Water Quality

Sampling Strategy for Turbidity, Suspended and Benthic Sediments

Technical Appendix Addendum

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Preface

This document is an addendum to the provincial criteria Technical Appendix document entitled "Ambient Water Quality Criteria for Turbidity, Suspended and Benthic Sediments in British Columbia Water Quality Criteria for Particulate Matter. A sampling strategy for turbidity, suspended sediments, substrate composition and bedload movement is described. The strategy can be used to verify whether criteria exceedances have occurred. The document will provide field personnel with general sampling designs and methods which they will need to adapt to their situation. It is recommended that the user be familiar with the concepts and criteria detailed in the Criteria Technical Appendix document prior to making comparisons between monitoring results and criteria.

Introduction and Objectives

It is said that watershed managers must be willing and be capable of investigating turbidity with a concurrent assessment of sedimentation and hydrological processes within a watershed (Carson 1996). This document is an extension of the Ambient Water Quality Criteria Document for Turbidity, Suspended and Benthic Sediments in British Columbia. The sampling strategy proposed herein serves the sole purpose of verifying or testing whether criteria exceedances are occurring. For long-term monitoring purposes, it may prove to be too costly unless sampling is automated. The strategy will focus primarily on the monitoring of lotic systems in British Columbia. Furthermore, because every watershed is different in terms of its physical, chemical and biological characteristics, all possible scenarios cannot explicitly be addressed. Instead, the strategy will recommend more general procedures that can be adapted to suit the requirements! of site-specific conditions.

Criteria exceedances are caused by anthropogenic activities such as forest management, road building, construction, dredging and gravel pit operations which can cause marked changes in the physical, chemical, and biological characteristics of the watercourses located nearby and those located downstream. Several Provincial codes of practice managing these activities are in place and ensure that environmental disturbances are kept to minimum. Moreover, pollution events still occur and codes of practice need to be continually updated in order to account for new scientific information.

Relevance to Criteria

In the criteria document, a recommendation was made to use the severity-of-ill-effects (SEV) model for the British Columbia aquatic life criteria development and for predicting the expected severity-of-ill-effects of suspended sediments. This method will assist BC Environment in their design, planning and implementation of control options. Because criteria interpretation hinges on site-specific conditions, the criteria are to be used as starting points on which site-specific objectives can be developed. The Provincial recommended aquatic life criteria for turbidity and suspended solids of an increase (from background) in 8 NTU and 25 mg/L, for 24 h or 2 NTU and 5 mg/L for 30 days during clear flow periods* recognizes that exposure duration plays a key role in the toxicity response. A sampling strategy is provided in this document to assist field personnel in their experimental design and methodology in order to attest whether turbidity, suspended sediment, bedload and substrate composition exceedances occur over the short and long-term.

**** Clear and turbid flows operational definition: In this document, the terms clear flow period and turbid flow period are used to describe the portion of the hydrograph when suspended sediment concentrations are low (i.e., less than 25 mg/L) and relatively elevated (i.e., greater than or equal to 25 mg/L), respectively. These new terms have been proposed because the commonly-utilized descriptive terminology (i.e., low flow and base flow, high flow or freshet flow, ascending or descending limb of the hydrograph, etc.) do not adequately identify the periods of low and elevated sediment transport in stream systems. In addition, many stream systems, such as those fed by lakes or reservoirs, run clear year-round. Therefore, it is possible that the water quality criteria for suspended sediments could be incorrectly applied if standard hydrological terms were utilized in this document. The clear and turbid flow periods for individual stream systems should be defined using data on the background concentrations of suspended sediment at the site-specific level. The recommended transition value (25 mg/L) was selected by examining the hydrographs for a number of streams in British Columbia and is intended to provide an operational definition of clear flow conditions that can be applied consistently in the province.***

Current Monitoring Programs

The monitoring of aquatic systems in British Columbia, as for the most of the rest of Canada, is conducted on a project by project basis. Routine fixed-stations of the past have given way to intensive short-term surveys to either obtain statistically sound data for regulatory purposes (cited in: Zrymiak and Cashman 1986), or because of resource constraints requiring the surveys to become focused and temporary. Past records of suspended sediments yields in the Province of British Columbia were made by the Water Survey of Canada, Sediment Survey Section of Environment Canada. Water samples were collected in as many as 41 hydrometric stations throughout the Province. British Columbia Hydro and Power Authority also collected water samples and monitored for suspended sediments at 19 stations in mostly Northern BC rivers (Church et al. 1988). Other large suspended sediment monitoring programs took place on the Lower Fraser River which had four fixed suspended sediment stations (Zrymiak 1982; McLean and Church 1986).

Currently a number of specific projects are being undertaken to measure either turbidity or suspended sediments in BC Rivers. From the available published literature these include, for example, a suspended sediment monitoring project in the West Kootenays, relating water quality and forest development and a description of problems and errors associated with turbidity measurements (Jordan 1996). In the Takla Lake region several monitoring projects characterizing suspended sediments with regards to the influence of water discharge and spawning salmon are ongoing (Cheong et al. 1995). These endeavour to improve suspended sediment measurement methodology and data quality.

In the last few years, a number of long-term monitoring programs have been proposed and/or initiated to evaluate the effects of forest management activities on water quality in British Columbia. For example, monitoring in community watersheds has been initiated throughout the province under Forest Renewal British Columbia (Beatty-Spence, pers. com. 1997. Nelson, BC). In addition, a number of focused monitoring programs have been implemented in high priority watersheds on Vancouver Island, the lower mainland, Okanagan region (*e.g.*, Salmon River), Kootenay Region (*e.g.*, Lardeau River), and elsewhere to identify specific impacts and expand our understanding of forestry/water quality/fisheries interactions in the province. Suspended and deposited sediments will be a primary focus of many of these projects.

Guidebooks promoting suspended sediment field surveys include, for example 'The Community

Watershed Guidebook' which is a tiered approach to water quality monitoring and a report by Preston (1996) stressing the importance of reconnaissance level surveys in a monitoring program for identifying potential and existing suspended sediment problems in aquatic systems (Preston 1996).

Objectives

Different objectives require different sampling designs. Of the different types of monitoring outlined by MacDonald et al. (1991), the current sampling strategy employs compliance monitoring. The objectives below collectively aim at verifying whether there are exceedances in suspended sediments in lotic systems. The compliance framework from which these stem is not an issue as criteria are not intrinsically legal binding but are embodied in different Provincial legislations and codes of practice and can become enforceable.

The objectives of the sampling strategy are to:

1. recommend sampling strategy to determine suspended sediment concentration, turbidity, substrate composition and bedload levels between potentially impacted site and a control site (or with historical data) that verify if the criteria have been exceeded,
2. recommend the type of physical sample to collect and current sampling techniques and equipment that can realistically be used by trained field personnel to verify 1), and
3. recommend the appropriate summary statistical analysis for this verification.

Issues

Other issues of a sampling program such as quality assurance aspects that deal with sample collection and handling maneuvers, analytical analysis and good laboratory practices will affect the variability in the observed results and should be addressed and are discussed elsewhere (Gilbert 1987; MacDonald et al. 1991; Andersson and White 1996; Zrymiak and Cashman 1986). Briefly discussed below are resource constraints, spatial and temporal variability, background levels and statistical considerations.

Resource Constraints

Perhaps the most significant element controlling the outcome of a sampling strategy are monetary constraints. In compliance monitoring, to ensure the scientific rigor and statistical validity in the observed result, all aspects of the strategy will need to be undertaken satisfactorily (*e.g.*, sampling locations, sample numbers and frequency). If monetary constraints curtail any of these requirements in the current sampling strategy, it is recommended that no sampling be exercised.

Time constraints can often be a limiting factor as well as the number of dedicated personnel. Sampling will need to be conducted over a 24 h or 30 d period to verify criteria exceedances. Analysis of one sample of water at a given time will not suffice in this verification. **This sampling strategy is based on the premise that exposure duration plays a key role in the toxicity response.**

Establishing Background Levels

A substantial quantity of information has been collected on the levels of suspended sediments, turbidity and deposited sediments in British Columbia. In many cases, this information will be useful for establishing background levels of these variables. In many other cases, the necessary data will not be available or the existing data will not be sufficient to accurately determine reference conditions in the stream system under investigation. In both of these cases, it will be necessary to establish baseline conditions prior to the implementation of developmental activities or establish appropriate reference sites in upstream areas or nearby stream systems. It is recommended that several years of background data from the basin or site where management will occur and a similar set of data from comparable, unmanaged site(s) be obtained (MacDonald et al. 1991).

Cost-effective approaches to the collection of information on background levels of suspended and deposited sediments should be used whenever possible. In many stream systems, it is possible to develop quantitative relationships between TSS concentration and turbidity. Such relationships are useful in that they facilitate estimation of TSS levels from measurements of turbidity. This is advantageous because in situ turbidity meters can be used to collect data automatically at fixed intervals, thereby reducing the need for wet chemistry analysis. By coupling such instrumentation with automatic water level monitors, it should be possible to establish relationships between discharges and TSS concentrations. Such relationships are fundamental for understanding sediment transport processes and identifying when non-compliance with the water quality criteria is most likely to occur.

Spatial and Temporal Variability

A variety of spatial and temporal sampling designs may be employed to determine whether anthropogenic activity is causing adverse effects to biota or criteria exceedances. The most common approach is a spatial design used to compare the concentration of suspended sediments in replicate water samples at control and impacted sites, the assumption being that any differences observed are due to the activity release (referred to as operational background levels, Section 2.1.1, Technical Appendix, Caux et al., 1997). As noted by Hurlbert (1996), this design involves 'pseudoreplication' (*i.e*., the control and impacted site replicates are not randomized) and thus the differences observed may be due to factors unrelated to the sediment release of the activity (*e.g*., natural differences in pool/riffle ratios, water chemistry or flow patterns). The same is true for before/after designs at impacted sites.

To deal with these shortcomings, Green (1979) proposed the use of a BACI (Before-After-Control-Impact) temporal design (referred to as pre-operational or historical background level, Section 2.1.1, Technical Appendix, Caux et al., 1997). In this design, samples are taken before and after the disturbance (*e.g*., before and after commencement of operations) in each of the control and impacted sites. Since sediment releases may be cyclical or irregular, sampling is usually conducted at several times both before and after the disturbance. The ideal solution to 'pseudoreplication' is to have replicate control and impacted locations. Replicated impacted locations are highly unlikely in any given field study. There is no reason, however, not to have replicated control locations (Underwood 1996). If pre-release sampling is done, control locations should be representative of the habitat of the impacted site, although they need not be identical. The analysis of variance (ANOVA) approach for this asymmetrical design is described in Underwood (1996).

Spatio-temporal variations need to be minimized and will always leave an element of uncertainty in the design and statistics of the sampling strategy. Approaches can be both parametric, as the design described in Underwood, but are more likely to have an asymmetrical distribution and be non-parametric. For this reason, non-parametric designs that have been successful in environmental monitoring programs are discussed below.

Sampling Design and Statistical Considerations

A variety of land and water uses have the potential to increase the rate of sediment transport in stream systems. While some of these activities are likely to increase sediment production over discrete and relatively short time intervals (*e.g.*, dredging, spawning channel cleaning, etc.), the effects of other activities are likely to be evident for protracted time periods (*e.g.*, forest management). The nature, duration and timing of these activities must be considered in the selection of tools for evaluating their effects on aquatic ecosystems. In this way, the most appropriate methods can be applied to each monitoring application. For example, continuous monitoring of stream turbidity may be required to detect exceedances of the water quality criteria when land use activities occur over protracted periods (*e.g.*, forest management). In contrast, intensive, short-duration sampling of TSS and turbidity may be more appropriate for activities that occur over a short period (*i.e.*, dredging operations).

In designing monitoring programs for evaluating the impacts of anthropogenic activities, it is also important to consider the characteristics of the receiving water system. Some of the key factors that should be considered include, but are not limited to:

- stream size;
- hydrological regime;
- ambient water quality conditions;
- existing land uses;
- existing water uses;
- structure of fish, invertebrate, and aquatic plant communities;
- presence and location of rearing habitats;
- presence and location of spawning habitats; and,
- location of primary access points.

Such information is required to assist in the design of the monitoring program by facilitating the identification of potential reference sites, sensitive habitats, potential treatment sites, and potentially confounding variables. In addition, this information will support the selection of evaluation tools and methods that are most appropriate for the stream system under investigation.

Identification of suitable control or reference sites is a fundamental component of the overall monitoring program design. Generally, these approaches have been used to establish reference conditions relating to sediment transport and streambed substrate composition in stream systems. When possible, it is desirable to establish baseline conditions in upstream and downstream areas prior to, during, and after the implementation of developmental activities. This information provides a basis for desegregating effects related to variable climatic conditions from those associated with the land use activity. When such baseline information is not available, a paired watershed or/and upstream sites can be used to establish reference conditions and provide a basis for comparison with treatment sites.

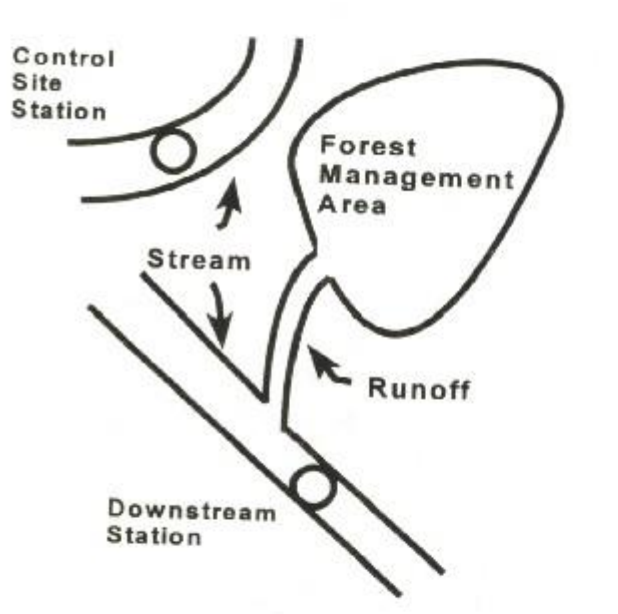
Suspended Sediments and Turbidity

The designs discussed below are to be used for activities that occur over a short period of time. These include, for example, dredging, spawning channel cleaning and construction. When exceedances are suspected from land-use activities occurring over the long term through continuous monitoring, the designs suggested below can also serve in the determination of criteria exceedances.

Statistical considerations are pivotal to the success of monitoring exercises. They are an integral part of the sampling design and should never be introduced following a sampling campaign. The following will outline some of the possible sampling designs that will achieve our objectives. Separate figures assist in the comprehension of individual designs.

Design #1

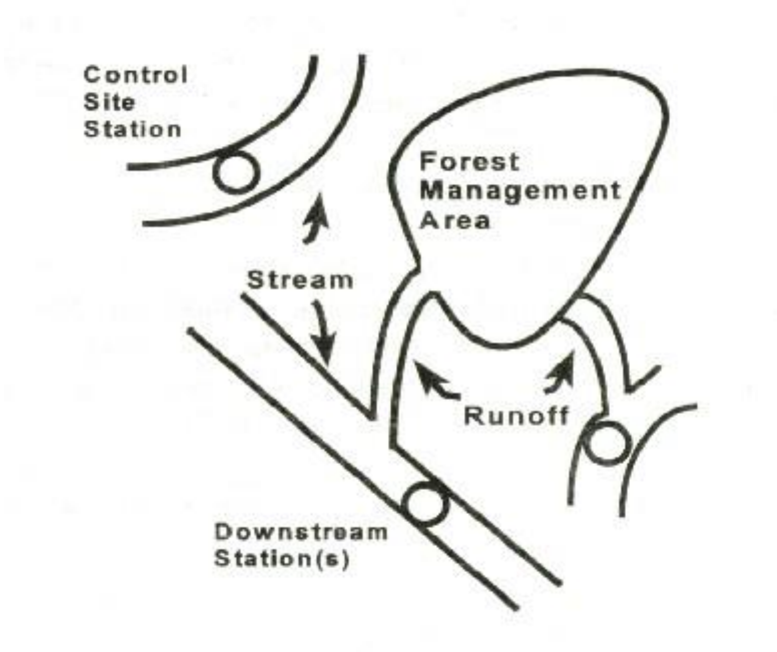
- Test: Mann-Whitney (Wilcoxson)(Snedecor and Cochran 1980)
- Two independent stations, a control site and a downstream potentially impacted site
- Sampling at both sites must be done concurrently
- Two data sets need not be normally distributed
- Moderate number of non detects (N.D.) permitted
- Many samples within station (*i.e*., depth integrated, etc.)
- H_O: two populations drawn from same mean



This design is to be used when one is not sure whether an adequate upstream station can be chosen. This can be due to, for example, the lack of flow, lack of accessibility, or because it is uncertain whether impacts are occurring at an upstream site. This test is similar to the independent-sample t test but non-parametric. The null hypothesis (H0) is that there is no difference between levels at one site at those of the other. The "mean" is this case refers to the central tendency of sample populations.

Design #2

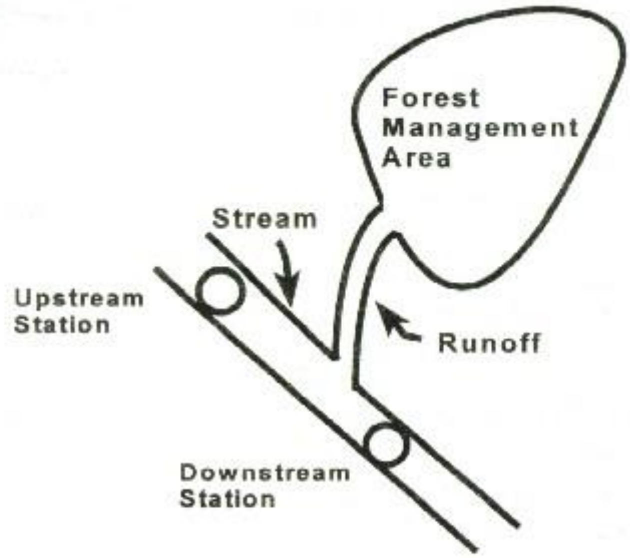
- Test: Kruskal-Wallis (Gilbert 1987)
- Many independent stations, a control site and downstream potentially impacted sites
- Sampling at sites must be done concurrently
- Data sets need not be normal
- Moderate number of N.D. permitted
- Many samples within station (*i.e.*, depth integrated, etc.)
- H_O: many populations drawn from same mean



This design is as above but applies when there are many independent populations. There could be a number of impacted streams where sampling is possible. For example, a forest management area may have many runoffs that are independent of each other.

Design #3

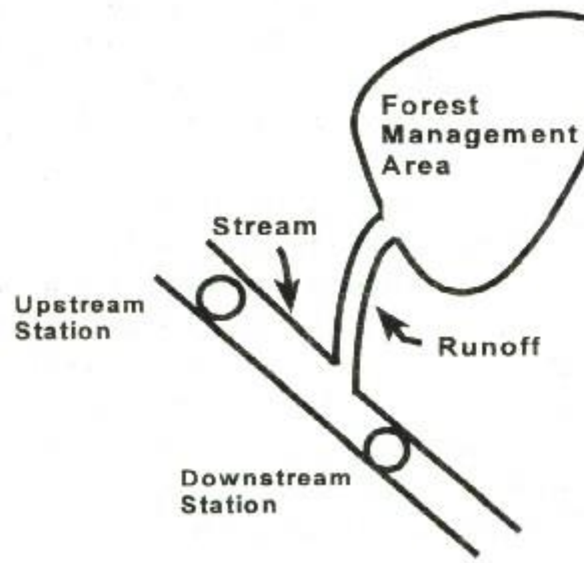
- Test: sign (Grivet 1980)
- Two dependent stations, an upstream control and a downstream impacted site
- Sampling at both sites must be done concurrently every hour for 24 h or every day for 30 days
- Two data sets need not be normally distributed or symmetrical
- A few N.D. permitted
- Can take average of many samples within station (*i.e.*, depth integrated, etc.)
- H_O: the median of the population of all possible differences is zero



Design #3 is the ideal situation to test criteria exceedances. The samples are considered dependent because they are taken on the same stream. Sample populations are made up of hourly samples for 24 hours or daily samples for 30 days. An advantage is that an average value from a depth integrated sample can be taken to represent a sample.

Design #4

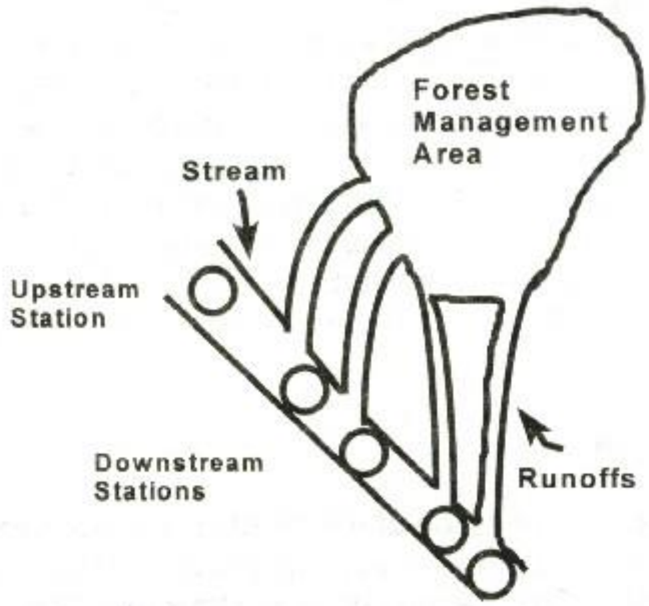
- Test: Wilcoxson Signed Rank (Hollander and Wolfe 1973)
- Two dependent stations, an upstream control and a downstream impacted site
- Sampling at both sites must be done concurrently every hour for 24 h or every day for 30 days
- Two data sets need not be normal but symmetrical
- No N.D. permitted
- Greater power than Sign test
- Many samples within station (*i.e.*, depth integrated, etc.)
- H_O: the median of the population of all possible differences is zero



This design is the same as that above but the distributions between the upstream and downstream sites need to be symmetrical but not necessarily normal. The Wilcoxson Signed Rank test has greater power to find differences in two sample populations than the Sign test.

Design #5

- Test: Friedman (Grivet 1980)
- Extension of Sign test
- Many dependent stations, an upstream control and many downstream potentially impacted sites
- Sampling at sites must be done concurrently every hour for 24 h or every day for 30 days
- Data sets need not be normal or symmetrical
- Moderate number of N.D. permitted, no missing values
- H_O: there is no tendency for one population to have larger or smaller values than any other population



This design is an extension of Design #3 but for many dependent stations through time. It is a very useful test because none of the data need to be normally distributed or symmetrical which is often the case. Samples are dependent because they are taken on the same stream. Such a design can be used on sloped terrain where runoffs are to the same stream.

While utilizing the above tests, it is recommended that field personnel become accustomed to the individual tests. The power of the test, and its limitations should be well known. Since significant differences between population means are sought, with large sample sizes, it is possible that these are below the 24 h criteria levels. Further investigation for the duration of 30 days should then be undertaken.

With the continuous monitoring of streams, investigators will want to report on trends. For example, they may focus their monitoring activity in nearby streams at one (Mann Kendall test) or several stations (homogeneity chi-square statistic) where anthropogenic inputs are suspected. Using the Mann-Kendall trend statistic S for time ordered series, positive or negative trends can me monitored with time. A slope estimator (Sen's nonparametric slope estimator) can be used to calculate the rate with which the trend is occurring. This procedure can assist field personnel decipher through extrapolation when a possible exceedance may occur. Other trend analysis methods are discussed in Gilbert (1987).

The sampling strategy for determining criteria exceedances has the advantage of not being dependent on discharge rates and sediment yields. Measurements are to be taken during clear flows which are usually associated with low flows (see Fig. 2, Section 2, Criteria Document; definition Section 1.1, Caux et al., 1997). It may be necessary, however, to estimate the total suspended sediment yield for a basin to determine whether suspended sediment discharge has augmented between several sampling periods. This would indicate if the water quality is degrading or ameliorating in the long term which could give justification to smaller scale compliance monitoring as discussed above. Methods for estimating total suspended sediment yield with probability sampling are discussed elsewhere (Thomas 1985). Other sampling needs may be to provide an indication of the relationship between turbidity and the mass of suspended sediments.

To establish this relationship! for a sampling location, simultaneous measurements of suspended sediment and turbidity must be made over the full range of expected discharges which controls the size and type of suspended sediments (MacDonald et al., 1991).

Location

For the detection of effects of land use activities, sampling should focus on third order streams or smaller according to the classification by Horton-Strahler (Andersson and White 1996). Second order streams may need to be sampled if third order streams are deemed too far away from the impact area or subject to potential inputs from other land use activities than the one under investigation.

When monitoring upstream and downstream from a site (*e.g*., bridge construction, dredging), with larger streams, depth-integrated (150-220 cm) samples may be taken at three to five transects of the stream and an average composite calculated. With smaller streams one sample in the centre of stream is all that is required. Turbidity samples are to be taken at a minimum depth of 10 cm below the surface with both wet and in situ readings. Sometimes a plume is evidenced from the source of release (*e.g*., municipal waste) and turbidity follows only one of the river banks requiring judgment sampling in order to make the data useful for the intended purpose (Gilbert 1987). Depending on the heterogeneity of the system, many points across a river at many depths may be taken and integrated to reduce the variability in the data (Churchland and Mah 1985).

Timing and Frequency

The only timing requirements for turbidity and suspended sediments are during periods of clear flows (see Relevance to Criteria). It is imperative for this sampling design to be effective that samples be taken during periods of clear flows which incorporate periods of low flow when the background turbidity is both low and consistent (MacDonald et al. 1991). In most lotic systems, for suspended sediments and turbidity, background levels are to be monitored in clear-flow periods. For example, for the North Fork Flathead River near Columbia Falls, clear-flow periods were from June to April of each year from 1975-1978. Clear-flow must not be confused with low-flow periods which gives a smaller window of opportunity for sampling background levels than clear-flow periods. Clear-flow periods are going to be determined on a site-specific basis (clear flows are further defined in Relevance to Criteria). Even though the majority of sediment load in streams is transported during spring freshets and storm events, these high-flow periods have been excluded from the determination of background levels in clear flows due to the extreme variability found in relationships between suspended sediment concentrations and discharge flows (MacDonald et al. 1991). Sampling frequency for turbidity and suspended sediments are every hour for 24 h or every day for 30 days (see Sampling Design and Statistical Considerations).

Substrate Composition

A stepwise process should be used to support the development of streambed substrate monitoring programs in forested watersheds in British Columbia. The first step in this process is to collect and evaluate the existing information on the watershed and nearby watercourses. Where possible, key types of information (*e.g.*, location of spawning habitats, etc.) should be included on maps of the watershed (*i.e*., at an appropriate scale). The areas that are likely to be affected by the land use activity should also be identified on the watershed map(s). Together, this information will provide a basis for identifying the areas that are likely and unlikely to be affected by the land use activities. As such, it should entail sampling sites for control and treatment areas.

The second step in the process involves conducting a preliminary reconnaissance to identify suitable sampling sites in the vicinity of each potential sampling site. Sampling sites for evaluating streambed substrate composition should be located in a depositional area that contains suitable salmonid spawning habitat (*i.e.*, water depth of less than one meter; water velocity of 10 to 75 cm/sec; Knapp et al. 1982). Importantly, the water depth, velocity, gradient and channel configuration should be measured and be similar at all of the sites selected (*i.e*., to minimize differences between control and treatment sites). All sites should be marked permanently above the high water mark and pinpointed using GPS (global positioning system) technology (*i.e.*, to identify the latitude and longitude of the site precisely).

Streambed substrate composition varies significantly within and between sampling sites, even under natural conditions (MacDonald and MacDonald 1987). Therefore, it is essential to design the sampling program such that it is possible to differentiate between natural variability and treatment effects. Spatial variability should be evaluated by establishing a minimum of three to four sites within the control area and within each treatment area. Cross-sectional variability should be evaluated by collecting at least four streambed substrate samples at each sampling site (*i.e.*, at equally spaced locations along a transect that is established at the site, perpendicular to flow). Temporal variability should be evaluated by collecting samples in the late summer or early fall and again in the spring prior to freshet. As changes in sediment transport associated with forest management activities can occur over a number of years, it would be advantageous to conduct monitoring prior to the initiation of activities, during timber harvest, and during the recovery period.

Bedload Sediments

The general approach to designing monitoring programs for streambed substrate composition should also be used to design bedload sediment monitoring programs. That is, potential reference and treatment sampling sites should be identified using the general information that has been compiled on the watershed. Subsequently, preliminary reconnaissance should be conducted to identify suitable sampling sites within each potential sampling area. It is essential to select sites for bedload sediment sampling in reference and treatment that have similar water depth, velocity, gradient, and channel configuration. Information on these variables should be collected when the sampling equipment is deployed and retrieved.

Because bedload transport is dependent on the hydraulic energy of the stream, there is likely to be substantial temporal and spatial variability in measurements of bedload composition and yield. For this reason, it is essential to design monitoring programs that can distinguish natural variability from treatment effects. Such designs require appropriate designation of reference and treatment areas, sampling of multiple sites within each area to evaluate spatial variability, replicate sampling to evaluate cross-sectional variability, and time series sampling to evaluate temporal variability and trends. As with the other types of sampling, it is essential to consider the nature, duration, and areal extent of land use activities while designing the monitoring program.

Sampling Method and Analytical Measurements

Turbidity Sampling

Several different techniques for turbidity measurements have been described (Allen 1979; Environment Canada 1979; Gippel 1995; Rex 1997). The photoelectric turbidimeter (*e.g*., a range of Hach instruments) should monitor turbidity ranges of 0.02 to 2000 NTU from 0 to 30 degrees C . Standard calibration range in NTU are for example from 0 to 500 NTU at 0 to 2.5 or 0 to 5 volt return. Other instrument requirements, potential error in measurements and maintenance procedures on turbidimeters are given by Andersson and White (1996), Gippel (1995) and Jordan (1996). The potential sources of error include biofouling (Jordan 1996), calibration drift (Gippel 1995), physical fouling, noise (*e.g.*, bubbles, electronic interference), power-up transients and water temperature changes (Jordan 1996; Andersson and White 1996). Technologies exist, however, to circumvent some of these problems (Rex 1997).

Wet samples taken by hand or with an trigger device (*e.g.*, Kemmerer sampling device) can be brought back to the laboratory and measurements must be made within a two hour time period following sample collection. Field portable apparatii, however, are preferred (manual or automated). Data quality objectives are plus or minus 2 NTU from the wet sample or portable meter value (Andersson and White 1996). With automated systems, field blanks may be necessary.

Turbidity Measurements

The most reliable method for determining turbidity is nephelometry (light scattering by suspended particles) which is measured by means of a turbidity meter giving Nephelometric Turbidity Units (NTU). Other methods giving Jackson Turbidity Units (JTU) or Formazin Turbidity Units (FTU) are available but have limitations or are not widely utilized. A nephelometer, much like a spectrophotometer, sends a beam of incident light through a water sample. Photo-electric cells in the instrument measure the light that is reflected at right angles to the sample. Presuming that all measures of scattered light in the sample are equal, light scattered perpendicularly will be a proportional measure of all scattered light and hence the turbidity of the sample. Nephelometers are available to take turbidity measurements in the field. Should water samples be taken back to the laboratory, they should be stored in the dark and measures taken within a 24 h period to avoid biodegradation, pH changes and settling of particles which will give misleading results. Environmental samples will vary within the normal range of 1 to 1000 NTU (Chapman 1992).

Suspended Sediments Sampling

There are a number of different automatic and hand held samplers that can collect suspended sediments (US Geological Survey 1977; Siegel 1985; Asper 1988; Scrudato et al. 1988; Thomas 1985). Suspended sediments are by definition different from bedload, the former being suspended and the latter rolls along the beds of streams and rivers. When flow is turbulent, saltation (bouncing of particles) can take place with the effect of blurring the distinction between the two phases (MacDonald et al. 1991). Thus, it is recommended to collect suspended sediments during clear flows (see Section 1.1) when the two phases are naturally distinct. Water samples can either be collected in bottles by grab sampling manually (in small or large streams), using Kemmerer type devices (in large streams or rivers) (Miles 1995), with the use of sampling pumps (Churchland and Mah 1985) or sediment traps (Asper 1988). These techniques are discussed below. Depth-integrated sampling is discussed elsewhere in publications of the Water Survey of Canada which uses the methods by the US Geological Survey (1977).

Small 250 ml glass (preferably amber) or plastic bottles (preferably opaque PVC) are to be used for manual sample collection. In small streams, lids are removed at the desired depth, recapped, and brought to the surface. A preservative (0.04% $CuSO4$) may be added if the samples are not immediately stored in the dark to curtail algal growth.

In larger systems where samples at deeper depths are required, a Kemmerer device may be utilized. This is an opened plastic or metal tube of different dimensions with two spring loaded stoppers at each end. A messenger is sent to trigger the release mechanism for the rubber stoppers which traps a volume of water inside the tube. Upon retrieval of the apparatus, it is recommended to shake its content prior to subsampling for the required 250 mL sample necessary for analysis. Other equipment such as single stage samplers and automated samplers triggered by increases in flow can also be used (Rex 1997).

Sampling pumps are often used to facilitate the collection of sampling. At the onset of experimentation, they will take more time to set up; for monitoring a station in the long term at several transects and depths within a river, however, they are indispensable. A peristaltic pump apparatus is described by Churchland and Mah (1985). Sediment traps are also useful to collect settling particles. It is required that a sampler collect particles in proportion to the product of their abundance and their sinking speed (Asper 1988). Settling particles are part of suspended sediments. In anthropogenically induced events, the difficulty is to distinguish these from background settling particles (see Establishing Background Levels). The most direct method available is the particle interceptor trap or sediment trap which ideally is a collection of cylinders that act as receptacles for the settling particles. Deployment strategies and measurement error are discussed by Asper (1988) and Rex (1997).

Depending on the heterogeneity of the system, several transects and depth-integration may be required. Spatial variability is evidenced through an increase in suspended sediment levels as one gets closer to the bottom and with non-uniformity in the size and concentration of suspendent sediments across a stream or river depending on the local turbulences and velocities in the system (MacDonald et al. 1991). Furthermore, once an integrated sample has been collected, the whole water sample should be used in the analysis of non-filterable residue to give accurate estimates of total suspended sediment concentration (Churchland and Mah 1985).

Suspended Sediments Measurements

Suspended matter is measured in the laboratory by both filterable and non-filterable residues of a water sample. Undissolved particles make up the non-filterable residues, these varying in size from approximately 10 nm to 0.1 mm in diameter, although it is usually accepted that the suspended solids are the fraction that will not pass through a 0.45 micron pore diameter glass fiber filter. For the purpose of deriving water quality criteria, this solids fraction, containing both biotic and abiotic components, will be referred to as total suspended sediments with the unit of measure being in micrograms/L. A sediment particle grade scale developed by the American Geophysical Union Subcommittee on Terminology and the settling velocities of these particles in water (Cooke et al. 1993) will be used as standard sediment terminology for criteria development (see Criteria Document, Table 1, Caux et al., 1997).

Non-filterable determinations must be made within the shortest period of time from sampling. If long periods of time are unavoidable, a quality assurance check is recommended to verify if aliquots of a larger initial sample (lightly shaken at 4 degrees C, kept in the dark), retain a constant suspended sediment level. Analytical methods for non-filterable residues are described in detail elsewhere (Environment Canada 1979; Churchland and Mah 1985; Greenberg 1981). Briefly, this consists of filtering the 250 ml sample through a preweighed 0.45 micron glass fibre filter under vacuum, drying the filter at 105 degrees C for 150 min and reweighing the filter to obtain the mass of non-filterable residue. Thus, the concentration of filterable residues in mg/L will be equal to 1000 times the difference in filter weights over the whole sample volume in mL.

Substrate Composition Sampling and Analytical Measurements

Several methods have been developed for collecting streambed substrate samples, including freeze-core samplers, pipe-dredge samplers, pipe samplers, McNeil-Ahnell samplers and gravel-cutter samplers, excavators and contact samplers (Yuzyk 1986; Rex 1997). The characteristics of the stream system under investigation (*e.g.*, water velocity, depth, particle size distribution, etc.) and logistical considerations (such as distance from access point) will dictate which method is most appropriate for a specific application. Hollow core samplers, such as the McNeil-Ahnell sampler, have proven to be useful for evaluating changes in streambed substrate composition in areas affected by logging and mining activities (Weaver and White 1985; MacDonald and MacDonald 1987). The main advantages of this type of sample are portability and ease of use. Freeze core samplers have also been used extensively in evaluations of streambed substrate composition, particularly when access to the site is not difficult (Rood and Church 1994; Rex 1997). Excavation techniques (*i.e.*, backhoes, etc.) are typically used in larger river systems, where application of the other methods is impractical.

Using a hollow core sample, a streambed substrate sample is collected by working the corer into the substrate (to a depth of 20 cm) and extracting the material within the core. This material should be collected in heavy-duty plastic bags and appropriately labelled. Evaluation of the results obtained from a number of studies indicates that 5 to 10 kg samples should be collected from each core to obtain reasonable estimates of substrate characteristics (Shirazi and Seim 1979). Because this type of sampling tends to disturb the fine materials contained in and on the streambed substrate, the water in the corer must be sub-sampled to determine the quantity and particle size distribution of mobilized fine sediments (MacDonald and MacDonald 1987; Rex 1997). At the laboratory, the streambed substrate samples and intracorer water samples are dried and shaken through a geometric sieve series, with mesh sizes ranging from 0.063 mm to 128 mm. The materials captured on each sieve and that passing through the smallest sieve should be weighed to the nearest 0.1 g (MacDonald and MacDonald 1987). The percent of the sample finer than each sieve size is then determined and incorporated into log-probability plots. These plots are then used to calculate the required substrate statistics (*e.g.*, % less than 2.00 mm, % less than 6.35 mm, Dg, and fredle number). Freeze-core sampling methods are described in Yuzyk (1986) and Rex (1997).

Bedload Sediments Sampling and Analytical Measurements

Methods for accurately measuring the concentrations and yields of bedload sediments in stream systems are not well established. Nonetheless, a number of procedures have been developed that provide information on relative bedload transport rates within a stream reach. Techniques that rely on the deployment of infiltration bags and gravel buckets integrate bedload transport over a pre-defined sampling period and, thereby, capture event-driven increases in bedload movement (Rex 1997). By carefully applying these methods in both treatment and control areas, it should possible to determine if land use activities have altered bedload transport rates. It is important to note that these methods also capture smaller-sized particles that are typically associated with suspended sediments (*i.e*., wash load). Therefore, it may be necessary to calibrate the results to estimate the bedload fraction (*i.e*., by discarding the fraction less than 0.25 mm in diameter; Sidle 1988).

Deployment of infiltration bags and gravel buckets involves similar procedures. After identifying suitable sites, a hole is excavated in the stream bed to a depth of greater than 30 cm. The diameter of the hole should be at least 10 cm wider than the diameter of the bag or bucket that is to be installed (Rex 1997). The infiltration bag or gravel bucket is then placed in the hole and the hole is backfilled with the parent materials from the streambed. In both cases, the apparatus is filled with reference gravel until it is flush with the surrounding bed material.

After the pre-determined time interval, the infiltration bags and gravel buckets are retrieved from the streambed. The samples can be coarse screened on site to remove the reference gravel or transported to the laboratory for analysis. In either case, the samples are dried and shaken through a sieve series that facilitates particle size distribution analysis (*i.e.*, 0.25 mm to 16 mm; Rex 1997). The percent of the sample finer than each sieve size is then determined and incorporated into log-probability plots. The total quantity of fine sediment and the particle size distribution at control and treatment size can then be compared using appropriate statistical tests.

Comparing Monitoring Results to Criteria

For turbidity, suspended sediments and bedload, the comparison between a monitored change in a level and the prescribed criteria is straightforward. When a statistically significant change is observed as described throughout this document, there is a criterion exceedance. This logic does not apply, however, for a fixed criterion such as substrate composition.

If the one of the substrate composition criteria has been exceeded, the lower confidence limit from the monitoring result mean should not encompass the criterion. If either the lower or upper confidence intervals encompass the criterion value, it is recommended that more samples be included in a new sampling campaign. Increasing the number of samples should reduce the confidence intervals attesting to the fact that an exceedance has occurred. If the confidence intervals still encompass the criterion, the exceedance is probably marginal. Whether this result is stated to be an exceedance of the criterion, becomes a management decision.

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