.46	0.54
Channel Width (m)	5.8	8.0
Weather	5/10	as u/s
Water Temp. (°C)	0.2	0.1
Dissolved O_2 (mg/L)	13.9	13.4
Turbidity (NTU)	0.98, 1.01, 1.05	0.71, 0.76, 0.70
Methods Deployed	Gravel Buckets	McNeil Cores, Gravel Buckets

Site Location and Description

	Upstream	Downstream
1st Installation – Sep 16		
McNeil #1	15 cm, 0.934 m/s	12 cm, 0.232 m/s
McNeil #2	18 cm, 0.843 m/s	12 cm, 0.256 m/s
McNeil #3	21 cm, 0.901 m/s	13 cm, 0.347 m/s
McNeil #4	21 cm, 0.769 m/s	12 cm, 0.447 m/s
McNeil #5	18 cm, 0.719 m/s	12 cm, 0.339 m/s
McNeil #6	15 cm, 0.662 m/s	7 cm, 0.223 m/s
	Infiltration was medium-high. No. 4 had very high infiltration.	Samples 1-5 were very silt/clay based. Sample 6 had more gravel than the others. Infiltration was low for all.
Gravel Bucket #1	15 cm, 0.934 m/s	12 cm, 0.388 m/s
Gravel Bucket #2	18 cm, 0.843 m/s	16 cm, 0.422 m/s
Gravel Bucket #3	21 cm, 0.901 m/s	16 cm, 0.273 m/s
Gravel Bucket #4	21 cm, 0.769 m/s	21 cm, 0.488 m/s
Gravel Bucket #5	18 cm, 0.719 m/s	18 cm, 0.504 m/s
Gravel Bucket #6	15 cm, 0.662 m/s	18 cm, 0.455 m/s
Infiltration Bags	Infiltration bags were not used due to high clay content.	
1st Installation – 2nd Removal		
McNeil #1	32 cm, 0.447 m/s	25 cm, 0.719 m/s
McNeil #2	30 cm, 0.414 m/s	23 cm, 0.628 m/s
McNeil #3	31 cm, 0.438 m/s	21 cm, 0.571 m/s
McNeil #4	31 cm, 0.389 m/s	21 cm, 0.504 m/s
McNeil #5	31 cm, 0.347 m/s,	21 cm, 0.513 m/s
McNeil #6	33 cm, 0.281 m/s	24 cm, 0.571 m/s
Gravel Bucket #1	40 cm, 0.529 m/s	23 cm, 0.662 m/s
Gravel Bucket #2	41 cm, 0.521 m/s	22 cm, 0.629 m/s
Gravel Bucket #3	41 cm, 0.513 m/s	23 cm, 0.662 m/s
Gravel Bucket #4	39 cm, 0.513 m/s	23 cm, 0.463 m/s
Gravel Bucket #5	36 cm, 0.488 m/s	23 cm, 0.703 m/s
Gravel Bucket #6	38 cm, 0.463 m/s	19 cm, 0.662 m/s
	Gravel Buckets replaced in same holes	Gravel Buckets replaced in same holes except #4 20 cm, 0.628 m/s

- The upstream site at Big Bend Creek was narrower in channel width and deeper. It was not possible to find similar depths at the downstream site.

2nd Removal and Site Closure	Upstream	Downstream
McNeil-Ahnell	None Taken	
Gravel Bucket #1	64 cm, 0.256 m/s	18 cm, 0.595 m/s
Gravel Bucket #2	65 cm, 0.232 m/s	21 cm, 0.604 m/s
Gravel Bucket #3	66 cm, 0.232 m/s	20 cm, 0.628 m/s
Gravel Bucket #4	65 cm, 0.215 m/s	22 cm, 0.562 m/s
Gravel Bucket #5	63 cm, 0.174 m/s	22 cm, 0.628 m/s
Gravel Bucket #6	61 cm, 0.174 m/s	21 cm, 0.604 m/s

Summary Statistics

(Results of Two- Way Anova – arc-sin transformed for McNeil cores and weights for Buckets)

Date	Technique	Site Difference	Interaction Effect	Grain Size Differences
September 16	McNeil Core	None; p =0.067	Yes; p = 0	More gravel upstream (P=0.03) More medium sand downstream (P = 0.00004)
October 22	McNeil Core	Yes; p =0.003	Yes; p = 0	Tukey's HSD – Higher Fine gravel U/S, Med. Sand D/S
	Gravel Buckets	Yes; $p = 6.7 * 10^{-9}$	Yes; p = 0	Tukey's HSD –Higher Med. and fine sand D/S
November 10	Gravel Buckets	Yes; p= 0.011	Yes; p= 0.01	Tukey's HSD – Higher Med. Sand D/S

CLUCULZ CREEK

General Site Identification

Forest District:	Vanderhoof
Biogeoclimatic Zone:	Sub-boreal Spruce dry warm climate (Stuart variant) SBSDW3
Ecoregion:	Nechako Lowland
Site Referral:	Norm Fallows, Vanderhoof
Forest Operator:	Canfor
Investigated Activity:	Removal of two smaller culverts- installation of pipe arch.
Dates Visited:	July 25, August 21, September 23, October 22, November 6 1997

General Physical Observations (pre-construction)

Cluculz Creek is located at kilometer 47.5 on the Bobtail Forest Service Road. Prior to the removal of the two smaller culverts and installation of the pipe arch, two stations were established, one upstream (u/s) and one downstream (d/s) of the road. The u/s or control station was located approximately 20 m upstream of the culvert and the d/s site was located approximately 20 m downstream of the culverts.

At the time of the initial visit, the creek was >5 m wide and had a gradient of 5-6%. The u/s and d/s site each had riffles and glides/runs.

The creek appeared to be carrying little or no sediment. It was thought that during culvert removal considerable sediment would be generated that may settle downstream so trapping methods, namely gravel buckets and infiltration bags, were selected. Further, to assess present streambed conditions McNeil-Ahnell cores were taken pre-construction and will be compared with those following road maintenance activities.

Upstream Site (U/S): The site was located approximately 40m from the road. McNeil-Ahnell cores were taken in the riffle zone. At the time of the first visit, it was discovered that stream survey crews would be working in the creek. No gravel buckets were deployed for this reason, as it would cause bias the collection of sediment.

Downstream Site (D/S): The site was located approximately 20 m from the road. The downstream site was located so close to the impact source because of a change in the channel morphology further downstream. The gradient became steeper past this 20 m location and there was a large woody debris barrier located at 30 m downstream. McNeil-Ahnell cores were taken in the riffle zone. No gravel buckets were deployed during the initial field visit for the same reason as mentioned above.

Site Location and Description

	UPSTREAM	DOWNSTREAM
1st Install – Jul 25		
Discharge (m^3/s)	As downstream	$0.591 m^3s^{-1}$
Weather	8/10 cloud cover	same as upstream
Water Temp. (°C)	n/a	n/a
Diss. O_2 (mg/L)	n/a	n/a
Turbidity (NTU)	n/a	n/a
Methods Deployed	McNeil-Ahnell Cores	McNeil-Ahnell Cores
GPS Location	N 53°43.416 W 123°36.025 Altitude 921 m	Same as Upstream
Channel Width (m)	6.0 meters	7.0 meters
Bankfull Width (m)	7.0 meters	7.0 meters
Bankfull Height (m)	1.0	0.1 meters
Floodplain	~5 meters	Little to no floodplain noted
Streambank	Fine gravel/cobble shore	High riparian vegetation, undercut
Pebble Count		
% <2mm	4	8
% 2- 4mm	1	2
% 4 – 8mm	2	3
% 8 – 16mm	4	3
% 16- 32 mm	15	30
% 32 – 64mm	24	24
% 64- 128mm	8	10
% 128 – 180mm	38	13
% 180 – 256mm		
% 256 – 512mm	4	3
% 512- 1024mm		4
Streambed Composition	4% Sand: 46% Gravel: 46% Cobble: 4% Boulder	8% Sand: 60% Gravel: 23%Cobble: 7% Boulder
Gradient (%)	6	5.5

Second Installation (August 15, 1997)

At the time of our second visit culvert replacement had begun. McNeil-Ahnell cores were taken, and gravel buckets were installed. Infiltration bags were not used, due to unsuitable substrate (bedrock) in u/s site. Gravel buckets were placed in the same area as the McNeil-Ahnell cores. While taking d/s velocity readings, incoming plumes of silt were noticeable. A small number of Kokanee were present, swimming upstream.

	UPSTREAM	DOWNSTREAM
2nd Install – Aug 15		
Turbidity (NTU)	1	12.7
Methods Deployed	McNeil Cores, Gravel Buckets	McNeil Cores, Gravel Buckets
2nd Removal	Aug 20	Aug 21
Discharge (m^3/s)	n/a	n/a
Weather	n/a	10/10
Water Temp. (°C)	n/a	14.1
Diss. O_2 (mg/L)	n/a	11.0
Turbidity (NTU)	1	2
Methods Deployed	McNeil Cores, Gravel Buckets	McNeil Cores, Gravel Buckets

Third Installation (August 20 and 21, 1997)

At the time of the third installation the culvert replacement had been completed and the stream banks were being back-filled. The creek morphology had changed greatly in that the creek was now more of a straight channel. The channel width had decreased both upstream and downstream. There was a noticeable increase of sediment on streambed, especially in the d/s site the downstream streambed substrate was tan in colour as opposed to its previous charcoal hue. The approach at this turn now had a higher slope than pre-construction. Kokanee were still present in the creek.

Physical Observations (post-construction)

Due to construction, the creek morphology had changed noticeably, and as a result the u/s and d/s stations were relocated. The riparian vegetation that provided cover to the creek had been removed, resulting in a much more exposed stream. The width of the creek at the site of flow measurements was reduced to 3.5 m from 7.0 meters. The streambank on either side of the road had been changed with the addition of large boulders to act as a rock revetment. Upstream of the road, the revetment extended to approximately 30 m on the left bank. Visually the creek appeared to be carrying little to no sediment. McNeil cores were not collected in the area covered with tan sand because this was the location of previous sampling so McNeils were collected downstream outside of this obvious zone of impact.

Upstream: The new station was located approximately 20 m upstream of the culvert in a riffle zone. McNeil-Ahnell cores were taken in the riffle area and gravel buckets were placed in the same sites. Infiltration bags were placed approximately 5 m downstream of the gravel buckets and not directly behind them.

	UPSTREAM	**DOWNSTREAM**
3rd Install – Sep 23		
Discharge (m^3/s)	Same as downstream	0.316
Weather		
Water Temp. (°C)		
Diss. O_2 (mg/L)		
Turbidity (NTU)		
Methods Deployed	McNeil Cores, Infiltration Bags, Gravel Buckets	McNeil Cores, Infiltration Bags, Gravel Buckets

Notes: At the time of the third removal, it was discovered that some of the gravel buckets had been washed away, likely due to high discharge. For the 4th installation the gravel buckets were placed in an area with slower flow. Two of the infiltration bags located D/S had been scoured, and the rims were exposed, therefore the sample was discarded.

	Upstream	**Downstream**
3rd Removal/4th Install	**Oct. 22**	**Oct. 22**
Discharge (m^3/s)	same as D/S	0.625
Weather	4/10 cloud cover	same as U/S
Water Temp. (°C)	3.7	same as U/S
Diss. O_2 (mg/L)	12.0 mg/L	same as U/S
Turbidity (NTU)	1.43, 1.35, 1.33	1.23, 1.11, 1.28
Methods	Gravel Buckets, Infiltration Bags	Gravel Buckets, Infiltration Bags

4th Removal – Nov 6 Discharge (m^3/s) Weather Water Temp. (°C) Diss.O_2 (mg/L) Turbidity (NTU)	 Same as downstream 2/10 Cloud, -4°C 2.3 13.4	 1.124 Same as Upstream Same as Upstream

Site Placement Depths and Velocities

	Upstream	Downstream
1st Install – Jul 25		
McNeil #1	12 cm, 0.347 m/s	10 cm, 0.331 m/s
McNeil #2	10 cm, 0.248 m/s	12 cm, 0.273 m/s
McNeil #3	12 cm, 0.240 m/s	12 cm, 0.265 m/s
2nd Install – Aug 15		
McNeil/ G.Bucket #1	21 cm, 0.339 m/s	16cm, 0.546 m/s
McNeil/ G.Bucket #2	18 cm, 0.463 m/s	12 cm, 0.446 m/s
McNeil/ G.Bucket #3	18 cm, 0.455 m/s	18 cm, 0.678 m/s
McNeil/ G.Bucket #4	18 cm, 0.496 m/s	10 cm, 0.604 m/s
2nd Removal – Aug.21		
G.Bucket #1	18 cm, 0.165 m/s	23 cm, 0.339 m/a
G.Bucket #2	21 cm, 0.488 m/s	18 cm, 0.604 m/s
G.Bucket #3	15 cm, 0.678 m/s	18 cm, 0.538 m/s
G.Bucket #4	18 cm, 0.554 m/s	12 cm, 0.504 m/s
McNeil #1	24 cm, 0.910 m/s	15 cm, 0.314 m/s
McNeil #2	21 cm, 0.686 m/s	15 cm, 0.165 m/s
McNeil #3	20 cm, 0.298 m/s	18 cm, 0.256 m/s
McNeil #4	15 cm, 0.901 m/s	18 cm, 0.562 m/s
3rd Install – Sept 23		
McNeil/ G.Bucket #1	14 cm, 0.554 m/s	11 cm, 0.554 m/s
McNeil/ G.Bucket #2	14 cm, 0.843 m/s	10 cm, 0.504 m/s
McNeil/ G.Bucket #3	15 cm, 0.769 m/s	12 cm, 0.562 m/s
McNeil/ G.Bucket #4	11 cm, 1.19 m/s	15 cm, 0.670 m/s
McNeil/ G.Bucket #5	15 cm, 0.876 m/s	13 cm, 0.761 m/s
McNeil/ G.Bucket #6	15 cm, 0.446 m/s	12 cm, 0.595 m/s
Infiltration Bag #1	9 cm, 0.248 m/s	7cm, 0.289 m/s
Infiltration Bag #2	9 cm, 0.356 m/s	7cm, 0.562 m/s
Infiltration Bag #3	8 cm, 0.298 m/s	6 cm, 0.132 m/s
Infiltration Bag #4	6 cm, 0.232 m/s	5 cm, 0.686 m/s
3rd Removal Oct. 22		
G.Bucket #1	Samplers Reinstalled	Samplers Reinstalled
G.Bucket #2		
G.Bucket #3		
G.Bucket #4		
G.Bucket #5		
G.Bucket #6		
Infiltration Bag #1		
Infiltration Bag #2		
Infiltration Bag #3		
Infiltration Bag #4		

4th Removal – Nov. 6		
Gravel Bucket #1	18 cm, 1.149 m/s	18 cm, 1.217 m/s
Gravel Bucket #2	20 cm, 1.745 m/s	22 cm, 1.223 m/s
Gravel Bucket #3	17 cm, 1.149 m/s	18 cm, 1.217 m/s
Gravel Bucket #4	18 cm, 1.149 m/s	22 cm, 1.223 m/s
Gravel Bucket #5	20 cm, 1.745 m/s	21 cm, 1.215 m/s
Gravel Bucket #6	17 cm, 1.149 m/s	21 cm, 1.215 m/s
Infiltration Bag#1	12 cm, 0.736 m/s	9 cm, 0.653 m/s
Infiltration Bag#2	18 cm, 0.926 m/s	9 cm, 0.397 m/s
Infiltration Bag#3	13 cm, 0.629 m/s	12 cm, 0.570 m/s
Infiltration Bag#4	13 cm, 0.868 m/s	12 cm, 0.752 m/s
McNeil Core#1	18 cm, 1.538 m/s	14 cm, 1.058 m/s
McNeil Core#2	15 cm, 0.820 m/s	15 cm, 1.025 m/s
McNeil Core#3	18 cm, 0.910 m/s	15 cm, 1.216 m/s
McNeil Core#4	13 cm, 0.860 m/s	17 cm, 1.340 m/s
McNeil Core#5	14 cm, 0.960 m/s	15 cm, 0.967 m/s
McNeil Core#6	19 cm, 1.100 m/s	16 cm, 0.794 m/s

Summary Statistics
(Results of Two- Way Anova – arc-sin transformed for McNeil cores and weights for Buckets)

Date	Technique	Site Difference	Interaction Effect	Grain Size Differences
July 25	McNeil Core	None; p =0.77	None; p = 0.98	None
August 21	McNeil Core Gravel Buckets	None; p = 0.92 Yes; p = $1.35*10^{-7}$	None; p=0.92 None; p= 0.09	None Site Difference Tukey's HSD- indicates all sands and silt/clay are higher downstream
September 23	McNeil Core	None; p =0.16	Yes; p = 0.025	Med Sand D/S (P= 5.04*10) Fine Sand D/S (p=$9.98*10^{-5}$) V.Fine Sand D/S (p=0.03) Silt/Clay D/S (p=0.0002)
October 22	Gravel Buckets Infiltration Bags	t-test – no differences t-test – no differences		
November 6	McNeil Cores Gravel Buckets Infiltration Bags	Yes; p=0.03 Yes; p=$6.4*10^{-17}$ Yes; p=0.01	Yes; p=$6.11*10^{-17}$ Yes; $1.7*10^{-20}$ Yes p=0.04	Site Difference – Tukey's HSD indicates higher gravel U/S, Coarse and Medium Sand D/S Site Difference- Tukey's HSD indicates higher gravel coarse and medium sand D/S Site Difference- Tukey's HSD indicates higher gravel upstream

GOVERNMENT CREEK

General Site Identification

Forest District: Prince George
Biogeoclimatic Zone: Sub-boreal spruce moist cool climate (Mossvale variant) SBSMK1
Ecoregion: Bowron Valley
Site Referral: Dave Stevenson
Operator: Dunkley Lumber
Investigated Activity: Bridge Construction
Dates Visited: July 23, 1997

General Physical Observations

Dave Stevenson (MELP habitat biologist) recommended this site for the 1996 field season. We were unable to visit the site that year and instead decided to include it in this year's program. This creek was the first site inventoried during 1997 and served as a training site. As a result, some of the information included for future creeks such as bankfull height and width was not collected for this creek.

The bridge investigated was constructed in the fall of 1996 on the 300 road at kilometer 12. It was thought that any resonant fines in the creek at the downstream site might be detected by McNeil coring. We attempted to inventory this creek again later in the summer as road construction activities and harvesting occurred but were unsuccessful due to time restraints. Both sites were contained in one sample reach that can be defined as two sets of the repeating units riffle and glide.

Upstream Site (U/S):
The upstream site is located approximately 100m up from the bridge construction area. The gradient in this area was approximately 5% and there was a prominent cobble bar at center stream. McNeil cores were taken near the left bank on a riffle bar.

Downstream Site (D/S):
The downstream site is located approximately 25m downs from the bridge. This site was chosen because it is the most similar site to that upstream. In addition, 10m downstream of this site Government Creek has a steep gradient shift changing to a cascade:pool sequence. McNeil cores were taken at the tail end of a riffle bar near the right bank. The right bank was chosen because the left bank was predominantly a depositional zone.

Site Location & Description

	UPSTREAM	DOWNSTREAM
GPS Coordinates	Same as d/s	53°32.138' N 122°28.896' W Altitude- 752 m
Channel Width (m)	8.0	8.0
Pebble Count Data		
% < 2mm	11	27
% 2 – 4 mm	6	5
% 4 - 8mm	4	2
% 8 – 16mm	13	11
% 16 –32mm	17	21
% 32 – 64mm	5	2
% 64 –128mm	14	1
% 128 – 180mm	20	13
% 180 –256mm	3	1
% 256 - 512mm	4	3
% 512 –1024mm	3	14
Streambed Composition	11% Sand, 45% Gravel, 41% Cobble, 3% Boulder	27% Sand, 41% Gravel, 18% Cobble, 14% Boulder
Gradient (%)	5	5

1st Installation

	UPSTREAM	DOWNSTREAM
Date	July 23, 1997	July 23, 1997 @ 10:15 am
Discharge (m^3/s)	0.56	As upstream
Weather	Same as d/s	7/10 cloud cover
Air Temp. (°C)	N/A	N/A
Water Temp. (°C)	N/A	N/A
Dissolved O_2 (mg/l)	N/A	N/A
Turbidity (NTU)	N/A	N/A
Methods Deployed	1) McNeil-Ahnell Cores	1) McNeil-Ahnell Cores
Site Placement Depths & Velocities	McNeil-Ahnell Cores 1. N/A 2. N/A 3. N/A	McNeil-Ahnell Cores 1. 5 - 10 cm 2. 8 cm 3. N/A (Meter malfunction)

NOTE: This was a one time sampling site. No trapping methods were installed.

Summary Statistics
(Results of Two- Way Anova – arc-sin transformed for McNeil cores and weights for Buckets)

Date	Technique	Site Difference	Interaction Effect	Grain Size Differences
July 23	McNeil Core	None; $p = 0.20$	Yes; $p = 8.7*10^{-5}$	Med. Sand D/S ($p=0.005$) Fine Sand D/S ($p=0.01$)

GREER CREEK

Site Identification

Forest District:	Vanderhoof
Biogeoclimatic Zone:	Sub-boreal Spruce dry cool (SBSDK)
Ecoregion:	Nechako Lowland
Site Referral:	Plateau Forest Products Road Crew
Forest Operator:	Plateau Forest Products
Investigated Activity:	Construction of a bridge for a new forest road.
Dates Visited:	August 7, August 21, and September 18 1997

General Physical Observations

Greer Creek is an S2 stream (fish bearing and between 5 and 15 m channel width) in the Vanderhoof Forest District. We were told of the bridge construction by road crew staff for Plateau Forest Products. The bridge was being constructed to open up a new area for logging.

The site was located at 4.5 km on the 31 road off of the Kluskus Forest Service Road. We established the site during the bridge construction and had hoped to remove it following bridge and approach completion. The goal of this program was to assess short-term effects that arise from the bridge construction activities.

The sample area was assumed to be within the same reach as there were two repeating units of a riffle:run complex. There were reports of sediment events prior to our date of installation. However, at no time during our visits did we note sediment plumes in the stream. Two methods were chosen for this assessment, McNeil cores and gravel buckets. The latter should pick up any depositing sediment from events occurring in our absence and the McNeil cores should show historical impacts between the upstream and downstream sites. There has been no activity in this reach area before so any change in fine sediment composition between the up and downstream sites would likely be due to the impact of bridge installation.

Upstream (U/S) Site:
The upstream site is located approximately 50 m u/s of the bridge construction and immediately upstream of a river bend. The creek was much wider and shallower here than at the downstream (D/S) site. As a result discharge reading were taken downstream as it was thought that they would provide more reasonable data. The stream bed is dominated with large substrate that makes coring difficult so coring sites were selected with reference to the ability to core. Gravel buckets were braced with cobble and likely did not have more than 20 cm of overlying water at any one time. The sampling area was deemed to be a run.

Downstream (D/S) Site:
The downstream site was approximately 30- 40 m downstream of the new bridge. This site was deeper and narrower than the upstream site. A riffle bar and shallow run upstream of the downstream pool were chosen for sampling. Similar to upstream the streambed material is dominated with large substrate.

Site Location and Description

	UPSTREAM	DOWNSTREAM
GPS Coordinates	As downstream	North 53° 48,411' West 124° 22.252' Altitude 898 m
Active Channel Width (m)	11.5 m	6.8 m
Bankfull Width (m)	Difficult to assess, ~ 20m	~20 m
Bankfull Height (m)	Left Bank (LB) = 2m, Right Bank (RB) = 0 (Floodplain)	RB=1.5m LB= 0.5m
Floodplain	15 m on RB	Up to 50m on LB
Streambank	No obvious sediment sources – Alder	No obvious sediment sources – Alder
Pebble Count Data		
% < 2 mm	4	11
% 2-4 mm	1	2
% 4 – 8mm	4	2
% 8 – 16 mm	6	8
% 16 – 32 mm	7	8
% 32 – 64 mm	8	20
% 64 – 90 mm	10	13
% 90 – 128 mm	10	9
% 128 – 180 mm	8	6
% 180 - 256 mm	9	4
% 256 – 512 mm	25	15
% 512 – 1024 mm	8	2
Streambed Composition		
% Sand	4	11
% Gravel	26	40
% Cobble	37	32
% Boulder	33	17
Gradient (%)	3	3
1st Installation – Aug 7		
Discharge (m^3/s^{-1})	0.15 m^3s^{-1}	Same as upstream
Weather	8/10 cloud cover, 15.7 °C	same as upstream
Water Temp. (°C)	n/a	n/a
Dissolved O_2 (mg/L)	10.9	10.9
Turbidity (NTU)	n/a	n/a
Methods Deployed	McNeil-Ahnell Cores, Gravel Buckets	McNeil-Ahnell Cores, Gravel Buckets

Notes: A second site visit, to recover samplers from August 7, was conducted on August 21. During this visit it was noted that the water level had dropped significantly. Animals removed three of the four gravel buckets installed at the d/s site. All the buckets were re-deployed but McNeil cores were not collected.

	UPSTREAM	DOWNSTREAM
1st Removal – Sept 18		
Discharge (m^3/s)	No data	No data
Weather	1/10 cloud cover	Same as u/s
Water Temp. (°C)	n/a	n/a
Dissolved O_2 (mg/L)	n/a	n/a
Turbidity (NTU)	n/a	n/a
Methods Deployed	last site visit	last site visit

Site Placement Depths and Velocities

	Upstream	Downstream
1st Installation – Aug 7		
McNeil/ G.Bucket #1	20 cm, 0.438 m/s	11 cm, 0.283 m/s
McNeil/ G.Bucket #2	16 cm, 0.232 m/s	15 cm, 0.356 m/s
McNeil/ G.Bucket #3	15 cm, 0.314 m/s	8cm, 0.314 m/s
McNeil/ G.Bucket #4	21 cm, 0.289 m/s	9 cm, 0.215 m/s
Site visit – Aug 21		
Gravel Bucket #1		
Gravel Bucket #2	NO MEASUREMENTS TAKEN	NO MEASUREMENTS TAKEN
Gravel Bucket #3	(Reset in original location)	(Reset in original location)
Gravel Bucket #4		
1st Removal – Sept 18		
G.Bucket #1	21 cm, 0.620 m/s	12 cm, 0.339 m/s
G.Bucket #2	16 cm, 0.372 m/s	21cm, 0.620 m/s
G.Bucket #3	17 cm, 0.298 m/s	17 cm, 0.314 m/s
G.Bucket #4	16 cm, 0.256 m/s	18 cm, 0.728 m/s
McNeil #1	13 cm, 0.678 m/s	11 cm, 0.108 m/s
McNeil #2	9cm, 0.265 m/s	9 cm, 0.323 m/s
McNeil #3	11cm, 0.372 m/s	9 cm, 0.405 m/s
McNeil #4	12 cm, 0.347 m/s	11 cm, 0.480 m/s
McNeil #5	12 cm, 0.323 m/s	9 cm, 0.339 m/s
McNeil #6	10 cm, 0.298 m/s	11 cm, 0.331 m/s

Summary Statistics (Results of Two-Way Anova – Arc-sin transformed for McNeil cores and weights for buckets)

Date	Technique	Site Difference	Grain Size Differences
August 7	McNeil Core	None; $p = 0.84$	N/A
September 18	McNeil Core	None; $p = 0.13$	N/A
September 18	Gravel Bucket	None; $p = 0.99$	N/A

MUGAHA CREEK

General Notes

Forest District:	Mackenzie
Biogeoclimatic Zone:	Sub-boreal Spruce moist cool climate (Williston variant SBSMK2)
Ecoregion:	Parsnip Trench
Who Referred Site:	Jim Tuck, MoF
Operator:	Finlay Forest Industries
Investigated Activity:	Channel Avulsion and Deactivated Bridge
Dates Visited:	September 9, October 8, November 12 1997

General Physical Observations

Two stations were established on Mugaha Creek, the first was 40-50 meters upstream (u/s) and the second 60-70 meters downstream (d/s) of the channel avulsion and bridge deactivation area. Although the initial goal of this program was to detect any affects from the bridge deactivation it is unlikely that affects from this activity can be separated from the large scale movement of sediment from a channel avulsion. During the initial site visit there was substantial flow through the creek. There is a large amount of deadfall and windthrow in the avulsed channel and the previous channel section is almost dry. Access to the upstream site was difficult due to the slumping caused by avulsion.

The newly created channel is considerably different than the original. It consists of an extended riffle and glide. It is approximately 50-60 meters long and has a gradient of 6.5^0. Because of the morphological differences in the avulsed channel the upstream and downstream sites were considered to be two separate reaches and site establishment methods were completed at each site.

No visible change in sediment load was observed during the three visits, the water was clear at all times. It was thought that rain events may spur an increase in erosion of the new channel's streambanks and cause increased loading at the downstream site. Also, it was thought that McNeil cores will show a increased loads downstream due to the avulsion and perhaps bridge deactivation.

Upstream Site (U/S):
Immediately upstream of the control site the creek forks . However, the majority of the flow (~ 95%) was visually determined to pass through our upstream station. Sampling will be done in the riffle-run areas.

Downstream Site (D/S):
Upstream of this site the avulsed and original channel confluence and where they mix a deep pool with large amount of surficial sediment. This site consists of a run-riffle.

	UPSTREAM	Channel Avulsion	DOWNSTREAM
GPS Coordinates	55°28.112 N, 123°05.768 W, 838 m		As upstream
Channel Width (m)	10.45 m	5.45m	10.0 m
Bankfull Width (m)	12.0 m	6.95m	12.0 m
Bankfull Height (m)	0.5 m	1.35m	RB = 0.5 m LB= 1.0 m
Floodplain	3-4 m	3-4m	RB= 5-7 m
Streambank	Fine textured erodible soil	Fine erodible soil	As upstream
Pebble Count Data			
% < 2mm	10	16	9
% 2 – 4mm	2	2	1
% 4 – 8mm	6	8	5
% 8 – 16mm	10	20	11
% 16 – 32mm	30	31	29
% 32 – 64mm	25	16	22
% 64- 128mm	10	7	11
% 128 –180mm	5		6
% 180 –256mm	1		4
% 256 –512mm	1		2
Streambed Composition	10% Sand, 73% Gravel, 16% Cobble, 1% Boulder	16% Sand, 77% Gravel, 7% Cobble,	9% Sand, 68% Gravel, 21% Cobble, 2% Boulder
Gradient (%)	4.0	4.5	4.0
1st Installation – Sept. 9			
Time	10:00	10:00	16:30
Discharge (m^3/s)		0.87 m^3s^{-1}	0.871 m^3s^{-1}
Weather	4/10 cloud cover, 12.6 °C		4/10 cloud cover, 14°C
Water Temp. (°C)	8.5°C		11.4°C
Dissolved O_2 (mg/L)	12.5 mg/l		11.5
Turbidity (NTU)	0.5 NTU		0.55 NTU
Methods Deployed	McNeil, Gravel Buckets, Infiltration Bags		McNeil Cores, Gravel Buckets, Infiltration bags

Notes:

- The field camera was later found to be non-operational so photos were not developed.

	UPSTREAM	DOWNSTREAM
1st Removal/2nd Install – Oct. 8		
Discharge (m^3/s)	No data	1.13 m^3s^{-1}
Weather	9/10 cloud, 30 km wind, snow, 0°C	same as u/s
Water Temp. (°C)	n/a	n/a
Dissolved O_2 (mg/L)	n/a	n/a
Turbidity (NTU)	n/a	n/a
Methods Deployed	last site visit	last site visit

	Upstream	Downstream
2nd Removal - Nov. 12		
Discharge (m^3s^{-1})	1.67	As upstream
Weather	0.2 °C	As upstream
Water Temp (°C)	0.1	As upstream
Dissolved O_2 (mg/L)	14.1	As upstream
Turbidity (NTU)	Not Working	As upstream
Methods Deployed	As last visit	As last visit

Site Placement Depths and Velocities

	Upstream	Downstream
1st Installation – Sept. 9		
McNeil #1	9 cm, 0.455m/s	6 cm, 0.273 m/s
McNeil #2	12 cm, 0.455 m/s	9 cm, 0.405 m/s
McNeil #3	12 cm, 0.562 m/s	9 cm, 0.157 m/s
McNeil #4	15 cm, 0.770 m/s	9 cm, 0.116 m/s
McNeil #5	10 cm, 0.198 m/s	15 cm, 0.364 m/s
McNeil #6	10 cm, 0.562 m/s	9 cm, 0.240 m/s
Gravel Bucket #1	29 cm, 0.810m/s	21 cm, 0.736 m/s
Gravel Bucket #2	30 cm, 0.843 m/s	21 cm, 0.711 m/s
Gravel Bucket #3	27 cm, 0.893 m/s	27 cm, 0.587 m/s
Gravel Bucket #4	32 cm, 0.860 m/s	27 cm, 0.769 m/s
Gravel Bucket #5	33 cm, 0.662 m/s	26 cm, 0.447 m/s
Gravel Bucket #6	32 cm, 0.695 m/s	26 cm, 0.488 m/s
Infiltration Bag #1	9 cm, 0.455 m/s	6 cm, 0.273 m/s
Infiltration Bag #2	12 cm, 0.455 m/s	9 cm, 0.157 m/s
Infiltration Bag #3	12 cm, 0.562 m/s	9 cm, 0.116 m/s
Infiltration Bag #4	15 cm, 0.769 m/s	9 cm, 0.240 m/s

	Upstream	Downstream
1st Removal / 2nd Installation October 8, 1997		
McNeil #1	20 cm, 0.620 m/s	12 cm, 0.356 m/s
McNeil #2	18 cm, 0.587 m/s	12 cm, 0.380 m/s
McNeil #3	17 cm, 0.587 m/s	12 cm, 0.405 m/s
McNeil #4	20 cm, 0.653 m/s	12 cm, 0.347 m/s
McNeil #5	19 cm, 0.604 m/s	11 cm, 0.397 m/s
McNeil #6	21 cm, 0.612 m/s	14 cm, 0.488 m/s
Gravel Bucket #1	20 cm, 0.620 m/s	15 cm, 0.455 m/s
Gravel Bucket #2	18 cm, 0.587 m/s	14 cm, 0.488 m/s
Gravel Bucket #3	17 cm, 0.587 m/s	14 cm, 0.513 m/s
Gravel Bucket #4	20 cm, 0.653 m/s	15 cm, 0.480 m/s
Gravel Bucket #5	19 cm, 0.604 m/s	15 cm, 0.414 m/s
Gravel Bucket #6	21 cm, 0.612 m/s	15 cm, 0.232 m/s
Infiltration Bag #1	10cm, 0.389 m/s	8 cm, 0.571 m/s
Infiltration Bag #2	12 cm, 0.579 m/s	12 cm, 0.256 m/s
Infiltration Bag #3	21 cm, 0.554 m/s	10 cm, 0.273 m/s
Infiltration Bag #4	20 cm, 0.587 m/s	15 cm, 0.480 m/s
U/S Infiltration Bag #1 (new)	18 cm, 0.588 m/s	
U/S Infiltration Bag #2 (new)	24 cm, 0.570 m/s	
U/S Infiltration Bag #3 (new)	21 cm, 0.736 m/s	
U/S Infiltration Bag #4 (new)	19 cm, 0.554 m/s	

Note:

- At the upstream and downstream sites there was some bedload movement noted by the presence of large substrate on the gravel buckets and infiltration bags.
- The upstream infiltration bags were moved to a site more representative of the downstream location.

	Upstream	Downstream
2nd Removal- Nov. 12		
McNeil #1	23 cm, 0.951 m/s	15 cm, 0.471 m/s
McNeil #2	23 cm, 1.149 m/s	12 cm, 0.612 m/s
McNeil #3	23 cm, 0.967 m/s	12 cm, 0.538 m/s
McNeil #4	24 cm, 0.893 m/s	15 cm, 0.703 m/s
McNeil #5	23 cm, 0.860 m/s	16 cm, 0.521 m/s
McNeil #6	22 cm, 0.339 m/s	15 cm, 0.571 m/s
Gravel Bucket #1	23 cm, 0.918 m/s	21 cm, 0.752 m/s
Gravel Bucket #2	21 cm, 0.992 m/s	22 cm, 0.562 m/s
Gravel Bucket #3	24 cm, 0.893 m/s	22 cm, 0.769 m/s
Gravel Bucket #4	24 cm, 0.719 m/s	22 cm, 0.736 m/s
Gravel Bucket #5	23 cm, 0.860 m/s	18 cm, 0.678 m/s
Gravel Bucket #6	24 cm, 0.885 m/s	17 cm, 0.678 m/s
Infiltration Bag #1	27 cm, 0.926 m/s	11 cm, 0.587 m/s
Infiltration Bag #2	29 cm, 0.612 m/s	12 cm, 0.653 m/s
Infiltration Bag #3	29 cm, 0.959 m/s	11 cm, 0.612 m/s
Infiltration Bag #4	21 cm, 0.736 m/s	15 cm, 0.719 m/s

Note:

- There appears to have been some bedload movement through the system as upstream and downstream sites have large bedload deposits on the gravel bucket samples. There appears to be more sand contained in the downstream bucket samples.
- As with the buckets the infiltration bags have a surficial layer of large bedload. It was very difficult to find the sampler ropes for both up and downstream site because of the overlying bedload.

Summary Statistics

(Results of Two- Way Anova – arc-sin transformed for McNeil cores and weights for Buckets and Bags)

Date	Technique	Site Difference	Interaction Effect	Grain Size Differences
September 9	McNeil Core	None; p = 0.82	None; 0.76	
October 8	McNeil Core	Yes; p =0.02	Yes; p = 0.0	Site Differences- Tukey's HSD indicates Coarse and Medium sand higher D/S
	Gravel Buckets	None; p = 0.3	None; p = 0.7	
	Infiltration Bag	None; p = 0.37	None; p = 0.99	
November 12	McNeil Cores	Yes; p=0.002	Yes; p=0.0	Site Differences – Tukey's HSD indicates Coarse and Medium Sand higher D/S
	Gravel Buckets	Yes; $p=6.7*10^{-8}$	Yes; p= 0.0	Site Difference- Tukey's HSD indicates Coarse and Medium sand D/S and Fine Gravel U/S
	Infiltration Bags	Yes; p=0.04	Yes; p=0.0	Site Difference- Tukey's HSD indicates Coarse and Medium sand D/S and Fine Gravel U/S

NITHI RIVER

General Site Identification

Forest District:	Vanderhoof
Biogeoclimatic Zone:	Sub-boreal spruce dry cool climate (SBSdk)
Ecoregion:	Nechako Lowlands
Site Referral:	Vince Sewell
Forest Operator:	Plateau Forest Products
Investigated Activity:	Bridge replacement.
Dates Visited:	August 6, August 20, September 3 1997

General Physical Observations

The site was located on the 223 road off the Holy Cross Forest Service Road. A new bridge was being installed for planned 1998 logging. This area had not been accessed before so both the road and bridge were new. Two stations were established roughly 50-70 meters up and downstream of the bridge construction. During all site visits it was noted that the river was in very low flow. However, road crew members told us that this was a recent event, 3 days prior to our first visit the river had extended over much of the now dry streambed.

The road crew had an extensive network of geotextiles and silt fences that seem to be effective because no sediment plumes were readily visible in the creek. This site was selected to note differences, if any, downstream of an apparently clean bridge construction site and to determine if rain events will affect the downstream sediment load.

Upstream Site (U/S):

The upstream site was located immediately downstream of a fork in the river and in a riffle zone. The streambed appears to be dominated by cobble-boulder substrate and has a fairly good periphyton cover (green algae). During the pebble count it was noted that black fly larvae (Simuliidae) dominated the invertebrate community. Given the relatively coarse substrate it was decided that this creek would not be a good candidate for infiltration bags. Instead, McNeil cores and gravel bucket data were collected.

Downstream Site (D/S):

The downstream site was established downstream of a number of river braids that confluenced upstream of a small pool. The sample site was a riffle zone predominated by small to medium cobble. As with the upstream site it was determined that infiltration bags would not be placed but rather McNeil cores and gravel bucket data would be collected.

This bridge construction had begun several days prior to our visit and we were told that there was some sediment input to the stream. At the downstream site the streambed appeared to have more infilling than that upstream. Also, there was little to no periphyton community and invertebrates were virtually absent outside of some black fly larvae.

Site Location & Description

	UPSTREAM	DOWNSTREAM
GPS Coordinates	54°56.491' N 124°55.014' W Altitude – 856 m	55°56.525' N 124°54.894' W Altitude 822 m
Channel Width (m)	4.3	4 – 5
Bankfull Width (m)	N/A	N/A
Bankfull Height (m)	RB = 1.5 - 2.5 LB = gravel/cobble bar	RB = 1.5 LB = bar
Streambank & Floodplain	N/A	N/A
Pebble Count Data		
% < 2mm	3	6.7
% 2 – 4mm	0	3.8
% 4 – 8mm	2	2.9
% 8 – 16mm	6	13
% 16 – 32mm	14	26
% 32 – 64mm	22	25
% 64- 128mm	23	8.6
% 128 – 180mm	10	5.8
% 180 – 256mm	7	1.9
% 256- 512mm	5	2.9
% 512 – 1024mm	8	2.9
Streambed Composition	3% Sand, 44% Gravel, 45% Cobble, 8% Boulder	6.7% Sand, 73.6% Gravel, 19.2% Cobble, 2.9% Boulder
Gradient (%)	4.5	4

1st Installation

	UPSTREAM	DOWNSTREAM
Date	Aug. 06, 1997	Aug. 06, 1997
Discharge (m^3/s)	0.163	Same as u/s
Weather	4/10 cloud cover	N/A
Air Temp. (°C)	23.8	Same as u/s
Water Temp. (°C)	16.7	19.0
Dissolved O_2 (mg/l)	11.7	11.3
Turbidity (NTU)	N/A	N/A
Methods Deployed	1) McNeil-Ahnell Cores 2) Gravel Buckets	1) McNeil-Ahnell Cores 2) Gravel Buckets
Site Placement Depths & Velocities	McNeil-Ahnell Cores 1. 09 cm, 0.165 m/s 2. 12 cm, 0.174 m/s 3. 13 cm, 0.223 m/s Gravel Buckets 1. 26 cm, 0.612 m/s 2. 30 cm, 0.174 m/s 3. 30 cm, 0.248 m/s	McNeil-Ahnell Cores 1. 13 cm, 0.207 m/s 2. 11 cm, 0.422 m/s 3. 09 cm, 0.215 m/s Gravel Buckets 1. 28 cm, 0.397 m/s 2. 36 cm, 0.314 m/s 3. 39 cm, 0.347 m/s

Returned on Aug. 20, 1997 to retrieve samples. Upon arrival, discovered that 2 of the d/s gravel buckets were removed by some small animal (possibly a mink or muskrat according to tooth marks on the buckets). The data was lost so three additional buckets were installed.

D/S Reinstallation

	DOWNSTREAM
Date	Aug. 20, 1997
Channel Width	3.6
Discharge (m^3/s)	0.022
Weather	5/10 cloud cover
Air Temp. (°C)	24.7
Water Temp. (°C)	N/A
Dissolved O_2	N/A
Turbidity (NTU)	N/A
Methods Deployed	1) Gravel Buckets
Site Placement Depths % Velocities	Gravel Buckets 1. 26 cm, 0.124 m/s * 2. 33 cm, 0.116 m/s 3. 32 cm, 0.108 m/s 4. 30 cm, 0.066 m/s * Old # 3 bucket

1st Removal & Site Closure

	UPSTREAM	**DOWNSTREAM**
Date	Sept. 03, 1997	Sept. 03, 1997
Channel Width	N/A	4.0
Discharge	N/A	N/A
Weather	N/A	N/A
Air Temp.	N/A	15.7
Water Temp.	N/A	13.5
Dissolved O	N/A	11.3
Turbidity	N/A	N/A
Site Placement Depths & Velocities	McNeil-Ahnell Cores 1. 10 cm, 0.199 m/s 2. 10 cm, 0.306 m/s 3. 12 cm, Surface flow but unable to take reading. Gravel Buckets 1. 20 cm, 0.099 m/s 2. 25 cm, Area has become a back water settling pool and has no flow. 3. 26 cm, 0.50 m/s	McNeil-Ahnell Cores 1. 15 cm, 0.000 m/s 2. 15 cm, 0.091 m/s 3. 15 cm, 0.215 m/s Gravel Buckets 1. 32 cm, 0.124 m/s 2. 33 cm, 0.100 m/s 3. 32 cm, 0.100 m/s # 1 was completely dry. Sample was not analyzed.

Summary Statistics

(Results of Two- Way Anova – arc-sin transformed for McNeil cores and weights for Buckets)

Date	Technique	Site Difference	Interaction Effect	Grain Size Differences
August 6	McNeil Core	None; $p = 0.09$	Yes; $p = 0.04$	T-test indicate: Higher Fine Sans D/S ($p = 0.02$)
September 3	McNeil Core Gravel Buckets	None; $p = 0.47$ None; $p = 0.6$	None; $p = 0.75$ None; $p = 0.9$	

SPRUCE CREEK

General Notes

Forest District:	Prince George
Biogeoclimatic Zone:	Sub-boreal spruce wet cool climate (Willow variant) - SBS WK1
Ecoregion:	Bowron Valley
Who: Referred Site:	Pierre Beaudry
Operator:	Northwood Pulp & Timber
Investigated Activity:	Construction of road 283
Dates Visited:	September 11, October 16, and November 20 1997

General Physical Observations

Road 283 was recently constructed for proposed logging on winter block 283. The road is located approximately 3 km from Spruce Creek and is on a steep 6^0 gradient. The construction area is close to an unnamed tributary of Spruce Creek. Ditch wall erosion at one of the steep switchbacks allowed runoff to directly enter the unnamed tributary. This runoff remained in suspension and was added to Spruce Creek causing the turbidity event noted by Pierre Beaudry . For the purpose of this inventory the tributary to Spruce Creek will be treated as a sediment point source.

The upstream and downstream sites on Spruce creek are considered two separate reaches because of the tributary confluence. As a result, three sites were established to accurately compare the systems. One in the tributary and the others were established in Spruce Creek u/s and d/s of the confluence. While the tributary is easily accessible from a spur road, Spruce Creek was difficult to reach because of deadfall and windthrow in the creek and riparian area.

A riffle/run complex approximately 50m in length separates the Spruce Creek stations. Site establishment procedures were conducted at both locations because they are separate reaches. The upstream site appears to have little to no sediment input in the recent past and has a large amount of moss growth/periphyton on the streambed substrate and is dark brown in colour. Downstream appears to have more silt in the substrate and a lower concentration of moss/periphyton growth, the substrate a light brown. This difference between sites may reflect increased sediment loads from the tributary or the increased discharge upon confluencing with the tributary. While there seems to be little or no sediment being transported in the creek or the tributary presently, it is expected that storm events will cause an influx of sediment into the tributary from the new 283 road. However, in the event of no rain, it is hoped that our cores will show a difference from past events.

Tributary:

The tributary site is located approximately 10 - 15 m d/s of the spur road bridge in a riffle/run area. Approximately 30 m u/s of the bridge, the 6 % gradient slowly reduces until it reaches the d/s site where the gradient is 2.5 %. While the creek appears to be carrying little or no sediment at the present time, there appears to be and increasing amount of fine sediment deposition in the tributary as the gradient decreases. Further, the substrate appears cemented together d/s of the bridge but relatively free of fines u/s of the bridge.

The tributary was considered to be the point source of sediment entering Spruce Creek. This site had approximately the same discharge as the control site. Sampling was done in riffle/run areas 10 to 15 meters d/s of the bridge. One set of McNeil cores was taken 10 to 15 meters u/s of the bridge on the first visit to ensure the tributary was similar at these two locations.

Upstream Site (U/S):
Located 10 m upstream of the confluence of Spruce Creek with the tributary. Sampling was done in the riffle/run areas.

Downstream Site (D/S):
Located approximately 50 meters d/s of the control site. There was a substantial amount of dead fall and wind throw at this site. Flow was higher here than at the other sites. Sampling was done in riffle/run areas.

Site Location and Description

	UPSTREAM	DOWNSTREAM	TRIBUTARY
GPS Coordinates	53° 41.092' N 121° 40.615' W Alt. 840 m	53°41.156' N 121°40.465' W Alt. 840 m	53°41.122' N 121°40.520'W Alt. 841m
Channel Width (m)	4.15	5.50	5.00
Bankfull Width (m)	5.00	7.00-8.00	7.00
Bankfull Height (m)	RB = 0.25 LB = 0.25	RB = 1-1.5 LB = 0.25	RB = 0.50 LB = 0.50
Stream Bank & Floodplain	RB: 60% slope. (photo) Vegetation cover include, devils club, grass, mosses, raspberry, conifers, etc. LB: Floodplain. Vegetation cover includes mosses, grass, ferns, alders, etc. Extends to waters edge. Small amounts of cobble and gravel exposed in some areas and are erodible.	Similar to u/s site. (control site)	Both RB and LB have a large floodplain due to the low and relatively flat stream bank and area. Vegetative cover – willow, devils club, alders, raspberry, bunchberry, large conifers, grass, etc. Stream bank has a combination of silt, sand, gravel and cobble. Finer material easily erodible.
Pebble Count			
% < 2mm	20	11.3	19
% 2 - 4mm	1	0	1
% 4 – 8mm	3	0	9
% 8 – 16mm	17	5.2	17
% 16 - 32mm	24	24.7	31
% 32 – 64mm	18	20.6	17
% 64 – 128 mm	9	15.5	5
% 128 - 180 mm	5	10.3	0
% 180 – 256 mm	3	10.3	0
% 256 – 512 mm	0	4.1	0
% 512 – 1024 mm	0	4.1	1
Streambed Composition	20% Sand, 63 % Gravel, 17% Cobble	11.3 % Sand, 50.5% Gravel, 36.1% Cobble, 4.1% Boulder	19% Sand, 75% Gravel, 5% Cobble, 1% Boulder
Gradient %	1.5	3.5	2.5

1st Installation

	Upstream	Downstream	Tributary
Date	Sept. 11, 1997	Sept. 12, 1997	Sept. 11, 1997
Discharge (m^3/s)	0.35	0.68	0.33
Weather	9/10 cloud cover	5/10 cloud cover	9/10 cloud cover
Air Temp. °C	17.7	12.0	17.7
Water Temp. °C	12.3	9.7	9.1
Dissolved O_2 (mg/l)	10.8	11.9	11
Turbidity (NTU)	0.39, 0.41	0.62, 0.71, 0.57	0.71, 0.81, 1.16, 1.04, 1.60
Methods Deployed	1) McNeil Cores 2) Gravel Buckets	1) McNeil Cores 2) Gravel Buckets	1) McNeil Cores 2) Gravel Buckets
Site Placement Depths & Velocities.	McNeil Cores 1. 15cm, 0.645m/s 2. 18cm, 0.744m/s 3. 18cm, 0.719m/s 4. 21cm, 0.653m/s 5. 26cm, 0.645m/s 6. 27cm, 0.670m/s	McNeil Cores 1. 18cm, 0.529m/s 2. 17cm, 0.496m/s 3. 17cm, 0.496m/s 4. 15cm, 0.587m/s 5. 15cm, 0.554m/s 6. 14cm, 0.628m/s	McNeil Cores 1. 8cm, 0.579m/s 2. 8cm, 0.595m/s 3. 12cm, 0.529m/s 4. 11cm, 0.471m/s 5. 5cm, 0.149, m/s 6. 4cm, To shallow
	Gravel Buckets 1. 14cm, 0.471m/s 2. 15cm, 0.414m/s 3. 12cm, 0.281m/s 4. 15cm, 0.372m/s 5. 14cm, 0.389m/s 6. 15cm, 0.579m/s	Gravel Buckets 1. 18cm, 0.529m/s 2. 17cm, 0.496m/s 3. 17cm, 0.496m/s 4. 15cm, 0.587m/s 5. 15cm, 0.554m/s 6. 14cm, 0.628m/s	Gravel Buckets 1. 8cm, 0.579 m/s 2. 8cm, 0.595m/s 3. 12cm, 0.529 m/s 4. 11cm, 0.471 m/s 5. 5cm, 0.149 m/s* 6. 4cm, To Shallow

* Shallow depth may have affected velocity reading.

Because of the visual evidence of more finer material settled to the bottom of the tributary d/s of the bridge as compared to u/s of the bridge, McNeil Core samples were taken u/s of the bridge as well as a pebble count conducted.

Tributary Upstream of the Bridge:

Streambed Substrate:	
	5.8% Sand
	0% Very Fine Gravel
	0% Fine Gravel
	11.5% Medium Gravel
	40.4% Coarse Gravel
	28.8% Very Coarse Gravel
	9.6% Small Cobble
	3.8% Medium Cobble
Broad Breakdown:	
	5.8% Sand: 80.7% Gravel: 13.4% Cobble

Site Placement Depths & Velocities:

McNeil Cores

1. 9cm, 0.232m/s   2. 6cm, 0.116m/s
3. 8cm, 0.331m/s   4. 8cm, 0.240m/s
5. 9cm, 0.504m/s   6. 11cm, 0.438m/s

1[st] Removal & 2[nd] Installation

	Upstream	**Downstream**	**Tributary**
Date	Oct. 16/97	Oct. 16/97	Oct. 17/97
Channel Width (m)	4.4	6.75	6.65
Discharge m^3/s	0.57	1.04	0.45
Weather	10/10 cloud cover	10/10 cloud cover	8/10 cloud cover
Air Temp. (°C)	N/A	10	7.3
Water Temp. (°C)	7.2	6.7	4.8
Dissolved O_2 (mg/l)	11.2	12.7	12.8
Turbidity (NTU)	1.14, 0.78, 1.09, 6.8, 1.38	1.22, 0.99, 0.74, 0.75, 0.98	0.54, 0.86, 0.66, 0.68, 0.67
Depth & Velocities at samples	McNeil Cores 1. 18 cm, 0.695 m/s 2. 18 cm, 0.852 m/s 3. 18 cm, 0.604 m/s 4. 19 cm, 0.761 m/s 5. 19 cm, 0.670 m/s 6. 19 cm, 0.876 m/s	McNeil Cores 1. 20 cm, 0.703 m/s 2. 18 cm, 0.645 m/s 3. 23 cm, 0.645 m/s 4. 19 cm, 0.662 m/s 5. 19 cm, 0.645 m/s 6. 21 cm, 0.579 m/s	McNeil Cores 1. 11 cm, 0.777 m/s 2. 11 cm, 0.819 m/s 3. 12 cm, 0.628 m/s 4. 12 cm, 0.835 m/s 5. 12 cm, 0.620 m/s 6. 12 cm, 0.604 m/s
	Gravel Buckets Removed 1. 18 cm, 0.364 m/s 2. 18 cm, 0.298 m/s 3. 15 cm, 0.248 m/s 4. 18 cm, 0.240 m/s 5. 16 cm, 0.174 m/s 6. 19 cm, 0.265 m/s	Gravel Buckets Removed 1. 20 cm, 0.662 m/s 2. 24 cm, 0.653 m/s 3. 23 cm, 0.719 m/s 4. 19 cm, 0.786 m/s 5. 18 cm, 0.670 m/s 6. 17 cm, 0.463 m/s	Gravel Buckets Removed 1. 14 cm, 0.604 m/s 2. 14 cm, 0.513 m/s 3. 19 cm, 0.480 m/s 4. 20 cm, 0.389 m/s 5. 15 cm, 0.496 m/s 6. 18 cm, 0.474 m/s
	Gravel Buckets Replaced 1. 15 cm, 0.695 m/s 2. 15 cm, 0.695 m/s 3. 16 cm, 0.628 m/s 4. 16 cm, 0.628 m/s 5. 16 cm, 0.620 m/s 6. 20 cm, 0.728 m/s	Gravel Buckets Replaced All gravel buckets were replaced in the same position except for # 6. 6. 17 cm, 0.744 m/s	Gravel Buckets Replaced All gravel buckets were replaced in the same position except for # 1. 1. 17 cm, 0.538 m/s

2[nd] Removal & Site Closure

	Upstream	**Downstream**	**Tributary**
Date	Nov. 21/97	Nov. 20/97	Nov. 21/97
Channel Width	4.85	6.75	4.4
Discharge	0.56	0.90	0.30
Weather	10/10 cloud cover	10/10 cloud cover	N/A
Air Temp. (°C)	1.0	-1.5	2.1
Water Temp. (°C)	1.8	1.3	1.6
Dissolved O_2 (mg/l)	13.3	14.7	13.2
Turbidity NTU)	0.34, 0.34, 0.45	0.34, 0.28, 0.39	0.23, 0.21, 0.25
Depth & Velocities at Samples	McNeil Cores 1. 18 cm, 0.703 m/s 2. 19 cm, 0.835 m/s 3. 18 cm, 0.802 m/s 4. 21 cm, 0.728 m/s 5. 18 cm, 0.695 m/s 6. 22 cm, 0.777 m/s	McNeil Cores 1. 18 cm, 0.521 m/s 2. 20 cm, 0.538 m/s 3. 17 cm, 0.653 m/s 4. 17 cm, 0.504 m/s 5. 17 cm, 0.645 m/s 6. 21 cm, 0.463 m/s	McNeil Cores 1. 10 cm, 0.488 m/s 2. 12 cm, 0.529 m/s 3. 10 cm, 0.422 m/s 4. 11 cm, 0.414 m/s 5. 12 cm, 0.538 m/s 6. 11 cm, 0.422 m/s

	Gravel Buckets Removed 1. 15 cm, 0.761 m/s 2. 15 cm, 0.777 m/s 3. 13 cm, 0.670 m/s 4. 17 cm, 0.752 m/s 5. 14 cm, 0.571 m/s 6. 16 cm, 0.637 m/s	Gravel Buckets Removed 1. 16 cm, 0.653 m/s 2. 18 cm, 0.529m/s 3. 18 cm, 0.678 m/s 4. 16 cm, 0.819 m/s 5. 17 cm, 0.513 m/s 6. 16 cm, 0.637 m/s	Gravel Buckets Removed 1. 15 cm, 0.521 m/s 2. 12 cm, 0.438 m/s 3. 16 cm, 0.471 m/s 4. 18 cm, 0.405 m/s 5. 12 cm, 0.364 m/s 6. 13 cm, 0.356 m/s

NOTE: In the tributary, d/s of the bridge, there is a newly formed bar approximately 0.4 - 0.5 m high composed mainly of silt, sand, and a little gravel. It is located d/s of a wind felled tree near the gravel bucket location. Also at this time, a bridge crossing Spruce Creek was discovered approximately 100 m u/s of the control site. This may have affected the u/s samples.

Summary Statistics

(Results of Two- Way Anova – arc-sin transformed for McNeil cores and weights for Buckets)

Date	Technique	Site Difference	Interaction Effect	Grain Size Differences
September 11	McNeil Core	None; p =0.9 None; p = 0.96	None; p = 0.8 None; p = 0.1	None – Spruce Creek None - Tributary
October 16	McNeil Core	None; p = 0.61	Yes; p=0.004	Crs. Sand U/S Spruce (p = 0.03)
	Gravel Buckets	Yes; p =0.0001	None; p= 0.4	Higher sample weight D/S Tukey's HSD- indicates higher sample weights for all at D/S
November 23	McNeil Core	None; p =0.72	None; p = 0.05	None
	Gravel Bucket	Yes; p= $6.1 * 10^{-6}$	Yes; p= 0.01	Higher sample weights D/S Tukey's HSD- indicates higher sample weights for all sizes D/S

YOUNGS CREEK

General Notes

Forest District: Prince George
Biogeoclimatic Zone: Sub-boreal Spruce Moist Cool Climate (Mossvale Variant) SBSMK1
Ecoregion: Nechako Lowland
Site Referral: Priority List established by BC Environment
Forest Operator: Lakelands
Investigated Activity: Decommissioned crossing.
Dates Sampled: July 26, October3, October 14, November 23 1997

General Physical Observations

Two stations were established, one upstream (u/s) and another downstream (d/s) of the decommissioned crossing. The u/s station is approximately 20 - 25 m u/s from the crossing and the d/s station is located approximately 5 - 10 m d/s from the crossing

Both sites consist of a riffle/run area with a small pool. The sites were within the same reach so most of the site establishment data was collected at the upstream site. However, the pebble count data was collected in a diagonal manner so that both sample areas were included.

Upstream Site (U/S):

Located approximately 20 - 25 m u/s from the crossing point. Consist of a riffle and a run with a small pool in the run area. Sampling conducted in the riffle and run area.

Downstream Site (D/S):

Located approximately 5 - 10 m d/s from the crossing point. Consist of a riffle and a run with a small pool in the run area. Sampling conducted in the riffle and run area.

Site Location & Description

	UPSTREAM	DOWNSTREAM
GPS Coordinates	54°13' N 123°03' W Altitude 654 m	Same as u/s
Channel Width (m)	12.6	Only measured once
Bankfull Width (m)	14	Only measured once
Bankfull Height (m)	N/A	N/A
Streambank & Floodplain	N/A	N/A
Pebble Count Data		Pebble count included both u/s and d/s sites.
% < 2mm	17	
% 2 – 4 mm	6	
% 4 – 8 mm	9	
% 8 – 16 mm	14	
% 16 – 32 mm	32	
% 32 - 64 mm	14	
% 64 – 128 mm	3	
% 128 – 180 mm	5	
Streambed Composition	17% Sand, 75% Gravel, 8%Cobble	
Gradient (%)	2.5	2.0

1st Installment

	UPSTREAM	DOWNSTREAM
Date	July 09, 1997	July 09, 1997
Discharge (m^3/s)	0.33	Same as u/s
Weather	4/10 cloud cover	Same as u/s
Air Temp. (°C)	N/A	N/A
Water Temp. (°C)	N/A	N/A
Dissolved O_2 (mg/l)	N/A	N/A
Turbidity (NTU)	N/A	N/A
Methods Deployed	1) McNeil-Ahnell Cores 2) Gravel Buckets 3) Infiltration Bags 4) Suspended Sediment Trap	1) McNeil-Ahnell Cores 2) Gravel Buckets 3) Infiltration Bags 4) Suspended Sediment Trap
Site Placement Depths & Velocities	McNeil-Ahnell Cores 1. 15 cm, Velocity N/A 2. 25 cm, Velocity N/A 3. 35 cm, Velocity N/A Gravel Buckets No data Infiltration Bags No data	McNeil-Ahnell Cores 1. 30 cm, Velocity N/A 2. 35 cm, Velocity N/A 3. 40 cm, Velocity N/A Gravel Buckets No data Infiltration Bags No data

1st Removal

	UPSTREAM	DOWNSTREAM
Date	July 26, 1997	July 26, 1997
Channel Width (m)	11.8	Only measured once
Discharge (m^3/s)	0.137	Same as u/s
Weather	4/10 cloud cover	Same as u/s
Air Temp. (°C)	15	Same as u/s
Water Temp. (°C)	N/A	N/A
Dissolved O_2 (mg/l)	N/A	N/A
Turbidity (NTU)	N/A	N/A
Site Placement Depths & Velocities	McNeil-Ahnell Cores 1. 10 cm, 0.422 m/s 2. 10 cm, 0.347 m/s 3. 14 cm, 0.132 m/s Gravel Buckets 1. 27 cm, 0.000 m/s * 2. 15 cm, 0.141 m/s 3. 24 cm, 0.000 m/s * 4. 15 cm, 0.182 m/s Infiltration Bags 1. 18 cm, 0.223 m/s 2. 15 cm, 0.091 m/s 3. 18 cm, 0.240 m/s	McNeil-Ahnell Cores 1. 12 cm, 0.786 m/s 2. 15 cm, 0.761 m/s 3. 12 cm, 0.339 m/s Gravel Buckets 1. 26 cm, 0.149 m/s 2. 28 cm, 0.000 m/s * 3. 30 cm, 0.025 m/s 4. 27 cm, 0.132 m/s Infiltration Bags 1. 24 cm, 0.240 m/s 2. 30 cm, 0.099 m/s 3. 24 cm, 0.199 m/s

Note: Discharge is only an approximate. Approximately half of the creek had depths to low to measure discharge.

* ⇒ Surface flow evident. However, not enough to affect velocity meter.

2nd Install

	UPSTREAM	DOWNSTREAM
Date	Oct. 3, 1997	Oct. 3, 1997
Channel Width (m)	6.9 (Different location than above location)	Only measured once
Discharge (m^3/s)	0.67	Same as u/s
Weather	10/10 cloud cover	Same as u/s
Air Temp. (°C)	9.0	N/A
Water Temp. (°C)	7.1	N/A
Dissolved O_2 (mg/l)	10.3	N/A
Turbidity (NTU)	Hach unit 11 standards 1 – 10 4.98 1 – 100 50.5 1 – 1000 525 Samples; 5.50, 5.89, 5.81	N/A
Methods Deployed	1) McNeil-Ahnell Cores	1) McNeil-Ahnell Cores
Site Placement Depths & Velocities	McNeil-Ahnell Cores 1. 16 cm, 0.744 m/s 2. 16 cm, 0.686 m/s 3. 18 cm, 0.835 m/s 4. 15 cm, 0.612 m/s 5. 15 cm, 0.513 m/s 6. 18 cm, 0.653 m/s	McNeil-Ahnell Cores 1. 16 cm, 0.414 m/s 2. 15 cm, 0.562 m/s 3. 15 cm, 0.819 m/s 4. 15 cm, 0.951 m/s 5. 17 cm, 1.158 m/s 6. 16 cm, 0.910 m/s

NOTE: At this time, gravel buckets and infiltration bags were installed. However, both had to be replaced.

Gravel Bucket & Infiltration Bag Replacement

	UPSTREAM	DOWNSTREAM
Date	Oct. 14, 1997	Oct. 14, 1997
Channel Width (m)	13.3 (not same location as before)	Only measured once
Discharge (m^3/s)	0.827	Same as u/s
Weather	N/A	N/A
Air Temp. (°C)	N/A	N/A
Water Temp. (°C)	N/A	N/A
Dissolved O_2 (mg/l)	N/A	N/A
Turbidity (NTU)	N/A	N/A
Site Placements Depths & Velocities	Gravel Buckets 1. 19 cm, 0.653 m/s 2. 17 cm, 0.496 m/s 3. 15 cm, 0.562 m/s 4. 18 cm, 0.620 m/s 5. 19 cm, 0.612 m/s 6. 21 cm, 0.761 m/s Infiltration Bags 1. 16 cm, 0.794 m/s 2. 15 cm, 0.769 m/s 3. 16 cm, 0.695 m/s 4. 22 cm, 0.893 m/s	Gravel Buckets 1. 18 cm, 0.323 m/s 6. 19 cm, 0.430 m/s Only two readings were taken because all buckets were placed in one area. Therefore all velocities are similar. Infiltration Bags 1. 15 cm, 0.868 m/s 2. 24 cm, 0.943 m/s 3. 21 cm, 0.562 m/s

2nd Removal & Site Closure

	UPSTREAM	DOWNSTREAM
Date	Nov. 24, 1997	Nov. 24, 1997
Channel Width (m)	N/A due to icy conditions	Same as u/s
Discharge (m^3/s)	~ 0.67	Same as u/s
Weather	10/10 cloud cover	Same as u/s
Air. Temp (°C)	Same as d/s	2.1
Water Temp. (°C)	Same as d/s	0.2
Dissolved O_2 (mg/l)	Same as d/s	13.4
Turbidity (NTU)	Standards same as d/s Samples; 0.98, 1.01, 1.05	Hach unit 11 standards 0 - 10 = 4.46 0 - 100 = 44.2 0 - 1000 = 532 Samples; 0.71, 0.76, 0.70
Site Placement Depths & velocities	McNeil-Ahnell Cores 1. 16 cm, 1.075 m/s 2. 15 cm, 0.918 m/s 3. 18 cm, 0.761 m/s 4. 16 cm, 1.001 m/s 5. 18 cm, 0.984 m/s 6. 15 cm, 1.100 m/s Gravel Bucket Water over gravel buckets were frozen over. Therefore, the flow could not be calculated. Infiltration Bags Infiltration Bags were completely frozen in. Could not recover the samples.	McNeil-Ahnell Cores 1. 19 cm, 1.141 m/s 2. 21 cm, 1.042 m/s 3. 17 cm, 1.000 m/s 4. 15 cm, 1.017 m/s 5. 18 cm, 1.075 m/s 6. 21 cm, 1.034 m/s Gravel Buckets 1. GB missing 2. 30 cm, 0.819 m/s 3. 27 cm, 0.637 m/s 4. GB missing 5. 22 cm, 0.645 m/s 6. 27 cm, 0.885 m/s Infiltration Bags 1. 18 cm, 0.430 m/s 2. 21 cm, 0.670 m/s 3. 23 cm, 0.323 m/s

Note: Icy conditions may have affected same of the samples. For instance, ice had to be removed from the tops of several samples including GB's and IB's.

Summary Statistics

(Results of Two- Way Anova – arc-sin transformed for McNeil cores and weights for Buckets)

Date	Technique	Site Difference	Interaction Effect	Grain Size Differences
July 9	McNeil Core	None; p =0.9	None; p = 0.5	
July 26	Gravel Bucket Infiltration Bag	None; p = 0.95 Yes; p = 0.04	None; p= 0.99 Yes; p = 0	 Higher sample weight D/S and fine gravel D/S (p = 0.01)
October 3	McNeil Core	None; p = 0.3	None; p=0.104	
November 24	McNeil Core Gravel Bucket	None; p =0.82 t-test	Yes; p = 0.05	Higher fine gravel U/S (p=0.003) Higher Crs. Sand D/S (p=0.002) Higher Gravel U/S (p = 0.0001) Higher Med. Sand D/S (p=0) Higher F. Sand D/S (p 0.006)

Appendix 2

TSS Analysis Procedure

Environment Canada Environnement Canada

Pacific Environmental Science Centre
2645 Dollarton Highway
North Vancouver, B.C. V7H-1V2

INORGANIC CHEMISTRY SECTION

STANDARD OPERATING PROCEDURE FOR:

NON-FILTERABLE RESIDUE
WHOLE BOTTLE NON-FILTERABLE RESIDUE
FIXED NON-FILTERABLE RESIDUE
AND
NON-FILTERABLE RESIDUE & FIXED NON-FILTERABLE RESIDUE

SOP ID: NFR

Version: NFR V2.6

Issue Date: September, 1999

Review date: September, 2000

Controlled Copy No.: ____________________

Authorized by: ____

Acting Head, Head, Inorganic Chemistry Section

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NON-FILTERABLE RESIDUE / NFR Version 2.6 Sept 1999 NFR
WHOLE BOTTLE NON-FILTERABLE RESIDUE/NFRWB
NFRWB
FIXED NON-FILTERABLE RESIDUE / FNFR FNFR
F.NFR

Gravimetric, Glass Fibre Filter, Dried at 103 ± 2°C, ignited at 550°C

REFERENCED DOCUMENTS

[1] Mettler Instrument AG. 1986. *Operating Instructions: Mettler J series balances*, publication ME-702563. Greifensee, Switzerland.

[2] Stevens, D.C. March 31, 1985. WTS Program Weights Data Collector. In *Balance Workstation Data Processing Programs*, pp. 3-66. West Vancouver: Environment Canada Laboratories, Revised January 9, 1997.

[3] Labware Cleaning Standard Operating Procedure V2.1, Environment Canada Laboratories Manual.

SCOPE AND APPLICATION

This method is applicable to all types of waters: fresh waters, ground waters and industrial or municipal waste waters in the range of 5 mg/L to 2000 mg/L non-filterable residues and 10 mg/L to 2000 mg/L fixed non-filterable residues using a 200 mL sample volume and 100 mL sample volume respectively, or the whole sample for whole bottle analysis. The minimum detectable concentration is lower using a larger sample. The upper range can be extended using a smaller sample volume.

SIGNIFICANCE AND USE

Non-filterable residue (NFR) causes abrasive injuries, clog gills and respiratory passages of various aquatic fauna, and blankets the stream bottom, killing eggs, fry and food organisms. NFR also causes turbidity, thus screens out the light. By carrying down and trapping bacteria and decomposing organic wastes on the bottom, NFR promote and maintain noxious conditions. Healthy fish can probably swim through water of high NFR content, but fish weakened by toxic substances may be unable to withstand the abrasive and clogging action of the particles. The test is often used as a general indicator for water quality and process control.

Fixed non-filterable residue test provides an estimate of the non-organic matter present in the solid fraction of the water.

DEFINITIONS

1. *Non-filterable residue (NFR)* is operationally defined to be the material retained on a VWR Brand Grade 696 glass fibre filter that has been dried at 103°C for one hour following the filtration of a well-mixed sample.

2. *Fixed non-filterable residue (FNFR)* is operationally defined to be the material that remains on a VWR Brand Grade 696 glass fibre filter that has been dried at 103°C for one hour and ignitied at 550°C for one hour following the filtration of a well-mixed sample.

3. The terms *residue, nonfilterable*, and *filterable* can also be called *solids, suspended*, and *dissolved* respectively.

SUMMARY OF METHOD

A well-mixed sample is filtered through a VWR Brand Grade 696 glass fibre filter (1.1 μm particle retention) that has been muffled at 550°C for 20 minutes and pre-weighed. The filter with the residue is then dried at 103°C for one hour and weighed again to constant weight; the resulting weight difference gives the total non-filterable residue (NFR). The filter with dried residue is then ignited in a muffle furnace at 550°C. The residue that remains gives the fixed non-filterable residue (FNFR).

SAMPLE HANDLING AND PRESERVATION

Collect the sample in a clean polyethylene or glass container. No chemical preservation is required. If duplicates are required for whole bottle analysis two containers must be collected. The samples should be stored at 4°C and analysed as soon as possible to minimise any micro-biological activity. Maximum holding time is 7 days. Equilibrium conditions may change sufficiently to alter the suspended fraction of materials in a water sample. Samples should be brought to room temperature before analysis.

INTERFERENCES

1. Use special handling to insure sample integrity when sub-sampling. The

sample must be stirred or shaken in order to homogeneously re-suspend all material.

2. Warm the sample to room temperature before analysis to minimise variation due to temperature effects that might alter the non-filterable fraction.

3. Some residues may contain materials that decompose below 103 - 105°C (e.g., ammonium carbonate).

4. The indicating silica gel in the desiccators should be regenerated when its colour has faded - place the tray in the oven at 103°C for approximately six hours to regenerate the original purple hue.

5. Because excessive residue on the filter may form a water-entrapping crust, limit the sample size (filtered sample volume) to that yielding no more than 200 mg residues.

6. For sample high in dissolved solids thoroughly wash the filter to ensure removal of dissolved material.

7. Prolonged filtration times resulting from filter clogging may produce high results owing to increased colloidal materials captured on the clogged filter.

8. Exclude large, floating particles or submerged agglomerates of non-homogeneous materials from the sample if it is determined that their inclusion is not desired in the final result.

METHOD PERFORMANCE

1. The effective working range thus varies with the sample volume: 5 - 2000 mg/L for 100 mL of sample; 1 - 400 mg/L for 500 mL of sample for NFR. The Method Detection Limit (MDL) setting at the 99% confidence level above zero (or the blank) is 5 mg/L for 100 mL sample for NFR and 10 mg/L for 100 ml sample for FNFR.

$$MDL = t_{.99} * \text{Std Dev}_{\text{near zero}}$$

where, t = Student's t value for a 99% confidence level and a standard deviation estimate with n-1 degrees of freedom [t = 3.14 for seven replicates].

$\text{Std. Dev.}_{\text{near zero}}$ = Standard deviation of the replicate analyses.

2. Method Blank: Analyse an aliquot of Type 1 deionised water with each batch of

24 samples to monitor contamination and background interference.

For current NFR and FNFR Method Blank Data see Tables A and B in Appendix 1.

3. Method Accuracy may be evaluated by analysing a synthetic reference sample consisting of a 75 µm sieved fraction (No. 200 mesh) of marine silt (which has been muffled at 550°C for one hour and diluted to volume in Type 1 water). Data limits to monitor method accuracy:

For current NFR and FNFR Method Accuracy Data see Tables D and E in Appendix 1.

4. Precision is affected by both the quantity and the nature of the entrained material. The following samples were analysed in the laboratory by a single analyst in one day to establish method repeatability in different matrixes.

Table 1 Single Analyst Method Repeatability for NFR (Data Current to April 1998) -

Sample	N	NFR & NFRWB Mean mg/L	Std Dev mg/L	% RSD
Mine Effluent	5	<5	1.2	0
Industrial Wastewater	5	28	0.7	39.4
Fresh Water	5	<5	0.7	0

Table 2 Single Analyst Method Repeatability for FNFR

Sample	N	FNFR Mean mg/l	Std. Dev.	RSD %
Mine effluent	5	13	1.9	14.6
Industrial wastewater	5	28	1.7	6.1
Fresh water	5	4	0.3	7.5

5. Method Precision: Repeatability data derived from duplicate measurements collected over at least a twelve-month period have been used to set (3 s) control limits to monitor system precision.

For current NFR and FNFR Single Analyst (Within-Run) Precision Data see Tables E and F in Appendix 1.

6. After the analysis is complete. Rinse glassware three times with Type 1 water and send to Wash-up area for cleaning if necessary. The filtering apparatus should be rinsed with Type 1 water and 200 - 300 mLs of Type 1 water poured through it.

7. Turn both drying ovens (90-95 & 103°C) and muffle furnace off at the end of the day, if not in use.

Note 1. It has been found that if regular NFR filters are heated to 550°C before use, they do not require pre-wash with Type 1 water, as is usually recommended.

Note 2. Because the aluminum dish and the filter cool almost immediately, it is not necessary to allow any cooling before weighing. This speeds the process, and it is actually more accurate to weigh the filters immediately.

Note 3. Use sufficient sample volume to deposit at least 1 mg of material onto the filter and no more than 200 mg since it will tend to impede filtration.

BATCH QUALITY CONTROL

1. Assign a Batch ID with every sample set analysed consisting of MMDDPP. This batch ID is the same Batch ID used in Section 3.3.2.

   For example, 0102NF
   MM - represents the month - January is 01
   DD - represents the date - in this case is the 2nd
   PP - represents the parameter NFR.

2. For every 24 samples, include a method blank and one check standard in everyday work. For every 12 samples, randomly select one sample to be analyzed in duplicate or run more frequently if required. For whole bottle analysis duplicates are only possible if two bottle have been submitted for analysis.

3. Assess whether the batch shows statistical control by considering:

   - the results for the method blanks

- the range of duplicate results
- the measured NFR/FNFR of the check standard

If any parameter lies outside the established (3 s) control limits, corrective action is then necessary. Document any non-conformance and the action taken in the Record Non-conformance form. Inform the lab supervisor immediately.

4. Report QA/QC Data for Blanks, Duplicates and Control in Excel file YYNFR.xls or YYFNFR.xls (e.g., 99nfr.xls) and insert appropriate notes to document non-conformance and action taken.

5. Analysis of Quality Control Charts and procedures followed are set out by Standard Method for the Examination of Water and Waste Water, 19^{th} Edition, 1995, in 1020 B Quality Control, 7 C, Control Chart: Chart Analysis.

CALCULATIONS AND DATA PROCESSING

The total non-filterable Residue (NFR) is given by:

$$\text{mg/L NFR} = \frac{(WRF-WF)\times 1000 \times 1000}{V}$$

where WF = weight of the muffled glass fibre filter (in g)
WRF = weight of the dried filter with residue (in g)
V = volume of sample filtered (in mL)

The fixed non-filterable Residue (FNFR) is given by:

$$\text{mg/L FNFR} = \frac{(MRF-WF)\times 1000 \times 1000}{V}$$

where WF = weight of the muffled glass fibre filter (in g)
MRF = weight of the dried ignited filter with residue (in g)
V = volume of sample filtered (in mL)

The results are automatically entered into the lab database by the RWTS program. If manual data entry is necessary, use either the RENT program or the [*Enter result*] command in the LGR program. When prompted for the Batch ID, enter the same Batch ID as in Section 3.3.2 or in the Batch Quality Assurance Section. Report the results to three significant figures provided it does not fall below the method detection limit.

The test code and billing code are:

NFR	104
NFRWB	119
FNFR	110

REFERENCES

[1] Vanous, R.D., P.E. Larson, and C.C. Hach. 1982. The Theory and Measurement of Turbidity and Residue In *Water Analysis: Inorganic Species, Part 1, Volume 1* (R.A. Minear and L.H. Keith, ed), pp. 163-234. Orlando: Academic press, Inc.

[2] APHA, AWWA, WPCF, Standard Methods for the Examination of Water and Wastewater, 19th Edition, Method 2540D Total Suspended Solids, p. 2-56 and 1020 B Quality Control, 7 C, Control Chart: Chart Analysis, pp. 1-4 to 1-7, 1995.

APPENDICES

1. Method Performance Table
2. Batch Record Form
3. Balance Calibration Log
4. Record of Non-conformance Form
5. Standard/Reagent Preparation Log

REVISION HISTORY

Version 2.6	July 1999	Revision of the procedure for whole bottle analysis (Buchner funnel no longer used), update of precision and accuracy data. Method for FNFR added.
Version 2.5	April 1998	Addition of NFRWB analysis, QA/QC Section revised and precision & accuracy data updated.
Version 2.4	December 1997	Method update of precision & accuracy; addition of Record of Non-Conformance Form.

Version 2.4	September 1997	Change of glass fibre filter from Whatman GF/C to VWRBrand Grade 696 glass fibre fiters; method performance data updated.
Version 2.4 update	May 1997	Format revision and method performance
Version 2.3	November 1995	More method details.
Version 2.2	September 1995	Format and method revised.
Version 2.1	December 1993	Method revision and performance data updated.
Version 2.0 updated.	June 1991	Repeatability data added to method and
Version 1.1	April 1987	Precision data added to method.
Version 1.0	January 1979	Method Introduced.

APPENDIX 1: METHOD PERFORMANCE TABLE

Table A NFR Method Blank - (Data Current to January 1999)

	N	Acceptable NFR mg/L	Mean NFR mg/L	Std Dev	Control Limits
Blank	234	< 5.	0.08	0.79	✂ 2.37

N - No. of analyses Std. Dev.- standard deviation of the mean

Table B FNFR Method Blank - (Data Current to December 1998)

	N	Expected FNFR mg/L	Measured FNFR mg/L	Std. Dev.	Control Limit
Blank	16	0	-1.20	1.07	✂ 3.21

Table C NFR Method Accuracy - (Data Current to January 1999)

Reference NFR Value mg/L	N	Mean % Recovery	Std. Dev.	Control Limits
150	130	97.12	3.06	✂9.18

Table D FNFR Method Accuracy - (Data Current to December 1998)

FNFR Reference Value (mg/L)	N	Mean % Recovery	Std. Dev.	Control Limit
150	13	96.6	4.5	✂ 4.5

Table E NFR Single Analyst (Within Run) Precision - Data Current to January 1999

NFR & NFRWB Analytical Range mg/L	No. of Sets of Duplicates	Mean Normalised Range	Std Dev	Control Limits for Normalised Duplicate Range
<5 to 1000+	382	0.018	0.050	0.169

Table F FNFR Single Analyst (Within Run) Precision - Data Current to December 1998

FNFR range mg/L	No. of sets of duplicates	Mean % Normalized range	Std. Dev.	Control Limit for duplicate range
0 to 1000	17	0.81	1.89	6.48

Appendix 3

Wentworth Scale

Wentworth Scale

Grain Class	Size Range (mm)
Clay	< 0.004
Silt	0.004< X <0.0625
Fine Sand	0.0625< X <0.2
Medium Sand	0.2 < X < 0.6
Coarse Sand	0.6 < X < 1
Very Coarse Sand	1 < X < 2
Very Fine Gravel	2 < X < 4
Fine Gravel	4 < X < 8
Medium Gravel	8 < X < 16
Coarse Gravel	16 < X < 32
Very Coarse Gravel	32 < X < 64
Small Cobble	64 < X < 90
Medium Cobble	90 < X < 128
Large Cobble	128 < X < 180
Very Large Cobble	180 < X < 256
Small Boulder	256 < X < 512
Medium Boulder	512 < X < 1024
Large Boulder	1024 < X < 2048
Very Large Boulder	2048 < X < 4096

Appendix 4

Proposed Field Forms

Site Establishment Field Form

Date & Time:	**Site Location (Name & UTM):**	
Time Arrive/Leave:	**Weather & Stage:**	
Stream Width	Active: Bankfull:	
Stream Depth (From Discharge)	Discharge (RIC Standard?): Equipment & last calibration:	
Pebble Count Data	Collector: Note Taker: Correct Procedure:	< 2mm: 2-4mm: 4-8mm: 8-16mm: 16-32mm: 32-64mm: 64-90mm: 90-128mm: 128-256mm: 256-512mm 512-1024mm:
Channel Gradient	Equipment Used: Number of Sections Measured:	Gradient Data:
Channel Morphology (General Description) i.e. riffle-pool (60:40% ratio):		
Streambank Description (Soil types relative amount of vegetation):		
Are there in-stream structures nearby?		
How many separate coring areas are within the chosen site?		
Site Sketch:		

McNeil Core Field Card

Date & Time:	**Site Location (Name & UTM):**
Time Arrive/Leave:	**Weather & Stage:**

General Comments:

Are McNeil cores taken in replicate sites?

McNeil	Depth	Velocity
#1		
#2		
#3		
#4		
#5		
#6		
#7		
#8		
#9		
#10		
#11		
#12		

1) Identifying the Sample Area:

Riffle Crest Sample Area Yes ☐ No ☐ Notes:

In-Stream Structures Nearby Yes ☐ No ☐ Notes:

2) Sample Collection Procedure

Upstream Approach Yes ☐ No ☐
Proper Core Insertion Yes ☐ No ☐
Sample Bucket Cleaned Yes ☐ No ☐
Hand Scoop Yes ☐ No ☐
Hand Rinse Yes ☐ No ☐
TSS Sample Mixed Yes ☐ No ☐
1-way Plunger Used Yes ☐ No ☐
McNeil Cleaned Yes ☐ No ☐
Rinse Water Poured Downstream Yes ☐ No ☐
Sample Labeled Yes ☐ No ☐
Coring Staff Consistent Yes ☐ No ☐
Core Site Pattern (clustered, linear, thalweg, channel bank, etc)

Site Sketch:

Gravel Bucket QA Site Card

Date & Time:	**Site Location (Name & UTM):**
Time Arrive/Leave:	**Weather & Stage:**

General Comments:
Are gravel buckets placed in replicate sites?

Bucket	Depth	Velocity
#1		
#2		
#3		
#4		
#5		
#6		
#7		
#8		
#9		
#10		
#11		
#12		

1) Identifying the Sample Area:

Glide or Run Sample Area Yes ▯ No ▯ Notes:

In-Stream Structures Nearby Yes ▯ No ▯ Notes:

2) Bucket Placement Procedure

Upstream Approach Yes ▯ No ▯
Bucket Placement Level and Flush Yes ▯ No ▯
Standard Reference Gravel Volume Yes ▯ No ▯
Lid Removed in Downstream Direction Yes ▯ No ▯
Placement Pattern (clustered, linear, thalweg, channel bank, etc)

3) Bucket Removal

Upstream Approach Yes ▯ No ▯
Lids Replaced in Upstream Direction Yes ▯ No ▯
Sample Labeled Yes ▯ No ▯

Site Sketch:
(If deployed with other techniques it is important to document bucket sites and sampling sequence)

Infiltration Bag QA Site Card

Date & Time:	**Site Location (Name & UTM):**
Time Arrive/Leave:	**Weather & Stage:**

General Comments:
Are bags placed in replicate sites?

Bag	Depth	Velocity
#1		
#2		
#3		
#4		
#5		
#6		
#7		
#8		
#9		
#10		
#11		
#12		

1) Identifying the Sample Area:

Glide, Run, Riffle Sample Area Yes ☐ No ☐ Notes:

In-Stream Structures Nearby Yes ☐ No ☐ Notes:

2) Bag Placement Procedure

Upstream Approach	Yes ☐	No ☐
Bag Placement Level and Flush	Yes ☐	No ☐
Standard Hole Width/Depth	Yes ☐	No ☐
Standard Reference Gravel Volume	Yes ☐	No ☐
Reference Gravel Flush with Streambed	Yes ☐	No ☐
Bags Installed in a Downstream Direction	Yes ☐	No ☐

Placement Pattern (clustered, linear, thalweg, channel bank, etc)

3) Bag Removal

Upstream Approach	Yes ☐	No ☐
Bags Removed in an Upstream Direction	Yes ☐	No ☐
Sample Labeled	Yes ☐	No ☐

Site Sketch:
(If deployed with other techniques it is important to document bag sites and sampling sequence)