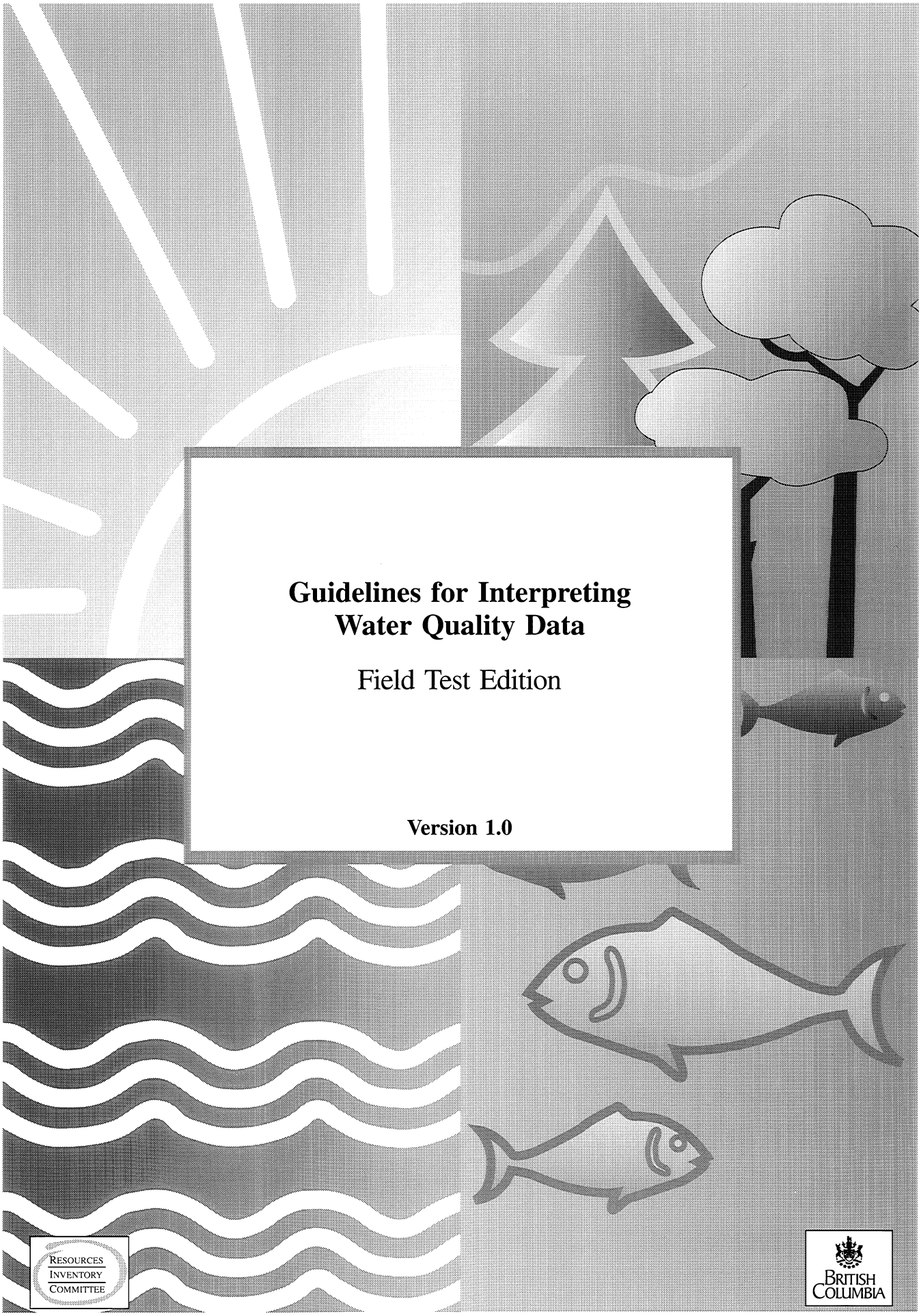

Guidelines for Interpreting Water Quality Data

Field Test Edition

Version 1.0

RESOURCES INVENTORY COMMITTEE

BRITISH COLUMBIA

Resources Inventory Committee

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The Resources Inventory Committee consists of representatives from various ministries and agencies of the Canadian and the British Columbia governments as well as from First Nations peoples. RIC objectives are to develop a common set of standards and procedures for the provincial resources inventories, as recommended by the Forest Resources Commission in its report "The Future of our Forests".

Aquatic Ecosystems Task Force

This document was prepared by N. Cavanagh, R.N. Nordin, L.W. Pommen and L.G. Swain.

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1. Introduction

This manual presents guidelines for interpreting and reporting water quality data in British Columbia. It is the final component of a five manual set which includes the "Guidelines for Designing and Implementing a Water Quality Monitoring Program in British Columbia" (Cavanagh et al., 1998) and the "Sampling Protocol Series"[1]1 (Cavanagh et al., 1994a,b,c). These manuals cover the minimum requirements to ensure that the sampling program most 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, data collection, and data interpretation that can be widely applied. Given the variability of the natural conditions and the anthropogenic inputs, this and the design manual are limited to providing guidance rather than specific protocols.

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.

The manual is for the interpretation of surface fresh water data only. It is not intended to provide guidance for the interpretation of groundwater or marine water data. These topics will be the subject of future manuals.

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1 Ambient Fresh Water and Effluent Sampling Manual Lake and Stream Bottom Sediment Sampling Manual Biological Sampling Manual

2. Screening/Editing Data (Quality Assessment)

Screening and editing is the initial phase in assessing water quality data. Ideally, it should be conducted as an ongoing process throughout the life of the monitoring program to ensure that the data quality objectives (i.e., maximum allowable introduced variability) that were established during the program design are continually being met.

It is during this phase that the Quality Assurance / Quality Control information obtained throughout the program is used (interpretation and use of each component follows below). This information provides an estimate of the total uncertainty and degree of contamination associated with the data. Total uncertainty is the variability (precision plus bias) associated with the sample collection and sample analyses. An allowable upper limit on total uncertainty (i.e., data quality objectives) should be established for each program and this value should not be exceeded. The limit will reflect the required level of confidence in the data and is arrived at with the assistance of a statistician (an example of the required level of confidence might be - 95% confidence that the data are within 30% of the true conditions). In those instances where the level is exceeded, all associated sample values (or outliers) must be flagged in both the database and in the final report. The decision whether to use data that fail to meet the prescribed data quality objectives is a matter of discretion, but all data must be included in the report. The authors must identify and provide the rationale for the exclusion of any data from interpretation. When exceedances are detected early in the monitoring program then the situation should be addressed prior to continued sampling to reduce further uncertainty.

2.1 Replicate samples

Replicate sampling (at a minimum duplicates that are collected either simultaneously or in close succession) provide a rough estimate of the overall precision associated with the field technique and laboratory analysis. When the data values for replicate samples have low variability, then contamination during collection or analysis is unlikely and uncertainty associated with data collection can be ruled out. When the data have high variability, contamination may have occurred during collection/analysis or as a result of environmental conditions that were highly variable. In these instances, the best attempt at documenting the true conditions is to record the mean of the values plus/minus one standard deviation (66% confidence) or, plus/minus two standard deviations (95% confidence). The standard deviation is a quantifiable representation of the imprecision. The following hypothetical example demonstrates how replicate data values should be interpreted when high variability exists (precision is low):

Triplicate samples at site X were analyzed for total phosphorus and yielded results of 24 µgP/L, 20 µgP/L and 32 µgP/L, respectively. In this case, the mean value is 25.34 µgP/L with a standard deviation of 6.11. The value should be recorded as 25.34±6.11 µgP/L. All that can be stated about the total phosphorus concentration at site X at that particular time is that it was likely to be in the range of 19.23-31.45 µg/L (with a confidence of 66%). For

greater confidence (i.e., 95%), the range must be expressed as 25.34±12.22 µgP/L (or 13.21-37.56 µgP/L).

Precision can be expressed as a relative percent mean difference when duplicates were collected as per the absolute value of the following equation:

$$\frac{(\text{data value A} - \text{data value B}) * 100}{(A+B)/2}$$

When three or more replicates were collected, precision can be expressed as a percent relative standard deviation by dividing the standard deviation of the analytical result by the mean and then multiplying by 100. Ideally the percent relative standard deviation should be close to 0%. For the above example the precision would be 24% (6.11 ÷ 25.34 x 100).

Note: the precision is influenced by how close the analytical value is to the method detection limit (MDL). The MDL is the level above which there is a high probability (e.g., 95%+) that a substance can be detected. The percent relative standard deviation increases rapidly as the analytic value approaches the MDL. Consequently, the use of percent mean difference or percent relative standard deviation is limited to analytical values that are at least five times the MDL. The following are 'rule of thumb' criteria for precision values (above which the data should be viewed with caution):

- 25% relative difference for duplicates (i.e., a value exceeding 25% is considered too imprecise);
- 18% relative standard deviation for triplicates;
- 10% relative standard deviation for six or more replicates.

Note: Information from replicate samples at one site cannot be used to infer ranges for values at other sites where replicates were not collected. A single data value at another site does not constitute a mean. Therefore the value in assessing replicate data early in the program is apparent. If imprecision exists then the source of variability should be assessed. To test the sample collection and handling techniques, field replicates must be submitted. To test the analytical process, replicate analyses of one sample must be done, or replicates of a certified reference sample (section 2.3) should be submitted "blind" to the laboratory. Since imprecision can be due to poor field or laboratory technique, it is necessary to identify specifically where the contamination was introduced. This can be accomplished through the use of blank samples as discussed in section 2.2. Once the source of contamination is identified, lab or field staff may require re-training to ensure that standard protocols are being followed [see *'Field Protocol Series'* (Cavanagh, *et al.,* 1994a,b,c) in the case of field staff]. If, after all this, environmental variability is suspected then a study of the site should be conducted to assess its suitability as a sample site.

2.2 Blank samples

Blanks are designed to detect contamination that contribute to imprecision and bias. For details about how each blank is prepared, refer to the 'Ambient Fresh Water and Effluent Sampling Manual' (Cavanagh, et al., 1994a). The different types of blanks are:

- **Trip blanks** - laboratory provided de-ionized water preserved prior to the sample trip in the same manner as the associated field sample. It remains unopened throughout the

duration of the trip. These blanks detect any widespread contamination resulting from the container or preservative during transport and storage.

- **Field blanks** - de-ionized water which is exposed to the sampling environment at the sample site and handled in the same manner as the real sample (e.g., preserved, filtered). These blanks provide information on contamination resulting from the handling technique and from exposure to the atmosphere.
- **Equipment blanks** - samples of de-ionized water that is 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) - de-ionized water that is 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.

When blank samples provide evidence of contamination, the real samples are likely to be biased high and towards false positive results. Under some circumstances, a correction factor can be incorporated into the real data, but this must be flagged in the report. Rules of thumb for assessing contamination are (1) not more than 5% of the blanks should exceed the 'method detection limit' and (2) blanks should not exceed 10% of the environmental levels (based on pilot study information) or 10% of the level of interest (e.g., a criterion or objective). These rules of thumb are, in effect, data quality objectives for contamination.

The following key represents a step-by-step process for addressing contamination:

1. Do all blanks show any level of contamination? If the answer to this question is no, then all field and analytical techniques that the blanks tested for can be considered clean and the real sample data are treated as uncontaminated. If the answer is yes proceed to step 2.
2. When blanks demonstrate that contamination has occurred (as per above), then the objectives of the study must be considered when deciding how to treat the real sample data. If the objective is to detect minute changes in variable concentrations then even small levels of contamination reduce the ability to interpret the data with confidence. In the case where the contamination values approach the real data values, the data collected during the particular sample trip may be invalid. Conversely, when the purpose of the study is to monitor for large variations, then small levels of contamination are not significant. In this case, a correction of the data can be made (subtract blank data values from the sample data values to get the reported value).

For pre- and post-blanks, such as the case with filtration blanks (before use of apparatus and after at least one real sample has been filtered), the situation is more complicated. If neither the pre- nor the post-blank are contaminated then the filtration apparatus was sufficiently cleaned before and between samples. If both blanks were contaminated to the same degree then it can be assumed that all the real samples were equally contaminated. If this level of contamination is not severe then the data can be corrected as above. A general rule regarding blanks is that if contamination is severe (i.e., blank values exceed data quality objectives), then the data for that particular sample round should be excluded from interpretation. If the post-filtration blank is contaminated while the pre-filtration blank is not, then it is assumed that the cleaning technique was insufficient and all samples (except the first collected) are generally invalid. This is the case because there is no way of calculating the degree to which

any one sample was contaminated by technique or previous samples. Under these circumstances staff must be retrained.

Note: Whenever blanks are found to be contaminated in excess of the data quality objectives, the source of contamination should be addressed to eliminate it in the future.

2.3 Reference samples

Standard reference samples aim to measure the accuracy of analyses performed by the analyzing laboratory. The variable concentrations in these reference solutions can vary depending on the source of the sample and the variable being tested. It is often desirable to use reference samples that are close to the criterion levels established to protect aquatic life, but preferably close to the range of values expected in the real samples. Therefore, the results present a measure of confidence in the laboratory's ability to provide reliable data in those variable ranges that are critical.

Accuracy is expressed as a percent by dividing the analytical result by the certified ('true') concentration of the reference solution and multiplying by 100. Ideally the expressed accuracy value should approach 100%. When reference sample values exceed 100% then the reported real sample values are expected to be the same increment greater than the true value. For example, if a reference sample certified at 300 µg/L for iron is reported by the analyzing lab to be 420 µg/L then the accuracy is 140%. It can therefore be expected that the lab may have over-estimated the iron concentration in the real samples by about 40%. The same rationale follows when the lab provides values that are below the true value for the reference sample (<100%).

The accuracy for measuring the concentration in the standard material must also be taken into account. Different laboratories can use different and equally valid test methods. This can lead to different results for the same sample, which leads to all certified reference samples having an acceptable range documented for each (e.g., ±10%). For the above example, the acceptable range would be 300 ± 30 µg/L. Analytical laboratories reporting values between 270 and 330 µgFe/L would be considered accurate and no correction of sample data would be necessary.

Whenever correcting data for these sorts of discrepancies, the data should always be flagged and the rationale for the correction explained.

2.4 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. The information gained from spiked samples is used to reveal any systematic errors (or bias) in the analytical method.

Since a spiked sample is analyzed in conjunction with un-spiked aliquots of the same sample, the accuracy of the analytical technique is tested. The difference between the reported spiked sample value and the un-spiked sample values should be the spike concentration. The accuracy can be expressed as a percent by dividing this calculated spike concentration by the 'true' spike concentration and multiplying by 100. If the value approaches 100% then the

analysis can be considered accurate and unbiased. Therefore, the aliquots that were un-spiked can be considered to be accurate. When the value deviates from 100% (either above or below) then it can be assumed that the laboratory is making similar errors with real samples (refer to section 2.3 for an explanation of how to account for analytical bias). A rule of thumb is that % recovery of spike should be 100±10%.

When either spiked or reference samples indicate that the analyzing laboratory is providing biased results, then it is necessary that the program manager consult with the lab in order that they may address the problem.

2.5 Summary of QA/QC

The following is a breakdown of the QA/QC sample types.

Sample type	**Measures**
Laboratory replicates	analytical precision
Field replicates	sampling + environmental + analytical precision
Certified reference samples	analytical accuracy
Certified reference replicates	analytical accuracy and precision
Spiked samples	analytical accuracy
Field blank	contamination (bias and imprecision) introduced during sample handling in the field and laboratory
Trip blank	contamination (bias and imprecision) introduced by the container, preservative and/or during transportation
Equipment blank	contamination (bias and imprecision) introduced through improper cleaning techniques
Filtration blank	contamination (bias and imprecision) introduced from the filtration apparatus and inadequate cleaning of apparatus
Laboratory blank	contamination (bias and imprecision) introduced during laboratory analysis

3. Compiling Data

All data should be summarized in tables that will be incorporated into the final report, either in the body of the report (when the number of variables is small), or as appendices. Summary tables for each site (Table 1) should be compiled and include basic statistics (# of values, minimum, maximum, mean, standard deviation, and period of record) for all field and laboratory data. This format allows for easy access to information such as the number of times any one variable was sampled and the range of conditions (worst-case to best-case occurrences). These are general tables that are not intended to partition out seasonal variability or frequency of criteria (or objective) exceedance. When compiling data that focus on seasonal effects such as high or low flow periods and spring overturn events, interpretation of related data is required (see Chapter 4).

Table 1 - Ambient Water Quality Data Summary of Hypothetical Site for the Period of 1991-92

Characteristics	# Of Values	Minimum	Maximum	Mean	Std Dev.
GENERAL					
Acidity T4.5 (mg/L)	13	30.9	34.1	32.6923	1.23184
Acidity P8.3 (mg/L)	13	<0.5	<0.5	<0.5	0.0
Coliform (CFU/cL)	14	1	2	1.9285	0.26726
Color (true) (col. units)	1	<5	<5	<5	
Chlorophyll *a* (µg/L)	14	0.6	3.3	1.9071	0.89224
Dissolved oxygen (mg/L)	229	4.13	15.56	11.3185	1.827
pH (pH units)	237	5.95	7.9	6.90101	0.42637
Secchi depth (m)	15	8.7	16	13.0433	1.93362
Specific cond (µS/cm)	9	72	79	74.555	2.408
Temperature (°C)	234	4	25	9.47829	5.99845
Turbidity (NTU)	17	0.1	0.9	0.32941	0.20237
METALS (µg/L)					
Aluminum	7	<20	<100	<31.43	30.23
Bismuth	6	<20	<20	<20	0.0
Boron	6	<10	40	<20	10.95
Cadmium	7	0	<.5	<0.07	0.19
Calcium	7	8750	12100	10578	1139
Chromium	7	0.0	10	1.429	3.78
Potassium	4	<400	600	<550	100
Silica (dissolved)	13	11100	13400	12553.8	570.987
Sodium	4	1750	2100	2000	168.32
Zinc	7	0.0	10	5	5
NUTRIENTS (µg/L)					
N - ammonia	27	<5	8	<5.22	0.69
N - nitrite	15	<5	<5	<5	0.0
N - nitrate + nitrite	27	<20	30	<20.74	2.66
N - Kjeldahl	21	<10	150	<81.905	31.878
P - ortho dissolved	1	<3	<3	<3	0.0
P - dissolved	27	<3	3	<3	0.0
P - total	27	<3	5	<3.333	0.62
Low Level nitrate + nitrite	13	<5	105	<18.53	32.18
Low Level nitrite	13	<1	15	<3.31	5
Low Level phosphorus (ortho)	13	<1	<1	<1	0.0

When available, physical characteristics about the study area should be tabulated (much of this information can be obtained from Water Survey of Canada - Environment Canada, or from Fisheries Branch or Water Management Branch, BC Environment). The following is a list of the information that should be included in the report:

Lake studies - Morphometric information

- Drainage basin area (watershed area)
- Lake elevation
- Lake surface area
- Lake volume
- Lake bathymetry (if available, the inclusion of a bathymetric map in the report is ideal)
- Volume of epilimnion
- Volume of hypolimnion

  (epilimnetic and hypolimnetic volumes can be calculated once the depth of the thermocline is determined. Volumes of each bathymetric layer above the thermocline can be summed to determine the epilimnetic volume and volumes of all bathymetric layers below the thermocline can be summed to determine the hypolimnetic volume)
- Mean depth
- Maximum depth
- Fetch (unobstructed length)
- Littoral area (expressed as % of total surface area)

Lake studies - Hydrologic information

- Evaporation rate (if no direct data exist, then assume 75 cm evaporated from surface per year)
- Outflow volume
- Inflow volume (evaporation rate + outflow volume)
- Flushing time

River studies - Morphometric information

- Drainage basin area
- River length and slope
- Average depth
- Average width
- Stream order (for stream of study and any tributaries to the stream of study)
- Major tributaries to the river
- System into which river flows

River studies - Hydrologic information

The following lists hydrologic (discharge) data that could be compiled for specific river sites when the data are available from the Water Survey of Canada:

- Average yearly water yield
- Mean flow - mean monthly, showing max., min. and avg.

- Minimum flow - 7-day average low flows, 2 and 10 year return periods. Daily low flows with return periods for period of record.
- Maximum flow - daily maximum flows with return period of 10 years or for period of record.

Additional information such as; water licenses issued in the study area, fisheries release records, wastewater discharges, Ministry of Health beach coliform data, land uses and agricultural activity should be compiled and tabulated/mapped. Much of this information can be obtained from:

Water Management, MELP

Fisheries Branch MELP

Pollution Prevention of Remediation 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

Any information concerning indigenous aquatic life and wildlife should also be presented. Much of this information can be obtained from:

Wildlife Branch, MELP

Fisheries Branch, MELP

Water Quality Section of Water Management Branch, MELP

Local angling groups

Local hunting groups

4. Presentation of Data and Data Analysis

4.1 Graphic tools

Whenever possible and meaningful, the raw data should be presented in graphical form and not simply described in the summary tables discussed earlier (Chapter 3). Graphical displays virtually always serve as an aid in the data presentation and interpretation processes; however there is little to be gained by generation graphs where data are close to the MDL or vary only to a minor degree throughout the year.

A plot of raw data values (for one site) against time is an important preliminary tool to assist in visualizing the data distribution and to provide a check for temporal patterns and extreme values (outliers). When data exist for more than one year, graphical presentation makes seasonal patterns readily apparent. Each seasonal effect (strata) should be partitioned and graphed alone such that trends that develop over the long-term become visually clear. Examples of partitioned graphic representations might be:

- the concentration of a particular variable (y-axis) during low-flow periods (x-axis),
- suspended sediments or turbidity during peak-flow periods,
- sediment load during peak-flow periods (synchronous with the hydrograph),
- nutrient values during the spring turnover periods in a lake,
- dissolved oxygen during peak temperature periods (summer), or
- chlorophyll *a* values during peak light/nutrient/temperature periods.

Figure 1 presents a comparison of a plot of an entire hypothetical data set against a plot of partitioned portions of the same data set.

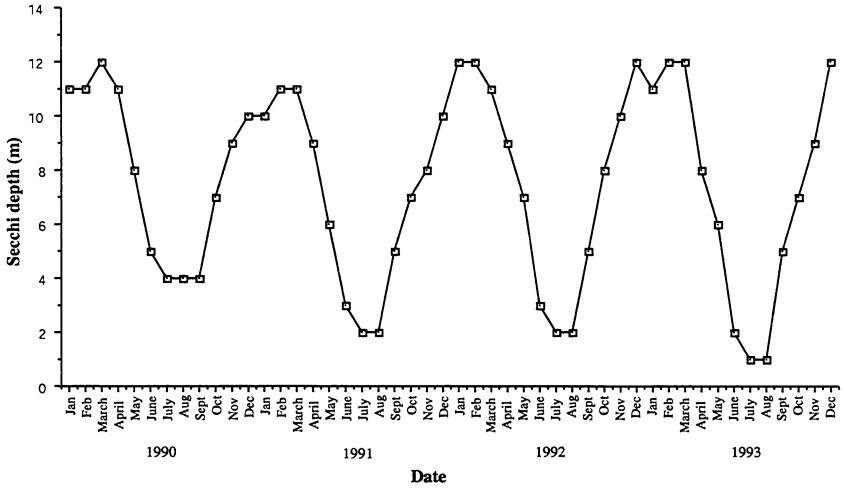

Figure 1a. A representation of all data demonstrating seasonal trends but not clearly showing long-term trends.

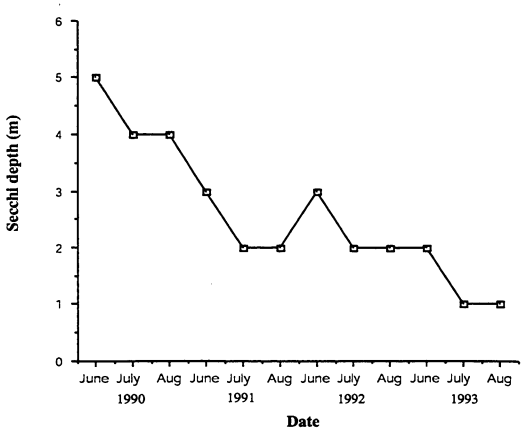

Figure 1b. A representation of partitioned data for critical period strata (summer months when conditions are suitable for algal blooms) showing long-term trends.

Figure 1. Clarity values at a specific site in a lake that is exposed to elevated nutrient inputs. Increased algal density during summer months has the effect of decreasing clarity. By partitioning the data, long-term trends become more apparent.

A good graphical technique to present a snapshot of spatial trends along the length of a flowing system is a plot of a variable of concern (y-axis) against distance (x-axis). The distance increments would coincide with site locations (generally the origin starts with the control site and each successive site represents a progressive distance downstream). This graphical presentation is ideal for impact assessments as it would amply reveal the worst-case site (generally the site immediately downstream from the discharge) and demonstrate the relationship between distance and dilution as well as assimilation processes. Figure 2 presents a hypothetical example of this graphical tool.

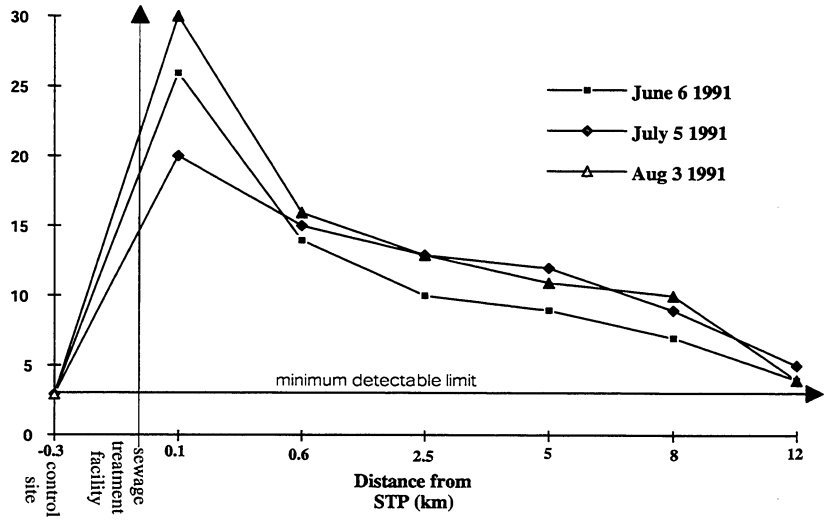

Figure 2. Hypothetical trends in phosphorus concentrations along the length of a river to which a sewage treatment plant discharges

A graphical aid that is particularly helpful as a display and interpretation tool for lake data is the 'depth profile'. This graph presents data values (x-axis) throughout the water column (y-axis) for a given day at a given site (Figure 3). This is an extremely useful tool in that it often clearly exposes the relationships between certain variables (e.g., dissolved oxygen and temperature) and the effect that depth has on these variables. It also presents information on the lake stratification structure, such as the location of thermocline and depth of the epilimnion and hypolimnion (essential to interpreting lake water quality data).

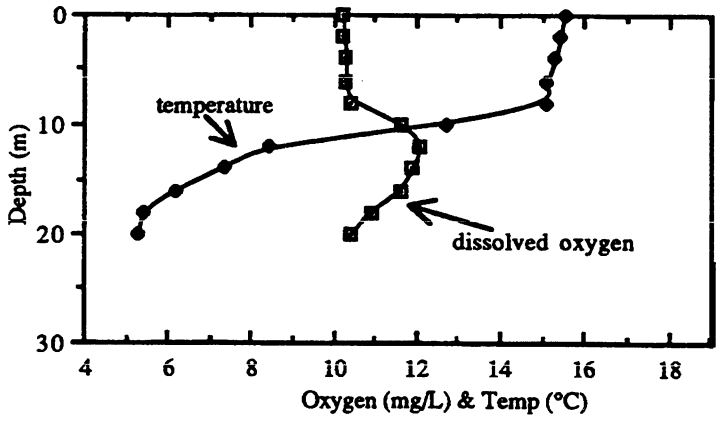

Figure 3. Hypothetical depth profile for dissolved oxygen and temperature in a lake

Another graphicaltool used for lake studies is the 'time/depth diagram' (Figure 4). This graphic presents values for a variable throughout the water column at a particular site for a defined period (generally a year to show seasonal effects). This is an ideal tool to demonstrate the effects that thermal stratification and de-stratification have on the distribution of other variables. **The relationship between water density (defined by its thermal characteristics - water density is greatest at 4_C) and the distribution of variables within the water column are an important consideration when assessing lake water quality.**

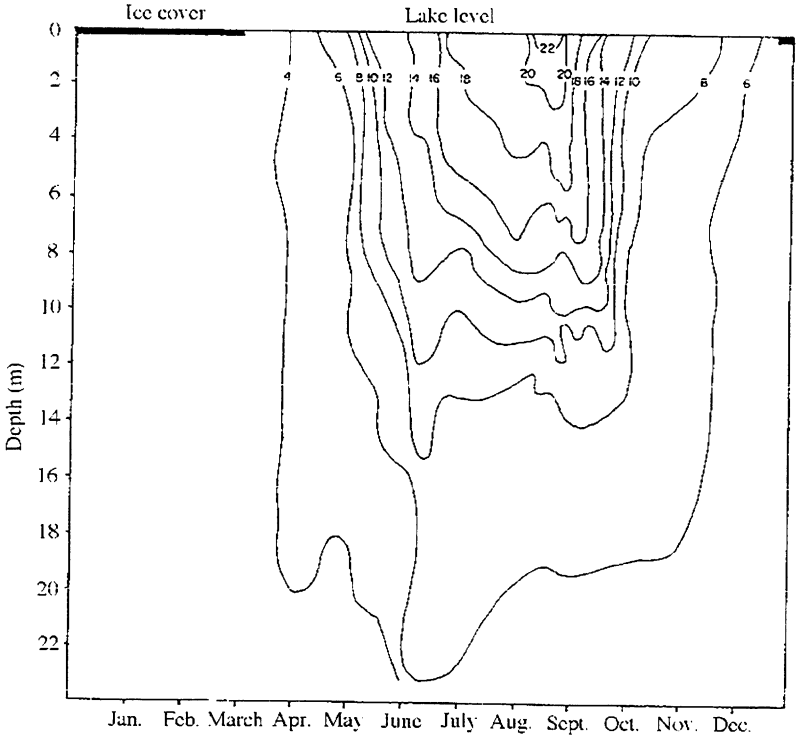

Figure 4. Hypothetical time-depth diagram for temperature

4.2 Statistics

The most reliable method of ascertaining water quality conditions is through statistical analyses of data. The specific analyses performed will have been decided upon during the design phase of the monitoring program. Consultation with a statistician during that initial phase ensures that the monitoring objectives are attainable, and provides guidance on the use of the various statistical tests. A complete discussion of all the statistics that are available for sampling programs is beyond the scope of these guidelines. However, the more general statistical tests are discussed in detail below. Under some circumstances, some of the more rigorous and robust tests, such as the ANOVA and non-parametric analyses are more appropriate than the ones discussed here. For a discussion of how these tests are applied refer to a statistical text. However, the following discussion includes those general statistics that are most likely to be applied in the context of water quality monitoring in British Columbia. As such, the following statistics will be the minimum required to test null hypotheses:

4.2.1 The Mean - The mean is the most widely used measure of central tendency. The most efficient, unbiased, and consistent estimate of the population mean, μ, is the sample mean, X (read as 'X bar'). It is calculated by summing the individual observations (_X*i*) and dividing by the number of sampling units (*n*). Hence

$$\overline{X} = \frac{\Sigma Xi}{n}$$

4.2.2 Deviation - The deviation is the quantity by which each individual data point differs from the arithmetic mean of the sample. Hence

$$\text{deviation for data point } Xi = |Xi - \overline{X}|$$

4.2.3 Variance - The variance is the mean of the squares of the deviations. The most efficient , unbiased estimate of the population variance, σ^2, is the sample variance s^2. It is calculated by first determining the 'sum of the squares of the deviations' (denoted SS) then dividing this value by the 'degrees of freedom' (the sample number, *n*, minus 1 - denoted v). Hence

$$SS = \Sigma(Xi - \overline{X})^2$$

$$s^2 = \frac{\Sigma(Xi - \overline{X})^2}{n-1}$$

4.2.4 Standard Deviation - The standard deviation (denoted *s*) is the positive square root of the variance. Hence

$$s = \frac{\sqrt{\Sigma(Xi - \overline{X})^2}}{n-1}$$

4.2.5 Percentiles - Percentiles are used for dividing samples into hundredths. For water quality sampling programs, this statistic is typically applied to toxicity testing and bacteriological criteria establishment.

An example of a toxicity percentile would be the expression LD_{50} (the 50th percentile of the lethal dose). This refers to a scenario in which 50% of the experimental subjects survive the particular dose of the contaminant while 50% do not.

An example of a percentile as it applies to bacteriological criteria establishment is the expression 'fewer than 10 fecal coliform bacteria per 100 mL of water (90th percentile)'. This criteria states that 90% of the samples collected must contain fewer than 10 bacteria per 100 mL of water. For example, if a single sample were collected on each of 30 consecutive days, then 27 of those samples would be required to have fewer than 10 coliform bacteria per 100 mL of water.

4.2.6 Hypothesis Testing (the F-test and the t-test) - As alluded to earlier, hypothesis testing for most water quality monitoring programs will seek to determine if a significant

difference exists (either spatially or temporally). One test that is applied to determine if a difference exists is the F-test. This test is most often used in water quality sampling programs to determine if variances are similar between either two sites or at one site between two time periods. In order to definitively state that a change has occurred as a result of human activity (treatment), it is necessary to establish that the variances between the control and treatment do not differ. The following discussion presents the formula for conducting the F-test. Appendix A provides an example. Later, applications of the t-test are discussed.

The F-test

In the case of comparing the variances of two sample populations, the F-test is considered a 'two-tailed test' because the null hypothesis is phrased to determine if the variance values of the samples are equal without regard for the direction of a potential difference. The following is the process for conducting a two-sample, two-tailed F-test:

1. Write the hypothesis in a mathematical form. Generally, the null and alternative hypotheses will be

$$H_o: s^2_1 = s^2_2$$

$$H_A: s^2_1 \neq s^2_2$$

Note: the null hypothesis is always phrased in a 'no impact' fashion.

2. Determine the F value according to the following formula

$$F = \frac{s^2_1}{s^2_2} \text{ or } F = \frac{s^2_2}{s^2_1} \text{ (whichever is larger)}$$

Note: see section 4.2.3 above for the formula to calculate the variance.

3. The next step is to determine if the calculated F ratio deviates so far from 1.0 such that the null hypothesis must be rejected. This is accomplished by comparing the calculated F value to the critical F value. To determine the critical F value, refer to an F-table and look up $F_{\alpha(2),v_1,v_2}$

   where:

   - α is the 'level of significance' established during the design phase of the program (typically $\alpha = 0.05$);
   - (2) refers to the fact that the analysis was a two-tailed test; and
   - v1 and v2 represent the degrees of freedom for each of the two samples (*n* minus 1 for each).

If the calculated F value is less than the critical F value then do not reject H_o.

Alternatively, if the calculated F value is greater than the critical F value then reject H_o.

Note: Under circumstances whereby the null hypothesis is not rejected, the variances are considered not the differ, and therefore, further tests to assess if an impact has occurred after

treatment (human activity) are valid. Conversely, when the null hypothesis is rejected, then the variances are considered to differ, invalidating further tests to assess impact.

The t-test

The test that will be presented next, the t-test, can be applied to determine if the concentration of a variable at a specific site significantly exceeds a criteria or objective value. The following discussion presents the formulas for conducting the t-test under alternative scenarios. Appendices B-D demonstrate each of the scenarios by way of example.

The alternative t-test scenarios that will most commonly be encountered in water quality monitoring programs are:

A two-sample, two-tailed t-test

In this case, two samples are required, generally an upstream and a downstream site. It is considered a 'two-tailed test' because the null hypothesis is phrased to determine if the mean values of the samples are equal without regard for the direction of a potential difference (i.e., if the null hypothesis is rejected, the test does not distinguish which mean value is greater than the other). An example of when this test might be applied would be a pre-treatment analysis of two sites (control and future treatment sites) to demonstrate that no difference exists between the two (and as such, the control is appropriately located). Future post-treatment differences that might be detected between the two sites would therefore, be attributable to the anthropogenic activity (treatment effect). The following is the process for conducting a two-sampled, two-tailed t-test:

1. Write the hypothesis in a mathematical form (arrived at during the program design phase of the project). Generally, the null and alternative hypotheses will be

$$H_o: \mu_{1(\text{upstream})} = \mu_{2(\text{downstream})}$$

$$H_A: \mu_1 \neq \mu_2$$

Note: the null hypothesis is always phrased in a 'no impact' fashion.

2. Determine the t value according to the following formula

$$t = \frac{\overline{X}_1 - \overline{X}_2}{S_{\overline{x}_1 - \overline{x}_2}}$$

where:

$$S_{\overline{x}_1 - \overline{x}_2} = \frac{\sqrt{S^2p + S^2p}}{n_1 + n_2}$$

and

$$S^2p = \frac{SS_1 + SS_2}{v_1 + v_2}$$

Note: see section 4.2.3 above for the formula to calculate the sum of the squares (SS). Recall that the degrees of freedom (v) is simply the number of samples (n) minus 1.

3. Refer to a t-table to determine the critical value of $t_{\alpha(2),v}$

   where:

   - α is the 'level of significance' established during the design phase of the program;
   - (2) refers to the fact that the analysis was a two-tailed test; and
   - v is the total degrees of freedom (simply $v_1 + v_2$).

4. Compare the calculated t value to the critical (table) t value to determine if the null hypothesis should be rejected.

$$\text{if } |t| \geq t_{\alpha(2),v} \text{ then reject } H_o$$

Note: a full example illustrating a two-sample, two-tailed t-test is provided in Appendix B.

A two-sample, one-tailed t-test

As above, two samples are required for this test. It is considered a 'one-tailed test' because it is designed to determine if the mean for one sample is significantly larger (or smaller) than the mean of the other sample (i.e., if the null hypothesis is rejected, the test does distinguish which sample is significantly greater than the other). An example of when this test might be applied would be a comparison between pre-treatment data and post-treatment data at one site. When the post-treatment mean value is apparently larger (or smaller), it would be appropriate to use the one-tailed test. Significant post-treatment differences would be attributable to the anthropogenic activity (treatment effect). The following is the process for conducting a two-sampled, one-tailed t-test:

1. Write the hypothesis in a mathematical form (it might have been speculated during the program development phase that an impact will likely occur as a result of a proposed land-use activity. In this case the one-tailed hypothesis would have been formulated during this early phase of the project. Conversely, the development of a one-tailed hypothesis might become warranted after data is collected). Generally, the null and alternative hypotheses will be

$$H_o: \mu_{1(\text{pre-treatment})} \geq \mu_{2(\text{post-treatment})}$$

$$H_A: \mu_1 < \mu_2$$

2. Determine the t value according to the following formula

$$t = \frac{\overline{X}_1 - \overline{X}_2}{S_{\bar{x}_1 - \bar{x}_2}}$$

   where:

$$S_{\bar{x}_1 - \bar{x}_2} = \frac{\sqrt{S^2p + S^2p}}{n_1 + n_2}$$

   and

$$S^2p = \frac{SS_1 + SS_2}{v_1 + v_2}$$

Note: see section 4.2.3 above for the formula to calculate the sum of the squares (SS). Recall that the degrees of freedom (v) is simply the number of samples (n) minus 1.

3. Refer to a t-table to determine the critical value of $t_{\alpha(1),v}$

   where:

   - α is the 'level of significance' established during the design phase of the program;
   - (1) refers to the fact that the analysis was a one-tailed test; and
   - v is the total degrees of freedom (simply $v_1 + v_2$).

4. Compare the calculated t value to the critical t value to determine if the null hypothesis should be rejected.

$$\text{if } |t| \geq t_{\alpha(1),v} \text{ then reject } H_o$$

Note: a full example illustrating a two-sample, one-tailed t-test is provided in Appendix C.

A one-sample, one-tailed t-test

In this case, one sample is all that is required for the test. It is considered a 'one-tailed test' because it is designed to determine if the mean for the sample is significantly larger (or smaller) than a specified value. An example of when this test might be applied would be to determine whether or not the mean concentration of a particular variable during a critical period exceeds the criteria (or objective) for that variable. The following is the process for conducting a one-sampled, one-tailed t-test:

1. Write the hypothesis in a mathematical form. Generally, the null and alternative hypotheses will be either

   H_o: $\mu \leq$ a specific numeric value (i.e., 200 µg/L Nickel)

   H_A: $\mu >$ than the value

   or

   H_o: $\mu \geq$ a specific numeric value (i.e., 6 mg/L Oxygen)

   H_A: $\mu <$ than the value

Note: in each of these scenarios, the null hypothesis is phrased in a 'non criteria exceedance' fashion.

2. Determine the t value according to the following formula

$$t = \frac{\overline{X} - \mu}{S_{\overline{x}}}$$

   where:

$$S_{\overline{x}} = \frac{\sqrt{S^2}}{n}$$

3. Refer to a t-table to determine the critical value of $t_{\alpha(1),v}$

   where:

- α is the 'level of significance' established during the design phase of the program;
- (1) refers to the fact that the analysis was a one-tailed test; and
- v is the degrees of freedom (simply n-1).

4. Compare the calculated t value to the critical t value to determine if the null hypothesis should be rejected.

$$\text{if } |t| \geq t_{\alpha(1),v} \text{ then reject } H_o$$

Note: a full example illustrating a one-sample, one-tailed t-test is provided in Appendix D.

5. Interpreting Data

The interpretation of water quality data involves integrating all the above information to evaluate the potential impacts to the aquatic ecosystem. This process is extensive and must be conducted systematically to avoid confusion.

During the design phase of the program, the variables of concern will have been clearly outlined; consequently, it will be these variables for which there is the most data. Interpretation and discussion of each variable should be tackled separately. The Water Quality Assessment portion of each report (see Chapter 6) will present a discussion of each variable as a separate sub-heading. Variables that have a significant impact on the concentration and/or distribution of others should be interpreted and presented first. For example, temperature has a very significant impact on other variables (i.e., increasing temperatures tend to elevate the solubility and toxicity of dissolved metals while dissolved oxygen levels generally decrease with increasing temperature). Thermal stratification events in lakes strongly influence the distribution of many variables within the water column. Temperature conditions within the study area may be the result of natural processes, but this variable should never be overlooked as it has impacts on the fate of many other variables.

When interpreting trends over time or space for each variable, the discussion is best expressed and supported using the visual (graphics) and statistical tools presented in Chapter 4.

Sections 5.1 ('Guide to Interpreting Ambient Water and Effluent Variables') provides basic descriptions of those water quality variables for which analyses are typically conducted. Many of these variables have provincial criteria values associated with them. If the monitoring program called for an analysis of other variables without B.C. criteria, it is recommended that guidelines prepared by CCME (Canadian Council of Ministers of the Environment) be used when assessing impact to the study area. Documents are available that provide detailed information for each variable (Nagpal, Pommen and Swain, 1997 - Approved and Working Criteria for Water Quality; CCREM and CCME, 1987-97 - Canadian Guidelines; EPA, 1986; Guidelines for Canadian Recreational Water Quality, 1992; Guidelines for Canadian Drinking Water Quality, 1996). Refer to the specific criteria document for more details. The full list of the British Columbia criteria documents is provided in the reference section of these guidelines. Sections 5.2 and 5.3 provide basic descriptions of sediment and biological variables (respectively). The majority of the criteria presented in the sediment sections are those prepared by CCME (as provincial criteria have not been developed for many sediment variables). Refer to the appropriate CCME documents for greater detail. It is important to note that criteria are continually being reviewed and revised. Therefore, people conducting data interpretations should seek out the most recent criteria.

Criteria are intended for use in assessing water quality data and preparing site-specific water quality objectives. The setting of objectives is not restricted to the values assigned by the criteria. In circumstances where the background levels are well below the criterion or where exceptional resources exist, then objectives can be set that are more rigorous than the criterion. When a monitoring program is being conducted in a water body for which

objectives have been set, then the objective values must be used (as opposed to criteria values) when assessing for impact or change.

5.1 Guide to Interpreting Ambient Water and Effluent Variables

The following guide defines each variable, discusses the importance of the variable to the aquatic environment, lists potential anthropogenic sources, and presents the BC criteria (if available).

5.1.1 General

1. Temperature

Definition: This is a measurement of the intensity (not amount) of heat stored in a volume of water. Surface water temperatures naturally range from 0°C under ice cover to 40°C in hot springs. Natural sources of heat include: solar radiation, transfer from air, condensation of water vapour at the water surface, sediments, precipitation, surface runoff and groundwater. Temperature is the primary influencing factor on water density.

Importance: Temperature affects the solubility of many chemical compounds and can therefore influence the effect of pollutants on aquatic life. Increased temperatures elevate the metabolic oxygen demand, which in conjunction with reduced oxygen solubility, impacts many species. Vertical stratification patterns that naturally occur in lakes affect the distribution of dissolved and suspended compounds.

Anthropogenic sources: industrial effluents, agriculture, forest harvesting, urban developments, mining.

Criteria:

- drinking water → maximum of 15°C for aesthetics
- aquatic life →±1°C, allowable change from natural level
- aquatic life (salmonids)

  →18-19°C maximum weekly average for adults and juveniles

  →8-10°C maximum weekly average for spawning

  →13-15°C maximum weekly average for embryo survival
- recreation → 15-35°C, range for bathing

2. pH

Definition: This is the measurement of the hydrogen-ion concentration in the water. A pH below 7 is acidic (the lower the number, the more acidic the water, with a decrease of one full unit representing an increase in acidity of ten times) and a pH above 7 (to a maximum of 14) is basic (the higher the number, the more basic the water). Natural fresh waters have a pH range from 4.0 to 10.0, although most lakes in B.C. have a pH of 7.0 or greater. Coastal streams commonly have pH values of 5.5 to 6.5.

Importance: High pH values tend to facilitate the solubilization of ammonia, heavy metals and salts. The precipitation of carbonate salts (marl) is encouraged when pH levels are high. Low pH levels tend to increase carbon dioxide and carbonic acid concentrations. Lethal effects of pH on aquatic life occur below pH 4.5 and above pH 9.5.

Anthropogenic sources: mining, agriculture, industrial effluents, acidic precipitation (derived from emissions to the atmosphere from cars and industry).

Criteria:

- drinking water → 6.5-8.5
- aquatic life → generally 6.5-9.0 unless background levels are otherwise and unique fauna and flora exist (i.e., boggy areas with pH below 6.5, marl lakes with pH above 9.0)
- livestock watering → 5.0-9.5
- irrigation → 5.0-9.0
- recreation → 5.0-9.0

3. Dissolved Oxygen (DO)

Definition: This is a measure of the amount of oxygen dissolved in water. Typically the concentration of dissolved oxygen in surface water is less than 10 mg/L. The DO concentration is subject to diurnal and seasonal fluctuations that are due, in part, to variations in temperature, photosynthetic activity and river discharge. The maximum solubility of oxygen (fully saturated) ranges from approximately 15 mg/L at 0°C to 8 mg/L at 25°C (at sea level). Natural sources of dissolved oxygen are derived from the atmosphere or through photosynthetic production by aquatic plants. Natural re-aeration of streams can take place in areas of waterfalls and rapids.

Importance: Dissolved oxygen is essential to the respiratory metabolism of most aquatic organisms. It affects the solubility and availability of nutrients, and therefore the productivity of aquatic ecosystems. Low levels of dissolved oxygen facilitate the release of nutrients from the sediments. Oligotrophic (low nutrient) lakes tend to have increased concentrations of dissolved oxygen in the hypolimnion (deeper waters) relative to the epilimnion (defined as orthograde oxygen profiles). Eutrophic (high nutrient) lakes tend to have decreased concentrations of dissolved oxygen in the hypolimnion relative to the epilimnion (defined as clinograde oxygen profiles).

Anthropogenic causes of decreased DO: forest harvesting, pulp mills, agriculture, sewage treatment plant effluent, industrial effluents, impoundments (dams).

Criteria:

- aquatic life (fish)

  → buried embryo and alevin stages for water column data

  9 mg/L (instantaneous minimum)

  11 mg/L (30-day mean)

  → buried embryo and alevin stages for inter gravel data 6 mg/L (instantaneous minimum)

  8 mg/L (30-day mean)

  → all life stages other than buried embryo and alevin for water column data

  5 mg/L (instantaneous minimum)

  8 mg/L (30-day mean)

- aquatic life (invertebrates)

  → 4.0 mg/L is the limit to avoid acute mortality while greater than 8.0 mg/L imparts no production impairment.

- recreation →2 mg/L, minimum for bathing

4. Specific Conductivity

Definition: This is the measurement of the ability of water to conduct an electric current - the greater the content of ions in the water, the more current the water can carry. Ions are dissolved metals and other dissolved materials. Conductivity is reported in terms of microsiemens per centimeter (μS/cm). Natural waters are found to vary between 50 and 1500 μS/cm. Coastal streams in BC have specific conductivity values of ≤100 μS/cm, while interior streams range up to 500 μS/cm.

Importance: Specific Conductivity may be used to estimate the total ion concentration of the water, and is often used as an alternative measure of dissolved solids. It is often possible to establish a correlation between conductivity and dissolved solids for a specific body of water [dissolved solids = conductivity x 0.55 to 0.9 (the most often used is 0.7)].

Anthropogenic sources: mining, roads (de-icing salts), industrial & municipal effluents.

Criteria: Due to its natural variability, there is no criterion recommended for this variable. Approved and Working Criteria give some guidance for livestock, irrigation, industrial and drinking water for dissolved solids that can be converted using the above formula [e.g., the Filterable Residue criterion for drinking water of 500 mg/L would convert to a conductivity value of about 700 μS/cm (500 ÷ 0.7 = 714 μS/cm)].

5. Turbidity

Definition: This is a measurement of the suspended particulate matter in a water body which interferes with the passage of a beam of light through the water. Materials that contribute to turbidity are silt, clay, organic material, or micro-organisms. Turbidity values are generally reported in Nephelometric Turbidity Units (NTU). Pure distilled water would have non-detectable turbidity (0 NTU). The extinction depth (for lakes), measured with a Secchi disc, is an alternative means of expressing turbidity.

Importance: High levels of turbidity increase the total available surface area of solids in suspension upon which bacteria can grow. High turbidity reduces light penetration; therefore, it impairs photosynthesis of submerged vegetation and algae. In turn, the reduced plant growth may suppress fish productivity. Turbidity interferes with the disinfection of drinking water and is aesthetically unpleasant.

Anthropogenic sources: forest harvesting, road building, agriculture, urban developments, sewage treatment plant effluents, mining, industrial effluents.

Criteria:

- drinking water at the point of consumption

  $\rightarrow$ 1 NTU maximum (health),

  $\rightarrow$ 5 NTU maximum (aesthetics)

- aquatic life

  $\rightarrow$ 5 NTU increase when background $\leq$ 50 NTU

  $\rightarrow$ 10% increase when background > 50 NTU

6. Residue, Non-filterable (Suspended solids)

Definition: This is a measure of the particulate matter that is suspended within the water column. Non-filterable residue values are reported in mg/L.

Importance: High concentrations of non-filterable residue increases turbidity, thereby restricting light penetration (hindering photosynthetic activity). Suspended material can result in damage to fish gills. Settling suspended solids can cause impairment to spawning habitat by smothering fish eggs. Suspended solids interfere with water treatment processes. Ongoing research is aimed at developing a suspended sediment stress index for use in British Columbia. The index would be a tool to evaluate the impacts of suspended sediments on aquatic ecosystems via a dose response model (where dose = concentration * duration).

Anthropogenic sources: forest harvesting, road building, industrial effluents, urban developments, placer mining, municipal sewage treatment plants.

Criteria:

- aquatic life → maximum increase of 10 mg/L when background is ≤ 100 mg/L. Maximum of 10% increase over background when background levels are >100 mg/L.

  → no induced benthic sedimentation of particles smaller than 3 mm in salmonid spawning habitat.
- wildlife → maximum of 20 mg/L when background is ≤100 mg/L. Maximum of 20% of background when background levels are >100 mg/L.
- industrial water supplies→ maximum of 20 mg/L when background is ≤100 mg/L. Maximum of 20% of background when background levels are >100 mg/L.

7. Residue, Filterable (Total dissolved solids - TDS)

Definition: This is a measure of the amount of dissolved material in the water column. It is reported in mg/L with values in fresh water naturally ranging from 0-1000 mg/L. Dissolved salts such as sodium, chloride, magnesium and sulphate contribute to elevated filterable residue values. Generally, streams on the coast of BC have dissolved solid concentrations <75 mg/L, while those in the interior of the province can have up to 750 mg/L.

Importance: High concentrations of TDS limit the suitability of water as a drinking source and irrigation supply. High TDS waters may interfere with the clarity, colour and taste of manufactured products.

Anthropogenic sources: mining, industrial effluent, sewage treatment, agriculture, road salts.

Criteria:

- drinking water → maximum of 500 mg/L
- livestock

→ (sensitive species) maximum of 1000 mg/L

→ (other species) maximum of 3000 mg/L

- irrigation → 500-3500 mg/L depending on crop and soil, designed to minimize salinization of fields.

8. Alkalinity

Definition: This is the measurement of the water's ability to neutralize acids. It usually indicates the presence of carbonate, bicarbonates, or hydroxides. Alkalinity results are expressed in terms of an equivalent amount of calcium carbonate. Note that this does not mean that calcium carbonate was found in the sample. Natural waters rarely have levels that exceed 500 mg/L. Alkalinity values in coastal areas of BC typically range from 0 to 10 mg/L, while interior regions of the province can have alkalinity values that exceed 100 mg/L.

Importance: Waters that have high alkalinity values are considered undesirable because of excessive hardness and high concentrations of sodium salts. Water with low alkalinity have little capacity to buffer acidic inputs and are susceptible to acidification (low pH).

Anthropogenic sources that destroy alkalinity: mining, industrial effluents, acidic precipitation.

Criteria:

- aquatic life → Swain (1994) has indicated that the following alkalinity values are related to the sensitivity of water bodies to acidic inputs:

  0-10 mg/L high sensitivity

  10-20 mg/L moderate sensitivity

  >20 mg/L low sensitivity

9. Hardness, total

Definition: The hardness of water is generally due to the presence of calcium and magnesium in the water. Other metallic ions may also contribute to hardness. Hardness is reported in terms of calcium carbonate and in units of milligrams per litre (mg/L). Waters with values exceeding 120 mg/L are considered hard, while values below 60 mg/L are considered soft.

Importance: Harder water has the effect of reducing the toxicity of some metals (i.e., copper, lead, zinc, etc.). Soft water may have corrosive effect on metal plumbing, while hard water may result in scale deposits in the pipes. If the water has a hardness of greater than 500 mg/L, then it is normally unacceptable for most domestic purposes and must be treated.

Anthropogenic sources: mining, industrial effluents.

Criteria:

- drinking water → 80 to 100 mg/L is the optimal range (>200 mg/L is considered poor but can be tolerated, >500 mg/L is unacceptable)
- food processing → 10-250 mg/L

10. Carbon, total organic (TOC)

Definition: This is a measure of the dissolved and particulate organic carbon in water. The bulk of organic carbon in water is composed of humic substances and partly degraded plant and animal materials. Organic carbon is resistant to microbial degradation. It is reported as mg/L and its range in natural waters may vary from 1 - 30 mg/L.

Importance: Carbon is a nutrient required for biological processes. High levels of organic carbon coincide with a lowering of dissolved oxygen concentrations.

Anthropogenic sources: agriculture, municipal and industrial waste discharges (especially pulp and paper plants).

Criteria: None. The U.S. EPA recently set 4 mg/L TOC as a limit to prevent trihalomethane formation in raw drinking water subject to chlorination.

11. Carbon, total inorganic

Definition: This is a measure of the sum of carbonates, bicarbonates, and carbonic acid. The relative amount of each of these three components is dependent on the pH of the water. At pH 7 to 8, which is typically encountered in most fresh water systems, the bicarbonate ion predominates (60-90% of the total inorganic carbon). Bicarbonate concentrations in surface waters are usually less than 500 mg/L and frequently less than 25 mg/L.

Importance: Carbon is a nutrient required for biological processes. The inorganic forms of carbon are part of the carbon cycle of the biosphere. The bicarbonate ions serve as the main buffer in freshwater systems and provide carbon dioxide for photosynthesis.

Anthropogenic sources: Many industries use bicarbonate salts due to their high solubility.

Criteria: None.

12. Colour, true

Definition: This is a measure of the dissolved colouring compounds in water. The colour of water is attributed to the presence of organic and inorganic materials; different materials absorb different light frequencies. Colour is expressed as Pt-Co units according to the platinum-cobalt scale. Water colour can naturally range from 0-300 Pt-Co. Higher values are associated with swamps and bogs.

Importance: Colour is regarded as a pollution problem in terms aesthetics, but is not generally considered a detriment to aquatic life. Increased colour may interfere with the passage of light, thereby impeding photosynthesis.

Anthropogenic sources: agriculture, industrial effluents (particularly pulp and paper mills).

Criteria:

- drinking water (aesthetic reasons) → 15 Pt-Co
- recreation → 15 Pt-Co is considered desirable

13. Cyanide

Definition: Cyanide is measured in various forms in water samples. It is reported in either µg/L or mg/L. Cyanide can combine with metals to form a variety of compounds. The form it takes is largely dependent on pH, temperature, dissolved oxygen, salinity, and the presence of other ions.

Importance: Cyanide is a toxic substance that renders tissues incapable of oxygen exchange. At pH less than 8, cyanide exists as undissociated hydrogen cyanide (HCN), which is more toxic to aquatic life than the free cyanide ion. Cyanide is acutely toxic to most species of fish at concentrations greater than 200 µg/L.

Anthropogenic sources: many industrial effluents, mining (especially gold mining).

Criteria:

- raw drinking water (strong-acid dissociable cyanide plus thiocyanate)

  → maximum 200 µg/L

- aquatic life (weak-acid dissociable cyanide)

  → maximum 10 µg/L

  → ≤5 µg/L, 30-day average

5.1.2 Nutrients (Nitrogen and Phosphorus)

1. Total Ammonia (NH3 & NH4+)

Definition: This is a measure of the most reduced inorganic form of nitrogen in water and includes dissolved ammonia (NH_3) and the ammonium ion (NH_4^+). Nitrogen is an essential plant nutrient and although ammonia is only a small component of the nitrogen cycle, it contributes to the trophic status of a body of water. Ammonia is generally reported in either µg/L or mg/L. Natural waters typically have ammonia concentrations less than 0.1 mg/L.

Importance: Excess ammonia contributes to eutrophication of water bodies. This results in prolific algal growths that have deleterious impacts on other aquatic life, drinking water supplies, and recreation. Ammonia at high concentrations is toxic to aquatic life.

Anthropogenic sources: sewage treatment plant effluents, agriculture, urban developments, recreation, industrial effluents, mining (blasting residuals).

Criteria:

- aquatic life → the criteria set for ammonia to protect aquatic life are dependent on the temperature and pH of the water. The matrix is too extensive to present here, but this information can be obtained from Nordin (1990) or Nagpal *et. al.*, (1997). However, as an example, at pH 7.0 and a water temperature of 15°C, the maximum concentration should not exceed 19.7 mg/L, and the average over 30-days should not exceed 1.77 mg/L. At 0°C, these values would be 23.2 mg/L and 2.08 mg/l, respectively.

2. Nitrite (NO_2^-)

Definition: This is a measure of a form of nitrogen that occurs as an intermediate in the nitrogen cycle. It is an unstable form that is either rapidly oxidized to nitrate (nitrification) or reduced to nitrogen gas (de-nitrification). This form of nitrogen can also be used as a source of nutrients for plants. Nitrite is generally reported in either µg/L or mg/L. It is normally present in only minute quantities in surface waters (<0.001 mg/L).

Importance: Since nitrite is also a source of nutrients for plants its presence encourages plant proliferation. Nitrite is toxic to aquatic life at relatively low concentrations.

Anthropogenic sources: sewage treatment plant effluents, agriculture, urban developments, recreation, industrial effluents, mining (blasting residuals).

Criteria:

- drinking water → maximum of 1 mg/L
- aquatic life

  → allowable concentrations rise with increased chloride concentrations. The lowest criteria are for chloride <2 mg/L: maximum nitrite of 0.06 mg/L

  → average of 0.02 mg/L
- livestock watering → maximum of 10 mg/L
- wildlife → maximum of 10 mg/L
- recreation → maximum of 1 mg/L

3. Nitrate (NO3-)

Definition: This is the measurement of the most oxidized and stable form of nitrogen in a water body. Nitrate is the principle form of combined nitrogen found in natural waters. It results from the complete oxidation of nitrogen compounds. It is generally reported in µg/L or mg/L. Without anthropogenic inputs, most surface waters have less than 0.3 mg/L of nitrate.

Importance: Nitrate is the primary form of nitrogen used by plants as a nutrient to stimulate growth. Excessive amounts of nitrogen may result in phytoplankton or macrophyte proliferations. At high levels it is toxic to infants.

Anthropogenic sources: sewage treatment plant effluents, agriculture, urban developments, recreation, industrial effluents, mining (blasting residuals).

Criteria:

- drinking water → maximum of 10 mg/L
- aquatic life → maximum of 200 mg/L and average of 40 mg/L
- livestock watering → maximum of 100 mg/L
- wildlife → maximum of 100 mg/L
- recreation → maximum of 10 mg/L

4. Total organic nitrogen

Definition: This is a measure of that portion of nitrogen that is organically bound. Organic nitrogen includes all organic compounds such as proteins, polypeptides, amino acids, and urea. It is reported as mg/L. Dissolved organic nitrogen can often constitute over 50% of the total soluble nitrogen in fresh water.

Importance: Organic nitrogen is not immediately available for biological activity. Therefore, it does not contribute to furthering plant proliferation until decomposition to the inorganic forms of nitrogen occurs.

Anthropogenic sources: sewage treatment plant effluents, agriculture, urban developments, paper plants, industrial effluents.

Criteria: None

5. Kjeldahl nitrogen

Definition: This is a measure of both the ammonia and the organic forms of nitrogen.

Importance: Excess ammonia contributes to eutrophication of water bodies. This results in prolific algal growths that have deleterious impacts on other aquatic life, drinking water supplies, and recreation. Ammonia at high concentrations is toxic to aquatic life. Organic nitrogen is not immediately available for biological activity. Therefore, it does not contribute to furthering plant proliferation until decomposition to the inorganic forms of nitrogen occurs.

Anthropogenic sources: sewage treatment plant effluents, agriculture, urban developments, paper plants, industrial effluents, recreation, mining (blasting residuals).

Criteria: None

6. Total nitrogen

Definition: This is a measure of all forms of nitrogen (organic and inorganic). Nitrogen is an essential plant element and is often the limiting nutrient in marine waters.

Importance: The importance of nitrogen in the aquatic environment varies according to the relative amounts of the forms of nitrogen present, be it ammonia, nitrite, nitrate, or organic nitrogen (each of which are discussed in detail above).

Anthropogenic sources: sewage treatment plant effluents, agriculture, urban developments, paper plants, industrial effluents, recreation, mining (blasting residuals).

Criteria: None

7. Total phosphorus

Definition: This is a measure of both inorganic and organic forms of phosphorus. Phosphorus can be present as dissolved or particulate matter. It is an essential plant nutrient and is often the most limiting nutrient to plant growth in fresh water. It is rarely found in significant concentrations in surface waters. It is generally reported in µg/L or mg/L. The total phosphorus concentrations in most lakes not affected by anthropogenic inputs is generally less than 0.01 mg/L (10 µg/L).

Importance: Since phosphorus is generally the most limiting nutrient, its input to fresh water systems can cause extreme proliferations of algal growth. Inputs of phosphorus are the prime contributing factors to eutrophication in most fresh water systems. A general guideline regarding phosphorus and lake productivity is: <10 µg/L phosphorus yields is considered oligotrophic, 10-25 µg/L P will be found in lakes considered mesotrophic, and >25 µg/L P will be found in lakes considered eutrophic.

Anthropogenic sources: sewage treatment plant effluent, agriculture, urban developments (particularly from detergents), industrial effluents.

Criteria (at spring overturn):

- drinking water → maximum of 10 µg/L
- aquatic life → lakes, in the range of 5-15 µg/L
- recreation → lakes, maximum of 10 µg/L

8. Orthophosphate (PO4-3)

Definition: This is a measure of the inorganic oxidized form of soluble phosphorus. It is generally reported in µg/L or mg/L.

Importance: This form of phosphorus is the most readily available for uptake during photosynthesis. High concentrations of orthophosphate generally occur in conjunction with algal blooms.

Anthropogenic sources: sewage treatment plant effluent, agriculture, urban developments, industrial effluents.

Criteria: None

5.1.3 Halides

1. Chloride

Definition: Of the halides, chloride appears in the highest concentrations in natural fresh water systems. It is reported as mg/L dissolved chloride. The average chloride concentration in natural fresh waters is approximately 8.3 mg/L. Halide concentrations are generally greater in lakes that are in proximity to marine regions.

Importance: Chloride is important in terms of metabolic processes, as it influences osmotic salinity balance and ion exchange. Higher chloride concentrations can reduce the toxicity of nitrite to aquatic life.

Anthropogenic sources: municipal water supply disinfection, sewage treatment plant effluents, urban developments, industrial effluents, mining.

Criteria: None

2. Fluoride

Definition: Fluoride may be present as the result of the natural decomposition of rocks, or when present in treated drinking water supplies, as the result of a local water fluoridation program. It is reported as mg/L total fluoride.

Importance: Fluoride prevents tooth decay. Excessive amounts of fluoride can result in mottled tooth enamel. The maximum acceptable concentration in drinking water is 1.5 mg/L.

Anthropogenic sources: fluoridation of drinking water supplies, mining, smelting.

Criteria:

- raw drinking water → 1.0 mg/L, 30-day average, with a maximum of 1.5 mg/L
- aquatic life

  → 0.2 mg/L, maximum when hardness <50 mg/L

  → 0.3 mg/L, maximum when hardness ≥50 mg/L
- wildlife → 1.0 mg/L, 30-day average, with a maximum of 1.5 mg/L
- industry → 1.0 mg/L, 30-day average, with a maximum of 1.5 mg/L
- livestock

  → (dairy cows, breeding stock, other long lived animals) 1.0 mg/L, 30-day average, with a maximum of 1.5 mg/L

  → (other livestock) 2.0 mg/L, 30-day average, with a maximum of 4.0 mg/L

5.1.4 Metals

1. Aluminum

Definition: Aluminum is measured in either the total or dissolved state in a water sample. It is reported in mg/L and is generally found in concentrations of less than 1.0 mg/L. It is rapidly sorbed to sediments and precipitated from solution.

Importance: Aluminum is not considered a serious threat to public health. It can precipitate out and form scale depositions during high heat industrial processes. It is important in areas of acidic inputs since it can cause deformation of embryos at low pH.

Anthropogenic sources: industrial effluent (particularly dye and paper manufacturing), mining (acid mine drainage).

Criteria:

- drinking water → maximum 0.2 mg/L dissolved aluminum for aesthetic reasons
- aquatic life → maximum 0.1 mg/L dissolved aluminum at pH ≥6.5 (average 0.05 mg/L)
- wildlife → maximum 5 mg/L total aluminum
- livestock watering → maximum 5 mg/L total aluminum
- irrigation → maximum 5 mg/L total aluminum
- recreation → maximum 0.2 mg/L dissolved aluminum

2. Cadmium

Definition: Cadmium is measured in either the total or dissolved state in a water sample. It is reported in mg/L or µg/L and is generally found in trace concentrations of less than 0.1 µg/L. At high pH cadmium precipitates from solution. Cadmium is closely associated with zinc and lead in the natural environment.

Importance: Cadmium has cumulative and highly toxic effects in all chemical forms. It accumulates in plant cells. Cadmium has been known to have extremely toxic effects on trout and zooplankton. Other heavy metals such as zinc and copper are known to increase cadmium's toxicity.

Anthropogenic sources: many industrial effluents (also released to atmosphere which then becomes aerial input), mining.

Criteria:

drinking water → maximum 5 µg/L

- aquatic life

  → maximum 0.02 µg/L (30 mg/L hardness)

  → maximum 0.03 µg/L (90 mg/L hardness)

  → maximum 0.05 µg/L (150 mg/L hardness)
- livestock watering → maximum 80 µg/L
- irrigation → maximum 5 µg/L
- recreation → maximum 10 mg/L

3. Copper

Definition: Copper is measured in either the total or dissolved state in a water sample. It is reported in either µg/L or mg/L and is generally found in trace concentrations in the range from 1-10 µg/L.

Importance: Copper is essential for all plant and animal nutrition. Increased quantities of copper make water distasteful to drink. Very large prolonged doses may result liver damage. Copper is acutely toxic to most forms of aquatic life at relatively low concentrations. In the presence of excess quantities of molybdenum in forage crops, copper can ameliorate molybdenum toxicity and prevent the onset of molybdenosis in cattle and other ruminants.

Anthropogenic sources: many industrial effluents (also released to atmosphere which then becomes aerial input), mining, urban developments (plumbing).

Criteria:

- drinking water → maximum 500 µg/L
- aquatic life → maximum of [0.094(hardness) + 2) µg/L

  → average 2 µg/L when hardness ≤ 50 mg/L

  → average 0.04 x (average hardness value) when hardness > 50 mg/L.
- wildlife → maximum 300 µg/L
- livestock watering → maximum 300 µg/L
- irrigation → maximum 200 µg/L
- recreation → maximum 1000 µg/L

4. Lead

Definition: Lead is measured as either the total or dissolved form in water samples. It is reported in either µg/L or mg/L. Generally low concentrations of lead are found in water owing to its low solubility. Unless located in regions of sulphide ores where lead concentrations can be as high as 800 µg/L, most natural waters in B.C. contain less than 3 µg/L of lead. Lead is more soluble in soft waters than in hard waters.

Importance: Lead is a toxic element that accumulates in the skeletal structures. The toxic effects of lead to fish decreases with increasing water hardness and dissolved oxygen.

Anthropogenic inputs: urban developments, industrial effluents, mining.

Criteria:

- drinking water → maximum 10 µg/L
- food processing → maximum 10 µg/L
- aquatic life → maximum 3 µg/L at hardness ≤8 mg/L

  → refer to table in the Approved and Working Criteria document (Nagpal et.al., 1997) for details when hardness exceeds 8 mg/L.
- wildlife → maximum 100 µg/L
- livestock watering → maximum 100 µg/L
- irrigation

  → maximum 400 µg/L for neutral and alkaline fine soils

  → maximum 200 µg/L for all other soils
- recreation → maximum 10 µg/L

5. Mercury

Definition: Mercury is reported as the total mercury in water or tissue samples. It is reported in µg/L or ng/L. Mercury is a trace metal in the earth's crust and occurs in only minute quantities in natural waters (typically 1-2 ng/L). Water samples with values of 5-10 ng/L (using ultra-clean techniques) are considered polluted. Due to these low concentrations, contamination during sample collection and analysis is a considerable problem, making it is difficult to measure mercury in ambient water samples accurately. Consequently, it is more frequently measured in tissue samples where concentrations are much higher and contamination is less likely.

Importance: Mercury compounds are highly toxic and have a long retention time in animal cells. Mercury bioaccumulates in the kidney and liver and can cause permanent brain damage.

Anthropogenic sources: Mercury compounds are used in a number of commercial and industrial processes (e.g., mining and smelting, fertilizer production). It was used as a slimicide in pulp and paper plants in the past. Impoundments, or the flooding of terrestrial areas, results in a release of mercury from sediments. Due to the fact that mercury is volatile, atmospheric deposition is a major pathway to aquatic systems.

Criteria:

- drinking water → maximum 1.0 µg/L
- food processing → maximum 1.0 µg/L
- aquatic life

  → maximum 0.1 µg/L

  → 0.02 µg/L, 30-day average
- wildlife → maximum 3.0 µg/L
- livestock watering → maximum 2.0 µg/L
- irrigation → maximum 1.0 µg/L
- recreation → maximum 1.0 µg/L

6. Molybdenum

Definition: Molybdenum is measured in either the total or dissolved state in a water sample. It is reported in mg/L or µg/L and is normally found in uncontaminated systems in concentrations of less than 10 µg/L.

Importance: Molybdenum is a biologically essential micronutrient that is active in oxidation-reduction enzyme systems. It is also a required element for nitrogen fixation. It is a low toxicity element that does not bioaccumulate in animal tissue. It does, on the other hand, accumulate in plant tissue. Consequently, it may limit the use of water for irrigation purposes since animals (especially ruminants) that consume forage with excess molybdenum can develop a condition known as molybdenosis.

Anthropogenic sources: industry (steel alloy and electronics manufacturing), agriculture (fertilizers), mining.

Criteria: expressed as total molybdenum

- drinking water → maximum 0.25 mg/L
- aquatic life → maximum 2.0 mg/L

  → ≤1.0 mg/L, 30-day average
- wildlife → maximum 0.05 mg/L
- livestock watering

  → maximum 0.08 mg/L for livestock that consume forages not irrigated or if no molybdenum-containing fertilizers are applied to feed

  → maximum 0.05 mg/L for all other livestock
- irrigation

  → ≤0.01 mg/L, 30-day mean for poorly drained soils - Cu:Mo<2:1 in irrigation, forage crops

  → ≤0.02 mg/L, 30-day mean for poorly drained soils - Cu:Mo>2:1 in irrigation, forage crops

  → ≤0.02 mg/L, 30-day mean for well drained soils - forage crops

  → ≤0.03 mg/L, 30-day mean for all soil, non-forage crops

  → 0.05 mg/L, maximum all soils and crops

7. Silver

Definition: Silver is measured in either the total or dissolved state in a water sample. It is reported in µg/L. Silver occurs in only trace amounts in natural waters.

Importance: Silver is toxic to aquatic organisms.

Anthropogenic sources: mining activities, industries (coin and jewelry production, photography, manufacture of chemicals and ink).

Criteria: expressed as total silver

- aquatic life

→ maximum 0.05 µg/L, 30-day mean when hardness ≤100 mg/L

→ maximum 0.1 µg/L, instantaneous measurement when hardness ≤100 mg/L

→ maximum 1.5 µg/L, 30-day mean when hardness >100 mg/L

→ maximum 3 µg/L, instantaneous measurement when hardness >100 mg/L

8. Zinc

Definition: Zinc is measured in either the total or dissolved state in a water sample. It is reported in mg/L or µg/L and is normally found in concentrations of less than 0.05 mg/L. In areas of naturally acidic waters it can reach a maximum of 50 mg/L.

Importance: Zinc is an essential element for plants and animals as it is necessary for the functioning of certain enzymes. Zinc is relatively non-toxic to terrestrial organisms. It is acutely and chronically toxic to aquatic organisms, particularly fish. Zinc toxicity decreases with increasing hardness, increases with increasing temperature, and increases with decreasing dissolved oxygen.

Anthropogenic sources: mining activities, industries (paints, rubber, textiles, printing), agriculture (fertilizers, pesticides), urban runoff.

Criteria: Ministry Draft Criteria

- drinking water → maximum 5 mg/L
- aquatic life

  → maximum 7 µg/L (≥90 mg/L hardness)

  → maximum 14.5 µg/L (100 mg/L hardness)

  → maximum 90 µg/L (200 mg/L hardness)

  → maximum 165 µg/L (300 mg/L hardness)

  → maximum 241 µg/L (400 mg/L hardness)
- livestock watering → maximum 2 mg/L
- irrigation

  → maximum 1 mg/L (soil pH <6)

  → maximum 2 mg/L (soil pH 6-7)

  → maximum 5 mg/L (soil pH >7)
- recreation → maximum 5 mg/L

5.1.5 Organics

1. Polychlorinated biphenyls (PCBs)

Definition: This a measure of a group of industrial chemicals that were used as plasticizers and thermal insulators in transformers and electrical wires. They are now banned for use in Canada. PCBs are highly resistant to biological, chemical and thermal degradation. They are inert chemicals that are relatively insoluble in water and tend to accumulate in sediments.

Importance: PCBs have varying degrees of toxicity depending on the percent of chlorine substitution. They bioaccumulate and tend to be in highest concentrations in fatty tissues. PCBs interfere with reproductive capabilities (this has been amply demonstrated with animals that are high on a food chain such as predatory birds).

Anthropogenic sources: municipal and industrial effluent discharges

Criteria: expressed as Total PCBs (see Approved and Working Criteria, 1997, for specific PCB congeners)

- aquatic life → maximum 0.0001 µg/L
- irrigation → maximum 0.5 µg/L

2. Chlorophenols

Definition: Chlorophenols are measured in water, sediment, or tissue samples. They are reported in µg/L (water) or µg/g (tissue). Chlorophenols are generally formed when phenolic substances are present in waters that are chlorinated. They have been used in the past as an anti-sapstain chemical in the lumber industry, but are no longer permitted for use in Canada.

Importance: Chlorophenols are highly toxic and cause severe taste and odour problems when present in low concentrations. They have a high oxygen demand which enhances their toxicity (particularly to fish).

Anthropogenic sources: phenolic substances are contributed to the aquatic environment through municipal and industrial effluent discharges, agriculture, and pesticides.

Criteria (water and tissue samples): → the maximum concentration for any water use depends on the type of chlorophenol (primarily dependent on the number of chlorine molecules bound). Refer to Warrington, 1993 for details.

3. Polychlorinated Dibenzo-p-dioxins and Polychlorinated dibenzofurans (PCDDs and PCDFs)

Definition: PCDD/Fs are a group of unwanted byproducts from industries that use chlorine in their processing. They have no use and are not produced intentionally except for scientific study. PCDD/Fs are persistent chemicals that are very insoluble in water and tend to accumulate in the sediments.

Importance: PCDD/Fs have varying degrees of toxicity depending on the number and location of the chlorine atoms on the molecule. Congeners of most concern are those substituted in the 2,3,7, and 8 positions. They bioaccumulate and tend to be in the highest concentrations in the fatty tissues. PCDD/Fs can cause a wide range of effects including dermal toxicity, thymic atrophy, immunotoxicity, teratogenicity, subcutaneous edema, wasting syndrome, delayed mortality, reproductive effects, reduced growth, and disruption of the endocrine system. They have also been linked to cancer in mammals.

Anthropogenic sources: chemical product impurities (e.g. pesticides, PCBs), industrial sources (e.g. pulp and paper mills), and combustion (e.g. waste incineration).

Criteria (water sample): The Draft Ministry Criterion for 2,3,7,8 PCDD in a water sample is a maximum of 0.06 pg/L TEQ's

4. Polycyclic Aromatic Hydrocarbons (PAHs)

Definition: PAHs are compounds composed of two or more benzene rings fused together. They are ubiquitous in the environment. The environmentally significant PAHs contain two to seven benzene rings. PAHs are used as intermediaries in pharmaceutical, photographic, and chemical industries. Some are used in the production of fungicides, insecticides, and surfactants. They are reported in µg/L in water or µg/L in sediments or tissues.

Importance: The lower molecular weight PAHs (two or three benzene rings) are acutely toxic to aquatic life. PAHs with four to seven rings are not as acutely toxic, but several are known to be carcinogenic.

Anthropogenic sources: fossil fuels, agricultural burning, industrial processes, pest treatment, urban runoff

Criteria (water sample):

- drinking water → maximum 0.01 µg/L Benzo[a]pyrene
- aquatic life

  → Anthracene - maximum 0.1 µg/L

  → Acridine - maximum 0.05 µg/L

  → Fluoranthene - maximum 0.2 µg/L

  → Pyrene - maximum 0.02 µg/L

  → Benz[a]anthracene - maximum 0.1 µg/L
- food processing industries → maximum 0.01 µg/L Benzo[a]pyrene

5.2 Guide to Interpreting Sediment Variables

5.2.1 Particle size distribution (induced benthic sedimentation)

Definition: This is a measure of the relative composition of material in the stream bed. It is most often recorded as the significant accumulation by weight (95% confidence level)

Importance. Particle size of bed material directly affects the flow resistance in the channel, the stability of the bed, and the amount of aquatic habitat. Flow resistance and bed stability are stream characteristics that are typically analyzed by hydrologists. Particle size assessments for aquatic habitat studies (although commonly conducted by fisheries biologists) are often an aspect of water quality sampling programs. Stream beds that have a high composition of fine material do not contain sufficient interstitial space for many benthic organisms (invertebrates and early life stages of salmonid fish). Coarser materials allow adequate interstitial flow to facilitate oxygen exchange. Therefore, the intrusion of finer sediments which are often caused by upslope disturbances results in the degradation of habitat. The sample collection and analysis techniques that are currently used in British Columbia not particularly conclusive. Efforts are underway to implement more comprehensive measures for assessing the composition of stream bed substrate. Future analysis will likely include techniques such as geometric particle mean diameter/egg diameter assessments, fredle index, embeddedness of substrate, percent fines (% < 2 mm, 6.35 mm, 9.52 mm), permeability, and interstitial dissolved oxygen concentrations.

Anthropogenic sources (fine particles): forest harvesting, road building, placer mining, agricultural run-off, urban run-off (storm drain discharge).

Criteria:

- no induced benthic sedimentation of particles smaller than 3 mm in salmonid spawning habitat
- more rigorous criteria are under development

5.2.2 Metals

1. Arsenic

Definition: This is measure of the total arsenic in a sediment sample. It is reported in μg/g. Arsenate (AsO_4^{3-}) is the stable form in well oxygenated waters and tend to sorb to clay particles in sediments.

Importance: Arsenic can be acutely or chronically toxic to mammals.

Anthropogenic sources: industrial effluent, application of arsenical pesticides, smelting operations.

Criteria:

Total → 6.0 μg/g, lowest effect level based on SLC
3.0 μg/g, severe effect level based on SLC

2. Cadmium

Definition: This is measure of the total cadmium in a sediment sample. It is reported in μg/g. Cadmium salts (chlorides, nitrates or sulphates) tend to sorb to clay particles in the sediments. Zinc and lead are closely associated with cadmium.

Importance: Cadmium can be toxic particularly in the presence of zinc and cyanide. Toxicity is particularly acute in mammals as well as in some species of fish (i.e., trout via inhibited reproduction). Cadmium reduces plant growth.

Anthropogenic sources: industrial effluent (electroplating operations, copper and nickel production), fossil fuel combustion.

Criteria:

Total → 0.6 μg/g, lowest effect level based on SLC
10.0 μg/g, severe effect level based on SLC

3. Chromium

Definition: This is measure of the total chromium in a sediment sample. It is reported in µg/g.

Importance: Chromium, as chromic and chromate ions are toxic to plants.

Anthropogenic sources: industrial effluent (manufacturing of paints, dyes, explosives, stainless steel, ceramics and paper), fertilizers, pesticides.

Criteria:

Total → 26.0 µg/g, lowest effect level based on SLC
110.0 µg/g, severe effect level based on SLC

4. Copper

Definition: This is measure of the total copper in a sediment sample. It is reported in µg/g. Copper carbonates, hydroxides, oxides and sulfides are relatively insoluble, therefore, when conditions are alkaline, these forms are sorbed in sediments.

Importance: Copper is essential for plant and animal nutrition. Copper is not highly toxic but does have chronic effects with prolonged exposure to high concentrations. Toxicity of copper is dependent on water temperature, hardness and turbidity.

Anthropogenic sources: industrial effluent (textiles, electrical products, anti-fouling paints), smelters, copper plumbing and equipment.

Criteria:

Total → 16.0 µg/g, lowest effect level based on SLC
110.0 µg/g, severe effect level based on SLC

5. Iron

Definition: This is measure of the total iron in a sediment sample. It is reported in mg/g. In aerobic conditions, iron is oxidized to ferric iron which precipitates into sediments. This process is facilitated with increasing pH.

Importance: Iron is essential respiration (part of the hemoglobin). High iron concentrations can cause the fixation of essential elements required by plants.

Anthropogenic sources: industrial effluent (burning of coke and coal), acid mine drainage, smelters.

Criteria:

Total → 2.1 mg/g, lowest effect level based on SLC
4.38 mg/g, severe effect level based on SLC

6. Lead

Definition: This is measure of the total lead in a sediment sample. It is reported in µg/g. Lead is insoluble and strongly absorbed by the sediments.

Importance: Lead is toxic to all animals. It accumulates in the skeletal structures. Toxic effects decrease with increasing dissolved oxygen and water hardness.

Anthropogenic sources: industrial effluent (printing, dyeing, photography, explosives) leaded fuels, motor oils, smelting and refining, batteries (production and disposal).

Criteria:

Total → 31.0 µg/g, lowest effect level based on SLC
250.0µg/g, severe effect level based on SLC

7. Mercury

Definition: This is measure of the total mercury in a sediment sample. It is reported in µg/g. Mercury concentrations in aqueous solutions are extremely small which is why it is more appropriate to measure mercury in sediments and tissues. Mercury compounds are readily sorbed to particulate matter which settle into sediments.

Importance: Mercury is highly toxic to animals. Mercury compounds are retained in tissues for extended periods. It is a substance that is rapidly biomagnified in the aquatic food chain.

Anthropogenic sources: industrial effluent (paints, electrical equipment, batteries, dental amalgams).

Criteria:

Total → 0.2 µg/g, lowest effect level based on SLC
2.0 µg/g, severe effect level based on SLC

8. Selenium

Definition: This is measure of the total selenium in a sediment sample. It is reported in μg/g. Selenium, in its elemental form is insoluble in water and is therefore, sorbed into the sediments readily.

Importance: Selenium is chronically toxic to animals. It is carcinogenic and is associated with tooth decay.

Anthropogenic sources: industrial effluent (electronics, paint, photography, xeroxing, vulcanizing rubber), refining (copper, lead), burning fossil fuels, sewage treatment.

Criteria:

Total aquatic life → 5 μg/g dry-weight in sediment.

9. Zinc

Definition: This is measure of the total zinc in a sediment sample. It is reported in µg/g. Zinc is highly abundant in nature. Zinc ions are readily sorbed to sediment particles.

Importance: Zinc is an essential nutrient for plants. It can be both chronically and acutely toxic to aquatic organisms, especially fish. Toxicity depends on a number of factors: toxicity decreases with increasing hardness, and it increases with increasing temperature, dissolved oxygen, copper and cadmium concentrations.

Anthropogenic sources: industrial effluent (paints, rubber, textiles, printing), fertilizers, pesticides, smelters, burning fossil fuels, mining.

Criteria:

Total → 120.0 µg/g, lowest effect level based on SLC
820.0 µg/g, severe effect level based on SLC

5.2.3 Organics

1. Organochlorine compounds (pesticides)

Definition: This is a measure of the concentration of an organochloride in the sediment. These are compounds that are commonly used as pesticides (primarily insecticides).

Importance: Organochlorides can be highly toxic and persistent in sediments. Their toxicity is related to the disruption of oxygen uptake, which leads to suffocation and death. They also have a tendency to accumulate in the fatty tissues of animals.

Anthropogenic sources: forest regeneration pesticide application.

Criteria: when sediment organic carbon is 1%, Benzene hexachloride:

Total BHC → 0.003 µg/g, lowest effect level based on SLC
12 µg/g, severe effect level based on SLC

α BHC → 0.006 µg/g, lowest effect level based on SLC
0.5 µg/g, severe effect level based on SLC

ß BHC → 0.005 µg/g, lowest effect level based on SLC
21 µg/g, severe effect level based on SLC

γ BHC (Lindane) → 0.003 µg/g, lowest effect level based on SLC
1.0 µg/g, severe effect level based on SLC

Aldrin → 0.002 µg/g, lowest effect level based on SLC
0.42 µg/g, severe effect level based on SLC

Chlordane → 0.007 µg/g, lowest effect level based on SLC
0.06 µg/g, severe effect level based on SLC

DDD [1,1 Dichlro-2, 2-bis (4chloro-phenyl) ethane]
→ 0.008 µg/g, lowest effect level based on SLC
0.06 µg/g, severe effect level based on SLC

Dieldrin → 0.002 µg/g, lowest effect level based on SLC
0.91 µg/g, severe effect level based on SLC

Endrin → 0.003 µg/g, lowest effect level based on SLC
1.30 µg/g, severe effect level based on SLC

Heptachlor → 0.0003 µg/g, lowest effect level based on SLC
0.01 µg/g, toxic effect threshold based on SLC

Heptachlor epoxide → 0.0003 µg/g, lowest effect level based on SLC (10th percentile)
0.01 µg/g, severe effect level based on SLC (90th percentile)

Hexachlorobenzene → 0.02 µg/g, lowest effect level based on SLC
0.24 µg/g, severe effect level based on SLC

Mirex (dechlorane) → 0.007 µg/g, lowest effect level based on SLC
1.30 µg/g, severe effect level based on SLC

DDT [1,1,1 Trichloro-2, 2-bis (4chloro-rophenyl) ethane]

Total DDT → 0.007 µg/g, lowest effect level based on SLC
0.12 µg/g, severe effect level based on SLC

Note: For sediment with organic carbon other than 1%, adjustment in criteria should be made by multiplying the criteria by the % organic carbon content of the sediment.

2. Polychlorinated biphenyls (PCBs)

Definition: This a measure of a group of industrial chemicals that were used as plasticizers and thermal insulators in transformers and electrical wires. They are now banned for use in Canada. PCBs are highly resistant to biological, chemical and thermal degradation. They are inert chemicals that are relatively insoluble in water and tend to accumulate in sediments.

Importance: PCBs have varying degrees of toxicity depending on the percent of chlorine substitution. They bioaccumulate and tend to be in highest concentrations in fatty tissues. PCBs interfere with reproductive capabilities (this has been amply demonstrated with animals that are high on a food chain such as predatory birds).

Anthropogenic sources: municipal and industrial effluent discharges

Criteria: British Columbia criteria

expressed as Total PCBs

→ maximum 0.02 µg/g dry-weight at 1% total organic carbon. If sediment organic carbon is not 1%, the criterion is = (0.02 µg/g) x (% organic carbon content).

3. Polycyclic Aromatic Hydrocarbons (PAHs)

Definition: PAHs are compounds composed of two or more benzene rings fused together. They are ubiquitous in the environment. The environmentally significant PAHs contain two to seven benzene rings. PAHs are used as intermediaries in pharmaceutical, photographic, and chemical industries. Some are used in the production of fungicides, insecticides, and surfactants. They are reported in µg/g (dry-weight) in sediments.

Importance: The lower molecular weight PAHs (two or three benzene rings) are acutely toxic to aquatic life. PAHs with four to seven rings are not as acutely toxic, but several are known to be carcinogenic.

Anthropogenic sources: fossil fuels, agricultural burning, industrial processes, pest treatment, urban runoff.

Criteria: when sediment organic carbon is 1% measured dry-weight

→ 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

Note: For sediment with organic carbon other than 1%, adjustment in criteria should be made by multiplying the criteria by the % organic carbon content of the sediment.

5.3 Guide to Interpreting Biological Variables

5.3.1. Bacteria, coliform

Definition: This variable provides an estimate of the degree of fecal contamination from human and animal wastes. The Total Coliform group (of micro-organisms) includes: fecal coliforms, common to the intestinal tract of both humans and warm-blooded animals, and non-fecal coliforms that are naturally present in soils and on vegetation. Coliform results are reported as Colony Forming Units (CFU) of Total Coliform bacteria counted in 100 millilitres of water submitted or, Most Probable Number (MPN) per 100 mL of water. Tests for both Total or Fecal Coliforms are conducted, although Fecal Coliforms provide a direct means of measuring human and animal waste inputs.

Importance. The presence of coliform bacteria in water may indicate contamination from human or animal wastes. The general philosophy associated with using an indicator organism is that if it can be shown that fecal contamination of the water has occurred, then pathogenic organisms may also be present.

Anthropogenic sources: sewage treatment plants, recreation areas, pulp and paper mills, livestock, urban runoff.

Criteria (fecal coliform):

- raw drinking water

→ no treatment, 0

→ disinfection, ≤10 (90th percentile)

→ partial treatment, ≤100 (90th percentile)

- livestock

→ general livestock use, 200 (maximum)

→ closely confined, no treatment, 0

→ closely confined, disinfection, ≤10 (90th percentile)

→ closely confined, partial treatment, ≤100 (90th percentile)

- irrigation

→ crops eaten raw, ≤200 (geom. mean)

→ general irrigation, ≤1000 (geom. mean)

- recreation

→ primary contact, ≤200 (geom. mean)

- industry

→ food processing/dairy, no treatment, 0

→ food processing/dairy, disinfection, ≤10 (90th percentile)

5.3.2 Quantification of macroinvertebrate communities

1. Biosurvey analyses of community structure

Biosurvey techniques provide a measure of the taxonomic diversity in an aquatic ecosystem. The diversity of the ecosystem is typically inversely related to impairment in water quality. Taxonomic richness is a measure of the total number of taxa present while taxonomic abundance is a measure of either the absolute number of individuals within a taxa per unit area, or the relative percentage of total numbers. Generally, taxonomic identification will have been conducted by a specialist. Otherwise, refer to Wetzel (1991) for a key to identify common freshwater taxa. Many diversity and biotic indices exist which combine taxonomic richness and abundance to further characterize the relationships between community structure and water quality conditions.

Generally, low taxonomic richness or abundance reflects some impairment of ambient conditions. Conversely, increases in richness and abundance reflect increases in water quality, habitat diversity, and/or habitat suitability. A thorough presentation of the interpretive techniques for richness and abundance is beyond the scope of this document. Refer to the document "Guidelines for Monitoring Benthos in Freshwater Environments" (EVS Consultants, 1993) for an extensive review of the specific data analysis methods (including a discussion of the multivariate analyses that are necessary for studies involving community analyses) and interpretation guidelines.

The EPT is one of the more commonly used indexes. This index is generally considered to be one of the easiest to use both in terms of the time required for sample processing and ease of application. It is also considered to be a sensitive indicator of stream perturbations. The EPT assesses impairment by determining the number of the pollution-sensitive organisms of the orders Ephemeroptera, Plecoptera, and Trichoptera (mayflies, stoneflies, caddisflies) in a defined streambed sample area. The EPT index generally increases with increasing water quality. See the "Streamkeepers' Handbook" Module 3 (Munro and Taccogna, 1994) for a discussion of how to interpret this index.

Other indices include:

- The Biotic Condition Index or BCI (Winget and Magnum, 1979). This index incorporates stream habitat, water quality, and environmental tolerance of aquatic invertebrates.
- The Rapid Bioassessment Protocols I, II, and III (Plafkin, *et al*,, 1989). These techniques use taxonomic abundance to distinguish among three categories of water quality (severely impaired, moderately impaired, not impaired).
- The Benthic Index of Biotic Integrity or IBI (Karr, *et al.*, 1986; Kerans and Karr, 1994). This index adopts a multimetric approach to evaluate stream biotic integrity. It classifies total taxa richness, individual group taxa richness, total abundance, and individual group relative abundance as biological attributes against which impacts are evaluated using an ANOVA.

2. Biomass

Macroinvertebrate biomass (weight of organisms per unit area for benthic invertebrate studies or unit volume for zooplankton studies) is a quantitative estimation of the standing crop. The standing crop is another sensitive indicator of perturbations. Generally, as water quality conditions are impaired, the standing crop is reduced. An exception to this is when the contaminants are nutrients (primarily phosphorus in fresh water) as these contaminants have an initial effect of promoting primary productivity. Biomass is a variable that is generally expressed as the ash free dry-weight. Biomass analysis includes a test of significant difference between comparable sites or time periods at a single site (see Appendices A-D for examples of hypothesis testing).

5.3.3 Quantification of periphyton and phytoplankton communities

Typically, most analyses that attempt to quantifiably link microflora to water quality conditions will involve assessments of chlorophyll *a* measurements. Biosurvey techniques are conducted but due to the fact that trained taxonomists must identify large numbers of organisms these techniques are not commonly used in water quality monitoring programs. Hence, the following discussion of biosurvey analyses will be limited to a general overview.

1. Biosurvey analyses of microflora populations

Both species and community structure parameters are commonly used to characterize microfloral aquatic ecosystems and water quality conditions. The species analysis primarily involves the use of selected species as indicators of water quality. It is essentially a qualitative technique that is simply based on the presence or absence of species (or genera) that are indicative of varying water quality conditions. For a general list of indicator phytoplankton taxa that reflect trophic status of lakes refer to Wetzel (1983) page 353.

As with invertebrate studies, community structure parameters for microflora involve species richness and abundance analyses. Changes in species composition that are detected by altered richness and abundance are indications of altered ambient conditions (only when natural variability is minimized through within strata sampling techniques). These analyses are equally applicable for both periphyton (attached algae) and phytoplankton (free floating algae). Refer to Wetzel et. al., (1979) for a comprehensive review of methodologies of periphyton analysis.

2. Chlorophyll-a

Definition: This is a measure of the phytoplankton or periphyton biomass in a body of water. It is reported as µg/L for plankton species and mg/m^2 for attached species. This variable directly relates to the productivity and trophic status of the body of water.

Importance: High chlorophyll-*a* concentrations are a direct result of high nutrient inputs and/or high light inputs in streams that are light limited. Values below 3 µg/L (plankton) are considered to indicate low productivity (oligotrophic waters). Values greater than 15 µg/L are generally considered to indicate high productivity (eutrophic waters). Elevated temperature and/or the input of either sediments or herbicides tends to result in lowered chlorophyll *a* concentrations.

Anthropogenic sources: agriculture, sewage treatment plant effluent (severity depends on the type of treatment), forest harvesting, urban development, recreation.

Criteria (attached algae):

- aquatic life → streams, maximum of 100 mg/m^2
- recreation → streams, maximum of 50 mg/m^2

There are not any criteria for planktonic chlorophyll-*a*, but Phosphorus criteria in lakes are designed to limit chlorophyll-*a* to certain levels.

5.3.4 Macrophyte taxonomy

Macrophytes are collected for one of three purposes: biomass studies, tissue analysis and taxonomy. Neither biomass studies nor tissue analysis are routinely conducted in British Columbia at present. As such, interpretation guidelines for these types of analyses will not be discussed here. For some elaborate water quality sampling programs, macrophyte taxonomy for the three groups of aquatic plants (floating, submergent, and emergent) might have been warranted (particularly if introduced species such as Eurasian Watermilfoil are of concern in the study). These studies generally require the services of highly specialized macrophyte taxonomists for both identification and interpretation. However, Warrington (1994) has produced a document entitled "Identification keys to the aquatic plants of British Columbia" that should be referred to if the focus of the study is not specifically intended to provide an inventory of a lake's macrophyte community. This document is intended to make it as easy as possible for non-specialists to identify aquatic plants without getting bogged down in difficult taxonomic problems. The publication includes a list of all species covered, a key to groups of aquatic plants based on their growth forms and habitat groups, a general key to the aquatic plants of British Columbia, a key to aquatic plants with finely dissected submerged leaves, keys to the families and genera identified in the general key, a set of brief notes on each species of aquatic plant, and a listing of partial synonymy of the species. That listing defines the author's species concept and allows access to other literature which may use different names. The illustrations show the types of dissected underwater leaves which may be found.

5.3.5 Fish taxonomy

Both resident and anadromous fish communities are of concern in British Columbia's freshwater systems. The use of fish taxonomy for water quality monitoring parallels macroinvertebrate and microflora studies of community structure studies. The Index of Biotic Integrity that Karr (1981) developed is equally as applicable to fish community structure as it is for macroinvertebrate communities. Guidelines for the interpretation of fish taxonomy studies are beyond the scope of this document. However, if fish taxonomy was a component of a water quality sampling program then consultation with the Fisheries Branch of the Ministry of Environment, Lands and Parks is advised.

5.3.6 Tissue analysis (fish)

Analysis of the chemical composition of biological tissues provide information about the occurrence and distribution of contaminants in aquatic systems. The chemicals for which the province has prepared tissue criteria are generally more highly concentrated in tissues, thus making there detection easier in tissues than in water or sediments. The following is a list of substances for which fish and shellfish tissue criteria have been approved in British Columbia.

Metals

1. Lead

Definition: This is measure of the total or dissolved lead in a tissue sample. It is reported in either µg/g. See section 5.1.4 for further discussion of this metal.

Criteria:

- fish or shellfish → 0.8 µg/g wet-weight

2. Mercury

Definition: This is measure of the total mercury in a tissue sample. It is reported in µg/g. Due to very low concentrations, it is difficult to accurately detect mercury in ambient water samples. Consequently, it is more frequently measured in tissue samples. Refer to Section 5.1.4 for further discussion of this metal.

Importance: Mercury compounds are highly toxic and have a long retention time in animal cells. Mercury bioaccumulates in the kidney and liver and can cause permanent brain damage.

Criteria:

- fish or shellfish →maximum 0.5 µg Hg/g wet-weight

Note: the values expressed here for fish and shellfish tissue samples are sufficient to prevent toxicity, but are considered at least one order of magnitude too high to prevent harmful bioaccumulation in fish or shellfish.

Organics

1. Polychlorinated biphenyls (PCBs)

Definition: This a measure of the total PCB in a fish or shellfish tissue sample. It is reported in µg/g. These are inert chemicals that are relatively insoluble in water and tend to accumulate in sediments and tissues. Refer to Section 5.1.5 for further discussion of these organic compounds.

Importance: PCBs have varying degrees of toxicity depending on the percent of chlorine substitution. They bioaccumulate and tend to be in highest concentrations in fatty tissues. PCBs interfere with reproductive capabilities (this has been amply demonstrated with animals that are high on a food chain such as predatory birds).

Criteria: expressed as Total PCBs

→ maximum 0.1 µg/g wet-weight (whole fish) of fish/shellfish tissue for wildlife consumption

→ maximum 2.0 µg/g wet-weight (edible tissue) of fish/shellfish for human consumption

2. Polycyclic Aromatic Hydrocarbons (PAHs)

Definition: This is a measure of total PAH in the tissue of fish and shellfish. It is reported in µg/kg (wet-weight). Refer to Section 5.1.5 for further discussion of these organic compounds.

Criteria:

→ fish/shellfish for human consumption (edible tissue) low consumer (50 g/wk) - maximum 4 µg/kg wet-weight
moderate consumer (100 g/wk) - maximum 2 µg/kg wet-weight
heavy consumer (200 g/wk) - maximum 1 µg/kg wet-weight

5.4 The Use of Surrogate Variables - Guide to Relate Surrogate Values to Other Variables

There are variables that are directly related to others, and as such, it is possible to calculate the value of variables that were not sampled from information about the sampled (surrogate) variables. The following discussion describes how to calculate the values of some variables when other surrogate variable data is available.

5.4.1 Total hardness when surrogates calcium and magnesium were sampled

With available calcium (Ca) and magnesium (Mg) values, the Total Hardness, expressed in $CaCO_3$ (Calcium carbonate) can be calculated. Total hardness of water is principally caused be Ca and Mg salts. Therefore, hardness in terms of $CaCO_3$ refers to the sum of the calcium as $CaCO_3$ and magnesium as $CaCO_3$. The process to calculate Total Hardness is:

- Convert Ca into $CaCO_3$ by dividing the Ca mg/L value with a factor of 0.4 [derived from the ratio of the equivalent weight of calcium (atomic weight divided by the valence = 40/2 = 20) and the equivalent weight of calcium carbonate (100/2 = 50), or 20/50 = 0.4].
- Convert Mg into $CaCO_3$ by dividing Mg mg/L by factor 0.24 (Eqw Mg = 24/2 = 12 so factor = 12/50 = 0.24).
- Sum the converted weights

Example:

Calcium, as Ca = 24 mg/L

Calcium, as CaCO3 = 24/0.4 = 60 mg/L

Magnesium, as Mg = 8 mg/L

Magnesium, as CaCO3 = 8/0.24 = 33 mg/L

Total Hardness as CaCO3 = 60 + 33 = 93 mg/L

5.4.2 Total Dissolved Solids when surrogate Conductivity was sampled

The ratio of Total Dissolved Solids (TDS), expressed in mg/L and Conductivity, expressed µS/cm should be between 0.55 and 0.9 (the value most often used is 0.7). Therefore, when the conductivity value is multiplied by a factor between 0.55 and 0.9, the value should be the TDS.

Example:

If the sampled Conductivity value was 800 µS/cm then the estimated TDS would be 0.7 * 800 = 560 mg/L.

Or, in the range 440 (0.55 * 800) - 720 (0.90 * 800) mg/L.

6. Reporting Format

A good monitoring report will be complete, comprehensive, clear, concise, and readable. All information should be presented with minimal use of jargon and technical terms. A reader with no training in water quality issues or with no prior knowledge of the subject area should not have to reference other sources to gain a full appreciation of the material presented in the report. As a safeguard, a glossary should always be included as an appendix for the benefit of readers who may not be familiar with all terms used (generally there is an extremely limited number of individuals that have sufficient knowledge of any one field to understand all the jargon associated with that field). Preferably, technical terms should be defined in the text as much as possible.

In an attempt to achieve a province-wide, consistent approach to organizing and presenting water quality information, the Water Quality Section of Water Management Branch has prepared the Writing Checklist for Objective Overviews. This document provides excellent step-by-step guidance for formatting the overview or summary reports. The style presented in the Writing Checklist was used here to format these monitoring manuals. The Writing Checklist also recommends a consistent approach to the content organization. Although the suggested document organization is specific to objectives reports, it could be considered an ideal framework for any water quality assessment. An alternative would be to follow the format of previous Technical Appendices, outlined in Developing Water Quality Objectives in British Columbia - A Users Guide (February, 1996). The following is a brief description of document organization as outlined by the Writing Checklist. For more details, obtain the Writing Checklist from:

Water Management Branch
PO Box 9340
STN PROV GOVT
Victoria, BC V8W 9M1

Title Page

The title page has four basic functions. The primary function is to label (title) the report in such a fashion that its purpose is distinguishable and unambiguous. The title must identify the reason for the study (i.e., trend, impact assessment) and the water body(ies) that was the focus of the study. The second function of the title page is to identify the author or agency that was responsible for producing the report. The third function is that it clearly identify the agency for whom the report was prepared, including that agency's division and ministry. The final function is to provide the date that the report was produced.

Copyright Page

The copyright page contains the Canadian Cataloguing in Publication Data (CIP) that is used by Canadian libraries.

Summary

The summary briefly describes the content and function of the report.

Preface

The preface (specific to objectives reports) describes the purpose of water quality objectives, how they are determined and used, and the relationship between objectives and monitoring. There is generally a standard Preface for these reports that can be obtained from the Water Quality Branch.

Introduction

This section introduces the study area and the rationale for the study. It might also include reference to, and discussion of relevant material such as documented studies previously conducted on the water body that is the focus of the current study or, literature that addresses similar subject matter (i.e., impacts on water quality from a specific activity).

Profile

The profile is a general discussion of the natural conditions and human activities within the watershed. Any numeric information should be presented in tabular form following the reference section of the report. Also, much of the characteristics discussed in the profile could be presented as figures (i.e., maps and hydrographs following the tables section). The tables and figures should be referred to in the profile section. The profile is generally divided into six sub-headings:

- Morphology - watershed location within the province including physiographic province name designation, general review of climatic conditions, area of watershed, name of system into which watershed flows, volume and surface area (for lake studies), periods of lake stratification;
- Hydrology - total number of streams within watershed (distinguish between permanent and ephemeral), stream orders, peak flow periods, low flow periods, yearly discharge at watershed outlet, lake flushing rate (time taken for volume of water equal to that of the lake to discharge at outlet);
- Land Uses - protected areas, recreation, development (residential, commercial, industrial), agriculture, forestry harvesting (cut permits issued to whom and size of historic and proposed cut blocks), road building, mills, mining, etc.;
- Water Uses - water withdrawal licenses (domestic, waterworks, agricultural and industrial) including total potential withdrawal amount, recreation;
- Aquatic Life and Wildlife - macrophytes, fish, waterfowl, zooplankton, phytoplankton, periphyton;
- Waste Discharges - point sources (commercial, industrial), potential or defined non-point sources (residential, commercial, agricultural, forestry activity, houseboats, marinas).

Water Quality Assessment (and Objectives)

This section consists of the presentation of the interpretive information obtained through the process in Chapter 5 above.

The Assessment sub-section is broken down under the various characteristics (variables) affecting water quality in the study area. Each variable of concern is discussed in detail.

In the case of Objectives Reports, a second sub-section is dedicated towards setting site-specific objectives. The Objectives sub-section sequentially presents each variable for which an objective is being set and provides the rationale for the set value (i.e., the most sensitive designated water use for the particular variable). Objective establishment can be either the ministry approved criteria value for a particular variable or, an arbitrary, more rigorous value if the background concentration for the variable dictates that this is appropriate. When it is deemed that the latter of these two scenarios should prevail, then consultation with ministry employees is necessary to determine what objective value is suitable.

The final component of this section consists a discussion of future monitoring recommendations (if any).

References

This section contains the full citations of any literature referenced throughout the body of the report.

Tables and Figures

Anything presented in a tabular format (i.e., raw data, site summary tables, hydrologic information, water licenses, waste discharge information etc.) should be compiled and presented as one section following the references.

Figures (maps and graphics) should be compiled and presented sequentially as a follow up sub-section to the Tables. The first figure should always be a map showing the location of the sample sites within the study area. Any anthropogenic activities (locations of urban developments, recreation areas, water withdrawals, point source discharges, agriculture, forest harvest, roads, etc.) should also be presented on maps.

Glossary

The glossary is designed to provide clear definitions of water quality terminology for general readers.

7. Peer Review

When the first draft of the report is complete, it must be sent for peer review. This process ensures that the interpretation, conclusions and recommendations are consistent with the data. An additional benefit of the peer review process is that it provides constructive feedback that helps writers improve their skills and knowledge.

Note: the organization for whom the study was conducted must be the first group to review the report such that they may provide input prior to further review.

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Appendix A.
Hypothesis Test of a Hypothetical Data Set to Determine if Variances Differ (the F-test)

Following is a two-sample, two-tailed F-test to test difference in variances between two data sets. Each data set are 10 samples collected during the critical peak-flow period (the month of March), one the year prior to proposed forestry activity, and the other after the onset of this activity. Non-filterable Residue was the variable of concern. The null hypothesis is that there is no difference in variances between the two years. If the null hypothesis is accepted then variances are considered equal and further assertions about possible impact resulting from the forestry activities will be considered valid.

H_o: $s^2_1 = s^2_2$

H_A: $s^2_1 \_ s^2_2$

Raw NFR Data For Study

Date (1996)	Pre-treatment	Date (1997)	Treatment
March 1	27 mg/L	March 1	90mg/L
March 4	80	March 5	200
March 7	15	March 8	310
March 10	115	March 11	110
March 14	130	March 15	40
March 17	60	March 19	90
March 20	200	March 23	333
March 24	70	March 26	120
March 27	50	March 29	53
March 30	73	March 31	90

$$F = \frac{s^2_2}{s^2_1}$$

$n_1 = 10$
$v_1 = 9$

$\overline{X}_1 = 82.0$
$s^2_1 = 2952.0$

$n_1 = 10$
$v_1 = 9$

$\overline{X}_1 = 143.6$
$s^2_1 = 10665.3$

$$F = \frac{10665.3}{2952.0}$$

$$F = 3.61$$

$F_{\alpha(2),V1,V2} = F_{0.05(2),9,9} = 4.03$

Therefore, do not reject H_0 (because calculated F is less than critical F). Further tests assessing possible impact are therefore valid.

Appendix B

Hypothesis Test of Hypothetical Data Sets to Determine If Impact has Occurred (the t-test)

Analysis of Hypothetical Pilot Study Data to Assess if Proposed Control Site and First Down-stream Treatment Site Exhibit Spatial Homogeneity - A Statistical Test of the Spatial Difference in the Mean Concentrations of Kjeldahl Nitrogen Between Two Sites

Following is a two-sample, two-tailed t-test to test difference in mean low-flow kjeldahl nitrogen concentration between proposed control and treatment sites. The null hypothesis is that there is no difference between the two sites for the period June-September. If the null hypothesis is accepted then it will be concluded that there are no natural inputs of nitrogen between the two sites and that the control site is appropriately located (i.e., spatial homogeneity exists). Samples were collected weekly from June 2/97 through Sept. 8/97.

H_o: $\mu_1 = \mu_2$

H_A: $\mu_1 \neq \mu_2$

Raw Data For Pilot Study

Date	Control	Date	Treatment
970602	130µg/L	970602	90µg/L
970609	50	970609	50
970616	70	970616	40
970623	50	970623	n.d.
970630	50	970630	80
970707	100	970707	80
970714	140	970714	100
970721	90	970721	120
970728	80	970728	70
970804	80	970804	90
970811	60	970811	70
970818	100	970818	100
970825	50	970825	60
970901	60	970901	50
970908	70	970908	90

Σ1180	Σ1090

$$t = \frac{\overline{X}_1 - \overline{X}_2}{S_{\overline{x}_1 - \overline{x}_2}}$$

$n_1 = 15$	$n_2 = 14$
$v_1 = 14$	$v_2 = 13$
$\overline{X}_1 = 78.67$	$\overline{X}_2 = 77.86$
$s = 28.75$	$s = 22.59$
$SS_1 = 11571.88$	$SS_2 = 6634.00$

SS can be determined on a calculator be squaring the standard deviation (*s)* and multiplying by the degree of freedom (v) [$SS_1 = (28.75)^2 * 14 = 11571.88$].

$$S^2p = \frac{SS_1 + SS_2}{v_1 + v_2} = \frac{11571.88 + 6634.00}{14 + 13} = 674.29$$

$$S_{\overline{x}1-\overline{x}2} = \sqrt{\frac{S^2p + S^2p}{n_1 + n_2}} = 6.82$$

$$t = \frac{78.67 - 77.86}{6.82} = 0.119$$

$t_{0.05(2),27} = 2.056$

Recall that the conditions for rejecting H_o are $|t| \geq t_{\alpha(2),v}$ and, since this is not the case, H_o must be accepted.

Therefore, accept H_o

An initial report that summarizes the results of the pilot study might include the following statements:

There was no difference in the mean Kjeldahl nitrogen values ($\alpha = 0.05$) between the control and treatment sites during the low-flow period of the pre-treatment pilot study. We conclude, therefore, that there is no natural (or otherwise) source of either ammonia or organic nitrogen that enters the aquatic system between the two sites. Therefore, the control site is appropriately located such that any future significant difference between the two sites can be reasonably attributed to a treatment effect (input from agricultural activity).

Appendix C

Hypothesis Test of Hypothetical Data Sets to Determine If Impact has Occurred (the t-test)

Analysis of Hypothetical Data to Assess if First Downstream Treatment Site Exhibits Temporal Difference Between Pre-treatment and Post-treatment Periods - A Statistical Test of the Temporal Difference in the Mean Concentrations of Kjeldahl Nitrogen at a Single Site

Assume a two-sample, two-tailed t-test has been conducted on the first year of post-treatment data for the same two sites as in Appendix A and the result was that the null hypothesis was rejected. In other words, the alternate hypothesis (that the mean values of the two sites are not equal) is assumed to be the case ($P < 0.05$). As such, it is also assumed that a treatment effect has occurred. The next step would be to determine if the mean value at the treatment site is elevated in 1998 relative to 1997 for the particular strata of interest (summer low flow period). To accomplish this, a two-sample, one-tailed t-test is required.

The following is a two-sample, one-tailed t-test to test difference in mean low-flow Kjeldahl nitrogen concentration between pre-treatment and post-treatment periods. The null hypothesis is that there is no difference between the two periods (June-September 1997 and June-September 1998). Samples were collected weekly from June through September for each year.

H_o: $\mu_{1\,(\text{pre-treatment})} \geq \mu_{2\,(\text{post-treatment})}$

H_A: $\mu_1 < \mu_2$

Raw Data For Treatment Site (First Site Downstream)

Date	Kjeldahl N	Date	Kjeldahl N
970602	90µg/L	980601	380µg/L
970609	50	980608	240
970616	40	980615	170
970623	n.d.	980622	370
970630	80	980629	90
970707	80	980706	200
970714	100	980713	70
970721	120	980720	290
970728	70	980727	190
970804	90	980803	160

Raw Data For Treatment Site (First Site Downstream)			
Date	**Kjeldahl N**	**Date**	**Kjeldahl N**
970811	70	980810	300
970818	100	980817	200
970825	60	980824	120
970901	50	980831	390
970908	90	980907	280
	Σ1090	980914	80
			Σ3530

$$t = \frac{\overline{X}_1 - \overline{X}_2}{S_{\overline{x}_1 - \overline{x}_2}}$$

$n_1 = 14$ $\quad$ $n_2 = 16$

$v_1 = 13$ $\quad$ $v_2 = 15$

$\overline{X}_1 = 77.86$ $\quad$ $\overline{X}_2 = 220.63$

$SS_1 = 6634.00$ $\quad$ $SS_2 = 169093.75$

$$S^2p = \frac{SS_1 + SS_2}{v_1 + v_2} = \frac{6634.00 + 169093.75}{13 + 15} = 6275.99$$

$$S_{\overline{x}1-\overline{x}2} = \sqrt{\frac{S^2p + S^2p}{n_1 + n_2}} = 20.45$$

$$t = \frac{78.67 + 2.63}{20.45} = 14.60$$

$t_{0.05(2),28} = 2.048$

Recall that the conditions for rejecting H_o are $|t| \geq t_{\alpha(2),v}$ and, since this is the case, H_O must be rejected.

Therefore, reject H_O

From the t-table, the probability that t is greater than 14.60 is determined to be:

$P(|t| \geq 14.60) < 0.001$

A report that summarizes the results of the study might include the following statements:

The mean Kjeldahl nitrogen values were significantly higher ($P < 0.001$) at the treatment site

after the initiation of agricultural activity on lands upslope of the stream. We conclude, therefore, that there is an input of ammonia and/or organic nitrogen to the stream from this agricultural activity.

Appendix D

Hypothesis Test of Hypothetical Data Sets to Determine If Impact has Occurred (the t-test)

Analysis of Hypothetical Data to Assess if an Objective is Exceeded - A Statistical Test to Determine if the Mean Concentration of Kjeldahl Nitrogen at a Single Site is Greater than the Objective Set for the Stream

Assume an objective had been set for this particular watercourse after the pilot study period. The objective was that the Kjeldahl nitrogen mean concentration for any low flow period should not exceed 150 µg/L. A one-sample, one-tailed t-test would be sufficient to test the null hypothesis that the mean data at the treatment site for the summer of 1998 is less than or equal to 150 µg/L. If the null hypothesis is rejected it would be assumed that the site is not in accordance with the objective (mean exceeds objective value).

The following is a one-sample, one-tailed t-test to test the above hypothesis.

H_o: $\mu_1 \leq 150\,\mu g/L$

H_A: $\mu_1 > 150\,\mu g/L$

Raw Data For Study

Date	Kjeldahl N
980601	380µg/L
980608	240
980615	170
980622	370
980629	90
980706	200
980713	70
980720	290
980727	190
980803	160
980810	300
980817	200
980824	120

980831	390
980907	280
980914	80
	Σ3530

$$t = \frac{X - \mu}{S_{\bar{x}}}$$

where:

$$S_{\bar{x}} = \sqrt{\frac{S^2}{n}}$$

$n_2=16$

$v_2=15$

$\overline{X} = 220.63$

$S^2 = 11272.91$

$S_x = 26.54$

$$t = \frac{220.63 - 150.00}{26.54} = 2.66$$

$t_{0.05(1),15}=1.753$

Recall that the conditions for rejecting H_o are $|t| \geq t_{\alpha(1),v}$ and, since this is the case, Ho must be rejected.

Therefore, reject Ho

From the t-table, the probability that t is greater than 2.66 is determined to be in the range: $0.005 < P(|t| \geq 2.66) < 0.01$ meaning that there is less than a 1% chance that the decision to reject the null hypothesis was the wrong choice.

In other words, the *t* value is strong enough that it is possible to increase our level of significance (the criteria for rejecting the null hypothesis, α) from 95% to 99% in our statement of confidence in the result. Therefore, when reporting that there exists a significant difference, it is allowable to use the greater level of significance even when this a value exceeds the one set in the program objectives (see report summary statements below). It simply means that there is more confidence in the interpretation.

A report that summarizes the results of the study might include the following statements:
The mean Kjeldahl nitrogen value (summer low flow period, 1998) at the treatment site was significantly higher ($P < 0.01$) than the objective set for the stream. Given that we have

concluded that the input of ammonia and/or organic nitrogen to the stream is due to agricultural activity [P ($|t| \geq 14.60$) < 0.001] (Appendix B), then it is concluded that the proprietor of the agricultural establishment is responsible for the objective exceedance.

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