Canadian Water Quality Guidelines for the Protection of Aquatic Life

PROTOCOL

A Protocol for the Derivation of Water Quality Guidelines for the Protection of Aquatic Life

Originally published in April 1991 as Appendix IX of *Canadian Water Quality Guidelines* (CCREM 1987). Updated and reprinted here with minor revisions and editorial changes.

Contents

Introduction

Change is an important characteristic of aquatic ecosystems. Species composition, various rate processes, degree of complexity, and many other community characteristics change over time. Changes in aquatic ecosystem structure and function may result from storms, floods, changes in rainfall patterns, sedimentation, and a variety of other natural causes. In addition, changes may result from societal stresses such as toxic chemical inputs and nutrient enrichment. An ecosystem may recover from both types of change, however, the recovery process will rarely produce a system identical to the original when a societal stress is involved (Cairns 1980). The guidelines found in the freshwater life chapter of *Canadian Water Quality Guidelines* (CCREM 1987, Chapter 3) were developed as one of a series of management tools to ensure that societal stresses, particularly the introduction of toxic chemicals, do not lead to the degradation of Canadian fresh waters.

Background

The freshwater life chapter of CCREM (1987) included water quality guidelines for approximately 65 water quality variables and continued to be updated and expanded with the addition of guidelines for industrial solvents, in-use pesticides, and other variables of concern to freshwater life. However, since the publication of *Canadian Water Quality Guidelines* in 1987, several concerns had been raised regarding the protocol used to develop guidelines for the protection of freshwater life. The protocol contained in the freshwater life chapter was

considered to be incomplete regarding the identification and selection of key studies and the mechanism of guideline derivation. Further, several jurisdictions had reassessed their protocols for guideline development, while other jurisdictions had requested a similar protocol for the marine environment. In response to these issues, the Canadian Council of Ministers of the Environment (CCME) Task Force on Water Quality Guidelines undertook a review of the protocol used in the freshwater life chapter of *Canadian Water Quality Guidelines*. The revised aquatic life protocol presented here, which includes a protocol for the derivation of marine life guidelines, was originally published in April 1991 as an appendix to CCREM (1987). All guidelines previously approved by the CCREM (now known as the CCME), however, continue to apply until a future review is deemed necessary.

Guiding Principles

The following is an update of the freshwater life chapter guiding principles for the development of freshwater aquatic life guidelines as originally adopted by the CCREM Task Force on Water Quality Guidelines. Provincial jurisdictions, however, may aim for greater or lesser levels of protection depending upon circumstances within each jurisdiction.

- In deriving Canadian water quality guidelines for aquatic life, all components of the aquatic ecosystem (e.g., algae, macrophytes, invertebrates, fish) are considered if the data are available. Where data are available but limited, interim guidelines are deemed preferable to no guidelines.

- The approach to the development of guidelines for aquatic life follows that of the International Joint Commission Water Quality Board (IJC 1975) and the Ontario Ministry of the Environment (OMOE 1979, 1992). This approach states that guidelines "are set at such values as to protect all forms of aquatic life and all aspects of the aquatic life cycles". The goal is to protect all life stages during an indefinite exposure to water. Whether this goal can be realized is a water management issue and does not affect the guideline derivation procedure.

- For most water quality variables, a single maximum value, which is not to be exceeded, is recommended as a Canadian water quality guideline. This maximum value is based on a long-term no-effect concentration.

- Unless otherwise specified, a guideline value refers to the total concentration in an unfiltered sample. Total concentrations will apply unless it can be demonstrated that (a) the relationship between variable fractions and their toxicity is firmly established and (b) analytical techniques have been developed that unequivocally identify the toxic fraction of a variable in a consistent manner using routine field-verified measurements.

The Guideline Derivation Protocol

The following is a brief overview of the guideline derivation protocol (see Figure 1).

Selection of Variables

Variables of concern at the national level are given priority for guideline development. For example, the Canadian Environmental Protection Act includes a Priority Substances List (Canada Gazette 1989) for which water quality guidelines are required. Variables are also selected for guideline development after consultation with federal and provincial jurisdictions.

Literature Search

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

- physical and chemical properties
- environmental concentrations
- environmental fate and behaviour
- bioaccumulation potential
- acute toxicity to aquatic biota
- chronic toxicity to aquatic biota
- genotoxicity
- information from other jurisdictions

Data Set Requirements

In order to proceed with the derivation process, minimum toxicological and environmental fate data set requirements must be met. In cases where there is insufficient information, an interim guideline can be derived providing that a less stringent minimum data set is available.

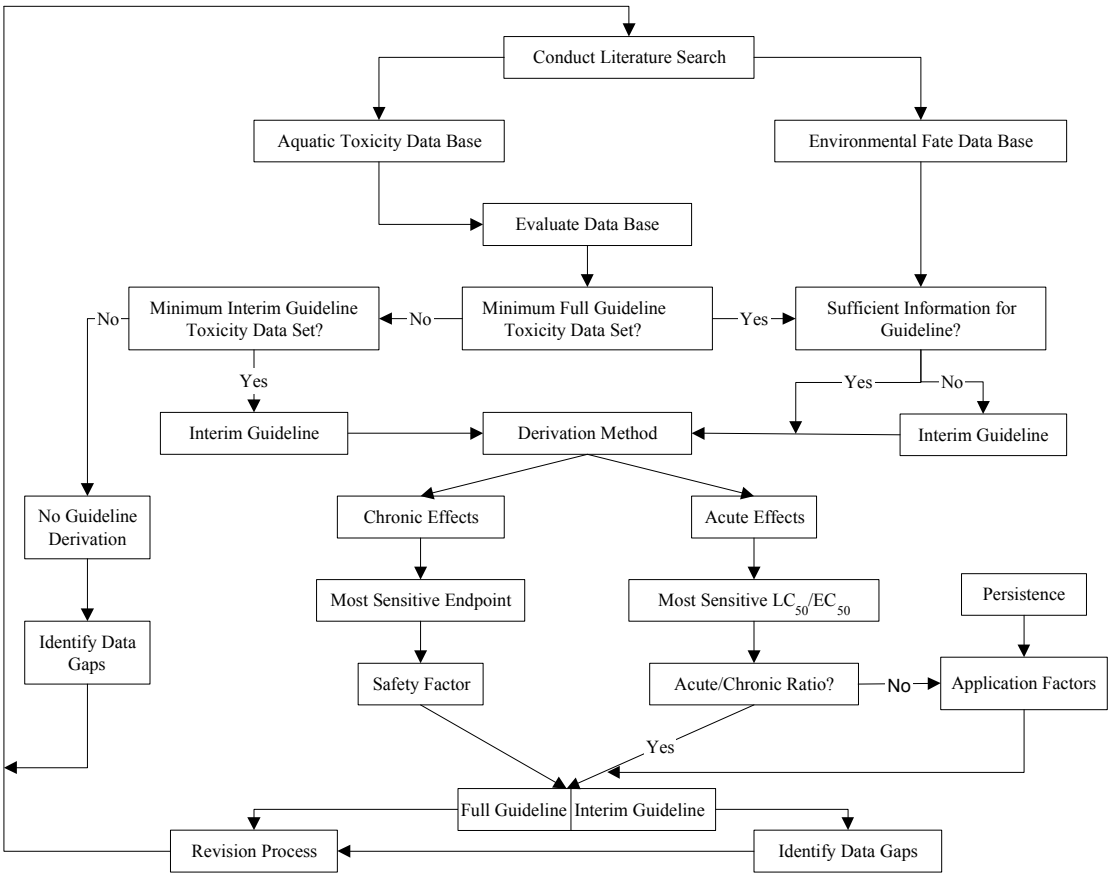

Figure 1. The protocol for deriving Canadian water quality guidelines.

Evaluation of Toxicological Data

Each toxicological study found in the literature search is evaluated to ensure that acceptable laboratory practices were used in the design and execution of the experiment. Each study is then classified as primary, secondary, or unacceptable.

Guideline Derivation

When available, the most sensitive lowest-observable-effects level (LOEL) from a chronic exposure study on a native Canadian species is multiplied by a safety factor of 0.1 to arrive at the final guideline concentration. Alternatively, the most sensitive LC_{50} or EC_{50} from an acute exposure study is multiplied by an acute/chronic ratio or appropriate application factor to determine the final guideline concentration. The derivation protocol is the same for full guidelines and interim guidelines.

The Use of Water Quality Guidelines and Objectives in Water Quality Management

Canadian water quality guidelines for aquatic life are developed to provide basic scientific information about the effects of water quality variables on water uses. This information is used to assess water quality issues and to establish water quality objectives for specific sites (Figure 2).

The need to develop water quality objectives often arises when an industry announces a new project that could affect water quality in a basin. Objectives may also be required to address an existing problem or to provide preventative watershed protection. Those charged with developing objectives (for example, Environment Canada, Indian and Northern Affairs Canada, provincial and territorial governments, and water management agencies such as the Prairie Provinces Water Board) must decide what uses are to be protected, obtain

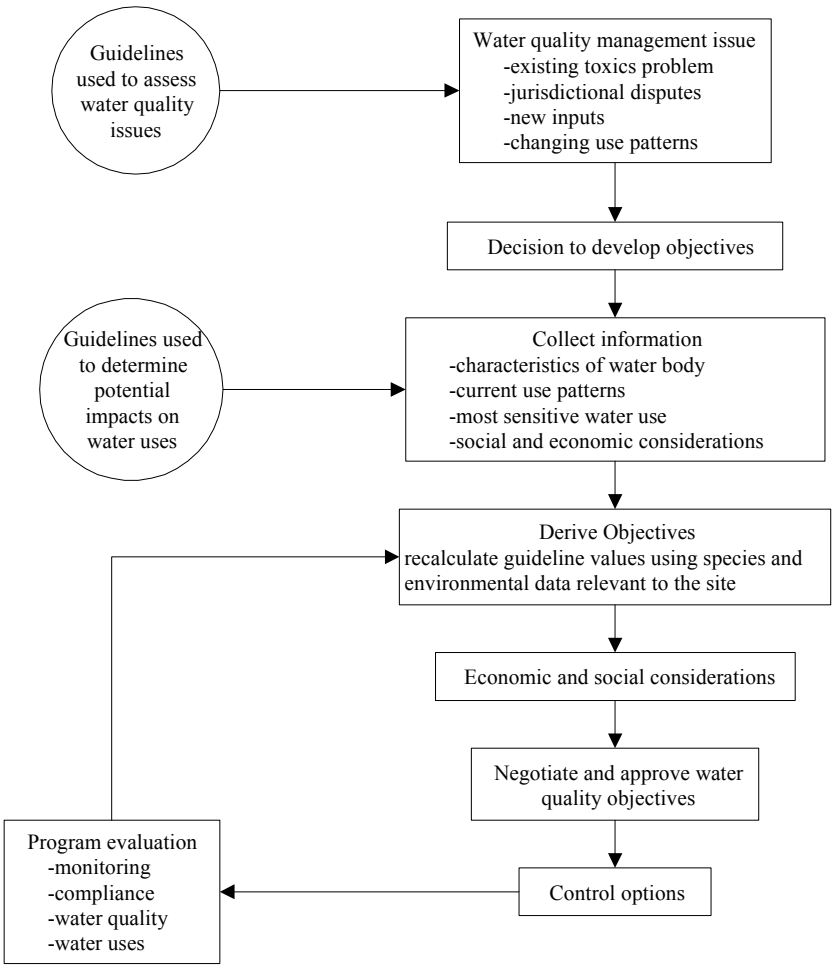

Figure 2. The role of water quality guidelines and objectives in water quality management.

the necessary information, formulate the objectives, and present them for approval to the appropriate jurisdiction (Figure 2).

Developing site-specific objectives to protect aquatic life is a complex process, especially when it concerns objectives for toxic substances. At a given site, there are many species, each of which can respond differently to the often large number of toxic substances produced by human activities. To develop a site-specific objective requires an extensive knowledge of the chemical, physical, and biological properties of the water body and, as well, the social and economic characteristics of the local area. Once this information has been acquired, objectives are derived using this protocol for guidelines, except that only species and environmental conditions relevant to the site are considered. Social and economic factors are then evaluated to determine if the objectives can realistically be attained. In general, when setting effluent regulations to meet objectives, social and economic factors are factored in by giving longer deadlines to smooth out the transition period. Periodic assessments then fine tune the objectives and pollution control program to ensure that the desired water quality is maintained.

As a minimum, water quality objectives should protect the existing and potential uses of a water body. Where water bodies are considered to be of exceptional value, or where they support valuable biological resources, it is the policy of the CCME that degradation of the existing water quality should always be avoided. Similarly, modifications of guidelines to site-specific objectives should not be made on the basis of aquatic ecosystem characteristics that have arisen as a direct result of previous human activities.

Guideline Derivation Protocols for Other Water Uses

Canadian Water Quality Guidelines includes guidelines that will protect and maintain other water uses (raw water sources for drinking water, recreation and aesthetics, irrigation, livestock water, and industrial water supplies). The protocols used to derive guidelines for these water uses are found in the appropriate chapters of *Canadian Water Quality Guidelines*. The long-term goal is to prepare revised guideline protocols for each of the major water uses in Canada. Each revised protocol will be made available to interested parties after review and approval by the CCME Task Force on Water Quality Guidelines.

Data Requirements for Guideline Derivation

Minimum Aquatic Toxicological Data Set Requirements for Full Freshwater Life Guidelines

The intended goal of freshwater aquatic guidelines is the protection and maintenance of all forms of aquatic life and all aquatic life stages in the freshwater environment. Therefore, it is essential that data from fish, invertebrates, and plants be included in the guideline derivation process. For this purpose, minimum data set requirements have been set. In the derivation protocol, full guidelines or interim guidelines may be derived from studies involving species not required in the minimum data set (e.g., amphibians, protozoa, bacteria), provided that the following minimum data set requirements are met.

Fish

- At least three studies on three or more freshwater species resident in North America are required, including at least one cold-water species (e.g., trout) and one warmwater species (e.g., fathead minnow).
- Of the above studies, at least two must be chronic (partial or full life-cycle) studies.

Invertebrates

- At least two chronic (partial or full lifecycle) studies on two or more invertebrate species from different classes are required, one of which includes a planktonic species resident in North America (e.g., daphnid).

Plants

- At least one study of freshwater vascular plant or freshwater algal species resident in North America is required.
- For highly phytotoxic variables, four acute and/or chronic studies on nontarget freshwater plant or algal species are required.

It is important to emphasize that the guideline derivation process for freshwater life need not always follow a fixed approach. Consideration must also be given to the nature of the variable. For example, the requirement for two chronic studies for fish may be waived when acceptable acute/chronic ratios from fish species exist to convert the results of acute studies, or if the toxicity of the variable has been shown not to increase during chronic exposures. Other scientifically justified exemptions may also be considered on a case-by-case basis.

The reduced requirements for plant toxicity studies were deemed necessary because fewer studies on plants have been conducted (Swanson and Peterson 1988). The minimum data set requirements for plants could be increased in the future if data availability improves.

Minimum Aquatic Toxicological Data Set Requirements for Interim Freshwater Life Guidelines

In cases where the minimum data set requirements for the derivation of full freshwater life guidelines are not met, interim freshwater life guidelines may be developed provided the following minimum data set requirements are met.

Fish

- At least two acute and/or chronic studies on two or more fish species are required, one of which includes a coldwater species (e.g., trout) resident in North America.

Invertebrates

- At least two acute and/or chronic studies on two or more invertebrate species from different classes are required, one of which includes a planktonic species resident in North America (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 guideline 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 an interim guideline to full guideline status needs to be clearly identified in order to stimulate research that will generate the necessary data.

Minimum Aquatic Toxicological Data Set Requirements for Full Marine Life Guidelines

U.S. Environmental Protection Agency criterion continuous concentrations (the U.S. equivalent of Canadian water quality guidelines) were calculated separately for fresh and marine waters. When compared, 35% of the freshwater criterion continuous concentrations differed from the marine water criterion continuous concentrations by a factor of greater than five (Hansen 1989). Given this information, Canadian water quality guidelines should be developed separately for freshwater and marine environments. For most variables, however, there is less toxicological information available for marine species, particularly phytoplankton and macroalgae, than is available for the freshwater environment (Hansen 1989). Since the goal of marine life guidelines is the protection and maintenance of all forms of aquatic life and aquatic life stages in the marine environment, it is essential that data from marine fish, invertebrates, and plants be included in the guideline derivation process. As with the requirements for freshwater life guidelines, minimum data set requirements have been set and outlined below. In this protocol, marine species include those species found in estuarine, coastal, and open ocean habitats, any of which may be used to derive a full guideline or an interim guideline.

Fish
- At least three studies on three or more temperate marine fish species are required, including at least two chronic (partial or full lifecycle) studies.

Invertebrates
- At least two chronic (partial or full lifecycle) studies on two or more temperate marine invertebrate species from different classes are required.

Plants
- At least one study on a temperate marine vascular plant or marine algal species is required.

Minimum Aquatic Toxicological Data Set Requirements for Interim Marine Life Guidelines

In cases where the minimum data set requirements for the derivation of full marine life guidelines are not met, interim marine life guidelines may be developed providing the following minimum data set requirements are met.

Fish
- At least two acute and/or chronic studies on two or more marine fish species are required, one of which is a temperate species.

Invertebrates
- At least two acute and/or chronic studies on two or more marine species from different classes are required, one 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 guideline derivation process. However, in the absence of data on plants, interim guidelines can be derived provided that this data gap is clearly identified. As with freshwater life guidelines, the information required to elevate an interim guideline to a full guideline needs to be clearly identified in order to stimulate research that will generate the necessary data.

Minimum Environmental Fate and Behaviour Data Set Requirements

In addition to the minimum toxicological data set requirements indicated above, studies that have investigated the major environmental fate processes and persistence of the variable in water, soil and 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, and bioaccumulation. However, it is not required 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 variable in the aquatic environment. Specifically, the following should be determined:

- the mobility of the variable and the compartments of the aquatic environment in which it is most likely to be distributed
- the kinds of chemical and biological reactions that take place during transport and after deposition
- the eventual chemical form
- the persistence of the variable in water, sediment, and biota

Where possible, the persistence of a variable 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 a full guideline needs to

be clearly identified in order to stimulate the necessary research.

Additional Information

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

- production and uses
- physical and chemical properties
- organoleptic effects (taste, odour, fish flesh tainting)
- sources to the aquatic environment
- methods of analysis and current detection limits
- concentrations in the aquatic environment
- mutagenicity, carcinogenicity, and teratogenicity
- sensitivity of birds and wildlife consuming aquatic organisms
- guidelines, objectives, and standards of other jurisdictions

Evaluation of Toxicological 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 toxicity data. To ensure a consistent scientific evaluation for each variable, the data included in the minimum data set should meet certain criteria. These include information on test conditions/design (e.g., flow-through, renewal, static), test concentrations, temperature, hardness, pH, adjuvants, 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 (for example, see ASTM 1980; EPS 1980; OECD 1981; Rand and Petrocelli 1985; USEPA 1985a, 1985b, 1985c; Sergy 1987; Swanson and Peterson 1988). Information useful for interpreting toxicity data is also available (Buikema et al. 1982; Rand and Petrocelli 1985, ch. 1–11) and should be consulted when necessary.

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 one 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).
- The predictability of laboratory exposures and effects to aquatic ecosystems has not been adequately tested (Sheehan et al 1984; Arthur 1988; Petersen and Petersen 1988).

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

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

Primary Data

- Toxicity tests must employ currently acceptable laboratory practices of exposure and environmental controls. Other types of tests using more novel approaches will he evaluated on a case-by-case basis.
- As a minimum requirement, variable concentrations must be measured at the beginning and end of the exposure period. Calculated concentrations or measurements taken in stock solutions are unacceptable.
- Generally, static tests are unacceptable unless it can be shown that variable 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 life-cycle test include a determination of effects on embryonic development, hatching, or germination success, survival of juvenile stages, growth, reproduction, and survival of adults.

- Responses and survival of controls must be measured and should be 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 evaluation process.

Secondary Data

- Toxicity tests may employ a wider array of methodologies (e.g., measuring toxicity while test species is 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, behavioral, and physiological effects.

- Calculated variable 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 criteria of primary or secondary data are not acceptable.

Guideline Derivation

Guidelines are preferably derived from the lowest-observable-effect level (LOEL) from a chronic study using a nonlethal endpoint for the most sensitive life stage of the most sensitive aquatic species investigated. However, when data of this type are unavailable, guidelines can be derived from acute studies by converting short-term median lethal or median effective concentrations (LC_{50}, EC_{50}) to long-term no-effect concentrations. Species not required in the minimum data set (e.g., amphibians) may be used provided that the life stage under investigation is completely aquatic. Each study chosen for the guideline derivation procedure must have demonstrated a clear dose–response relationship and, where applicable, the LOEL must be statistically significant.

Guideline Derivation from a Chronic Study

The most sensitive LOEL is multiplied by a safety factor of 0.1 to arrive at the guideline value. This safety factor has been chosen to account for differences in sensitivity to a chemical variable due to differences in species, laboratory versus field conditions, and test endpoints (Kimerle 1986; Mayer et al. 1986; Mayer and Ellersieck 1988).

Guideline Derivation from an Acute Study

When available, acute/chronic ratios (ACRs) can be used to convert the median lethal results of a short-term study to an estimated long-term no-effect concentration (Kenaga 1982). An ACR is calculated by dividing an LC_{50} or EC_{50} by the no-observed-effect level (NOEL) from a chronic exposure test for the same species (i.e., LC_{50}/NOEL). It is important to note that an ACR should only be used from studies that were designed for this purpose in order to avoid complications arising from different test conditions or different test populations. Further, the use of an ACR needs to be carefully rationalized since the available evidence indicates that for a given chemical variable, ACRs may vary between species with different sensitivities and across major taxonomic groupings (Mount 1977; Stephan 1985). The guideline value is derived by dividing the most sensitive LC_{50} or EC_{50} by the most appropriate ACR.

In the event that ACRs are not available, the alternate method of choice to derive a guideline value from an acute study is to multiply the LC_{50} or EC_{50} value by a universal application factor. At present. ACRs are not available for all variables and, to meet this situation, universal application factors have been widely used (USEPA 1972). The application factor (AF) for nonpersistent variables ($t_{½}$ in water < 8 weeks) is 0.05; for persistent variables, the AF is 0.01. These application factors are now endorsed by the majority of Canadian jurisdictions involved in developing water quality criteria, guidelines, or objectives (e.g., International Joint Commission, Ontario, Manitoba, Saskatchewan, British Columbia). However, it must be emphasized that, although the above universal application factors have been empirically tested and supported (e.g., Kenaga 1982), several studies (Buikema et al. 1982; Mayer et al. 1986; Mount 1977) have suggested that these factors may be inappropriate for several variables (e.g., diazinon, zinc). Therefore, the use of universal application factors for deriving a full guideline or an interim guideline

should be used only in the absence of chronic data and in the absence of ACRs for acute data.

Review and Approval of Canadian Water Quality Guidelines

Detailed technical reports prepared in support of Canadian water quality guidelines are reviewed by members of the CCME Water Quality Guidelines Task Group and other scientific and technical experts. Final approval is the responsibility of the CCME Water Quality Guidelines Task Group.

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For further scientific information, contact:

Environment Canada
Guidelines and Standards Division
351 St. Joseph Blvd.
Hull, QC K1A 0H3
Phone: (819) 953-1550
Facsimile: (819) 953-0461
E-mail: ceqg-rcqe@ec.gc.ca
Internet: http://www.ec.gc.ca

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Facsimile: (204) 945-7172
E-mail: spccme@chc.gov.mb.ca

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