Derivation of Water Quality Guidelines to Protect Aquatic Life in British Columbia

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Table of Contents

1) Definitions

LC50 - A concentration of a pollutant or effluent at which 50 percent of the test organisms die; a common measure of acute toxicity (US EPA online).

EC50 - A concentration of a pollutant or effluent at which 50 percent of the test organisms display non-lethal effects.

ECx – A concentration of a pollutant or effluent at which x percentage of the test organisms display non-lethal effects after a specific exposure period.

LCx – A concentration of a pollutant or effluent at which x percentage of the test organisms display lethal effects after a specific exposure period.

Uncertainty factor, safety factor, application factor - Mathematical adjustments to guideline values to account for incomplete knowledge. Uncertainty factors are used to help account for various uncertainties including those listed in Section 6e.

NOEC (no-observable-effect-concentration) - The highest tested concentration of a substance that has been reported to have no harmful (adverse) effects on organisms tested.

LOEC (lowest-observable-effect-concentration) - The lowest tested concentration of a substance that has been reported to cause harmful (adverse) effects on organisms tested.

MATC – (maximum acceptable toxicant concentration) – The MATC is calculated as the geometric mean of the NOEC and the LOEC for a chronic level exposure.

Bioaccumulation — General term describing a process by which chemical substances are accumulated by aquatic organisms from water directly or through consumption of fine suspended particles, sediment and food containing the chemicals (CCME 1999).

Bioconcentration — A process by which there is a net accumulation of a chemical directly from water alone into aquatic organisms resulting from simultaneous uptake (e.g., by gill or epithelial tissue) and elimination (CCME 1999).

Biomagnification — Result of the processes of bioconcentration and bioaccumulation by which tissue concentrations of bioaccumulated chemicals increase as the chemical passes up through two or more trophic levels. The term implies an efficient transfer of chemicals from food to consumer so that residue concentrations increase systematically from one trophic level to the next (CCME 1999).

2) Summary

This document, originally prepared by Singleton et al. (1995), outlines the procedure used to derive water quality guidelines (previously referred to as criteria) in British Columbia (B.C). This procedure will help to provide a sound basis for defensible guidelines, encourage research and identify data gaps. It will also provide a consistent format for the derivation of guidelines and serve as a checklist to ensure the appropriate information has been considered.

The following is a brief overview of the procedure used to derive water quality guidelines to protect aquatic life in B.C.

At the provincial level, substances of concern are identified and ranked for guidelines development after consultation within the Ministry of Environment. Substances are then selected for guidelines development after consultation with federal and other provincial jurisdictions to avoid duplication of efforts.

For each substance selected, a literature search is conducted to obtain information on the following:

- physical and chemical properties;
- environmental concentrations with special emphasis on B.C. levels;
- environmental fate and behaviour;
- bioaccumulation potential;
- acute toxicity to aquatic biota;
- chronic toxicity to aquatic biota;
- mode of toxic action;
- information from other jurisdictions; and,
- other relevant information (e.g., effects on wildlife, agriculture etc).

To proceed with guidelines derivation, certain minimum toxicity and environmental fate data requirements must be met. In cases where there is insufficient information to set full guidelines, interim guidelines can be derived. Key toxicity studies found in the literature

search are evaluated to ensure that acceptable laboratory practices were used in the design and execution of the experiments. Each key study is judged on its scientific acceptability.

When available, the lowest reliable LC50 or EC50 from a short-term toxicity test, and the ECx/ICx representing a low-effects threshold from a reliable long-term exposure study, preferably on sensitive native B.C. species, are selected. These values are then multiplied by an appropriate uncertainty factor (i.e. safety factor) to derive a short-term maximum (acute) and a long-term average (chronic) guideline. For certain substances, only a single long-term average guideline is set which is based on the ECx/ICx representing a low-effects threshold from a long-term exposure study.

The preferred endpoints to derive a long-term average guideline are endpoints representing a low-effects threshold for a species from a critical study. The preference ranking of endpoints is consistent with the CCME (2007) Type B guidelines and is done in the following order: most appropriate ECx/ICx representing a low-effects threshold > EC15-25/IC15-25 > LOEC > MATC > EC26-49/IC26-49 > non-lethal EC50/IC50 > LC50.

Regression based toxicity estimates (i.e. ECx) are preferred to hypothesis based toxicity values (i.e. NOEC and LOEC) for water quality guidelines development. The scientific community has expressed many concerns regarding the statistical soundness of hypothesis based toxicity tests (Chapman et al. 1996; NGSO 2005; CCME 2007; Warne and van Dam 2008). When using the hypothesis based approach, confidence intervals cannot be calculated, and endpoint values are biased by the experimental design. An advantage of the regression based approach is that confidence intervals can be calculated for individual ECx endpoints, and a clearly-defined level of effect can be compared across species.

3) Introduction

The B.C. Ministry of Environment develops province-wide ambient water quality guidelines for substances or physical attributes that are important in both fresh and marine surface waters of B.C. This work has the following goals:

- to provide protection of the most sensitive aquatic life form and most sensitive life stage indefinitely;

- to provide a basis for the evaluation of data on water, sediment, and biota for water quality and environmental impact assessments;
- to provide a basis for the establishment of site-specific ambient water quality objectives;
- to identify areas with degraded conditions that need remediation;
- to provide a basis for establishing wastewater discharge limits; and,
- to report to the public on the state of water quality and promote water stewardship.

The Ministry's definition of a guideline is:

A maximum and/or minimum value for a physical, chemical or biological characteristic of water, sediment or biota, applicable province-wide, which should not be exceeded to prevent specified detrimental effects from occurring to a water use, including aquatic life, under specified environmental conditions.

Water quality guidelines are province-wide in application, but use-specific, and are developed for the following water uses:

- source drinking water;
- aquatic life (and their consumers) and wildlife;
- agriculture (livestock watering and irrigation);
- recreation and aesthetic; and,
- industrial (water supplies).

NOTE: The Ministry of Environment's drinking water quality guidelines are used to assess ambient source water quality prior to any form of treatment. Health Authorities regulate the quality and treatment of drinking water by authority set out in the Drinking Water Protection Act and Regulations. Health Canada develops guidelines for recreational water quality; the Ministry of Environment adopts these guidelines for assessments of recreational waters.

The guidelines are set after considering the scientific literature, results from toxicity tests, guidelines from other jurisdictions and conditions in B.C. The scientific literature gives information on the effects of toxicants on various life forms. This information is rarely conclusive because it is usually based on laboratory tests on a limited number of species which can be raised in the laboratory; these studies only approximate field conditions and do not account for mixtures of contaminants or indirect effects through food webs. To compensate for some of these uncertainties, guidelines have incorporated uncertainty factors. Ambient background conditions in the province are also considered for those substances that occur naturally.

This document describes how guidelines are derived to protect aquatic life, and applies to toxic chemical substances more than the physical properties of water (e.g., temperature, pH, suspended solids). Derivation of water quality guidelines to protect other water uses will be described under separate cover.

New science and tools may be developed for use in creating water quality guidelines. New tools could include the use of “omics” (genomics, proteomics, metabolomics etc.) to identify contaminants with similar modes of action (MOA) or the impacts of mixtures of contaminants on organisms. Ecotoxicogenomics is a new approach to help predict the impacts of contaminants of emerging concern (Poynton and Vulpe 2009). DNA microarrays can help to identify biomarkers of exposure to contaminants and identify genes, proteins, or metabolites, which are altered depending on the pollutant’s specific MOA. Phenotypic anchoring (the ability to demonstrate that a molecular event causes or is associated with a toxicological outcome or disease state) provides an important line of evidence for linking genomics with traditional toxicological endpoints (Poynton and Vulpe 2009).

Presently, neither water quality guidelines, nor water quality objectives which are derived from them, have any direct legal standing. They are intended as a tool to provide policy direction to those making decisions affecting water quality provided that they do not allow legislated effluent standards to be exceeded. Water quality guidelines and objectives can be used to establish the allowable limits in waste discharges. These limits are set out in waste

management permits, approvals, plans, or operating certificates which do have legal standing.

a) Background

This document fulfills the following needs:

- to maintain consistency in the derivation of water quality guidelines;
- to lay out the procedure in clear terms;
- to serve as a checklist to ensure that all aspects are considered; and,
- to encourage research and provide a better basis upon which to set more defensible guidelines.

Water quality guidelines to protect aquatic life have been prepared for many substances of concern and guidelines for other substances continue to be prepared including other priority substances needed for water quality assessments and objectives in B.C. Until guidelines for certain substances are approved by the Ministry Executive, the Ministry uses what is termed 'working' guidelines for water quality, many of which have been recommended by the Canadian Council of Ministers of the Environment (CCME) and others adopted from other jurisdictions and the scientific literature. However, it should be noted that B.C. does not derive provincial guidelines or objectives using the CCME's (2007) species sensitivity distribution (SSD) protocol, which is currently in a test phase.

b) Guiding Principles for the Development of Water Quality Guidelines for Aquatic Life

There are several fundamental principles used in developing water quality guidelines in B.C. These are:

- B.C. guidelines are science-based and intended for generic provincial application. They do not account for special site-specific factors where they exist, or for socio-economic factors.
- All higher components of the aquatic ecosystem (e.g., algae, macrophytes, invertebrates, amphibians, and fish) are considered if the data are available. Where data are available but limited, the development of interim guidelines is preferable to no guidelines at all.

- The approach to develop guidelines for aquatic life reflects the philosophy that all forms of aquatic life and all aquatic stages of their life cycle are to be protected during indefinite exposure. Protection of aquatic life is characterized by protection of individuals and as such, also protects populations. It should be noted however, that this approach may not protect individuals weakened to some degree through age, illness, or injury. Whether this goal can be realized is a separate issue and does not influence the guideline derivation procedure.
- For some substances both a short-term maximum (acute) and a long-term average (chronic) guideline are recommended as provincial water quality guidelines, provided sufficient toxicological data are available. Short-term maximum guidelines are set to prevent severe effects such as lethality to aquatic organisms from short-term exposures to contaminants. Long-term average guidelines are set to protect aquatic organisms from sub-lethal and lethal effects over the long-term. Both conditions should be met to protect aquatic life. For other substances which may not be acutely toxic but, due to their low water solubilities (e.g., PCBs and dioxins), ability to bioaccumulate, or mode of action (e.g., endocrine disruptors), the guideline is a single value representing a long-term, no-effect level, which should not be exceeded at any time.
- Unless otherwise specified, a guideline refers to the total concentration of a substance in an unfiltered sample. Total concentrations will apply unless it can be demonstrated that the relationship between other measures of the substance and their toxicity is firmly established, and analytical techniques have been developed that unequivocally identify the toxic fraction of a substance in a consistent manner using routine field-verified measurements.
- B.C. guidelines are generally the basis for the derivation of site-specific water quality objectives, which take local circumstances into account.

4) Data Requirements for Guidelines Derivation

To set water quality guidelines, certain basic data must be available. Where insufficient data are available to set guidelines, interim guidelines may be set. The interim guidelines may be upgraded to full guidelines status when the data gap is filled. While minimum data

requirements have been recommended for both guidelines and interim guidelines, it is important to emphasize that these are intended as a guide, not legal standards.

Flexibility and the use of scientific judgement as well as innovative new approaches are recognized as necessary and important components of the derivation process. For example, consideration must be given to the nature of the substance such as its mode of toxic action, its bioaccumulation potential, or if it exhibits delayed toxicity. Exemptions from the minimum data requirements may be considered on a case-by-case basis provided they are documented and scientifically justified. The final decision of whether guidelines or interim guidelines are recommended is based, in part, on the confidence the Ministry has in the guideline. If interim guidelines are recommended, then it is the responsibility of the authors to recommend the information needed to elevate interim guidelines to full guidelines status.

a) Minimum Aquatic Toxicity Data Requirements for Freshwater Guidelines

The goal of freshwater aquatic life guidelines is the protection and maintenance of all forms of aquatic life and all life stages in the freshwater environment. Therefore, it is essential that, at a minimum, data for fish, invertebrates, and plants be included in the guidelines derivation process. For this purpose, minimum data requirements have been recommended. Data from amphibians are also highly desirable. Guidelines or interim guidelines may also include studies involving species not required in the minimum data set (e.g., protozoa, bacteria), when reasonable justification exists.

<u>Full Guidelines - Freshwater</u>

Fish

- To set a long-term average guideline, at least 3 long-term studies on 3 or more freshwater species resident in B.C., including at least 2 cold-water species (e.g., trout).
- To set a short-term maximum guideline, at least 3 short-term studies on 3 or more freshwater species resident in B.C., including at least 2 cold-water species.

Invertebrates

- To set a long-term average guideline, at least 2 long-term (partial or full life-cycle) studies on 2 or more invertebrate species from different classes, 1 of which includes a planktonic species resident in B.C. (e.g., daphnid).
- To set a short-term maximum guideline, at least 2 short-term studies on 2 or more invertebrate species from different classes, 1 of which includes a planktonic species resident in B.C.

Plants

- At least 1 study on a freshwater vascular plant or freshwater algal species resident in B.C.
- For highly phytotoxic substances, 3 short-term and/or long-term studies on freshwater plant or algal species.

The reduced requirements for plant toxicity studies were deemed necessary because fewer studies on plants have been conducted (CCME 2007). The minimum data requirements for plants could be increased in the future if data availability improves.

Amphibians

When available, toxicity studies using amphibians should be included.

In cases where the minimum data requirements for full guidelines derivation are not met, interim water quality guidelines may be developed provided the minimum data set for interim guidelines requirements are met (see below).

Interim Guidelines - Freshwater

Fish

- At least 2 short-term and/or long-term studies on 2 or more fish species, 1 of which includes a coldwater species (e.g., trout) resident in B.C.

Invertebrates

- At least 2 short-term and/or long-term studies on 2 or more invertebrate species from different classes, 1 of which includes a planktonic species resident in B.C. (e.g., daphnid).

If a toxicity study indicates that a plant species is the most sensitive species in the data set, then this study shall be used in the interim guidelines derivation process. However, in the absence of data on plants, interim guidelines can be derived provided that this data gap is noted. The information that is required to elevate interim guidelines to full guidelines status needs to be clearly identified to stimulate research that will generate the necessary data.

b) Minimum Aquatic Toxicity Data Requirements for Marine Guidelines

Recognizing that toxicants may react differently in marine water than in fresh water, and that different species are involved, the data requirements are different to reflect the need for separate guidelines for the marine situation. This need for separate marine guidelines has been demonstrated by the US EPA and supported by the CCME (CCME 2007).

For most substances, however, there are fewer data available for marine species, particularly phytoplankton and macroalgae, than are available for the fresh water environment (Hansen 1989). Since the goal of marine aquatic guidelines is the protection and maintenance of all forms of aquatic life and aquatic life stages in the marine environment, it is recommended that data for marine fish, invertebrates, and plants be included in the guidelines derivation process. As with the requirements for fresh water aquatic life guidelines, minimum data requirements have been recommended. In this data set, marine species include those species found in estuarine, coastal, and open-ocean habitats, any of which may be used to derive a guideline or interim guideline.

<u>Full Guidelines - Marine</u>

Fish

- To set a long-term average guideline, at least 3 studies on 3 or more temperate marine fish species, including at least 2 long-term (partial or full lifecycle) studies.

- To set a short-term maximum guideline, at least 3 short-term studies on 2 or more temperate marine fish species.

Invertebrates

- To set a long-term average guideline, at least 2 long-term (partial or full lifecycle) studies on 2 or more temperate marine invertebrate species from different classes.
- To set a short-term maximum guideline, at least 2 short-term studies, on 2 or more temperate marine invertebrate species from different classes.

Plants

- At least 1 study on a temperate marine vascular plant or marine algal species.

In cases where the minimum data requirements are not met, interim water quality guidelines can be derived provided the minimum data requirements for interim marine guidelines are met (see below).

Interim Guidelines - Marine

Fish

- At least 2 short-term and/or long-term studies on 2 or more marine fish species, 1 of which is a temperate species.

Invertebrates

- At least 2 short-term and/or long-term studies on 2 or more marine species from different classes, 1 of which is a temperate species.

If a toxicity study indicates that a plant species is the most sensitive species in the data set, then this study shall be used in the interim guidelines derivation process. However, in the absence of data on plants, interim guidelines can be derived provided that this data gap is noted. As with freshwater aquatic life guidelines the information that is required to elevate interim guidelines to full guidelines status needs to be clearly identified to stimulate research that will generate the necessary data.

c) Minimum Environmental Fate and Behaviour Data Requirements

In addition to the minimum toxicity data requirements outlined above, studies that have investigated the major environmental fate processes and persistence of the substance in water, soil, sediment, air and biota are required. Potential fate processes include volatilization, hydrolysis, oxidation, photolysis, aerobic and anaerobic biodegradation, long-range transport, soil and sediment sorption/desorption, bioconcentration and bioaccumulation. It is not necessary to have information on each potential fate process. Rather, the intent is to be able to identify the major environmental pathways and fate of a substance in the aquatic environment. Specifically, the following information should be summarized as part of the documentation supporting the guideline:

- the physical and chemical properties;
- the mobility of the substance and the compartments of the aquatic environment in which it is most likely to be distributed;
- the kinds of chemical and biological reactions and/or mechanisms that occur during transport and after deposition;
- the eventual chemical form(s);
- the persistence of the substance in water, sediment, and biota; and
- the ambient background concentrations for those substances that occur naturally (guidelines for some substances are based solely on background concentrations when they occur naturally and fluctuate widely, e.g. turbidity and suspended solids).

Where possible, the persistence of a substance should be expressed in terms of its half-life. Where significant environmental fate information is lacking, interim guidelines are set. In these cases, the information required to elevate the interim guideline to full guideline status needs to be clearly identified to stimulate the necessary research.

d) Additional Information

The following are not required elements of the minimum data set, but should be included when available because they are useful in assessing the potential hazard of a substance:

- production and uses;

- organoleptic effects (taste, odour, fish flesh tainting);
- sources to the aquatic environment;
- methods of analysis and current detection limits;
- concentrations in the aquatic environment;
- mode of toxic action;
- toxic equivalents;
- toxicity of the metabolites and breakdown products;
- sensitivity of birds and wildlife consuming aquatic organisms; and,
- guidelines, criteria, objectives, and standards from other jurisdictions.

5) Evaluation of Toxicity Data

Since standard protocols for toxicity testing may become outdated or are not always available or followed, a great deal of variability exists in the quality of published data. To ensure a consistent scientific evaluation for each substance, the data included in the minimum data set should meet certain standards. These include information on test conditions/design (e.g., flow-through, renewal, static), test concentrations, temperature, hardness, pH, adjuvants (i.e., synergistic effects), experimental design (controls, number of replicates) and a description of the statistics used in evaluating the data.

A variety of standardized test protocols have been developed for fish, invertebrates and plants. When appropriate, these should be consulted during the evaluation process:

- Coho salmon (*Oncoryhnchus kisutch*; ASTM 2007);
- Rainbow trout (*Oncoryhnchus mykiss*; DOE 2007a; 2007b);
- Brook trout (*Salvelinus fontinalis*; ASTM 2007);
- Fathead minnow (*Pimephales promelas*; DOE 2008);
- Threespine stickleback (*Gasterosteus aculeatus*; DOE 2000a);
- Channel catfish (*Ictalurus punctatus*; ASTM 2007);
- Bluegill sunfish (*Lepomis macrochirus*; ASTM 2007);
- Green sunfish (*Lepomis cyanellus*; ASTM 2007);
- Water fleas (*Daphnia magna, Daphnia pulex, Daphnia pulicaria, Ceriodaphnia dubia*; DOE 1996; 2000b; 2007c; ASTM 2007);

- Amphipods (*Gammarus lacustris, Gammarus fasciatus, Gammarus pseudolimnaeus*; ASTM 2007a; *Hyalella azteca*; DOE 1997a);
- Crayfish (*Oronectes* sp*., Cambarus* sp*., Procambarus* sp*., Pacifastacus leniusculus*; ASTM 2007);
- Stoneflies (*Pteronarcys* sp.; ASTM 2007);
- Mayflies (*Baetis* sp*., Ephemerella* sp*., Hexagenia limbata, Hexagenia bilineata*; ASTM 2007);
- Midges (*Chironomus* sp.; ASTM 2007; DOE 1997b);
- Snails (*Physa integra, Physa heterostropha, Amnicola limosa*; ASTM 2007);
- Planaria (*Dugesia tigrina*; ASTM 2007);
- Frog (*Rana* sp.; ASTM 2007);
- Toad (*Bufo* sp.; ASTM 2007); and,
- Green alga (*Selenastrum capricornutum*; DOE 2007d; ASTM 2007).

It is likely that these standard tests could be adapted for use with numerous other species that are closely related to the species listed above. However, additional quality assurance data should be collected to assure the validity of the toxicity test when non-standard species are used.

When consulting test protocols, it is important to be aware of the following limitations:

- protocols consider only a few well-studied species and biological processes;
- our knowledge of extrapolation from 1 species to another (i.e. comparative ecotoxicology) is very limited;
- there is limited knowledge of the effects of metabolites and other environmentally transformed products of the parent chemicals;
- protocols do not take into account cumulative effects of chemicals or compensatory responses of organisms (such as acclimation or reduced density-dependent mortality amongst juveniles); and,
- the results of laboratory exposures and the relationship to the effects on aquatic organisms in various ecosystems has not been adequately tested (Sheenan et al. 1984; Arthur 1988; Petersen and Petersen 1988; Reiley et al. 2003).

Therefore, it is essential that the evaluation of toxicity data not follow a rigidly fixed format. Once evaluated, key data are classified as primary, secondary, or unacceptable as described below.

All data included in the minimum data set should be primary for guidelines derivation to proceed. For interim guidelines derivation, primary or secondary data may be used. Unacceptable data cannot be used in either derivation procedure.

a) Data Classification

Primary Data

- Toxicity tests must employ currently acceptable laboratory practices of exposure and environmental controls. Other types of tests using more novel approaches (e.g., omics including genomics, proteomics, metabolomics) will be evaluated on a case-by-case basis.
- As a minimum requirement, substance concentrations must be measured and reported at the beginning and end of the exposure period. Calculated concentrations or measurements taken in stock solutions are unacceptable.
- Generally, non-renewed static tests are unacceptable unless it can be shown that substance concentrations did not change during the test and that adequate environmental conditions for the test species were maintained.
- Preferred endpoints from a partial or full lifecycle test include a determination of effects on embryonic development, hatching, germination success, survival of juvenile stages, growth, photosynthesis, reproduction, and survival of adults.
- Endpoints should be demonstrated to be ecologically relevant toxic endpoints. These generally include but are not exclusive to reproduction, growth, development and survival of young and adults. Other endpoints (e.g., behaviour, deformities etc.) will be evaluated on a case-by-case basis.
- Response and survival of controls must be measured and reported, and appropriate for the life stage of the test species used.
- Measurements of abiotic variables such as temperature, pH, dissolved oxygen, and water hardness should be reported so that any factors that may affect toxicity can be

included in the derivation process.

Secondary Data

- Toxicity tests may employ a wider array of methods (e.g., measuring toxicity while test species are exposed to additional stresses such as low temperatures, lack of food, or high salinity).
- Static tests are acceptable.
- Preferred test endpoints include those listed for primary data as well as pathological, behavioural, enzymatic, and physiological effects. These endpoints should be linked to some ecological relevance.
- Calculated substance concentrations are acceptable.
- All relevant environmental variables should be measured and reported.
- The survival of controls must be measured and reported.

Unacceptable Data

- Toxicity data that do not meet the conditions of primary or secondary data.

6) Guidelines Derivation

There are 4 levels or categories of water quality guidelines to protect aquatic life in B.C. These are:

- short-term maximum and long-term average guidelines derived from short-term and long-term studies, respectively;
- a single long-term average guideline derived from long-term studies;
- a single long-term average guideline derived from bioaccumulation studies; and,
- an interim guideline derived from short-term and/or long-term studies or bioaccumulation studies.

The choice of which level to apply depends on a number of factors such as the quantity and quality of toxicity data, and the nature of the substance.

The preferred endpoints to derive a long-term average guideline are endpoints representing a low-effects threshold for a species from a critical study (similar to CCME 2007 Type B

guidelines). The preference ranking of endpoints is done in the following order: most appropriate ECx/ICx representing a low-effects threshold > EC15-25/IC15-25 > LOEC > MATC > EC26-49/IC26-49 > non-lethal EC50/IC50 > LC50.

As previously mentioned, regression based toxicity estimates (i.e. ECx) are preferred to hypothesis based toxicity values (i.e. NOEC and LOEC) for water quality guidelines development. Regression based toxicity estimates are to be reported with their confidence intervals. Where regression based toxicity estimates are not available, hypothesis based toxicity estimates may be used.

Species not required in the minimum data set (e.g. amphibians) may be used in the derivation procedure provided that the life stage under investigation is aquatic. In addition, bioconcentration data may be used to derive guidelines to protect the organisms, or consumers of the organisms, from harmful effects.

a) Derivation of Short-term Maximum and Long-term Average Guidelines

Qualifications and Setting Guidelines

To qualify for this category, the nature of the substance must first be considered. For example, if persistence, bioconcentration, bioaccumulation or delayed mortality is a concern then the substance would not qualify for this approach. If the substance meets this first set of conditions then the toxicity data are summarized in a tabular and/or graphical format and separated into short-term and long-term data. The decision of whether data are short-term or long-term depends primarily upon the exposure period. Short-term toxicity data generally, but not always, refer to the results of short-term tests with toxicity endpoints that occur within 96 hours of exposure (see CCME (2007)). Long-term toxicity data generally, but not always, refer to tests that exceed 96 hours of exposure duration. However, the normal longevity of the species tested or life stage tested must also be considered in this decision. For example, 96 hours is a relatively short time in the life cycle of most fish, whereas it may constitute most or all of the life cycle of some invertebrates or lower life forms. Again, applying scientific judgment is appropriate here.

Another condition that must be met to qualify for this approach is that sufficient short-term and long-term data must be available to set both a short-term maximum and long-term average guideline. This decision is not always possible at this stage, especially if the toxicity of a substance is affected by some environmental factor such as water hardness or pH. Toxicity modifying factors are important to identify and evaluate in the guideline derivation procedure. Short-term and long-term data are graphed. Graphing toxicity data serves several useful purposes in the process of guidelines derivation and evaluation.

These are:

- to provide an indication of whether a relationship exists between the substance toxicity and any modifying environmental factor;
- to determine if there is a distinction in magnitude between short-term and long-term data so that both a short-term maximum and long-term average guideline can be set;
- to serve as an initial screening tool for identifying the key short-term and long-term toxicity data; and,
- to provide a visual representation of the relationships among the toxicity data, the proposed guidelines, and guidelines from other jurisdictions.

Once the key short-term and long-term data have been identified, they are evaluated in terms of their scientific soundness and rated as primary, secondary, or unacceptable. Appropriate uncertainty factors (typically between 2 and 10) are then applied to (divided by) the primary key short-term and long-term data to derive short-term maximum and long-term average guidelines. If no-effect data for sensitive life stages of sensitive species fall within the safety range for long-term data (i.e., between the lowest effect data and the calculated safe value), then the no-effect endpoint may be adopted as the long-term guideline. It should be noted that the magnitude of the uncertainty factor may vary from substance to substance depending upon the quality and quantity of toxicity data. The appropriate uncertainty factor to be applied is decided on a case-by-case basis and is based on data quality and quantity, toxicity of the contaminant, severity of toxic effects, and bioaccumulation potential. Scientific judgement is used to maintain some flexibility in the derivation process.

Ambient background concentrations for substances that occur naturally may also play a role in the size of an uncertainty factor. Guidelines set far below levels that occur naturally in B.C. waters, and in which aquatic life thrive, would be impractical and unusable for assessing the environmental impact of anthropogenically generated substances.

When there is a relationship between the toxicity of the substance and some modifying environmental factor (additive, synergistic or antagonistic), then the guideline may be specified in terms of the modifying factor.

Short-term maximum guidelines are intended to protect against any severe effects such as lethality (e.g., LC50) or equivalent (e.g., EC50) to the most sensitive species over a defined short-term exposure period (i.e., 96 hours). Long-term average guidelines are intended to protect the most sensitive species and life stage against sub-lethal and lethal effects for indefinite exposure.

Averaging Periods

The averaging period approach is a refinement to the guideline approach, reflecting more closely the thresholds of average toxicity. This approach allows concentrations of a substance to fluctuate above and below the guideline provided that the short-term maximum is never exceeded and the long-term average is met over the specified averaging period. The goal is to provide a balance between acceptable levels of protection to counter long-term toxicity without being too stringent, and the practical application of the guidelines in terms of monitoring requirements.

The averaging period for the long-term average guideline may differ depending upon the substance under investigation and is somewhat arbitrary (e.g., 5 in 30 days have been used for B.C. water quality objectives and guidelines). These averaging periods were chosen as reasonable and practical durations to address long-term effects and to fit into monitoring timetables for provincial agencies. Five samples are considered the minimum needed to calculate the average; however, in some cases where the concentrations fluctuate widely in nature, more than 5 samples may be necessary. On the other hand, if concentrations are uniform and rarely exceed the long-term average guideline, less frequent monitoring may be

justified. In this case, failure of any individual sample to meet the long-term average guideline would serve as an alert signal to increase the monitoring.

For some substances, such as residual chlorine, the B.C. guidelines are time-related whereby the averaging periods for ambient monitoring are based on the toxicity exposure-duration data (Singleton 1989). The minimum duration of the averaging period for residual chlorine is set at the threshold of long-term toxicity. For freshwater this threshold is 4 days, but for marine waters it is only 2 hours.

b) Derivation of a Single Guideline from Long-term Studies

This category applies to those substances that do not meet the criteria outlined in Section 5a (Derivation of Short-term Maximum and Long-term Average Guidelines from Short-term and Long-term Studies). Examples include:

- insufficient short-term and long-term data;
- an overlap of short-term and long-term toxicities such that the distinction between them is not clear;
- the substance is persistent and has bioconcentration / bioaccumulation potential;
- the substance does not exhibit short-term severe toxicity under normal environmental conditions; or
- the substance has exhibited delayed toxicity after short-term exposure.

The derivation process for this category is basically the same as that for the average guideline in the foregoing category. This single guideline typically is based on the ECx/ICx representing a low-effects threshold preferably using a non-lethal endpoint (unless the lowest-effects threshold is a lethal endpoint) and apply an appropriate uncertainty factor (usually divided by a value between 2 and 10). This approach is used to derive a preliminary water quality guideline regardless of whether bioaccumulation is a concern.

When bioaccumulation of a particular substance is a concern, then an additional assessment must be made. If the bioaccumulation assessment results in a safe limit lower than the preliminary water quality guideline, then the preliminary guideline can be adjusted

accordingly. This derivation process is described more fully below.

c) Derivation of Water Quality Guidelines from Bioaccumulation Data

If a substance bioaccumulates in the tissues of an organism from the water, suspended particles, sediment, or food, resulting in a toxic effect on the organism, their offspring, or their consumers, then a thorough assessment of bioaccumulation is required for guideline derivation. In this case, bioaccumulation data or models may be used to derive a long-term average water column guideline which may, if appropriate, be augmented with guidelines for sediment and/or tissue, with supporting rationale. However, the minimum data requirements for derivation of full or interim aquatic life guidelines still applies to substances that bioaccumulate.

To derive a water quality guideline from bioaccumulation data, only those studies that meet the criteria to be classified as primary or secondary data may be used. As well, some additional basic information is necessary:

- reliable laboratory determination of body burdens in aquatic organisms exposed to known concentrations of the substance in water at equilibrium (i.e., to calculate a bioconcentration factor, BCF);
- if other exposure routes are important, the combined uptake concentrations of a substance from water, suspended particles, sediment and diet, in addition to the target tissue concentrations, should be calculated (i.e., to calculate a bioaccumulation factor, BAF);
- where appropriate, the BCF/BAF should be lipid-normalized for those contaminants that accumulate in fatty tissues ;
- the range of exposure test concentrations should include those well below known toxic thresholds for the test species; and,
- the harmful effects of body burden levels on the exposed aquatic organism and their consumers should be characterized.

Laboratory generated data is most desirable for use in guideline derivation (controlled conditions, standard protocols, higher confidence in results). Controlled mesocosm or

microcosm studies may also be acceptable if they meet the minimum requirements of primary or secondary data. It is recognized that lab studies do not necessarily reflect natural conditions and bioaccumulation data may be difficult to generate in the laboratory. The use of field generated bioaccumulation data is not generally permissible for use in the derivation of guidelines (unknown initial exposure concentrations and other co-variables), but may provide important information or verification of laboratory toxicity thresholds. As such, they may be used to augment guideline development with the following caveats:

- provide justification for use of the data (e.g., appropriateness of the study endpoints, comparability of species, difficulty obtaining lab data);
- explain the study design, quality assurance, analytical, and statistical techniques employed;
- estimate exposure concentrations (including real measurements, use of tissue to tissue regressions or other models) and important co-variables that may alter toxicity;
- ensure, where models have been used to estimate exposure/toxicity, that the regressions have not been extrapolated beyond the range of the field data; and,
- attempt to quantify uncertainty of the estimates (confidence intervals, standard error/deviation).

For example, to derive a water quality guideline based on bioaccumulation data, the lowest-effect tissue residue threshold that induces a harmful effect in the exposed organism, its progeny, or its consumers should be determined (or selected from the literature). This value is then divided by the highest reliable BCF or BAF to derive a water column ECx or ICx representing a low-effect threshold for the water. To derive a water quality guideline to protect the organism from accumulating harmful body burdens, the low-effect threshold is divided by an appropriate uncertainty factor (typically between 2 and 10) as follows:

$$WQG = (\text{Lowest Harmful Tissue Residue Level (ECx or ICx)} \div \text{BCF or BAF}) \div \text{Uncertainty Factor}$$

If only a no-effect tissue threshold concentration is available then this value may be used in place of the low-effect tissue threshold concentration, provided the effects studied involve sensitive long-term endpoints for sensitive species. If a no-effect value is used, then an uncertainty factor may not be required, however, justification for this must be provided. The resulting derivation would be as follows:

WQG = No-Effect Tissue Residue Concentration ÷ BCF or BAF

.

To determine the final water quality guideline, the value calculated here, is compared to the preliminary water quality guideline determined using the process outlined in Section 6b (the derivation of a single guideline from long-term studies, but without the incorporation of BCFs or BAFs). The final water quality guideline should be the most scientifically defensible of the two values. It is possible that a large discrepancy may exist between the values derived by each method, given the variability of BCFs/BAFs for many substances (e.g., laboratory-derived BCFs may range over three orders of magnitude), and the sometimes subjective nature of uncertainty factors. In such cases, a statistical value, such as the geometric mean, may be considered as the final guideline. The rationale for this alternative statistical approach is that if the values derived by the two methods are similar, then there is a high level of confidence in the guideline. However, when the range between the two values is wide for a particular substance, there is less confidence that either of the values is accurate. Hence, the assumption may be made that the safe level (guideline) probably lies somewhere between the two values.

d) Interim Guidelines Derivation from Short-term or Long-term Studies

The procedure for the derivation of interim water quality guidelines is similar to that used to derive guidelines, except that the minimum data requirements are not as rigorous. In addition, secondary data are acceptable for the derivation of interim guidelines, but unacceptable data should not be used. Long-term data are preferred over short-term data as a basis to derive an interim water quality guideline. The information that is required to elevate

interim guidelines to full guidelines status needs to be clearly identified to stimulate research that will generate the necessary data.

e) Uncertainty

It should be noted that there are several sources of uncertainty when it comes to developing water quality guidelines and therefore it is necessary to apply uncertainty factors when developing guidelines. Sources of uncertainty include:

- laboratory to field differences;
- single to multiple contaminants (additive, synergistic, antagonistic effects);
- toxicity of metabolites;
- intra and inter-species differences (limited species to conduct tests on, which may not include the most sensitive species);
- indirect effects (e.g. foodweb dynamics);
- whole life-cycle vs. partial life-cycle (many toxicity studies are only conducted on partial life-cycles and it can be difficult to determining the most sensitive life stage);
- delayed effects;
- other stressors (habitat loss) or contaminants in the environment that may have an unknown effect (cumulative effects); and,
- impacts of climate change (species may be more vulnerable with additional stressors).

The appropriate uncertainty factor to be applied is decided on a case-by-case basis and is based on data quality and quantity, toxicity of the contaminant, severity of toxic effects, and bioaccumulation potential. Scientific judgement is used to maintain some flexibility in the derivation process.

7) Administrative Procedure

The overall process of guideline development and approval is outlined in Figure 1.

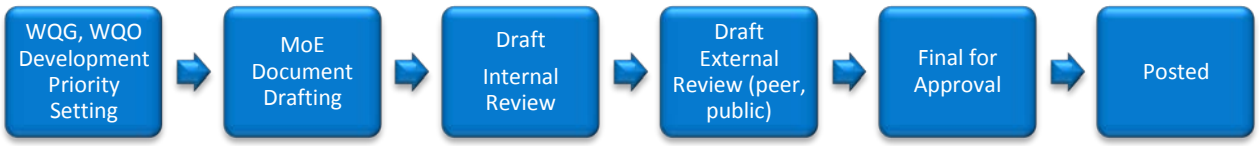

Figure 1. Schematic of water quality guideline development process.

Several steps must be followed to formally establish guidelines as Ministry policy:

1) Conduct an internal review within the appropriate provincial and federal agencies of the first draft of the technical report containing all relevant information pertaining to the substance of concern, the recommended guidelines and their application, to ensure quality and accuracy of all material.
2) Conduct an external review of the second draft of the technical report by scientific experts, other government and non-government stakeholders, and Ministry staff. The draft reports are posted to the Ministry website for public review (note: all review comments that are received will be considered during the review period).
3) When neccessary, additional consultation may be conducted to address specific issues associated with a guideline report. The need for such consultation will be determined by the Ministry.
4) All public and stakeholder review comments, and the Ministry response to comments, will be made available on the Ministry web site.
5) Submit the report(s) for approval and sign off by Ministry Executive (Assistant Deputy Minister level), or his/her designate.
6) Obtain a library catalogue number (CIP) from the legislative library (Catalogue Section).

The review time should be limited to approximately one month for each of the first and second drafts. It is recognized that extensions to the review period may be necessary and will be provided at the discretion of the Ministry.

Copies of the final report are made publicly available through the Ministry of Environment website.

The guidelines are subject to review and revision as new knowledge becomes available, or as circumstances dictate.

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