Guidelines for Designing and Implementing a Water Quality Monitoring Program in British Columbia

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FIELD TEST EDITION

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1. Introduction

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This manual presents guidelines for preparing the experimental design of fresh water monitoring programs. It is intended to be used prior to use of the `*Sampling Protocol Series*'[1] (Cavanagh *et al.*, 1994a,b,c) and the `*Guidelines for Interpreting Water Quality Data'* (Cavanagh *et al.*, 1998). Reports prepared in this series provide the minimum requirements to ensure that the sampling program (investigation) effectively addresses all concerns regarding potential impacts to a fresh water body. This is accomplished through the development of a structured approach to program design that can be widely applied. Given the high degree of variability of both the impact sources and the environment, this manual is limited to general guidance rather than hard and fast rules.

The manual is intended to provide assistance to BC Environment staff, forest specialists, water specialists, consultants, or those under a requirement to undertake a sampling program for the Ministry of Environment, Lands and Parks.

Accurate, reliable data are essential for determining trends in water quality, evaluating whether designated water uses are being impaired, and assessing whether the applicable water quality objectives are being met.

1. Ambient Fresh Water and Effluent Sampling Manual

Lake and Stream Bottom Sediment Sampling Manual

Biological Sampling Manual

An effective monitoring program should be designed to accomplish combinations of or, in some circumstances, all of the following:

· delineate and identify sources of natural variability and define the limits of this variability;

· provide data leading to an accurate assessment of the state or health of the aquatic ecosystem(s);

· portray trends in water quality and provide warning of abnormal changes or conditions that might be damaging to the aquatic environment and associated species;

· identify the potential agent(s) of any abnormal change that is detected; and,

· identify the locations within the watershed that are most sensitive to abnormal changes or conditions.

Given these requirements, the program designer must:

· adopt the operational responsibility of developing and implementing a program;

· be aware of the necessity to consider normal variation and strive to delineate the limits of this variation for the watershed under consideration;

· be aware of current and proposed activities that have the potential to abnormally alter water quality;

· recognize symptoms and diagnose abnormal conditions; and

· be capable of analyzing and interpreting data.

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2. Program Purpose

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Monitoring programs often involve a series of repetitive measurements for the purpose of detecting immediate or long term change. Monitoring programs in British Columbia are arbitrarily classified here in one of the following four categories:

· Compliance monitoring,

· Trend monitoring,

· Impact assessment monitoring, or

· Survey monitoring.

It should be noted that the information from each of these categories is obtained specifically for the needs of that particular category. However, data from some categories may be useful for other categories.

2.1 Designated Water Uses

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Monitoring programs in the province of British Columbia are generally initiated to determine if any designated use for a particular water body is impaired. Designated water uses are a function of the human activities within a given watershed and the requirements of the local terrestrial and aquatic biota. They are generally defined as those human and non-human requirements of a water resource. It is necessary to include a discussion of water uses in these guidelines because it is often the most sensitive water use designation within a watershed that directs the monitoring design. The sensitive uses identified for water bodies in British Columbia include (in order of decreasing sensitivity for most variables); aquatic life, drinking water (including food processing), recreation, irrigation, wildlife watering, livestock watering, and industry. A single water body can have multiple water use designations, however, a monitoring program is typically designed to determine if anthropogenic activities are affecting the most sensitive designated use.

The utility of sampling a specific water quality variable (such as a particular metal concentration or water temperature) differs for each designated water use. The document "Approved and Working Criteria for Water Quality" (Nagpal *et al.*, 1997) provides most of the criteria for many of the designated water uses.

The most recent edition of this document should be referred to when designing a water quality monitoring program as it is essential that the most sensitive designated use for a specific variable be considered as the benchmark when analyzing for that variable. The use designation of "protection of aquatic life" (which refers to more than fish) is applied to most water bodies in British Columbia. Water bodies from which water withdrawals are made for the purpose of providing domestic water supplies are given the designation `drinking water'. This designation is also particularly sensitive. For some water quality variables (i.e., microbiology, turbidity) it is the most sensitive or tied with other water uses as the most sensitive. Water bodies from which withdrawals are made for specific activities are given water use designations that are associated with those activities. For example, water withdrawals made for agricultural purposes would result in water use designations of `livestock watering' and/or `irrigation'.

2.2 Monitoring Classifications

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2.2.1 Compliance monitoring

Compliance (or attainment) monitoring is used to determine if water quality objectives or permit conditions are being met. Objectives are site-specific and outlined in provincial documents called "*Water Body Name*. Water Quality Assessment and Objectives". In some cases, the objectives for a particular water body are more restrictive than the provincial criteria demands for some variables. This can happen when baseline data have demonstrated that background levels of these variables are lower than criteria and therefore, the objectives are set to reflect the natural conditions. Conversely, naturally higher concentrations than criteria can lead to water quality objectives that are less restrictive. Since objectives documents usually define the variables, site locations, sample frequency, and method of measurement, compliance monitoring is generally the least difficult to design. The primary concerns in the design phase therefore becomes limited to allocating the budget appropriately and ensuring that the personnel undertaking the work are suitably trained.

Compliance monitoring is also a component of permit obligations. Industries or municipalities that discharge liquid waste are issued a government permit that specifies the maximum allowable concentrations of particular variables in both the effluent and possibly in the receiving waters. Through the permit, the permitees can be directed to sample effluent and ambient waters at specified sampling frequencies. Once again, many of the design aspects of such monitoring programs have been defined within the permit.

There are general formats that are followed for many compliance monitoring programs. For example, there may be a requirement to sample at a minimum frequency within a given time frame (e.g., five times within 30 days for bacterial sampling at swimming beaches). Or, sampling effort might reflect the time of year that the objective is most likely to be exceeded, otherwise known as the `critical period' (typically periods of low or high stream flow). The most intense sampling should occur at locations most likely to exceed the objective.

2.2.2 Trend monitoring

Trend monitoring is used to detect subtle changes over time that may result from a potential long-term problem. Measurements are made at regular time intervals to determine if long-term trends are occurring for a particular variable. Examples would be the measurement of pH or ions to determine the severity of impacts that acidic precipitation might be having on several water bodies over a defined geographic region, or the effects of climate change on water chemistry.

Trend monitoring is a commitment that extends over a long period (i.e., usually 10 years or more) to ensure that true trends are detected. It is essential that the program minimizes variability through time. Therefore, as much as possible, the program should remain consistent in terms of frequency, location, time of day samples are collected, and the collection and analytical techniques that are used.

Lakes are less likely to exhibit the same degree of short term temporal variation as rivers. Consequently, lakes are in some ways more suited for long-term trend assessments. Lakes act as natural collectors of atmospheric deposition and are also integrators of all the inputs within the watershed. Therefore, they are also ideally suited for assessments of whole watershed activities (upstream from the lake). Lakes also act as sinks for suspended materials and therefore, analyses of sediments can be ideal for determining both historical (core samples) and ongoing (repeated grab samples over the duration of a monitoring program) long-term trends. It must be noted however, that lakes do exhibit spatial variation over the year as they stratify and de-stratify. Typically, spring and fall overturn periods produce relatively homogeneous conditions throughout the water column and therefore, these are good periods to sample for long-term trends.

2.2.3 Impact assessment monitoring

Impact assessment monitoring measures the effects on water quality of a particular project (anthropogenic) or event (natural). Projects, in this case, refer to anything associated with industrial activities, resource extractive activities, impoundments (dams), agricultural activities, and urban or recreational developments. Events refer to fires, floods, land slides, volcanic activity, etc.

An ideal impact assessment monitoring program is one that has both test and control sites, is initiated prior to project start-up, continues while the project is operational, and extends for a defined post-project time period. In the case of anthropogenic impacts, it is ideal that the monitoring program be initiated prior to the start-up date of the proposed project. In this case, a baseline (pre-operation/treatment) assessment is carried out which can provide data to which post-treatment data can be compared, and allow for better estimates of the limits of normal variation. The baseline or pilot information should include an inventory of the existing ecosystem components (aquatic and terrestrial flora and fauna) and water uses in the project area.

When baseline information is not collected, an upstream (or reference) site is the next best option. These post-treatment-only studies are less robust in that they do not consider the local normal variability as effectively as a study that includes pre-treatment information.

2.2.4 Survey monitoring (inventory)

Survey monitoring is used to characterize existing water quality conditions over a specified geographic area. As such, it is more of an inventory rather than a true monitoring process because it does not address changes over time. It is often conducted within watersheds that have not been previously sampled and which are so remote that there exists little or no direct anthropogenic activity. It is generally carried out in a limited manner (once or twice per lake or river) unless the resulting data promote cause for concern. Consequently, this type of inventory occasionally serves as the first step towards establishing one of the above, more extensive monitoring programs.

An example of a survey monitoring program was carried out in the early 1980's by BC Environment. To determine (on a provincial perspective) resources potentially at risk from distant industrial activity via diffuse acidic inputs, a large number of lakes in the province were sampled from float planes. Surface water chemistry samples were collected at the center of each lake. These data made it possible to map the lakes in the province that are potentially sensitive to acidic inputs. One major shortcoming of this type of monitoring is that only those lakes large enough to allow a plane to take-off or land are surveyable. However, a general province-wide `picture' was obtained in a short time period through the use of this monitoring strategy. A second example is data collected by Fisheries Branch lake inventory staff as part of a long-term effort to characterize lakes of the province for their fisheries resources.

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3. Quality Assurance and Quality Control

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The Definition of quality assurance (QA) accepted by the Canada - British Columbia Water Quality Monitoring Agreement is "a system of activities whose purpose is to provide the producer or user of a product or service the assurance that it meets defined standards of quality with a stated level of confidence" (Taylor, 1987). Separate QA programs exist for both the field sampling procedures (collection, preservation, filtration and shipping components) and analytical procedures (laboratory component). Therefore, QA is essentially the management system that operates to ensure credible results. The quality control (QC) component of this system is a set of activities intended to control the quality of the data from collection through to analysis. It consists of day-to-day activities such as: the adherence to written protocols; up-to-date and suitable training of personnel; the use of reliable, well maintained and properly calibrated equipment; the regular use of QC samples (blanks, reference samples, spikes and replicates); and, diligent record keeping. Quality assessment is an evaluation process that focuses on the quality of the data measurements. It attempts to identify introduced variability (sampling and analytical) through estimates of accuracy, precision, and bias. Together, quality control and quality assessment operate as a feedback system throughout the duration of the sampling program to provide early warnings of dubious data. Additionally, this feedback is the primary tool to determine if the current monitoring effort (i.e., site locations, sample frequency, selected variables) meets the program objectives.

The prime objective of the field QA program is to maximize accuracy by reducing introduced variability. Accuracy is the degree of agreement of a measured value with the true value of the quantity (variable) of concern (Csuros, 1994). Both random and systematic errors are factors that reduce accuracy and therefore, these errors must be minimized. Random errors refer to the precision (or random variation) of the data, while systematic errors refer to bias (or systematic deviation) in the data (Keith, 1991). Precision describes the degree of mutual agreement among repeated individual measurements under the same condition. Imprecise data is primarily the result of inconsistent field techniques and lab analysis, and the introduction of contaminants. Therefore, the best means of ensuring high precision is to maintain consistency during the sample collection, filtration, preservation and analytical processes. Bias describes a repeated skewed error in the measurement. An example of bias would be data values that are repeatedly higher (or lower) than true values due to the use of equipment that has been calibrated incorrectly. Other sources of bias include: unrepresentative sampling; instability of analyte (variable) over time; interference (such as temperature effect); and contamination from any number of sources. Accurate samples are ones, therefore, that exhibit high precision and low bias. An appropriately designed field QA/QC program (Section 3.1) will operate to maximize precision while minimizing bias (for the sampling portion of the program).

It must be stressed at this point, that the range of anthropogenic and natural inputs, and the variability of physiogeographic conditions, simply preclude the development of an optimal water quality monitoring program on the first attempt. Both natural and introduced variability requires that the development of each new monitoring program be considered an iterative process. Iterative cycles are required to establish and refine the program. It is unrealistic to expect that the selection of variables, sampling locations, and sampling frequency will be optimal from the program outset. Feedback loops are critically important as a quality assessment technique for the design and execution of monitoring programs. Therefore, ongoing analysis of data is essential [see the RIC publication `*Guidelines for Interpreting Water Quality Data* (Cavanagh *et al.*, 1998)]. The information obtained from regular analysis of data dictates where program resources should be directed in the future. The ability to adapt the program to conditions and variability found in the field ensures efficiency and quality of data collection efforts. **A monitoring program should never be considered a static, fixed process**.

3.1 Design of the QA/QC program

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The field quality assurance (QA) program is simply a series of basic precautions that are necessarily obeyed if the program is to be a success. These precautions are generally a matter of ensuring that the field staff maintain consistency and that they are diligent while in the process of collecting, preserving, filtering and shipping samples. Refer to the `*Ambient Fresh Water and Effluent Sampling Manual'* (Cavanagh, *et al.*, 1994a) for a full review of the QA component of any sampling program.

The program design must incorporate appropriate quality control (QC) techniques for minimizing potential imprecision and bias in the data. Once again, diligence and consistent adherence to protocols are the best means of reducing both these forms of errors. Recall, for example, that bias in water quality studies can be introduced through various mechanisms (poor equipment calibration, unrepresentative sampling, instability of analyte, interference, and contamination). The first four of these mechanisms can be dealt with by ensuring strict adherence to the sampling protocols [see `*Sampling Protocol Series*' (Cavanagh, *et al.*, 1994a,b,c)]. Equipment must be regularly calibrated as specified by the manufacturers instructions. Unrepresentative sampling will be mitigated if sample collection techniques are thorough. The instability of analyte (or variable) is dealt with through appropriate filtration and preservation. Interference would be addressed through appropriate preservation and documentation of site conditions (i.e., temperature measurements). The fifth mechanism discussed above (that influences both precision and bias), contamination, is a more complex problem to address. The major sources of contamination include:

· contamination by field staff during sample collection,

· contamination from the sampling device,

· contamination from the preservative,

· contamination from the sample bottle, and/or

· contamination during sample processing such as from atmospheric deposition during filtering and preserving.

The use of QC samples is the prime means of identifying the stage in the process during which the contamination was introduced. There are different forms of QC samples. Field blanks and replicate samples are specifically intended to detect contamination introduced throughout the sampling component of the program. Spiked and reference samples are intended to detect contamination introduced during the analytical process (lab component of the program). These samples are discussed in greater detail in Section 3.2 of this guideline.

Potentially, as much as 35% of the program budget can be allocated to these QA/QC measures. As a general rule, all new monitoring programs should incorporate rigorous QA/QC until a consistent, acceptable level of data quality has been demonstrated. The standard for program variability requires that analytical variance be less than 4% of the observed variance in the concentrations of the selected variables, and that the sum of the sampling variance plus analytical variance be less than 20% of the observed variance. See Clark, *et al.* (1996) for a discussion of how the different forms of variability can be estimated. Once data quality is assured, a less rigorous (less costly) QA/QC program can be adopted. The initial amount allocated will ultimately depend on one or more of the following:

· Level of experience of the field staff and familiarity with the analyzing laboratory. When both the lab and field staff are unfamiliar to the program designer, then funds directed towards QA/QC should be divided equally between the two (17.5% each). Conversely, if either has demonstrated consistency and reliability in the past, then funding requirements can be decreased for that component (to about 5% each).

· The type of program. Impact assessment and survey (or baseline) monitoring generally require more QA/QC funds than compliance and trend monitoring. Compliance monitoring is usually conducted as an extension of an existing monitoring program. Consequently, previous QA/QC efforts have established a satisfactory degree of accuracy and precision. For trend monitoring, there usually is more consistency in the field techniques, personnel, and laboratory analytical techniques.

· State of the aquatic environment. There is no need to invest significant funds for QA/QC when the values obtained for particular variables are consistently well above the minimum detectable limit (MDL) or conversely, well below levels of concern for defined water uses. When values are well above the MDL, a false positive is highly unlikely, and therefore the funds might be of better use if directed elsewhere (e.g., towards more frequent monitoring). When the water body exhibits no evidence of unusual concentrations of water quality characteristics (i.e., values are well below the level of concern to protect the designated water uses) then a portion of the budget might be of better use when allocated to a separate program (i.e., a different watershed that is of higher priority).

3.2 Descriptions of common QC samples

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The full description, application and protocol of the major kinds of QC samples are presented in the `*Sampling Protocol Series*' (Cavanagh, *et al.*, 1994a,b,c). An abbreviated description is presented here.

3.2.1 Blanks

Blanks may be of paramount importance in the event that erratic results are obtained. Blanks may identify unsuspected contaminants associated with de-ionized water purity, improper cleaning procedures, preservatives, samplers, filters, travel, sampling technique or air contaminants that may have been sorbed by the samples during collection. Blanks are classified as:

· **Trip blanks** are meant to detect any widespread contamination resulting from the container or preservative during transport and storage.

·**Field blanks** are exposed to the sampling environment at the sample site and handled in the same manner as the real sample (e.g., preserved, filtered). Consequently, they provide information on contamination resulting from the handling technique and from exposure to the atmosphere.

·**Equipment blanks** are samples of de-ionized water that have been used to rinse sampling equipment. This type of blank is useful in documenting the effectiveness of the cleaning or decontamination of equipment.

·**Filtration blanks** (or rinsate blanks) are de-ionized water that has passed through the filtration apparatus in the same manner as the sample. Analysis of the filtrate provides an indication of the types of contaminants that may have been introduced through contact with the filtration apparatus. Filtration blanks are also used as a check for potential cross-contamination through inadequate field filtration/cleaning techniques.

3.2.2 Spiked samples

Spiked samples for each variable being tested can be prepared by spiking aliquots of a single water sample with pre-measured amounts of the variable of interest. An aliquot of the same sample is left un-spiked. The difference in the analytical results between the two samples should equal the theoretical spike addition. The information gained from spiked samples is used to reveal any systematic errors (or bias) in the analytical method.

3.2.3 Reference samples

Reference samples are used to document the bias and precision of the analytical (laboratory) process. There are two types of reference samples. The choice as to which reference sample is selected depends on the expected concentrations being measured, and whether comparable concentrations are available in existing reference samples.

The first, and simplest type of reference sample, is provided by a laboratory that is not involved in the analysis of the `real samples'. This independent laboratory prepares a reference sample by adding a known quantity of the variable of interest to given quantity of pure water (this allows for a calculated concentration and verifies the concentration by analysis). Aliquots of this bulk sample are then submitted to recognized laboratories for analysis to obtain a mean concentration and standard deviation. The values for the calculated concentration, the mean concentration and the standard deviation are provided with the sample.

The second type of reference material is a certified reference sample. It is obtained from a scientific body such as the National Research Council. The sample is an aliquot of a very large batch sample that was collected from one place at one time. The batch sample has been preserved to ensure stability of the certified variables, and has been subjected to analysis by a large number of independent laboratories using several different analytical techniques. Consequently, the distributing agency can provide a mean value and confidence interval for the variable of concern.

Laboratories will use certified reference samples for their own QC. However, when implementing a monitoring program, it is desirable to submit additional reference samples `blind' to the analyzing laboratory so that the reported value obtained under routine analytical conditions can be compared to the `true' value. Reference samples can be submitted non-blind, but these samples will usually receive special attention and represent the best quality that the laboratory is capable of producing. Simultaneous submission of multiple samples of the same reference batch yields the laboratory precision.

3.2.4 Replicate samples

Replicate samples (usually duplicates - as a minimum) are often collected at one or more sites to assess precision of the entire program (field and laboratory components). Replicate measurements on a single sample (normally every 20th sample) or the use of multiple submissions of spike or reference samples yields the laboratory precision. Replicate field samples collected in quick succession yields the field laboratory precision. Consequently, the subtraction of the values for laboratory precision from the values obtained for field and laboratory precision yields the field precision. The use of replicates for this purpose assumes that the variability among replicates is affected by the sampling method or technician. In most cases natural variability (heterogeneity) between samples collected in close succession at a single point will be low. The pilot study should assess short-term variability to confirm that this is the case for all sites.

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4. Recommended Steps For the Monitoring Program Design

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The most essential task in designing any monitoring program is to ensure that it provides a true measure of the conditions of the ambient aquatic environment (whether it be the water, sediment and/or the biological component). To accomplish this, representative samples must be obtained. The term representative means that the sample resembles the population of all possible samples. To achieve representativeness for data comparability and consistency, it is necessary to **standardize** sampling as it relates to program objective formulation, QA/QC data quality criteria (discussed earlier in Chapter 3), statistical considerations, variable selection, site selection, sampling frequency, sample collection techniques, sampling devices, sample handling, sample preservation, and sample identification. Program objective formulation, QA/QC data quality criteria, statistical considerations, variable selection, site selection and sampling frequency are design components outlined in this guideline manual. The other five standardized components are presented in the `*Sampling Protocol Series* '(*Ambient Fresh Water and Effluent Sampling Manual, Lake and Stream Bottom Sediment Sampling Manual, and Biological Sampling Manual*) (Cavanagh *et al.*, 1994a,b,c).

The quality of data collected from a water monitoring program will be largely dependent upon the considerations given to each level in the planning of the data collection network. The program must be designed to address specific concerns, particularly during those periods when the potential impacts are greatest. The outcome must be statistically testable and yield reliable and quantifiable results. If the monitoring program is properly designed and is fully replicable, then the data analysis will yield specific conclusions with an identified level of risk.

MacDonald *et al.* (1991) introduced a flow chart of the general steps associated with the water quality monitoring design (Figure 1). The major components of this process are outlined in the following sections with specific reference to their application to BC Environment.

Appendix A provides a framework for developing a water quality monitoring program. The framework presented in Appendix A is intended to assist a program designer to develop the entire monitoring program in a systematic manner. The following three appendices (B through D) use this framework to provide examples of monitoring designs based on three of the monitoring classifications in British Columbia (impact assessment, compliance and trend monitoring).

Figure 1. Program design flow chart

(from McDonald *et al.* 1991)

4.1 Define program objectives

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The first, and most crucial step in developing an experimental design is to identify and define the study objectives clearly. Each objective is derived from a particular question that **needs** to be answered. All too often, the question is not clearly identified and the resulting monitoring program lacks clear direction. In this case, the data do not lead to information from which conclusions can be effectively drawn. Very precise formulation of the monitoring objectives should lead to an efficient and effective water quality monitoring program. Objectives should be written simply and should reflect both public questions and scientific and/or managerial needs.

> To start the process, a general objective should be formulated. This objective will be defined by the monitoring classification (Chapter 2) but reflect the conditions particular to the study (see Box 1). At this point, there is no guidance with regard to variables, frequency, or location of monitoring.

Guideline Box 1. Examples of General Objectives Development

· **Impact assessment -** assess the effects of a land use activity/project (i.e., logging, road building, mills, agriculture, mining, recreation, urban developments, etc.) on water quality of stream X or lake X.

· **Compliance -** monitor compliance with or attainment of ambient water quality objectives in watershed X,

· **Trend -** determine trends in lake X water quality over a designated period of time and space,

· **Survey -** establish a baseline set of water quality data for a water body, watershed, or region X (may dictate the need for other forms of monitoring).

Next, any existing data pertaining to the particular study area should be compiled and reviewed as these will help to further refine the program objectives. Historical data might be available for existing sites (e.g., in the EMS, ENVIRODAT or other databases) or through other agencies (e.g., Fisheries Branch, Pollution Prevention and Remediation Branch, Wildlife Branch, Hydrology Branch, Ministry of Health, Regional District Offices, Environment Canada, BC Hydro, angling/hunting groups, etc.). These data might also provide baseline information that can be used to assess normal limits of natural variability and direct further design efforts (such as the determination of site locations and sample frequencies). Even information regarding general basin characteristics could be of significant assistance (existing access or road networks, drainage area, topography, regional climatic cycles, geochemical properties, soil characteristics, etc.). A review of air photo maps can provide information regarding the location of sensitive areas within a watershed (i.e., areas prone to slides), and the location of areas subject to transient events (debris chutes, intermittent streams, flood plains, etc.). In sum, any information that is available for the study area can assist the program designer to develop all aspects of the monitoring program, or at least minimize and avoid difficulties with subsequent data collection. However, if no monitoring data are currently available then information for similar (preferably adjacent) watersheds or projects should be considered for review.

The general objective is then refined to a specific objective. The specific objectives should be posed in the form of a question (see Box 2). This step should attempt to isolate the activity which is likely to affect a specific water use (for impact assessment monitoring programs) and reiterate the nature of the monitoring classification. It implicitly starts to define the other design factors such as variables, frequency, location, data analysis techniques, and the duration of the monitoring project.

Guideline Box 2. Examples of Specific Objective Development (and monitoring implications)

· **Impact assessment -** Does agricultural activity upstream from an urban development increase bacterial and nutrient contamination at drinking water withdrawal sites? (monitor bacteria levels and nutrient concentrations at domestic water withdrawal sites during periods of high surface runoff);

· **Impact assessment -** Do forestry activities in the watershed adversely alter stream conditions such that aquatic life is impaired? (monitor stream temperature, dissolved oxygen and biological indices at prime habitat sites during low flow periods and turbidity and suspended sediments during high flow periods);

· **Compliance -** Have conditions changed within the watershed such that variable ranges no longer comply with ambient water quality objectives? (monitor variables outlined in objectives reports at pre-determined sites at critical times and sites stated in the specific report)

· **Compliance -** Have management efforts within the watershed resulted in improved water quality conditions such that water quality objectives are now consistently attained? (monitor variables outlined in objectives reports at pre-determined sites at critical times stated in the specific report)

· **Trend -** Is there a long-term trend in the pH of lakes that are located within a 50 km radius of an industrial centre? (monitor pH, conductivity, and dissolved oxygen throughout the water column at the deepest point of the lakes at consistent time intervals for 10 or more years)

· **Survey -** Are there distinguishing water quality characteristics of lakes throughout the province such that `aquatic ecological zones' can be delineated according to similarities between lakes within each zone? (monitor large suite of variables at deepest point of lakes once during lake turnover period and once during thermal stratification period at each of many lakes)

Once the question to be addressed is defined, it must be converted into a testable form. This is usually accomplished through standard statistical hypothesis formulation, whereby null and alternative hypotheses are devised (see Box 3). A null hypothesis (abbreviated H_O) is a statement of no difference between two populations. If, through statistical tests, it is concluded that H_O is false then the alternate hypothesis (abbreviated H_A) is assumed to be true. Multiple null hypotheses can be devised for a single program, such as comparing the differences between years and/or seasons at a single site, as well as differences between sites in a single season. Conversely, a different hypothesis can be created to test what is occurring for each of the variables of concern.

Guideline Box 3. Examples of Hypothesis Definition

Derived from example 1 in Box 2.

· **Impact assessment -**

H_O: The nutrient concentration does not differ between site A and site B during the period of high surface runoff (where site A is the reference site upstream of agricultural activity and site B is the treatment site downstream of the agricultural activity).

H_A: The nutrient concentration does differ between site A (upstream) and site B (downstream of agricultural activity).

or

H_O: The nutrient concentration does not differ between 1995 (pre-agriculture) and 1996 (post-agriculture) at site B.

H_A: The nutrient concentration does differ between 1995 (pre-agriculture) and 1996 (post-agriculture) at site B.

Note: The standard types of tests of hypotheses (the F-test and the t-test) are discussed in `*Guidelines for Interpreting Water Quality Data'* (Chapter 4 and Appendices A- D of that document).

4.2 Address immediate considerations

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Following the objective formulation phase, there are immediate considerations that must be addressed prior to further development of the program. Two equally important considerations are the statistical requirements and budgetary limitations of a program. The monitoring resources must be divided according to the budgetary constraints such that the results are statistically defensible. There are minimum statistical requirements that must be met to meet the objectives of any program (discussed in Section 4.2.1). Once these requirements are delineated, the available funds will dictate whether the program is feasible. As such, an evaluation of the available budget is also an immediate consideration (discussed in Section 4.2.2). Practicality dictates that all monitoring programs be formed to fit within the limits of the budget allocated to it. The funds that are available will dictate how the remainder of the program is designed (including the QA/QC allotment, the variable selection, the number of sites to be sampled, the duration of the project, and the sampling frequency). In extreme cases, a severely constraining budget may preclude any further effort unless additional funding can be obtained. A third consideration that is necessary to review prior to further development is the personnel requirements (discussed in Section 4.2.3).

4.2.1 Statistical requirements

Water quality sampling, like most sampling exercises, has a statistical component. Therefore, it is essential that the statistical aspects of the program be determined prior to designing the remaining elements of the program. To ensure broad applicability of these guidelines, it is not possible to delineate hard and fast rules but rather, it is the intention here to discuss the key statistical principles that facilitate the development of sound water quality monitoring programs. Therefore, beyond a basic review of statistical design, the focus of this section will be to provide guidelines that will assist program designers to accommodate major statistical compromises that are inherent in environmental monitoring programs. The goal will be to:

i) consider the effects of local natural variability (environmental heterogeneity) and recognize the importance of attempting to delineate the normal limits of this variability;

ii) identify suitable sampling strata to adapt the monitoring program to minimize the effects of natural variability (increase the ability to distinguish effects of anthropogenic activity from natural events);

iii) establish the statistical significance level (the criterion for rejecting or not rejecting the null hypothesis);

iv) recognize the importance of power in statistical design - the probability of detecting a difference when one exists; and

v) estimating the sample size necessary to test the null hypothesis with a specified degree of uncertainty (or, minimum number of sample measurements necessary to meet the objectives).

Note: The following discussion consists of general guidelines that attempt to address, in a simplified manner, statistical considerations that are complex. These guidelines are intended to provide assistance in the preparation of the statistical component of standard sampling programs that assume normal data distribution. For further elaboration of the issues discussed here, refer to literature that addresses these issues in greater detail (Antcliffe, 1992; Ehrman & Clair, 1993; Gilbert, 1987; Green, 1979, 1984, 1993; Taylor, 1991). Statistical requirements of more elaborate sample designs (i.e., non-normal data distributions) are beyond the scope of these guidelines and it is recommended that program designers refer to the above literature if the complexity of the program is greater than what this basic discussion entails. Furthermore, it is always wise to review a program design with a statistician to ensure that it is statistically robust (capable of meeting the objectives).

Probably the key question in water quality monitoring is whether significant change has occurred. This may be in the context of upstream/downstream, before/after of for trend data sets. Standard statistical designs to test this question are based upon a series of experimental units. The experimental units are the objects on which measurements are made, and for water quality monitoring programs, these units are usually the sample sites (they may be entire streams, lakes, or watersheds). An ideal monitoring program would allocate half of the experimental units to some treatment (human activity) while the other half would be left as untreated controls. Both the treated and untreated experimental units are considered to be representative samples of much larger populations. Repeated measurements on the experimental units generate the data used to describe the sampled populations, and to draw inferences about the larger population from which the experimental units were drawn (MacDonald, *et al.*, 1991). For the purpose of water quality monitoring, the populations refer to each of the possible water quality variables (parameters), including those of physical, chemical or biological nature.

The two most common approaches to assessing change are (1) to measure a selected variable over time at the site of interest; and (2) to compare data from a treated site with data from an untreated site. In scenario (1) there is only one experimental unit. The onset of a human activity can be used to separate the data into two groups. The analysis would involve a test for significant change over time by comparing means and variances over the initial (pre-treatment) period to the means and variances following the onset of the human activity. Although this approach is simple and appealing, statistical inferences cannot truly be made about the absolute cause of a change at the sample site. The paired-sampling approach (scenario 2 above) is a stronger method because it provides a basis for separating the treatment effect from other extraneous factors. Further elaboration on the paired-sampling approach applies the use of multiple pairs which increases the sensitivity of the sampling program to detect change. More complicated designs exist to analyze multiple factors and to deal with correlated data (part of the information contained in one observation will also be contained in other observations). These designs are beyond the scope of this guideline document, but information about these techniques can be found in the literature (Gilbert, 1987; Millard, *et al.*, 1985).The ability to distinguish a difference between the experimental units is based on four interacting factors:

> 1) natural variability (which influences sampling frequency and the number of sites),
>
> 2) level of significance (one's confidence that a concluded inference of change is, in fact, real)
>
> 3) power (the probability of detecting a difference when one exists), and
>
> 4) sample size.

These factors present a degree of statistical compromise that must be identified for each monitoring program.

Recall that the services of a statistician early in the program design will establish the degree to which these factors should be incorporated to meet the program objectives.

(1) Natural Variability. The single most confounding aspect of any environmental sampling program is natural variability in space and time. Regular normal differences, either in space or time, are referred to as strata. Data values between locations within a watershed or, at a single location over time frequently differ in terms of means and variances. The different data distributions that occur over time strata are often easily explained. Diurnal effects such as pH fluctuations are a form of a daily temporal stratification. Seasonal effects such as temperature, or high stream flows during spring freshet, create distinctly different means and variances than during other seasonal periods. Another cause in temporal variability is the life pattern sequences of the biological components of the ecosystem. Also, storm events can alter the physical, chemical and biological characteristics of a water body for days or weeks within a period that would otherwise experience little variability.

Significant natural inputs to a waterbody often necessitate that sampling sites are required upstream and downstream for the input. Normal spatial variability in the mean values is typical between two sample sites if there exists an input that alters the conditions between the two sites. Spatial variability could be the result of obvious inputs such as a tributary or non-obvious inputs such as subsurface leachates into a stream due to the local geology.

Normal variability must be considered and accounted for during the course of all monitoring programs (particularly impact assessment programs). If no regard is given to these normal changes then claims about abnormal (human induced) changes cannot be substantiated. The prime objective of the pre-treatment (before activity) data collection period (or the pilot study) would be to delineate which geographical areas and time periods naturally differ from others. These pilot studies must establish the mean values for the variables of concern within each identified strata; and, establish what the limits of the normal variability (variance) within a strata are likely to be (see Boxes 4 and 5 for an example). Often the year-to-year variability can be so large that an ideal pilot study could, or should, encompass a two to three year period. These pilot projects could be reduced in magnitude if data are available for the region (i.e., within the watershed, adjacent watersheds, regional climatic patterns, etc.) such that extrapolations can be made. To provide a valid analysis of trends, or the degree of anthropogenic impacts (abnormal variations), subsequent sampling efforts should be directed towards areas that were initially similar (same stratum), specifically during those time strata that are considered to be critical periods (discussed in greater detail in Section 4.6). When data are collected within a stratum, the effects of normal variability among strata are removed and detected changes can be more confidently attributed to treatment effects (human activity). A discussion of how to minimize the confounding effect of identified spatial variability is presented in Section 4.5 (Locate Sample Sites). A discussion of how to minimize the confounding effect of identified temporal variability is presented in Section 4.6 (Develop the Sample Frequency Regime).

Guideline Box 4. An example of How to Delineate Natural Time Strata in Order to Identify a Critical Period

· A pre-treatment pilot study was conducted at a stream site adjacent to proposed future forestry activity. Non-filterable Residue (suspended sediments) data was collected once monthly to estimate natural seasonal patterns for this variable. The NFR data follow:

January - 2 mg/L

February - 3 mg/L

March - 70 mg/L

April - 40 mg/L

May - 20 mg/L

June - 7 mg/L

July - 3 mg/L

August - 2 mg/L

September - 3 mg/L

October - 2 mg/L

November - 6 mg/L

December - 3 mg/L

· Therefore, the spring freshet in March and April is identified as the critical period based on the one year pilot study. Levels of suspended particulate matter become naturally elevated during this peak flow period.

Guideline Box 5. An Assessment of Mean Variable Concentration and Variability During a Critical Period

· A second pre-treatment study (following year) focuses on the month of March alone (a single stratum). The same site was sampled 10 times over 30 days during this critical period. The data collected during this period are intended to establish the mean NFR value for the critical period and to delineate the limits of the normal variability (variance) during the freshet. The NFR data follow:

March 1 - 27 mg/L

March 4 - 80 mg/L

March 7 - 15 mg/L

March 10 - 115 mg/L

March 14 - 130 mg/L

March 17 - 60 mg/L

March 20 - 200 mg/L

March 24 - 70 mg/L

March 27 - 50 mg/L

March 30 - 73 mg/L

· The arithmetic Mean NFR value for the 10 samples collected

during the 30 day period is $\bar{X}$ = 82.0 mg/L (T X_i / n).

· The observed variance (s^2) for this data set is

s^2 = 2952.0[T (X_i - $\bar{X}$)^2 / n-1]. Recall from Chapter 3 that observed variance is $s^2_{environment} + s^2_{sampling} + s^2_{analysis}$ and that sampling and analytical variance must not exceed 20% of the observed variance if the data is to be considered acceptable. We will assume that the data quality assessment process (as per Clark, *et al.*, 1996) confirmed that this data was credible.

· It can be concluded from this statistic that even within the stratum, the pulsed nature of the peak flow period tends to elevate the variability. A test of whether the mean NFR concentrations differ between this and future data (post-treatment) will depend on whether the variances between the two data sets differ. Equal variances will be required if assertions about impacts are to be made. The F-test is the statistical tool used to determine if variances differ (discussed in detail in *Guidelines for Interpreting Water Quality Data*).

<u>(2) Level of Significance</u> - The level of significance refers to the probability that an apparently significant difference is not real but simply due to chance. The circumstance under which there is a statistically concluded difference when, in fact, there is no difference is referred to as a "Type I" error. Conversely, the reverse of this scenario, not detecting a difference when, in fact, there is a significant difference is referred to as a "Type II" error. The level of significance is an arbitrarily assigned value that becomes the criterion for the rejection of the null hypothesis. Establishing a level of significance, therefore, is a process whereby the program designer determines what the upper allowable limit of making a Type I error can be.

The significance level (denoted as the a value) for most statistical tests is set at 0.05, meaning that there is 1 in 20 chance that an observed difference is due to chance [or 95% confident that it will not result in a

Type I error (1-a)]. However, since the setting of the a value is an arbitrary process, there are circumstances where a higher a value (less statistical significance) is appropriate. Under these circumstances the program designer is prepared to increase the possibility of making a Type I error. When a watershed is deemed to be of high priority in terms of the value it accrues for a particular water use, then it is justifiable to increase the possibility of making this type of error (a might be as high as 0.20 or 80% confidence). In other words, the cost of not identifying adverse change is greater than the cost of erroneously concluding a change has occurred. For example, raising alarm that drinking water might be contaminated when, in fact, it isn't, is possibly more responsible (both economically and ethically) than not raising the alarm when contamination has occurred.

(3) Power - The power of a statistical test is the probability of detecting a difference when, in fact, there is a difference (i.e., the probability of rejecting the null hypothesis when it is, in fact, false). In other words, it is the probability of avoiding a Type II error (not detecting a difference when one exists). Whereas, the probability of committing a Type I error is a, the specified significance level (typically valuing 0.05-0.20), the probability of committing a Type II error is b. Therefore, if power is the probability of avoiding a Type II error, then it is denoted as 1-b. Statistical power increases with increasing sample size, treatment effect (measurable change), and decreases with increasing variance among replicates. For a given sample size, *n* (discussed below), the value of a is inversely related to the value of b. In other words, lower probabilities of committing a Type I error are associated with higher probabilities of committing a Type II error, and the only way to reduce both types of errors simultaneously is to increase *n*. For a given a, larger samples will result in statistical tests with greater power (1- b). (Zar, 1984)

(4) Sample Size. Under ideal circumstances (unlimited resources) it is inherently obvious that the larger the sample size, the greater the capacity of the study to estimate a true population mean based on a sample mean calculation. This is the case because uncertainty is reduced with each additional sample collected. However, practicality dictates that collecting an extremely large number of samples is unproductive, both in terms of program budget and diminishing returns (the marginal benefit of collecting each additional sample becomes progressively less to a point where the data obtained from each new sample provides virtually no new information).

A variety of statistical techniques can be used to estimate the appropriate sample size given the statistical objectives and the known variability of the variable of concern (refer to Gilbert, 1987, for details). Given that these guidelines encourage sampling programs that consider natural variability, then techniques to estimate sample size that are based on stratified sampling are recommended. The statistical objectives will involve estimating the population mean with a specified acceptable error or significance level (i.e., a=0.05), a stated probability level (i.e., b=0.10), and either a minimum detectable spatial or temporal difference, or a pre-specified margin of error. Since there are multiple techniques of estimating the sample size required to provide defensible results, and, since each of these techniques are somewhat elaborate, these guidelines will not specifically outline one. It is, therefore, recommended that program designers refer to the literature or consult with a statistician to establish exactly what the sample size should be.

Without reliance on such rigorous statistical standards, a general rule of thumb that can be used if no information is available and a pilot study is not possible is that a sample size of "about 10" should be sufficient. This number represents a reasonable compromise between the cost of sampling and the need to reduce the uncertainty of the population estimates (Mac Donald, *et al.*, 1991). A study conducted by Peters (1995) for the Ministry of Environment, Lands and Parks demonstrated that 5-day sample regimens (n=5) from within a 30-day period produced mean and variance results that were not statistically different than the mean and variance results for the entire period (n=30).

4.2.2 Budget constraints

A key consideration in developing a monitoring program is cost. If the budget is insufficient to meet the program objective definitively (answer the required question with statistical confidence) then, either the objective has to be revised and simplified or the funds redirected to other programs. There is no point in conducting a program if it cannot provide valid information with the funds available. It is crucial that every effort is made to fit the objectives to the available budget. It is good practice to consult a statistician once the objective hypotheses have been formulated. This person will not only advise the program designers of the statistical tools and design necessary to answer the required question, but this input will clarify where monitoring effort should be better concentrated (hence defining the allocation of funds). This input will assist the program designer to determine if the budget will be sufficient to meet the minimum statistical requirements.

A general rule-of-thumb regarding the budget for monitoring programs is that the proportion of labour costs (sample collection) to analyses costs (lab work) is 1:1. Additionally, the QA/AC costs can range from 10 - 35% of the overall cost.

The development of an impact assessment monitoring program is generally the most costly because it often requires a baseline assessment of a large suite of variables over a significant number of sites (essentially this is a pilot study). This initial characterization of the baseline conditions includes an intensive QA/QC program and is typically followed by an analysis of the data to determine which variables and sites are the most appropriate to monitor regularly. Once this initial cost is incurred, the remaining budget dictates the allocation of resources to a scaled-down QA/QC program (which can be high for new studies), and a reduced set of variables, number of sites, and possibly sample frequency.

The sites, sampling schedule and variables for compliance monitoring are defined by the Water Quality Assessment and Objectives report or in the permit authorization. Therefore, the cost of this type of monitoring program is generally pre-defined.

Trend monitoring can also involve a baseline assessment of a large suite of variables over a number of sites, prior to an analysis of the data, to lead to a more rigid program. The sampling frequency will generally be from weekly to monthly, and the duration generally five years or more. Therefore, the budget primarily restricts the number of sites to be monitored.

As alluded to above, the analytical costs can be one of the most restrictive components of a program (as much as half the budget). The cost of analyzing some organics, for example, are significantly greater than other analyses. Therefore, all variables for a monitoring program must be carefully rationalized. For example, it may be possible to use some variables that are relatively inexpensive to analyze (as long as these help to meet the program objectives) in lieu of more expensive ones. An example of this would be to measure specific conductivity instead of total dissolved solids, or turbidity instead of suspended solids, or AOX (adsorbable organo-halides) instead of a suite of chlorinated organics. When changes are noted for these `surrogate' variables, further analyses for the other variables may be warranted (discussed in greater detail in Section 4.4.4). Regular analyses of the more costly variables should be restricted to programs (or even specific sites within a watershed) that are subject to potential impacts by the contaminant of concern. Another means to minimize cost is to carry out focused investigations for a few contaminants. In such cases, it may be possible to analyze only known contaminants of concern at all sites, but a broader spectrum of contaminants at a subset of sites. This subset should be located in specific areas, such as the most immediate upstream control site and first treatment site, or at sites directly adjacent to a critical resource.

When impacts are unknown (or not suspected), such as the case with survey monitoring, it is necessary to conduct an exploratory assessment that analyses for many variables. Consequently, survey monitoring that involves multiple watersheds can become very costly. The budget therefore, often dictates how many watersheds can be included in this type of study.

Guideline Box 6. Strategies For Cost Efficiency

· Collaborate with other agencies that are already working in the watershed. Often data exists due to efforts of agencies such as:

-Water Licensing (of Water Management, MELP),

-Fisheries Branch (MELP),

-Pollution Prevention (MELP),

-Ministry of Health (regional offices),

-Ministry of Forests,

-Ministry of Energy, Mines and Petroleum Resources,

-Parks (of Ministry of Environment, Lands and Parks),

-Regional District Offices,

-Ministry of Agriculture and Food,

-Municipal water purveyors,

-Federal, Provincial and private fish hatcheries,

-Water Survey of Canada,

-BC Hydro,

-Angling groups.

Available data can provide information about factors such as natural variability (discussed in Section 4.2.1) in the watershed and background concentrations (information that is costly to establish). Whenever possible, it is advisable to establish sites at the same location as other agency sites (particularly hydrologic study sites operated by the Water Survey of Canada).

· Use surrogate variables (discussed in Section 4.4.4). Some variables are much less expensive in terms of the cost of data collection and analysis and provide similar types of information.

· Adjust the degree of statistical rigor (discussed in Section 4.2.1). A reduction in the required level of significance would result in fewer samples necessary to meet the objectives (reducing sample frequency)

4.2.3 Personnel requirements

Consideration should always be given to the staffing requirements of any water quality monitoring program. For the purpose of consistency (quality control), the entire sampling schedule should ideally be conducted by the same people. When the program dictates that the operation of certain pieces of equipment is required, then staff members assigned to the project must be aware of all handling and safety procedures associated with these equipment. When boating is necessary, then at least one member of the field staff must be trained in boat operations and safety. When hazardous chemicals are used (e.g., preservatives), then the staff must be trained in accordance with the Workplace Hazardous Materials Information System (WHMIS) and Transportation of Dangerous Goods Act regulations.

All field sampling staff should have basic knowledge that consists of at least the following:

1) the program objectives,

2) calibration and proper use of all field equipment used for the program (see `*Sampling Manual Series*'),

3) the theory and procedures for all QA / QC components of the study (clean techniques, blanks, replication, reference samples) (see `*Sampling Manual Series*'), and

4) expected ranges of field measurement values.

One person should have the responsibility for coordinating the sampling activities (including completion of all requisition forms sent with the samples to the laboratory). This same person should interact with laboratory personnel before and during sample analysis to avoid confusion.

4.3 Conduct preliminary field inspection (reconnaissance survey)

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Once the objectives of the program are developed (including an evaluation of the budget constraints and statistical requirements) and related information is reviewed, it is wise to conduct a preliminary field inspection prior to further development of the program. The importance of actually "ground-truthing" an area at this stage of design cannot be over emphasized. These reconnaissance surveys should assist the program designer to (1) establish possible linkages between upslope or riparian activities and instream water quality which would further direct monitoring efforts and (2) develop a greater understanding of the watershed processes.

Ideally, the survey should be conducted during a time period having the same seasonal characteristics as those during which proposed human activities are likely to have the greatest impact (critical period). For example, if the greatest potential impact from a future project is expected to occur during periods of high stream flows (such as sediment input from road building), then the reconnaissance survey should be conducted during the season when high flows occur. **Note: if the survey is conducted during the early phases of the season of interest, then the initiation of the pilot study is possible during this same "critical" period.** The program designer would look specifically for locations within the watershed (with the aid of previously obtained information such as from air photo maps) that are subject to natural inputs of sediment. This information could assist the program designer to ascertain which locations naturally experience variability and, therefore, are ideally suited as sample sites to establish limits of this variability (at least for use during the pilot study and/or survey monitoring programs). Recall that, for the purpose of detecting human induced change, it is desirable to locate treatment sites in areas of low variability.

In watersheds where human activities currently exist, the reconnaissance survey should document the location and magnitude of these activities and, any observed linkages between an activity and water quality. For example, often the simple process of walking or driving a road network during a run-off event can provide a useful qualitative review of processes within the watershed and indicate where road-related water quality problems are developing.

Whenever possible, field data should be collected during the reconnaissance survey. These data would not necessarily be incorporated into future analysis, but rather provide preliminary information about expected background levels and possible spatial variability. Hence, this information can help the program designer establish sample site locations and determine which variables to evaluate during the study. For example, an unexpected specific conductivity value at one location might warrant the establishment of two sites (one upstream and one downstream of the specific conductivity anomaly). At these sits all variables such as ions for sodium, sulphate, chloride, calcium, and magnesium that result in altered specific conductivity would be tested for during the upcoming pilot study.

All information regarding the type, location, and magnitude of proposed land activities (treatments) should be reviewed by the program designer prior to conducting the reconnaissance survey. The observations made during the survey will dictate what further data regarding proposed land treatment activities will be necessary to obtain to make adequate linkages between these activities and future instream conditions.

4.4 Identify the variables of concern

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Variables measured are highly dependent on the objectives of the program, the budget of the program, current and proposed human activities, and basin characteristics. However, the single most important factor to identifying variables is to establish which variables are likely to be the most sensitive indicators of potential change or trends given the objective of the program.

Note: In the case of trend and compliance monitoring, the variables are clearly defined according to the specific requirements of each program. For survey monitoring (where detecting change is not the objective), a general suite of variables should be assessed for all components of the aquatic ecosystem (water, sediment, and biological indicators).

For impact assessment monitoring, the variables selected must be ones that will definitively link any potential water quality concern to the current and proposed land use activities (treatments) within the watershed. Often the pilot (baseline) study component of impact assessment programs will involve a larger suite of variables than during the remainder of the program. It is during this initial phase of the program that it is necessary to develop significant knowledge of the background conditions. Analysis conducted on this initial data will assist the program designer to refine details of the overall program (including the variable selection). However, a general rule of thumb for impact assessment studies is to make an inventory of the variables likely to be altered as a result of the activities that are currently ongoing, and those that are possibly due to take place in the watershed. A list of the major activities that typically take place in the province of British Columbia and a general summary of the potential impacts of each on the aquatic environment are presented in Appendix E. This Appendix presents a list of the variables that are sensitive indicators for each of these activities. It must be emphasized that this list is not exhaustive and that there may be issues of a more local or regional concern that would require other variables to be added to the program (as defined by the pilot study). Conversely, as a cost saving measure, there may be no need to sample all variables at all sites. **The most important site-specific variables to consider are those that are predicted to be altered, or are already elevated in the environment.**

When the budget allows, the variables sampled during the pilot study phase of impact assessment programs and for survey monitoring programs should ideally include:

· all water column field measurements [temperature, dissolved oxygen, specific conductivity, pH, and Secchi depth (for lakes)],

· water column nutrients (phosphorus, nitrogen) to assess the trophic state of the water body,

· water column and sediments metals package (to assess the inputs from natural geological sources) (note: the ICP metals package for use of low-level metals analysis in the water column is generally not adequate. ICP-MS metals package is a better option),

· water column turbidity and suspended sediments in rivers or streams (to assess natural inputs of suspended materials due to stream bank erosion or upslope instability),

· stream bottom sediment particle-size distribution (to provide background information when proposed activities might alter this characteristic)

· miscellaneous organics in sediments and biota (sediments and biota are the most likely receptors of anthropogenic chemicals such as PCP's or pesticides), and

· biological indicators such as benthic invertebrates, zooplankton, phytoplankton, periphyton, fish (community characteristics).

The following sections are general discussions of water chemistry, sediment, and biological variables in terms of the applicability of each to water quality monitoring programs. For greater details regarding specific variables, refer to Chapter 5 of *Guidelines for Interpreting Water Quality Data* (Cavanagh, *et al.*, 1998). This chapter serves as a review of many water chemistry, sediment, and biological variables. It provides a definition of each variable including natural expected ranges, it discusses the importance of each variable to the aquatic environment, it lists potential anthropogenic sources of the variable itself or activities that result in a change to the variable, and finally, it presents the BC criteria values for each variable.

4.4.1 Water chemistry

Water chemistry conditions are the most commonly monitored aspects of water quality monitoring programs in British Columbia. This is due to the ease of collection and analysis associated with this form of monitoring. However, there are inadequacies associated with programs that exclusively rely on water chemistry analyses. Chemical variables are limited because they only represent the water quality conditions at the time of sampling. Therefore, only when the samples are collected frequently, as with automated continuous monitoring stations, can robust extrapolations about temporal variations be made. There are, however, variables that when collected in conjunction with indicators of long-term change (sediment or biological variables), allow conclusions to be drawn about linkages between these changes and upslope activities.

4.4.2 Sediment analyses

Sediment sampling and analyses are primarily conducted when activities within a watershed are likely to (1) provide an input to aquatic ecosystems of dissolved contaminants that adhere to the finer sediments and accumulate in sediments over time, or (2) cause upslope or stream-channel erosion. The contaminants of primary concern for the former of these two scenarios are metals or organics. The sample process involves the collection of surficial fine grained sediments either in lakes or low flow stream segments (pools). The latter of these two scenarios involves the collection of stream sediment within a defined area and depth to determine particle size distribution or deposition rates.

Sediment pore water sampling is a relatively new technique that is currently not widely used in British Columbia. It is typically used to evaluate the processes and impacts of the transport of contaminants across the sediment/water interface into overlying water, and to evaluate the effects of contaminants in the pore water on benthic biota (Murdoch and Azcue, 1995).

Although Chapter 5 of *Guidelines for Interpreting Water Quality Data* provides a review of some sediment variables, a detailed description of many water quality variables in the sediments of uncontaminated lakes in BC can be found in Rieberger (1992).

4.4.3 Biological variables

Biological sampling is an aspect of water quality monitoring programs that is becoming more widely applied throughout the province. This is the case because organisms are sensitive to change and reflect the cumulative effects of past and present conditions. The tolerance levels of individual organisms varies, and as such, some organisms are better indicators of environmental extremes than others.

Biological analysis involves the collection of organisms (algae, invertebrates, or fish) for either the measurement of contaminants within tissues or, the evaluation of community characteristics (diversity indices, taxonomic richness, abundance, dominance, presence/absence of intolerant taxa). An important distinction must be made regarding the use of biota for making linkages between land activities and water quality. A clear understanding of the functional relationships within the ecosystem are required to make inferences about changes in water quality conditions and community structure. The `*Streamkeepers' Handbook*' (Mungo and Taccogna, 1994) is a good source for defining the functional feeding groups of benthic invertebrates.

The rationale for incorporating biological assessments into water quality monitoring programs are (from Gurtz, 1994):

· biota respond to a wide variety of natural and anthropogenic environmental influences, including: stresses from point and non-point sources, toxic effluents, nutrient enrichment, altered flow patterns, and physical habitat degradation;

· biota integrate over space. Stream organisms can serve as monitors for disturbances in the upstream landscape. Thus, an examination of biological communities in a stream provides a means to evaluate effects of human activities throughout the whole catchment; and

· biota, in many cases, provide a more sensitive indication of environmental change than analyses of water chemistry or sediment conditions. For example, biological tissue may concentrate contaminants at level more easily detected than in water or sediment.

The criteria for the selection of indicator species for tissue analysis are as follows:

· They should be readily available (i.e., widely distributed, relatively abundant, easy to collect, and easy to identify to lowest appropriate taxonomic level).

· Analysis should be made on a bulk sample such that a bias that might arise through the analysis of one large individual is avoided. The composite of smaller individuals or species is likely to provide more substantiated results.

· There must be reasonable potential that the species is likely to accumulate contaminants (e.g., bottom feeders or species that are very localized in there movement habits).

The criteria for the selection of biota for community characterization studies (taxonomic richness, abundance, indicator species, biotic indices) are as follows:

· They should be readily available (i.e., widely distributed, relatively abundant, easy to collect, and easy to identify to lowest appropriate taxonomic level).

· If indication of change at a specific site is required by the monitoring objective, then the indicator species must be sedentary in their habits (i.e., benthic invertebrates or algae). However, when the monitoring objective is more general (i.e., survey of whole watershed integration), then species with extensive ranges (i.e., fish) will provide a reliable indication.

· If the expected impact is short-term then biota with short life cycles should be selected (algae or sensitive life stages of benthic invertebrates). However, if the expected impact is long-term then biota with long life cycles should be collected (fish).

4.4.4 Use of surrogate variables

Often budget constraints dictate that it is not possible to collect a large suite of variables at each sample site or during each sample trip. There are, however, some variables that can be sampled intermittently. Since some variables are related to others, it is possible to calculate the value of un-sampled variables by use of information obtained about the sampled (surrogate) variables (discussions of how to do so are presented in *Guidelines for Interpreting Water Quality Data*). The following are variables that can be directly calculated when surrogate information is known:

· Total hardness (surrogates are calcium and magnesium).

· Total dissolved solids (surrogate is specific conductivity).

Perhaps the most significant application of surrogate variables is derived from field measurements. Field measured variables (i.e., temperature, turbidity, dissolved oxygen, specific conductivity and pH) serve as indirect surrogates in that they alert the sampling staff to anomalous conditions. Therefore, these inexpensively measured variables are significant in terms of designing the monitoring program. For example, a program designer might wish to maintain a relatively frequent sampling regime to maximize the chance of detecting a transient impact from a particular land-use activity (i.e., agriculture). However, in this particular case, budget constraints provide limitations that must be considered. Therefore, to ensure an adequate frequency regime, costs must be reduced elsewhere. The designer might choose to reduce the sampling frequency of some of the more costly (analytical costs) variables to once in every four sampling trips. All field measurements and one or two other key variables (e.g., phosphorus, coliform bacteria) might be sampled during each trip. In this case, the field variables act as surrogates in that they alert field staff of altered conditions. When the field variable values differ from expected ranges, then the staff would be alerted to collect all variables (even if it were not a full variable sampling trip).

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4.5 Locate sample sites

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Beyond defining the study objectives, the location of permanent sampling sites is probably the next most critical design factor in a monitoring program. Site selection can be classified as a two-step process: the selection of the macro-location followed by the selection of the micro-location. Macro-locations identify the areas within the watershed that are selected to satisfy the objectives of the program. Micro-locations are independent of the objectives and are selected on the basis of ensuring the representativeness of the sample and ease and **safety** associated with sample acquisition.

As a general rule, past and present monitoring sites should be maintained when new studies are implemented (as long as program objectives can be met using these sites). This ensures long-term continuity in data sets.

4.5.1 Macro-location (location within the watershed)

Flexible criteria for site selection are required due to the variability of the environment (basin size, geology, climate, seasons, etc.), the monitoring objectives (compliance, trend, survey, or impact), and available information (background). Access to the site is also an important consideration. Bridges are a logical choice for locating a stream sampling site because they provide easy access and permit sampling at any point in the cross-section. However, special care and equipment are required when collecting samples from bridges (refer to the *Ambient Fresh Water and Effluent Sampling Manual* for details). Site location can be chosen without regard to access if the stream is navigable by boat, and the additional resources needed for sampling by boat are available (funds, people, time, etc.).

For compliance monitoring, the sites are generally already established through previous studies and are clearly outlined in the *Water Quality Assessment and Objectives* reports. Generally, sites are located at:

i) the mouths of main tributaries,

ii) upstream and downstream from industrial projects, resource extraction activities, waste outfalls, and urban centres,

iii) near-shore lake locations that are adjacent to industrial projects, resources extractive activities, waste outfalls and urban centres,

iv) deepest point in lake,

v) at points of major water withdrawals, and/or

vi) jurisdictional boundaries (provincial, international).

For trend monitoring, the location of the site(s) within each watershed should be such that it provides an indication of change in the water quality within the basin as a whole. The site will often be located at the deepest point of the lake or, within the stream (river) that is the outlet of the watershed. Smaller watersheds will display trends more readily than larger watersheds because they are more sensitive to change.

For survey monitoring (baseline information) where the purpose is to establish the general overall condition of the water body, the sites are selected to detect as many integrated inputs as possible. In flowing systems, the site would be at the mouth of the river, while in lakes the site would be located at the deepest point (generally near the center).

For impact assessment monitoring, a preliminary inspection of the activities in the watershed will provide guidance with respect to establishing monitoring sites that best address the most significant impact areas. Ideally, the monitoring program should be implemented prior to initiation of a project, in which case, baseline data will be collected at all sites chosen. At least one control site should be located immediately upstream from the proposed project location. The distance between the upstream (control) site and the first downstream (treated) site should be minimal. This reduces the possibility of other, non-project inputs confounding the data (i.e., reducing spatial variability). Where ideal control sites are not possible (due to other upstream inputs), additional sites should be established to assess the contributions of other potential contaminant sources (e.g., effluents, tributaries, groundwater seepage).

To obtain true background levels, a second control site should be located at the headwaters of the stream (when accessible). Theoretically, control sites further downstream from the headwater control site provide information that addresses the magnitude of diffuse inputs from natural causes, while sites downstream from existing projects provides information that addresses direct inputs. A station at the mouth of the stream reflects the integration of all inputs and allows for an estimate of the pollution load that the stream contributes to the system into which it flows (ocean, lake, reservoir, or higher order stream).

When a project is due to be developed on the shore of a lake, it will be necessary to determine the location of proposed point sources discharged directly into the lake. This location will become a site where both surface and depth profile data will be collected. Sites near shore, that are adjacent to the development, should be established to monitor non-point sources. Additional sites should be located at the mouths of tributaries to the lake, and one should be located at the outlet of the lake. A site should be located at the deepest point in the lake to monitor overall conditions (depth profile).

4.5.2 Micro-location (actual sampling site)

Complex interactions exist between the physical, chemical and biological components of the aquatic ecosystem. Full understanding and interpretation of the data require that these mutual interactions be considered when selecting the specific sample site. Biological and sediment samples should be collected at, or very near, the same location as water chemistry samples. Location of benthic organism sampling stations where vertical mixing of wastes or tributary streams is complete is essential (influences must reach the bottom if their effects are to be detected). Benthic invertebrate samples and periphyton samples (attached algae) are best collected from riffled stream segments. When evaluating cause and effect on biotic community structure between upstream and downstream sites, it is essential that the sites are similar in terms of flow characteristics, canopy cover, and bottom characteristics (size of particles).

With respect to point source discharges, the closest downstream site should be located within a representative point in the effluent plume at the edge of the initial dilution zone (up to 100 m from the effluent discharge). Other sites should be located a sufficient distance downstream to allow for homogeneous mixing to occur. Ideally, these latter sites would be located at stretches in the stream where samples collected from all points in the cross-section would yield the same concentrations of all variables. In large rivers, a pilot study may be necessary to determine that the cross-section is well-mixed and the sample point is representative. This can be achieved by collecting samples across the cross-section and analyzing the data using an analysis of variance technique (ANOVA). Refer to a statistical text or a statistician for details.

In smaller streams, single grab samples should be collected in the middle of the cross-section at slightly greater than half the depth of the stream (0.6 depth). Vertical mixing in flowing systems is usually rapid, therefore sampling at one depth is generally representative (the exception to this is in estuaries where fresh and salt water layers exist).

Whenever possible, water quality monitoring sites should be located close to water quantity stations. This facilitates those assessments that are dependent on water quality/quantity relationships (e.g., evaluations of loadings and flow-dependent concentrations).

In lakes, it is important to consider that with each deep site, depth profiles may be required. Natural stratification processes in deep lakes affect the distribution of variables. Depending on the objectives of the study, sampling individual strata may be a necessity.

4.6 Develop the sample frequency regime

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4.6.1 Manual sampling (moderate frequency)

Sampling frequency is a function of the statistical objective of the monitoring program. More measurements will increase the precision, reduce the likelihood of bias, and increase the power of the statistical component of the program. At newly established sites, the samples may initially be collected at a high frequency so that within a defined time period, a sufficient number of observations are available for a statistical evaluation of variations, cycles and trends. Often, a pilot or baseline study is a critical component for determining sample frequency as it identifies sample strata (stream reaches, seasons, etc.).

Individual programs may require that sampling effort be greatest during `critical periods' (strata). For example, the critical time to monitor for compliance with objectives could be during those periods when dilution is minimized (generally low-flow periods) such that the waste concentration is high, while an impact assessment monitoring program might be based on loadings that are associated with high flow periods (i.e., sediment loads associated with road building). The former of these two scenarios might involve a sampling regime that consists of weekly sampling during summer low flow periods and monthly sampling during winter high flow periods (coastal areas). Conversely, scenario might involve sampling twice a week during freshet periods (spring runoff) and only monthly during summer low-flow periods. Also, critical periods might be a function of water uses, such as spawning periods, fry emergence, primary contact recreation, irrigation requirements, etc.

NOTE: The critical period for each program (and possibly for different variables within each program) will differ. Examples of critical periods for some variables might be: summer for coliforms, freshet for non-filterable residue, summer for dissolved oxygen in lakes, spring for stream invertebrate community structure, etc. Consequently, the objectives and the information obtained in a pilot study must be strongly considered when determining sample frequency and timing efforts.

The program design must address the natural variability of water quality (particularly seasonal and flow-related variability). Samples might be collected at regularly spaced time intervals during the low flow periods (i.e., low variability) with effort increasing (becoming more frequent) during the peak flow periods. Data collected throughout these peak periods (during the ascending and descending arms of the hydrograph) facilitate the measurement of contaminant loads. Discharge measurements are required to determine loadings.

Turbidity and suspended sediments are highly dependent on stream discharge rates, particularly during the ascending portion of the hydrograph. Since virtually all sediment transport occurs during high flow events, and since there can be considerable variation in sediment transport within an event, frequent sampling is required during high discharge periods. Specific conductivity is often inversely correlated with stream discharge rates.

Monitoring nutrient loads (especially ammonia) requires frequent sampling. In smaller watersheds, there is a rapid response in flows and quality to rain and snowmelt events. Significant changes often occur within hours and very frequent measurements (using automated samplers if possible) may be necessary if the monitoring objective is to capture extreme values. When automated sampling is not practical, manual sampling at a minimum of a daily rate is the next best option.

The specific schedule for the sampling of nitrogen and phosphorus will depend on the monitoring objective. More intensive sampling is required when the input source is sewage waste disposal, mining effluents where blasting has occurred, and agriculture or forest fertilization. In the case of agriculture, there is a nutrient surge in conjunction with runoff events (particularly at spring snowmelt for interior locations or at high elevations).

The sampling frequencies for dissolved oxygen, pH, and temperature are more complex because they often fluctuate both daily and seasonally. To obtain meaningful data, a monitoring program must either sample over these entire time periods or determine the most critical period and then sample consistently at that time. This would require that a pilot study be conducted to determine the most sensitive periods for a particular variable.

For effluent sampling, frequency is specified in the Waste Management Permit and is governed by the variability of the discharge. In general, the more variable the discharge with respect to either quality or flow, the higher the sampling frequency should be. Composite sampling requires that a specified sampling frequency be performed over a defined period of time, most commonly 24 hours.

4.6.2 Automated sampling (high frequency)

Often program objectives require that monitoring be conducted at very high frequencies. For example, it might be necessary to detect infrequent transient events, or highly variable water quality conditions that occur on an hourly or daily time frame. Under these circumstances, it is not feasible to collect the samples manually. Automated monitoring stations can be established at one or more strategic locations within the watershed to sample pH, specific conductivity, temperature, turbidity, dissolved oxygen, specific ions, flow velocity, and stage/water level/streamflow at any desired frequency. In recent years, automated monitoring has become a component of many water quality monitoring programs in British Columbia. The Ministry of Environment, Lands and Parks has released a manual titled *"Automated Water Quality Monitoring"* (Andersson and White, 1997) that should be referred to if automated monitoring is being considered as a component of a sampling program.

4.7 Conduct pilot study (full sample run and analysis of data)

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For impact assessment monitoring programs, the next step is to start the pilot project. Recall that the focus of this phase of the program is primarily to identify and quantify variability (both natural and that caused by sample collection techniques or analytical processes). As such, the pilot project must be very rigorous with regards to the QA/QC. A large portion of the QA/QC costs will be incurred at this point, but this initial cost is absolutely necessary. Once this is accomplished, the strata within which future sampling efforts will be concentrated can be defined. It must be reiterated that by definition, pilot projects have the flexibility to allow for adjustments in design. Inevitably there are some unforeseen factors that force some modifications to the project (such as a natural input of a contaminant that forces adjustment of site locations). Consequently, it is essential that data obtained during this phase of the program be analyzed in a timely fashion (refer to *`Guidelines for Interpreting Water Quality Data and Reporting the Results of a Water Quality Monitoring program in British Columbia'*). Rapid data analysis is needed to indicate whether the project is feasible as planned. Generally, if the program is designed well, then only moderate changes in the program design will be necessary. However, on the rare occasion that drastic changes are required, it will be necessary to re-evaluate the monitoring objectives in terms of whether the existing budget is sufficient to meet the needs of a more elaborate program.

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Sources of Information Related to Design Manual

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Andersson, S.M. and White, T.T. 1997. Automated Water Quality Monitoring. Field Test Edition. Water Quality Branch, Environmental Protection Department, British Columbia Ministry of Environment, Lands and Parks.

Antcliffe, B. 1992. Impact Assessment and Environmental Monitoring: The Role of Statistical Power Analysis. Canadian Environmental Assessment Research Council, Hull, Quebec.

Associated Water & Air Resources Engineers Inc. 1973. Handbook for Monitoring Industrial Wastewater. Prepared for: U.S. Environmental Protection Agency. Technology Transfer.

Beak Consultants. Technical Guidance Manual for Aquatic Environmental Effects Monitoring at Pulp and Paper Mills. Volume 1: Study Design and Interpretation. Draft.

Canter, L.W. 1985. River Water Quality Monitoring. Lewis Publishers Inc. Chelsea, Michigan.

Cavanagh, N.S., Nordin, R.N., Swain, L.G., and Pommen, L.W. 1994a. Ambient Fresh Water and Effluent Sampling Manual. British Columbia Ministry of Environment, Lands and Parks.

Cavanagh, N.S., Swain, L.G., Nordin, R.N., Pommen, L.W. 1994b. Lake and Stream Bottom Sediment Sampling Manual. British Columbia Ministry of Environment, Lands and Parks.

Cavanagh, N.S., Nordin, R.N., and Warrington, P.D. 1994c. Biological Sampling Manual. British Columbia Ministry of Environment, Lands and Parks.

Cavanagh, N.S., Nordin, R.N., Pommen, L.W. and Swain, L.G. 1998. Guidelines for Interpreting Water Quality Data. British Columbia Ministry of Environment, Lands and Parks.

Clark, M.J.R., Laidlaw, M.C.A., Ryneveld, S.C. and Ward, M.I. 1996. Estimating Sampling Variance and Local Environmental Heterogeneity for Both Known and Estimated Analytical Variance. *Chemosphere*, 32, No. 6: 1133-1151.

Desilets, L. 1988. Criteria for Basin Selection and Sampling Station Macrolocation. Environment

Canada. Scientific Series No. 164. Inland Waters Directorate. Water Quality Branch. Ottawa.

Ehrman, J.M. and Clair, T.A. 1993. The Use of Multivariate Statistics to Predict pH Changes in Environment Canada's Atlantic Region Lake Monitoring Network. Monitoring and Evaluations Branch, Atlantic Region, Environment Canada, Moncton, New Brunswick.

Environment Canada. 1987. Water Quality Monitoring Design - Proceedings of the Technology Transfer Workshop. Technical Workshop Series No. 6. Inland Waters / Lands Directorate, Ottawa.

EVS Environment Consultants. 1992. Proceedings of the Benthos Monitoring Workshop. February 11-12, 1992, Vancouver, B.C. Prepared for: Environment Canada, 223 West Esplanade, North Vancouver, B.C.

EVS Environment Consultants. 1993. Guidelines for Monitoring Benthos in Freshwater Environments. Prepared for: Environment Canada, 224 West Esplanade, North Vancouver, B.C.

Gilbert, R.O. 1987. Statistical Methods for Environmental Pollution Monitoring. Van Norstrand Reinhold. New York, NY.

Green, R.H. 1978. Optimal Impact Study Design and Analysis. Biological Data in water Pollution Assessment: Quantitative and Statistical Analyses, ASTM STP 652, K.L. Dickson, John Cairns, Jr., and R.J. Livingston (Editors) American Society for Testing and Materials. pp. 3-28.

Green, R.H. 1984. Statistical and Nonstatistical Considerations for Environmental Monitoring Studies. *Environmental Monitoring and Assessment*, 4: 293-301.

Green, R.H. 1993. Application of Repeated Measures Designs in Environmental Impact and Monitoring Studies. *Australian Journal of Ecology*, 18: 81-98.

Golder Associates Ltd. 1995. Review of Artificial Substrates for Benthos Sample Collection. Aquatic Effects Technology Evaluation (AETE) Program.

Gurtz, 1994. Design of Biological Components of the National Water-Quality Assessment (NAWQA) Program. In. Loeb and Spacie (Editors) Biological Monitoring of Aquatic Ecosystems. Lewis Publishers, London.

Haffner, G.D. 1986. Water Quality Branch Strategy for Assessments of Aquatic Environmental Quality. Environment Canada. Scientific Series No. 151. Inland Waters Directorate. Water Quality Branch. Ottawa.

Lawrence, K.H. (Editor). 1988. Principles of Environmental Sampling. ACS Professional Reference Book. American Chemical Society.

Loeb, S.L. and Spacie, A. (Editors). 1994. Biological Monitoring of Aquatic Systems. Lewis Publishers, London.

MacDonald, L.H. 1994. Developing a monitoring project. *Journal of Soil and Water Conservation*. 49(3): 221-227.

MacDonald, L.H., Smart, A.W. and Wissmar, R.C. 1991. Monitoring Guidelines to Evaluate Effects of Forestry Activities on Streams in the Pacific Northwest and Alaska. Center for Streamside Studies (CSS). United States Environmental Protection Agency. Water Division.

Millard, S.P., Yearsley, J.R. and Lettenmaier, D.P. 1985. Space-Time Correlation and Its Effects on Methods for Detecting Aquatic Ecological Change. *Can. J. Fish. Aquat. Sci.* 42: 1391-1400.

Ministry of Environment, Lands and Parks. 1994. Guide to the Environmental Assessment of Mine Development Proposals in British Columbia.

Murdock, A. and MacKnight, S.D. (Editors). 1994. Handbook of Techniques for Aquatic Sediment Sampling. Second Edition. Lewis Publishers, London.

Nagpal, N.K. and Pommen, L.W. 1997. Approved and Working Criteria for Water Quality. Water Quality Branch, Water Management Division, British Columbia Ministry of Environment, Lands and Parks. 45p.

Norecol Environmental Consultants Ltd. 1992. Field QA / QC Protocols for Monitoring and Predicting Impacts of Acid Rock Drainage. Prepared for: Energy, Mines and Resources Canada and the British Columbia Ministry of Energy, Mines and Petroleum Resources.

Peterman, R.M. 1990. Statistical Power Analysis Can Improve Fisheries Research and Management. *Can. J. Fish. Aquat. Sci.* 47(1): 2-15.

Pommen, L.W. 1994. Mercury Monitoring Issues. Paper Presented at the Environmental Protection Impact Biologists' Meeting, February 21-22, 1994, Victoria, BC.

PTI Environmental Services. 1991. A Project Manager's Guide to Requesting and Evaluating Chemical Analyses. Prepared for: U.S. Environmental Protection Agency.

Rieberger, K. 1992. Metal Concentrations in Bottom Sediments from Uncontaminated B.C. Lakes. Water Quality Branch, Water Management Division, British Columbia Ministry of Environment, Lands and Parks.

Robertson, E. 1990. Monitoring Acid Mine Drainage. Prepared for: Energy, Mines and Resources Canada and the British Columbia Ministry of Energy, Mines and Petroleum Resources.

Sanders, T.G., Ward, R.C., Loftis, J.C., Steele, T.D., Adrian, D.D. and Yevjevich, V. 1983. Design of Networks for Monitoring Water Quality. Water Resources Publications, Littleton, Colorado.

Taylor, J.K. 1987. Quality Assurance of Chemical Measurements. Lewis Publishers, Inc.

Taylor, J.K. 1991. Statistical Techniques for Data Analysis. Lewis Publishers, Boca Raton, Florida.

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Appendix A.

Framework Form For Designing A Water Quality Sampling Program In British Columbia

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Project Manager ___________________________________

Company conducting sampling program ____

Agency for whom program is conducted ____

Waterbody (watershed) ____

Program objective

Statistical considerations

Results of preparatory field inspection

Quality Assurance and Quality Control Considerations

List of variables of concern (including expected natural ranges for region)

Sample site locations with rationale for site selection

Sample frequency regime

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Appendix B.

Hypothetical Design For An Impact Assessment Monitoring Program

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Project Manager: Joanne Smith

Company conducting sampling program: Smith and Jones Environmental Consultants

Agency for whom program is conducted: B.C. Ministry of Environment, Lands and Parks

Waterbody (watershed): Clear River (refer to map) - Southern Interior of British Columbia

Designated water uses in the watershed: aquatic life, wildlife watering, recreation

Monitoring classification: impact assessment monitoring

Program objective - general:

Conduct a water quality sampling program to (1) establish a baseline set of water quality data that will contribute to enhancing greater understanding of regional background conditions and (2) monitor the effects on the Clear River of proposed forestry activities (cutting, yarding, road building). The intention of the second objective is to ensure that the most sensitive identified water use (aquatic life - salmonid) will not become impaired particularly when seasonal effects are likely to compound impacts. Detected impacts will warrant mitigative action.

Program objective - specific (posed in form of questions that will be answered after data has been collected over a defined time interval):

Have the mean values of selected water quality variables changed from pre-operational conditions?

if yes then:

Do the values of any selected variables at impacted sites violate criteria requirements for salmonid aquatic life?

Background information:

1. Watershed map - see attached

2. Historical data summary - none available

Previous sampling site locations (map) - none

Data values - none

Personnel and budgetary constraints:

Two members of staff will be responsible for conducting the sample program, Joanne Smith and Jeff Black. Joanne Smith is an Environmental Engineer that is WHMIS and First Aid certified. Jeff Black is a technician. Smith and Jones Environmental Consultants bill $500 / day for the professional services of Joanne Smith and $250 / day for the services of Jeff Black.

Budget:

The total annual budget allocated to the program is $72,000

With 48 half days of projected sampling trips (see sample frequency section at end of form), the distribution of cost would be:

Labour (sample collection) $ 18,000 ($750 * 24 days)

Laboratory analysis $ 18,000 (1:1 proportion with labour)

QA/QC $ 21,000 (about 30% of annual budget)

Annual report preparation $ 9,000 (26 days @ $250 + 5 days @ $500)

Expenses $ 6,000 (fuel, equipment maintenance, miscellaneous)

Statistical considerations:

The statistical design is based on a comparison of water quality variables both before and after, and upstream and downstream of proposed forestry activity. Sampling will be stratified by wet and dry periods. The duration of the monitoring plan allows for statistical testing of the differences between years (at a single site), seasons (at a single site) and locations (upstream-downstream sites at a single time). Throughout the project, information will be collected about the management practices conducted within the watershed as per the Forest Practices Code (type and extent of forestry related activities). By combining this land-use information with water quality data (pre and post forestry activity), the project expects to be able to qualitatively and quantitatively document the magnitude and impact of forest harvest activities on the water quality of Clear River. The level of significance that will be used to test the hypothesis that impacts have occurred (i.e., forestry activity has resulted in treatment site alterations) is a = 0.10. The power will be b = 0.10.

Results of reconnaissance survey:

Reconnaissance survey conducted on March 23, 1997

Weather - overcast, intermittent light rain, air temperature - 4·C

Field notes - Area predominantly second growth forest 90-100 years. Walked along creek from near headwater 2.5 km downstream through area of proposed forestry activity. River predominantly riffles, some pools. Water clarity very good. Conducted field analyses at two sites. First site upstream of proposed forestry activity near headwater, accessed via hiking trail. Second site adjacent to proposed cutblock (on opposite side of creek).

Field data results - Upstream site: water temperature 5·C, dissolved oxygen 12 mg/L, conductivity 105 µS/cm

Downstream site: water temperature 5·C, dissolved oxygen 12 mg/L, conductivity 113 µS/cm

Quality Assurance and Quality Control Considerations:

The techniques outlined in the *Field Protocol Series* of the RIC standards for quality assurance will be strictly adhered to. In terms of quality control, a full suite of blanks (trip, field, equipment and filtration blanks) will be conducted on each sampling trip and, some variables will selected for spiked, reference and replicate sampling during each sample trip (as per RIC standards).

List of variables of concern (including expected natural ranges for region and criteria for most sensitive identified water use):

These first four variables are to be sampled on each sampling trip.

Temperature - natural ranges: lower limit 1·C (winter), upper limit 16·C (summer) criteria: maximum 15·C for embryo survival, 10·C during spawning season notes: Temperature to be measure during each sampling period. Season of greatest potential impact - summer

Dissolved oxygen - natural ranges: lower limit 8 mg/L (summer), upper limit 17 mg/L (winter) criteria: lowest limit 6 mg/L (water column for embryo and larval stages) notes: Dissolved oxygen to be measured during each sampling period. Season of greatest potential impact - variable (summer due to increasing temperatures, spring if high runoff causes inputs of suspended sediment)

Conductivity - natural ranges: lower limit 20 µS/cm, upper limit 400 µS/cm criteria: none established for aquatic life notes: Conductivity to be measured during each sampling period. Season of greatest potential impact - spring if high runoff causes inputs of suspended and dissolved sediment

Turbidity - natural ranges: 0 NTU, upper limit 20 NTU criteria: induced change not greater than 5 NTU notes: turbidity sampled monthly, more frequently if conditions become impaired as indicated by surrogate variables. Season of greatest potential impact - spring and fall during periods of high rain and snowmelt when increased runoff causes inputs of suspended and dissolved solids.

Notes: The following variables are to be sampled monthly unless above surrogate variables indicate dramatic change (i.e., DO drops and/or conductivity becomes elevated). Under these circumstances, field personnel are instructed to collect the full suite of variables.

Suspended solids - natural ranges: 0 mg/L, upper limit 100 mg/L criteria: induced change not greater than 10 mg/L notes: suspended solids sampled monthly, more frequently if conditions become impaired as indicated by surrogate variables. Season of greatest potential impact - spring and fall during periods of high rain and snowmelt when increased runoff causes inputs of suspended and dissolved solids.

Chlorophyll *a* - natural ranges (periphyton): lower limit 0 mg/m^2, upper limit 90 mg/m^2 criteria: maximum 100 mg/m^2 notes: Chlorophyll *a* sampled monthly. Season of greatest potential impact - summer.

Substrate sedimentation- criteria: no increase in the weight of particles less than 3 mm in diameter. notes: sedimentation sampled monthly, more frequently if conditions become impaired as indicated by surrogate variables. Season of greatest potential impact - spring and fall during periods of high rain and snowmelt when increased runoff causes erosion.

Benthic invertebrates - criteria: none

> notes: for the purpose of this study the objective will be no changes in seasonal patterns for taxa richness and abundance. Sampled monthly unless conditions become impaired as indicated by surrogate variables.

Sample site locations with rationale for site selection:

Site 1: (refer to map) - control site A, near headwater of Clear Creek.

Rationale: Good access via hiking trail, 800 meter easy walk from parking lot. Site likely to be best indication of background water chemistry levels.

Site 2: (refer to map) - control site B, 500 meters upstream of any proposed forest activity, 1.5 km downstream of control site A.

Rationale: Most easily accessible site immediately upstream of activity being monitored. No tributaries to Clear Creek between site and proposed activity. Therefore, it is a reference area that will not be exposed to impacts from forestry activities but will likely exhibit similar natural characteristics to the exposed sites. Address magnitude of diffuse inputs from natural sources.

Site 3: (refer to map) - first treatment site, located at lowest limit of proposed logging activity, 1 km downstream of Site 2.

Rationale: Address magnitude of greatest impact. Area expected to be subject to highest exposure to potential impacts.

Site 4: (refer to map) - second treatment site, located 1 km downstream of site 3.

Rationale: Address magnitude of impact downstream of activity at location where salmonid fish habitat is known to be good (anecdotal information from recreational fishers). Area expected to be subject to less exposure to impacts but within the zone of influence of potential impacts.

Site 5: (refer to map) - third treatment site, located at mouth of Clear Creek (2 km downstream of site 4).

Rationale: Address the magnitude of impacts from logging activity at a distance of 3 km downstream from the direct impact and to evaluate the sediment and nutrient load provided by Clear Creek to Clear Lake.

Sample frequency regime:

Sampling will be conducted at two week intervals during periods (strata) where impacts are expected to be low (periods of little rain or snowmelt - May, June, July, August, September, December, January, February). Total = 16 sampling trips

Sampling will be conducted twice per week during periods (strata) when impacts are expected to be high (periods of high runoff - October, November, March, April). Total = 32 sampling trips.

A full season of the sampling program will be conducted prior to any forestry related activity being initiated in the watershed.

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Appendix C.

Hypothetical Design For A Compliance Monitoring Program

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Project manager: John Smith

Company conducting sampling program: Smith Environmental Consultant

Agency for whom program is conducted: B.C. Ministry of Environment, Lands and Parks

Waterbody (watershed): Delta area of the Splendor River (refer to map) - Heavily urbanized Lower Mainland Region of BC

Designated water uses in the watershed: aquatic life, recreation, irrigation, industry

Monitoring classification: compliance monitoring

Program objective - general:

Conduct a water quality sampling program to determine if water quality is impaired for designated water uses at locations down stream of a sewage treatment plant outfalls (secondary treatment facility). The intention of the objective is to ensure that the most sensitive identified water use (aquatic life - salmonid) will not become impaired, particularly during critical periods (juvenile salmonid migration seaward and adult salmonid return migration). Non-compliance will warrant mitigative action.

Program objective - specific (posed in form of questions that will be answered after data has been collected over a defined time interval):

Do the mean values of any selected variables, particularly within critical period time strata, at any one site violate criteria requirements for salmonid aquatic life?

Background information:

1. Watershed map - ministry of environment water quality sample site location maps, urban development maps, agricultural and soils maps

2. Historical data summary - much data exists for Splendor River including region of current study (most data collected by ministry of Environment, Lands and Parks). Data available from SEAM data base and past reports. Critical period information (salmon migration pattern data) available from Fisheries and Oceans.

> *Previous sampling site locations (map)* - Five MELP sample sites ideally located for current study (one control upstream, one site located at outfall and three sites downstream within the potential zone of influence - 25, 100 and 200 metres)
>
> *Data values* - SEAM data base

Personnel considerations:

Two members of staff will be responsible for conducting the sample program, John Smith and Jennifer White. John Smith is an Impact Biologist with a Masters in Fisheries Biology. He is WHMIS, Small Boats Operation, and First Aid certified. He bills $500 / day for his professional services. Jennifer White is a water quality technician employed by Smith Environmental Consultant. Her time is billed out at $250 / day.

Budget:

The total annual budget allocated to the program is $90,000

With 76 half days of projected sampling trips, the distribution of cost would be:

Labour (sample collection) $ 28,500 ($750 * 76 days * 0.5 days)

Laboratory analysis $ 28,500 (1:1 proportion with labour)

QA/QC $ 21,000 (about 25% of annual budget due to previous efforts in the watershed)

Annual report preparation $ 9,000 (26 days @ $250 + 5 days @ $500)

Expenses $ 3,000 (fuel, equipment maintenance, miscellaneous)

Statistical considerations:

The statistical design is based on a comparison of water quality variables at one upstream control site and multiple downstream treatment sites (existing MELP sites). Sampling will be stratified by non-critical and critical periods (salmon migration). The upstream sample will serve as a control to test if significant difference exists between that site and each of the downstream sites. When this is found to be the case, each of the downstream sites will tested to determine if the mean values for particular variables within a time strata exceed the criteria set for that variable as per the protection of salmonid aquatic life. The level of significance that will be used to test the null hypothesis that criteria have not been exceeded (i.e., the sewage treatment plant is in compliance with the established criteria) is a = 0.20. This is a relatively weak statistical significance but we feel that it is justifiable to increase the possibility of making a "type I" error (falsely concluding that a criterion has been exceeded) in order to ensure greater protection of the highly valued salmonid resource.

Results of reconnaissance survey:

No reconnaissance survey required due to abundance of previous data.

Quality Assurance and Quality Control Considerations:

25% of the budget will be allocated to ensuring QA/QC. The techniques outlined in the *Field Protocol Series* of the RIC standards for quality assurance will be strictly adhered to. In terms of quality control, a full suite of blanks (trip, field, equipment and filtration blanks) will be conducted on each sampling trip and, some variables will selected for spiked, reference and replicate sampling during each sample trip (as per RIC standards).

List of variables of concern (including expected natural ranges for region and criteria for most sensitive identified water use):

Ambient water variables

Dissolved oxygen - natural ranges: lower limit 6 mg/L (summer), upper limit 10 mg/L (winter) criteria: lowest limit 3 mg/L to avoid acute mortality.

> notes: Dissolved oxygen to be measured during each sampling period. Season of greatest potential impact - variable (summer due to increasing temperatures)

Ammonia - typical natural ranges: lower limit <0.02 mg/L, upper limit 2.00 mg/L criteria: the criteria to protect aquatic life from chronic effects from ammonia depend on temperature and pH. Temperature conditions in Splendor River typically don't exceed 10·C and pH is generally 7.5. For these conditions, a mean 30 day ammonia concentration of 1.85 mg/L will protect salmonid aquatic life.

notes: Ammonia to be measured during each sampling period.

Bacteriological - Indicators include: Fecal coliform, E. coli, Enterocouccus and Pseudomonas aeruginosa.

No criteria are established for the protection of salmonid aquatic life. Therefore the criteria for irrigation will be applied. Criteria are:

Fecal coliform - =200 / 100 mL (geometric mean)

E. coli - =385 / 100 mL (geometric mean)

Enterocuccus - =100 / 100 mL (geometric mean)

Pseudomonas aeruginosa - =100 / 100 mL (75th percentile)

NOTE: Suspended sediments and Turbidity are variables that are typically altered by sewage treatment. However, the Splendor River near its delta is naturally heavily ladened with suspended sediments. Therefore, sampling for these variables would likely provide inconclusive evidence in terms of impacts associated with sewage treatment.

Sediment variables

Polycyclic Aromatic Hydrocarbons - The following are the PAH's that will be tested for in sediments at two sites down downstream of the outfall (with criteria value):

Naphthalene - maximum 0.01 µg/g

Acenaphthene - maximum 0.15 µg/g

Fluorene - maximum 0.2 µg/g

Anthracene - maximum 0.6 µg/g

Phenenthrene - maximum 0.04 µg/g

Acridine - maximum 1.0 µg/g

Fluoranthene - maximum 2.0 µg/g

Benz[a]anthracene - maximum 0.2 µg/g

Benzo[a]pyrene - maximum 0.06 µg/g

Metals - The following are the metals associated with sewage treatment operations that will be tested for in sediments at two sites down downstream of the outfall (with criteria value):

Arsenic - maximum 6.0 µg/g

Chromium - maximum 26.0 µg/g

Iron - maximum 2.1 mg/g

Sample site locations with rationale for site selection:

Ambient water sample sites

Site 1: (refer to map) - control site 150 metres upstream of sewage plume.

Access from pilings downstream from Beland Bridge.

Sample at two depths with van Dorn (1 and 4 metres).

Rationale: Determine variable concentrations in area expected not to be influenced by sewage treatment plant

Site 2: (refer to map) - at outfall within effluent plume

Access by boat.

Sample at 1m and 4m (depth sample to be taken in mid-plume).

Rationale: Determine variable concentrations in effluent.

Site 3: (refer to map) - impact site within initial dilution zone (100m offshore and 25m downstream of outfall)

Access by boat.

Sample at 1m and 4m.

Rationale: Address magnitude of impact within initial dilution zone (plume visually evident at this location)

Site 4: (refer to map) - impact site beyond initial dilution zone (100m offshore and 100m downstream of outfall)

Access by boat.

Sample at 1m and 4m.

Rationale: Address magnitude of impact beyond initial dilution zone (plume no longer evident at this location)

Site 5: (refer to map) - impact site beyond initial dilution zone (100m offshore and 200m downstream of outfall)

Access by boat.

Sample at 1m and 4m.

Rationale: Address magnitude of impact further downstream of outfall.

Sediment sample sites

Site 1: (refer to map) - impact site within initial dilution zone (50m downstream of outfall)

Offshore fines.

Rationale: Address magnitude of impact within initial dilution zone (plume visually evident at this location).

Site 2: (refer to map) - impact site outside (beyond) initial dilution zone (200m downstream of outfall)

Offshore fines.

Rationale: Address magnitude of impact further downstream of outfall.

Sample frequency regime:

Sampling will be conducted at 1 (one) week intervals throughout the entire year. However, during critical periods (strata) when fish migratory patterns dictate, sampling frequency will be increased to three times a week (expected total is 12 weeks of salmonid migration). Therefore, the total sampling trips will be 76 (3 * 12 + 1 * 40).

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Appendix D.

Hypothetical Design For A Trend Monitoring Program

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Project manager: Laura Patterson

Company conducting sampling program: Water Quality Branch, B.C. Ministry of Environment, Lands and Parks

Agency for whom program is conducted: B.C. Ministry of Environment, Lands and Parks

Waterbody (watershed): Lakes of Lower Phrayzer Valley area, Southwestern British Columbia

Designated water uses in the watershed: aquatic life, wildlife watering, recreation.

Monitoring classification: trend monitoring

Program objective - general:

Conduct a 10-year water quality sampling program to determine if gradual lake acidification is occurring in waterbodies located within the airshed of a major urban centre located on the southwest coast of British Columbia. The intention of the objective is to detect any long-term trend that would be attributable to acidic precipitation.

Program objective - specific (posed in form of questions that will be answered after data has been collected over a defined time interval):

Do the mean values of selected variables at any one site exhibit any trend in acidity?

Background information:

The lakes in the study area are primarily used for recreation (body contact). They are accessed by logging roads. There are some shoreline provincial and forestry camp sites.

1. Watershed map - parks maps

2. Historical data summary - Beach bacteriological data (not pertinent to current study)

Previous sampling site locations (map) - none

Data values - none

Personnel considerations:

One member of ministry staff, Laura Patterson (M.Sc.), will be responsible for conducting the sample program. A Co-op student will assistant her on each trip.

Budget:

The total budget allocated to the program is $350,000

With 24 days of projected sampling trips per year, the distribution of cost would be:

<u>Annual Budget</u>

Labour (sample collection) $ 8,000 ($310 * 26 days)

Laboratory analysis $ 8,000

QA/QC $ 10,000 (about 35% of annual budget)

Expenses <u>$ 6,000</u> (fuel, equipment maintenance, miscellaneous)

$ 32,000

* 10 years = $320,000

+ two reports @ $ 15,000 = $350,000

Statistical considerations:

The statistical design is based on a comparison of water quality variables at each site over time. A single lake that is not located within the airshed will serve as the control site. Each other lake will serve as a unit (treatment site) within which trends will be assessed. Sampling will be conducted at regular (bi-weekly) intervals throughout the year to conduct a time series analysis to detect trends. The level of significance that will be used to test the null hypothesis that no trend exists is a = 0.05. This choice of a relatively strong statistical significance is because it is important that the possibility of making a "Type I" error (falsely concluding that a trend toward increasing lake acidification) be minimized. Claims of increasing acidification that would stimulate a demand for a change in policy towards more rigorous emission standards of both automobiles and industry would necessarily require vigorous statistical confidence.

Results of reconnaissance survey:

No reconnaissance survey conducted due to nature of study. The study dictates that the sample site locations (lakes) are best determined be reviewing a large scale map of the region. The center of each lake will be the specific site location.

Quality Assurance and Quality Control Considerations:

35% of the budget will be allocated to ensuring QA/QC. This value is high because no prior information is available. The techniques outlined in the *Field Protocol Series* of the RIC standards for quality assurance will be strictly adhered to. In terms of quality control, a full suite of blanks (trip, field, equipment and filtration blanks) will be conducted on each sampling trip and, some variables will selected for spiked, reference and replicate sampling during each sample trip (as per RIC standards).

List of variables of concern (including expected natural ranges for region):

Ambient water variables

pH - natural ranges: lower limit pH 6.5, upper limit pH 7.5

criteria: 6.5-9 for the protection of aquatic life

Conductivity - natural ranges: =100 µS/cm

criteria: none

Sample site locations with rationale for site selection:

Ambient water sample sites

Site 1: (Lake A) - control site 20 km north of urban centre, outside of city airshed

Access from boat launch, northern shoreline.

Sample at center of lake.

Rationale: Compare variable values to those of treatment sites (lakes) such that detected trend can be attributable to treatment effect (urban centre).

Site 2: (Lake B) - 15 km north east of urban centre, within airshed.

Access from boat launch at western end of lake

Sample at center of lake

Rationale: Assess acidification trend within close proximity of urban centre.

Site 3: (Lake C) - 55 km directly east of urban centre, within airshed.

Access from boat launch at western shore of lake

Sample at center of lake

Rationale: Assess acidification trend within moderate proximate of urban centre.

Site 4: (Lake D) - 100 km directly east of urban centre, within airshed.

Access from boat launch at southern end of lake

Sample at center of lake

Rationale: Assess acidification trend at distance from urban centre.

Sample frequency regime:

Sampling will be conducted at two week intervals year round.

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Appendix E.

Potential Effects on Water Quality of Common Waste Discharges and Land Use Activities in B.C.

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Forest Harvest (cutting and yarding)

· altered stream flow and run off patterns (general increase of peak flows and summer low flows) (typically monitored by hydrologists)

· altered stream channel characteristics (typically monitored by hydrologists or geomorphologists)

· increase of total water yield (typically monitored by hydrologists)

· disturbance of soil, increasing potential for erosion

· increased turbidity and suspended sediments

· decreased intergravel dissolved oxygen concentrations

· altered macroinvertebrate community structure

· altered juvenile coldwater fish abundance

The following are potential effects when the cutting occurs near the stream channel-

· increase of organic material reaching stream systems

· increased light penetration to stream systems

· increase of algal production in light-limited systems

· increased water temperature

Recommended variables to monitor include: turbidity, suspended sediments,

dissolved oxygen, benthic invertebrates, water temperature, chlorophyll *a*

Road Building and Use

· increased rate of erosion

· increased suspended sediments and turbidity

· decreased intergravel dissolved oxygen

· altered macroinvertebrate community structure

· increased conductivity due to de-icing (salts)

Recommended variables to monitor include: turbidity, suspended sediments, dissolved oxygen, benthic invertebrates, conductivity

Appendix E. Continued

Pulp and Paper Mills

· altered temperature

· increased carbon

· increased ammonia

· increased organics

· increased bacterial contamination

· increased oxygen demand (reduced dissolved oxygen)

· altered biological community structures

· increased colour

Recommended variables to monitor include: temperature, colour, dissolved oxygen, pH, ammonia, benthic invertebrates, coliform bacteria (*E. coli*), organics (dioxins/furans in fish tissue and

sediments, resin acids, chlorophenolics, AOX). Sodium or chloride are often useful tracers of effluent location and dilution.

Agriculture

· altered timing and patterns of runoff

· increased sediment load

· altered sediment size distribution

· increased bacterial contamination

· increased nutrient levels (from livestock waste and application of fertilizers)

· increased algal productivity or standing crop

· increased temperature

· increased BOD and COD (decreased dissolved oxygen)

· altered macroinvertebrate community structure

Recommended variables to monitor include: turbidity, suspended sediments, coliform bacteria, phosphorus, nitrogen, dissolved oxygen, benthic invertebrates, temperature, chlorophyll *a* (standing crop)

Appendix E. Continued

Urban Development

· altered timing and patterns of runoff

· increased turbidity and suspended sediments

· increased toxins (from storm drains - metals, organics, pesticides)

· increased bacterial contamination (septic fields, stormwater, combined sewer overflows)

· increased nutrients (septic fields, detergents and garden fertilizers)

· increase light penetration to stream systems (stream bank clearing)

· increase in algal production and standing crop

· increased temperature in stream systems

Recommended variables to monitor include: turbidity, suspended sediments, oil & grease, Polycylic Aromatic Hydrocarbons, metals package, coliform bacteria, phosphorus, nitrogen, dissolved oxygen, benthic invertebrates, temperature, chlorophyll *a*

<u>Sewage Treatment</u>

-Primary treatment-

· increased suspended and dissolved solids and turbidity

· increased BOD and COD (decreased dissolved oxygen)

· increased nutrients (particularly ammonia)

· increased bacterial contamination

· increased sediment PAH's

· increased sediment metals

Recommended variables to monitor include: turbidity, non-filterable residue, filterable residue, dissolved oxygen, phosphorus, nitrogen (ammonia), chlorophyll *a*, coliform bacteria, sediment PAH package, sediment metals

Appendix E. Continued

-Secondary treatment-

· increased BOD and COD

· increased nutrients (particularly ammonia)

· increased algal productivity

· increased bacterial contamination

· increased sediment PAH's

· increased sediment metals

Recommended variables to monitor include: dissolved oxygen, ammonia, carbon, chlorophyll *a*, bacteria, sediment PAH package, sediment metals

-Tertiary treatment-

A/O treatment facilities

· low level increase of nutrients

Barden-pho treatment facilities

This treatment method should theoretically have a minimal impact on the ambient aquatic environment.

Recommended variables to monitor include: as a precaution, occasional effluent sampling for dissolved oxygen, phosphorus and nitrogen should be monitored for tertiary treatment facilities to ensure that they are performing to specifications. Ambient monitoring for chlorophyll *a* should conducted in conjunction with the above schedule.

Recreation

· increased bacterial contamination

· increased nutrients

· increased algal productivity

Recommended variables to monitor include: phosphorus, nitrogen, coliform bacteria, chlorophyll *a*

Appendix E. Continued

Mining

-Placer mining-

· destabilization of stream channel

· increased suspended solids and turbidity

· altered conductivity

· increased heavy metals concentrations

· decreased intergravel dissolved oxygen

· altered temperature

· altered macroinvertebrate community structure

· altered juvenile coldwater fish abundance

Recommended variables to monitor include: metals package, conductivity, turbidity, suspended solids, dissolved oxygen, temperature, pH, benthic invertebrates

-Hardrock mining-

· altered dissolved ions

· altered temperature

· increased heavy metals concentrations

· increased turbidity and suspended solids

· altered pH

· altered conductivity

· increased nitrogen (due to blasting)

· altered macroinvertebrate community structure

· altered juvenile coldwater fish abundance

Recommended variables to monitor include: metals package, conductivity, turbidity, suspended solids, ammonia, nitrate, nitrite, temperature, pH, benthic invertebrates

Appendix E. Continued

-Coal mining-

· increased turbidity and suspended solids

· increased nitrogen (due to blasting)

· altered pH

· increased metals (if acid generation occurs)

· altered macroinvertebrate community structure

Recommended variables to monitor include: metals package, turbidity, suspended solids, ammonia, nitrate, nitrite, pH, benthic invertebrates

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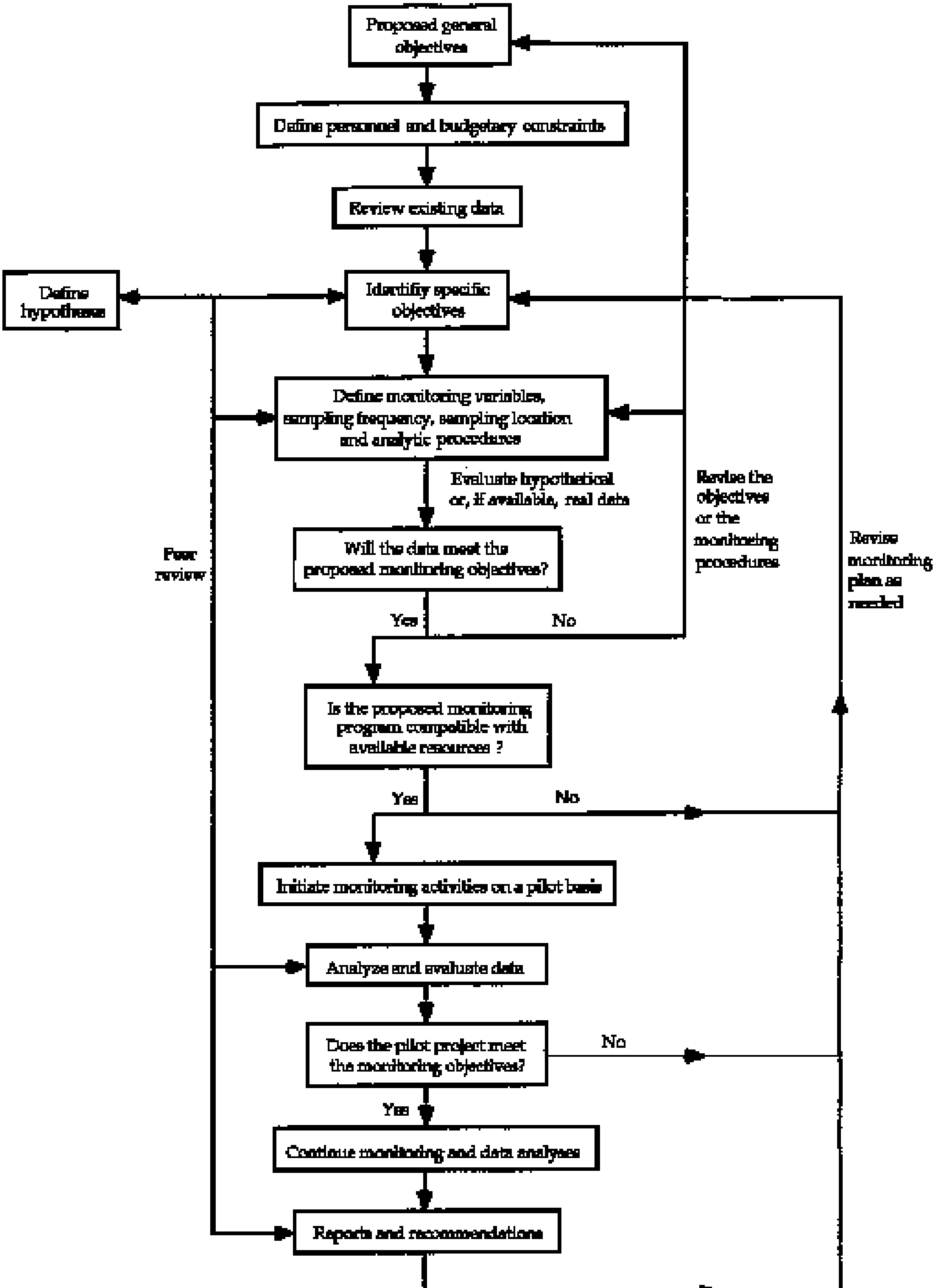
Proposed general objectives
Define personnel and budgetary constraints
Review existing data
Define hypotheses
Identify specific objectives
Define monitoring variables, sampling frequency, sampling location and analytic procedures
Evaluate hypothetical or, if available, real data
Will the data meet the proposed monitoring objectives?
Yes
No
Revise the objectives or the monitoring procedures
Peer review
Is the proposed monitoring program compatible with available resources ?
Yes
No
Revise monitoring plan as needed
Initiate monitoring activities on a pilot basis
Analyze and evaluate data
Does the pilot project meet the monitoring objectives?
No
Yes
Continue monitoring and data analyses
Reports and recommendations