# Guidelines for Monitoring Fine Sediment Deposition in Streams

Field Test Edition

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For further information about the Resources Information Standards Committee, please access the RISC website at: http://srmwww.gov.bc.ca/risc/.

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# 1.0 Introduction

Incremental fine sediment loading within a stream is known to negatively effect both stream morphology and biota. Suspended sediments resulting from urban development, agriculture, mining, and forest harvesting can cloud water, which shades plants and delays the visual response of fish. Once settled, these sediments can reduce interstitial oxygen concentrations, which suffocates benthic invertebrates, fish eggs, and alevins (Bjornn and Reiser 1991, MacDonald et al. 1991, Waters 1995).

Although increased levels of depositing fine sediments are known to negatively effect the aquatic environment, a concerted effort to review measurement techniques and their application in managing land use activities has been lacking. This manual outlines a method to monitor fine sediment generated by forest harvesting practices but it may be expanded to other land use activities. Further, the techniques presented may prove useful for those sampling programs focussed on tracing sediment bound contaminants. Regardless of the source, the techniques described in this manual will be effective for the assessment of increased fine sediment loading, where fine sediment is defined as having a diameter of less than six millimeters. The information presented in this guide follows a multi-year field testing program conducted within the Omineca-Peace region of the British Columbia Central Interior.

## 1.1 Program Goals and Objectives

This project's overall **strategic goal** is to provide a Resources Inventory Committee (RIC) manual that will help guide quantitative assessment of the effects of forest harvesting practices on the aquatic environments of British Columbia, in order that those forest practices will be effectively managed. The information collected with the guidance of this manual can be used by the resource manager to determine operator **compliance** with the Forest Practices Code (FPC) and the **effectiveness** of the FPC at protecting the aquatic environment.

This manual's **specific objective** is to identify and guide the selection of effective and practical methods that quantify the deposition of fine grained sediment in streams with active channel widths of less than 15m. Although it is assumed these techniques can be applied in all regions of the province, this review is based on their application in the central interior. It is the responsibility of other resource managers to determine method applicability within their region. In addition to providing a description of sampling techniques, this guide presents a framework for developing forest related impact assessment studies.

This document is a companion to the RIC manual "Lake and Stream Bottom Sediment Sampling Manual" by Cavanaugh et al (1997). Although Cavanaugh et al.

discuss stream sediment sampling, this report provides more detail, presents several other techniques and outlines the process for selecting the appropriate technique.

This document provides information under the following headings:

- **Program Development for Sediment Monitoring** (study objectives, site establishment routines, appropriate spatial and temporal placements, appropriate monitoring techniques).

- **Techniques that Collect Depositing Sediments** (equipment specifications, sediment capture type, preferred sampling habitat, replicate sampling requirements, QA/QC).

- **Data Analysis and Reporting** (lab methods, data analysis techniques, reporting).

- **Summary** (program expectations and issues requiring further investigation).

## 1.2 A Synopsis of Biological Effects and Sediment Criteria

The effects of forest harvesting activities on receiving water quality and freshwater biota as summarized by MacDonald et al. (1991) include sediment loading, nutrient loading, temperature modification, and herbicide contamination. Of these, the introduction of fine grain sediment to adjacent watercourses has been found to cause the most significant and widespread negative effect. Fine grained sediments form an integral part of the streambed complex. However, this document attempts to fulfil the need for methods that assess incremental fine sediment deposition. It is not directed toward the assessment of coarse sediment or organic debris.

### 1.2.1 Sediment Effects on Biological Communities

The effect that a sediment load has on an aquatic community is dependent on several factors, including the biological community and life stage in relation to sediment grain size, concentration, and transport method. The volume of literature available on this topic is immense. We provide here a brief summary of the effects specific to periphyton, benthic invertebrates, and fish by making reference to more recent articles.

- Periphyton (and macrophytes) – Primary producers can be affected by the shading nature of sediment, both in the water column (light extinction via reflection, scattering, and absorption) and as it blankets the streambed, which reduces light for epilithic plants. Depositing sediment can also affect primary producers through its abrasive action as it moves along the streambed. Direct contact with sediment may scour periphyton from the streambed or may damage periphyton and plant structures. Both the blanketing and abrasive actions of sediment have the potential to decrease periphyton biomass and lower community diversity. Refer to Lloyd et al. (1987), Van Nieuwenhuyse (1986) and Waters (1995).

- Benthic Invertebrates – Invertebrates living on or within the stream substrate can be affected by an increase in the depositing sediment load. Depositing fines can fill streambed interstices and block access to the underside of stones, thereby decreasing available habitat and reducing oxygen exchange. If the depositing fine sediment load is significantly increased and sustained, the benthic invertebrate community may shift toward more silt-tolerant species. If the increased fine sediment load does not deposit but remains in suspension near the streambed, it can abrade individuals and increase invertebrate drift. Either situation will result in reduced diversity. Refer to Culp et al. (1983 and 1986), Lloyd et al. (1987), Waters (1995), Shaw and Richardson (2001), Minshall et al. (2001).

- Fish – Fish response to increases in sediment concentration depends upon species and life stage. Generally, the response to either suspended or depositing sediment may be behavioural (e.g. avoidance) and /or physiological (e.g. gill damage). Depositing sediments may limit available spawning habitat, stress eggs via reduced oxygen and metabolic waste exchange, and affect alevin emergence by way of substrate embeddedness. Continuous behavioral or physiological sediment-related stress might result in mortality, particularly of the egg/alevin life stages. Sediment can also have an indirect effect on fisheries via food chain impacts to periphyton and benthic invertebrates. Refer to Andersson et al. (1996), Newcombe and Jensen (1996) and Waters (1995), Shaw and Richardson (2001).

### 1.2.2 Aquatic Life Criteria and Biologically Significant Grain Sizes

A variety of sediment grain size fractions have been considered by environmental managers and researchers in their efforts to identify aquatic impacts. A recent review of this literature by Caux et al (1997) has led to the amendment of the British Columbia Water Quality Guidelines for turbidity, suspended and benthic sediments. New guidelines recommend that streambed composition at salmonid spawning sites should not exceed 10% of < 2 mm, 19% of < 3 mm, and 25% of < 6.35 mm. Further, the guidelines recommend that the geometric mean diameter and Fredle number (Sec. 4.2.2) not be less than 12 mm and 5, respectively.

The literature reports a variety of biologically relevant grain sizes for salmonid redds:

- McNeil and Ahnell (1964) studied the success of pink salmon spawning as a function of streambed permeability and substrate particle size. They suggested that an increase in sediment volume of particles less than 0.833 mm would result in both decreased permeability and reproductive success.

- Chapman (1988) reported that coho and chum salmon survival was inversely proportional to increases in particles less than 3.3 mm.

- Chapman (1988) reported on the work of McCuddin (1977) who found, using experimental troughs, that the survival and emergence of chinook salmon and steelhead in gravel-sand mixtures decreased as the proportion of sand (0.063-2 mm) increased above 10-20%. Further, he found that any percentage of 6-12 mm particles above 15% or of particles less than 6 mm above 25% reduced survival of newly fertilized eggs.

Regardless of the specific grain size studied, it is readily apparent that an excess of fine grain sediment has the potential to negatively affect salmonids. This manual does not promote the use of one grain size over another as an aquatic criterion. Rather, it addresses the need for methods to quantify fine depositing sediment in stream environments regardless of the criterion applied. Although the selection of a criterion lies with the program manager, the grain size or index chosen must reflect the environment sampled and be useful for comparative purposes.

## 1.3 Report and Method Limitations

Several qualifications, both with regard to this RIC manual and with the methods presented herein, require mention.

This report does not present an exhaustive list of assessment techniques for depositing sediment. Rather, it describes those best documented in the literature and often employed in the Omineca-Peace Region. Although a work-in-progress, this review provides several viable approaches for quantitatively assessing depositing sediment increases due to forest harvesting activities in central interior watersheds.

These techniques can be employed in large systems but we recommend their application be limited to wadeable creeks having active channel widths of less than 15 m. Although the definition of a wadeable stream is subjective, we suggest that sample sites be chosen with respect to the safety of field staff and as designated by Worker's Compensation Board (WCB) guidelines. In addition to safety considerations, sampling in larger streams may not be cost effective. Land-use effects are likely to be more severe and thereby most detectable in smaller streams.

The majority of methods referred to in this manual can be used to characterize grain size composition over much of the range typically found in streams (i.e. from clays to cobbles) but we will focus on the fine grain fractions (< 6mm) because of their biological relevance. This grain size was selected with reference to fisheries literature and provincial guidelines for the protection of aquatic life. It does not follow sedimentological convention, which would focus on the upper limit of fine gravels (8 mm).

Water quality monitoring and assessment programs strive to gather information about spatial and temporal variability. Studies of sediment transport and fate require the selection of and adherence to a suitable monitoring design. This may best be achieved by adhering to the steps presented in the following section.

# 2.0 Program Development for Sediment Monitoring

The success of a sediment monitoring program depends on effective program development. The importance of this process cannot be overstated. Experimental design, site selection and in-field activities are all determined during this process. Numerous journal articles and provincial documents emphasize the importance of program development, including MacDonald et al. (1991), MacDonald (1992), MacDonald and Smart (1993), Bunte and MacDonald (1995), MacDonald and Carmichael (1996), Cavanaugh et al. (1997b), Caux et al (1997).

The framework presented for assessing forest harvesting effects on sediment transport and storage in streams (Figure 1) is largely based on the above literature. The framework has a broad scope, which allows for its adaptation to a variety of industrial activities and water quality characteristics, permitting its use throughout British Columbia. Prior to using the framework to develop a sampling program the overall objectives must first be established.

## 2.1 Establish Program Objectives

Establishing program objectives is an essential first step in the development process. Failure to give this step adequate attention invariably leads to confusion during the assessment and results in a substandard product.

The **strategic goal** of sediment monitoring programs developed with this framework is to quantitatively assess the effects of forest harvesting and other land use practices on aquatic environments of British Columbia, so that those practices can be effectively managed to maintain aquatic habitat quality.

The specific **objective** of sediment monitoring programs developed to meet this goal is to quantify fine grained depositing sediments that are generated by forest harvesting activities. Although this report emphasizes forest harvesting, these techniques are applicable to managing any land use that has the potential to increase the depositing sediment load.

To meet the **objective**, each monitoring program should include the:

- application of a framework (Figure 1) for assessing forest harvesting activities that have the potential to affect the aquatic environment; and, within that framework, the
- development of a specific aquatic effects monitoring program that will assess the impact of forest harvesting activities on sediment movement in streams.

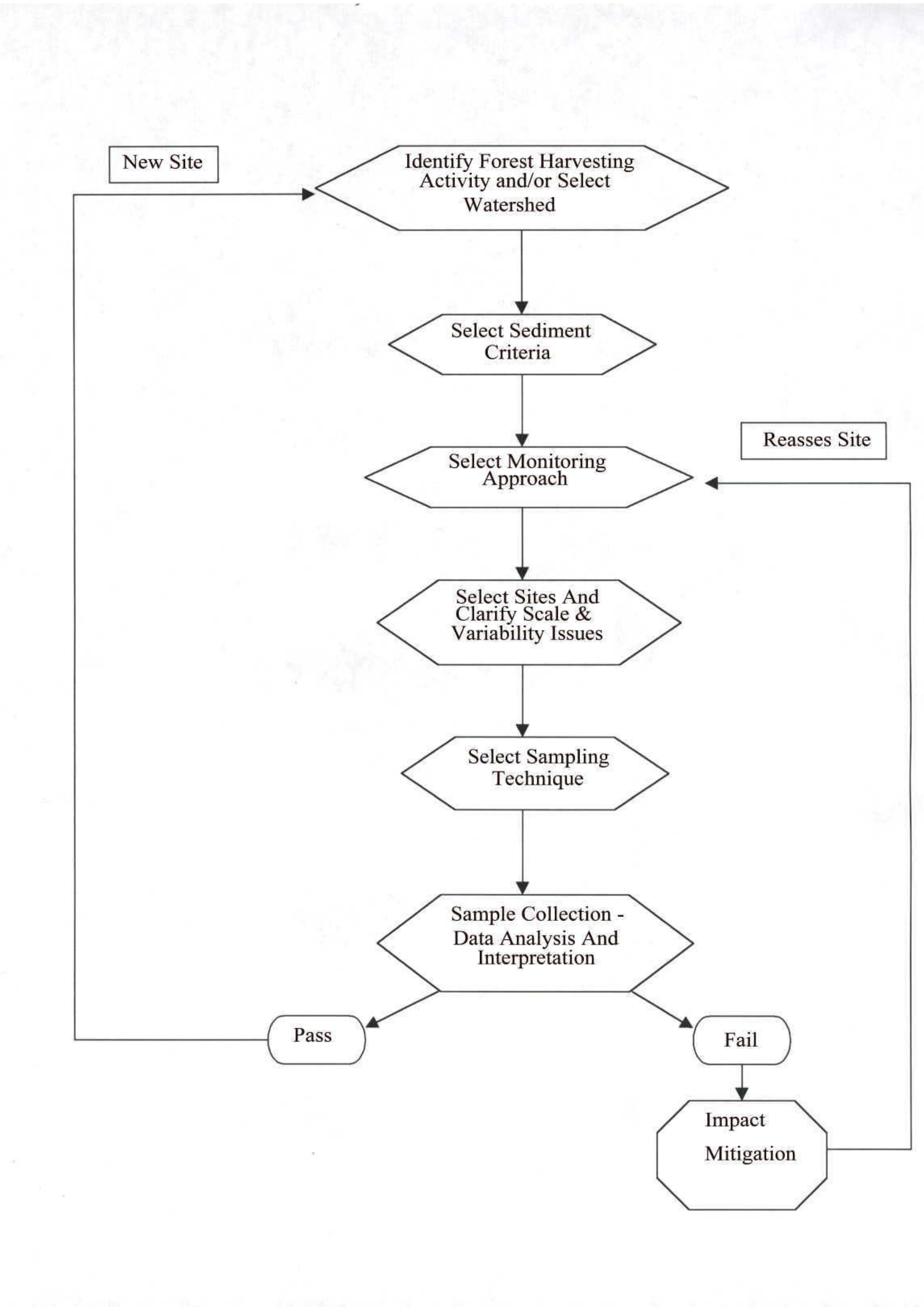



**Figure 1 –Omineca-Peace regional framework for assessing forest harvesting activity affects on sediment transport in streams.**

## 2.2 Establish the Project Methodology

Once program objectives are established, it is necessary to select the most effective assessment method, as per the framework (Figure 1). To assess the effect of forest harvesting activities on fine sediment in the aquatic environment, the following steps are recommended:

1. Identify and prioritize regionally significant forest harvesting activities and their potential aquatic effects and/or select watersheds in each ecoregion, hydrological zone or other preferred planning unit for study based on;
   - their resource values (aquatic life, potable supply, aesthetic value);
   - the potential for local harvesting activities to damage these values.
2. Determine the sediment transport form of interest (suspended or bedload) and appropriate water quality criterion.
3. Identify the appropriate monitoring program design and assessment approach.
4. Select monitoring sites and determine how issues of scale and variability will be addressed.
5. Select techniques (McNeil cores, gravel buckets, etc.).
6. Collect, analyze, and interpret data.
7. Report on the forest harvesting activity effect on sediment transport and fate.

Steps 5 to 7 are presented separately in chapters 3 and 4.

### 2.2.1 Step 1: Identify and prioritize regionally significant forest harvesting activities & select watersheds for impact assessment

Sampling programs will typically focus on either a priority watershed(s) or a specific forest harvesting activity. Regardless of program focus, the inclusion of government habitat staff and forest licensees in the planning process is necessary. These individuals often have the most current knowledge about activities in regional watersheds and may know which are the highest priority activities, watersheds and sites.

### 2.2.2 Step 2: Select the sediment transport form and criterion of interest

Sediment moves through a stream in one of two forms, as suspended load or as bedload (Leopold, 1997). Suspended load is that portion of sediment that remains in suspension while bedload moves along the streambed in a rolling, sliding or saltating manner (Kearey, 1996).

A watershed's priority resource will dictate the type of sediment that should be monitored. For example, if we are concerned about potable supply, suspended sediment should be monitored. However, if we are concerned about the survival to emergence of salmon fry downstream of placer mining operations, the fine sediment composition of the bed should be monitored.

Once the form of sediment to be monitored has been chosen, the specific grain size or criterion of interest should be selected. This may include the application of provincial guidelines or may be project specific. For example, a legal investigation of the change in streambed substrate due to a specific industrial activity may require strict adherence to grain size proportions as determined by provincial guidelines. However, a study on downstream effects of a sand/loam supplier will require a concentrated focus on sand fractions ($2mm < X < 0.063mm$) because that grain size range can be directly related to the sand/loam supplier's operation.

### 2.2.3 Step 3: Select the monitoring design and assessment approach

To facilitate the collection of data that will meet program objectives, it is essential to identify the appropriate monitoring design. All monitoring designs have specific spatial and temporal characteristics and may be broadly categorized as spatial or temporal assessment programs.

A spatial assessment program uses reference and exposed sites to identify the effect caused by a specific activity. Although this may require intensive monitoring it may only be for a short period of time. Conversely, a temporal program can model long term effects of a selected activity but perhaps simply at one site. Selected parameters can be measured at regular intervals to establish a reliable time series that can show the effects of and subsequent recovery from the investigated activity.

Several approaches are outlined by MacDonald et al. (1991). Most of the following designs can determine the effect of forest harvesting activities:

1. *Trend Monitoring:* A long term sampling program, which can determine the temporal variability of the measured parameter. This variability may be natural or influenced by development activities.

2. *Baseline Monitoring:* A temporal sampling program to collect information on conditions prior to forest development. Data collected during this period can be compared with those collected after forest harvesting activities are implemented.

3. *Effectiveness or Compliance Monitoring:* A short-term spatial program to determine if prescribed activities produce the desired or legislatively prescribed effects. This program requires sampling up and downstream of a prescribed activity, such as silt fencing, to determine if the fencing prevents fine sediment addition to the downstream area.

4. *Project or Impact Assessment Monitoring:* A spatial program employed to determine if an activity has a negative effect at a specific site. For example, will road construction in the riparian zone of a creek increase the fine sediment load downstream? It differs from effectiveness monitoring because the results generated may be used to charge the offender.

Once the assessment approach has been selected, the sampling schedule and program duration can be clarified. These important steps allow staff to determine whether the program can be completed within budget and time constraints. Program objectives may need to be redefined at this stage.

### 2.2.4 Step 4: Select sites and determine how issues of scale and variability will be addressed

Successful site selection requires practical office and field components with due consideration given to answering how scale and variability will effect sample results. Although contiguous processes they are presented separately for clarity.

Sediment data can be influenced by several sources of variability, including spatial which is defined by the sample site's location relative to the investigated activity, measurement uncertainty, and natural variability (MacDonald, 1992). A successful monitoring program will address these issues. A brief description of each follows:

- Sediment storage: Sediment storage is a scalar effect dependent upon channel dimension and morphology, the presence of large woody debris and water velocity. It is commonly understood that the amount of sediment stored in a stream is greater than that captured at its outlet (Megahan, 1982). Stored sediment is released over time, resulting in a lag response between the addition of sediment and the subsequent increase in sediment yield at a downstream monitoring location (MacDonald, 1992). This lag response is channel specific and requires that monitoring programs consider the influence of sediment storage in the study watershed. This may involve sampling near the suspected sediment source to capture those additions before they settle out and are stored. Or, it may involve sampling at two locations downstream of a source for an extended period of time so that the lag response between them can be estimated.

- Measurement uncertainty (error): This uncertainty is the combination of error in field and lab procedures. Sampling error is typically addressed through QA/QC programs (refer to Section 3). Generally, field QA/QC requires careful site selection and replication of the sampling procedure, while laboratory QA requires acceptable precision between initial and re-sieved samples (in the case of deposited sediments).

- Natural Variability: This can be defined as the variation that exists between sample replicates and/or sites due to spatial and temporal effect, but separate from the effects of the investigated sediment source. The combination of measurement uncertainty and natural variability produces the “total assay error” in precision measurements.

Variability can be considered with respect to the spatial or temporal assessment design used, as follows:

**Spatial Monitoring**

For the purpose of discussion we assume here that both reference and downstream sites are monitored and that the number of replicates collected is adequate to ensure representative data. The active channel width should be less than 15 m.

Dilution effects on spatial monitoring can be addressed by ensuring that tributaries do not join the stream between monitoring sites (i.e. by establishing both sites in one reach). If this is not possible, tributaries that flow into the stream between those sites must be gauged and sampled for sediment to measure their influence on the downstream site.

Establishing control and treatment sites in a single reach will reduce the effect of sediment storage by limiting the available storage area between the sites. If sampling is conducted near the suspected source, the probability of collecting sediment that can unequivocally be related to that source will be higher.

Collecting samples in similar environments, as determined with site establishment data, should minimize spatial variability (Appendix 1). The effect of temporal variability on spatial sampling should be minimal because samples are collected at both sites for the same period of time.

**Temporal Monitoring**

For the purpose of discussion we assume here that only one site is monitored and that the number of replicates collected is adequate to ensure representative data.

Storage time will be assessed over the duration of the program. Temporal programs monitor downstream effects of forest activities over a series of seasons and years. These data may be used to determine the lag time between an upstream sediment influx and the downstream effect.

Temporal variability is assessed over the course of the program by collecting data over several seasons and years. Spatial variability effect on temporal sampling is minimal because the same location is sampled each time.

Good site selection is prerequisite to a successful monitoring program. Sediment is ubiquitous, it’s generation often the result of natural erosion processes. To separate the effects of forest harvesting activities or other land uses from natural sediment generation, sites must be chosen carefully, with due consideration to scale and variability. Where possible, several reference and treatment sites should be monitored because these data will provide more information on natural variability and the variability associated with the activity of interest (Manly, 2001).

Given these considerations, site selection will include both office and field components as follows:

**Office level: site overview**

The office level site overview is intended for the preliminary selection of sites. This requires the use of forest development plan maps, road engineering maps, air photos and the watershed/activity priority lists. The selection process can be accelerated by input from regional habitat biologists or others familiar with local watershed activities. Using the available tools, preliminary sites can be selected with reference to the following questions:

*What is known about the area?*

Existing field notes and discussions with staff that have visited the area may provide useful information about site conditions and ease of access.

Available sediment data from the study area should be reviewed as a means of assisting the selection of sample size. If no such data exist, which may typically be the case, other regional programs or those within similar settings should be reviewed. Alternatively, Rood and Church (1994 ) provide a method for using pre-sample data to determine the appropriate number of replicates required to achieve a set level of precision (Section 3).

*What natural resources are present?*

Site selection should be influenced by the presence of highly valued natural resources such as salmonids, endangered species, or high water quality.

*What is the cost-benefit of assessing the selected site?*

Depending on the project objective (i.e. is sampling watershed or activity focussed), it may be reasonable to establish several sites in a single watershed. This would provide more information about the watershed's response to forest harvesting activities and may be more useful than individual sites within several watersheds. Establishing several sites within a watershed reduces the spatial variability associated with different ecoregions. Further, it may be more cost-effective by reducing travel costs. If other programs are occurring in the project area, partnerships may be developed that could reduce operational costs.

*What biogeoclimatic influences exist?*

Sediment transport is influenced by climate, geology and hydrology (Leopold, 1997). These influences must be clarified prior to comparing study results across a region. For example, if a program was implemented to study sediment additions from a specific stream crossing design it will likely be greater in those areas with poor soil stability. As such, statements on the effectiveness of this crossing design must be qualified by stating each study area's soil stability as well as the precipitation levels experienced and the hydrologic period when the study was conducted. A spring survey in areas dominated by sand cannot be compared to late summer surveys in areas dominated with bedrock.

**Field level: site reconnaissance**

A reconnaissance survey of the preliminary sites should be conducted to determine site accessibility and similarity. During this visit, the physical attributes of the sites can be factored into judgements about the environmental and practical limitations of access. Previously studied sites, identified during the overview, can be visited and appraised for their use to the current program.

Site access is a key consideration in any program but particularly so for depositing sediment monitoring. Most of the equipment used and the samples collected are heavy and difficult to transport over rough ground. Accordingly, sediment monitoring sites must be close (i.e. within several hundred metres) to road or helicopter access. Sampler fatigue and poor data quality may be the result of unrealistic access expectations.

Many features that determine the utility of a site will not be visible from mapping or air photography. Water depth and velocity are two obvious features. In-stream structures and habitat complexes are also important. The influence that these may have on site placement and data quality must be considered. For example, samples should not be collected immediately downstream of woody debris dams because they are sediment storage sites. As such, they may store or release sediment irrespective of the source activity. Seasonal effects must also be considered. High flow sample programs should be initiated only after reconnaissance during similar high flow conditions.

The availability of good sites might also influence the type of method deployed. Sediment traps may be eroded and lost from high velocity sites, leaving corers as the only realistic sampling option.

**Field level: site establishment**

Site establishment data should be collected at those sites approved for sampling during the field reconnaissance process. Site establishment includes the gathering of data that provides a basic understanding of local channel morphology and hydrology. This information can be used to confirm that field staff chose similar sampling areas/environments between and within sites. Without this information, the data may actually reflect differences in the sample areas rather than effects of the source activity.

Site data can also be used to explain outliers and justify their exclusion from statistical analysis. For example, if one of six replicates contained an uncharacteristically high silt content and was also the only one collected from the edge of a pool in a glide zone, its omission from statistical analysis may be justified.

Site establishment includes the collection of:

1. Stream width (wetted and bankfull).
2. Stream depth (reported as the average).
3. Discharge and velocity (by meter).
4. Streambed gradient (by survey level or clinometers).
5. Streambed characterization (Wolman/modified pebble count procedure).
6. General streambank characteristics (soil characteristics, vegetative cover).
7. Channel morphology (sinuosity, degree of aggradation/degradation).
8. Sketch a map of the habitat units (relative presence of pool/riffle/run/glide).
9. Placement depth, velocity, and area.

Steps 1, 2, 3, and 9 are collected during each sampling trip, streambed gradient may be collected several times over a long term sampling program, and the remaining measures are collected at the beginning and end of the sampling program. A complete description of the site establishment procedures is provided in Appendix 1.

# 3.0 Depositing Sediment Collection Techniques

Selection of the appropriate sediment collection technique is crucial to successful program development. It requires an understanding of program objectives and stream morphology, as well as the strengths and weaknesses of each technique. Selection consists of two steps: drafting a list of potential techniques to meet program objectives and subsequent selection of those techniques that best suit site conditions.

Two classes of depositing sediment collection techniques are presented here, namely streambed corers and sediment traps. Other bedload and streambed elevation sampling techniques are presented in Appendix 5. Of the corers and traps, only the streambed corers can be used to ensure adherence to BC substrate guidelines because they capture information on the composition of all sediments in the streambed.

The following description of each technique will include:

- the sediment form captured by the technique;
- the equipment specification and known variations in design or sampling process;
- the most appropriate sampling habitat;
- the specific field protocol (with photos where available);
- a suggested number of sample replicates;
- a quality assurance / quality control (QA/QC) plan.

As part of the sampling design, it is important that when selecting the number of sample replicates staff should consider the level of precision required, the size of the stream to be sampled, the amount of sample collected by each technique, and sample cost. Estimates of sampler and analysis costs are provided in Appendix 6.

## 3.1 Common Safety, Quality Assurance, and Quality Control (QA/QC) Procedures

Safety is the most important program consideration. Sampling should be conducted by at least two field staff in water depths and velocities that are considered safe by each staff member and all applicable WCB guidelines should be followed. A further benefit of working in pairs is that one member can check the other's sampling procedure to ensure consistency.

Both quality assurance (QA) and quality control (QC) are central to the forthcoming discussion of methods. As a basic definition, QA tasks are performed to determine data acceptability while QC tasks are performed to protect and ensure data quality.

For example, the re-sieving of 10-20% of samples is QA whereas the washing of sampling equipment between samples is QC.

Many QA/QC procedures are common to the sediment collection techniques identified in this manual. To reduce repetition, those procedures are stated here.

### 3.1.1 Training

All new operators should be adequately trained, which would include a review of this manual, other relevant literature, and equipment instructions. Prior to their involvement in a formal sampling program however, new members should demonstrate their familiarity with the sampling equipment and collection methods to an experienced staff member or contract monitor. Another basic consideration at this stage is to ensure that operators have the physical strength and stamina to conduct some of these strenuous sampling techniques. Further, it is recommended that at least one member of the field staff have specific experience using the chosen technique.

It is important that operators understand the invasive nature of these methods and their potential negative affect on fish habitat and spawning success. As such, operators must consult with DFO and WLAP/MSRM when using any technique that disturbs the streambed. Operators should also be aware that there are provincial instream work windows which vary by location and species present. Information on timing windows is available from WLAP regional staff.

### 3.1.2 Field Quality Control

Field quality control procedures include the following:

- Locate sampling sites that are representative of the stream. Each replicate location should be chosen to ensure that depth, velocity and habitat are similar both within and between sites. Depth and velocity of each replicate should be measured during any trip to the site.
- To ensure consistency in sampling technique, the same individual should collect the samples for a given program or at least manage the sampling program. If this is not possible, ensure that there is an overlap in operator tenure.
- To minimize streambed disturbances before sample collection only one staff member should gather site data and establish transects. When returning to retrieve samplers, that same individual must take care not to compromise the quality of existing, possibly buried samples.
- The same note taker should be maintained through a program and/or a standard field note template should be developed.
- Sample technique must be consistently followed. Any deviations from the procedures must be documented in the field notes.
- To avoid contaminating sediment samples, the sample area should be approached in an upstream direction. Streambed corers should be collected in an upstream

direction starting at the furthest downstream sampling location. Sediment traps should be installed in a downstream direction starting at the furthest upstream sample and subsequently retrieved in an upstream direction.

- Many samplers have several different models and each of these will have different equipment specifications that will maximize efficiency in a given set of environmental conditions. As such, it is important to maintain the use of one model, if it is operating successfully, once a program has been initiated to avoid introducing equipment bias into the collected data.
- The deployment of at least two sediment techniques is recommended to strengthen conclusions drawn from the data. Similar trends may be found between sampling techniques. For example, McNeil core data may document changes in streambed composition due to depositing fine sediment that is also captured by gravel buckets
- Ensure that samples are labeled in a consistent format.
- Example audit (field QA) sheets are provided in Appendix 2.

### 3.1.3 Analytical Quality Assurance

Lab QA should include the re-sieving of at least one sample per site (or at least 10%) of all submitted samples on a per site basis. The initial and re-sieve values of each grain size should be within 5% of each other. If not, all samples from that site require re-sieving.

If samples are split before analysis because of their bulk, 10-20% of the splits should be sieved and the data compared to ensure the splitting procedure is not introducing bias to the data set.

Each monitoring program may include a QA component in which reference samples are regularly submitted for lab analysis. This could include single mixtures of known grain sizes that are created by the client to test lab bias (accuracy) and identical replicate samples for lab precision assessment.

In those cases where lab analysis is limited to total suspended solids, the application of duplicates, split samples and blanks, as described by Cavanaugh et al. (1997b), is recommended. Where available, other accepted quality assurance standards ca be used such as those from the Water Survey of Canada and the American Society for Testing and Materials (ASTM).

### 3.1.4 Program Audits

To ensure consistency of field technique in long term temporal or large scale spatial programs, an experienced monitor from outside of the main program group should regularly audit each technique included here. This would include the observation and photographing of sample collection as well as the completion of audit field forms (Appendix 2). Monitors may include staff from other sampling programs or agencies such as WSC.

## 3.2 Streambed Corers

Coring techniques gather data on streambed grain size composition. Several designs exist but they all operate on the same general principle: insertion of a cylinder into the streambed and removal of substrate. The cylinder size and manner of sample removal separate these techniques into two classes, freeze corers and McNeil corers.

### 3.2.1 Freeze Corers

**Before using this technique, staff must have appropriate safety equipment and training to transport and handle the hazardous materials used in the freezing process.**

Freeze coring was introduced by Walkotten (1973) and has been most often applied in the collection of streambed samples within salmonid spawning grounds. The original design involved inserting a narrow cylinder into the streambed. A gaseous carbon dioxide coolant was injected into the cylinder causing the streambed around the core to freeze. The core and attached sediment plug were then removed and thawed, often with the use of a propane torch. The sediment could be analyzed as a composite sample or be divided into sub-samples by depth.

Several modifications to the original Walkotten design have been made over the last twenty years. Each signified an attempt to increase the corer's efficiency by either increasing or standardizing the mass of collected sediment. Designs commonly referenced in the literature include:

- A single probe freeze corer that uses $CO_{2\,(g)}$ or $CO_{2\,(g)}$ and acetone/methanol, as in Figure 2 (Walkotten 1973, Scrivener and Brownlee 1989).
- A tri-tube freeze corer that uses $CO_{2\,(g)}$ or $CO_{2\,(g)}$ and acetone, as in Figure 3 (Everest et al., 1980).
- A modified freeze corer that uses $N_{2\,(l)}$, as in Figure 4 (Rood and Church, 1994).

The primary advantages of freeze coring are*:*

1. It is a commonly used technique for effectively assessing streambed composition, particularly spawning gravels.
2. Samples can be vertically stratified and sub-sampled to assess fine sediment deposition and vertical movement over time.

**Figure 2 - Single probe freeze corer. (Photo courtesy of Jessy Harper, Agra Earth & Environmental).**

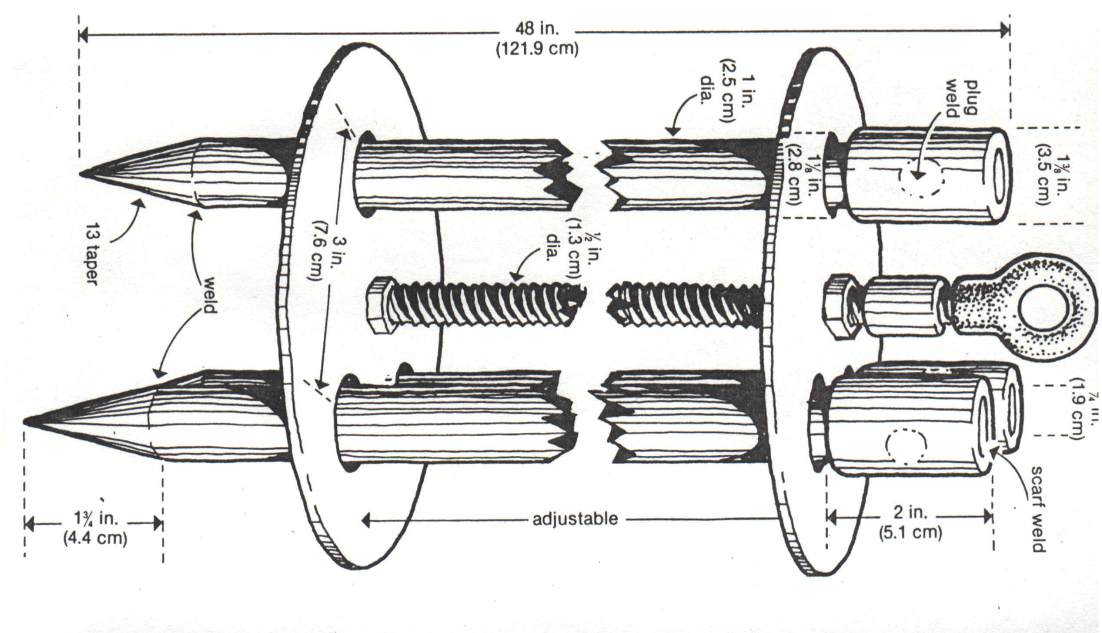



**Figure 3 - Tri-probe freeze corer. (Everest et al., 1980).**

**Figure 4 – Roadside photo of the modified freeze corer outer tube, which standardizes the volume of sediment that can be sampled (Rood and Church, 1994).**

3. It determines redd burial depths and the ability of the fish to clean gravels within redds. Further, it provides data on fine sediment composition at several depths in relation to the egg pocket, and can be used to determine the survival to emergence of juvenile salmon (Ringler and Hall, 1988). It is also the only technique that can provide this information retrospectively. Salmonid redd depths are provided in Appendix 7.

4. It can collect deeper, larger and more representative amounts of sediment than the McNeil corer. Sample weights of 2 to 20 kg per core are possible depending on the freeze corer design, whereas the standard McNeil corer collects 5 to 8 kg.

5. The equipment is larger than the McNeil corer so it can collect samples in deeper water. It can be used in riffles, glides, runs, and shallow pools.

6. Department of Fisheries and Oceans reports that modified freeze corers do not disturb fine sediments more than other coring methods during insertion (Herb Herunter, personal communication).

The primary disadvantages of this technique are:

1. It can under sample fine sediments (Young et al., 1991a). During the insertion process, fine sediments may be disturbed and pushed further into the streambed.

2. The ad-freezing of coarse grains to the outside of an unshielded corer may bias the sample to the larger grain sizes. The Rood and Church design combats this process by ensuring the sample volume is consistent as only that portion of the sample contained within the outer tube is analyzed.

3. The equipment is bulky and can be heavy (up to 45 kg excluding the sediment plug), which limits its use to easily accessible sites. This bulk also limits the concurrent application of other techniques because the coring equipment takes up most of the storage area in a vehicle.

4. The equipment requires considerable strength to operate properly.

5. The collection cost can be up to $50.00 per core. Cost is a function of sample design and expense of the coolant. Dry ice ($CO_{2(s)}$) is typically $2-3/kg, while liquid nitrogen ($N_{2(l)}$) is $4-5/L.

6. This technique is not recommended for winter sampling because the thawing of samples with a torch during subzero temperatures can be time consuming.

**Field Protocol**

1. Each sampling location should be chosen to ensure that depth, velocity and habitat are similar both within and between sites. Alternatively, set one or more transects perpendicular to the flow and collect samples at equal distances along the channel's cross-section. This latter approach presented by Adams and Beschta (1980) and Rood and Church (1994), collects data on cross channel variability.

2. Approach each sampling location from the downstream direction, taking care to start sampling at the most downstream location.

3. For the original freeze corer design place the tip of the probe on the streambed surface at a 90 degree angle to the bed. One person holds the probe while it is gently tapped with a sledgehammer into the streambed. Once held firmly by the substrate, the core can be hit more forcefully. To minimize probe damage from the hammer, a metal sleeve or block of wood should be used as the contact point. Other modified designs incorporate an internal slide hammer, which is better than a sledge because of increased control over core placement (Herb Herunter, personal communication).

4. When using the modified corer, place the core barrel on the streambed surface at a 90-degree angle to the bed. Twist it into the streambed while applying a downward force. The probe can be inserted once the top of the core barrel is flush to the streambed. One person can keep this probe vertically positioned. Drive the probe into the streambed using a sledgehammer. To minimize probe damage from the hammer, a metal sleeve should be used as the contact point (Rood and Church, 1994).

5. Ensure the probe is inserted to the required depth. If a modified corer is used, ensure that the top of the core barrel is flush to the streambed and that the probe cannot be pushed further into the substrate. If the single or tri-probe corer is used, insert the probe to the appropriate depth as determined by a visible marker on the outer corer wall.

6. Inject coolant into the core. It is assumed that staff will have the appropriate equipment and training to handle the hazardous materials involved in the freezing process. If liquid nitrogen is used, inject 6 to 8 liters into the core tube. If dry ice and acetone/methanol are used, add 3.5 kg of dry ice and 2 liters of acetone/methanol (Jessy Harper, Agra Earth & Environmental, personal communication). The acetone/methanol can be reused for subsequent cores.

7. Freezing time varies with the technique used and substrate sampled. For liquid nitrogen this typically takes 5 to 10 minutes (allows for complete volatilization) while for dry ice and acetone/methanol it takes 50 to 60 minutes.

8. Removal of the core will likely require two people. Ensure a sample splitter, for vertical sub-sampling, and sample bags or buckets are nearby. To remove the sample, heat it with a blowtorch and/or chisel it from the probe.

9. Ensure sample buckets or bags are appropriately labeled.

**Suggested Number of Replicates**

This manual cannot recommend the collection of a preferred number of freeze corer replicates because of the technique's limited use in the Omineca-Peace. Nor, unfortunately, does the literature provide specific guidelines for replicate selection. Scrivener (1994) was able to detect a 5% difference in composition in 5 to 10 m wide streams with only 10 replicates. Adams and Beschta (1980) used 3 cores to assess habitat quality. Rood and Church (1994) suggest 30 to 50 cores per riffle area in larger channels (greater than 30 m width) to detect a 10% change in streambed composition. De Vries(1970) and Church et al. (1987) present bulk sample standards, which suggest a total sample weight based on the largest stone observed in the stream reach (see section 3.2.3).

Another approach is to conduct a pilot survey so that its data can be used to determine sample replicate requirements for a pre-selected level of precision. This desired level of precision can be applied in the following formula, detailed by Rood & Church (1994):

$$N = (t_{\alpha N}\, C_V / I)^2 = (t_{\alpha N}\, s / \Delta F)^2$$

$$I = \Delta F / F$$

Where:

$N$ = required sample number, $t_{\alpha N}$ = student's t at a selected confidence level

$C_v$ = coefficient of variation for each sample, $s$ = standard deviation of $F$

$F$ = mean percent fines, $\Delta F$ = acceptable range of error around $F$ (e.g. 10 or 20%).

**Quality Assurance and Control Program (QA/QC)**

The QA/QC program for freeze core sampling requires well trained operators, carefully planned field quality control, assessment of analytical bias and precision and independent program audits, all undertaken with due consideration of personnel safety. Refer to section 3.1 for QA/QC considerations. Specific requirements include:

- Independent program audits should evaluate potential problems associated with: sampling approach; $90^0$ core placement; sample depth; freezing time; sample removal; splitting procedure and sample labeling protocol.
- The coring process will significantly alter streambed substrate. Samples should not be obtained at locations of previous cores within the same program year.

### 3.2.2 McNeil Corer

The McNeil corer is a device that is commonly used for assessing the composition of spawning gravel and collecting information on fine sediment addition from industrial activity. It was introduced as an alternative to the visual estimation of streambed surface composition and the collection of substrate samples with a shovel (McNeil and Ahnell, 1964). This equipment was seen as a significant improvement over previous methods because it was designed to collect fine particles. Prior to the application of this corer, limited information existed on fine particle composition in streams and its affect on both streambed permeability and salmonid spawning success. The McNeil corer has been used as a fisheries habitat tool and an impact assessment technique for monitoring natural or man-made changes in streambed composition (McNeil and Ahnell 1964, MacDonald and McDonald 1987, Schuett-Hames et al. 1994).

Although the corer shape has remained constant, several modifications have been made with respect to its size and construction material. Originally, the corer was made of stainless steel. It stood approximately 0.6 m high with a 0.3 m diameter basin and a 0.10 to 0.15 m core tube diameter that penetrated 0.15 m into the streambed (Figure 5). Although still used today, this model is considered bulky and heavy (approximate weight of 18 kg) (Schuett-Hames et al., 1996).

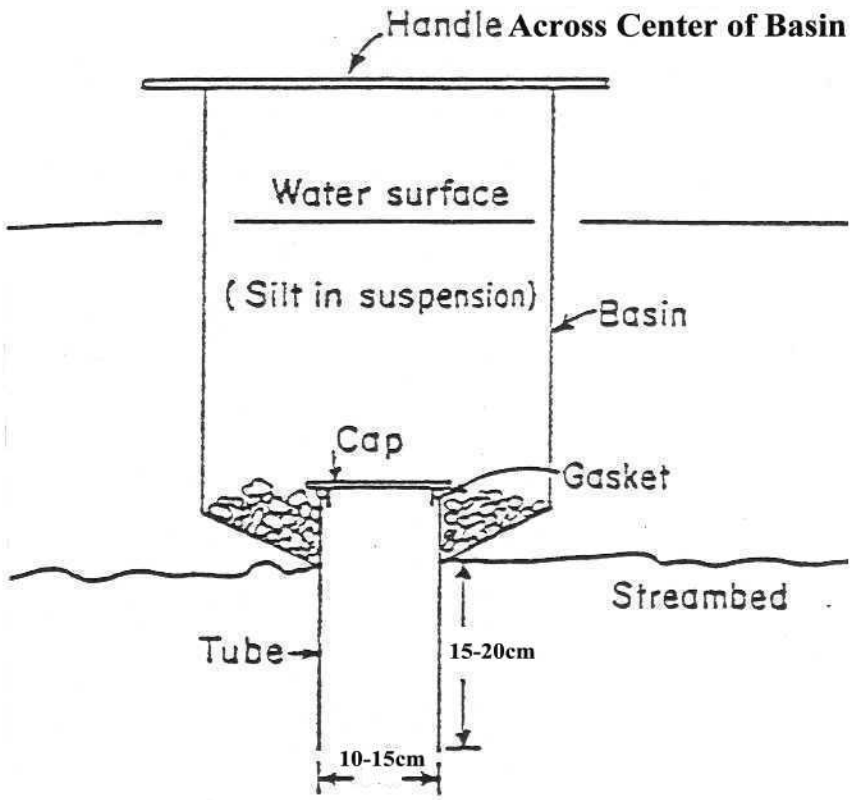



**Figure 5 - McNeil core schematic from McNeil and Ahnell, 1964.**

A physically larger, but lighter model has seen several years of use in the Omineca-Peace Region. We have bolted a ring of triangular steel teeth to the base of the aluminum design used by MacDonald and McDonald (1987). This modified corer stands just under 0.9 m tall, with a 0.6 m outer basin diameter. The core tube is designed to penetrate the streambed to a depth of 0.25 m and has a diameter of 0.2 m, which denotes the upper grain size limit that can be sampled (Figure 6). Subsequent to the construction of this sampler, we learned that Platts et al. (1983) suggested increasing the core tube depth and diameter to 0.3 m.

The use of heavy gauge aluminum rather than stainless steel reduced the corer's weight to roughly 4.5 kg and the larger core tube allowed for sampling of a wider range of substrate. In addition, the core teeth can be removed for sharpening or replacement. Another advantage of the removable ring is that it allows the testing and adoption of alternate tooth designs. For example, a number of steel pegs rather than teeth might provide better spacing to facilitate core penetration of cobble streambeds. Another useful modification is to bore holes in the side of the basin where handles would be located. A steel bar can be inserted through these holes, which provides more torque than handles (Dr. Michael Church, University of British Columbia, Personal Communication). Further, the bar is removable, which makes the corer easier to transport.

**Figure 6 - Modified McNeil core design. (1 liter bottle for scale)**

As a general rule it is recommended that the McNeil Corer have a larger core tube diameter so that a wide range of substances can be sampled. However, the study objectives may be such that a smaller core tube diameter would be preferable. For example, the truncation limits proposed by Church et al (1987) (Sec 3.2.3) might be used, removing the need to collect large grain sizes. Finally, the device should be wide enough to allow upper body access to the basin and be tall enough to provide support during sample collection.

The main procedural modifications observed in the literature involve the collection of the inner core water sample. During the removal of sands and larger particles, fine sediment will be suspended within the core tube. This suspended sediment can compose a large fraction of the total fine particle mass and must be quantified. McNeil & Ahnell (1964) collected these samples by capping the core tube and pouring the trapped basin water into a sample bucket (Figure 5). This procedure was improved on by using a flat plunger, equal to the core tube diameter and with a one-way valve that evacuated the core tube's entire water sample into the corer's outer sample basin (Figure 7). This sample was then emptied into one or two five-gallon buckets and allowed to settle for field or lab analysis. Rather than collecting the entire water sample, MacDonald and McDonald (1987) collected a 1 liter subsample after measuring the water's height in the core tube and mixing the sample. This subsample was then analyzed for grain size and mass, which was extrapolated back to the total sample volume. This latter technique has been adopted in the Omineca-Peace region.

The primary advantages of the McNeil corer are:

1. The modified McNeil corer is substantially lighter than either the freeze corer or the original McNeil design, and is easily transported.

2. The corer is simple to operate.

3. Unlike the freeze corer, the McNeil corer requires no auxiliary equipment.

4. In laboratory settings with known mixtures of sediment it was shown to collect a more accurate sample than freeze coring (Young et al., 1991a).

5. The core sample does not need to be thawed, so it is a faster, more viable winter technique than freeze coring.

6. It is perhaps the most economical method for collecting streambed grain size information (Platts et al., 1983).

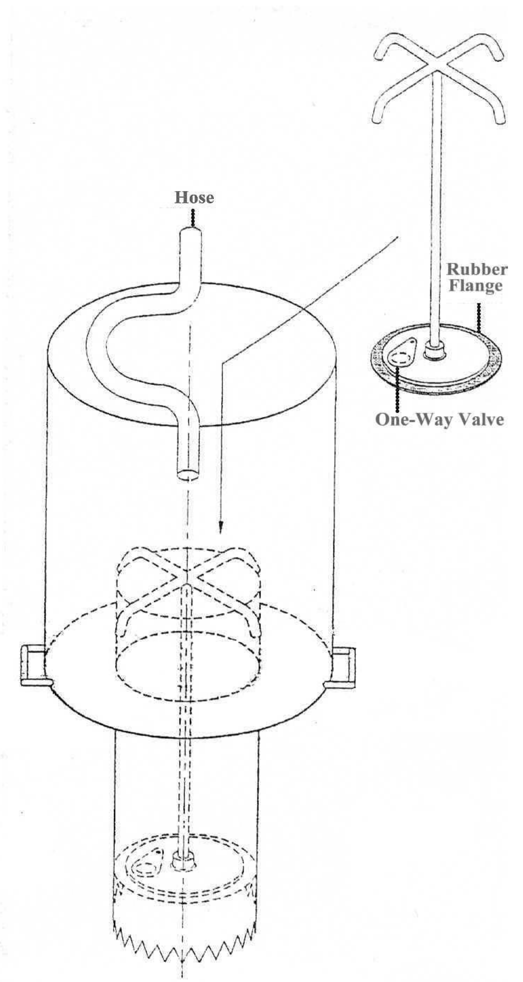



**Figure 7: McNeil core one way plunger apparatus for evacuating the core tube water sample (Dan Royea, Hallam Knight & Piesold, personal communication)**

The primary disadvantages of this technique are:

1. There is some potential loss of fine sediment when the core tube is worked into the streambed especially where substrate is coarse.

2. There is a potential for fine sediment to enter the inner tube with infiltrating water. However, it is assumed that excavating no farther than the top of the core's teeth will minimally disturb the substrate below.

3. Sample sites are limited by depth: Schuett-Hames et al. (1994) suggest operational depths of less than 0.6 m, whereas we recommend application in riffle or glide areas of less than 0.3 m to prevent flooding of the sample basin.

4. The sample cannot be sub-divided by depth as can freeze corer samples.

5. Coring becomes more difficult as substrate size increases. It may be impossible to use this technique if the substrate is very large and/or "cemented" to the point that the core tube cannot be worked a suitable depth into the streambed.

**Field Protocol**

1. Replicate sample locations should be selected so that they are drawn from similar habitats. With the aid of a velocity meter select each sampling location so that depth and velocity are similar within and between sampled sites, i.e. accept a 10-20% degree of variation in either measure when selecting sites. Although this does not guarantee that each location has or will experience similar conditions for fine sediment exchange over the course of the sampling program, they are critical habitat measurements that can be collected by staff that are specifically related to fine sediment deposition at the time of sampling. Suitable locations can be marked with labeled stones. Care should be taken not to walk directly on the sample locations. Alternatively, set transects perpendicular to flow at riffle crests and sample across each of them (Figure 8). This latter approach, which is presented by Schuett-Hames et al. (1994), measures cross-channel variability.

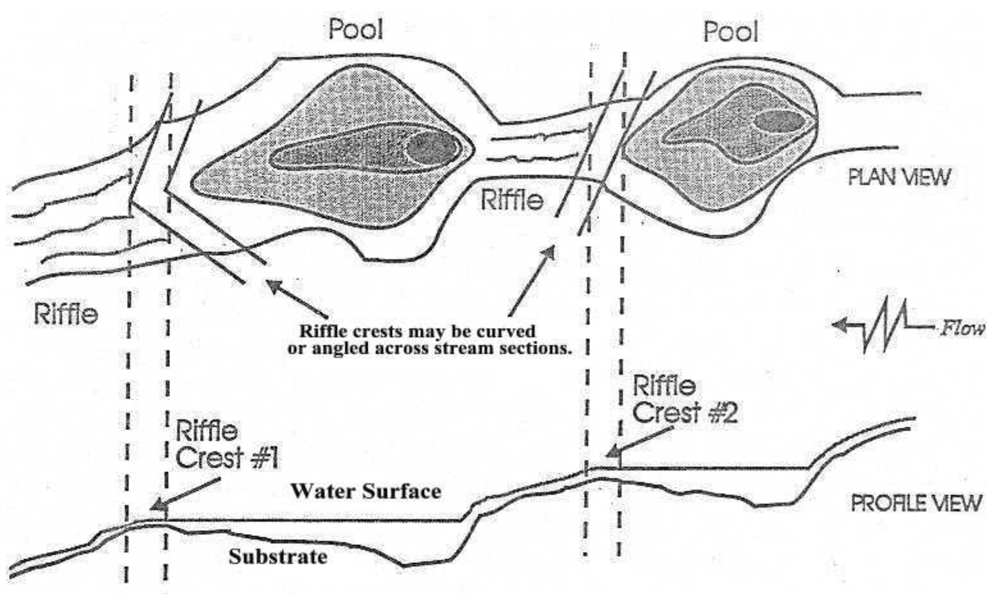



**Figure 8 - Designation of riffle crest areas to collect McNeil cores (Schuett-Hames et al., 1994).**

2. Ensure that only one staff member establishes transects or collects site data to minimize streambed disturbance before sampling.

3. Approach each sampling location in an upstream direction. Face upstream and place core teeth on the streambed.

4. Position one's body over the corer and firmly grab the corer handles (Figure 9).

5. While keeping the McNeil corer perpendicular to the streambed turn the sampler and apply force to drive it into the streambed. ***Do not rock the corer.***

6. Check McNeil core depth by ensuring the sample basin is flush to the streambed (Figures 5 and 10).

7. Agitate the core sample with a trowel or by hand to “break it up” and facilitate its removal.

8. Remove the sample by hand or scoop into a properly labeled sample bucket or bag (Figure 11). It is recommended that latex/rubber gloves be used to remove the sample because sharp sand grains can cut fingertips and can lodge deeply under the fingernails.

**Figure 9 - Proper body positioning for collecting McNeil core.**

9. Continue removing sample until the top of the core teeth is reached.

10. Add any sample that fell into the corer basin or that stuck to the sampler’s hand to the sample bucket or bag.

11. As the sample is removed, water will infiltrate into the core tube, the rate being dependent on substrate porosity and intergravel velocity. Once the sediment sample has been collected a water sample can be obtained by either:

- Using a rubber/neoprene plunger with a one-way valve to pump all core water into the basin and then by pouring this water into one or more five gallon buckets, or

- Allowing water to infiltrate the core tube to a depth suitable for the collection of a 1 liter suspended solids sample. Measure and record the core tube water height, stir the sample water by hand to resuspend settled fines and immediately collect a 1 liter sample. This sample should have colour similar to the core tube water. If not, replace it and repeat the process. It should be recognized that this procedure may bias the sample toward the finer sand and silt/clay fractions because the largest sand grains will settle very quickly, possibly before water sample collection. However, assuming that the technique is applied in a standard fashion, exclusion of the heavier grains will occur at all sample sites making comparisons between them valid.

**Figure 10 - To ensure that the core is fully inserted, the sample basin should be flush with the streambed.**

12. Once the sediment and water samples have been collected remove the corer, rinse it, and discard the rinse water downstream .

13. Continue upstream to the next sample site.

**Suggested Number of Replicates**

The number of sample replicates collected in a monitoring program depends upon the program objectives, the required level of precision, the sampling design and the McNeil corer design. The literature provides several options, including:

- Equations presented by Rood & Church (1994) (Sec. 3.2.1),

**Figure 11 - Sediment removal from core tube directly into 4 -litre bucket. Note: water has not entered the sample basin and grit on the sampler's hand was washed off into the sample bucket.**

- Bulk sample standards of de Vries(1970) and Church et al. (1987) (Sec. 3.2.3),

- Rice (1995) recommends the collection of 70 kg of dry material for British Columbia's coastal streams when focussing on sediment less than 64 mm.

- MacDonald and McDonald (1987) collected 4 oversized McNeil core samples at equally spaced distances along a channel cross-section. Using this procedure, they noted substantial within-site variability of fine sediment composition, which they attributed to velocity. Despite this within-site variance, their design had sufficient power to distinguish a significant increase in fine sediment downstream.

- Schuett-Hames et al. (1994) used a McNeil corer design similar to the original. They suggest collecting a minimum of 12 samples in each riffle zone.

A variety of replicate numbers have been used. We recommend either of the following:

1. Where samples are collected in similar environments as determined by depth, velocity, and sample habitat, we recommend collecting a minimum of 6, 7, and 9 samples for streams having active channel widths of 5, 9, and 11 meters respectively (Appendix 5).

2. Samples collected along a channel transect can be composited, as suggested by Rice (1995) or analyzed individually as suggested by MacDonald and McDonald (1987). If samples are composited, the total sample weight should fall within the guidelines of de Vries(1970) or Rood and Church (1994) (Sec. 3.2.3).

**Quality Assurance and Control Programs**

The QA/QC program for McNeil coring requires well trained operators, carefully planned field quality control, assessment of analytical bias and precision and independent program audits, all undertaken with due consideration of personnel safety. Refer to section 3.1 for QA/QC considerations. Specific requirement include:

- Independent program audits should evaluate potential problems associated with: deviation in sample site location procedures; upstream sampling approach; core placement and insertion technique; sample depth; sample removal; hand rinse; core rinse; water sample collection and sample labeling.

- The coring process will significantly alter streambed substrate. Samples should not be obtained from previous core locations within the same program year.

### 3.2.3 Bulk Sample Standards for Coring Techniques

Both freeze cores and McNeil cores can be used to collect volumes of sediment necessary to meet the bulk sample standards suggested by the International Standards Organization (ISO) (de Vries, 1970) and the truncated sample standards proposed by Church et al. (1987) and refined by Milan et al. (1999). Although these sample volumes may be too large for remote monitoring or less intensive spot check programs, they are suggested for those cases where a qualified statement about the accuracy of samples is required.

These standards determine sample volume as a function of the largest grain sizes contained within a sample. These large grain sizes are typically the least represented portion within a collected sample and so effective sampling will ensure they, as well as the finer fractions, are adequately represented. The de Vries standard assumes that the $D_{84}$, the grain size located at the $84^{th}$ percentile of the total grain size distribution, is suitably large for estimating sample volume. In addition, de Vries proposes three standard levels of precision, namely low, medium, and high. Sample volumes increase exponentially with increased precision. For example, using a $D_{84}$ of 30 mm the low precision sample weight is 60 kg, the medium is 600 kg, and the high is 6000 kg (Figure 12).

The Church et al. standards set the sample volume with respect to the largest grain size used in the analysis, the truncated grain size. Particles above this truncated size are not subjected to grain size analysis. For example, following the collection of a freeze core the sample may be pre-screened to 30mm. All materials greater than 30mm may be weighed for future reference but they are not sieved. Instead, only the less than 30mm fraction is analyzed for grain size composition.

The Church et al. sample volumes have been calculated with the assumption that they ensure a minimum of 100 grains of the truncated particle size are contained within the analyzed portion. In addition, sample volumes can be collected to ensure that the weight of this largest particle is no more than 0.1, 0.5, 1, 2, or 5% of the total sample weight. The lower the contribution of the large grain size fractions to total sample weight, the more representative that sample is of the streambed. For example, a 0.1% sample for a 30mm truncation requires a larger sample volume (50kg) than a 1% sample (5kg) (Figure 13). In general, the sample weights recommended by Church et al are considerably less than the de Vries standards.

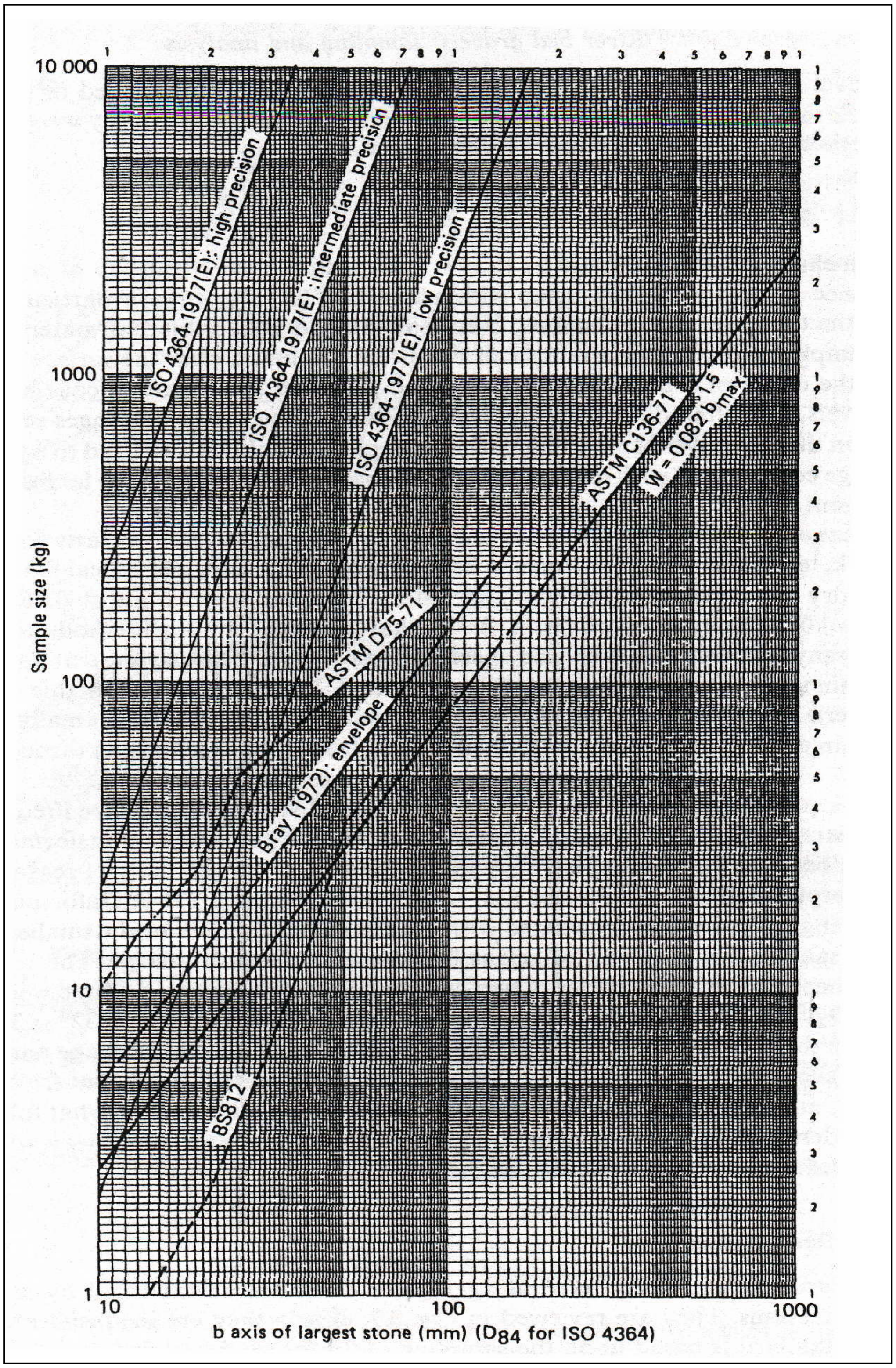
Milan et al. (1999) suggest amendments to the Church et al standards because they were not developed with due consideration to particle shape and density. Instead, they were formulated assuming that all grains were spheroid, with densities of 2.7 $g*cm^{-3}$. Using their data from freeze core samples collected in the River Rede of Northumberland, UK, Milan et al. argue that the 0.1% sample volumes suggested by Church et al may under or over-sample depending upon the grain's shape and the sorting of particles sampled. Particle shape was defined as the ratio between the long (a), intermediate (b), and short axis (c) as follows:

Equant (block) b/a > 0.67 and c/b >0.67,

Rod b/a < 0.67 and c/b >0.67,

Disc b/a >0.67 and c/b < 0.67,

Blade b/a > 0.67 and c/b <0.67



10 000
1000
100
10
1
Sample size (kg)
10
100
1000
b axis of largest stone (mm) ($D_{84}$ for ISO 4364)
ISO 4364-1977(E): high precision
ISO 4364-1977(E) : intermediate precision
ISO 4364-1977(E) : low precision
ASTM D75-71
Bray (1972): envelope
BS812
ASTM C136-71
$W = 0.082\ b_{max}^{1.5}$

**Figure 12. Bulk sample standards including that based on the intermediate axis of the $D_{84}$ stone proposed by DeVries (1970). (From Church et al., 1987).**

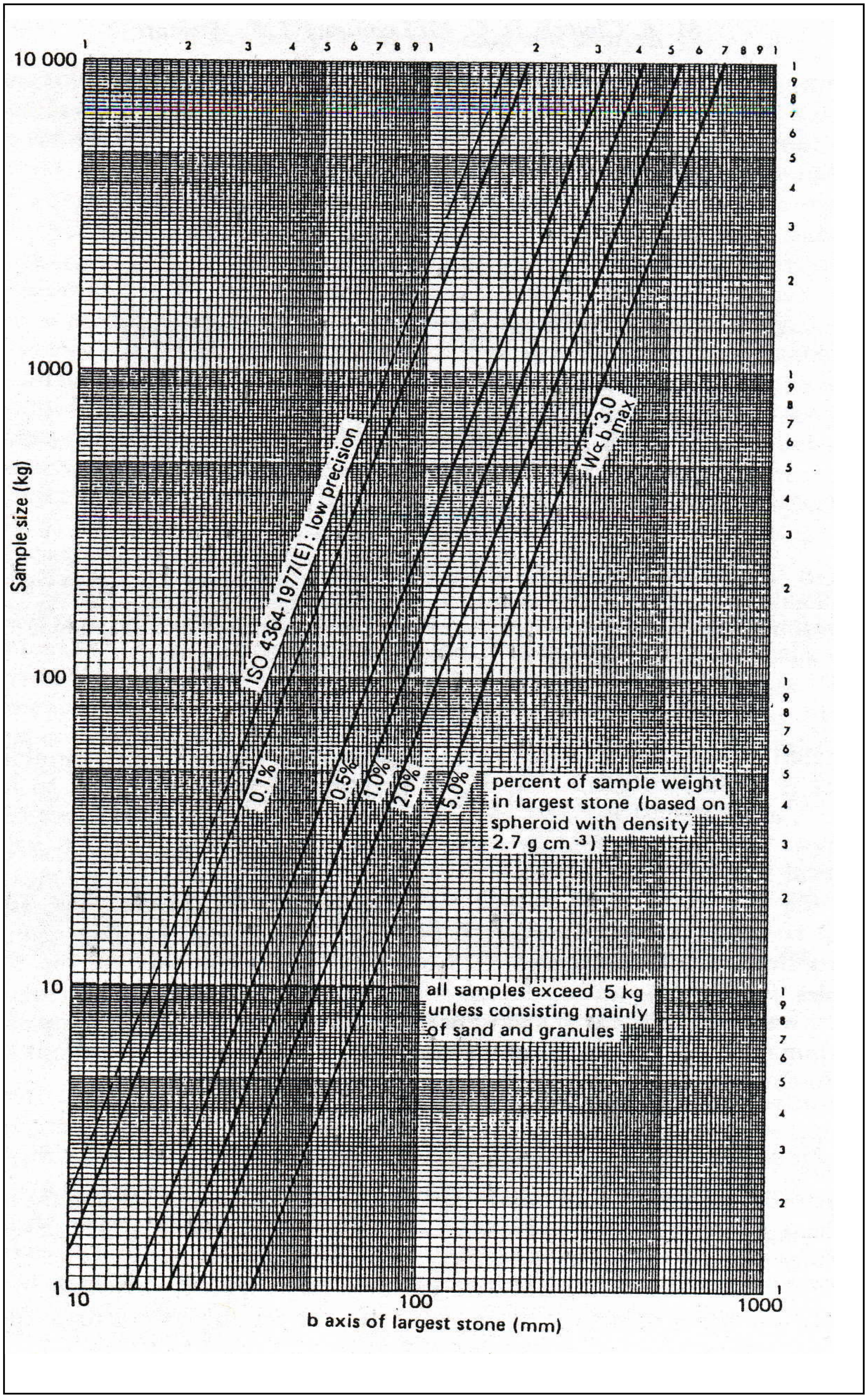


**Figure 13 - Bulk sample standards based on the intermediate axis of the largest stone included in the analysis (From Church et al., 1987).**

They suggest that the Church et al. volumes (at 0.1%) will over sample the coarser grains (block and rod shapes) while the fine grains (disc shaped) will be under sampled and the blade shaped grains will be adequately sampled. In addition to the effect of particle shape, they argue that streambed sorting plays an important role in determining adequate sample volumes. Specifically, they recommend increasing sample volumes when streambed sorting is low. Their proposed volumes exceed those of Church et al. by between 0 and 80% depending upon the dominant particle shape included in the sample and the degree of sorting in the streambed.

## 3.3 Sediment Traps

Sediment traps are devices that collect particles as they either pass over, deposit on, or infiltrate through the sample media. Two basic designs are presented in this section and each captures a specific type of depositing sediment. Gravel buckets collect sediment that deposits on and moves vertically into the streambed. This includes bedload that moves across the substrate in saltating or sliding mode as well suspended matter that deposits from the water column. Infiltration bags collect sediment that deposits on and moves vertically into the streambed as well as that which moves horizontally through the streambed. Prior to describing these techniques some discussion of sample media is necessary.

### 3.3.1 Sample Media

Both gravel buckets and infiltration bags can use natural or artificial (reference) gravel as their sample media. The choice of media depends upon the program's objective. If the objective is to determine changes in streambed composition then natural gravels may be the most appropriate choice. If the objective is to assess the addition of depositing sediment from a selected activity, artificial gravels that are selected to maximize trapping efficiency may be most appropriate.

#### 3.3.1.1 Natural Gravels

Natural gravels can be extracted from dry bars and cleaned at a site downstream of the sample area. These cleaned gravels may be mixed into known proportions of specific grain sizes. For example, Larkin et al. (1998) used gravel buckets containing 19.05mm, 9.53mm, and 4.76mm gravels in proportions of 50%, 30%, and 20% respectively. They state that this mixture represented the 'ideal' spawning gravel grain size composition. Another approach is to remove fines from natural gravels and place them in buckets in unknown proportions.

The advantages of using natural gravels include:

1. Use of local substrate may better simulate natural conditions,
2. Site establishment is made easier because reference gravels do not need to be carried in to the site.

The disadvantages of using natural gravels include:

1. Unknown trapping efficiency,
2. Increased disturbance of the stream area during media extraction,
3. Use of natural gravels in pre-set mixtures does not ensure that these mixtures exist in the stream.

#### 3.3.1.2 Artificial Gravels

Cleaned artificial or reference gravels can be selected to maximize trapping efficiency given some information of local flows in the sample area. Meehan and Swanston (1977) determined that in the absence of storm flow and assuming a similar diameter of 1.9 cm, gravel shape could affect the amount of fine sediment (<0.833mm) that accumulated in spawning gravels. They found that round gravels were most efficient at trapping fines when the discharge was less than 0.2 $m^3/s$ and angular gravel was most effective at discharges greater than 0.4$m^3/s$. Between 0.2 and 0.4 $m^3/s$ the round and angular gravels were comparable.

The advantages of using artificial gravels include:

1. Their known grain size mixture and trapping efficiency,
2. Their use will minimize disturbance to the sample stream,
3. To simulate streambed surface conditions, natural material may be laid on top of the artificial substrate, which would allow both maximum trapping of deposited sediment and replication of natural settling conditions within the top layer of the natural streambed.

The disadvantages of using artificial gravels include:

1. They may not represent the streambed's natural substrate,
2. Reference gravel is brought to the site.

### 3.3.2 Gravel Buckets

Gravel buckets are sediment traps used to measure bedload movement over and sediment deposition onto the streambed. Although no date of origin has been noted in the literature, the earliest citation found for this technique was Slaney et al. (1977).

The literature provides a variety of bucket designs the complexity of each is related to the research discipline and data application. For example, a fluvial geomorphology research program may require complex equipment to gather data on bedload transport and depositional loading rates whereas a fisheries program may require simpler equipment to assess habitat quality. To demonstrate the variety in design, the following examples are presented:

- Phillips and Walling (1997) buried a sealed plastic box flush to the streambed. The box contained natural "clean" streambed material and was opened only during storm events to capture some of the fine sediment that these events generated.
- Lisle and Eads (1991) suggest using four liter gravel filled buckets to measure deposition and vertical infiltration of fine sediment into streambeds during storm events. The reference gravel used in the buckets can be from outside the area and of a known size or can be removed from the sample area and cleaned (Lisle and Eads, 1991).
- Four liter buckets, as suggested by Lisle and Eads (1991), have been used extensively in the Omineca-Peace region to assess forest harvesting affects on water quality. Each bucket is filled with washed angular gravel that is approximately 1.8 cm in diameter. This gravel will trap more fine sediment than will round gravel at velocities greater than 0.4 m/s (Meehan and Swanston, 1977).
- Four liter buckets filled with a standard gravel mixture of 1.9 cm, 0.9 cm, and 0.47 cm (50%, 30%, 20% respectively) have been proposed as a technique for evaluating erosion control methods (Larkin & Slaney 1997, Larkin et al., 1998).

Regardless of the specific design used, gravel buckets can provide data on depositing sediment and vertical infiltration of fine sediment into the streambed. The following discussion will focus on the four liter bucket sampler used in the Omineca-Peace Region.

The primary advantages of the four liter bucket samplers are:

1. Although not commonly mentioned in the literature, gravel buckets are suggested as being a robust technique that can effectively monitor erosion control and watershed restoration programs (Larkin and Slaney, 1997).

2. They provide an integrated measurement over time.

3. They gather data on sediment composition and mass that can be used to determine depositing sediment burden.

4. They are difficult to contaminate because they are placed into the streambed as sealed units and are resealed before removal.

5. They are simple to use and inexpensive to replace.

6. They are relatively small and light, which facilitates transport to remote sites. The same is not true for larger (i.e. 20 liter) buckets.

7. Gravel mixtures can be altered to suit program needs and site conditions. Either standardized gravel mixtures that optimize sediment trapping must be brought to the site or cleaned gravel that is supplied from the sample reach, which simulates natural conditions, can be used.

8. They are capable of producing precise data. Lisle and Eads (1991) deployed two rows of six 8-liter buckets in a channel cross section. This generated two sets of data with coefficients of variation of 0.11 and 0.09.

9. They require no commitment of personnel between installation and collection (i.e. they are passive samplers).

The primary disadvantages are:

1. They cannot collect data on sediment moving horizontally through the streambed.
2. They cannot be used in water deeper than 0.8 m unless deployed by scuba divers.
3. They are susceptible to loss through hydrological scour and fill activities, animal activity and vandalism.
4. They can become exposed over the placement period if water levels drop.
5. Gravel buckets do not represent natural streambed conditions. Regardless of whether natural or artificial media are used gravel buckets have impermeable walls, so infiltration of fines into and out of the sample is not possible. Instead, buckets act to collect and retain settled sediment, which makes them an effective monitoring and assessment tool.
6. They cannot be placed for more than a 30-day period because they may start to lose collected sediment (Larkin and Slaney, 1996). Actually, depending on the degree of impact and sediment load, the placement duration may be much less (i.e. one day), as can be observed downstream of bridge washouts. For longer placements in nutrient rich streams, it is possible that periphyton growth in the bucket may increase sediment capture.

   A new bucket design, developed for long term placements, may address the issue of overfill (Herb Herunter, DFO, personal communication). This new design has experimental gravel only in the top third of the bucket (supported by coarse wire screen and plexi-glass stands), leaving the remaining two thirds for sample storage. The application of this new design is currently being investigated.

**Field Protocol**

1. Each sampling location should be chosen to ensure that depth, velocity and habitat are similar both within and between sites. Experience has shown that buckets should be placed in a glide or run complex of moderate depth (less than 0.8m) and closer to the thalweg than to streambanks. An alternate approach

suggested by Lisle and Eads (1991) is the installation of several buckets that are equally spaced along two or more channel cross-sections.

2. A hole is dug to the approximate depth of the gravel bucket (~20 cm for 4 liter buckets). Place the larger excavated material to the side so that it can be used to fill in the areas around the bucket. If part of a temporal program, serious consideration should be given to installing metal, concrete or rubber sleeves in order to maintain consistent sampling sites. These can be sealed when not in use.
3. Place the sealed bucket containing reference gravel in the hole (or sleeve) so that the cover is flush to the streambed (Figure 14). Ensure that the bucket is level.
4. To facilitate recovery, it is recommended that the bucket handle be flagged with bright flagging tape or anchored with brightly painted rebar (neon pink or red are most visible). If vandalism is a concern rebar or flagging may not be practical. Instead, magnets can be attached to the bucket rim. Buried samples having these magnets may be found with the aid of a metal detector (Dr. M. Church, UBC, personal communication).
5. Once buckets have been placed, velocity and depth should be re-measured at each one (Figure 15).
6. Ensure that all upstream work is complete and that any sediment generated by field activities has settled out before removing bucket covers. Remove covers while moving in a downstream direction and exit the channel below the last bucket.
7. During retrieval, approach buckets in an upstream direction. Replace the lids before conducting any upstream work.
8. Prior to removal, measure depth and velocity at each bucket. These data will provide an indication of hydrological change over the sampling period.

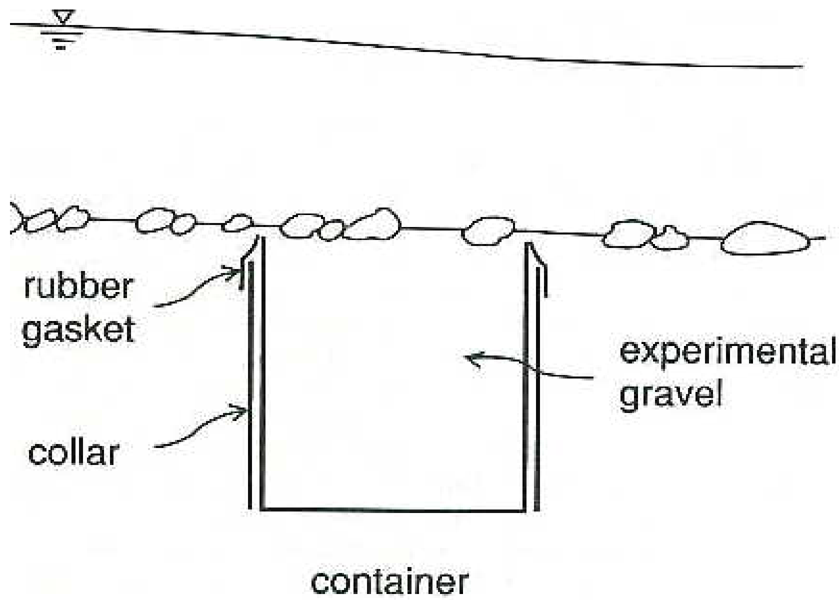



**Figure 14: Gravel bucket schematic showing placement in rubber sleeve. Bucket opening is flush to streambed surface and has natural material on top to simulate streambed. (From Lisle and Eads, 1991).**

**Suggested Number of Replicates**

The recommended number of sample replicates will depend on the program objectives, the required level of precision and the size of the gravel buckets. As previously mentioned, Lisle and Eads (1991) were able to collect very precise data with two rows each containing six 8-liter buckets. Larkin et al. (1998) deployed 10 traps for 30 and 60 day periods.

We recommend either of the following approaches with regard to replicate sampling:

1. Where samples are collected from similar environments, we recommend collecting a minimum of 8, 9, and 10 samples in gravel bed streams having active channel widths of 5, 9, and 11 meters, respectively (Appendix 5).

2. If samples are to be collected without regard to within and between site similarity (i.e. velocity, depth, and proximity to thalweg or streambank), establish at least two cross sections (three or more is recommended) and place a minimum of four buckets along each section. These data may have a high coefficient of variation because of the potentially different sampling environments. If data within a row are found to be highly variable, it may be best to composite them as this will incorporate channel variability and may best represent site conditions.

**Figure 15 - Gravel buckets placed flush to the streambed. Water depth and velocity are measured at each bucket before removing bucket lids.**

**Quality Assurance and Control Program (QA/QC)**

The QA/QC program for gravel bucket sampling requires well trained operators, carefully planned field quality control, assessment of analytical bias and precision and independent program audits, all undertaken with due consideration of personal safety. Refer to section 3.1 for QA/QC considerations. Specific requirements include:

- Independent program audits should evaluate potential problems associated with: deviation in upstream sampling approach; bucket placement; similarity of bucket depth and velocity within and between sites; downstream removal of lids or upstream replacement of lids and proper sample labeling.

- Buckets are solid walled containers that will alter local horizontal infiltration of sediment through the streambed. As such, if they are used in combination with infiltration bags, install the buckets downstream of the bags (Figure 16).

- Gravel bucket samples will normally be smaller than McNeil core samples except where depositing sediment loads are very high (Figure 17). In those cases the sample may be split.

**Figure 16 - Infiltration bags should be installed upstream of gravel buckets.**

**Figure 17 - Overfilled gravel bucket. This sample can only be used qualitatively because the effective sample period is not known.**

### 3.3.3 Infiltration Bags

Infiltration bags measure the amount of sediment moving vertically and horizontally through a streambed. The concept originated from open wire baskets, such as those used by Sear (1993). Open-wire baskets were problematic because there was a considerable loss of sediment during their removal from the streambed. Sear (1993) addressed this issue by placing each basket within a collapsed polythene bag that was forced open with a foam collar. Prior to removing the basket from the streambed the bag was lifted up over the basket preventing the loss of some 26 to 40% of the sample (Sear, 1993).

An alternative to the baskets presented by Sear is the infiltration bag (Lisle and Eads, 1991). These bags consist of a steel ring with recovery lines and a resilient waterproof fabric bag that is attached to the ring with a hose clamp. The bag is collapsed into the ring and they are buried in the streambed to a predetermined depth with the mouth of the bag facing upwards. A tripod mounted winch or pulley system removes the bag using the recovery lines attached to the steel ring. Although not commonly referenced in the literature, infiltration bags have been used with some success in the Omineca-Peace (Rex and Carmichael, 1998b). Further, they have been used to capture and compare sedimentation effects of biosolids released from a pulp mill diffuser in the Upper Fraser River (Simon Biickert and Dr. Ellen Petticrew, University of Northern British Columbia, personal communication).

The infiltration bag design (Figure 18) used in the Omineca-Peace consists of a rust proof and brightly coloured steel ring of 20 cm diameter and 5 cm height. The ring has three holes drilled one cm from its top to which bright nylon lines are attached for bag location and removal. These holes are equally spaced around the ring. The bottom of the ring includes a steel rod flange over which a sample bag is pulled and above which a ring clamp is applied. The sample bag is made of a resilient waterproof fabric and is 30 to 35 cm in length.

Primary advantages of the infiltration bags are:

1. They provide data on sediment burden in the streambed above the bag at the time of sampling. This can be related to fisheries spawning success in the sample area.

2. They provide an integrated measurement over time.

3. They require no commitment of personnel between installation and collection.

**Figure 18 - Infiltration bag, top view into ring with collapsed bag. (1 liter sample bottle for scale)**

Primary disadvantages are:

1. They require at least 12 liters (18 kg) of reference gravel per bag. As a result, sites must be easily accessible.

2. Samples and equipment can be damaged or lost due to vandals, wildlife or hydrologic forces of scour and fill.

### Field Protocol

1. Each sampling location should be chosen to ensure that depth, velocity and habitat are similar both within and between sites. Experience has shown that bags should be placed in a glide or run complex of moderate depth and closer to the thalweg than to streambanks.
2. Excavation of the series of infiltration bag holes and bag placement should be done in a downstream direction. This will allow sediment generated by in-stream activities to move downstream of the sample area.
3. Dig a hole that is approximately 35 cm deep and 30 cm in diameter. It is important to dig this hole substantially wider than the ring to prevent backfilling when the ring is placed in the hole (Figure 19).

4. Allow disturbed sediment to settle or flush from the area.
5. Collapse the infiltration bag into the ring and place it level in the bottom of the hole. If sloughing is a problem use a sheet metal sleeve to support the walls during placement of the bag and reference gravel.
6. Hold the three recovery lines above the top of the hole. Pour reference gravel into the hole until it is level with the surrounding streambed. Ensure that the lines are exposed and visible. Continue downstream to the next location and exit the stream below the last placement site.
7. During retrieval, approach bags in an upstream direction. Locate the infiltration bag lines and install the tripod with its winch or pulley system directly over the bag site. Prior to removing the bag measure site depth and velocity at the downstream edge of the reference gravel. This data may be affected by previous excavation and reference gravel placement but should still provide some indication of hydrological change over the sample period.

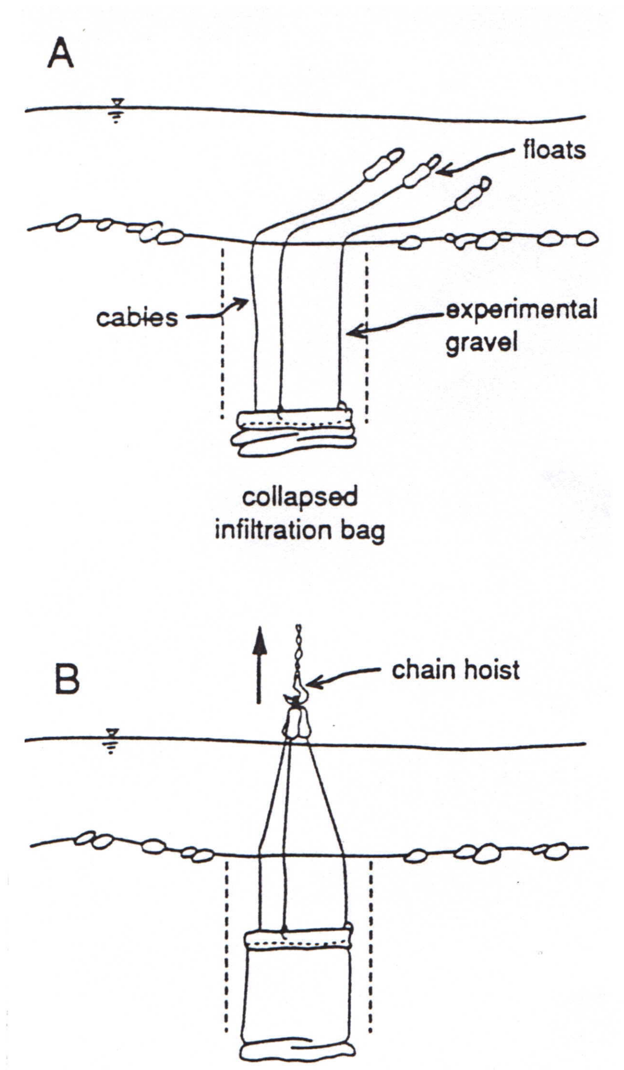



**Figure 19 - Infiltration bag placement showing the (a) column of reference gravel and collapsed bag as well as (b) bag expansion during removal with chain hoist. (Lisle and Eads, 1991)**

8. The tripod must be centered over the infiltration bag to ensure the bag is removed properly. That is, the bag must pass through the reference gravel column without contacting the natural streambed. A tripod is recommended for this purpose because it provides more consistent application and direction of force than would manual removal. If necessary, a tripod with a pulley and/or a winch would allow one person to remove bags without assistance (Figure 20).

**Figure 20 - Infiltration bag removal by a sole staff member. Photos left to right: tripod's pulley system is used to bring bag up through reference gravel to streambed surface, the bag is capped and removed from the streambed, and brought to processing area.**

9. Attach recovery lines to the winch hook and pull gently. Care must be taken to watch for the ring breaking the bed surface. Once the ring breaks the surface cap cover it (4 liter gravel bucket lid works) to prevent hydrologic disturbance of the top portions of the sample.

10. Remove bags from the rings, tie seal, label and store them in coolers or buckets to prevent loss of sample. These samples can later be transferred from bags to buckets for shipping to the analyst. Alternatively, samples can be transferred to large lidded sample buckets (6-12 liters) in the field. However, this requires considerable time because each bag must be thoroughly rinsed to ensure all fine sediments have been removed.

11. If required, plant another set of bags using the same procedure.

**Suggested Number of Replicates**

Unfortunately, this technique has not often been referred to in the literature so little published information exists about acceptable replicate numbers. Lisle and Eads (1991) recommend installing bags at equal distance along channel cross sections. This was done in the Omineca-Peace but the bags were not installed near streambanks.

Where samples are collected in similar environments as determined by depth, velocity, and sample habitat, we recommend collecting a minimum of 4, 8, and 10 samples in gravel bed streams having active channel widths of 5, 9, and 11 meters respectively meters (Appendix 5).

**Quality Assurance and Control Program (QA/QC)**

The QA/QC program for infiltration bags sampling requires well trained operators, carefully planned field quality control, assessment of analytical bias and precision and independent program audits, all undertaken with due consideration of personal safety. Refer to section 3.1 for QA/QC considerations. Suggested requirements include:

- Independent program audits should evaluate potential problems associated with sampling approach, settling of disturbed fines before bag placement, placing reference gravel level to streambed, each sampling site's depth and velocity, downstream placement of bags and upstream removal of bags and proper sealing and labeling of collected bags.

- Typically, reference gravel will be screened from the sample before shipping to the analyst so as to reduce shipment costs.

- A set percentage of samples (10 to 20 %) should be re-sieved and sample weights compared to ensure adequate lab precision.

# 4.0 Sample Analysis, Data Interpretation and Reporting

The precise collection of samples means little if they are analyzed improperly, interpreted incorrectly or reported ineffectively. This section provides information on sample analysis procedures, sediment quality measures, and statistical analysis procedures. Further, pseudoreplication effects and procedures to address them are discussed. Finally, a short report template, with suggested minimum report requirements is provided in Appendix 3.

The data generated by a sediment monitoring program can be used to determine changes in streambed composition and may help to predict subsequent biological effects. The statistical significance of observations between sites or over time is determined by the application of statistical procedures using selected sediment quality measures described in the following sections. Biological effects are not addressed in this report. Instead we defer to provincial guidelines (Caux et al, 1997) and other applicable literature.

## 4.1 Sample Analysis

Sample analysis, in this case sediment sieving, can be conducted in the field or the lab depending upon the required level of precision. Two analytical sieving procedures, volumetric and gravimetric, have been referenced in the literature. The appropriate type to use will depend upon the required level of data precision, program funding, availability of sieving equipment and the time within which the data are required.

Regardless of the procedure used, screen sizes must be chosen carefully. They should reflect current and anticipated data application needs. It is usually better to add extra screens in order to broaden the data's future applicability and value. For example, in the Omineca-Peace sediment collection was focused on fine sediment (less than 6 mm). Core samples were pre-screened to 16 and 9 mm before being submitted for lab analysis, but the larger gravel and cobble fractions were not quantified. Because this program was narrowly focussed on quantifying fractions less than the aquatic life criterion of 6 mm, the data could not be interpreted using measures of central tendency such as geometric mean diameter or the Fredle Index. Although a conscious choice was made to work with percent composition, a proven indicator of change due to land based activities (Young et al., 1991b), the data's value for later use in fish habitat studies is limited. Such studies, particularly the estimating of salmonid survival to emergence, require a broad range of sediment grain size data to calculate central tendency measures.

### 4.1.1 Volumetric Analysis

Volumetric analysis, used by McNeil and Ahnell (1964), determines the particle size composition of wet samples. This procedure can be performed in the field or lab. McNeil and Ahnell (1964) state that "… two men can sort a sample and measure the volume of solids retained on each sieve in about 10 minutes". This method is considerably faster than gravimetric analysis, and is also cheaper because it does not require the use of a commercial lab or the purchase of expensive sieving equipment. However, it can provide less accurate data than gravimetric analysis and as a result has lost popularity in recent literature.

This is considered a "wet" method because sieved samples are not oven or air-dried. Instead, they are placed on an angle and given a period of time (typically less than 10 minutes) to drain excess water. Sieve contents are then poured into a water column and the resultant water displacement is measured.

**Equipment**

(Adapted from McNeil and Ahnell (1964) and Schuett-Hames et al. (1994))

- The choice of sieves is project dependent. A geometric array may include 8 or 12 inch sieves of 64, 32, 16, 8, 4, 2, 1.0, 0.5, and 0.25 mm. The 0.85mm sieve is often included because of its continued reference as a habitat quality indicator;
- Sieve holder or stand;
- Catch basin;
- Water for gravel washing (pressurized, if possible);
- Displacement flask with hose clamp or tap to control flow;
- Graduated cylinders modified with hosing to attach to bottom of the catch basin;
- Several graduated cylinders (1 liter, 500 ml, 100 ml);
- Kitchen timer or stopwatch;
- Brush and cup.

**Procedure**

The sieving area must provide shelter from rain so that each sample can dry as much as possible within the allotted time.

1. Ensure all equipment is clean.
2. Stack sieves in descending order in their stand above the catch basin and ensure that a graduated cylinder is attached to the bottom of the catch basin (Figure 21).
3. Enter sample information on a data sheet.
4. Pour sample sediment into the top sieve and gently wash and shake the sieves to facilitate sediment movement down through the sieve series. Add the remaining sample material, as space becomes available.

5. Continue to rinse the contents of the top sieve until all visible fine particles have been removed. This may require visual inspection and handling of the coarser sediments to determine how "gritty" they feel.

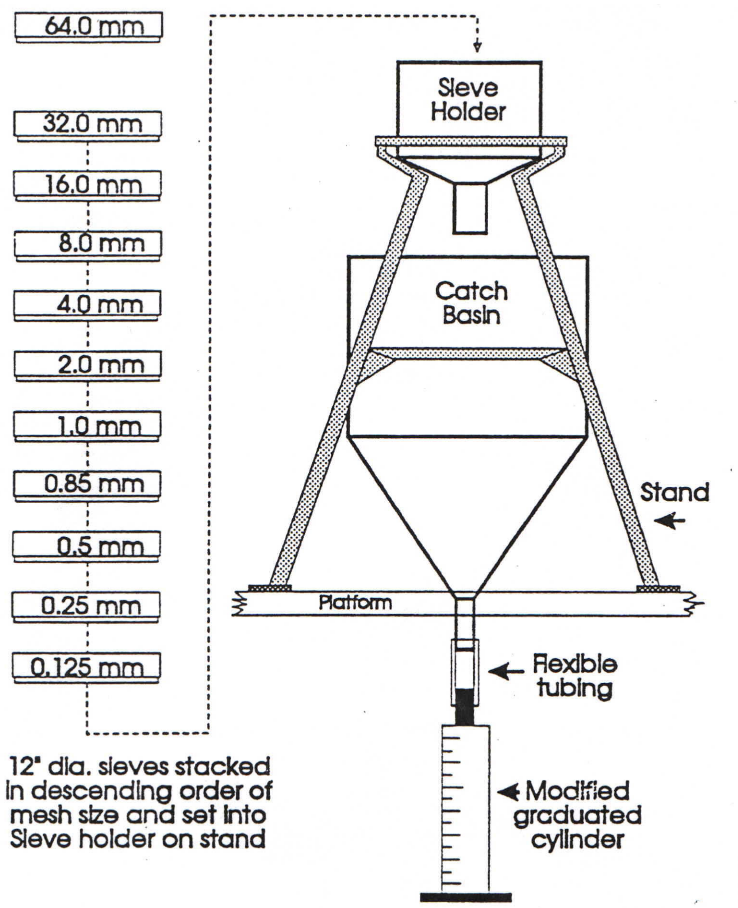



**Figure 21 - McNeil core sample volumetric analysis equipment including the stand, sieve series and catch basin with graduated cylinder. (Schuett-Hames et al., 1994)**

6. Once free of fine material, remove the sieve and place it on an angle to drain, wash contents of the next sieve, and so on. Washing the finer grain fractions (less than 1 mm) will take much more time as they can form layers in the sieve. Patience is required at this stage.
7. Moderate water use during washing will ensure that water in the catch basin does not overflow.
8. Allow 10 or 20 minutes after the last sieve has been set to drain for fine sediment in the catch basin to settle down into the graduated cylinder (refer to step 15). McNeil and Ahnell (1964) waited 10 minutes while Schuett-Hames et al. (1994) suggest 20 minutes. Regardless of the time used, ensure that it is consistently applied across samples.

9. While waiting for this fine sediment to settle, prepare the displacement flask by filling it to a designated water level and closing the outlet valve (Figure 22).
10. Empty a clean and drained sieve sample into the flask (Figure 22). Rinse all particles from the sieve and flask walls into the flask using water drawn from the top of the flask.
11. Place a graduated cylinder at the end of the flask's outlet hose (Figure 22) and open the valve to allow flow into the cylinder. Read and record this sample volume (Figure 22) as milliliters on the data sheet.

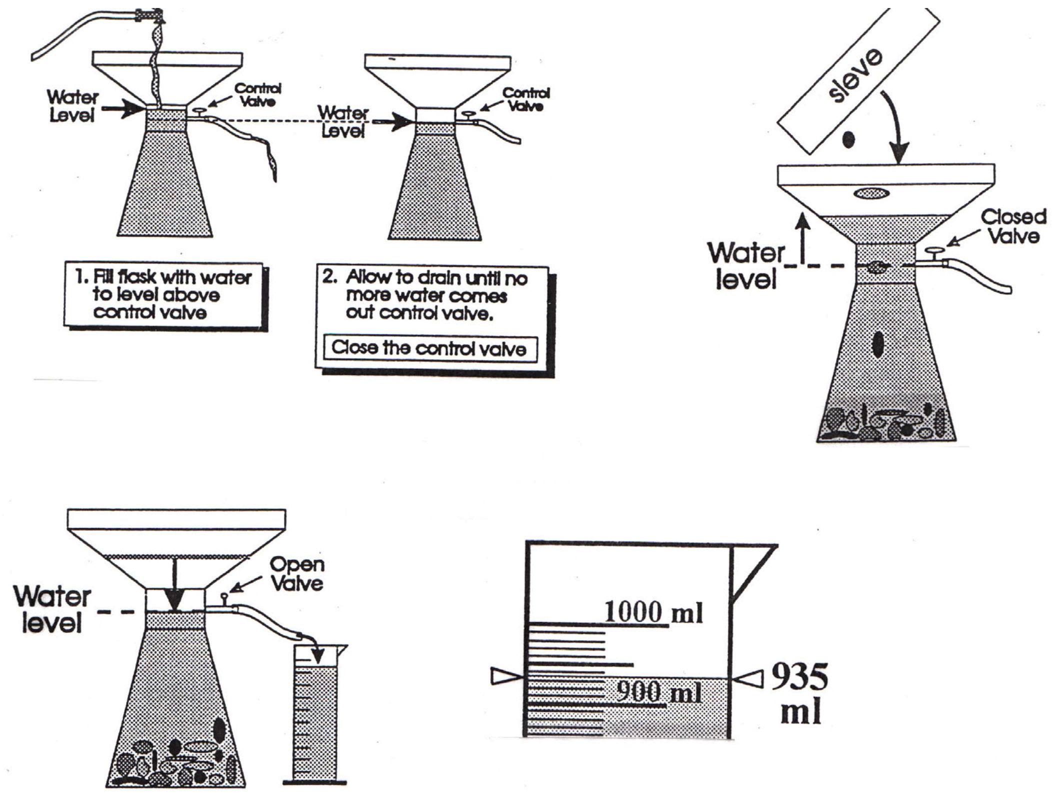



**Figure 22 - Collect volumetric data (left to right): filling displacement flask; emptying sieve contents; draining displacement flask into graduated cylinder; and reading the displaced volume in milliliters. (Schuett-Hames et al., 1994)**

12. Measuring the displacement volume is easy for large fractions but as the sieve size decreases (less than 2 mm) it will become necessary to rinse the sieve using water from the flask (a cup will help) and perhaps a brush to remove embedded grains.
13. Repeat the process until all sieves have been measured. The displacement flask should be large enough to allow measurement of all sieve samples.
14. Once the selected time period of 10 or 20 minutes has passed, remove the graduated cylinder from the collection basin and let it stand for 60 minutes. Then measure the fine sediment volume in milliliters.

### 4.1.2 Gravimetric Analysis

Gravimetric analysis is commonly used in the fields of materials testing and soils. It is a "dry" method in which samples are oven or air-dried according to specific standards (e.g. those of the American Society for Testing and Materials (ASTM)). This type of analysis is commonly seen in recent literature because it provides more precise data than does volumetric analysis. However, it is also more costly due to equipment expense and/or commercial lab fees and it requires a longer time for sample analysis. Where budgets allow ASTM standards should be followed. However, these can be adapted to suit specific program requirements or budgetary constraints as was done in the Omineca-Peace region.

For programs in the Omineca-Peace region the contracted provincial soil lab employed a modification of the ASTM standard to fit budget constraints. The technique is described as follows:

**Equipment**

- Sieves: 8 inch sieves of 6.3, 4.0, 2.8, 2.0 mm and 500, 250, 125, 63 µm. (Sieve size is dependent on the program focus and could include 1.4 and 1.0mm sieves);
- Balance capable of reading to 0.1 grams;
- Pre-weighed plastic sheets cut to fit drying trays (edged baking pans);
- Pre-weighed aluminum dishes (pie plate size & 70 mm diameter weigh boats);
- Drying oven;
- Wash bottle.

**Procedure**

1. Remove sediment from the sample container by inverting it onto a drying tray lined with a pre-weighed plastic sheet. Use a wash bottle to rinse fine sediments into the bottom of the pail and wash these onto the tray. Spread the sediment in a thin layer to promote drying as quickly as possible.

2. After the sample on the tray is air-dried to a constant weight, record the weight of the air-dry sample and plastic sheet. After removing the sample for dry sieving, re-weigh the plastic sheet to check for unseen residue.

3. This air-dried sample will be subjected to analysis by dry and wet sieve techniques. For the dry sieve analysis, place the sample, by portions, into 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. Screen the air-dried sample through each sieve by shaking horizontally (by hand) until particles no longer pass through to the next sieve. Remove each sieve plus its sieved fraction and record its weight.

4. For the wet sieve analysis, assemble a stack of 500, 250, 125 and 63 μm sieves, each of which should be pre-rinsed. Add subsamples of sediment from the thoroughly mixed "minus 2 mm" fraction to the top sieve and slowly wash each portion through the stack. The subsamples should be appropriate amounts (approximately 50 g) to avoid overloading or clogging of the sieves and to allow all material to be presented to the sieve mesh surface. Check all sieves visually to ensure they are not being clogged.

5. For the final stage of sieving, once water passing through the sieves runs clear, remove them one at a time (i.e. from coarse to fine) and transfer the retained particles on each sieve into a labeled, pre-weighed aluminum dish. Contents are then oven-dried at $105^{o}$C. Record the total oven-dry weight, including the aluminum dish weight.

6. This method requires that the less than 63 μm (silt/clay) fraction be determined by subtraction of larger fraction weights from the total "minus 2 mm" sample weight. The silt/clay fraction is lost with the wash water.

## 4.2 Pseudoreplication

Prior to addressing sediment quality measures and their statistical analysis, it is necessary to discuss the potential for pseudoreplication and its effect on data interpretation. Pseudoreplication was defined by Hurlbert (1984) as being "the use of inferential statistics to test for treatment effects with data from experiments where either treatments are not replicated, or replicates are not statistically independent".

Pseudoreplication artificially increases the number of observations (i.e. degrees of freedom), which can lead to artificially significant results. That is, the null hypothesis may be rejected even though it is true. For example, eight samples collected from a randomly chosen quadrant within a riffle zone are not independent samples and therefore not true replicates. Although it may not be possible to collect independent data because of program constraints, this should be considered during data analysis.

Pseudoreplication can be addressed by:

1. Using 'replicate" samples to determine a site mean (i.e. a mean for each grain size both up and downstream) for each visit. Use these means, gathered over several periods before and after the investigated activity, in an ANOVA to determine the site differences, or

2. Establishing a minimum of two control and treatment sites so that the differences within and between sites can be assessed with an ANOVA or t-test of means,

3. Using a simple-difference analysis for those studies where a before-after-control-impact design is followed (Manly, 2001).

An ANOVA of means is commonly understood but the simple difference test is not typically referenced in the literature and so is described here in more detail. Essentially, it requires the subtraction of the mean for the treatment site from the mean for the control site. These differences between control and treatment are compared before and after the investigated activity with a t-test to determine significance (Manly, 2001). For example, consider the following hypothetical data set for a gravel bucket program:

**Table 1. Example data for a simple difference test. Assessment of a fictitious road crossing before and after construction where gravel buckets were used to capture depositing sediment of less than 6 mm diameter. (Sample weights in kg)**

| Before | | After | |
|---|---|---|---|
| Control | Treatment | Control | Treatment |
| 1.8 | 2 | 1.9 | 2.8 |
| 1.2 | 1.9 | 1.5 | 2.4 |
| 1.4 | 1.5 | 1.2 | 2.0 |
| 1.6 | 1.6 | | |

The purpose of the above study is to determine whether there is a significant difference between sites. The null hypothesis is that *there are no differences between stations.* A total of seven random observations were collected, four before and three after construction. They have respective differences of (mean of the treatment – mean of control difference) -0.25 kg before construction and–0.83 kg after. The change in the mean difference after construction is –0.83kg-(-0.25kg) =-0.58kg. Using a two-sample t-test these data yield a t=3.315 (df=5), which is significant (p=0.02). So, there is a difference between sites following construction and there appears to be more fine sediment depositing at the treatment site.

## 4.3 Sediment Quality Measures

Once sieve data have been generated, the appropriate sediment quality measure, either **raw data** or **central tendency**, must be selected. Raw data measures consist of each size (sieve) fraction's weight or percent composition (by weight or volume). Central tendency measures generate one number to best describe the entire particle size range.

The following statistical procedures are drawn from the literature. Based on our review, we believe the procedures and statistical tests described below and summarized in Table 2 best suit the analysis of sediment data.

First, some general comments:

- Not all the measures discussed below are applicable to each collection technique. For example, the Fredle index is typically calculated using grain size data that range from silt/clay to small cobble, and it is therefore not suitable for sediment trap data.

- Sediment data will have been collected to assess spatial or temporal variability. It should be the goal of all assessment programs to determine whether this variability is statistically significant. This can only be done through the application of a suitable monitoring design. As such, all programs must carefully select and adhere to a single design as well as to the monitoring techniques and QA/QC protocols mentioned previously.

- It is recommended that data generated from the sieving procedures be viewed in graphical format before higher level statistical analyses are attempted. This may include the use of simple descriptive statistics, line/bar graphs, box plots or stem and leaf diagrams. This step will allow familiarization with the data and may uncover issues, that if addressed promptly, can prevent future problems and may in fact enhance data interpretation. For example:

    1. Are the data normally distributed? If not, what transformation is required?

    2. How large are the coefficients of variation within sites and grain classes? Are the data more variable within or between sites?

    3. Are total sample weights significantly different between or within sites?

    4. Can data outliers be attributed to replicates that were taken from locations significantly different from the norm (i.e. with regard to depth and velocity)? If so, remove them and view the data again.

    5. Do grain size confidence limits overlap between sites? Can significant differences be expected between sites?

- A size fraction, as referred to below, is the range of sediment captured on a sieve. For example, the portion of sample passing through a 2 mm screen but retained on a 1 mm screen is termed “Very Coarse Sand” in the Wentworth scale. Note that all size fractions referred to in this manual are based on the Wentworth scale (Appendix 8).

### 4.3.1 Raw Data

Raw data can be presented as **weight** (by gravimetric analysis) or **percent composition** (by gravimetric or volumetric analysis). These data can be applied in two manners:

- Portions of sediment less than a selected grain size (i.e. the 6 mm aquatic life criterion) can be tallied and compared across samples, and/or
- Each size fraction less than the criterion of interest (e.g. fine gravel, coarse sand, etc. through to silt/clay) can be compared across samples.

To facilitate the following descriptions weight and percent composition data are discussed separately:

**Weight Data**

Grain size sample weights are particularly useful for trapping techniques (i.e. gravel buckets and infiltration bags) because they can determine if sediment loading has increased at one site compared to others. These data will indicate total sediment and specific size fraction loading differences between sites. The following approaches assume that the sample unit is standardized so care must be taken to ensure this requirement is met. One of the following approaches is recommended to do this:

- To compare differences between sites for each size fraction below the criterion of interest first run an F-test to determine if parametric tests such as t-tests, one-way ANOVAs for each grain size can be used. If parametric methods cannot be used the non-parametric Kruskal-Wallis test should be applied.
- A two-way ANOVA, using site and grain size as factors, can identify a significant difference in size fraction weights between sites. If such a difference is found, the specific fractions that differ between sites can be isolated using Tukey's post-hoc comparison or Scheffe's method.

**Percent Composition Data**

Percent composition data refer to the percent of total sample weight contained within each size fraction and it is a measure most commonly used in the analysis of core data. It standardizes samples for differences that exist in total sample weight. For example, 700 g of coarse sand in a sample weighing 7 kg at an upstream site will have the same percent composition as 650 g of coarse sand in a sample weighing 6.5 kg at a downstream site.

When percent composition data are used as a sediment quality measure, the entire sample should be sieved (whole sample analysis). Pre-screening a sample will complicate data analysis, as discussed below:

*Whole Sample Analysis*

When the entire sediment sample has been sieved, percent composition data can be used as follows:

- Percent composition data below the criterion of interest (e.g. 6 mm) can be tallied for each replicate and compared over time or between sites. Appropriate statistical procedures will include an F-test to assure normality followed by t-tests or the Kruskal-Wallis test for non-normal data (Sokal and Rohlf, 1994).
- To compare differences between sites in each of the fractions below the criterion of interest, a one-way ANOVA can be used for each fraction. Alternatively a

single two-way ANOVA, using site and grain size as factors, can be employed. If the two-way ANOVA indicates a significant site difference, the specific grain sizes causing the difference can be located with Tukey's post-hoc comparison (Sokal and Rohlf, 1994) or Scheffe's method (Devore, 1991).

*Pre-Screened Sample Analysis*

If the site is remote and/or to reduce shipping costs, material coarser than the criterion of interest (e.g. 6 mm) can be removed from the sample. This pre-screened data may be less accurate and precise than lab data because of increased variability introduced through wet screening.

Data interpretation using the reduced sample volume may be problematic because remaining size fractions will be equal to or less than the criterion. As a result, the data variance will not be independent of the mean, which limits application of some parametric statistics. To address this issue one or more of the following methods should be employed:

- Transform data using the arcsine transformation (Sokal & Rohlf, 1994) then use it with sample site location as two factors in a two-way ANOVA. This statistic will determine if site differences exist. If so, the grain size classes that differ significantly between sites can be located using Tukey's post-hoc comparison or Scheffe's method, as above.
- If for some reason it is not possible or timely to transform the data, it may still be possible to use the two-way ANOVA with some qualification. This ANOVA will not find site differences because both sites have percent compositions adding to 100%. Instead, look for a significant interaction effect, which if found, indicates that percent composition values are influenced by the synergistic affect of site location and grain size (Sokal and Rohlf, 1994). This means that some significant differences exist in size fractions between sites. These can be located with graphs followed by t-tests to determine significance.
- Alternatively, assume a non-normal distribution and use the Wilcoxon sign-rank test or Mann-Whitney U-test.

### 4.3.2 Measures of Central Tendency

Central tendency measures are those of location. They attempt to describe the entire data set with a single value. As such, they typically cannot provide information about data distribution or dispersion (Sokal and Rohlf, 1994). These indices are normally employed when a wide range of grain size information has been gathered, such as with streambed corers, shovels or the Helley-Smith sampler. Several central tendency measures commonly seen in the literature are provided below with their associated formulae. These are the geometric and graphic geometric mean diameter, the median and $D_{90}$ particle sizes and the Fredle Index.

#### Geometric and Graphic Geometric Mean Diameter

The geometric mean diameter proposed by Lotspeich and Everest (1981) uses the "method of moments" as follows:

$Dg = D_a^{Pa} * D_b^{Pb} * D_c^{Pc} * \ldots D_z^{Pz}$ , where:

Dg = geometric mean diameter (mm)

$D_{a\ldots}$= midpoint diameter of material between sieves… (e.g. 3 mm)

$P_{a\ldots}$= Proportion of the entire sample weight on sieve a… (e.g. 0.1)

Another approach, used by Platts et al. (1983), is the graph-generated geometric mean diameter. They present this as a measure of sediment effects on salmonid incubation. It is determined as follows:

1. Plot percent finer data (than each sieve) on log paper. The generated curve is referred to as a "gradation curve".
2. Determine the 16th and 84th percentile from the graph.
3. Apply these data points to the following formula:

   $Dg = (D_{84} * D_{16})^{1/2}$ , where:

   Dg = graphed geometric mean diameter

   $D_{84}$= grain size of the 84th percentile

   $D_{16}$= grain size of the 16th percentile

   Note: Folk (1965) claims that $Dg = (D_{84} * D_{50}*D_{16})^{1/3}$ is a better measure, especially for skewed data

Platts et al. (1983) suggest that this measure is better than percent fines for use in habitat studies. It relates to the whole particle size distribution and to salmonid embryo survival at least as well as percent of fine sediment (percent fines). Young et al. (1991b) determined that either of these forms of geometric diameter, and, in fact, all measures of central tendency were better estimates of salmonid survival to emergence than percent fines data. However, the percent fines data was better at determining streambed compositional changes due to land management activities.

### Median Particle Size and the $D_{90}$

Both the median particle size ($D_{50}$) and the $D_{90}$ are commonly observed in the literature (Young et al. 1991b, Poulin 1991, Rood and Church 1994, Rice 1995). These can be determined from the gradation curve and correspond to the 50th and 90th percentiles, respectively. These measures provide some indication of the coarseness of the sample material.

### Fredle Index

The Fredle index contains reference to the mean diameter but also addresses dispersion of other values around this central measure (Platts et al., 1983). This index was proposed by Lotspeich and Everest (1981) and is popularly employed in the literature. In addition, there are provincial criteria for Fredle Index values (MELP, 1999). It is calculated as follows:

$F= Dg/So$ or $F = Dg/(D_{75} / D_{25})^{1/2}$ , where

F = Fredle Index

Dg = geometric mean diameter

So = sorting coefficient

$D_{75}$ and $D_{25}$ = the $75^{th}$ and $25^{th}$ percentiles, respectively

As the Fredle index value increases, so does pore size and streambed permeability (Platts et al., 1983). As a result, sites with low Fredle numbers tend to be lower quality incubation habitat. A modified Fredle index that uses the standard deviation of the geometric mean diameter rather than the sorting coefficient is discussed in Young et al. (199b1). It is rarely mentioned in the literature and so was not included in this discussion.

These indices can be compared between or within sites by statistics, as described above, including the t-test, F test, one-way ANOVA and non-parametric tests. Alternatively, they can be graphed to show temporal trends or spatial differences.

**Table 2: Sediment collection techniques, sediment quality measures and possible statistical analyses.**

| Technique | Sediment Quality Measure | Statistical Analyses |
|---|---|---|
| Freeze Corers and<br>McNeil Corers | Percent Composition<br>Geometric Mean Diameter<br>Fredle Index<br>$D_{50}$ and $D_{90}$ | F-test, t-test, ANOVA<br>Kruskal Wallis, Wilcoxon rank sign test, Mann-Whitney- U Test |
| Gravel Buckets and<br>Infiltration Bags | Percent Composition<br>Weight | F-test, t-test, ANOVA<br>Kruskal Wallis, Wilcoxon rank sign test, Mann-Whitney- U Test |

# 5.0 Summary

This RIC manual aims to foster the application of sediment monitoring programs throughout the province to assess the effects of land use activities on depositing sediment loads. The strategic goal and specific objective of this manual were to present guides for developing quantitative assessment programs and selecting effective and practical methods. These have been addressed with consideration of the following:

- Fine sediment can negatively effect stream biota;
- A clear need exists for methods that will allow the quantification of fine depositing sediment in stream environments in order that aquatic life criteria for depositing sediment may be applied;
- Good monitoring program development requires a clear statement of program objectives, application of a framework for assessing forest harvesting activities and the development of a specific aquatic effects monitoring program;
- Techniques are available to quantify sediment deposition, streambed composition, cross section morphology, suspended sediment load, and bedload, each with appropriate QA/QC procedures;
- A variety of referenced sample analysis procedures, sediment quality measures and statistical tools are available with which to interpret sediment data.

The techniques documented in this manual will provide information on the alteration of fluvial sediment loads due to land use activities in localized areas. However, program success will depend on good program development, the foundation of which is the clear definition of program objectives. Clear objectives permit one to select the appropriate monitoring design and assessment approach, which in turn determine applicable monitoring techniques and data analysis procedures.

We believe the process described in this manual is a viable method for assessing localized industrial effects on sediment movement in streams. Although these techniques can be applied at the watershed scale, a watershed monitoring program is highly complex and **requires** an effective planning process that **includes** input from appropriate resource staff such as hydrologists and geomorphologists.

We hope the procedures outlined here will be widely applied and look forward to receiving comments and recommendations from user groups during a three year field test period. Data gathered throughout the province with these techniques should be compiled and reviewed with respect to varying environmental conditions. That data review should lead to finalization of this manual. The process outlined here will provide quantitative information that supports or has the potential to improve prescriptive resource management.

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# Appendix 1: Site Establishment Procedures

Prior to the deployment of any sediment transport monitoring method it is necessary that an adequate site description be completed. Site data should be collected for the following two reasons:

1. Comparison of method efficiency between similar sites.

2. Future placement of sediment data in the EMS database,

To effectively assess the application of these methods in the field, their environmental limitations must be determined. Also, for future comparisons to be relevant, it is necessary that the method of deployment be replicated in each region. The minimum requirements for the characterization of site conditions includes the collection of data on:

1. Site referencing (official name, watershed codes, UTMs)

2. Stream width (wetted and bankfull),

3. Stream depth (reported as the average across the channel),

4. Habitat units (pool/riffle/run/glide presence),

5. Channel gradient (survey level or clinometer)

6. Stream discharge,

7. Streambed characterization (Wolman/modified pebble count procedure),

8. General streambank characteristics (soil characteristics, vegetative cover),

9. Channel morphology (sinuosity, degree of aggradation/degradation),

10. Placement depth and velocity.

Due to the amount of information required for site description, it is recommended that a minimum of four hours be assigned to this process. Also, sediment transport information will be of little relevance if site information is not included in the report.

The following is a brief description of the minimum requirements. Other obvious characteristics that may influence sediment transport should be included in the description if adequate field time is available (ex. pool quality, large woody debris, streambank slope and WRP structures).

1. Site Reference

In order for the site to be uniquely identified, proper site referencing is required. This includes:

(a) Watershed Codes: a unique 45-digit referencing number. See page 6 in the "Reconnaissance (1:20,000) Fish and Fish Habitat Inventory: Site Card Field Guide". For general discussion, refer to the "User's Guide to the Watershed/Waterbody Identifier v.2.2" located at the RISC website.

(b) Name (official/gazetted) and Name (alias): see page 5 in the "Reconnaissance (1:20,000) Fish and Fish Habitat Inventory: Site Card Field Guide".

(c) UTMs and Associated Method Codes: see pages 8 and 9 in the "Reconnaissance (1:20,000) Fish and Fish Habitat Inventory: Site Card Field Guide".

2. Stream Width (wetted and bankfull)

Wetted channel width is the horizontal distance over the stream channel and stream bank that is covered by water (Platts et al., 1983). Bankfull width is the "normal" high-water mark of the stream and is usually indicated by a definite change in vegetation and sediment texture (FPC Fish-stream Identification Guidebook 1998). This is the level at which the largest amount of sediment is transported (Harrelson et al., 1994). Indicators of bankfull width include changes in streamside vegetation, slope, bank material, undercuts and stain lines. The height of bankfull discharge should be noted and the channel width at this height determined. It is recommended that a standard 30 meter surveyor's tape be used to collect these data. For a description of measurement standards and method codes, see the "Reconnaissance (1:20,000) Fish and Fish Habitat Inventory – Site Card Field Guide" pages 11-12 and Appendix 1. Also refer to Section 4.2.3 in the "Reconnaissance (1:20,000) Fish and Fish Habitat Inventory: Standards and Procedures Manual".

2. Stream Depth

Stream depth is the vertical height of the water column from water surface to channel bottom (Platts et al., 1983). The average stream depth should be reported following measurement of stream velocity.

3. Habitat Units

   The habitat units present at the site should be noted and their relative presence estimated (i.e. percentage of the sample reach). This will allow the calculation of riffle to pool ratios and provides information to local managers that may help determine potential fish habitat quality (Johnston and Slaney, 1996). The sample reach must consist of a minimum of two repeating habitat units where a unit is defined as a sequence of habitat types such as riffle and pool or pool and run.

4. Channel Gradient

   Channel gradient is perhaps the most fundamental and important of the collected measures. It provides information on potential velocity in the stream and the potential movement of sediment. In addition, it relates specifically to the designation of fish streams under the Forest Practices Code.

   Gradient may be determined through a reach survey with a surveyor's level, followed by calculation of the average gradient. Alternatively, clinometers may be used as follows: Field staff should position themselves over the longest length of channel possible (a minimum of several channel widths). Level shots are taken between workers, each of whom is standing at the shoreline along the same side of the channel. Sighting is to the same distance from the ground (i.e. eye to eye for individuals of the same height, eye to chin if the individual upstream is 10 cm taller etc.) This procedure should be carried out along five areas within the sample reach to calculate average gradient. (MoF, December 1996) For recording procedures and method codes see page 14 of the "Reconnaissance (1:20,000) Fish and Fish Habitat Inventory: Site Card Field Guide".

5. Velocity and Discharge

   Velocity measures should be taken at 20 to 25 evenly spaced intervals along a channel cross section, randomly chosen at the site in accordance to WSC standards. If the water's depth is less than 0.75m take only one velocity measure per location at 60% of the depth (i.e. 40% of the distance from the streambed). However, if the water's depth is greater than 0.75m two velocities should be collected at each location, one each at 20% and 80% of the column depth (Clark and Associates, 1997). Each velocity reading must occur over a minimum of 40 seconds. Discharge is then calculated by summing the product of each interval's velocity and area.

6. Streambed Characterization

Streambed characterization involves a general description of streambed morphology. This may include measures of substrate embeddedness and grain size. While both are accepted measures, the latter, through pebble counts, is suggested here because of its relative simplicity.

Pebble counts require the random selection of a cross-section near the intended study site. Pools and riffles should be sampled in the same proportion as they occur in the study reach. Starting at bankfull elevation, the first particle blindly touched with the forefinger at the toe of the left or right wader is selected. The intermediate axis, or width, of the particle is recorded on a tally sheet containing pebble count size classes of the Wentworth scale. This procedure is repeated for each small step taken across the channel width for a minimum of 100 readings. A modified version of this procedure by Bevenger and King (1995) has been presented as a means to assess cumulative watershed affects from forestry and agriculture.

7. Streambank Characterization

General notes regarding the physical extent of the floodplain, its vegetation and conditions of bankfull height should be taken. For classification of vegetation type and stage see page 22 in the "Reconnaisance (1:20,000) Fish and Fish Habitat Inventory: Site Card Field Guide". Typically, the floodplain is the flat depositional surface adjacent to the stream channel. However in areas such as the BC central interior this may be a terrace, so where a clear distinction is possible it should be recorded in the field notes.

Bankfull height was defined above as the level at which stream water begins to overflow into the floodplain. Indicators of bankfull discharge noted here include: the height of depositional features such as sand dunes; a change in vegetation; slope breaks along the bank; change in streambank particle size; stain line or lichen breaks on boulders and undercuts in the bank (Harrelson et al., 1994).

8. Channel Morphology

For consistency with provincial directives it is recommended that individuals follow the procedures provided in the FPC Guidebook "Channel Assessment Procedure Field Guidebook: December 1996". Also see pages 28-29 in the "Reconnaissance (1:20,000) Fish and Fish Habitat Inventory: Site Card Field Guide.

9. Sample depth and velocity

> Regardless of the sediment method used it is important that information about depth and velocity be taken at the site. These data allow the reader to determine in which habitat the method was deployed, ex. near-shore or thalweg. In addition, they provide information that may later explain some of the within-site variability that was observed.

Due to the expected variabilities between habitat units (i.e. riffle vs. pool), it is recommended that replicate samples be taken in the same habitat unit.

These site description data will be entered into provincial water quality or biophysical databases. In order to maximize comparability between data collected through this and other similar biophysical habitat classifications undertaken in BC, the reader must seek further detail on standards (e.g., specified units, classifications, codes, etc.) in the RISC documents:

Reconnaissance (1:20 000) Fish and Fish Habitat Inventory Standards and Procedures

Reconnaissance (1:20 000) Fish and Fish Habitat Inventory: Site Card Field Guide.

Reconnaissance (1:20 000) Fish and Fish habitat Inventory: Reach Information Guide – Version 1.0.

These can be located at the RISC website at
http://srmwww.gov.bc.ca/risc/pubs/aquatic/index.htm

**Literature Cited**


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# Appendix 2: Example Audit Sheets

## Site Establishment QA Site Card

| **Date & Time:** | **Site (Name & UTM):** | **EMS ID:** |
|---|---|---|
| **Sub-Contractor:** | **Weather & Stage:** | |
| **Stream Width** | Active:<br><br>Bankfull: | |
| **Stream Depth** (From Discharge) | Discharge (RIC Standard?):<br>Equipment & last calibration: | |
| **Pebble Count Data** | Collector:<br>Note Taker:<br>Correct Procedure: | < 2mm:<br>2-4mm:<br>4-8mm:<br>8-16mm:<br>16-32mm:<br>32-64mm:<br>64-90mm:<br>90-128mm:<br>128-256mm:<br>256-512mm<br>512-1024mm: |
| **Channel Gradient** | Equipment Used:<br>Number of Sections Measured: | Gradient Data: |
| **Channel Morphology**<br>(General Description)<br>i.e. riffle-pool (60:40% ratio): | | |
| **Streambank Description**<br>(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 QA Site Card

| Date & Time: | Site (Name & UTM): | EMS ID: |
|---|---|---|
| **Sub-Contractor:** | **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: |

**1) 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 | | |
| Core Site Pattern (clustered, linear, thalweg, channel bank, etc) | | |

**Site Sketch:**

**Gravel Bucket QA Site Card**

| Date & Time: | Site (Name & UTM): | EMS ID: |
|---|---|---|
| **Sub-Contractor:** | **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

<table>
<tr><td>Date & Time:</td><td colspan="2">Site (Name & UTM):</td><td>EMS ID:</td></tr>
<tr><td colspan="2">Sub-Contractor:</td><td colspan="2">Weather & Stage:</td></tr>
<tr><td colspan="4">General Comments:<br>Are bags placed in replicate sites?<br><br>Bag Depth Velocity<br>#1<br>#2<br>#3<br>#4<br>#5<br>#6<br>#7<br>#8<br>#9<br>#10<br>#11<br>#12</td></tr>
<tr><td colspan="4">1) Identifying the Sample Area:<br>Glide, Run, Riffle Sample Area Yes ☐ No ☐ Notes:<br><br>In-Stream Structures Nearby Yes ☐ No ☐ Notes:</td></tr>
<tr><td colspan="4">2) Bag Placement Procedure<br>Upstream Approach Yes ☐ No ☐<br>Bag Placement Level and Flush Yes ☐ No ☐<br>Standard Hole Width/Depth Yes ☐ No ☐<br>Standard Reference Gravel Volume Yes ☐ No ☐<br>Reference Gravel Flush with Streambed Yes ☐ No ☐<br>Bags Installed in a Downstream Direction Yes ☐ No ☐<br>Placement Pattern (clustered, linear,<br>thalweg, channel bank, etc)</td></tr>
<tr><td colspan="4">3) Bag Removal<br>Upstream Approach Yes ☐ No ☐<br>Bags Removed in an Upstream Direction Yes ☐ No ☐<br>Sample Labeled Yes ☐ No ☐</td></tr>
<tr><td colspan="4">Site Sketch:<br>(If deployed with other techniques it is important to document bag sites and sampling sequence)</td></tr>
</table>

## Freeze Corer QA Site Card

| | | |
|---|---|---|
| **Date & Time:** | **Site Location (Name & UTM):** | **EMS ID:** |
| **Sub-Contractor:** | **Weather & Stage:** | |

**General Comments:**
Are Freeze cores taken in replicate sites?

| Core | 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: |
| Salmonid Redd Area | Yes ☐ | No ☐ | Notes: |

**2) Sample Collection Procedure**

| | | |
|---|---|---|
| Upstream Approach | Yes ☐ | No ☐ |
| Core Type | | |
| Proper Core Insertion | Yes ☐ | No ☐ |
| Sample Container Cleaned | Yes ☐ | No ☐ |
| Freezing Process | $N_2$ ☐ | Dry Ice and Acetone ☐ |
| Freeze Time Standardized | Yes ☐ | No ☐ |
| Sample Split (incl. Technique) | Yes ☐ | No ☐ |
| Core Cleaned Prior to Sampling | 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:**

# Appendix 3: Suggested Short Report Requirements

The following short report format was developed in the Omineca-Peace with the purpose of conveying inventory findings to habitat staff in a concise manner. Although it addresses key issues that need to be understood by the reader the format is presented as a general guide and can be adapted to suit the needs of other programs. Each section heading is followed by key considerations to be addressed for that topic:

Background

- Provide information on the system being inventoried such as its location and why it was chosen.
- State what activity is being investigated.
- State the resource value that may be affected and how it may be affected.
- Define the project's objectives and what sediment criteria will be used to determine effects.

Site Description and Program Design

- Describe the sample location(s). If a spatial assessment is employed discuss the similarities and differences between sites and the potential affects of these differences on collected data.
- Describe prominent channel morphology features (specific reference to field notes).
- Introduce specific information about the activity such as its magnitude (photos) and suspected affect.
- Present the monitoring design and aquatic assessment approach.
- Describe the selected data collection techniques, QA/QC protocols, sample analysis, sediment quality measures and statistical procedures.
- Describe anticipated effects of the activity investigated if a similar situation has been encountered at other but similar locations.
- Tabulate the date of each monitoring visit and specific tasks completed.

Results

- Data should be presented in a graphical format where possible.
- Statistical results should be clearly stated (e.g. $F= 75.0$, $p=1.35 * 10^{-7}$) including their power.

Discussion and Conclusion

- Discuss the effect of the investigated activity upon sediment composition.
- Discuss resource effects with reference to the selected criteria.

- Discuss whether project objectives were attained.

Appendix

Transcribed field notes including all the site establishment information should be provided

# Appendix 4: Minimum Sample Number Requirements per Given Stream Width

Background:

When the Omineca-Peace Region initiated its sediment inventory program in 1997, six sample replicates were collected at each of our sampling locations. A sample number of six was selected with reference to the literature review and preliminary field investigations conducted and summarized in Rex & Carmichael (1997). It was noted during the statistical analysis of many sample sets that six replicates provided repeatable or "tight" datasets for smaller streams (< 8 m active channel width) but not for larger streams. Other regions employing these techniques reported similar findings.

Based on this finding and our intention to draft a RIC manual, a sample size estimation program was implemented. The goal of this program was to estimate minimal sample size requirements for several techniques per given stream width.

Method:

<u>Sites</u>

Given the financial restraints at the time this sampling program was implemented, only three streams were sampled. These streams, Cluculz (5m), Spruce (9m), and Youngs Creek (11m) were selected because of staff familiarity and proximity to Prince George. Further, these systems have similar gradients, habitat complexes, and surficial sediments but they have different discharge and active channel widths. It was thought that by selecting this array of channel widths, sample size estimates could be generated for those stream widths typically sampled.

<u>Sampling Techniques</u>

Three sampling techniques were chosen for this study. The McNeil core, gravel bucket, and infiltration bag techniques were selected because they were the most commonly used techniques during our regional inventory. They also collect different forms of sediment information, namely streambed composition, depositing sediment, and infiltrating sediment.

To determine estimates for minimum sample number within each stream class we "oversampled" each creek. During our regional inventory we had collected 6 replicates at each location so we believed that doubling this replicate number to 12 would oversample the area. Twelve samples were collected for McNeil cores and gravel buckets but only 10 were collected for infiltration bags because of equipment availability. Although this is not a statistically based approach for determining sample size, it is practical. It sets realistic standards for field staff and program expectations. The collection and transport of these samples is strenuous. If more than 12 samples are required to gather tight data this would restrict the application of these techniques to roadside sites. The goal of this manual is to present a sampling program that can be widely employed.

Field Schedule

Three field visits were conducted for each creek, resulting in two McNeil core and gravel bucket datasets and one infiltration bag set for each creek (Table 1). The sampling techniques were deployed in accordance with the respective procedures outlined in this manual. Transcribed field notes are provided in the Appendix 4a.

Table 1: Site visit and duties performed.

| Visit | Duties |
|---|---|
| First Visit | Site Establishment, 12 McNeil Cores collected, 12 Gravel Buckets installed |
| Second Visit | Gravel Buckets removed and a second set installed (same holes), 10 Infiltration Bags installed |
| Third Visit | 12 McNeil Cores collected, Gravel Buckets & Infiltration Bags removed |

Laboratory Analysis

The McNeil core water, gravel bucket, and infiltration bag samples were analyzed by the contracted provincial laboratory whereas the McNeil core gravel samples were processed locally in our regional warehouse. All samples were numbered so that their site depths and velocities could be used for later grouping. Infiltration bag and gravel bucket total sample weights (dry weight) and the McNeil core < 6.35mm fraction (wet sample), plus the corresponding TSS sample data, were organized into tables by sample trip and sample number. An example dataset is provided in Table 2.

Table 2: Gravel bucket data from Cluculz Creek on October 9, 1998.

| Sample Number | Sample Depth (cm) | Velocity of Overlying Water (m/s) | Sample Weight < 6.35mm (grams) |
|---|---|---|---|
| 1 | 8 | 0.39 | 78.1 |
| 2 | 9 | 0.32 | 90.4 |
| 3 | 8 | 0.34 | 81.3 |
| 4 | 8 | 0.31 | 124.8 |
| 5 | 8 | 0.36 | 85.2 |
| 6 | 9 | 0.32 | 92.8 |
| 7 | 10 | 0.34 | 94.7 |
| 8 | 10 | 0.37 | 122 |
| 9 | 8 | 0.27 | 74.4 |
| 10 | 7 | 0.32 | 70.6 |
| 11 | 8 | 0.32 | 89.7 |
| 12 | 10 | 0.31 | 76.9 |

Data Analysis

To simulate the decisions made by field staff the data were grouped by similar depth, velocity, or combination thereof. As an example, using the data presented in Table 2 and a required sample size (e.g. 6, 8, 9, and 12) the sample series presented in Table 3 may be selected.

Table 3: Sample groupings based on similar depth and a required sample size.

| Sample Number | Sample Depth (cm) | Sample Weight (grams) |
|---|---|---|
| 10 | 7 | 70.6 |
| 9 | 8 | 74.4 |
| 4 | 8 | 124.8 |
| 11 | 8 | 89.7 |
| 3 | 8 | 81.3 |
| 5 | 8 | 85.2 |
| 1 | 8 | 78.1 |
| 2 | 9 | 90.4 |
| 6 | 9 | 92.8 |
| 12 | 10 | 76.9 |
| 7 | 10 | 94.7 |
| 8 | 10 | 122 |

Similar samples for 6 replicates,
Similar samples for 8 replicates (The 6 replicates plus these two others)
Similar samples for 9 replicates (The 8 replicates plus this observation)
Similar samples for 12 replicates

Each series of sample data can be used to generate the mean, standard deviation and coefficient of variation. The coefficient of variation is a measure of the variability within a population. It is calculated according to the following formula provided by Sokal and Rohlf (1969):

$CV = s * 100/ Y$ where, $s$ = standard deviation,

$Y$ = mean

The coefficient of variation allows us to compare the degree of variability around the mean irrespective of the mean's magnitude (Sokal and Rohlf, 1969). This rudimentary statistic was used here as a relative indicator of sample size because we wish to collect representative data from similar habitats with a low degree of variability. For the purpose of this analysis we are choosing that number of samples resulting in the lowest CV.

It is important for all program developers to consider whether or not these sample size estimates are applicable to their monitoring goals. We suggest in this report that similar habitats be sampled between sites or over time so that changes within that habitat can be documented with respect to a spatial or temporal control. These data cannot be used to measure whole system response to a perceived sediment influx. Instead, they identify change in stream substrate within the chosen habitat. To estimate whole system response it would be necessary to sample several different habitats and to incorporate channel morphology measures such as sinuosity, riffle to pool ratios and others as outlined in several Provincial watershed restoration program manuals.

Results:

Generally, all three techniques returned "tight" data with the exception of Youngs creek gravel bucket and infiltration bags. The majority of sample replicate combinations returned CVs in the range of 5 to 30%, often showing only a minimal decrease in CV with increased sample number.

The recommended sample number for each technique/stream size combination was estimated by averaging the sample numbers producing the lowest CV for depth and velocity within each sample set.

<u>Gravel Buckets</u>

The gravel bucket samples exhibit a low degree of variability regardless of the sample size in Cluculz and Spruce Creeks. However, the data are quite variable for Youngs Creek, the largest of the three systems. Based upon the data presented in Tables 4 and 5 it is recommended that 8, 9, and 10 samples be collected in streams with active channel widths of 5, 9 and 11meters respectively.

Table 4: Gravel bucket coefficients of variation for given sample size. Replicates grouped by sample depth (highlighted cells indicate that sample number with the lowest CV).

| | Cluculz Creek | | Spruce Creek | | Youngs Creek | |
|---|---|---|---|---|---|---|
| | Replicates | C.V. | Replicates | C.V. | Replicates | C.V. |
| Set # 1 | 6 | 20.4 | 6 | 16.8 | 6 | 90.6 |
| | 9 | 18.1 | 8 | 17.0 | 8 | 88.7 |
| | 12 | 19.0 | 10 | 16.6 | 10 | 68.5 |
| | | | 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 5: Gravel bucket coefficients of variation for given sample size. Replicates grouped by sample velocity (highlighted cells indicate that sample number with the lowest CV).

| | Cluculz Creek | | Spruce Creek | | Youngs Creek | |
|---|---|---|---|---|---|---|
| | Replicates | C.V. | Replicates | C.V. | Replicates | 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 | | |

Infiltration Bags

The infiltration bag samples show an increasing degree of variability as the active channel width increases. Based upon the data presented in Table 6 it is recommended that 4, 8, and 10 samples be collected in streams with active channel widths of 5, 9, and 11 m respectively.

Table 6: Infiltration bag coefficients of variation for given sample size (highlighted cells indicate that sample number with the lowest CV).

| | Cluculz Creek | | Spruce Creek | | Youngs Creek | |
|---|---|---|---|---|---|---|
| | Replicates | C.V. | Replicates | C.V. | Replicates | C.V. |
| Depth | 4 | 23.2 | 4 | 31.9 | 4 | 54.7 |
| | 7 | 37.5 | 6 | 28.7 | 6 | 44.1 |
| | 10 | 31.4 | 8 | 28.8 | 8 | 41.3 |
| | | | 10 | 44.3 | 10 | 38.2 |
| 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 |

McNeil Core

The McNeil core samples returned the most problematic data of the three techniques because the data show a decrease in the required sample number as the active channel width increases. According to Tables 7 & 8 the required sample number for 5m wide streams is 10, for 9m it is 7 and for 11m it is 9. This observation contradicts the traditional thought of increased sample size with increased stream width. However, it can be explained by the high variability in sample site depth and velocity observed at the Cluculz Creek site. Given this high variability and the low increase in precision with increased sample number at Cluculz Creek (Cluculz = 2.6%, Spruce = 4.9%, Youngs = 7.9%) the recommended sample size for streams that are 5, 9, and 11m is 6, 7, and 9 respectively.

Table 7: McNeil core coefficients of variation given sample size, replicates grouped by sample site depth (highlighted cells indicate sample number with the lowest CV).

| | Cluculz Creek | | Spruce Creek | | Youngs Creek | |
|---|---|---|---|---|---|---|
| | Replicates | C.V. | Replicates | C.V. | Replicates | 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 8: McNeil Core coefficients of variation given sample size, replicates grouped by sample site velocity (highlighted cells indicate the sample number with the lowest CV).

| | Cluculz Creek | | Spruce Creek | | Youngs Creek | |
|---|---|---|---|---|---|---|
| | Replicates | C.V. | Replicates | C.V. | Replicates | 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 |

Discussion

The sample number estimates provided here are guidelines, not strict standards. It is expected that the appropriate sample number will deviate from those proposed where streams have different surficial substrate composition, discharge, habitat, gradient and site depth and velocity measures. It is anticipated that program managers will employ these estimates as minimum guidelines for their own program and that they will review their data to formalize sample number requirements specific to each project.

Providing that this manual is reviewed following a three year field test period it is recommended that a more formal review of sample size requirements be completed using a larger data set than presented above. This should include a review of sampling programs throughout the province so that regional sampling requirements can be formulated.

# Appendix 5: Other Techniques

The literature provides reference to many sediment collection techniques that do not fall within the definition of a streambed corer or sediment trap. Although the focus of this report is on traps and cores, which were predominantly used in the Omineca-Peace region, five other techniques are presented because of their prominence in the literature and for consideration by other regions. These techniques are:

1. Channel Cross Section Surveys and Scour Chains – techniques used separately or in concert to measure changes in streambed elevation due to scour and fill activities.
2. Helley-Smith Sampler – a commonly used technique to measure bedload transport rates through a channel cross section.
3. Depth Integrating Sampler - a technique used to measure suspended sediment load passing through a cross section.
4. Shovel – a technique used to measure streambed composition.
5. Pit or Bedload Traps – a technique used to measure bedload transport.

## Channel Cross Section Surveys and Scour Chains

Cross section surveys and scour chains can be used to measure changes in streambed elevation that result from scour and/or fill as well as general bedload movement. Although cross section surveys are often used independently, the combination of these techniques provides a more complete picture of bedload movement at a cross section.

Cross section surveys measure streambed elevations in transects perpendicular to the centerline of the channel (Lisle and Eads, 1991). Following site selection, this technique involves the identification of a benchmark and the establishment of permanent cross sections (Clark and Associates, 1997). Each section is then surveyed on a scheduled basis to gather data on bed elevation changes over time.

This technique is capable of providing a high degree of precision and accuracy for modeling river system response to sediment input (Qinghua and Wenhao, 1991). However, if only employed on a low frequency (i.e. annually or bi-annually), many storm events and subtle changes in bed morphology will be missed. As a result, this technique would not likely gather data on the maximum scour or fill events.

Cross section surveys can employ additional techniques to improve the understanding of changes in channel morphology. Scour chains are perhaps the most popular. This simple technique has been used for at least thirty-five years as a measure of maximum scour events at channel cross sections (Leopold et al., 1995). Scour chains are available in a variety of designs, ranging from plain rope attached to a dowel or bottom plate to perforated plastic balls or plastic beads strung on a wire rope that is itself anchored to a machined steel tip (Figure 23). Whereas simple chains provide information on scour or fill relative to the survey line, plastic balls or beads are released from the bed and slide up the line during scour events. The depth of scour can be readily estimated by counting the number of balls or beads released.

The primary advantages of cross section surveys and scour chains are:

1. They are both commonly reported in the literature.
2. When used in combination, they provide information on streambed changes, including maximum scour events and bedload movement when the survey interval is short enough to capture such events.
3. Scour chains provide an integrated measurement over time rather than an instantaneous result.
4. The equipment is light and can be transported to remote sites with relative ease.

Primary disadvantages of these techniques are:

1. They do not provide information on grain size composition.
2. Channel cross section surveys provide instantaneous measures at least two surveys are required to determine a change in streambed elevation with time.
3. Scour chain insertion can modify the porosity and structure of the streambed, which may result in the artificial increase of scour activity around the chain.
4. Chains can be damaged or lost due to vandals, wildlife, hydrologic forces of scour and fill, or snagging on semi-submerged debris.

**Field Protocol**

The following protocol focuses on scour chains. It is not the purpose of this manual to discuss detailed hydrometric survey techniques. For information on these procedures, refer to Clark & Associates (1997), Harrelson et al. (1994) and Platts et al. (1983).

1. Locate appropriate cross sections that represent the stream reach.
2. Install scour chains at regularly spaced intervals along the surveyed cross section. Lisle and Eads (1991) recommend that random chain placement not be used because:
    - scour and fill activities involve most if not all of the channel width;
    - chains are easier to relocate when on a transect;

- chain data can be directly related to cross section survey elevations.

3. Scour chains can be dug into the streambed manually or inserted with the use of a drill, probe, or driving rod. If chains are dug into the streambed, carefully re-pack the streambed to reduce the degree of artificial scour.
4. If a driving rod is used, the design will reflect the type of scour chain employed. A simple rope or chain can be inserted with a steel bar or probe as described by Lisle and Eads (1991) (Figure 23). A perforated ball or sliding bead scour chain should be installed with a hollow tube and post driver, as described by Nawa and Frissel (1993) (Figure 24).

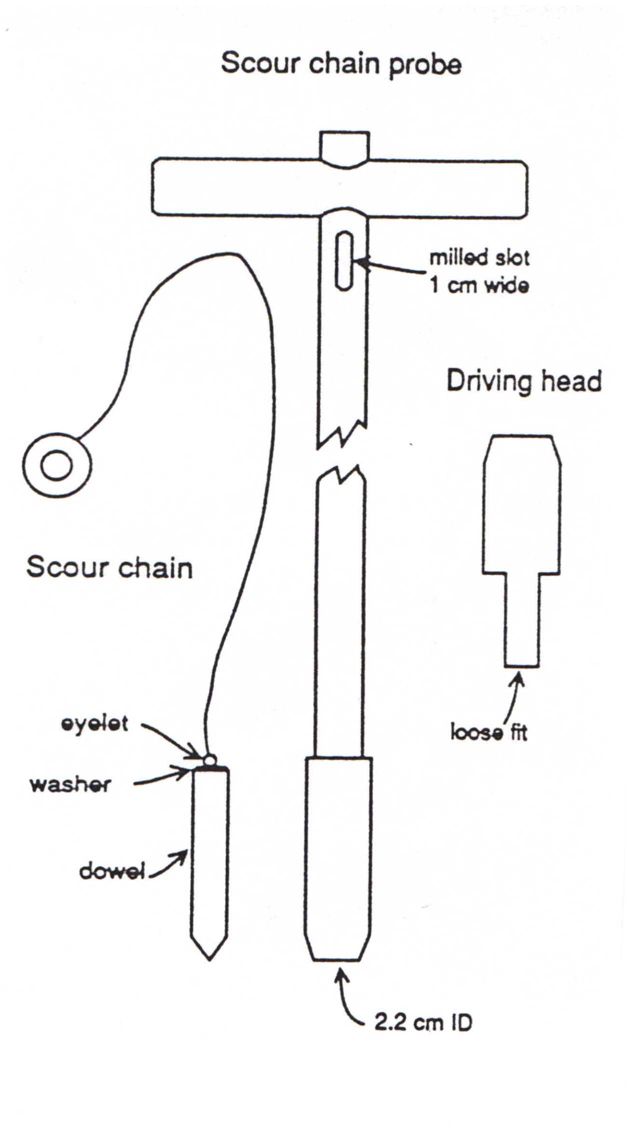


**Figure 23 - Scour chain and driving probe from Lisle and Eads, 1991.**

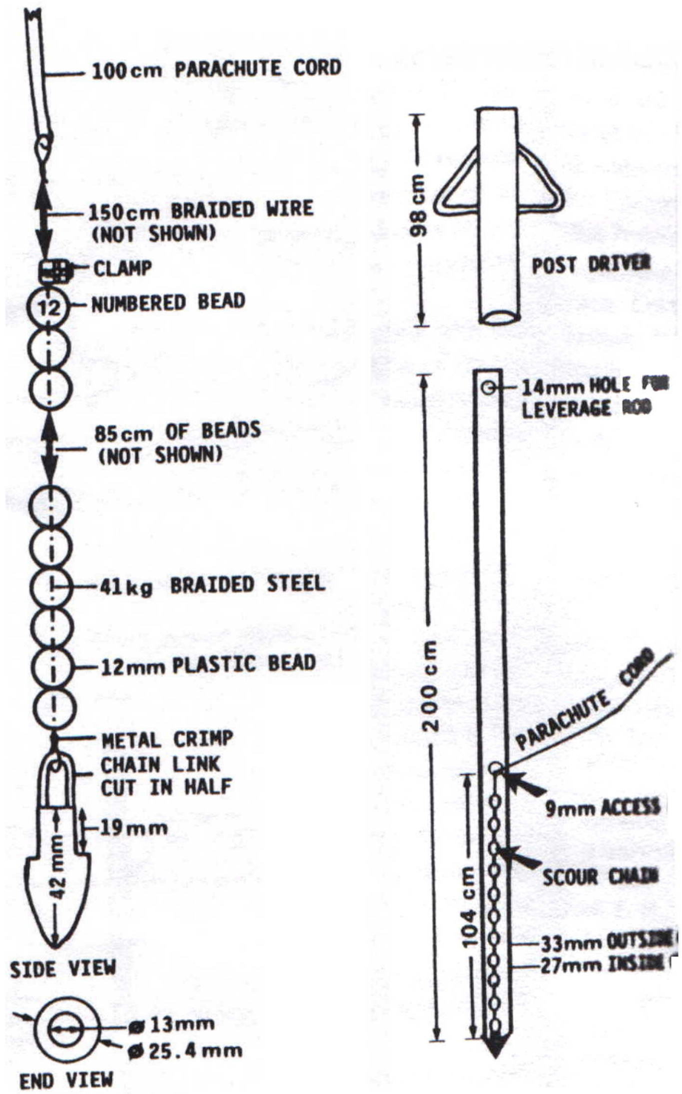


**Figure 24 - Bead monitor, hollow tube and post driver from Nawa and Frissel, 1993.**

5. Insert the chain vertically into the streambed to the required depth, typically between 30cm and 1 m depending on anticipated scour events. Ensure the chain is long enough to extend to the reference point and still have 10 cm or more on the streambed surface that can be marked with flagging tape or a painted washer to facilitate the chain's later recovery.
6. Measure the length of chain remaining on the streambed surface and survey the streambed elevation.
7. Upon returning to the site, note the visible chains. Re-establish the cross-section without disturbing the locations of buried chains.
8. If visible, measure the length of chain remaining on the streambed. If either the ping-pong ball or sliding bead monitors are used, count the number of balls or

beads protruding from the streambed. If there is no change in chain length or if no balls or beads are visible, proceed to the next visible chain.

9. Those chains that are buried beneath substantial fill and are not visible can be relocated using placement distances from the last cross section survey. Once located, gently excavate that site until the burial depth is reached. Burial depth is determined as that depth where the chain is bent (Figure 25).

10. Measure scour chain elevations and compare to original streambed profile to determine the magnitude of scour or fill events.

11. Refill the excavated hole and leave a length of chain on the surface to measure future events.

12. When cross section survey and scour chain sites are located upstream of core sites, collect the cores first. If located upstream of sediment traps, collect deployed traps first and reinstall them last. These protocols should prevent downstream capture of sediment re-suspended by survey and chain placement procedures.

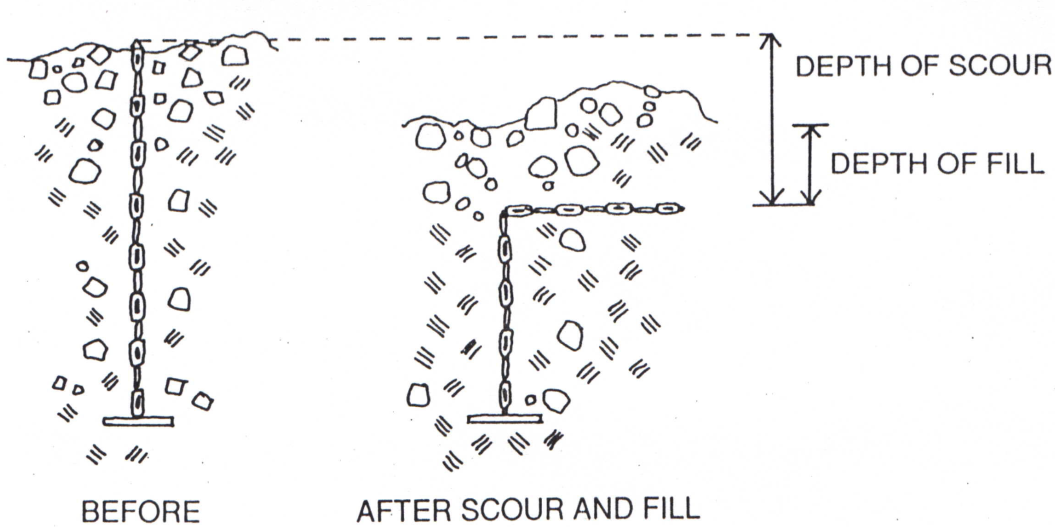


**Figure 25 - Scour chain placement showing depth of scour and depth of fill (Harrelson et al., 1994).**

**Suggested Number of Replicates**

Scour chains were not used in combination with cross section surveys in the Omineca-Peace Region because local monitoring programs were of short term. Instead, scour chains were used in a qualitative fashion. That is, we measured changes in exposure or burial depth to indicate scour or fill events for each sample period. This coarse data allowed determination but not quantification of events.

Several sources do recommend replicate numbers for scour chains. These are:

- Lisle and Eads (1991) suggest placing a chain every one half to two metres across the channel at two to five cross sections.
- Nawa and Frissel (1993) suggest placing eight chains across each of two channel cross sections. Further, they state that an experienced crew of two people can complete this task in one day.
- Harrelson et al. (1994) suggest installation of five to ten chains per cross section.
- Leopold et al. (1995) installed one to four scour chains per cross section. They used thirty cross sections over a distance of 9.6 km.
- Haschenburger and Church (1998) installed scour chains at 2 m distances across each of 18 channel cross sections that were established along 1101m of Carnation Creek.

#### Quality Assurance and Quality Control (QA/QC) Program

The success of these techniques depends on the skill of the survey crew. As such, the only recommendation is that field staff demonstrate their surveying technique and understanding of installation procedures to an experienced staff member and/or certified surveyor.

## Helley-Smith Sampler

The Helley-Smith sampler is widely recognized as a standard technique by which to determine bedload transport rates (MacDonald, L.H., personal communication, 1997 and Platts et al. (1983)). This device uses the pressure difference between its inlet and outlet to collect representative bedload samples (Ashworth and Ferguson, 1989). The pressure drop at the sampler's outlet maintains entrance velocities similar to natural conditions (Figure 26).

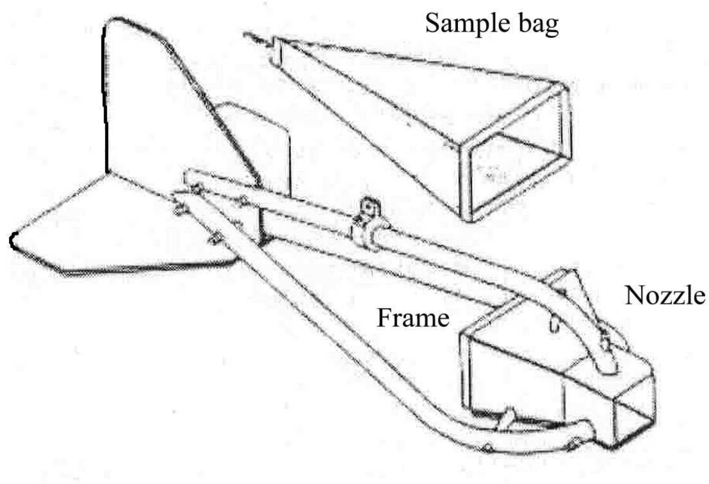


**Figure 26 - Helley-Smith bedload sampler schematic. (Edwards and Glysson, 1988)**

The Helley-Smith sampler captures bedload sediment moving along the streambed surface. It can be used in combination with depth integrating samplers (see below) to determine the total sediment discharge through a channel cross section (Edwards and Glysson, 1988).

Recent field studies in a cobble-gravel river indicate that sampler is biased toward the finer fractions (< 3mm). Further, it was found that the Helley-Smith generally captured significantly less material than a pit trap (Sterling and Church (*In Press)*, 2000). They recommend that the Helley-Smith not be used in cobble-gravel rivers but rather be restricted to the sand/gravel bed for which it was designed.

Helley-Smith samplers are available in a variety of sizes to suit a range of river and substrate conditions. Small creeks and rivers may employ simple wading rod versions that weigh up to 18 kg, whereas large rivers may require cable-reel suspension versions that weigh up to 250 kg (Edwards and Glysson, 1988).

The primary advantages of the Helley-Smith technique are:

1. It is commonly used to assess bedload transport rates and bedload grain size distribution.
2. Sampler openings are available in a variety of sizes to suit substrate grain size.
3. In a controlled study this sampler was found to have a capture efficiency of 100% for particles ranging between 0.5 mm and 32 mm diameter at transport rates up to 1.5 kg $m^{-1}s^{-1}$ (Ashworth and Ferguson, 1989). However, in cobble-gravel bed rivers the sampler was found to be biased toward the finer fractions (Sterling and Church, 2000). The Helley-Smith sampler was designed for sand/gravel bed rivers. Improper seating of the sampler on the more rough cobble/gravel would open the samplers orifice to sediment suspended just above the bed more so than saltating or sliding coarser grains of the streambed.

The primary disadvantages of this technique are:

1. It provides an instantaneous measure of bedload transport.
2. It does not provide information on streambed compositional changes.
3. The equipment is heavy, limiting its application to easily accessible sites.
4. Edwards and Glysson recommend collecting 40 individual bedload samples per cross section (i.e. labour and time intensive).

**Field Protocol (After Edwards and Glysson, 1988)**

Several sampling designs can be used when collecting bedload with the Helley-Smith sampler. They are the single equal width increment method (SEWI), the multiple equal width increment method (MEWI) and the unequal width increment method (UWI). The SEWI method provides more information about cross-sectional variability than MEWI or UWI. Further, the UWI technique requires prior knowledge of the stream depth and velocity across the channel because intervals should be spaced with respect to slope changes or to delineate equal portions of cross channel bedload discharge (Edwards and Glysson, 1988). No one method will work best so, if possible, the authors suggest that several trial runs with each method over many hydrological stages be completed to see which is best suited for a particular stream. These methods have several initial steps in common:

1. Collect these bedload samples before disturbing the channel in the process of measuring stream discharge.

2. Establish the channel cross section with a survey tape.

3. To collect each sample, quickly lower the Helley-Smith to the streambed and use a stopwatch to measure sample interval.

4. To determine sample interval, collect several test samples at the thalweg. The sample interval is that period of time required to fill 40% of the sample bag. It depends upon flow conditions and can range from seconds during high flow to several hours during low flow, but typically does not exceed 60 seconds.

5. It is recommended that one transect be established for the SEWI method and a second established for either the UWI or MEWI method:

- For the SEWI method, collect samples midway between each of 20 evenly spaced verticals along the cross section (Figure 27). Samples should be no closer than 0.3 m to each other. Two runs of 20 samples each should be conducted along the cross section to collect the required 40 samples. The sample interval must be the same for each vertical during a sample run, but can differ between sample runs.

- For the MEWI method, collect samples midway between four or five equally spaced verticals along the cross section. Repeat until 40 samples are collected. If samples are to be composited for each cross section, ensure sampling interval is consistent between runs. If each vertical sample will be analyzed individually, sample interval can vary but must be recorded on the sample bag.

- For the UWI method, collect samples midway between 4 to 10 unevenly spaced verticals along the cross section. Selection of verticals can be subjective, but the same verticals must be used for each sample run to a total of 40 samples. Employ similar procedures as in MEWI for composite or individual sample analysis.

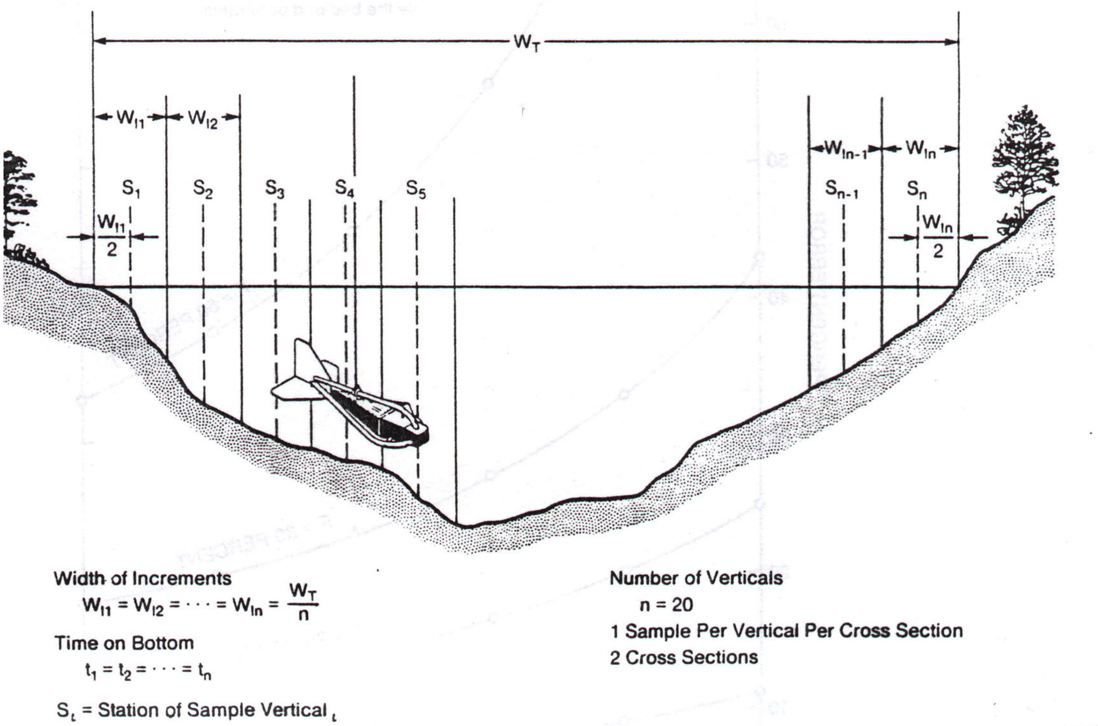


**Figure 27 - The SEWI sample design for collecting Helley-Smith samples (Edwards and Glysson, 1988). A bridge use may be necessary depending upon flow conditions.**

6. Formulae for determining bedload discharge are provided in Appendix 9.

## Suggested Number of Replicates

Edwards and Glysson (1988) recommend a minimum of 40 sample replicates.

### Quality Assurance and Control (QA/QC) Program

This technique has not been used in the Omineca-Peace Region. Nor, unfortunately, does the literature provide suitable QA/QC guidelines. However, it is recommended that programs using the Helley-Smith sampler employ general QA/QC considerations referred to in section 3.1.

- Ensure the Helley-Smith sampler employed is appropriate for site conditions and that the acceptable model is maintained for the entire sampling program.

- Independent program audits should focus on site selection, sample interval estimation procedures, consistency of sampling staff and sample interval, upstream sampling and sample labeling.

- Sample period must be documented to ensure adequate temporal comparison. Bedload movement will be more significant during the higher flow periods with the majority of it moving over a few days or hours during spring freshet.

## Depth Integrating Sampler

The depth integrating sampler collects water and suspended sediment isokinetically and continuously as it is passed vertically through the water column. This technique provides more representative data than a simple surface grab sample (Martin et al., 1992).

These samplers are available in a variety of sizes to accommodate specific stream conditions. Hand-held models such as the DH-48 (Figure 28) are suitable for collecting sediments in wadeable streams. Samplers are supplied with two or more nozzles, each having a velocity range in which it is best applied.

**Figure 28 - A depth integrating sampler, model DH-48. (1 liter sample bottle for scale)**

The primary advantages of the depth integrating sampler are:

1. It collects more representative samples than do surface grabs.
2. It can be adapted to suit a range of stream velocities.

3. Combined with discharge data, it can provide a reliable estimate of the suspended sediment load.
4. Combined with bedload estimates, it can determine total sediment discharge through a stream cross section.

**Field Protocol**

Edwards and Glysson (1988) discuss several monitoring techniques. These or WSC approved programs should be followed. An abridged version of the most commonly used procedure, the equal width increment (EWI) method, is presented here:

1. Establish the channel cross section with a survey tape.

2. Measure stream velocity and select the appropriate nozzle (information provided by equipment supplier).

3. The number of samples collected should range between 10 and 20. The exact number will reflect the required degree of precision.

4. To determine the number of sample increments, divide the channel width by the number of samples required. Sample collection sites are the midpoint of each increment.

5. Place the depth integrated sample bottle into the sampler.

6. Test sample the deepest, fastest part of the cross section. Determine and record the vertical transit rate (cm/s) to and from the streambed necessary to collect no more than 80% of the bottle volume. Apply this same transit rate to all other sample increments (Figure 29). Sample volumes will be proportional to discharge through each increment.

7. The vertical transit **rate** must be consistent between sample sites. To ensure consistency, time the transit rate with a stopwatch and use a fixed point such as the survey tape to gauge the sampler's movement through the water column.

8. These samples can be composited to determine the total suspended load of the cross section. Alternatively, each sample can be analyzed individually to determine cross section variability.

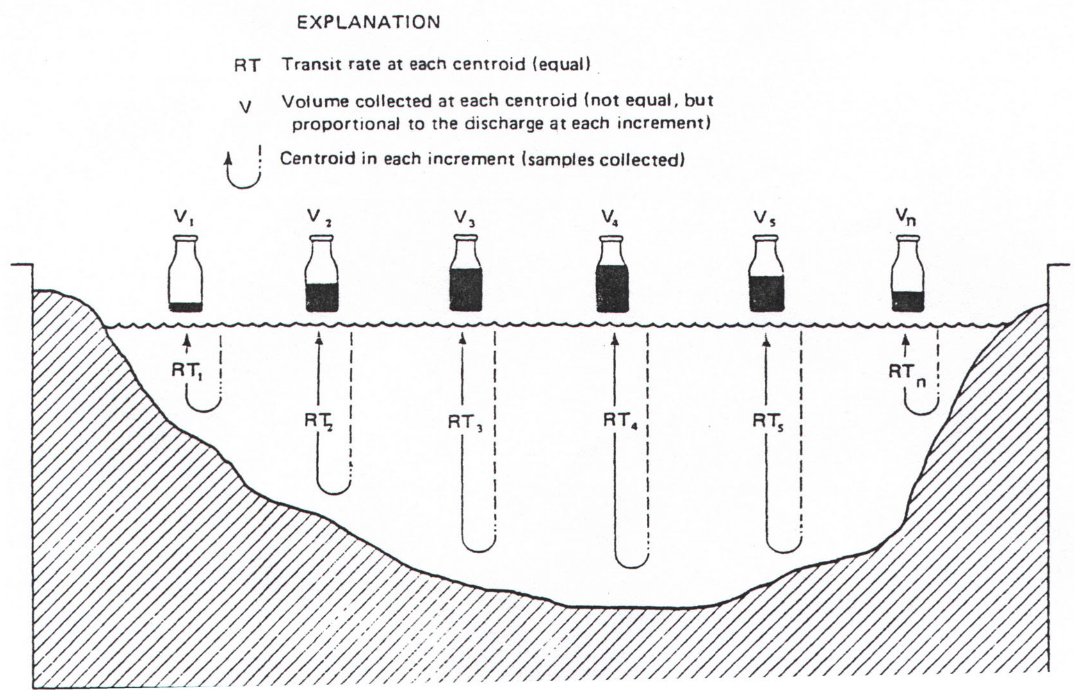


**Figure 29 - The equal width increment technique requires consistent application of transit rate at each increment, which may result in dissimilar sample volumes along a cross section. (Edwards and Glysson, 1988)**

**Suggested Number of Replicates**

Replicate number will depend upon stream width. Edwards and Glysson recommend the collection of 10 to 20 samples in one channel cross section. However, in small streams where sediment is less variable due to turbulent flow the appropriate sample number may be less than 10. For example if the creek is 3m wide, 6 samples at 0.5 m intervals may suffice. The decision to reduce sample numbers can be verified with a turbidity meter. Quite simply, if turbidity is relatively constant across channel width and depth, fewer samples are required.

**Quality Assurance and Quality Control**

This technique has been used in the Omineca-Peace as a quality assurance tool for automated turbidity monitoring programs. Its use as an independent monitoring technique has been limited. As such, a well established QA program has not been established. Refer to section 3.1 for QA/QC guidelines. Suggested requirements include:

- Independent program audits should confirm staff estimation of the vertical transit rate, consistent application of this rate, upstream sampling, and sample labeling.

- Laboratory analysis will be limited to total suspended solids, so the application of duplicates, split samples and blanks, as described by Cavanaugh et al. (1997b), is recommended.

## Shovels

Perhaps the oldest and most readily available streambed sampling technique is the shovel. Although sedimentologists only use shovels to sample exposed areas (i.e. above water), it has been used by fish biologists as an alternative to some coring techniques.

The primary concern about streambed sampling with a shovel is the loss of sediment as the shovel is lifted through the water column. Techniques such as streambed corers were designed to counteract this loss of sediment producing more accurate and precise results. As observed for the other techniques, sample results will vary with the shovel design.

Despite the variety of techniques available, the shovel is still popular. It has been used to collect sediment bound contaminants for pulp mill monitoring studies (Rex and Carmichael, 1996 unpublished). Lab comparison studies by Young et al. (1991a) determined that shovels collected more accurate samples than single or tri-probe freeze cores, but that they were not as accurate as the McNeil corer. These authors suggest that the accuracy of shovel samples could be improved with the use of stilling wells.

Based on these and similar findings of Grost et al (1991), a comparison of three shovel designs with the McNeil corer was conducted by Schuett-Hames et al. (1994). Their shovel designs included:

- Standard # 2 round point shovel;
- Standard # 2 round point shovel with a stilling well;
- Modified shovel, consisting of 0.32 cm thick steel plating that was 33 cm long and 22 cm wide. Short side walls were welded on to prevent material from sliding off the blade.

This comparative study was done using a smaller volume McNeil corer than the modified version recommended above. The core tube had a diameter of 15 cm and length of 23 cm.

The McNeil corer was found to be the most efficient technique for collecting particles less than 0.106 mm. Of the shovel techniques, the # 2 round point shovel and stilling well combination collected samples most similar to the McNeil corer. This shovel and well combination collected 3% less volume than the McNeil core for those particles less than 0.106 mm. Therefore, if a loss of 3% fines is acceptable, this combination may prove preferable to the McNeil corer, which collects samples of twice the weight. If a high degree of accuracy is required, Schuett-Hames et al. (1994) recommend the McNeil corer.

The use of shovels to collect sediment information is still somewhat experimental and is not commonly observed in the literature. As such, it is recommended that local resource managers test this technique before adopting it into a formal monitoring program. It can be deployed alongside other techniques for comparison in field conditions to assess variability and sampling consistency.

This technique has not been used in the Omineca-Peace for assessing forest harvesting effects on sediment storage. As such, the following protocol has been adapted from Schuett-Hames et al. (1994).

**Field Protocol**

1. Select sites as for McNeil coring, along riffle crests.

2. Approach the site in an upstream direction.

3. Hold the blade at a $90^0$ angle to the streambed.

4. Work the blade into the streambed by stepping on the footplate and moving the handle from side to side.

5. Once the footplate is flush to the streambed push the stilling well into the bed. The stilling well, as seen in Figure 30, is made of ¼ inch sheet aluminum.

6. Pull back on the handle while maintaining pressure on the footplate until the blade breaks the surface of the streambed.

7. Hold the shovel near the blade to keep it horizontal to the flow so as to prevent spilling of sediment from the sides. Transfer the sample to a clean, labeled bucket. Rinse the blade so that wash water containing sediment is transferred to the sample bucket.

**Figure 30 - Shovel and stilling well sample procedure. (Schuett-Hames et al., 1996)**

**Suggested Number of Replicates**

No replicate numbers have been recommended by Schuett-Hames et al. (1994), but it is assumed that they would be similar to those recommended for the McNeil corer.

**Quality Assurance and Control (QA/QC) Program**

The QA/QC program for the shovel sampling technique requires well trained operators, carefully planned field quality control, analytical bias and precision quality assurance and independent program audits, all undertaken with due consideration of personal safety. Refer to section 3.1 for QA/QC considerations. Suggested requirements include:

- Independent program audits should evaluate potential problems associated with: deviation in sample rejection procedures; site selection; upstream site approach and sample labeling.
- The coring process will significantly alter streambed substrate. Samples should not be obtained at locations of previous cores within the same program year.
- The field crew must be trained in the stringent application of the following sampling procedures:

    1. Reject the sample if improper insertion angle is used.

2. Reject the sample if insertion depth is shallow.

3. Reject the sample if extensive disturbance of the substrate occurs.

4. Use proper site selection techniques.

## Bedload or Pit traps

Bedload or pit traps are similar to gravel buckets in that they are containers buried into the streambed with their opening flush to the streambed's surface. They differ from gravel buckets in that they are often larger and are empty. Bedload that slides or saltates along the streambed will fall into the trap opening. The trap is emptied on a set schedule and the sample collected represents a composite measure of bedload movement since the last collection period. Pit traps come in an array of designs and complexity, but they all operate in a similar manner by retaining sediment that falls into them. Three designs follow:

- An empty 20 liter plastic bucket containing a removable sample bag was placed in a concrete sleeve flush to the streambed. A lid that prevented bedload or depositing sediment larger than 10 mm from entering the sample bucket was hinged to the sleeve. This device was deployed for several hours or days. Collected data was used in combination with continuous discharge measurements to determine accumulation and transport of fine grain classes over a gravel bar (Church et al. 1991).
- A similar design was used by Scrivener (1994) on a year round basis to measure bedload movement. Depth of captured sediment was measured on a regular interval and four samples per year were removed from the bucket for grain size analysis. The program used these buckets to determine particle size change in bedload due to forest harvesting activities. It was also used in combination with freeze-core data to assess changes in spawning gravel composition.
- Sterling and Church (2000) deployed three pit traps constructed of a 29 cm diameter concrete water pipes that were installed vertically in a gravel bar. Pipes were covered with a steel lid that had 13 cm wide lots along its length so that 90% of the lid was open for bedload to fall into the trap.

Regardless of the specific design used, all pit traps provide data on bedload movement

The primary advantages of pit traps are:

1. They provide a more accurate measure of bedload transport than Helley-Smith sampler in coarse bottom streams (Sterling and Church, 2000)

2. They provide an integrated measurement over time.

3. They gather data on bedload sediment composition and mass.

4. They are simple to use and inexpensive to replace.
5. They require no commitment of personnel between installation and collection (i.e. they are passive samplers).

The primary disadvantages are:

1. Fine sediments can be lost through resuspension. Sterling and Church (2000) state that their traps would underestimate the < 3mm fraction. A 3:1 aspect (length to width ratio) ensures pit traps do trap most fine sediment fractions (Hargrave and Burns, 1979). However, even with this aspect some fines will still be under represented. These can be determined by a series of calculations based on Froude number and pit trap water velocities as described in Sterling and Church (2000).
2. They may be heavy and difficult to install in streams.
3. They cannot be used in water deeper than 0.8 m unless deployed by scuba divers.
4. Typically, the trap lip protrudes over the streambed which may bias the sample to larger grain sizes. Specifically, as scour removes sediment around the lip particles equivalent to the exposed lip depth may not be able to step up to the trap opening (Sterling and Church, 2000).

**Field Protocol**

Pit traps have never been used in the Omineca-Peace region so the following protocol has been hypothesized following a review of the literature. It is subjective, so if the reader wishes to use these traps, field trials may be appropriate prior to the proposed sampling period.

1. Each sampling location should be chosen to ensure that depth, velocity and habitat are similar both within and between sites.
2. A hole is dug to the approximate depth of the pit trap (0.5-1m ). If part of a temporal program, serious consideration should be given to installing metal, concrete or rubber sleeves in order to maintain consistent sampling sites.
3. Place the trap in the hole and collect depth and velocity behind and at the sides of the trap. Ensure that the trap is level and that the sample bag is in place.
4. To facilitate recovery, the trap deployment area may be flagged or otherwise marked.
5. Ensure that all upstream work is complete and that any sediment generated by field activities has settled out before installing the next trap downstream. Exit the channel below the last trap.
6. During retrieval, approach traps in an upstream direction.
7. Prior to removal, measure depth and velocity at each trap. These data will provide an indication of hydrological change over the sampling period.

8. Remove trap lid (if lidded) and retrieve the sample from its bag, ensuring that sample is not lost to passing flows. If the bag is removed from the trap replace it with a new one. Label the sample appropriately and move upstream to the next sample.

**Suggested Number of Replicates**

Church et al. (1991) used 12 traps randomly spread throughout the sample reach while Scrivner (1994) used five traps equally spaced across the channel cross section.

**Quality Assurance and Control Program (QA/QC)**

The QA/QC program for pit trap sampling requires well trained operators, carefully planned field quality control, assessment of analytical bias and precision and independent program audits, all undertaken with due consideration of personal safety. Refer to section 3.1 for QA/QC considerations. Specific requirements include:

- Independent program audits should evaluate potential problems associated with: deviation in upstream sampling approach; trap placement; similarity of water depth and velocity above traps within and between sites; and proper sample labeling.

# Appendix 6: Sampler Construction and Sediment Analysis Costs

| Sampler | Sampler Cost ($) | Sample Extraction Cost ($) | Analysis Cost[1] |
|---|---|---|---|
| Freeze Corer | 300 – 1200[2] | 30 – 50 | $$$$ |
| McNeil Corer | 300 – 500 | None | $$$$ |
| Gravel Bucket | 4- 6[3] | None | $$ |
| Infiltration Bag | 40 – 60[3] | None | $$ |
| Shovel & Stilling Well | 100-300 | None | $$$$ |
| Helley-Smith | 1000 - 1500 | None | $$$ |
| Cross-Section Survey and Scour Chains | 400 - 700 | None | None |
| Pit Trap | 100 – 400 | None | $$$ |
| Depth Integrating Sampler | 500 - 700 | None | $ |

[1] Relative measure based upon the number of sieves required for the analysis. Sieving costs vary between labs but should range between $7 and $10 per sieve. The suspended sediment trap and depth integrating sampler will only require TSS filtration and so will be the cheapest of analyzed samples.

[2] Price will vary based upon model selected, with a single probe corer being the cheapest and the modified or tri-probe corer costing in the upper range. Extraction cost will vary based on freezing process used, with acetone and dry ice being cheaper than liquid nitrogen.

[3] Price includes equipment and reference gravel cost for one sampler. Many samplers may be necessary depending upon program design

# Appendix 7: Salmonid Redd Depths

British Columbia salmonid spawning times and maximum redd length/area and depths from Scott and Crossman (1973) unless otherwise stated.

| Fish | Proper Name | Months | Maximum Depth (cm) | Length (cm) or Area ($m^2$) |
|---|---|---|---|---|
| Chinook Salmon | *Oncorhynchus tshawytscha* | July to November | 43.7[3] | 366 |
| Coho Salmon | *O. kisutch* | October to January | N/A | N/A |
| Chum Salmon | *O. keta* | July to January [1] | 40.6 | 2.27 $m^2$ |
| Kokanee/ Sockeye Salmon | *O. nerka* | September to December[2] | 10 | 26 cm |
| Pink Salmon | *O. gorbuscha* | mid-July to late October | 45.7 | 91.5 cm |
| Cutthroat Trout | *Salmo clarki* | November to May | 20.3 | 30 cm |
| Rainbow/Steelhe ad Trout | *S. gairdneri* | March to August | N/A | N/A |
| Dolly Varden | *Salvelinus malma* | September to November | 30.5 | 24 cm |

[1] Location dependent, southern populations arrive on the grounds later in the year.

[2] Later months for Ontario populations

[3] From Bjornn, T.C. and D. W. Reiser. 1991. Habitat requirements of salmonids in streams, p. 83-138. In Influences of Forest and Rangeland Management on Salmonid Fishes and Their Habitats. W.R. Meehan (ed.) American Fisheries Society Special Publication. 751 p.

**Literature Cited**

Scott, W.B. and E.J. Crossman. 1973. Freshwater fishes of Canada. Fisheries Research Board of Canada. Bulletin 184, 966p.

# Appendix 8: Wentworth Scale

| Grain Class | Size (mm) |
|---|---|
| Clay | < 0.004 |
| Silt | 0.004 < X < 0.0625 |
| Fine Sand | 0.0625 < X < 0.25 |
| Medium Sand | 0.25 < X < 0.5 |
| Coarse Sand | 0.5 < 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 9: Bedload Discharge Calculations for Helley-Smith Sampler

(After Edwards and Glysson, 1988)

Bedload transport rate at a water column interval within the channel cross section may be determined by the following equation:

$R_I = KM_I / t_I$

Where:

$R_I$ = bedload transport rate measured by the bedload sampler at interval I in tonnes per day per foot

$M_I$ = mass of sample collected at interval I in grams

$T_I$ = time the sampler was on the bottom at vertical I in seconds,

K = a conversion factor used to convert grams per second per meter into tonnes per day per meter

K = (86,400 sec/day) (100cm /NW)

NW= nozzle width in cm

For NW= 7.5 cm, K = 1.267

NW= 15 cm, K= 0.633

The total cross section's bedload discharge can be calculated using the following formula if:

sample times $t_I$ are equal at each interval,

SEWI or MEWI method used, and

First sample was collected at one half the interval width from the starting bank.

$Q_B = K (W_T / T) M_T$

Where:

$Q_B$ = bedload discharge as measured by bedload sampler, in tons per meter,

$W_T$ = total stream width, in meters

T = total time sampler was on the bed (multiply sample time by number of sample intervals)

$M_T$ = total mass of sample from all intervals in grams, and

K = conversion factor described above.