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MONITORING AND ADAPTIVE MANAGEMENT FRAMEWORK

Draft Report

metrovancouver

SERVICES AND SOLUTIONS FOR A LIVABLE REGION

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1. INTRODUCTION

Condition 7 of the BC Minister of Environment's approval of the Integrated Liquid Waste Resource Management Plan (ILWRMP) requires that municipalities, with the coordination of Metro Vancouver, develop a monitoring and adaptive management framework for assessing watershed health and the effectiveness of Integrated Stormwater Management Plans (ISMPs). To meet this requirement, Metro Vancouver (Metro) formed a technical working group composed of members of the Stormwater Interagency Liaison Group (SILG), the Environmental Monitoring Committee (EMC) and the Ministry of Environment (MoE). The group has produced a draft Adaptive Management Framework (AMF) for monitoring stormwater, assessing the effectiveness of ISMPs, and recommending adaptive management practices.

In addition to fulfilling provincial requirements, monitoring watershed health may be useful in achieving other objectives such as meeting recreational water quality objectives in receiving waters for public health and providing baseline data for climate change adaptation.

Northwest Hydraulic Consultants Ltd. (NHC) and Dillon Consulting Limited (Dillon) were retained to review the Draft Framework in order to identify information gaps, make revisions and provide comments. Following this review, the working group made further revisions to produce an implementable framework and useful guidance document.

This report - the Adaptive Management Framework (AMF) - is intended for Metro Vancouver and member municipalities. It is anticipated that the AMF would be adopted by municipalities as a guide to monitoring watershed health and assessing ISMP effectiveness in order to satisfy Condition 7.

1.1. OVERALL APPROACH

The Adaptive Management Framework provides an approach for:

- monitoring watershed health
- tracking ISMP implementation and effectiveness
- identifying impacts/threats to watershed health
- selecting adaptive management practices
- tracking the effectiveness of adaptive management practices
- reporting out on all components listed above

The AMF is intended to be a 'living document'. It is envisioned that the framework will be updated by SILG/EMC every 5 years, or as required, to reflect advances in stormwater/rainwater management and monitoring techniques, and to build on the accumulated experience of stakeholders in the ISMP process.

The document covers five major areas: (1) the monitoring framework, (2) data collection methodology, (3) assessing and reporting your results, (4) adaptive management actions and (5) supporting information.

The monitoring framework (Sections 2-5) sets out the decision process for planning and implementing a successful monitoring program. Section 6 gives an overview of data collection protocols aimed at ensuring that valid and useful data are collected. This information can then be used to assess your results (Section 7) and report them (Section 8). Adaptive management practices based on your results are given in Section 9. Additional information on supplemental monitoring options (Section 10) and land use types (Section 10) is also provided.

1.1.1. WEIGHT OF EVIDENCE APPROACH

An important feature of the Adaptive Management Framework (AMF) is that it enables municipalities to show they are taking measurable and defensible steps to protect watershed health. To this end, the Minister has required that a 'weight of evidence' approach be taken. Multiple interpretations of the term 'weight of evidence' exist, ranging from qualitative to quantitative. At the qualitative end of the spectrum, the term indicates an informal weighting of various lines of evidence to develop an overall assessment of conditions. The more quantitative approaches use a formal matrix which quantitatively weights the scores of various indicators to generate an amalgamated score. In consultation with Metro Vancouver, the project team has interpreted 'weight of evidence' to mean:

- indicators must be quantifiable and scientifically defensible;
- categories or thresholds should be used to simplify assessment of monitoring results where possible; and
- overall synthesis of the various indicators should be qualitative.

1.1.2. ADAPTIVE MANAGEMENT

The focus of the framework is on adaptive management in order to stimulate a continuous improvement in watershed health. As such, monitoring results which indicate a watershed health issue should trigger adaptive management practices aimed at mitigating the problem. As opposed to prescribing specific adaptive management practices, the AMF will refer to a menu of options which municipalities may use as a reference tool for selecting appropriate actions. If available, recommendations from an ISMP should also be implemented since they are customized to the specific needs of a drainage system. The framework can then be used following implementation of adaptive management practices to monitor effectiveness.

1.1.3. COORDINATION BETWEEN MUNICIPALITIES

Coordination between municipalities could be used to achieve economies of scale and avoid overlapping costs and duplication of efforts, particularly for drainage systems which cross municipal boundaries. This approach can be applied to both the development of an Integrated Stormwater Management Plan and application of the AMF.

It is anticipated that following stakeholder comments and further revision, the revised AMF will be adopted by municipalities. A key to the successful adoption of the revised Draft Framework will be selecting technically sound watershed health parameters and data collection protocols without imposing an unreasonable financial burden on municipalities.

The AMF is aimed at helping municipalities assess the implementation and effectiveness of ISMPs by tracking the results of watershed health indicators. It can also be used as a means to monitor watershed health when no ISMP has been developed. The document should be straightforward to apply and flexible enough to allow modifications based on conditions in a particular watershed.

1.1.4. GOALS AND OBJECTIVES

The primary goal of the AMF is to:

(1) Monitor and protect watershed health, and

(2) Assess the implementation and effectiveness of ISMPs.

Additional goals are to:

- Avoid imposing an unreasonable financial burden on municipalities.
- Use a weight-of-evidence approach to monitoring watershed health.
- Prescribe a monitoring framework for data directly related to watershed health.
- Include monitoring indicators which provide useful information in the absence of long term data records and/or calibrated watershed models.
- Provide guidance for technically sound and consistent monitoring practices.
- Link monitoring outcomes to relevant adaptive management practices (AMPs).
- Stimulate continuous improvements in watershed health.

2. MONITORING FRAMEWORK

Natural pre-development conditions vary widely between Metro Vancouver watersheds, as well as within them. Superimposed on the natural variability, the type and extent of watershed health impacts from development can also differ depending on stream type and land use in the contributing watershed. To account for some of this variability and to focus monitoring efforts on the expected impacts, we have developed distinct monitoring programs based on three stream types: lower gradient streams; higher gradient streams; and piped systems.

Consideration was initially given to a decision tree approach which included two land use types (urban and rural) in addition to the three stream types. However discussions with stakeholders indicated that a simpler and more straightforward framework limited to differentiating between stream types was preferable. The stream type distinctions allow monitoring efforts to broadly target the impacts likely to affect the various stream types, without overly complicating the framework.

2.1. SYSTEM CLASSIFICATION

Three types of systems have been distinguished - lower gradient streams, higher gradient streams and piped systems. The categories are distinguished to account for variations in natural conditions and monitoring techniques. Lower gradient systems, for the purposes of this framework are defined as natural watercourses, ditches and canals with gradients less than one percent (<1%). Higher gradient systems include natural watercourses with gradients greater than one percent (>1%).

Conditions often vary within individual watersheds. Therefore, the system classification should be representative and monitoring sites should be chosen to best reflect any impacts from land use in the system. The intent of the framework is to use monitoring results to identify issues that can be mitigated through adaptive management practices.

Those municipalities with a large or varied drainage system may want to consider monitoring and reporting on a sub-watershed level or monitoring at more than one location within a system (e.g. at both lower gradient and piped locations). Doing so may provide a more comprehensive profile of a complex watershed and produce more meaningful monitoring results.

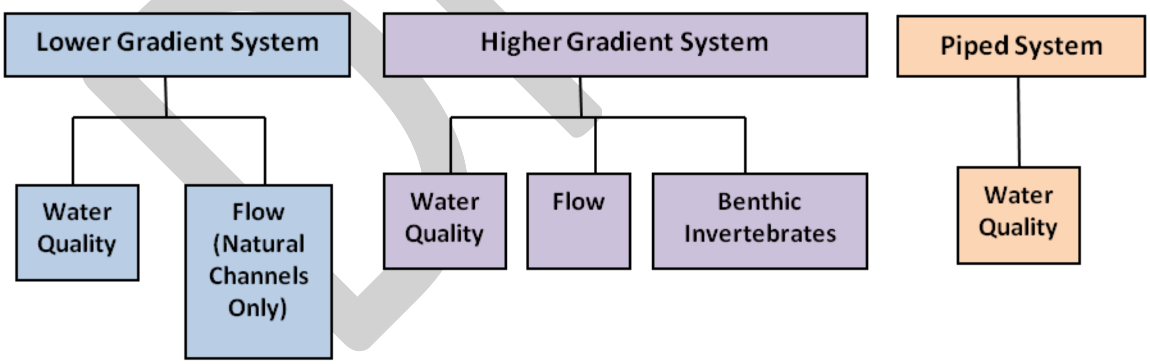
2.2. WHAT TO MONITOR BASED ON SYSTEM CLASSIFICATION

Table 1 and Figure 1 identify the components to be included in the monitoring programs for each system type.

Table 1 - Monitoring programs based on System Type

Stream Type	Water Quality	Hydrometric	Benthic Invertebrates
Lower Gradient	Yes	Yes (natural channels only)	No
Higher Gradient	Yes	Yes	Yes
Piped Systems	Yes	No	No

Figure 1 - Monitoring programs based on System Type



2.3. FREQUENCY OF MONITORING FOR EACH SYSTEM

As a minimum, monitoring is to be carried out every 5 years for a given drainage system. Because there are multiple systems within each municipality, local governments may use a program that monitors a few systems each year. The five year cycle was selected as a compromise between adequately capturing spatial and temporal variations and budgetary limitations. Consideration was given to the fact that adaptive management actions are required as part of the AMF and account for effort in excess of the monitoring.

If a more robust program is desired, Section 10 recommends supplemental measures which can be taken by municipalities with the resources to do so.

3. LOWER GRADIENT SYSTEM

Lower gradient streams include natural watercourses, ditches and canals with gradients less than one percent. In the Lower Mainland, many of these streams are tidally influenced, and this should be considered in the design of monitoring programs. They are generally slow flowing which can cause increased water temperatures, finer sediment beds, and the presence of submergent macrophytes. Natural lower gradient streams will tend to have steep banks composed of fine cohesive bank sediments. Substrates are generally composed of fine sediments. Channel pattern is often meandering single channel, although multiple channels may exist, especially in wetland areas. Photo A1 and Photo A2 show typical lower gradient streams in urban and rural areas, respectively.

Habitat types in natural lower gradient streams include undercut banks, pools, instream woody debris, and overhanging vegetation. Habitat diversity in lower gradient streams is typically low as compared to higher gradient streams. Land development and the associated loss of riparian vegetation can cause increased runoff and subsequent stream bank erosion and sedimentation, further reducing habitat diversity.

In addition to loss of riparian vegetation, land development and alterations such as agricultural activity and dikes can impact lower gradient streams through groundwater abstraction, water storage, irrigation, and input of pollutants.

3.1. WATER QUALITY IN LOWER GRADIENT STREAMS

Agricultural and other activities associated with lower gradient areas create opportunities for numerous non-point sources of water pollution including increased runoff containing fertilizers, manure, pesticides and sediment generated from eroding soils. However, lower gradient streams are not necessarily limited to rural areas. In the Lower Mainland, lower gradient streams can receive runoff from adjacent industrial/commercial areas or upstream urban areas.

As a result of the impacts associated with agriculture, urbanization and other forms of land development, water quality in lower gradient areas tends to be poor. Effects can be correlated with decreased dissolved oxygen levels; increased water temperatures; presence of higher levels of ammonia (associated with agricultural waste water) and nitrates; and increased turbidity and suspended solids.

3.1.1. WATER QUALITY PARAMETERS TO MONITOR IN LOWER GRADIENT STREAMS

It is recommended that water quality is monitored in all lower gradient systems (canals, ditches natural channels).

The parameters to measure are:

Dissolved oxygen, temperature, turbidity, pH, conductivity, nitrate, E. coli, fecal coliforms, total iron, total copper, total lead, total zinc, total cadmium.

3.1.2. WHEN TO MONITOR WATER QUALTIY IN LOWER GRADIENT STREAMS

Samples should be collected during two periods of the year – in the wet season (between Nov and Dec) and in the dry season (between July and August). Each of these seasonal monitoring periods will require collecting 5 samples over a 30 day period, preferably on a weekly basis.

3.2. FLOWS IN LOWER GRADIENT STREAMS

Natural lower gradient streams will tend to be less flashy than their higher gradient counterparts, due to the moderating influence of wetlands and floodplain storage. Overbank flows are stored and released over longer periods of time, thus attenuating peak flows and extending the duration of storm hydrographs. In agricultural or urbanized lowlands, wetlands may have been drained and streams may be disconnected from their floodplains, resulting in higher peak flows and increased flood risk. Hydrometric monitoring in lower gradient streams may be complicated due to tidal influences, pumping and surface water abstractions/inputs.

3.2.1. FLOWS MONITORING IN LOWER GRADIENT STREAMS

It is recommended that flow be monitored in Lower Gradient systems with natural channels. As a minimum, one year of continuous flow data should be collected. The data will be analyzed for the indicators listed below.

For a more detailed discussion about these indicators and why there were chosen see Section 7.3 (Hydrologic Indicators).

Hydrologic Indicators

TQmean, low pulse count, low pulse duration, summer baseflow, winter baseflow, high pulse count, high pulse duration.

Flow monitoring for canals and ditches is optional. See Section 10 (Supplemental Monitoring) for more details.

4. HIGHER GRADIENT SYSTEMS

Higher gradient streams include natural watercourses with gradients greater than one percent (ditches and canals will generally not be this steep). They are relatively fast flowing streams that drain sloped terrain, often onto broad alluvial floodplains where they become low gradient rivers. These streams vary widely in terms of morphology, and may include channel patterns ranging from meandering single channel through anastomosing and braided. Bed configuration varies as well, often characterized by riffle-pool sequences, or in steeper streams, step-pool sequences. Channel substrate usually is composed of coarse sediments (i.e. boulder, cobble, gravels, and sand).

Photos 3 and 4 show typical higher gradient streams in urban and rural areas.

4.1. WATER QUALITY IN HIGHER GRADIENT STREAMS

Water quality is typically better in these faster flowing streams and more conducive in supporting aquatic life, specifically salmonids and macro invertebrates less tolerant of pollution. Water quality parameter correlations associated with higher gradient streams include lower and more stable water temperatures (water temperature tends to remain cooler); higher levels of dissolved oxygen; and more neutral levels of pH. However, an increase in impervious surfaces in higher gradient (urban) areas typically results in the introduction of metals, oils, and grease from surface runoff.

4.1.1. WATER QUALITY PARAMETERS TO MONITOR IN HIGHER GRADIENT STREAMS

It is recommended that water quality be monitored in all higher gradient systems.

The parameters to measure are:

Dissolved oxygen, temperature, turbidity, pH, conductivity, nitrate, E. Coli, fecal coliforms, total iron, total copper, total lead, total zinc, and total cadmium.

4.1.2. WHEN TO MONITOR WATER QUALITY IN LOWER GRADIENT STREAMS

Samples should be collected during two periods of the year – in the wet season (between November and December) and in the dry season (between July and August). Each of these seasonal monitoring periods will require collecting 5 samples over a 30 day period, preferably on a weekly basis.

4.2. FLOWS IN HIGHER GRADIENT SYSTEMS

Natural higher gradient streams tend to respond to rain events faster and with greater sensitivity than their low gradient counterparts. For a given precipitation input, soil type, and surrounding land use, steeper streams generate higher peak flows over shorter periods of time. Wetlands are generally not present in steeper reaches, although some natural higher gradient streams with modest gradients (closer to 1%) will have floodplain storage.

In urbanized or agricultural catchments the increase in impervious area introduces contaminants from paved roadways and surfaces. There is also a reduced opportunity for infiltration and evapotranspiration which can cause higher gradient streams to be flashier; have higher peak flows; lower winter baseflows; and more frequent high flow events. Summer baseflows may increase or decrease depending on conditions.

4.2.1. WHAT FLOWS TO MONITOR IN HIGHER GRADIENT STREAMS

It is recommended that flow be monitored in all Higher Gradient systems. As a minimum, one year of continuous flow data should be collected. The data will be analysed for the indicators listed below. For a more detailed discussion about these indicators and why there were chosen see Section 7.3 (Hydrologic Indicators).

Hydrologic Indicators

TQmean, low pulse count, low pulse duration, summer baseflow, winter baseflow, high pulse count, high pulse duration.

4.3. BENTHIC INVERTEBRATES IN HIGHER GRADIENT STREAMS

Healthy higher gradient streams will have more instream habitat complexity, with features such as woody debris and undercut banks. Species of higher gradient streams have limited temperature tolerances, high oxygen needs, and less tolerant to pollutants (i.e., salmonids). Biological indicators of higher gradient streams are typically those EPT taxa (i.e., Ephemoptera [mayfly], Plecoptera [stonefly], and Tricoptera [caddisfly]) that are pollution sensitive and therefore indicative of good to excellent water quality.

4.3.1. WHAT BENTHIC INVERTEBRATES TO MONITOR IN HIGHER GRADIENT STREAMS

Is it recommended that benthic invertebrates be monitored in all higher gradient systems using the multi-metric benthic index of biological integrity (B-IBI based on 10 sub metrics) but should also consider the composition of samples for number and variety of species.

4.3.2. WHEN TO MONITOR BENTHIC INVERTEBRATES IN HIGHER GRADIENT STREAMS

Benthic sampling should be conducted at one period during the year. See Section 6.3 (Benthic Invertebrate Methodology) for more information.

5. PIPED SYSTEMS

Piped systems are water conveyance systems which primarily feature subsurface piped infrastructure. The design philosophy behind them is a legacy of a previous civil engineering practices where routing runoff to receiving bodies as quickly as possible was the primary means of reducing flood hazard in developed areas. Source control measures are increasingly used to reduce runoff but piped systems still account for the majority of urban drainage infrastructure. Photo A shows a typical stormwater outfall for a piped system in an urban area.

Monitoring piped systems is important for considering the quality of water which is being discharged to receiving waters and the impacts it can have on both aquatic life and recreational use. Stormwater runoff has been identified as the primary transport mechanism for the introduction of non-point source pollutants to receiving water bodies and as the leading cause of degradation of receiving water quality (Goonetilleke et al., 2005; Birch et al., 2004).

5.1. WATER QUALITY IN PIPED SYSTEMS

Water quality in piped systems is dictated by surface (road and roof) runoff to catch basins. Given that piped systems are typically found in urban environments, water quality issues are expected to be related to metals, hydrocarbons and bacteria.

5.1.1. WHAT WATER QUALITY PARAMETERS TO MONITOR IN PIPED SYSTEMS

It is recommended that water quality be monitored in all piped systems.

The parameters to measure are:

Dissolved oxygen, temperature, turbidity, pH, conductivity, nitrate, E. Coli, fecal coliforms, total iron, total copper, total lead, total zinc, and total cadmium.

5.1.2. WHEN TO MONITOR WATER QUALITY PARAMETERS IN PIPED SYSTEMS

Samples should be collected during two periods of the year – in the wet season (between November and December) and in the dry season (between July and August). Each of these seasonal monitoring periods will require collecting 5 samples over a 30 day period, preferably on a weekly basis.

6. DATA COLLECTION METHODOLOGY

The monitoring protocols developed here are intended to guide municipalities in planning and implementing ISMP monitoring programs for watershed health. Data collection methodology must account for spatial variability on the watershed, stream, reach and site scales as well as temporal variability. The objective of the guidelines is to maximize the value of field measurements in terms of their ability to provide information about watershed health. This can be accomplished through proper site selection; field sampling procedures; quality assurance/quality control (QA/QC); and data analysis. The latter is discussed in Section 7 (Data Analysis and Assessment).

6.1. WATER QUALITY SAMPLING METHODOLOGY

Individual water quality samples can provide snap shots of the chemical composition of water at a particular location and time. As part of the AMF, the water quality program requires sampling twice during the year –in the wet season (between November and December) and in the dry season (between July and Aug). Each seasonal monitoring period will occur over a 30-day period, with samples collected five times (preferably on a weekly basis).

Sampling protocols have been developed in accordance with the Guidelines for Designing and Implementing a Water Quality Monitoring Program in BC (Cavanagh et. al., 1998) and the Guidelines for Interpreting Water Quality Data (Ministry of Environment, Lands and Parks, 1998).

For the purposes of consistency, the sampling should be conducted by the same Qualified Environmental Professional (QEP) continuously throughout the program. The QEP conducting the sampling should be aware of all handling, safety, and sampling procedures associated with the physical sampling and required equipment. This includes familiarization with relevant Material Safety Data Sheets (MSDS) and precautions necessary for handling chemicals.

6.1.1. SITE SELECTION

As outlined in EVS (2003), a qualitative reconnaissance of the study watershed should be carried out prior to sampling in order to assess the overall conditions of the site and identify suitable areas for sampling (e.g., avoid areas with disturbances such as cattle crossings or recently cleared land). The site selected should be representative of the watershed as a whole and should be located sufficiently downstream of a point to assess potential land use impacts on the entire sub-watershed or cumulative impacts in an area. Efforts should be made when selecting a reach to avoid impacts from localized disturbances. Once sample sites are selected, they should be adequately recorded for subsequent sampling sessions.

6.1.2. FIELD SAMPLING PROCEDURES

A combination of in-situ measurements and water samples will be collected concurrently during each sampling event. The specific parameters to be assessed are listed in Section **Error! Reference ource not found.**.

Grab samples should be collected directly from each site by hand or by using an extendible sample pole where steep banks prohibit access. At each sampling location, new powderless nitrile gloves should be worn to minimize potential contamination, and relevant site details should be recorded onto field data sheets, which are provided in the Appendix and can be printed out.

Mandatory site information to be recorded includes:

- name and location of sampling point, including UTM coordinates;
- name of sampler
- date and time of sampling – this should be consistent with the chain of custody (COC) form;
- a relevant description of site conditions (e.g., weather, water level/flow, substrate characteristics, water clarity, etc.);
- field in situ parameter results (temperature, DO, pH);
- record of equipment calibration;
- photographic record (substrate, upstream, downstream)

The photographic record should include a shot of the substrate at the sampling location in addition to both an upstream shot and downstream shot taken from a consistent (marked) location so that photos from different years can be compared. All photos should be dated and consistently labelled.

Transport and Storage

Samples collected for laboratory analysis should be bottled and transported as per specific requirements for the individual parameters. The appropriate bottles, method and allowable period of storage vary according to the parameter of interest (follow instructions provided by the laboratory). A laboratory supplied chain-of-custody (COC) record should be completed on site following sample collection and shipped to the laboratory with the labelled samples. Once samples have been collected they should be stored at an appropriate cool temperature (as per laboratory requirements) and handled in such a manner as to prevent potential contamination and damage to containers and/or the sample labels.

Photo 1: Water Quality Sample Collection

Photo 2: Water Quality Sample Transfer

6.1.3. LABORATORY ACCREDITATION

Laboratories in Canada may apply for accreditation of their ability to conduct specific test methods according to ISO 17025 standards. The Canadian Association of Laboratory Accreditation (CALA) and the Standards Council of Canada (SCC) promote high standards of laboratory performance by carrying out proficiency testing and on-site auditing of laboratories.

Water quality sampling conducted as part of the Adaptive Management Framework should be analyzed by a laboratory with an ISO 17025 accreditation for the parameters identified in the water quality portion of the framework.

6.1.4. DETECTION LIMITS, ACCURACY AND METHODS

The detection limit is the lowest concentration of a chemical that can be reliably measured. The detection limit depends on the equipment used for analysis and the method of analysis. It can also be affected by the concentration of other parameters present in the water.

A Reporting Detection Limit (RL or RDL) is the limit of detection for a specific target parameter for a specific sample after any adjustments have been made to account for that sample's characteristics, such as matrix effects or dilutions needed. A report from the lab may refer to this as "DL", "RDL" (reporting detection limit), or "RL" (reporting limit). The Reporting Limit should be considered when planning a monitoring program.

To compare the concentration of a parameter to a water quality guideline, the Reporting Detection Limit (RDL) must be less than the guideline. If the Reporting Detection Limit will be greater than the guideline level that is being compared to for assessment, then the laboratory should be consulted to discuss options for reporting the parameter of concern with a lower detection limit.

Table 2 provides recommendations for Reporting Detection Limits (RDL's), accuracy and recommended methods for framework parameters.

Table 2 - Reporting Detection Limits and Accuracy

	Optimal Reporting Detection Limits (RDL's) (+ notes on accuracy and methods)
General Parameters	
Dissolved Oxygen (mg/L)	Accuracy for 0 - 20 mg/L is +or- 0.2 mg/L or +or- 2% of the reading, whichever is greater
pH (relative units)	0.2 units
Water Temperature (degrees C)	+or- 0.2 degrees C
Conductivity (uS/cm)	1 us/cm
Turbidity (NTU)	0.1 NTU
Nutrients	
Nitrate (as Nitrogen, mg/L)	lowest possible RDL; recommend less than or equal to 0.005 mg/L
Microbiological Parameters	
E. Coli (freshwater) (CFU/100ml)	lowest possible RDL; 50 CFU/100ml or less facilitates effective comparison to water quality assessment table; MF (membrane filtration) method

Fecal coliforms (freshwater) (CFU/100ml)	lowest possible RDL; 50 CFU/100ml or less facilitates effective comparison to water quality assessment table; MF (membrane filtration) method
Metals	
Total Iron (ug/L)	Ask lab for "*low level ICPMS*" package that includes Total Iron, Total Cadmium, Total Copper, Total Lead and Total Zinc
Total Cadmium (ug/L)	
Total Copper (ug/L)	
Total Lead (ug/L)	
Total Zinc (ug/L)	

6.1.5. UNITS

Laboratories may report the concentration of parameters in milligrams per litre (mg/L) or micrograms per litre (µg/L or ug/L).

When looking at the results from a lab and comparing them to previous results, or to the results from a different lab, or to water quality guidelines, it is important to make sure that the units are the same.

In the Adaptive Management Framework, the water quality assessment table specifies the units that the data needs to be in for comparison to the green, yellow and red assessment categories.

If units from the lab reporting do not match those required for assessment, then conversion of the lab results to appropriate units is needed prior to assessment.

1 mg/L = 1000µg/L (micrograms per litre)
1 mg/L = 1 ppm (part per million)
1 µg/L = 1 ppb (part per billion)

6.1.6. QUALITY ASSURANCE/QUALITY CONTROL PROGRAM (QA/QC)

The water quality monitoring program should include appropriate quality assurance (QA) measures to ensure consistency with field processes and quality control (QC) techniques for minimizing potential imprecision and bias in the data.

The QA component exists for the field sampling procedures (*e.g.,* collection, preservation, filtration, and shipping components) and analytical procedures (laboratory component). The QC component is a set of activities intended to control the quality of the data from collection through to analysis (Cavanagh et. al., 1998). This involves the regular usage of QC samples (blanks and replicates), and diligent record keeping.

A QA/QC program should be implemented to ensure that the performance of the water quality meters and field sample collection procedures do not introduce bias into the surface water quality results. The QA/QC procedures are intended to ensure that samples collected and tested on site adequately represent conditions at the time of measurement on the site.

The field QA/QC program requires:

- use of a standardized field data sheet to ensure consistency with data collection;
- daily equipment calibration and record keeping;
- collection and analysis of replicate samples; and,
- collection and analysis of a field blank and trip blank.

Equipment Calibration

All equipment used to collect and/or assess *in situ* readings (temperature, dissolved oxygen, pH) should be calibrated immediately prior to sample collection. Calibration should be completed according to the manufacturer's instructions and recorded in field notes and the data sheet.

Replicate and Blank Samples

A minimum of 10% of the analytical laboratory analysis monitoring cost should be devoted to QA/QC. This should include a combination of replicate samples, field blanks and trip blanks. A replicate is an extra sample collected at the same time and place as a regular sample so that the results can be compared.

Blank samples are designed to detect contamination that may contribute to imprecision and bias (Ministry of Environment, Lands and Parks, 1998). A combination of field blanks and trip blanks should be collected concurrently with the standard water quality sampling. Field blanks are important in determining potential contamination from the sampling technique and/or exposure to the atmosphere. The field blank is handled in the same manner as the regular sample but uses de-ionized water provided by the laboratory which is poured in the field. Should de-ionized water not be available, bottled distilled water (spring water should not be used when sampling metals) may be used as an alternative; however, this should be noted in both the field notes and the laboratory COC. Field blanks should be analyzed for the same list of parameters outlined in the sampling program.

A trip blank is laboratory de-ionized water poured into the sample bottle prior to the sample trip. The trip blank will remain unopened throughout the duration of the trip. These help determine contamination resulting from the container during transport and storage. A trip blank is typically only analyzed should results from the field blank sample analysis show evidence of contamination.

6.2. FLOW MONITORING METHODOLOGY

As a minimum, municipalities should establish the flow monitor gauge and develop a stage-discharge rating curve (discussed in Section 6.2.1) for one year of flow monitoring.

If resources allow, consideration should be given to leaving flow monitors in every drainage system permanently. In years when no monitoring program is in place the gauge could run continuously, data could be downloaded at the intervals required to avoid loss and /or shutdown, and at least one discharge measurement could be collected for rating curve maintenance. This allows data collection to be maintained over the long term without unnecessary costs related to re-establishing the gauge and rating curve. For more information on this see Section 10 Supplemental Monitoring.

6.2.1. SITE SELECTION FOR WATER LEVEL GAUGES

Each watershed and monitoring program has unique characteristics that should be considered when selecting flow monitor gauge sites. Depending on the size of watershed and budget available, one or more water level gauges may be installed. As a rule of thumb when the number of gauges to be installed is limited, a gauge should be installed on the mainstem of the largest stream in the watershed, downstream of all major tributaries. In this manner, runoff from the entire watershed can be measured and individual contributions of tributaries can be estimated by area scaling or flow gauging. In some cases it may also be beneficial to collect data at a tributary catchment which is distinct in character (e.g. physiographically, soil types, land use).

Water level gauges should be sited in areas with relatively straight, aligned banks; in close proximity to good flow measurement sites (varies depending on measurement technique, see below); good access; no tributaries between the gauge and flow measurement site; and no wetlands immediately downstream or in the vicinity of the site (Resources Information Standards Committee, 2009).

6.2.2. SITE SELECTION FOR FLOW MEASUREMENTS

Flow measurements are required to develop a stage-discharge rating curve. The rating curve expresses the relationship between recorded water levels (stage) at the gauge and measured discharge. This relationship is used to translate the continuous water level record into a continuous discharge record. Flow measurements should be taken in close proximity to the water level gauge, with no tributaries entering the stream in between the two. Desirable site characteristics depend on the type of flow measurements to be collected. Standard flow measurement techniques include:

- velocity-area methods (e.g. current meter or acoustic doppler velocimeter i.e. ADV);
- tracer dilution methods (salt or rhodamine);
- rated structures (weir or flume); and
- volumetric measurement.

For velocity-area methods, conditions approximating laminar flow conditions are preferred. The site should have a single, well-defined channel; fairly uniform depth and velocity; and no instream vegetation (Resources Information Standards Committee, 2009). Dilution gauging requires sites with more turbulent flow and limited pool storage to encourage mixing. For this type of measurement, sites with known groundwater discharge/recharge, or abrupt slope breaks should also be avoided as groundwater flux will affect the results. The necessary channel conditions for use of rated structures depend on the type of structure, but in general a single-thread channel is required with relatively straight banks and uniform flow. Volumetric measurement is ideally suited to small discharges where plunging flow occurs, for example at a perched stormwater pipe or culvert outfall.

6.2.3. DATA COLLECTION PROTOCOLS

Hydrometric data collection should follow the Manual of British Columbia Hydrometric Standards (Resources Information Standards Committee, 2009) requirements for 'Grade A' data. Data which qualifies as 'Grade B' due to difficult site conditions is also acceptable. The guidelines include requirements for instrumentation, stream channel conditions, field procedures, rating curve accuracy, and data QA/QC. Some of the key requirements are:

- use of a recording water level gauge with precision of 2 mm or less;
- gauge installation at a stable cross-section in a relatively straight reach of the channel with minimal weeds and boulders;
- a minimum of five manual flow measurements per year until the rating curve is established and stable;
- a minimum of one flow measurement per year when rating curve is stable (this would include years in which no other monitoring is scheduled); and,
- a discharge rating accuracy of less than 7%.

6.2.4. DATA QA/QC

Hydrometric data QA/QC is an integral part of a successful monitoring program. The QA/QC process should include the following components:

1. Data compilation and review. Water level time series data should be compiled, plotted and reviewed for errors. Once the rating curve has been developed, the discharge time series should undergo a similar process.
2. Examination of sensor and physical water level measurements. Physical water level measurements recorded during each flow measurement should be compared to the concurrent water level sensor record. In the case of anomalies, the sensor and benchmark elevations should be checked.
3. Review of observations made during site visits. Field notes and photos from site visits should be reviewed in case of anomalous measurements, and to ensure conditions and procedures were conducive to valid measurement.
4. Detailed error analyses and error estimates. Error for flow measurements should be less than 7%, and should incorporate instrument precision, field conditions, and operator error (if any). Error estimates for rating curves and time series should also be completed.
5. Suitability of individual discharge measurements for rating curve development. Individual flow measurements should be assessed for accuracy based on field conditions, agreement with previous measurements and water level data, and equipment or operator error. Measurements with error greater than 7% should be discarded or used with caution.
6. Assignment of grade levels to discharge measurements as described in Resources Information Standards Committee (2009). The grading of individual discharge measurements ensures that field staff and reviewers strive for a high standard.

6.3. BENTHIC INVERTEBRATE SAMPLING METHODOLOGY

Benthic invertebrate communities are an important component to assess the overall health of a stream or watershed. Benthic invertebrates are influenced by both physical (substrates, flow) and chemical (water quality, sediment quality) and as such can provide an overall measure of biological health.

Benthic invertebrates should be collected a minimum of once every 5 years, although more frequent collection (particularly for rapidly changing watersheds) would allow for a better understanding of changes in stream health over time. For the Adaptive Management Framework, it is recommended that sampling take place in the late summer or early fall (August to September) as per most standard protocols, when invertebrates are abundant and stream flows are low prior to the onset of fall rains. Some local municipalities have sampled benthic invertebrates in spring, following the vegetation bud out period, in streams that have no flow in the late summer/early fall period and where data has been historically collected during this time period. For considering trends over time, it is important that the sampling dates be consistent across sampling years to allow for the most meaningful comparison of results. Sampling should not be carried out within a few days after a large rainfall event.

Where possible, benthic sampling locations should be the same as the water quality assessment sites to allow for the comparison of benthos community findings to water quality information.

Specific details regarding collection methods are provided below.

6.3.1. BENTHIC INVERTEBRATE SAMPLING METHODOLOGY

For the collection of benthos samples in Lower Mainland flowing watercourses, it is recommended that a Surber sampler with a 250 µm mesh size be used. For each sample collected, the Surber sampler is placed within a random, shallow riffle, and the substrate agitated for three minutes to dislodge benthic invertebrates and wash them into the Surber sampler. Three (3) replicate samples (3 jars per stream) should be collected consisting of a composite of three Surber placements in each jar. The composite samples ensure that an adequate number of organisms are collected in each sample. Replicate samples should be collected within a 50m long sampling reach, depending on availability of suitable riffles.

Organisms should be transferred into a pre-labelled, leak-proof plastic sample bottle (250mL or 500mL PET plastic jars work well) and preserved with 10% buffered formalin. All samples should be labelled with an internal paper label slip. Samples may then be shipped to a qualified taxonomist for analysis. The taxonomist should be certified by the Society for Freshwater Biology taxonomic certification programme.

Background information on field equipment, factors to consider in site selection, and sample preservation can be found in established protocol documents such as EVS (2003), Beatty et al. (2006), Cavanagh et. Al., (1997), and Rosenberg et. Al, (n.d.).

6.3.2. BENTHIC INVERTEBRATE SAMPLING QA/QC

A QA/QC program for biomonitoring is essential to the success of the program and should include standardized field forms and COC forms; the preparation of a reference collection for potential third-party verification and analyses; and data management. A benthos QA/QC program can also include sample re-sorts to evaluate sorting efficiency.

7. DATA ANALYSIS AND ASSESSMENT

7.1. WATER QUALITY DATA ANALYSIS

Prior to initiating data analysis, the sample site, dates of sampling, and the parameters on the data sheets provided by the laboratory should be cross-referenced and verified with the field program notes and requisitions. Holding times (time from collection to analysis) and "temperature (of samples) on arrival" should be assessed to ensure samples met QA/QC requirements for valid test results. Results of the field QA/QC program (Section 6.1.6) should be reviewed to confirm the validity of the data collected. Any potentially anomalous data should be flagged and discussed with the laboratory.

Once the data are verified, the results can be tabled and the mean value can be calculated. Values below reportable detection limits (RDL or RL) should be set equal to the RDL (or RL) prior to the calculation of the mean.

7.2. WATER QUALITY RESULTS ASSESSMENT

Water quality monitoring is required for all system types as part of the Adaptive Management Framework's core monitoring program.

In development of the Adaptive Management Framework, three considerations associated with the water quality assessment have been:

1. how to best evaluate water quality while balancing the need for good data with the reality of municipal resource levels,
2. how to evaluate and interpret the range of data obtained in a simple consistent way that could help inform management decisions and,
3. how to ensure meaningful actions are taken based on issues indicated by the data.

To address these considerations the water quality assessment adopts three approaches.

- A "core monitoring program" has been identified as the basic program, and a set of supplemental monitoring recommendations have been provided (see Section 10). A municipality may choose to increase the number of sites monitored and/or add supplemental monitoring for a more rigorous assessment of watershed conditions than the core program provides.
- Indicator parameters for the core program have been classified as either "priority" indicators or "secondary" indicators (see Table 3). Both types of indicators should be measured. Priority indicators are generally considered to be the most relevant and meaningful for each system type when considering watershed health and adaptive management. Secondary indicators provide supporting information.
- A "traffic light" (green, yellow, red) ranking system (see Table 4) has been developed that provides a simplified approach to help municipalities assess water quality conditions rapidly, track change over time, and prioritize adaptive management actions.

The Core Monitoring

Specific parameters (in the core program) to be assessed include general parameters (collected in the field with a hand held meter), nutrients, microbiological parameters, and metals:

General parameters:

- dissolved oxygen (DO) (meter)
- pH (meter)
- water temperature (meter)
- conductivity (meter or lab sample)
- turbidity (meter or lab sample)

Nutrients:

- nitrate (as nitrogen)

Microbiological parameters:

- *Escherichia Coli*
- Fecal Coliforms

Metals:

- total iron
- total copper
- total lead
- total zinc
- total cadmium

Priority and Secondary Indicators

A summary of “priority” and “secondary” water quality indicators, by system type, is provided below in Table 3. Priority indicators focus on impacts typically associated with a particular system and will generally provide the most useful information.

Though every system type samples both priority and secondary indicators, the results of their primary indicators should be the focus when deciding on a course of adaptive management action. Secondary indicators help with interpretation of results for Priority indicators and are useful when trying to determine the cause of an impact.

Table 3 - Priority (P) and Secondary (S) water quality indicators for each drainage system type

Parameter	Discussion	Higher Gradient	Lower Gradient	Piped
General Parameters				
Dissolved Oxygen	Watercourses with flowing water, such as mountain streams, tend to contain more dissolved oxygen (DO), than low flow or still waters. Bacteria in water can consume oxygen as organic matter decays. DO in surface water is also controlled by temperature, with cold water holding more DO than warm water. This parameter is considered to be more important in lowland watercourses, particularly during the summer, where low DO levels can negatively influence resident fish.	**P**	**P**	S

pH	Changes in pH can indicate the presence of particular effluents that may be detrimental to aquatic life, such as road runoff or a spill (e.g., the introduction of concrete wash water can significantly increase water pH).	S	S	S
Water Temperature	Elevated water temperatures can affect the development of fish eggs, rearing of juvenile fish, and the movement and migration of adult salmonids. Increased water temperature is a potential indicator of loss of riparian habitat upstream (reduced shading), increase water retention (perhaps due to an increase in number and size of stormwater detention ponds).	**P**	**P**	S
Conductivity	Conductivity is a broad measure of ionic concentration. Watershed geology and relative contribution of groundwater exert a strong influence on background conductivity. However more urbanized systems typically have a much higher conductivity level relative to natural forested streams with similar geology and groundwater inputs. Discharges to streams can change the conductivity depending on their make-up. A failing sewage system would raise conductivity because of the presence of chloride, phosphate, and nitrates; an oil spill would lower conductivity.	S	S	S
Turbidity	Increased turbidity could indicate that there is increased erosion upstream. Higher amounts of dissolved or suspended solids result in increasing turbidity.	**P**	**P**	**P**
Nutrients				
Nitrate (as Nitrogen)	High levels of nitrogen can be indicators of pollution from man-made sources, such as septic system leakage, poorly functioning wastewater treatment plants, or fertilizer runoff. Some nitrate enters water from the atmosphere, which carries nitrogen-containing compounds derived from automobiles and other sources.	**P**	**P**	**P**
Microbiological Parameters				
Escherichia. Coli	The presence of *E. coli* can indicate contamination from human and animal waste. Animal waste typically enters watercourse via stormwater.	**P**	**P**	**P**
Fecal Coliforms	High fecal coliform bacteria can indicate contamination with fecal material (humans or other animals). Sources can include agricultural runoff, effluent from septic systems (groundwater contamination) or sewage discharges. Bacteria (from bird and wildlife fecal material) also enter aquatic systems via stormwater. Human waste contamination can occur via combined server overflows (CSOs) or from spill events.	**P**	**P**	**P**
Metals				
Iron	Stormwater is a significant source of a wide range of metals including iron, copper, lead, zinc, and cadmium. Sources include roof flashings and shingles, gutters and downspouts, galvanized pipes, vehicle exhaust, and tire and brake linings/rotors. High levels of iron can also be an issue in agricultural drains in parts of the Lower Mainland. The issue occurs when iron is mobilized from farm soils or from groundwater seepage (iron is oxidized).	**P**	**P**	**P**
Copper	See above	**P**	**P**	**P**
Lead	See above	**P**	**P**	**P**
Zinc	See above	**P**	**P**	**P**
Cadmium	See above	**P**	**P**	**P**

Sources: EVS 2003; USGS 2013 (http://ga.water.usgs.gov/edu/runoff.html); McKenzie et al. (2009); Macdonald 2003; BC Ministry of Agriculture 1988; Michaud 1994.

Color Coded Ranking System for Water Quality Assessment

Overview

The framework, when implemented, gives information on watershed health status, and helps prioritize where to focus limited resources on adaptive management. A "traffic light" (green, yellow and red) water quality assessment approach was developed to provide a simplified system to help municipalities quickly identify where water quality conditions are good and where there may be concerns with water quality. This water quality assessment system, when considered along with the benthic invertebrate and hydrometric indicator information, gives a more holistic assessment of stream health in watersheds that are potentially at risk from urban land use and non-point source pollution.

With repeat monitoring over time, changes in watershed health status can begin to be tracked. This gives a feedback loop, providing information for decision making about plans and actions in watersheds. As development and re-development proceed in watersheds, this tiered water quality assessment approach can provide information to help communities work toward preventing declines (e.g. greens moving to yellows, and yellows moving to reds) and work toward improving the situation where impacts are occurring.

The green, yellow and red rankings have been developed based on Provincial water quality guidelines. Appendix D provides more specific information about how the green, yellow and red threshold levels were developed.

Determining Rankings

Individual water quality sampling results (from each sampling date) are to be included, by parameter, in the "Monitoring Results Report Sheet" (see Appendix D), along with the mean (average) values for each parameter. The Geometric Mean (see Appendix D) should be used to summarize bacteria instead of the arithmetic mean. The mean value (or geometric mean value, in the case of bacteria) for each parameter (including metals) is to be ranked (and color coded) according to the green, yellow and red rankings given in Table 4. The rankings for parameters, are reported alongside the monitoring data in the "Monitoring Results Report Sheet".

In this management framework, the parameters are considered to be of two types – "Priority" and "Secondary" parameters. The "Priority" and "Secondary" parameters are identified and described in Table 3 for the different drainage system types. Both "Priority" and "Secondary" parameters are to be monitored. "Priority" parameters are the parameters that tend to be most directly informative for adaptive management purposes, and as such should be the prime consideration when city-wide Adaptive Management Plans are being developed. The secondary parameters tend to be parameters that will help with interpretation of "priority" water quality parameters when "priority" water quality parameters receive yellow or red rankings. Although this is the general approach of the framework, very extreme values in secondary parameters on their own, can be suggestive of spill issues or point source pollution issues and should be considered in the context of the city-wide adaptive management plan.

Interpreting Color Ranking

The general interpretation of individual parameter rankings is the following -

- **Green Priority Indicator** = suggests that water quality for this parameter, at least at the current monitoring location, is good. Based on this monitoring, no further monitoring for this parameter is required in the drainage system for 5 years. No adaptive management is required based on this monitoring.
- **Yellow Priority Indicator** = suggests that water quality is either closely approaching a level of concern for this parameter or is already in non-attainment with Provincial Water Quality guidelines. The level of the parameter result (relative to water quality guidelines and/or objectives) and the incidence of additional priority indicators of concern should be considered in development of the city-wide Adaptive Management Plan. Consider for supplemental water quality monitoring and/or adaptive management actions.
- **Red Priority Indicator** = suggests that water quality is in non-attainment with Provincial Water Quality guidelines. The level of the parameter result and the incidence of additional priority indicators of concern should be considered as part of the city-wide Adaptive Management Plan. Recommend supplemental water quality monitoring and/or adaptive management actions.
- **Green, Yellow or Red Secondary Indicator** = provides supporting information for interpretation of Priority Indicators and for identification of the source of an impact

For each watershed the full set of water quality rankings should be considered, with priority parameters guiding adaptive management and secondary parameters providing supporting information. Rankings for water quality in the watershed will help determine whether adaptive management actions are warranted and rankings will help identify priority areas.

- ***Watersheds with all green priority water quality rankings*** = No further monitoring required in drainage system for 5 years. No adaptive management required based on this monitoring.
- ***Watersheds with single or multiple yellow and/or red priority rankings*** = Actions to address water quality issues should be considered by each municipality as part of the development and implementation of a city-wide (multi-watershed) adaptive management plan. This city-wide (multi-watershed) adaptive management plan should be based on highest priority values and issues (for more information see Section 9 - Adaptive Management Planning). Monitoring for these watersheds continues on the 5 year cycle, however implementation of adaptive management actions (which may include more focused investigative monitoring) occurs with timelines guided by the city-wide adaptive management plan and with input, as warranted, from senior agencies.

Table 4 - Classification of water quality results

	Green Level	Yellow Level	Red Level
General Parameters			
Dissolved Oxygen (mg/L)	11 or greater	<11 to 6.5	<6.5
pH (rel. Units)	6.5 to 9.0	<6.5 to 6.0 or >9.0 to 9.5	<6 or >9.5
Water Temperature (deg. C)			
low flow summer	< 16	16 - 18	over 18
wet weather fall winter	7 – 12	5 - 7 or 12 - 14	<5 or >14
Conductivity (uS/cm)	<50	50-200	>200
Turbidity (NTU)	0 to 5	5 to 25	>25
Nutrients			
Nitrate (as Nitrogen, mg/L)	<2	2 - 5	>5
Microbiological Parameters			
E.Coli (freshwater) CFU/100ml)	Geomean <77	Geomean 78 - 385	Geomean >385
Fecal coliforms (CFU/100ml)	Geomean <200	Geomean 201-1000	Geomean >1000
Metals (Total Metals µg/L) *			
Iron	<800	800 - 5,000	>5,000
Cadmium	<0.03	0.03 - 0.15	> 0.15
Copper	<3	3 - 11	>11
Lead	<5	5 - 30	>30
Zinc	<6	6 - 40	>40

* Rank values assume Hardness approximating 100 mg/L $CaCO_3$.

7.3. HYDROLOGIC DATA ANALYSIS

Hydrologic indicators of stream health were selected from a review of the literature. Criteria for indicator selection included:

- sensitivity to land use changes and urbanization;
- correlation with measures of biological stream health; and
- ability to be calculated from a single year's daily flow data.

Although a number of indicators are listed, they are all easy to calculate or extract from the annual flow data. The effort required is minimal and the results are meaningful in selecting the most appropriate and effective adaptive management practices.

Substantial research exists in relation to the identification of appropriate indicators for hydrologic alteration as a result of urbanization, most notably in Washington State (Booth et al., 2001, 2004; Cassin et al., 2005; DeGasperi et al., 2009; Konrad and Booth, 2005; Richter et al., 1996). Comparatively less effort has been devoted to identifying indicators of hydrologic alteration stemming from agricultural land use (Nejadhashemi et al., 2011; Poff et al., 2006).

A single set of hydrologic indicators are used for both urban and rural land use areas, since the effects of both types of alteration are similar in quality if not degree. Both urban and rural land use result in flashier discharge patterns, with more frequent high flow events. Flow tends to be re-distributed from baseflow to storm flow. Infiltration and natural storage (i.e. soil moisture and wetland) tend to diminish. These effects are generally more pronounced when land is converted from forest cover to urban land use, as compared with conversion from forest cover to rural/agricultural land use, because urban landscapes have a greater proportion of impervious surface.

FLASHINESS

The term 'flashiness' has a number of definitions, but generally relates to a set of characteristics including: rapid rates of change in flow; high variability of flow; more frequent increases and decreases in flow; high frequency of floods; low seasonality of floods and low flow events; increased magnitude of flood peaks relative to wet season baseflow; increased rate of stormflow recession; and decreased duration of time that the mean discharge rate is exceeded (Baker et al., 2004). Storm hydrographs of flashy streams tend to have higher peak flows and shorter durations as compared to more stable streams.

T_{Qmean}

We selected T_{Qmean}, the proportion of the year during which daily discharge exceeds the annual average discharge, as an indicator of flashiness (Table A3). A number of studies have linked T_{Qmean} with the degree of urban or rural development in watersheds (Booth et al., 2001, 2004; DeGasperi et al., 2009). Both types of development tend to decrease T_{Qmean} due to quicker recession of storm flows and increased frequency of high flow events.

T_{Qmean} has also been positively correlated with B-IBI index, a measure of biological health (Cassin et al., 2005; DeGasperi et al., 2009). As streams become flashier and T_{Qmean} decreases, B-IBI tends to decrease due to the dislodgment of key taxa. Increased erosion and deposition associated with flashier discharge could also be a contributor to lower B-IBI scores in flashy streams.

Decreasing T_{Qmean} indicates increasing flashiness, and would trigger consideration of appropriate AMPs (Table A4). Typical values of T_{Qmean} for healthy streams with natural forest cover in the Pacific Northwest are in the range of 0.40; however T_{Qmean} is positively correlated with basin area (Cassin et al., 2005; DeGasperi et al., 2009), and basins with smaller areas will tend to have lower values of T_{Qmean} since they are naturally flashier. The literature has not explored methods of accounting for this confounding influence, so T_{Qmean} should not be used to compare watersheds with different areas.

Low Flows

Land development affects the temporal distribution and magnitude of low flows primarily by reducing the amount of infiltration and groundwater recharge that occurs in the watershed. Developed areas tend to have lower magnitude low flows with more frequent spikes in discharge during the dry season. Soil compaction and degradation; increase in impervious area; water diversion and extraction; and constructed stormwater conveyance infrastructure all contribute to these effects.

We have selected four indicators of low flow alteration to account for both temporal and magnitude effects. Low Pulse Count, Low Pulse Duration and Low Pulse Range measure frequency and duration of low flows. Summer Baseflow and Winter Baseflow both measure magnitude of low flows.

Low Pulse Count

Low pulse count is the number of times daily flow drops below 0.5 times the mean annual discharge (MAD). Richter et al. (1996) defined the low pulse threshold based on pre-development flows, however DeGasperi et al. (2009) define the low pulse threshold as 0.5 times the MAD with the justification that mean flow is not significantly altered by urban development in Puget Lowland streams (an area physiographically and climatically similar to the Lower Mainland).

This indicator has been correlated with measures of development and biological health (Cassin et al., 2005; DeGasperi et al., 2009). Based on the definition above, the metric can be calculated from a single year's flow data, however calculating MAD based on a single year's data will introduce undesirable variability. Longer records will produce a more representative MAD, and therefore a better basis for comparison of low pulse counts on a year-to-year basis.

Low Pulse Duration

Low pulse duration is the average duration of low flow pulses during a calendar year. A low pulse is defined as a drop in discharge below 0.5 times the MAD. Low pulse duration has been correlated with measures of development and biological health (Cassin et al., 2005; DeGasperi et al., 2009). This indicator is expected to decrease with land development, as low flow periods are more frequently interrupted by small runoff events.

Summer Baseflow

Summer baseflow is the average of all daily discharges during July through September with seven-day antecedent rainfall less than 1 mm. Summer baseflow behaves inconsistently in response to development. Decreases have been linked to shallow groundwater extraction, surface drainage and water diversion (Hartley and Funke, 2001; Konrad and Booth, 2005). Summer baseflow may also increase due to the use of imported water for residential irrigation and septic systems (Konrad and Booth, 2005). Considering the variable response of baseflow to development, consideration of specific activities in the watershed should be incorporated into interpretations of baseflow alteration. Baseflow is also highly dependent on basin area, soil characteristics and other factors, and should not be compared across basins without accounting for these influences.

Winter Baseflow

Winter baseflow is the average of all daily discharges during November through March with seven-day antecedent rainfall less than 1 mm. In pluvial watersheds in the Pacific Northwest, urban development tends to result in decreasing winter baseflow by limiting shallow subsurface storage upon which wet season baseflows depend (Konrad and Booth, 2005).

High Flows

Land development affects the magnitude, frequency and duration of high flows. Loss of forest cover and soil compaction, greater impervious area, and stormwater conveyance infrastructure cause reduced infiltration and evapotranspiration, and quicker delivery of runoff to streams. As a result, high flow events occur more frequently and the magnitude of large events tends to increase. Due to stormwater receding more quickly, the duration of high flow events is reduced.

High Pulse Count

High pulse count is the number of times daily flow increases above twice the MAD. We defined the high pulse threshold in relation to the MAD for the same reasons in our definition of Low Pulse Count, above. If the daily discharge record never exceeds 2 times the MAD (e.g. in groundwater fed streams), the 80^{th} percentile flow should be used as the high pulse threshold. High Pulse Count has been correlated with measures of development and biological health (Cassin et al., 2005; DeGasperi et al., 2009). The metric can be calculated from a single year's flow data, and is expected to increase with land development.

High Pulse Duration

High Pulse Duration is the average duration of high flow pulses (as defined above) during a calendar year. High pulse duration has been correlated with measures of development and biological health (Cassin et al., 2005; DeGasperi et al., 2009). This indicator is expected to decrease with land development due to quicker rise and recession of storm flows.

7.4. HYDROLOGIC RESULTS ASSESSMENT

Ideally, the measured values for the hydrologic indicators would be scored against target thresholds or ranges based on pre-development conditions in the watershed. As a minimum, municipalities should evaluate hydrologic indicators in a given system by their trend over time. That is, a watershed should be compared to itself over time to determine if changes are taking place.

In watersheds where pre-development hydrologic conditions have already been established (e.g. during the ISMP process), comparison of current indicator values with pre-development values is the most practical and robust method of assessing hydrologic alteration. We encourage municipalities to require assessments of pre-development conditions as part of all ISMPs. If a goal of Integrated Stormwater Management is to maintain or re-establish natural pre-development hydrologic conditions, this information is essential.

If municipalities are not able to establish pre-development conditions, indicators should be evaluated by their trend over time (Table 4). Several years of flow data would be required to establish any trends, and the reliability of such trends will increase with longer flow records. By contrast, comparison to pre-development conditions could be done immediately following the first year of data collection.

Trend-based evaluation will in most cases allow municipalities to rate watershed health conditions as improving or degrading, however, it relies on assumptions of stable climatic conditions over the monitoring periods. Climatic variability may have a larger effect on year-to-year values for hydrologic parameters than moderate development impacts.

Table 5 - Hydrologic response to land development

Hydrologic Attribute	Indicator	Definition	Units	Expected Response to Land Development	Target
Flashiness	T_{Qmean}	Proportion of the year during which daily flow exceeds the annual average discharge.	Unitless	Decrease	Stable or increasing 5-year trend
Low Flow	Low Pulse Count	Number of times each calendar year that daily flow drops below 0.5 times the mean annual discharge	Count	Increase	Stable or decreasing 5-year trend
	Low Pulse Duration	Average duration of low flow pulses during calendar year	Days	Decrease	Stable or increasing 5-year trend
	Summer Baseflow	Average of daily discharges during July through September with seven-day antecedent rainfall less than 1 mm	m^3/s	Increase or Decrease	Stable 5-year trend
	Winter Baseflow	Average of daily discharges during November through March with seven-day antecedent rainfall less than 1 mm	m^3/s	Decrease	Stable or increasing 5-year trend
High Flow	High Pulse Count	Number of times each water year that daily flow increases above twice the mean	Count	Increase	Stable or decreasing 5-year trend

Hydrologic Attribute	Indicator	Definition	Units	Expected Response to Land Development	Target
		annual discharge			
	High Pulse Duration	Average duration of low flow pulses during water year	Days	Decrease	Stable or increasing 5-year trend

7.5. BENTHIC INVERTEBRATE DATA ANALYSIS

Since benthic invertebrate communities are relatively sedentary, they can reflect site specific environmental conditions. The benthic invertebrate communities associated with aquatic systems are highly variable and may be influenced by a wide range of factors, including, but not limited to:

- water quality;
- sediment quality;
- flow regime (duration, magnitude of high/low flows, water depths, etc.);
- substrate characteristics (particle size, stability, etc);
- degradation of aquatic habitat (erosion, siltation, etc.); and
- reduced riparian areas (loss of food sources).

Typically, high diversity and numbers of benthic invertebrates are indicative of good water quality and instream habitat conditions, whereas presence of only pollution tolerant species or absence of macroinvertebrates suggests degraded water quality and instream habitat.

Prior to completing the assessment of benthic invertebrate data it is important that all data be reviewed for consistency and completeness. Specific tasks should include the screening of data and removal of all "non-benthic groups" (using appropriate references such as Mandaville, 2002). In addition, some data may need to be "collapsed" to the family level to allow for the use of all relevant data.

<u>Taxonomic Standard</u>

Benthic invertebrate taxa are generally identified to family, genus, and species depending on available taxonomic keys and the practicality of identification (e.g. gross morphology vs. Detailed microscope analysis). This is often referred to as "lowest practical taxonomic level" (LPTL). A standardized level of taxonomic resolution is essential for creating a consistent dataset that can be analyzed for changes over time. The Adaptive Management Framework recommends taxonomic identification to the "lowest practical taxonomic level".

Subsampling

Rarely are all the organisms in benthic invertebrate samples identified and enumerated. Instead a representative subsample is used to estimate the composition and abundance of taxa in the sample. Subsampling reduces the time and cost of taxonomic identification while providing a high quality, consistent dataset. It also allows for better statistical comparison of taxa richness. The recommended subsampling standard for benthic invertebrate samples from streams in Metro Vancouver is 400 organisms. Subsampling can be undertaken using a grid or box using published methods.

As noted previously, composite samples consisting of three Surber placements are often needed to ensure enough organisms are captured in each sample jar to meet the 400 organism requirement. Total abundance can be calculated based on the proportion of the sample used for subsampling.

There are a wide variety of approaches to analyze benthic invertebrate data including the use of summary tables and graphics, the use of metrics (both single and multiple metric approaches – e.g., B-IBI), and the use of more detailed multivariate statistical techniques.

The benthic invertebrate assessment combines a number of metrics to provide a more robust analysis of benthic invertebrate communities and allow for an improved assessment of potential changes over time. "B-IBI" and "Total Taxa Richness" indicators are part of the main reporting (see Appendix 1 Monitoring Results Report Sheet) for the AMF, and information on these indicators is provided below. Information is also provided on "Total Abundance" and "Community Composition" indicators, since municipalities may be interested in calculating these additional indicators for a better understanding of benthic invertebrate health.

Benthic Index of Biological Integrity

The multi-metric benthic index of biological integrity (B-IBI) has been used in Washington State since the mid 1990's (e.g., Karr and Chu 1999). The use of the B-IBI was adapted by Metro Vancouver in early 2000 as part of the Greater Vancouver Regional District's Liquid Waste Management Plan (LWMP) which required the completion of ISMPs in urban watersheds. Details regarding how the B-IBI is calculated can be found in Page et al., (2008). Studies have indicated that B-IBI measures decline as urban land cover increased both across entire basins and within riparian zones (e.g., Morley 2000); this can be correlated to percent total impervious area. Morley (2000) also found that channel roughness and hydrologic flashiness were negatively correlated with B-IBI in Puget Sound streams (i.e., flashy systems typically had lower B-IBI numbers). B-IBI has useful statistical properties that allow it to be used to detect trends in stream health using linear regression (Fore et al., 1994).

The B-IBI is based on 10 sub-metrics (Fore et al., 1994), including:

- total number of taxa;
- number of mayfly (Ephemeroptera) taxa;
- number of stonefly (Plecoptera) taxa;
- number of caddisfly (Trichoptera) taxa;
- number of long-lived taxa, defined as living at least 2 – 3 years in the immature state;

- number of intolerant taxa;
- percent of individuals in tolerant taxa;
- percent of predator individuals;
- number of clinger taxa; and
- percent dominance: the sum of individuals in the three most abundant taxa, divided by the total number of individuals found in the sample.

7.6. BENTHIC INVERTEBRATE RESULTS ASSESSMENT

The B-IBI scores the health of a stream on a scale of 10 to 50 as summarized in Table 6. The scores include qualitative ranking comments ranging "very poor" to "excellent". The challenge is that the system cannot be easily applied to all types of watercourses found in the Lower Mainland. The B-IBI is well suited for higher gradient (sloped) watercourses which are typically characterized by flowing water and coarser substrates (e.g. cobble, boulder, and gravel).

Of the ten (10) sub-metrics that comprise the B-IBI, the majority are driven by taxa that are more typical of these types of substrates and flowing water (e.g., number of mayfly, stonefly and caddisfly taxa; number of intolerant taxa; number of clinger taxa).

Table 6 - Values and rankings for B-IBI scores

B-IBI Score	Rank	Comments
46-50	Excellent	Pristine, no habitat degradation
38-44	Good	-
28-36	Fair	-
18-26	Poor	-
10-16	Very Poor	Impacted watershed, heavily urbanized

Total Taxa Richness

Taxa richness is the total number of unique taxonomic groups (e.g., family, genus, species) identified; taxa richness is calculated by simple adding up the total number of distinct taxa from each sample site. This is a simple metric which captures all the different invertebrates collected from a stream site and can be applied across all stream types and land uses. In general, the overall biodiversity of a stream declines as flow regimes are altered, habitat is lost, or water quality is degraded. Roy et al. (2003) found that taxa richness was negatively related to urban land cover and positively related to forest land cover.

Total Abundance

The total abundance of all taxa collected at a site is one of the simplest and easiest variables to obtain from a set of benthic samples. This variable is a fundamental attribute of community structure, and responds in broadly predictable ways to most types of environmental stress (Taylor et al., 1997). Changes in total abundance are easily compared among sites and between sampling periods. The disadvantage to this measure is that while it tends to respond in predicable ways to gross perturbations (e.g., reduced abundance due to chemical spill, or increased abundance due organic enrichments); it is often too coarse to detect subtle trends.

Community Composition

The evaluation of the overall composition of benthic invertebrate communities can assist with the assessment of stream health. The percent composition of major invertebrate groups (e.g., oligochaetes, chironomids, mayflies, stoneflies, caddisflies, etc.):

- is relatively easy to calculate;
- reflects the different communities found at a particular location (i.e., the number of groups summarized will depend on the diversity found at the site); and
- can be presented graphically (e.g., bar or pie charts).

The dominance of some groups (described as indicator taxa) can be indicative of degraded conditions or the presence of pollution (Table 7). The assessment of community composition can also include a review of the abundance of representative indicator taxa (e.g., some species of stoneflies).

Table 7 - Benthic invertebrate response to land development

Group	Description	Expected Response to Disturbance/ Pollution	References
% Chironomidae	With declining water quality, it is expected that the proportion of pollution-tolerant chironomids will increase within the benthic community.	Increase Tolerant	Taylor and Bailey 1997 Mason 2002 Plafkin et al. 1989 Winner et al. 1980
% EPT (Ephemeroptera, Plecoptera, Trichoptera)	Most EPT taxa are considered sensitive to environmental stress and therefore the overall abundance of these groups can be correlated with stream health. It must be noted however that the presence/absence of these groups is also greatly influenced by flow conditions and substrate characteristics.	Decline Intolerant	Taylor and Bailey 1997 Plafkin et al. 1989
% Isopods	Isopods such as Asellidae tolerant to impacts	Increase Tolerant	Wisseman 1996
% Oligochaetes	An increase in the proportion of oligochaetes may indicate nutrient enrichment and/or a change in the substrate towards more soft-substrate conditions.	Increase Tolerant	Plafkin et al. 1989 Luritsen et al. 1985 Schloesser et al. 1985

8. REPORTING

An important component of the framework is reporting out, by Municipalities and Metro Vancouver, on both watershed assessment and adaptive management.

Municipalities will prepare a report card type summary for each drainage system monitored which will be detailed in this section. Metro Vancouver will collate the municipal reports and prepare a summary of the results for submittal in the Biennial Integrated Resource and Liquid Waste Management Plan. Metro Vancouver will also provide an update in each Biennial report on progress with the Framework process itself and conduct periodic reviews as specified in Section 1.1.

The reporting package to be completed by each municipality for a drainage system is comprised of five parts: (1) Cover Sheet, (2) Monitoring Results Summary Sheet, (3) Photo Sheet, (4) ISMP Implementation Sheet, and (5) Adaptive Management Sheet. Each is detailed in the following sections and examples provided. Blank template sheets are provided in Appendix D. As specified on the Cover Sheet, photographs of the monitoring site are required. In order to provide a more thorough description of a drainage system, municipalities may optionally provide orthophotographs and/ or land use figures. Putting the monitoring data in context will allow for a better understanding of limitations and provide guidance on the most productive actions for improving watershed health.

8.1. COVER SHEET

The cover sheet provides the background on the drainage system being reported so that results can be reviewed and interpreted in context. For example, a drainage system with agricultural land use may experience water quality impacts. This information is used to guide adaptive management decision making. In the example given, a municipality may not have much ability to affect the water quality associated with agriculture, so adaptive management actions may be better directed towards other issues in the system which will be more effective. The report will serve to identify such issues to MoE.

Climate and development are also important background information included on the cover sheet as both can influence on monitoring results.

An example of a completed cover sheet is provided on the next page.

Monitoring and Adaptive Management Report Cover Sheet

Municipality: City of Blackford

Name of Drainage Area or Watershed: Roland Creek

ISMP Status: (Completed/Ongoing/None): Completed

ISMP Name and Date: Roland Creek ISMP, 2007

Size (ha): 960

General Classification (Higher Gradient /Lower Gradient/Piped): Higher Gradient

Monitoring Locations (Pipe/Outfall/Instream): Instream

GPS Coordinates of Monitoring Locations (attach map of system with locations shown):

Roland Creek at Governor Drive and 13th Street – 10 U 514511.11E; 5440749.22N; Elevation = 2m

Degree and Age of Development (Green, Developing, Built-Out, Redeveloping):

40% of existing urban land use is planned for redevelopment in the next 3 years. Older housing stock expected to redevelop.

Major Land Use Types - % of residential (H/M/L or mixed), commercial, industrial, institutional, and/or agricultural:

3% Agricultural, 2% Suburban Residential, 11% Industrial, 75% Urban, 9% Forested

Summer/Winter Temperature and Precipitation Averages (Normal, Hot/Cool, Wet/Dry):

Summer – warm/wet

Winter – cool/dry

Riparian Area (stream setback) protection:

☐ RAR ☐ SPR ☐ Other (please explain):

Notes:

8.2. MONITORING

The sheet submitted with the package shall report average water quality results in addition to individual results from the 5 samples collected in both wet and dry season. Water quality ranking (red/yellow/green) shall be based on the average value.

Water quality cells should be fill coloured with the ranking applicable to the results.

Flow Monitoring Results are to be reported as calculated values according to Section 7.3. If a pre-development value or past records are available, then results should be compared in order to determine the trend as stable, increasing or decreasing. Trend targets are listed in the table so that it can be determined, at a glance, how the reported results compare to trends which are beneficial to stream health. For example, it is desirable to have a stable or increasing TQmean value while a decreasing TQmean value indicates impacts.

Benthic Invertebrate scores are to be listed and the results compared to past records, if available, to determine a trend as stable, increasing or decreasing.

See example of a completed monitoring results report sheet on the next page.

MONITORING RESULTS REPORT SHEET						
WATER QUALITY MONITORING RESULTS						
Wet Season	**AVERAGE**	**1**	**2**	**3**	**4**	**5**
Temperature (Celsius)	8.5					
Dissolved Oxygen (mg/L)	10.1					
pH	7.1					
Conductivity (uS/cm)	144					
Turbidity (NTU)	4.2					
E.coli	148					
Fecal Coliforms	1.8					
Nitrate (as Nitrogen, mg/L)	1.063					
Total Iron (ug/L)	363					
Total Cadmium (ug/L)	0.01					
Total Copper (ug/L)	2					
Total Lead (ug/L)	0.3					
Total Zinc (ug/L)	5					
Dry Season						
Temperature (celsius)	16.2					
Dissolved Oxygen (mg/L)	6.2					
pH	6.5					
Conductivity (uS/cm)	190					
Turbidity (NTU)	5.7					
E.Coli	75					
Fecal Coliforms	62					
Nitrate (as Nitrogen, mg/L)	0.4					
Total Iron (ug/L)	773					
Total Cadmium (ug/L)	0.01					
Total Copper (ug/L)	2.5					
Total Lead (ug/L)	0.5					
Total Zinc (ug/L)	7					

FLOW MONITORING RESULTS			
	Value	**Trend – Stable, Decreasing, Increasing (S, D,I)**	**Target***
MAD (L/s)	441	N/A	
TQ Mean	0.48	Increasing	S or I
Low Pulse Count	42	No previous data	S, or D
Low Pulse Duration (Days)	12	Decreasing	S or I
Summer Baseflow (L/s)	9	Stable	S
Winter Baseflow (L/s)	34	Increasing	S or I
High Pulse Count	12	Stable	S or D
High Pulse Duration (Days)	4	Decreasing	S or I
BIOMONITORING RESULTS			
	SCORE	**Pre-Dvpt Value or Trend (S, D or I)***	**Trend Target ***
B-IBI Score	14	Stable	S or I
Total Taxa Richness	12	Decreasing	S or I
* See Table 4 Hydrologic response to land development			

8.3. PHOTOGRAPHIC RECORD

The photographic record will serve to further inform MoE and others about site characteristics in the absence of a physical inspection. They will also provide consistency in comparing data from future monitoring cycles by helping to ensure the same locations are used. The following photographs are to be included:

(1) Substrate at the water quality monitoring location

(2) Looking upstream from the water quality monitoring location

(3) Looking downstream from the water quality monitoring location

(4) Flow monitoring location (equipment set up)

(5) Benthic sampling location

Photo 3: Substrate at the Water Quality Monitoring Location

Photo 4: Looking upstream from the water quality monitoring location

Photo 5: Looking downstream from the water quality monitoring location

8.4. ISMP IMPLEMENTATION

If an ISMP has been completed for a drainage system, the ISMP Implementation table should be completed and submitted with the reporting package. See example of completed table below.

ISMP Implementation Table

ISMP Recommendation	Implemented (Y/N)	Years Since Implementation	Description of Action and Degree of Implementation
Soil amendment on new developments	Y	2	300mm absorbent soil installed on new residential and commercial developments.
Disconnect downspouts	N	N/A	Strategy being developed.
Detention Ponds	Y	3	Two detention ponds constructed, total storage volume 750 m^3.

8.5. ADAPTIVE MANAGEMENT PLAN

Municipalities will report on their municipal wide adaptive management plan. See Section 9.1 Adaptive Management Planning for more details. See example of a completed adaptive management plan table below.

Adaptive Management Plan Table

Drainage System Name	Target Issue	Adaptive Management Action	Year to Implement
Newbury Heights	Water quality	Sediment sampling	2014
Porter Mountain	Low Base Flows	Raingardens	2015
Star Creek	Sediment & Erosion	Bank Stabilization	2016

9. ADAPTIVE MANAGEMENT

9.1. ADAPTIVE MANAGEMENT PLANNING

The goal of adaptive management planning is to put the monitoring results to work in order to achieve the most cost effective and measurable improvements in every drainage system.

Rather than preparing an adaptive management plan for each drainage system, municipalities will prepare a plan for adaptive management on a municipal wide basis. A municipal adaptive management plan will prioritize issues arising from the water quality, flow monitoring and benthic results in all systems monitored to date and then schedule measures to address the highest priority issues first. Phasing adaptive management actions will also help to keep costs manageable.

Prioritization of watersheds and associated issues should be based on the following:

- Value of the system for aquatic life and human health/safety
- Prevention of further system degradation
- The potential for improvement
- Amount of exceedance relative to the thresholds/targets
- Number of contaminants exceeding the thresholds/targets
- Opportunities to address through compatible processes or funding resources

When assessing water quality results, municipalities should focus on adaptive management actions that target the primary indicators for their drainage system type which show yellow or red results. See Section *7.2 Water Quality Assessment* for more information.

9.2. ADAPTIVE MANAGEMENT PRACTICES

Adaptive Management Practices (AMPs) are measures taken in response to the degradation of watershed health by land development. AMPs can involve engineered infrastructure, but increasingly are incorporating non-structural measures aimed at restoring natural pre-development hydrologic, water quality and aquatic habitat conditions. This section of the AMF provides an overview of commonly used AMPs to illustrate the types of measures available for addressing watershed health issues. AMPs relevant to each of the indicators of water quality, and hydrologic alteration are presented below in Table 7.

AMPs have been divided into functional categories including: source controls; runoff detention and infiltration facilities; runoff pollution control; runoff treatment; outreach and education; and mitigation of construction impacts. These AMP's are provided as general applications and may be used in absence of or in conjunction with those recommended in an ISMP. Whenever possible, the AMP's recommended in an ISMP should be implemented as they are customized to the needs of a specific watershed and reflect a more vigorous consideration of the elements involved.

Source Controls

Source control involves limiting the volume, frequency and magnitude of runoff delivered to conveyance infrastructure, streams and receiving bodies. Reducing runoff generation at or near its source limits stormwater impacts to stream health by minimizing the hydrologic alteration generally associated with urban development. In turn this reduces the impacts of development on water quality, stream morphology, and biological health. Source control AMPs should be considered when monitoring results indicating high urban pollutant loads, flashy discharge, increased frequency of high flows, or poor biological health. When implemented on a watershed scale as part of new development and re-development, they have the potential to greatly reduce watershed health impacts with lower costs than traditional end-of-pipe type solutions.

Metro Vancouver (2012) provides design guidance for source control measures, including:

- absorbent landscapes (e.g. amended soils)
- bio-retention facilities (e.g. rain gardens)
- vegetated swales;
- pervious paving;
- infiltration trenches, sumps and drywells; and
- green roofs.

Other measures which aim to reduce impacts to watershed health by limiting runoff generation include (Hinman, 2005; Washington Department of Ecology, 2012):

- retention and re-establishment of riparian area vegetation;
- disconnection of downspouts;
- rainwater harvesting;
- minimal excavation foundations; and
- tree retention and re-establishment

Photo 6: A Rain Garden

Photo 7: A Roadside Infiltration Trench

Runoff Detention Facilities

Runoff detention facilities limit the volume, frequency and duration of runoff by capturing flow already in the conveyance system. For larger scale developments with limited opportunity for source controls, detention facilities may provide a viable alternative. These can include detention ponds; detention tanks; detention vaults; and control structures.

Runoff Pollution Control

Runoff pollution control measures prevent or reduce the release of pollutants into receiving waters. These measures typically involve source controls and can be operational or structural in nature. Ideally, a treatment train approach is used which includes a sequence of pollution control measures. Measures should be selected based on their ability to address contaminants or issues of concern.

Operational Pollution Control Measures

Operational measures can include non-structural measures such as:

- documenting spill response and cleanup procedures;

- spill prevention plans;
- controlling soil and sediment and movement on a site
- spatial tracking of spills;
- inspection of pollutant sources;
- preventative maintenance on equipment;
- public education efforts: outreach to homeowners, developers, industry, construction companies, dog owners, point source polluters; website campaigns;
- signage, education and outreach programs;
- cross connection identification e.g. smoke testing, dye testing;
- dog waste management;
- street sweeping;
- catchbasin cleaning; and
- identification of point source pollution.

Structural Pollution Control Measures

Structural pollution control measures physically prevent pollutants from entering stormwater. Examples include enclosing or covering a known pollutant source; segregating a pollutant source to prevent water ingress or egress; or diversion of contaminated stormwater to appropriate treatment facilities.

Runoff Treatment

Runoff treatment facilities remove pollutants including suspended sediment, metals, nutrients, some bacteria and viruses, and organic compounds using processes such as sedimentation, filtration, bioremediation, ion exchange, adsorption, bacterial decomposition, and physical separation. Some common types of treatment facilities are described below.

- Wetpools are open ponds which treat runoff by a treatment chain or combination of sediment settling, biological uptake and vegetative filtration. Wetpools can often be combined with detention facilities.
  - Biofiltration treats runoff through filtration, infiltration and sedimentation effects caused by vegetation.
  - Oil/water separation makes use of the buoyancy of hydrocarbons to physically separate them from runoff.
  - Bioretention/infiltration of runoff into native soils with or without amendment can remove pollutants via filtration, adsorption and biological processes.
  - Filtration involves removing low concentration of suspended solids by passing flow through various media such as sand, perlite, zeolite and carbon.

Photo 8: A Biofiltration Site

Instream Habitat Rehabilitation

Watercourses which have been impacted by development may benefit from instream habitat rehabilitation measures. Priority should be placed on watershed scale measures to reduce or eliminate hydrologic alteration and water quality impacts, however once these aspects of stream health are improving, streams may require some intervention to facilitate the re-establishment of viable habitat. Such measures might include:

- re-establishment of riparian buffer;
- in stream complexing (large woody debris, boulder clusters);
- bedload augmentation;
- sediment basins;
- removal of fish migration barriers/impediments;
- bank stabilization;
- wetland rehabilitation or construction
- rehabilitation or construction of various habitat types (spawning, rearing, and over-wintering).

Implementing habitat rehabilitation measures requires careful consideration of conditions in the stream and watershed. Improper selection, siting, design or construction of these measures has the potential to induce more harm than benefit. However when properly implemented, rehabilitation measures may greatly improve overall watershed health.

Riparian Habitat Rehabilitation

Riparian vegetation provides shade for aquatic life and lowers water temperature. It also provides important nutrients to streams through leaf litter and can filter out pollutants to improve water quality. Some measures to improve the riparian habitat might include:

- protecting existing riparian setbacks and identifying opportunities for additional riparian area.
- enhancing riparian areas through the removal of invasive species, planting with native vegetation and removing hard surfaces;
- encouraging good private property riparian area management through the use of Outreach Programs.

Supplemental Monitoring

Supplemental monitoring can help to identify problem sources and better inform the adaptive management plan.

Additional monitoring could include measures such as:

- Increased number of water quality sites (longitudinally on one stream, or on tributaries, or on other streams in the watershed)
- Increased frequency of monitoring for better trend assessment in rapidly changing watersheds
- Sediment sampling for metals or organics such as polycyclic aromatic hydrocarbons (PAHs);
- Implementation of continuous water quality monitoring
- Flow monitoring in piped systems to determine relative contaminant loadings
- Flow monitoring in ditches and canals

See Section 10 (Supplemental Monitoring) for a complete list of options.

Land Use and Transportation Planning

Many contaminants are deposited on the roadways and parking lots from vehicles and are conveyed in stormwater runoff to receiving waters. Land use planning can protect features of the landscape that help to keep the water clean such as riparian zones and natural wetlands. Road designs can include pocket rain gardens and other bio-retention facilities as well as other infiltrating source controls to clean, regulate or infiltrate road runoff. Good planning can help to minimize impervious surfaces and reduce car use by facilitating the use of alternate transportation.

Outreach Programs

Outreach programs can be developed to encourage public behaviors which benefit watershed health. This is particularly effective for actions which occur on private property and for those over which the municipality may not have any legal tools to exercise. It is important to consider that these programs must go beyond education in order to be effective. Simply telling people about what is 'right' and 'wrong', or demonstrating consequences, have not proven to be effective approaches in changing behaviour. Social psychology and marketing experts can be great resources in crafting a unique message, creating a powerful campaign and targeting the audience you wish to reach. If resources are limited, education about effective outreach techniques can be found through on-line webinars, courses, books, and the internet.

Mitigation of Construction Impacts

Construction activities related to land development or re-development can impact stream health via the generation of suspended sediment from exposed soils, soil erosion, sediment deposition, increased runoff, and introduction of contaminants. In cases where monitoring programs identify poor stream health downstream of rapidly developing areas or large construction sites, construction AMPs should be considered. Many of these actions are part of environmental regulations and local bylaws already in place, however some are not and others may not be adequately implemented.

WDOE (2012) suggests 13 'elements' of mitigating runoff impacts from construction, and lists specific Best Management Practices for each. The elements include:

1. Preserve vegetation/mark clearing limits. This includes retaining the duff layer, native top soil and natural vegetation as much as possible.
2. Establish construction access. Limiting construction access to one point is desirable, and access point should be stabilized. Wheel washes should be performed on site.
3. Control flow rates. This may include construction of temporary detention facilities.
4. Install sediment controls, such as containment ponds, traps or filters.
5. Stabilize soils with techniques such as seeding, sodding, mulching, plastic covering, erosion control blankets (ECB), application of polyacrylamide (PAM), and application of gravel.
6. Protect slopes and minimize sediment generation by reducing slope length (e.g. terracing), reducing slope steepness, and roughening surfaces. Stormwater may be diverted from slopes using berms, pipes or swales.
7. Protect drain inlets. This involves removing suspended sediments from site runoff prior to discharging. If sediment does accumulate at drain inlets, they should be cleaned.
8. Stabilize on-site channels and outlets, with the use of liners, erosion control blankets, armouring, and/or check dams.
9. Control pollutants. Proper handling of potential contaminants on-site such as fuel, chemicals, etc.
10. Control dewatering. Highly turbid or contaminated water should not be discharged to

stormwater systems without appropriate treatment. Keep clean water and turbid or contaminated water separate.

11. Maintain BMPs. Temporary and permanent erosion and sediment control measures should be maintained throughout the life of the project, and should be removed soon after completion.
12. Manage the project. This involves phasing construction projects as much as possible, limiting work to the appropriate seasons, and inspecting and maintaining all erosion and sediment control measures.
13. Protect Low Impact Development BMPs. If bioretention facilities exist they should be protected from sedimentation and compaction during construction, and restored at project completion.

Table 8 - Adaptive Management Practices recommended for specific impacts

Indicator	AMP Trigger	Impact	Examples of Recommended AMPs
Dissolved Oxygen	Exceeds yellow or red thresholds	• potential impacts to resident fish, such as salmonids (intolerant to reduced DO) • potential alterations to benthos communities – loss of intolerant taxa	• enhancement of riparian areas to increase shading (reduce water temperatures and increase oxygen carrying capacity) • instream habitat to enhance aeration (e.g. riffles) • source controls (to reduce organic matter and associated consumption of oxygen)
Water Temperature	Exceeds yellow or red thresholds	• potential impacts to resident fish, such as salmonids (intolerant of elevated temperatures) • potential alterations to benthos communities – loss of intolerant taxa	• enhancement of riparian areas (plantings) to increase shading • retention or re-establishment of tree cover • reducing impervious surfaces • in-stream complexing to provide increased shading / cover
Turbidity	Exceeds yellow or red thresholds	• potential impacts to fish including smothering of eggs and direct impacts to fish gills; also potential impacts on fish behaviour and feeding • potential alterations to benthos communities (e.g., reduced feeding activity of filter feeders)	• inventory and assessment of erosion sites and implementation of remedial actions as applicable • operations and maintenance activities such as street cleaning and catch basin cleanout • establishment and enforcement of sediment / erosion bylaws / policies • education and outreach

Indicator	AMP Trigger	Impact	Examples of Recommended AMPs
Nutrients (e.g., Nitrates)	Exceeds yellow or red thresholds	• potential for increased algal growth within watercourse which could alter resident aquatic communities such as benthos • direct toxicity of nitrate to amphibians and aquatic life • potential indirect impacts to aquatic biota due to reduced dissolved oxygen levels	• identification of sources and implementation of appropriate source controls (e.g., cross connections, control of runoff from agricultural fields; application of fertilizers on fields during wet periods, septic field and yard maintenance education, etc.)
Metals	Exceeds yellow or red thresholds	• potential direct toxicological impacts to aquatic biota • potential accumulation of metals in sediments	• identification of sources and implementation of appropriate source controls (e.g., swales, infiltration galleries, disconnect downspouts, detention ponds/tanks, etc.) • educational programs
Microbiological Parameters	Exceeds yellow or red thresholds	• potential human health issues if water is used for recreation or irrigation • no direct impacts to aquatic biota, however high bacteria levels can be associated with loadings of organics and nutrients that can affect dissolved oxygen levels	• source controls, dog waste mgmt; control of agricultural and urban runoff • educational programs • cross connection ID

T_{Qmean}	Lower than pre-development value, or decreasing trend	increased flashiness	• more frequent disturbance of benthic organisms • increased erosion and sediment deposition • increased pollutant loads	• source controls • runoff detention facilities • riparian buffer • wetland rehabilitation/construction • infiltration facilities
Low Pulse Count	Higher than pre-development value, or increasing trend	more frequent interruption of seasonal low flows by small runoff events	• disruption of benthic organisms and salmonid alevins/fry • increased pollutant loads	• source controls • runoff detention facilities • riparian buffer • wetland rehabilitation/construction • rain gardens, infiltration facilities
Low Pulse Duration	Lower than pre-development value, or decreasing trend	more frequent interruption of seasonal low flows by small runoff events	• disruption of benthic organisms and salmonid alevins/fry • increased pollutant loads	• source controls • runoff detention facilities • riparian buffer • wetland rehabilitation/construction
Summer Baseflow	Altered from pre-development value, increasing or decreasing trend	alteration of water table elevation due to groundwater pumping, surface water abstraction or diversion, drainage, or irrigation with imported water	• drying of stream channels, fish stranding, desiccation of biota • decreased flow available for water supply	• wetland rehabilitation/construction • soil augmentation • infiltration facilities • protection of groundwater recharge areas • limit groundwater pumping for foundation protection (require underground structures to be tanked)
Winter Baseflow	Lower than pre-development value, or decreasing trend	decreased shallow subsurface storage	• decreased pool habitat • decreased flow for available for water supply	• source controls • runoff detention facilities • riparian buffer • tree retention and re-establishment • wetland rehabilitation/construction • retention and re-establishment of trees
High Pulse Count	Higher than pre-development value, or increasing trend	more frequent runoff events	• more frequent disturbance of benthic organisms • increased erosion and sediment deposition • increased pollutant loads	• source controls • runoff detention facilities • riparian buffer • wetland rehabilitation/construction • retention and re-establishment of trees
High Pulse Duration	Lower than pre-development value, or decreasing trend	faster rise and recession of stormflow	• more frequent disturbance of benthic organisms • increased erosion and sediment deposition • increased pollutant loads	• source controls • runoff detention facilities • riparian buffer • wetland rehabilitation/construction

10. SUPPLEMENTAL MONITORING

The monitoring program represents a compromise intended to optimize available resources for data collection and analysis, without imposing an excessive financial burden on municipalities. While the program will provide useful information for decision making and initiation of AMPs, the supplemental monitoring actions proposed herein could potentially improve the reliability, statistical power and utility of monitoring results. They are included for consideration by municipalities with the resources and inclination to implement a more rigorous monitoring program or to include with other complementary programs.

Increased Monitoring Frequency

Water quality and benthic invertebrate monitoring capture conditions during discrete windows in time. Under the proposed monitoring program water quality is monitored over two five week periods every fifth year, and benthic invertebrates are sampled once every fifth year. However water quality and biotic distributions can vary widely over time.

It is recognized that continuous monitoring of water quality and benthic invertebrates is not feasible for the AMF, however monitoring more frequently than every five years would better identify temporal trends in stream health. Sampling every fifth year might require 25 years to positively identify temporal trends, whereas an annual cycle could achieve the same statistical power in five years' time.

Watersheds with changing land use would benefit from monitoring every one to two years while those with stable land use can consider monitoring every three to five years.

Additional Water and Sediment Quality Parameters

The water quality parameters proposed under the AMF framework are intended to cover various pollution types (nutrients, metals, and bacteria). However it may be beneficial for some municipalities to include additional parameters as appropriate based characteristics of the stream and land use in the contributing area.

For example, the collection of total suspended solids (TSS) samples in addition to turbidity measurements may be appropriate for municipalities that currently have erosion sediment control bylaws which are tied to TSS measurements.

Sediment sampling for metals and polycyclic aromatic hydrocarbons (PAH) is recommended for sediments in sensitive environments which receive significant stormwater inputs such as those from a primarily piped system.

Additional Water Quality Monitoring for Yellow or Red Threshold Exceedances

Should the assessment of priority indicator parameters suggest potential issues (yellow or red exceedances) at the specific sampling locations or within the watershed, the following additional steps can be initiated:

Data re-evaluation and confirmation: For yellow and red exceedances an evaluation of individual replicates is recommended to determine potential data outliers that may be skewing mean values. Should an outlier be detected and confirmed as a spatially discrete event (e.g., a small, single occurrence spill), this should be investigated further.

Additional Assessment and Analysis: If exceedances are confirmed, results for secondary parameters (already collected along with priority parameters) should be assessed to help provide a more detailed snap-shot of water quality at the site under investigation.

If the data re-evaluation and additional assessment steps confirm potential concerns within the watershed, additional monitoring can be initiated to further identify the cause of poor water quality. Options could include additional water quality sites, additional monitoring parameters, the use of continuous sampling equipment, or the assessment of loading (flow and concentration) to help prioritize actions.

Inclusion of Flow Monitoring in Ditches and Canals

Flow monitoring of ditches and canals may be beneficial in determining the causes of water quality or biological deficiencies. The interplay between flow, water velocities, water quality and benthic invertebrates is complex, and impacts to watershed health may be related to several or all of these inputs to the system. Monitoring in lowland streams and canals may be complicated by tidal flow, pumping and/or water transfers.

Calculating and Tracking % Intact Riparian Buffer

It is recommended that % Intact Riparian Buffer be tracked over time and considered relative to monitoring results and as part of adaptive management planning.

An intact riparian corridor is an essential pre-condition for healthy stream habitat, and the proportion of intact riparian buffer has been shown to be correlated with measures of urban development and biological integrity (May et al., 1997).

To calculate percent intact riparian buffer, the total stream channel length must first be determined, including tributaries. For each stream riparian buffers are then applied to both banks as per the regulation used by the municipality (30m for SPR or varying for RAR). The percentage of area within this buffer with intact riparian vegetation is then determined. Tracking the % riparian buffer within a drainage system over multiple monitoring cycles will determine whether these percentages are changing over time.

Calculating and Tracking % Effective Imperviousness Area

It is recommended that % Effective Impervious Area be tracked over time and considered relative to monitoring results and as part of adaptive management planning.

Hydrologic alteration in urbanized areas, in particular increased flashiness, has traditionally been linked to changes in percent total impervious area (%TIA). However research indicates that percent effective impervious area (%EIA) is a more relevant parameter for predicting stream degradation due to urban development (Walsh et al., 2005). Effective impervious area is defined as impervious surfaces that are connected via sheet flow or discrete conveyance to a drainage system.

Impervious surfaces are considered ineffective if the runoff is dispersed through at least one hundred feet of native vegetation; residential roof runoff is infiltrated; or continuous runoff modeling indicates that all runoff is infiltrated (Washington Department of Ecology, 2012).

To minimize the level of detail required in determining the %EIA assumptions can be made in for discrete areas. For example, a recent housing subdivision in which extensive source controls were required for permitting may be designated as ineffective impervious area without verification of individual building plans, so long as assumptions are clearly stated in the analysis.

Long Term Flow Monitoring

It is recommended that when resources allow, and where it is justified, longer duration flow monitoring be done to:

- assess stream health indicators over time, particularly for the first cycle of monitoring to provide a stronger dataset for the comparison of future monitoring results
- to better assess watersheds that are experiencing rapid change in land use
- to provide a longer term dataset in representative catchments that can be used to help interpret the results from similar catchments with shorter records or data gaps

The representativeness of hydrologic statistics can be greatly improved by collecting longer term hydrologic records. Furthermore, longer records are beneficial because:

1. A large majority of costs associated with hydrometric monitoring are concentrated in the first year or two of data collection (primarily associated with initial rating curve development).
2. The inherent randomness of hydrologic processes means that short records can fail to identify (or falsely identify) changes over time.
3. Meaningful calculation of many hydrologic statistics requires a minimum period of record of 10-15 years. Calculation of extreme values (e.g. 100-year discharge) requires longer records. Extreme values are required for the design of stormwater infrastructure and flood/erosion hazard mitigation.
4. The existence of a long term record in a representative catchment can allow for the development of extended hydrometric records in similar catchments where overlapping but shorter-term data are available.

It is recommended that municipalities establish the gauge and develop a stage-discharge rating curve (Section 6.2.2) during the first iteration of ISMP monitoring. In years when no monitoring program is in place, the gauge should run continuously, data should be downloaded at the intervals required to avoid loss and/or shutdown, and at least one discharge measurement should be collected for rating curve maintenance. This allows data collection to be maintained over the long term without unnecessary costs related to re-establishing the gauge and/or rating curve.

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Appendix 1

PHOTOGRAPHS

Photo A1 - A lower gradient watercourse with natural channel (Nicomekl River, Langley, BC). The stream morphology and habitat are relatively natural, but conditions will be influenced by inputs from the urban catchment.

Photo A2 - A ditched, lower gradient watercourse (Old Logging Ditch, Surrey BC). The straightened channel and lack of habitat complexity are typical of ditched streams in agricultural areas.

Photo A3 - A higher gradient stream in an urban area (Still Creek, Vancouver, BC). The creek flows out of a large culvert. Stream banks are armoured and bed morphology has been altered by limited sediment supply.

Photo A4 - A higher gradient stream in a rural area (Coquiltam River, Coquitlam, BC. The stream retains its natural morphology, riparian vegetation and habitat complexity, but could have inputs from upstream industrial activity.

Photo A5 - Piped system outfall (Ambleside, West Vancouver, BC).

Appendix 2

BLANK REPORTING PACKAGE SHEETS

Monitoring and Adaptive Management Report Cover Sheet

Municipality:

Name of Drainage Area or Watershed:

ISMP Status: (Completed/Ongoing/None):

ISMP Name and Date:

Size (ha):

General Classification (Higher Gradient /Lower Gradient/Piped):

Monitoring Locations (Pipe/Outfall/Instream):

GPS Coordinates of Monitoring Locations (attach map of system with locations shown):

Degree and Age of Development (Green, Developing, Built-Out, Redeveloping):

Major Land Use Types - % of residential (H/M/L or mixed), commercial, industrial, institutional, and/or agricultural:

Summer/Winter Temperature and Precipitation Averages (Normal, Hot/Cool, Wet/Dry)

Riparian Area (stream setback) protection:

☐ RAR ☐ SPR ☐ Other (please explain):

Notes:

MONITORING RESULTS REPORT SHEET						
WATER QUALITY MONITORING RESULTS						
Wet Season	**AVERAGE**	**1**	**2**	**3**	**4**	**5**
Temperature (Celsius)						
Dissolved Oxygen (mg/L)						
pH						
Conductivity (uS/cm)						
Turbidity (NTU)						
E.coli						
Fecal Coliforms						
Nitrate (as Nitrogen, mg/L)						
Total Iron (ug/L)						
Total Cadmium (ug/L)						
Total Copper (ug/L)						
Total Lead (ug/L)						
Total Zinc (ug/L)						
Dry Season						
Temperature (celsius)						
Dissolved Oxygen (mg/L)						
pH						
Conductivity (uS/cm)						
Turbidity (NTU)						
E.Coli						
Fecal Coliforms						
Nitrate (as Nitrogen, mg/L)						
Total Iron (ug/L)						
Total Cadmium (ug/L)						
Total Copper (ug/L)						
Total Lead (ug/L)						
Total Zinc (ug/L)						

FLOW MONITORING RESULTS			
	Value	**Trend – Stable, Increasing, Decreasing (S, D,I)***	**Target***
MAD (L/s)			
TQ Mean			S or I
Low Pulse Count			S, or D
Low Pulse Duration (Days)			S or I
Summer Baseflow (L/s)			S
Winter Baseflow (L/s)			S or I
High Pulse Count			S or D
High Pulse Duration (Days)			S or I

BIOMONITORING RESULTS			
	SCORE	**Pre-Dvpt Value or Trend (S, D or I)***	**Trend Target ***
B-IBI Score			S or I
Total Taxa Richness			S or I

* See Table 4 Hydrologic response to land development

Photographic Record Sheet

(Photograph)

(Description)

(Photograph)

(Description)

(Photograph)

(Description)

(Photograph)

(Description)

ISMP Implementation Table

ISMP Recommendation	Implemented (Y/N)	Years Since Implementation	Description of Action and Degree of Implementation

Adaptive Management Plan Table

Drainage System Name	Target Issue	Adaptive Management Action	Year to Implement

Appendix 3

BACKGROUND INFORMATION ON WATER QUALITY ASSESSMENT APPROACH FOR ADAPTIVE MANAGEMENT FRAMEWORK

Background Information on Water Quality Assessment Approach for Adaptive Management Framework

A "traffic light" (green, yellow and red) water quality assessment approach was developed to provide a simplified screening system to help municipalities identify where water quality conditions are good and where there may be concerns with water quality. This water quality assessment system, when considered along with the benthic invertebrate and hydrometric indicator information, gives a more holistic assessment of stream health in watersheds that are potentially at risk from urban land use and non-point source pollution. With repeat monitoring over time, changes in watershed health status can begin to be tracked.

This gives a feedback loop, providing information for decision making about effectiveness of plans and actions in watersheds. As development and re-development proceed in watersheds, this tiered water quality assessment approach can provide information to help communities work toward preventing declines (e.g. greens moving to yellows, and yellows moving to reds) and work toward improving the situation where impacts are occurring.

The green, yellow and red categories have been developed primarily based on Provincial water quality guidelines. To provide a simplified approach, the water quality assessment table allows each parameter to be classified into the green, yellow or red category based on the **average** water quality for each parameter by season. The average is calculated for each parameter, from the individual sampling results (by season) that were collected on individual sampling days during the sampling program. For classifying bacteria results, a "**geometric mean**" should be used instead of an average. Use of the geometric mean is the generally accepted protocol for assessment of bacterial data. For more information on the geometric means see Appendix D.

A number of approaches were used for development of the water quality categories:

- Provincial water quality guidelines can provide "maximum" (based on an individual sample) guidelines and/or "average" guidelines depending on the parameter. Where average guideline levels were available these were used as a guide for development of the water quality categories. Where average guidelines were not available, the maximum guidelines were used to help develop water quality categories for this management framework (e.g. Iron).

- Where multiple guidelines exist for each parameter based on different aquatic lifestages (e.g. dissolved oxygen) or species (e.g. temperature) the guideline most protective or applicable for aquatic life was chosen to guide category development.

- To take a precautionary approach (trying to prevent exceedances of guidelines) warning is provided, by the lower end of the yellow category, when a watercourse is approaching an exceedance of the guideline (e.g. metals, nitrate). For the metals category, the green category represents from zero to 80% of the guideline level. The yellow category represent from 80% to 5x the guideline level or to the individual maximum guideline value, whichever is lower. The red category represents over 5x the guideline level or over the individual guideline maximum value, whichever is lower. To simplify the approach, for the metals dependent on hardness, the rank values assume a hardness approximating 100mg/L CaCO3.

- For parameters with no guideline levels (e.g. conductivity) and with guidelines that require comparison to baseline levels (e.g. turbidity), alternate approaches (e.g. comparison to water quality model for turbidity, comparison to regional baseline grab sample data, comparison of grab sample and automated data, use of research/guidance documents) were used to identify categories.

- The bacterial guidelines for swimming water use were used to guide category development for bacteria since these levels would be considered protective of children playing in creeks in urban areas. These category levels would be informative for tracking cross connections or identifying "hot spots" where significant contributions of fecal and organic material may be entering watercourses. The cut off between the yellow and red categories represent five times the guideline level.

Overall there has been some generalizing of water quality guidelines in order to create a simplified management approach to assessing non-point source pollution issues and to help guide the adaptive management program. This is meant to provide a graduated system (green, yellow, red categories) that can allow progress to be noted if it is occurring, following adaptive management actions. In some cases this may result in a slightly more protective approach (e.g. where the more protective guideline of multiple guidelines was used and is applied broadly) than if a pure "guideline attainment/non-attainment" approach were used. In other cases, the system may result in a slightly less protective approach (e.g. where a "maximium" guideline level is used to guide category development in a framework where rank will be assigned based on an average value) than would occur if a pure "guideline attainment/non-attainment" approach was used. Overall, on a regional basis it is likely that these will offset and that overall, having a simplified management system will allow for more effective plans/actions and improvements in environmental protection.

The following section provides detailed information on water quality guidelines for each of the parameters included in the water quality assessment component of the Adaptive Management Framework. This information on water quality guidelines is as of fall 2013, and is provided as an "unofficial" version of the guidelines. For the official version of provincial water quality guidelines please refer to the provincial internet site. In the event that there is a discrepancy in the guideline numbers between those shown here and those shown on the website, the official guidelines on the provincial website should be chosen. It is important to note that guidelines do get revised over time and the website will provide more accurate information. (http://www.env.gov.bc.ca/wat/wq/wq_guidelines.html)

General Parameters

Dissolved Oxygen (mg/L)

Adaptive Management Framework (AMF) Water Quality Assessment

Dissolved Oxygen is critically important for the survival of fish and other aquatic life. The Adaptive Management Framework uses a mean dissolved oxygen level of 11 mg/L or more as a green level, from less than 11mg/L to 6.5 mg/L as a yellow level, and less than 6.5 mg/L as a red level as shown in Table 1 below. The table shows which of the provincial guidelines are in attainment/non-attainment within each of these categories. The AMF ranking system provides a generalized approach to rapidly screen for potential water quality concerns

Table 1: Green, yellow and red rankings for dissolved oxygen **as used in AMF**

11 mg/L or more	**Less than 11 to 6.5mg/L**	**Less than 6.5mg/L**
Meets Provincial mean guideline for protection of buried embryo/alevin life stages	Does **not** meet **mean** guideline for protection of buried embryo/alevin life stages	Does **not** meet **mean** guideline for protection of buried embryo/alevin life stages
Meets Provincial mean guideline for protection of **all life stages other than** Buried Embryo/Alevin	May or may **not** meet **mean** guideline for protection of **all life stages other than** buried embryo/alevin life stages	Does **not** meet **mean** guideline for protection of **all life stages other than** buried embryo/alevin life stages

Provincial Water Quality Guidelines (as of Sept 2013)

Provincial water quality guidelines for dissolved oxygen (Table 2) are shown below:

Dissolved Oxygen Table 2: Dissolved oxygen guidelines for fish life stages in the water column

Life Stages	**All Life Stages Other Than Buried Embryo / Alevin**	**Buried Embryo / Alevin Life Stages**
Dissolved Oxygen - concentration	Water Column mg/L O_2	Water Column mg/L O_2
Instantaneous Minimum	5	9
30-day Mean	8	11

1. For the buried embryo / alevin life stages these are in-stream concentrations from spawning to the point of yolk sac absorption or 30 days post-hatch for fish; the water column concentrations recommended to achieve interstitial dissolved oxygen values when the latter are unavailable. Interstitial oxygen measurements would supersede water column measurements in comparing to criteria.
2. The instantaneous minimum level is to be maintained at all times.
3. The mean is based on at least five approximately evenly spaced samples. If a diurnal cycle exists in the water body, measurements should be taken when oxygen levels are lowest (usually early morning).

pH (relative Units)

Adaptive Management Framework (AMF) Water Quality Assessment

Table 3 below shows the green, yellow and red rankings that are used in the AMF water quality assessment. Although the provincial pH guideline is based on individual values, the Adaptive Management Framework uses averages to make the process simpler. The green category is the same as the guideline. The yellow and red categories represent sequential steps away from the general guideline, on both the high and low side of the guideline. In the framework, pH is presented as a “secondary” parameter to help interpret “priority” parameters and to help with identification of impacts.

Table 3: Green, yellow and red rankings for pH as used in AMF

6.5 to 9.0	<6.5 to 6.0 or >9 to 9.5	<6 or >9.5
Most common pH range for streams in our region; generally unrestricted change permitted within this range, with provisos as per pH technical guideline appendix	Less common, but possible in our region; In these ranges there are restrictions about how much change can occur due to potential shifts in species composition and toxicity issues, as per provincial pH guideline. Anthropogenic decreases in pH below pH 6.5 are not permitted.	There are restrictions about how much change can occur due to potential shifts in species composition and toxicity issues, as per provincial pH guideline. Anthropogenic decreases in pH below pH 6.5 are not permitted.

Provincial Water Quality Guidelines (as of fall 2013)

The Provincial guideline is 6.5 to 9.0. for individual pH measurements. More detail is provided (in the adjacent box) on systems that fall outside that range.

The British Columbia freshwater pH criteria are compatible with the CCREM guidelines (i.e., 6.5 to 9.0) but contain refinements in several areas. The B. C. criteria recognize that the pH of freshwaters can naturally drop below 6.5; however, anthropogenic decreases in pH below pH 6.5 are not permitted. Increases in pH for natural waters with a pH < 6.5 is permitted as long as the water body does not have an unique acidophilic fauna or flora (e.g., bog). Under these circumstances, site specific ambient water quality monitoring and objectives are required to set limits on the permissible increase in pH.

Between pH 6.5 and 9.0, the B. C. criteria and the CCREM guidelines are similar. The only difference is that the B. C. criteria recognize the importance of low carbon dioxide concentrations on the phytoplankton community structure and high carbon dioxide concentrations and its potentially toxic effects to aquatic life.

For pH > 9.0, the CCREM guidelines suggest that short term increases to pH 9.5 are permitted; however, the B. C. criteria do not permit any statistically significant increases because of the limited data on the tolerance of fish to pHs between 9.0 and 9.5. The B. C. criteria recognize that the elevation of pH in lakes to cause calcium carbonate precipitation is an effective and important lake restoration technique. Consequently, the criteria permits short-term increases (2-3 days) to pH 9.5 provided the treatment is not toxic to aquatic life. See Section 5.10.2.3 for definition of statisitically significant change in pH.

Table 9

Summary of the pH Criteria for the Protection of Aquatic Life:

Freshwater

pH < 6.5	No statistically significant* decrease in pH from background. No restriction on the increase in pH except in boggy areas that have a unique fauna or flora. Site specific ambient water quality objectives to restrict the pH increase in areas with a unique fauna and flora are recommended.
pH 6.5-9.0	Unrestricted change permitted within this pH range. This component of the freshwater criteria should be used cautiously if the pH change causes the carbon dioxide concentrations to exceed a 10 µmol/L minimum or a 1360 µmol/L maximum. Carbon dioxide concentrations below 10 µmol/L can cause a shift in the phytoplankton community to cyanobacteria (Section 5.2.2.2), while CO_2 concentrations above 1360 µmol/L can be toxic to fish (Section 5.7.11). See Appendix 2 for the method to determine CO_2 concentrations.
pH >9.0	No statistically significant* increase in pH from background. Short-term increases (2-3 days) to pH 9.5 are permitted for lake restoration projects. Decreases in pH are permitted as long as carbon dioxide concentrations are not elevated above 1360 µmol/L. CO_2 concentrations above 1360 µmol/L may be toxic to fish (Section 5.7.11). See Appendix 2 for the method of determining CO_2 concentrations.

Water Temperature (degrees C)

Adaptive Management Framework (AMF) Water Quality Assessment

The numbers chosen for the green, yellow and red categories for the Adaptive Management Framework were based on a review of the provincial water quality guidelines and the associated optimum temperature ranges of specific life history stages of salmonids.

Table 4: Green, yellow and red rankings for temperature as used in AMF

Low flow period - summer	**<16**	**16 - 18**	**over 18**
Wet weather – fall winter	**7 - 12**	**5 – 7 or 12 - 14**	**<5 or >14**
	Summer – meeting the guideline for protection of coho and cutthroat rearing Fall - Meets maximum incubation temp guideline.	Summer – approaching or exceeding the guideline for protection of coho rearing and cutthroat rearing Fall – Does not meet maximum incubation temp guideline.	Summer – exceeding the guideline for protection of coho rearing and cutthroat rearing Fall – Does not meet maximum incubation temp guideline.

Provincial Water Quality Guidelines (as of Sept 2013)

The Provincial water quality guideline for temperature (Table 5) for freshwater aquatic life for streams with known fish distribution is shown in Table 5. The guideline is + or – 1 degree Celsius change from the optimum temperature ranges for each life history phase of the most sensitive salmonid species present. For streams with unknown fish distribution the mean weekly maximum temperature (MWMT) is the average of the warmest daily maximum temperatures for seven consecutive days.

Temperature Table 5: Summary of Water Quality Guidelines for Temperature

Water Use	Recommended Guideline
Freshwater Aquatic Life - streams with bull trout and/or Dolly Varden	Maximum Daily Temperature is 15 degrees Celsius Maximum Incubation Temperature is 10 degrees Celsius Minimum Incubation Temperature is 2 degrees Celsius Maximum Spawning Temperature is 10 degrees Celsius
Freshwater Aquatic Life - streams with known fish distribution	+ or - 1 degree Celsius change beyond optimum temperature range as shown in Table 2 for each life history phase of the most sensitive salmonid species present Hourly rate of change not to exceed 1 degree Celsius
Freshwater Aquatic Life - streams with unknown fish distribution	MWMT = 18 degrees Celsius (Maximum Daily Temperature = 19 degrees Celsius) Hourly rate of change not to exceed 1 degree Celsius Maximum Incubation Temperature = 12 degrees Celsius (in the spring and fall)
Freshwater Aquatic Life - lakes and impoundments	+ or - 1 degree Celsius change from natural ambient background
Marine and Estuarine Aquatic Life	+ or - 1 degree Celsius change from natural ambient background the hourly rate of change up to 0.5 degrees Celsius - see footnote
Wildlife and Livestock Watering Irrigation and Industrial Water Supplies	+ or - 1 degree Celsius change from natural ambient background the hourly rate of change should not exceed 0.5 degrees Celsius

1. The MWMT, mean weekly maximum temperature is defined as the average of the warmest daily maximum temperatures for seven consecutive days.

2. The natural temperature cycle characteristic of the site should not be altered in amplitude or frequency by human activities.

Table 6: Optimum temperature ranges of specific life history stages of salmonids and other coldwater species for guideline application

Species	Incubation	Rearing	Migration	Spawning
Salmon				
Chinook	5.0-14.0	10.0-15.5	3.3-19.0	5.6-13.9
Chum	4.0-13.0	12.0-14.0	8.3-15.6	7.2-12.8
Coho	4.0-13.0	9.0-16.0	7.2-15.6	4.4-12.8
Pink	4.0-13.0	9.3-15.5	7.2-15.6	7.2-12.8
Sockeye	4.0-13.0	10.0-15.0	7.2-15.6	10.6-12.8
Trout				
Cutthroat	9.0-12.0	7.0-16.0	—	9.0-12.0
Rainbow	10.0-12.0	16.0-18.0	—	10.0-15.5
Char				
Bull Trout	2.0-6.0	6.0-14.0	—	5.0-9.0
Dolly Varden	—	8.0-16.0	—	—

Conductivity (uS/cm)

Adaptive Management Framework (AMF) Water Quality Assessment

There are no formal provincial water quality guidelines for conductivity. The values in the table for conductivity are based on baseline water quality data collected in this region, and based on general water quality monitoring experience from regional MoE Environmental Quality staff about common baseline levels and levels that are frequently found in watercourses impacted by non-point source pollution. For the framework, "conductivity" is identified as a "secondary" parameter for use in helping to interpret "priority" parameters and to help with identification of impacts.

Table 7: Green, yellow and red rankings for conductivity **as used in AMF**

<50	50 - 200	>200
Indication of lower level of impact from non-point source pollution	Potentially some level of impact from non-point source pollution	Likely some impact from non-point source pollution

Turbidity (NTU)

Provincial water quality guidelines for turbidity are designed to have a comparison to natural background conditions to determine whether guidelines are being met or not. This is the case for total suspended solids guidelines as well. Since there may not be opportunities to gain accurate natural background water quality measurements in urbanized systems, an alternate approach was used to identify green, yellow and red categories.

Turbidity can rise rapidly during precipitation events in developing watersheds, particularly where land disturbance has occurred and where sediment flushes with runoff into receiving waters. When grab sample and automated (continuous) data for turbidity are compared, it is clear that grab sampling typically underestimates the true level of impact compared to automated data which assesses both the magnitude and duration of turbidity events. In the framework, grab sampling has been chosen due to resource limitations and logistics.

Water quality monitoring data that included grab sample data and automated turbidity data was considered to determine what level of average in the grab sample data corresponded with turbidity impacts according to the Newcombe model* for protection of clear water fishes (which considers the impacts of both magnitude and duration of individual turbidity events), and what level tended to correspond with non-compliance with provincial turbidity guideline levels. Automated data sets were reviewed that showed baseline predevelopment turbidity levels, development period turbidity levels, and post-development turbidity levels to see how land development may impact turbidity levels.

Table 8: Green, yellow and red rankings for turbidity **as used in AMF**

0 to 5	5 to 25	>25
Turbidity generally expected to be a lower concern	Turbidity can be a concern depending on the magnitude and duration of individual events that are occurring	Impacts from turbidity are of concern and severity depends on the magnitude and duration of individual events

* Newcombe, C.P. 2003. Impact Assessment for Clear Water Fishes Exposed to Excessively Cloudy Water. Journal of the American Water Resources Association 39(3):529-544.

Nutrients

Nitrate

Adaptive Management Framework (AMF) Water Quality Assessment

The provincial water quality guideline (average) for nitrate is 3.0 mg/L. This guideline is related to toxicity for aquatic life. The numbers for the green, yellow and red categories have been chosen based on this.

Table 9: Green, yellow and red rankings for nitrate **as used in AMF**

<2	2-5	>5
Meeting the guideline	Approaching the guideline, to **not** meeting the guideline	**Not** meeting the guideline

Provincial Water Quality Guidelines (as of Sept 2013)

For nitrate (as N), the 30 day average concentration to protect freshwater aquatic life is 3.0 mg/L. The 30 day average (chronic) concentration is based on 5 weekly samples collected within a 30-day period.

Bacteria

Adaptive Management Framework (AMF) Water Quality Assessment

The green, yellow and red categories for fecal coliforms (Table 10) and *E. Coli* (Table 11) have been chosen based on the provincial water quality guideline for swimming water with the recognition that citizens within urban areas do have various levels of contact with watercourses and are potentially swimming in beach areas fed by urban watercourses. The dividing line between yellow and red categories is five times the guideline level.

Fecal Coliforms

Table 10: Green, yellow and red rankings for fecal coliforms **as used in AMF**

Geometric Mean <200 /100ml	**Geometric Mean 201 - 1000**	**Geometric Mean >1000**
Meets the guideline	Does **not** meet the guideline	Does **not** meet the guideline

E. coli

Table 11: Green, yellow and red rankings for E.coli **as used in AMF**

Geometric Mean <77 /100ml	**Geometric Mean 78-385**	**Geometric Mean >385**
Meets the guideline	Does **not** meet the guideline	Does **not** meet the guideline

Provincial Water Quality Guidelines (as of Sept 2013)

Table 12: Subset of provincial water quality guidelines for microbiological indicators

Water Use	Escherichia coli	Enterococci	Fecal coliforms
Aquatic Life - shellfish harvesting	less than or equal to 43/100 mL 90th percentile	less than or equal to 11/100 mL 90th percentile	less than or equal to 43/100 mL 90th percentile
Aquatic Life - shellfish harvesting	less than or equal to 14/100 mL median	less than or equal to 4/100 mL median	less than or equal to 14/100 mL median
Livestock - general livestock use	200/100 mL maximum	50/100 mL maximum	200/100 mL maximum
Irrigation - crops eaten raw	less than or equal to 77/100 mL geometric mean	less than or equal to 20/100 mL geometric mean	less than or equal to 200/100 mL geometric mean
Irrigation - public access - livestock access	less than or equal to 385/100 mL geometric mean	less than or equal to 100/100 mL geometric mean	None applicable
Irrigation - general irrigation	less than or equal to 1000/100 mL geometric mean	less than or equal to 250/100 mL geometric mean	less than or equal to 1000/100 mL geometric mean
Recreation - secondary contact - crustacean harvesting	less than or equal to 385/100 mL geometric mean	less than or equal to 100/100 mL geometric mean	None applicable
Recreation - primary contact	less than or equal to 77/100 mL geometric mean	less than or equal to 20/100 mL geometric mean	less than or equal to 200/100 mL geometric mean

Notes on subset of bacteria water quality guidelines -

- ***Medians and geometric means are calculated from at least 5 samples in a 30-day period. Ten samples are required for 90th percentiles.***
- ***These recreation and shellfish harvesting criteria are applicable to fresh and marine waters, except the E. coli criteria, which apply only to fresh water.***
- ***Only a few salad greens which cannot be adequately washed to remove adhering or trapped pathogens are of concern under the crops eaten raw section of irrigation. Examples include lettuce, cabbage, broccoli, cauliflower and similar crops.***

Metals Guidelines

Adaptive Management Framework (AMF) Water Quality Assessment

To simplify the assessment, the framework adopted green, yellow and red levels based on an assumed sample hardness approximating 100mg/L. The green level goes from 0 to 80% of the guideline level. The yellow level goes from 80% of the guideline level to whichever is smaller of "five times the guideline level" or the value for the individual maximum guideline (if available). The red level is values over "five times the water quality guideline level" or over the value for the individual maximum guideline, whichever is smaller. The only guideline for iron is a maximum guideline so for this parameter the green category is 0 to 80% of this guideline, the yellow is 80% to 5 times the guideline and the red is over 5 times the guideline. For Zinc, since 90mg/L does approximate 100mg/L that mean guideline was used to determine the division (at 80% of the guideline) between green and yellow ranks for protection of stream health.

Table 13: Notes on green, yellow and red rankings for metals as **used in AMF**

Green level for metals	**Yellow level for metals**	**Red level for metals**
Meets the guidelines	Approaching the guideline level to **not** meeting the guideline	Does **not** meet the guideline

Water Quality - Metals (ug/L)	**Green Level < 80% of guideline**	**Yellow Level 80% guideline to 5x WQGL (or to individual maximum guideline value) whichever is lowest**	**Red Level over 5 x WQGL (or over individual maximum guideline value) whichever is lowest**	**Water Quality Guideline**
Iron (total)	<800 ug/L total iron	800 - 5,000 ug/L total iron	>5,000 ug/L total iron	1000 total iron
Cadmium (total)	<0.03 ug/L	0.03 - 0.15 ug/L	>0.15 ug/L	.010 when CaCO3 30mg/L .030 when CaCO3 90 mg/L .050 when CaCO3 150 mg/L
Copper (total)	<3 ug/L	3 - 11 ug/L	>11 ug/L	2 mean, 6.7 max when CaCO3 50 mg/L 4 mean, 11.4 max when CaCO3 100 mg/L
Lead (total)	<5 ug/L	5 - 30 ug/L	>30 ug/L	5 mean, 34 max when CaCO3 50 mg/L 6 mean, 82 max when CaCO3 100 mg/L 11mean, 197 max when CaCO3 200 mg/L
Zinc (total)	<6 ug/L	6 - 40 ug/L	>40 ug/L	7.5 mean, 33 max when CaCO3 <or= 90 mg/L 15 mean, 40 max when CaCO3 100 mg/L 90 mean, 115 max when CaCO3 200 mg/L

**** assuming Hardness approximating 100mg/L CaCO3***

Total Iron

The Provincial Water Quality Guideline (as of Sept 2013) for Total Iron is 1mg/L (or 1000ug/L) as an **individual sample maximum** for protection of aquatic life.

Total Cadmium

The Provincial Water Quality Guideline (as of Sept 2013) for Total Cadmium is based on hardness and is calculated from the following equation:

µg/L, total cadmium = 10 exp (0.86[log{hardness}]-3.2) 0.01 at 30 mg/L $CaCO_3$ 0.02 at 60 mg/L $CaCO_3$ 0.03 at 90 mg/L $CaCO_3$ 0.04 at 120 mg/L $CaCO_3$ 0.05 at 150 mg/L $CaCO_3$ 0.06 at 210 mg/L $CaCO_3$

For simplicity in the AMF water quality assessment, rank values assume a hardness approximating 100mg/L CaCO3.

Note: This guideline is in the process of being reviewed and may be adjusted in future.

Total Copper

Table 14: The provincial water quality guideline (as of Sept 2013) for Total Copper

	Total Copper 30 day avg ug/L	**Maximum Total Copper ug/L**
Fresh Water Aquatic Life (when average water hardness as $CaCO_3$ is less than or equal to 50 mg/L)	less than or equal to 2 µg/L	(0.094 x (hardness)+2) µg/L (hardness as mg/L $CaCO_3$)
Fresh Water Aquatic Life (when average water hardness as $CaCO_3$ is greater than 50 mg/L)	less than or equal to 0.04 x (mean hardness) µg/L	(0.094 x (hardness)+2) µg/L (hardness as mg/L $CaCO_3$)

For simplicity in the AMF water quality assessment, rank values assume a hardness approximating 100mg/L CaCO3.

Total Lead

For simplicity in the AMF water quality assessment, rank values assume a hardness approximating 100mg/L CaCO3.

Table 15: Subset of the provincial water quality guidelines for lead (see official guidelines for details)

Water Use	30-Day Average (µg/L Total Lead)	Maximum (µg/L Total Lead)
Fresh Water Aquatic Life (water hardness as Ca CO_3 less than or equal to 8 mg/L	None proposed	3 µg/L total lead
Fresh Water Aquatic Life (water hardness as Ca CO_3 greater than 8 mg/L)	Less than or equal to 3.31 + $_{e}$(1.273 ln (mean hardness) - 4.704)	$_{e}$(1.273 ln (hardness) - 1.460)
Marine and Estuarine Aquatic Life	Less than or equal to 2 µg/L total lead —— (80% of the values less than or equal to 2 µg/L total lead)	140 µg/L total lead

The average is calculated from at least 5 weekly samples taken in a period of 30 days. If natural levels exceed the criteria for aquatic life, the increase in total lead above natural levels to be allowed, if any, should be based on site-specific data.

Total Zinc

For simplicity in the AMF water quality assessment, rank values assume a hardness approximating 100mg/L CaCO3.

Table 16: Subset of the provincial water quality guidelines for zinc

Water Use	Guideline (µg/L Total Zinc)
Freshwater Aquatic Life - maximum concentration —— water hardness less than or equal to 90 water hardness equal to 100 water hardness equal to 200 water hardness equal to 300 water hardness equal to 400	Use the Equation 33 + 0.75 x (hardness -90) —— 33 40 115 190 265
Freshwater Aquatic Life - 30 day average concentration	Use the Equation 7.5 + 0.75 x (hardness -90)

——	——
water hardness less than or equal to 90	7.5
water hardness equal to 100	15
water hardness equal to 200	90
water hardness equal to 300	165
water hardness equal to 400	240

1. When the ambient zinc concentration in the environment exceeds the guideline, then further degradation of the ambient or existing water quality should be avoided
2. These are instantaneous maximums
3. Averages are of five weekly measurements taken over a 30-day period.
4. Water hardness is measured as mg/L of CaCO3

Appendix 4

Calculation of the Geometric Mean (Geomean) for Bacteria

Calculation of the Geometric Mean (Geomean) for Bacteria

Analysis of water quality data for bacteria is done by using the geometric mean, rather than a standard mean. Since microbes tend to be associated with particulate material, it is possible to have clumps of bacteria collected, which can lead to higher variability in the data. The geometric mean is used because it dampens the influence of individual high or low values. It is calculated by multiplying together a minimum of 5 individual bacterial sample results collected over a 30 day period and then taking the n_{th} root of this value. The formula for the geometric mean is shown below:

$$GM_{\bar{y}} = \sqrt[n]{y_1 y_2 y_3 \ldots y_n}$$

Where n is the number of dates sampled,
y_1 is the first sampling result,
y_2 is the second sampling result….

This can be calculated using Excel or other spreadsheet programs. The geometric mean should be calculated for each of the following data groupings -

- the five *E.coli* samples collected in the late summer (dry season) sampling,
- the five *E.coli* samples collected in the fall (wet season) sampling,
- the five fecal coliform samples collected in the late summer (dry season) sampling, and
- the five fecal coliform samples collected in the fall (wet season) sampling.