COMMENT PERIOD ENDS DECEMBER 13, 2002

BRITISH COLUMBIA

Ministry of Water, Land and Air Protection

P3 DRAFT

CRITERIA FOR CONTAMINATED SITES

Criteria for Managing Contaminated Sediment in British Columbia

Technical Appendix

Prepared pursuant to Section 11.1(d) of the Contaminated Sites Regulation
under the *Waste Management Act*

Approved: _____ _____
Director of Waste Management Date

_____ _____
Deputy Minister Date

COMMENT PERIOD ENDS DECEMBER 13, 2002

For further information, contact:

Toxics, Special Waste and Pesticides Section
Environmental Management Branch
Environmental Protection Division
Ministry of Water, Land and Air Protection
P.O. Box 9342 Stn Prov Govt
Victoria, British Columbia V8W 9M1

Telephone: (250)-387-4441

COMMENT PERIOD ENDS DECEMBER 13, 2002

PREPARED BY

Michael W. Macfarlane[1] and Donald D. MacDonald[2]

ACKNOWLEDGEMENTS

The authors' wish to thank members of the Federal/Provincial Technical Steering Committee, Richard Glue, Vic Enns (Environment Canada, Pacific & Yukon), Karen Hutton (Fisheries and Oceans Canada, Habitat and Enhancement Branch), Narender Nagpal, Doug Walton and Glyn Fox (BC Water Land & Air Protection) for their comments and helpful suggestions towards the preparation of this report.

The authors' also wish to thank John Ward (BC Water Land & Air Protection); Al Colodey, Cecelia Wong, Colin Gray, Mike Nassichuck (Environment Canada, Pacific & Yukon), Bonnie Antcliffe (Fisheries and Oceans Canada), Sylvain Oullet, Sherri Smith and Lars Jorgensen (Environment Canada, Guidelines & Standards Division), Chris Ingersoll (US Geological Survey), Ed Long (NOAA), Judy Crane (Minnesota Pollution Control Agency) and the Science Advisory Group on Sediment Quality Assessment for their valued critique of previous drafts. We have tried to incorporate their suggestions and caveats in the preparation of this report. The authors additionally wish to express their gratitude to Mary Lou Haines, Dawn Smorong and Rebecca Lindskoog for their technical assistance, meeting support and hours of data analysis and that made this document possible.

Funding for the work was provided by the British Columbia Ministry of Water, Land and Air Protection.

[1] Toxics, Special Waste and Pesticide Section
Environmental Management Branch
Environmental Protection Division
Ministry of Water, Land and Air Protection
P.O. Box 9342 Stn Prov Govt
Victoria, British Columbia V8W 9M1

[2] McDonald Environmental Sciences Ltd.
#24 - 4800 Island Highway North
Nanaimo, British Columbia V9T 1W6

COMMENT PERIOD ENDS DECEMBER 13, 2002

PREFACE

Traditionally, concerns relative to the management of aquatic resources in freshwater and marine systems have focussed primarily on water quality. However, contaminated sediments also represent an important environmental concern for several reasons. First, sediment associated contaminants can be directly toxic to sediment-dwelling organisms. Secondly, contaminated sediments can impact fish communities through direct toxicity and reductions in the abundance of fish food organisms. Thirdly, certain contaminants can bioaccumulate in the food web and, in so doing, adversely affect piscivorous wildlife and human health. Bioaccumulation in fish and other aquatic organisms can also result in the imposition of consumption advisories for fish and shellfish that adversely affect the uses of aquatic ecosystems. Finally, contaminated sediments can compromise human health due to direct exposure during wading or swimming. As such, contaminated sediments in freshwater and marine ecosystems pose potential hazards to aquatic organisms, aquatic-dependent wildlife species, and human health (Long and Morgan 1991; Ingersoll *et al.* 1997)**.**

In British Columbia, the federal and provincial governments share authority for assessing and managing contaminated sediments (i.e., under the *Fisheries Act* - FA, the *Waste Management Act* -WMA, and, the *Canadian Environmental Protection Act* - CEPA). Currently, standard procedures for assessing contaminated sediments have not been established by either level of government. In addition, sediment quality criteria (SedQC) have not been formally established for assessing or managing contaminated sites. As such, decisions regarding the selection of assessment procedures and the establishment of remedial targets were being made on a site-by-site basis. It was the position of the agencies, referenced below, that this approach was unsustainable in the longer term.

In recognition of the need to establish harmonized procedures for assessing and managing contaminated sites in British Columbia, the ***Federal/Provincial Technical Committee on the Development of Sediment Quality Criteria for Assessing and Managing Contaminated Sites*** (Sediment Technical Committee; consisting of representatives of the British Columbia Ministry of Water, Land, and Air Protection - BCWLAP, Environment Canada - EC, and Fisheries and Oceans Canada - DFO) was established in January, 1998. This committee was charged with the task of developing a joint federal-provincial framework for assessing and managing contaminated sediments, a guidance manual to support the design and implementation of sediment quality assessments at contaminated sites, and SedQC to support the management of contaminated sediments. In the ensuing four years, the committee produced the following documents:

- '*Criteria for Managing Contaminated Sediment in British Columbia*' – Draft . (Macfarlane and MacDonald 1999);
- *'Development and Evaluation of Numerical Sediment Quality Criteria for Sediment Contaminated Sites in British Columbia: A Retrospective'* (MacDonald 2001); and
- *' Guidance Manual to Support the Assessment of Contaminated Sediment in Freshwater, Estuarine and Marine Ecosystems'* –Draft. (MacDonald and Ingersoll 2002a, 2002b and Ingersoll and MacDonald 2002).

These documents described the joint federal-provincial framework, provided guidance on the assessment of contaminated sediments, and presented the SedQC and their applications that were recommended by the committee members.

Under the tiered management process set forth under the Contaminated Sites Regulation (CSR), a responsible party may choose between either the numerical approach (i.e. criteria-based approach) or the risk based approach to address concerns regarding sediment quality conditions at a contaminated site. In general, a weight-of-evidence approach, which relies on the use of multiple lines of evidence, is recommended to support decision-making activities at sites. While no single line of evidence should drive decision making in the weight-of-evidence approach, some lines of evidence may be weighted higher than others (i.e. that is more valued) in consideration of the decisions that needs to

be made. For example, it may be appropriate to select the criteria-based approach at small sites where the costs of collecting the detailed data needed to support human and ecological risk assessments are likely to exceed remediation costs. At larger, more complex sites, the costs associated with conducting detailed risk assessments may be justified to reduce uncertainties and focus limited resources on selecting the remedial actions that provide the greatest benefits. Regardless of the size or complexity of a site, the remediation of sediments **may not** be approved by the regulatory agencies if the resulting remedial impacts are more significant than leaving the sediments in place

Central to the Ministry's view to remediating sediment quality and restoring ecosystem health is that control of contaminants at their source remains the primary imperative for remedial actions. Only through the abatement of inputs of contaminants from sources to the receiving environment can other sediment management actions, such as sediment removal, be economically viable, ecologically relevant, and sustainable.

This document describes the application of the generic sediment quality criteria only. It is intended to identify the requirements and expectations for sites where the responsible persons (BC 1996) have elected to remediate sediments to achieve final contaminant concentrations in sediments that are less than or equal to the criteria. It is important to understand that the sediment quality criteria presented in this document are not intended to be used to assess ambient sediment quality conditions or to establish sediment quality objectives at sites other than those identified under the Contaminated Sites Regulation (CSR).

Additional information on the assessment and remediation of contaminated sites is provided in the detailed companion document entitled, *Guidance Manual to Support the Assessment of Contaminated Sediments in Freshwater, Estuarine and Marine Ecosystems* (MacDonald and Ingersoll 2002a, 2002b and Ingersoll and MacDonald 2002).

Guidance on the derivation of site-specific criteria is also provided in MacDonald and Ingersoll (2002a, 200b) and Ingersoll and MacDonald (2002), while information on the application of the risk-based approach to site remediation is provided in BCE (1998a) and EPA, (1989).

Environment Canada, Fisheries and Oceans Canada and the Ministry are committed to a periodic review of these criteria, and the approach used to establish them, in order to ensure that they are consistent with the best scientific information available at the time. Accordingly, these agencies will be working together in efforts to establish a regional sediment chemistry/effects database that will serve as a key component of this effort.

COMMENT PERIOD ENDS DECEMBER 13, 2002

TABLE OF CONTENTS

LIST OF TABLES

1.0 INTRODUCTION

The Contaminated Site Regulation (CSR), as promulgated under the provincial *Waste Management Act,* provides detailed guidance on a range of issues related to the assessment and management of contaminated sites, including standards for soil and water. While no specific guidance on the management of contaminated sediments was established in the CSR, the need to develop such guidance is indicated in the *Waste Management Act*. Specifically, Section 26 (1) of the *Act* states that:

> *"a contaminated site means an area of land in which the soil or any groundwater lying beneath it, or the water or the underlying sediment, contains: a special waste; or, another prescribed substance in quantities or concentrations exceeding prescribed criteria, standards, or conditions."*

Thus, criteria for assessing and remediating contaminated sediments in freshwater, marine and estuarine environments are required to support the assessment, remediation and management of sediments at contaminated sites in British Columbia and to ensure such work is undertaken in a consistent and logical manner.

The regulatory authority under which the Director may establish standards for use in the assessment and remediation of contaminated sites can be found in section 26 (1) of the *Waste Management Act* (BC 1996) and section 11 (1) (d) of the Contaminated Sites Regulation (BC 2002).

This document provides additional guidance to and details on the Ministry's Criteria for Managing Contaminated Sediment at Sites in British Columbia. These criteria are to be used to determine if sediments are contaminated, to assess the need for remedial measures, and to develop remediation targets (i.e., target clean-up concentrations of contaminants of potential concern [COPCs]) for sediments at contaminated sites.

2.0 BACKGROUND

2.1 PURPOSE

This document presents the sediment quality criteria (SedQCs) for assessing and managing contaminated sediments in British Columbia. The criteria presented in this document are intended to apply to sites with contaminated aqueous sediments. In the context of the document, aqueous sediments are defined as soft, sedimentary deposits comprised primarily of particles < 6.35 mm (Singleton 1995). The criteria apply to sediments from the sediment/water interface to depth.

Caution needs to be applied at sites containing other materials which could be present below bodies of water, such as gravel, cobble, boulders, logs, wood fibre, hog fuel, slag, tires, paint chips, asphalt, or solidified coal tar. The criteria herein were not expressly developed in consideration of these materials, however these materials may pose potential impacts to the health of benthos. The criteria herein may be used at sites containing such materials, however the potential impacts are best addressed on a site specific basis.

As indicated above, the criteria presented in this document are solely intended to facilitate the assessment and management of sediments at contaminated sites. They are not intended to replace the sediment quality guidelines (SQGs) that have been established to support broader environmental management objectives in the Province (BCE 1998; CCME 1998). That is, the sediment quality guidelines (SQGs) continue to represent the long-term targets for sediments in all areas, except those regulated under the CSR.

It is important to note that the SedQCs are intended to define the concentrations of sediment-associated contaminants which, if exceeded, pose unacceptable risks to sediment dwelling organisms. However, these SedQCs may not provide an adequate basis for assessing risks to piscivorous wildlife or human health that are associated with food web transfer of persistent, bioaccumulative substances from sediments to aquatic organisms. For this group of substances, bioaccumulation-based SedQCs are also needed to support the assessment and management of contaminated sediments; however, such SedQC values are largely unavailable at this time. At this time, bioaccumulation risks are most effectively assessed through the application of tissue residue criteria (TRCs) and related approaches.

The criteria contained in this document should not be used alone in situations where contaminants may be released from sediments or contaminated sediments may be deposited elsewhere. Additional factors (such as the potential for off-site impacts, etc.) need to be assessed and applicable policy and regulatory requirements need to be considered under such circumstances. For example:

- the provisions of the Special Waste Regulation (BC 1988) provide a basis for *in situ* management and classification of special wastes;
- the Contaminated Site Regulation (BC 1997) defines the maximum acceptable concentrations for COPCs for disposal on land and specifies groundwater protective thresholds;
- pursuant to Section 28.2(1) of the *Waste Management Act* (BC 1996) persons conducting or providing remediation must give preference to alternatives that provide permanent solutions to the maximum extent practicable; and,
- it is Ministry preference that for certain types of substances (e.g., non-aqueous phase liquid; NAPL) that removal be undertaken to the extent feasible and that these materials be disposed of appropriately.

In addition, a tiered-testing approach has been specified by Environment Canada for evaluating the acceptability for open water disposal of dredged materials. This framework relies on the Canadian sediment quality guidelines to establish screening and rejection levels (CCME 1998).

The definitions and terms used in this document are included in Appendix 1.

2.2 USES OF SEDIMENT QUALITY CRITERIA

Sediment quality criteria herein are intended to serve as benchmarks which define the conditions needed to protect sediment-dwelling organisms, wildlife, and human health at sites with contaminated sediments. These benchmarks may be used in a variety of ways, including:

- as indicators of sediment quality at a site (i.e., during site screening);

- for identifying the COPCs (i.e., during site investigation);
- to support the design of sampling programs (i.e., during site investigation);
- for interpreting sediment chemistry data (i.e., during site investigation);
- for identifying potentially unacceptable levels of risk to the environment at a site (i.e., during site investigation);
- for determining if a site is contaminated (i.e., during site investigation);
- for determining the factors that are most likely associated with measured or potential effects (i.e., sediment toxicity);
- for determining if site remediation, risk assessment, or risk management are necessary (i.e., following detailed site investigation);
- as a basis for establishing site management goals and remediation targets (i.e., during remedial action planning);
- as a basis for developing legally-enforceable standards (i.e., developing a remediation plan);
- for evaluating the adequacy of site remediation (i.e., confirmation that site remediation has been successfully completed); and,
- for the purposes of issuing certification of satisfactory site remediation.

The criteria are not intended to be applied or interpreted as thresholds to pollute up to, nor should they be interpreted as acceptable thresholds for ambient environmental quality outside of the boundaries of a contaminated site.

2.3 INFORMATION REQUIREMENTS

Several types of information are needed to assess sediment quality conditions, to develop remedial action plans, and to establish remediation targets for sites with contaminated sediments (Appendix 2), including:

- designated current and future uses of the aquatic ecosystem;
- location of critical and important habitats in the area;
- existing and historic sources of contamination;
- identity of COPCs;
- type of environmental media affected (i.e., bulk sediments, pore-water, biological tissues, etc.);
- identity of actual and potential receptors at and nearby the site;
- aquatic resource uses (e.g., utilization of habitats by fish, fish residence timing, fish and shellfish consumption by wildlife and humans, etc.);
- potential for off-site impacts;

- spatial distribution (lateral and vertical extent of contamination), concentrations, and forms of COPCs and other variables of interest at the site and at appropriate reference sites (i.e., to establish background levels of COPCs);
- an evaluation of sediment and water body hydrodynamics that could influence sediment transport in the study area (i.e., through sediment resuspension, erosion, dredging, or other means); and
- location of sediment hot spots as defined by contours (vertical and lateral) of special wastes, concentrations greater than the Typical Site Criteria ($SedQC_{TCS}$), and, where applicable, greater than the Criteria for Sensitive Contaminated Sites ($SedQC_{SCS}$), and the ambient Sediment Quality Guidelines (i.e. SQGs).

Acquisition of this site-specific information requires the completion of a preliminary and/or a detailed site investigation. Guidance on the design and implementation of preliminary and detailed site investigations is provided in Chapters 4 and 5, respectively, of MacDonald and Ingersoll (2002b). Ministry and federal agencies (i.e., Environment Canada and Fisheries and Oceans Canada) staff should be consulted about their requirements for site characterization at the outset of any such investigation. The Ministry must be provided with accurate information about the current and intended uses of the aquatic ecosystem, aquatic resources, and associated upland areas within the vicinity of the site under investigation.

During the planning stage of the site investigation, it is important to determine acceptable methods for sampling sediments in the field, for handling, transporting, and storing sediment, pore-water, and tissue samples, for conducting chemical analyses and other testing procedures, and for managing, evaluating and interpreting the resultant data. A sampling and analysis plan (SAP) and associated quality assurance plan (QAP) must be submitted to the Ministry for approval prior to implementing a sampling program. Guidance on the design and implementation of the SAP and QAP are provided in Chapter 6 and Appendix 2 of MacDonald and Ingersoll (2002b).

3.0 DESIGNATED USES OF AQUATIC SYSTEMS

3.1 FACTORS CONSIDERED IN ESTABLISHING THE SEDQCS

The narrative objectives set forth herein recognize that water-based economic activities (such as shipping, operation of small craft marinas, waterfront development, and tourism-related activities) are essential to the vitality of communities in the province. While these activities contribute significantly to the local economy, they also have the potential to degrade water quality conditions (i.e., through spills or stormwater runoff) and/or reduce the stability of sediments (i.e., through navigational dredging or disturbance by the wash from vessel propelers). The agencies do not expect, nor propose that these activities cease, but recognize that the potential for maintaining an unaltered benthic invertebrate community is likely reduced in these areas, even in the absence of chemical contamination in the sediments. In recognition of the challenges that are associated with the management of sediments at contaminated sites in British Columbia, two types of narrative Sediment Quality Criteria (SedQC) were established:

- Sediment Quality Criteria Sensitive Contaminated Sites ($SedQC_{SCS}$); and

- Sediment Quality Criteria Typical Contaminated Sites ($SedQC_{TCS}$)

The $SedQC_{SCS}$ are intended to identify remedial contaminant concentrations below which harmful effects on sediment-dwelling organisms are unlikely to be observed. In contrast, the $SedQC_{TCS}$ are intended to identify contaminant concentrations which offer a moderate level of protection to benthos at contaminated sites. The narrative objectives for both sets of SedQCs do not address the potential for bioaccumulation, nor the associated effects on those species that consume aquatic organisms (i.e., wildlife and humans).

3.2 STRATEGY FOR ESTABLISHING SEDIMENT QUALITY TARGETS

Both theoretical and empirical approaches have been used to derive SQGs for freshwater, estuarine and marine ecosystems. Seven distinct approaches were evaluated to support the selection of procedures for deriving SedQCs for contaminated sites in the province, including: the screening level concentration, effects range and effects level, apparent effects threshold, equilibrium partitioning, logistic regression modeling, consensus-based, and tissue residue approaches (Crane *et al*. 2000). Following a review of these approaches, the Federal/Provincial Technical Committee agreed to adopt an effects based approach to establishing SedQCs. In response to stakeholder concerns received by the Ministry during the review of the 1999 Draft Criteria document (Macfarlane and MacDonald 1999), it was agreed that the results of evaluations of the reliability and predictability of the CCME's (1998) Probable Effects Level (PELs) would be used to select the SedQCs that most directly meet the narrative objectives for the criteria (see Sections 4.1 and 4.2).

The assessment of effects-based SedQCs for the protection of sediment-dwelling organisms focused on preliminary criteria values for eight trace metals, 13 individual PAHs, total PAHs, total PCBs, and 10 organochlorine pesticides. Reliability analyses were carried out using the refined SEDTOX database, which encompasses data from Canada and the United States (US EPA 2000; Field *et al.* 1999, and 2002). $SedQC_{SCS}$' values were considered to provide a reliable basis for assessing the quality of sediments if more than 75% of the sediment samples were correctly predicted to be non-toxic (MacDonald *et al*. 2000). The $SedQC_{TCS}$ values were considered to be reliable if greater than 75% of the sediment samples were correctly predicted to be toxic (MacDonald *et al*. 2000). Consequently, the target levels of both false positives (i.e., samples incorrectly classified as toxic) and false negatives (i.e., samples incorrectly classified as not toxic) were approximately 25% using the $SEDQC_{SCS}$ and $SedQC_{TCS}$ values (MacDonald *et al*. 2000). The SedQCs were considered to be reliable only if a minimum of 20 samples were included in the evaluation of reliability (CCME 1995).

The results of numerous evaluations (i.e., Long and MacDonald 1998; Field *et al.* 1999; Long *et al.* 2000) have provided some important insights for assessing the applicability of various SedQCs. These investigators concluded that the marine SedQCs for individual substances provide relevant tools for assessing sediment quality conditions. However, chemical contaminants rarely occur alone in contaminated sediments; rather, contaminants are usually present as complex mixtures. For this reason, it has been recommended that marine SQGs be used in combination to assess sediment quality conditions (i.e., by calculating mean SQG-quotients [SedQC - Q's]; Long and MacDonald 1998; Long *et al.* 2000; Fairey *et al.* 2001). Similar recommendations have been developed to support the application of freshwater SedQCs using the chemical mixture model (MacDonald *et al.* 2000; Ingersoll *et al.* 2001).

The predictive ability of the SedQCs (through the use of mean SedQC-Qs) is likely to increase when they are used together to classify sediments at contaminated sites. The rationale for this stems from the evaluations of the incidence of toxicity within the ranges of mean Probable Effect Concentration Quotients (PEC-Qs): =0.1, >0.1 to =0.5, >0.5 to =1.0, >1.0 to =5.0, and >5.0 used by Ingersoll *et al*. (2001) and Long *et al*. (1998) to evaluate the predictive ability of freshwater and marine SedQGs, respectively. Mean SedQC - Qs are calculated using the methods that were recommended by Ingersoll *et al*. (2001). In brief, the mean $SedQC_{TCS}$-Qs are calculated as follows:

$$\text{SedQC-Q} = \frac{\text{substance chemical concentration (in dry wt.)}}{\text{corresponding substance SedQC value}}$$

$$\text{mean SQC - Q} = \frac{(\text{mean SedQC - Qmetals} + \text{SedQC - QTotal PAHs} + \text{SedQC - QTotal PCBs})}{n}$$

where n = number of classes of chemicals for which sediment chemistry data were available (i.e., 1 to 3).

For comparison, the underlying data were re-evaluated to calculate the mean SedQC-Qs that corresponded to EC20 and EC50 metrics (i.e., logistic regression models were developed using the percent survival data recorded in toxicity tests, as opposed to the toxic/not toxic designations).

As part of the evaluation of the 1999 Draft Criteria (Macfarlane and MacDonald 1999), an analysis of the predictive ability of the CCME PELs (CCME 1998) was performed. The results of the predictive ability evaluation indicated that the PELs when used together in mean PEL-Qs, provided a reasonable basis for predicting the presence and absence of sediment toxicity. The evaluations performed indicated that:

- the probability of observing chronic toxicity (i.e., as indicated by significantly reduced survival, growth, maturation, or reproduction of amphipods) is low (i.e., 14%) in freshwater sediments with mean PEL-Qs of < 1.0;
- there is a 50% probability of observing chronic amphipod toxicity in freshwater sediments at mean PEL-Qs of about 1.31;
- the probability of observing acute toxicity (i.e., as indicated by significantly reduced survival of amphipods) is relatively low (i.e., < 30%) in marine sediments with mean PEL-Qs of < 1.0; and,
- there is a 50% probability of observing acute amphipod toxicity in marine sediments at mean PEL-Qs of about 1.15.

These analyses provided the Technical Committee with the necessary means to establish a suite of remediation criteria that would be consistent with the narrative goals established by the agencies for the management of contaminated sediments at sites in the Province.

3.3 IMPLICATIONS FOR ESTABLISHING SEDIMENT QUALITY CRITERIA

The results of the foregoing evaluations of the reliability and predictive ability indicate that there are definable relationships between contaminant concentrations and sediment toxicity in both

freshwater and marine sediments. As such, evaluation of chemistry data using the SedQC provides a reliable basis for estimating the probability of observing toxicity in marine and freshwater sediments.

4.0 REMEDIAL CRITERIA

4.1 SEDIMENT QUALITY CRITERIA FOR SENSITIVE CONTAMINATED SITES ($SEDQC_{SCS}$)

At sites with sensitive habitats, the principal sediment management objectives are to restore sediments to a state that will facilitate the restoration of productive and diverse benthic macroinvertebrate communities in the ***near-term*** and to minimize the risks to organisms at higher trophic levels in the food web. For this reason, the effects-based SedQC criteria for sensitive contaminated sites ($SedQC_{SCS}$) should represent levels that provide a relatively high level of protection for sediment-dwelling organisms. That is, the $SedQC_{SCS}$ are sediment contaminant concentrations below which there is a relatively low probability (i.e. < 20%) of observing sediment toxicity.

The concentration-response relationships that were developed to support the evaluation of the predictive ability of the CCME PELs (CCME 1998) provide a basis for refining the criteria for sensitive sites. More specifically, the $SedQC_{SCS}$ were established by multiplying the PELs for each substance by a probability value (P value) that was derived for the selected toxicity test endpoints (i.e. survival or growth of freshwater amphipods in 28 to 42 day toxicity tests and survival of marine amphipods in 10-d toxicity tests). For both freshwater and marine sediments a PEL-Q of 0.6 was found to approximate a 20% probability of observing sediment toxicity (i.e., a P20). Therefore, the $SedQC_{SCS}$ adopted as the sediment quality criteria for sensitive sites were established to correspond to the P20 value.

4.1.1 $SedQC_{SCS}$ Administrative Rules

The $SedQC_{SCS}$ values apply to sites identified as meeting the definition of a sensitive contaminated site as established in Schedule 2. These criteria are considered to be broadly applicable because differences in land use activities do not influence the importance of sediments to benthic organisms (i.e., sediments represent essential habitats for benthic organisms). The information in Schedule 2 and other supporting documentation will be used by the agencies to determine if the $SedQC_{SCS}$ apply at a contaminated site.

In general terms:

- the $SedQC_{SCS}$ are to be applied to a depth of 100 cm in areas where the sediment bed has been demonstrated to be stable (i.e., non-erosional, not subject to navigational dredging, etc.);
- the $SedQC_{SCS}$ will apply to depths of greater than 100 cm in areas where the sediment bed has been demonstrated to be unstable (i.e., erosional, subject to navigational dredging, etc.) or the stability of the bed is unknown; or it is demonstrated that there is on-going transport of contaminants at depth into the shallower portions of the sediment bed at rates capable of contaminating sediments in the top 100cm to levels exceeding the $SedQC_{SCS}$

- the $SedQC_{SCS}$ must be used during the site investigation process to determine if a sensitive site contains contaminated sediments;
- the $SedQC_{SCS}$ will apply at contaminated sites that have sediments that border or include habitat protection or conservation zones, or where biological habitat mapping (e.g., such as has been conducted by FREMP or BIEAP) have designated the area as a high productivity zone. Schedule 2 provides a checklist of factors to be considered in applications to the Ministry in support of the $SedQC_{SCS}$ values.

Administrative rules are necessary to ensure the proper application of the $SedQC_{SCS}$. One of the principal applications of the $SedQC_{SCS}$ is determining if a sensitive site is contaminated. This evaluation involves a comparison of the results of field investigations conducted at sites (i.e., sediment chemistry data) with the $SedQC_{SCS}$ for individual substances and the $SedQC_{SCS}$ for chemical mixtures (i.e. a mean $SedQC_{SCS}$-Q of 1.0). Accordingly, a site is a contaminated site if any of the following conditions exist:

- The 90th percentile concentration of one or more analytes equals or exceeds their respective $SedQC_{SCS}$ (i.e., 9 of 10 measurements must be below the $SedQC_{SCS}$);
- The concentration of one or more analytes exceeded their respective $SedQC_{SCS}$ by a factor of two or more in any sediment sample;
- The 90th percentile mean $SedQC_{SCS}$-Q for the contaminant mixture equals or exceeds 1.0; or
- The mean $SedQC_{SCS}$-Q for the contaminant mixture in any sediment sample equals or exceeds 2.0.

Mean $SedQC_{SCS}$ – Qs are calculated using the methods that were recommended by Ingersoll *et al*. (2001). In brief, the mean $SedQC_{SCS}$-Qs are calculated as follows:

$$SedQC_{SCS}\text{-}Q = \frac{\text{substance chemical concentration (in dry wt.)}}{\text{Corresponding substance specific } SedQC_{SCS} \text{ value}}$$

$$\mathbf{meanSedQC_{scs} - Q} = \frac{\mathbf{(meanSedQC_{scs} - Qmetals + SedQC_{scs} - QTotalPAHs + SedQC_{scs} - QPCBs)}}{\mathbf{n}}$$

where n = number of classes of chemicals for which sediment chemistry data were available (i.e. 1 to 3).

The presence of sediments containing contaminant concentrations qualifying as Special Wastes, under the Special Waste Regulation (SWR), necessitates exceptions to the limits of potential remedial actions. Where Special Waste is present, remedial measures should focus on the removal of these wastes, to the extent feasible. The handling, treatment and disposal of these materials is to be conducted in accordance with the provisions of the SWR.

4.2 SEDIMENT QUALITY CRITERIA FOR TYPICAL CONTAMINATED SITES ($SEDQC_{TCS}$)

At most sites (termed typical sites in this discussion), the principal sediment management objectives are to restore sediments to a state that will facilitate restoration

of productive and diverse benthic macroinvertebrate communities in the ***longer-term*** and to minimize the risks to organisms at higher trophic levels in the food web. For this reason, the SedQC for typical contaminated sites ($SedQC_{TCS}$) should be established at levels that provide a moderate level of protection for sediment-dwelling organisms. That is, the $SedQC_{TCS}$ are intended to define contaminant concentrations below which there is a relatively moderate probability (i.e., roughly 50%) of observing sediment toxicity. The results of the predictive ability analyses support the definition of $SedQC_{TCS}$ values that correspond to the narrative sediment management objectives that have been established for managing contaminated sites in British Columbia. More specifically, the $SedQC_{TCS}$ were established by multiplying the CCME (1998) PELs by the PEL-Q that corresponded to a 50% probability of observing the selected toxicity test endpoints (i.e. survival and growth of freshwater amphipods in 28 to 42d toxicity tests and survival in marine amphipods in 10d toxicity tests). For freshwater and marine sediments, PEL-Qs of 1.31 an 1.15, respectively, corresponded to a 50% probability of observing sediment toxicity (i.e. P50). The arithmetic mean of the freshwater and marine P50 values (i.e. 1.2 PEL-Qs) was adopted for the purposes of criteria derivation.

4.2.1 $SedQC_{TCS}$ Administrative Rules

The $SedQC_{TCS}$ values can be applied at most contaminated sites (i.e. sites of simple to moderate complexity) to establish clean-up targets to guide the design and implementation of remedial action plans (i.e., decisions regarding the remediation of contaminated sites can be made using sediment chemistry data alone).

More comprehensive assessments should be considered and conducted at sites with large volumes of contaminated sediments, at sites that are contaminated with highly bioaccumulative substances, and/or sites with substances for which $SedQC_{TCS}$ are not currently available (i.e. sites of medium to high complexity). Such assessments should be designed to obtain high quality data on the concentrations of substances of potential concern in sediments, on the toxicity of sediments, on the structure of benthic macroinvertebrate communities, and on the levels of bioaccumulative substances in fish and invertebrate tissues.

> At typical sites, pollution prevention initiatives, active source control measures (e.g., best management practices, effluent treatment upgrades), active remediation, and natural recovery may be considered in achieving the Ministry's long-term goals of protecting and maintaining the designated uses of aquatic ecosystems.

Administrative rules are necessary to ensure the proper application of the $SedQC_{TCS}$. One of the principal applications of the $SedQC_{TCS}$ is determining if a "typical site" is contaminated. This evaluation involves a comparison of the results of field investigations conducted at sites (i.e., sediment chemistry data) with the $SedQC_{TCS}$ for individual substances and the $SedQC_{TCS}$ for chemical mixtures (i.e. a mean $SedQC_{TCS}$-Q of 1.0). Accordingly, a site is considered to be a contaminated site if any of the following conditions exist:

- the 90th percentile concentration of one or more analytes equals or exceeds their respective $SedQC_{TCS}$ (i.e., 9 of 10 measurements must be below the $SedQC_{TCS}$);
- the concentration of one or more analytes exceeded their respective $SedQC_{TCS}$ by a factor of two or more in any sediment sample;
- the 90th percentile mean $SedQC_{TCS}$-Q for the contaminant mixture equals or exceeds 1; or
- if the mean $SedQC_{TCS}$-Q for the contaminant mixture in any sediment sample equals or

exceeds 2.

Mean $SedQC_{SS}$ – Qs are calculated using the methods that were recommended by Ingersoll *et al*. (2001). In brief, the mean $SedQC_{TCS}$-Qs are calculated as follows:

$$SedQC_{TCS} = \frac{\text{substance chemical concentration (in dry wt.)}}{\text{Corresponding substance } SedQC_{TCS} \text{ value}}$$

$$\mathbf{meanSedQC_{TS} - Q} = \frac{\mathbf{(meanSedQC_{TS} - Qmetals + SedQC_{TS} - QTotalPAHs + SedQC_{TS} - QPCBs)}}{\mathbf{n}}$$

where n = number of classes of chemicals for which sediment chemistry data were available (i.e. 1 to 3).

The $SedQC_{TCS}$ values are intended to apply to relatively small areas in the immediate vicinity of a contaminated site

In general terms;

- the $SedQC_{TCS}$ are to be applied to a depth of 100 cm in areas where the sediment bed has been demonstrated to be stable (i.e., non-erosional, not subject to navigational dredging, etc.);
- the $SedQC_{TCS}$ will apply to depths of greater than 100 cm in areas where the sediment bed has been demonstrated to be unstable (i.e., erosional, subject to navigational dredging, etc.) or the stability of the bed is unknown; or it is demonstrated that there is on-going transport of contaminants at depth into the shallower portions of the sediment bed at rates capable of contaminating sediments in the top 100cm to levels exceeding the $SedQC_{TCS}$;
- the $SedQC_{TCS}$ must be used during the site investigation process to determine if a typical site contains contaminated sediments; and,
- the $SedCQ_{TCS}$ should be used to determine if remedial measures are needed at the site and to establish target clean-up goals for contaminated sediments.

The presence of sediments containing contaminant concentrations qualifying as Special Wastes, under the Special Waste Regulation (SWR), necessitates exceptions to the limits of potential remedial actions. Where Special Waste is present, remedial measures should focus on the removal of these wastes, to the extent feasible. The handling, treatment and disposal of these materials is to be conducted in accordance with the provisions of the SWR.

The $SedQC_{SCS}$ values should be applied to surface sediments immediately beyond the $SedQC_{TCS}$ zone that is approved by the Ministry. Additionally, contaminant concentrations should be shown to further decline to near ambient SQG's within 10m of the $SedQC_{SS}$ transitional zone.

4.3 TISSUE RESIDUE CRITERIA

The Ministry recognizes the need to establish criteria for several classes of bioaccumulative substances, including metals, polycyclic aromatic hydrocarbons, polychlorinated biphenyls, polychlorinated dibenzodioxins and furans, and organochlorine pesticides. Establishing bulk sediment criteria for bioaccumlative substances, while feasible, would necessitate assumptions for a default foodweb and physical environment setting. Rather than imposing these assumptions, the agencies recommend the use of empirical contaminant measurements of these substances in benthos and prey items present at a site to identify potential regulatory concerns. The tissue residue criteria (TRCs) for the protection of wildlife (Table 3) are intended to protect predatory wildlife species from adverse effects associated with the bioaccumulation of contaminants in benthos, fish and shellfish tissues consumed by wildlife species (i.e. indirect exposure pathways).

The potential for adverse effects on wildlife, from bioaccumulation of sediment-associated contaminants, must be evaluated at all potential contaminated sites in the Province where these substances are present. The TRC in Table 3 (CCME, 2001) represent concentrations of bioaccumulative contaminants that would be unlikely to adversely effect the wildlife species that consume aquatic organisms.

An ecological risk assessment will be required at sites where the contaminant concentrations in tissues of benthos and fish are shown to exceed the TRC or relevant background sediment concentrations (guidance on the determination of background levels of sediment-associated contaminants is provided in Ingersoll and MacDonald (2002)).

4.4 SEDIMENT PORE-WATER

Sediment pore-water has been identified as a major route of exposure of infaunal and epibenthic organisms to sediment contaminants (USEPA 1993; Di Toro *et al*. 1991; Adams *et al*. 1985; Carr *et al*. 2001). Several methods have been developed for the extraction (Carr and Chapman 1995; Winger and Lasier 1991; Jahnke 1988; Hesslin 1976; Edmunds and Bath 1976; Presley *et al*. 1967 : Carr *et al*. 2001) and toxicity testing of pore water with aquatic organisms (Carr 1998; Hooten and Carr 1998; Ankley *et al*. 1992; Carr *et al*. 1989; Carr *et al*. 2001). Despite advances in pore-water research, a number of critical issues have been identified regarding pore-water extraction and toxicity testing methods currently used in regulatory programs. Furthermore, despite the importance of pore-water tests in regulatory, environmental assessment, and monitoring programs, several issues associated with these procedures and their applications have yet to be fully resolved. For these reasons, the Ministry does not propose to adopt prescriptive guidance or rules for the evaluation of sediment pore-water at contaminated sites. Rather, proponents undertaking the investigation of contaminated sediments are encouraged to make use of the recommendations and considerations identified by Carr *et al* (2001) at the recent SETAC Technical Workshop on Pore-water Toxicity Testing. The 2001 SETAC workshop (Carr *et al*, 2001) concluded that:

- it is important to conduct both pore-water and solid-phase tests whenever possible, which enhances the ability to discriminate sediment quality;
- toxicity data from pore-water tests should be used along with the parallel data from tests of other sediment phases to form a weight of evidence and to determine concordance among

the triad components;
- sampling, extraction, and storage techniques are critically important for achieving the most field-representative samples of pore-water. Several sampling methods were suggested, and method selection should be based on the objective of the study;
- it is nearly impossible to avoid artifacts and chemical changes when removing pore water from sediment and using it in a toxicity test. Since artifacts are always introduced to some extent, the determination of contaminant concentrations in the pore water is recommended, in addition to the regular contaminant measurements conducted in the whole sediment, as a means of providing information on routes and levels of exposure, aiding in the interpretation of test results, and identifying sources of toxicity;
- the measurement of several pore-water features, a number of which can act as confounding factors (e.g., salinity, alkalinity, pH, conductivity, DO, NH_3, H_2S, Eh), should be recorded shortly after pore-water collection and after storage. This would help in interpreting test results, understanding the contribution of these factors to concordance/discordance between solid-phase and pore-water test methods, and contributing to TIE procedures;
- a variety of test species should be used, in order to enrich the database and help account for different modes of action and species sensitivity;
- the use of indigenous species is not recommended or suggested as important for the understanding of potential biological impacts as identified from the results of pore-water toxicity tests. The use of water column organisms for pore-water toxicity tests was considered scientifically appropriate;
- it is also important to know the tolerance levels of the test species to major confounding factors;
- the sediment depth to be sampled for pore water should match the depth of interest for each particular survey; and,
- among the desirable attributes for pore-water toxicity tests used in the Sediment Quality Triad (SQT) approach, the ability to identify causality seemed to take precedence over other aspects, although it was recognized that non-specific assays are useful exploratory tools to identify toxicity.

5.0 CRITERIA APPLICATIONS AND REMEDIATION OPTIONS

5.1 SPECIFIC APPROACHES AND APPLICATIONS

B.C. Ministry of Water, Land and Air Protection has adopted two approaches for managing sediment contaminated sites in British Columbia: a criteria-based approach and a risk-based approach. A responsible person, as defined under the CSR, may choose either approach for addressing contamination in sediments at a contaminated site.

The criteria-based approach provides a basis for defining acceptable concentrations of contaminants at a site relative to the protection of aquatic life, wildlife, and/or human health (i.e., sediment quality criteria). These criteria provide the basis for determining when a site is contaminated, when sediment remediation is needed, and when sediment remediation has been satisfactorily completed. The criteria-based approach is particularly relevant for establishing remediation targets when removal of contaminated sediments is the preferred remedial option. At such sites, criteria can be adopted directly as remediation targets.

The criteria should be applied at sites with contaminant concentrations above background levels, with typical assemblages of aquatic organisms, and typical levels of organic carbon (i.e., 0.4 to 10.1% for freshwater sediments; 0.1 to 4.7% for marine and estuarine sediments).

Ingersoll and MacDonald (2002) provide procedures for calculating site-specific criteria. These procedures are designed to account for background levels of contaminants at appropriate non-contaminated reference sites, unique assemblages of benthic organisms in the vicinity of the site, and atypical levels of key variables at the site (e.g., TOC; see Ingersoll and MacDonald 2002 for further guidance). The site-specific procedures are intended to support the derivation of criteria that are more directly relevant to a specific site, yet provide levels of protection to receptors similar to that offered by the generic criteria.

The second approach to sediment remediation involves the application of risk assessment and risk management procedures and are discussed in Section 6.0.

Assessment and Remediation Considerations:

It may be prudent to select the criteria-based approach at small sites where the cost of collecting the detailed data needed to support human and ecological risk assessments is likely to greatly exceed the costs for remediation. Also, the remediation of small sites based on the criteria-based approach may be technically less challenging and offer the potential for accelerated regulatory compliance over the alternative. At larger, more complex sites, however, the costs associated with conducting detailed risk assessments may be justified to reduce uncertainties and focus limited resources on the remedial actions that provide the greatest benefits.

5.2 APPLICATION OF CRITERIA FOR IDENTIFYING SITES WITH CONTAMINATED SEDIMENTS

The sediment quality criteria for the protection of the designated uses of freshwater systems, and of estuarine and marine systems, must be used to determine if a site contains contaminated sediments, as defined under the *Waste Management Act.* As a first step, the designated uses of the aquatic ecosystem at and nearby the site must be established. Next, the COPCs are identified, using the procedures described in MacDonald and Ingersoll (2002b). Subsequently, the concentrations of COPCs at the site are determined and compared to the sediment quality criteria that have been established for each of the designated uses and the results interpreted in accordance with the guidance provided in Sections 4.1 and 4.2.

5.3 APPLICATION OF CRITERIA FOR DEFINING REMEDIATION TARGETS

The sediment quality criteria for bulk sediments and tissues, listed in Tables 1, 2, and 3, provide a basis for establishing remediation targets (i.e. target clean-up levels) under the criteria-based approach for sites with contaminated sediments in British Columbia. Remediation targets specify tolerable concentrations of substances in bulk sediments and tissue samples. Generally, the criterion for the most sensitive designated use of the aquatic ecosystem form the remediation target for each substance of concern.

Where approved by the Ministry and Fisheries and Oceans Canada, the $SedQC_{TCS}$ criteria can be adopted directly as the remediation targets within the approved sediment zone. The remediation targets for each substance of concern represent the criterion for the most sensitive designated use.

Where site-specific sediment quality criteria have been established by a responsible person, and have been approved following review by the Ministry and/or federal agencies, site-specific criteria can be adopted as the remediation targets.

5.4 CRITERIA FOR SUBSTANCES FOR WHICH GENERIC CRITERIA ARE NOT AVAILABLE

Tables 1 and 2 contain numerical thresholds for a variety of substances that have the potential to contaminate sediments in freshwater, estuarine, and marine systems. While these tables provide criteria for many of the substances that occur in sediment at contaminated sites, other substances may be encountered for which criteria are not listed in the tables. The Ministry should be consulted for guidance regarding the significance of such non-scheduled substances at a site. Additional guidance on the assessment of Non Scheduled Toxic Substances (NSTS) is available from the Ministry (WLAP 2002 in preparation).

6.0 RISK-BASED STANDARDS

The risk-based approach can be used to support remedial action planning at any contaminated site in British Columbia. This approach is often used where the scale and scope of remedial efforts based on the criteria approach can legitimately be reduced. Typically this is done by demonstrating to the satisfaction of the Ministry that risks are less than or equal to those upon which the criteria are based. Where this can be satisfactorily demonstrated, a greater choice of risk management and remedial options generally becomes available for use at the site. Central to the Ministry's goal of restoring ecosystem health at contaminated sites is the view that control of contaminants at their source remains the primary imperative for remedial actions. It is only through the abatement of inputs of contaminants from sources to the receiving environment that other sediment management actions, such as sediment removal, become economically viable, ecologically successful, and sustainable.

In the risk-based approach, the potential risks posed by sediment-associated contaminants to both human health and the environment are evaluated on a site-specific basis and compared to risk levels that are considered to be acceptable and technically-feasible to achieve (Ingersoll *et al.* 1997). The risk-based approach is particularly relevant to contaminated sites at which the effects of sediment-associated contaminants can be mitigated by reducing exposure through specific risk management actions (e.g., containment, *in-situ* treatment, partial removal, etc.), or where exposure can be demonstrated to be reduced through administrative, engineered or natural process of chemical attenuation. The risk-based approach may involve the application of tiered assessments, which incorporate more site-specific information and increasingly sophisticated assessment methods during the course of the process.

There are numerous procedures and methods that can be used in conducting risk assessments.

Where the risk-based approach is used, exposures to a substance of concern at a site must be reduced to protect human health and the environment. To protect human health, exposures to substances must be reduced so that the level of risk associated with exposure to a substance is less than or equal to the risk-based standards of the CSR. Ecological risk assessments should be conducted in accordance with Contaminated Site Protocol #1: Guidance and Checklist for Tier 1 Ecological Risk Assessment of Contaminated Sites in British Columbia (MELP 1998). The Tier 1 document provides specific guidance for addressing concerns related to exposures of aquatic organisms and aquatic-dependent wildlife species to toxic and bioaccumulative substances. For aquatic systems, risks resulting from exposure to substances must be reduced to the acceptable ecological risk levels specified in the Tier 1 protocol (i.e. typically the EC_{20} values). [Additional Tier 1 Guidance for sediments is anticipated to be developed by the Ministry at a future date.]

Upon completion of a risk assessment, the Ministry will decide whether the information available is adequate to justify a risk management decision. Generally four possible decisions outcomes result, including:

1. the information is adequate to conclude that human health and ecological risks are acceptable and, hence, there is no need for further remediation;
2. the information is adequate to conclude that human health and ecological risks are acceptable under the proposed risk management plan and, hence, the proposed remediation measures may be implemented;
3. the information is inadequate and the uncertainty too high to make a decision, therefore, the risk assessment is rejected pending the provision of additional data; or,
4. the information is adequate and indicates there exists a real or potential unacceptable risk under the proposed risk management plan, therefore, further or alternative remediation measures are required.

The Ministry's decision will be based on its confidence in the results the risk assessment and its ability to accurately reflect the conditions of the site and the state of the science in exposure and effects assessments. The extent of human health and ecological protection, the technical feasibility of proposed remediation measures, and the degree of permanence of these remediation measures are additional considerations taken into account by the Ministry.

7.0 BACKGROUND LEVELS OF CONTAMINANTS OF POTENTIAL CONCERN

At certain sites, background levels of COPCs may exceed the criteria for bulk sediments listed in Tables 1 and 2. In such cases, the background levels of those substances (i.e. based on the median or the 95th percentile concentration - depending on whether background data is obtained from existing studies or by the reference site approach) is used to establish criteria for assessing and remediating contaminated sediments.

If the risk-based approach has been selected to support remedial action planning, then the risk levels associated with exposure to background concentrations of COPCs in sediments become the applicable risk-based standard for the site.

Contaminated media must not be used as a reference for determining background concentrations. Ingersoll and MacDonald (2002) describes recommended procedures for establishing background levels of sediment-associated contaminants at sites.

8.0 RELEASES OF CONTAMINANTS FROM A SITE

The criteria provided in this document are primarily intended to apply to *in situ* bulk sediments at sites with contaminated sediments. However, contaminants in sediments may also be released from a site by a number of means, including:

- sediment transport by natural processes, such as tidal action and erosion (i.e. the hydrodynamics of the aquatic system in question);
- evaporative losses of volatile organic chemicals from exposure of contaminated sediments to air (e.g. due to tidal effects or draw-down effects in lakes or rivers);
- surface water recharge from contaminated pore-water;
- sediment re-suspension resulting from the wash from propellers of pleasure craft and commercial vessels;
- excavation and redeposition of contaminated sediments; and,
- transfer of bioaccumulative substances to sediment-dwelling organisms and, subsequently, into the food web.

The criteria contained in this document are not intended to be the sole basis for assessing environmental quality at sites where contaminants may be released from sediments or contaminated sediments may be re-deposited elsewhere. At such sites, additional factors (such as off-site impacts, etc.) also need to be assessed and applicable policy and regulatory requirements need to be considered. For example, the provisions of the Special Waste Regulation (BC 1988) provides a basis for *in situ* management and classification of special wastes. The CSR defines maximum acceptable concentrations for COPCs in sediments that may be deposited to land. The CSR (BC 1997) also lists the Ministry's standards for the protection of groundwater and groundwater flow to surface waters. In addition, interim contaminant testing guidelines have been specified by Environment Canada to determine the acceptability of contaminated sediments for disposal at designated open water disposal sites.

9.0 SPECIAL WASTE REGULATION

The sediment quality criteria presented in Tables 1 and 2 are intended to provide a basis for evaluating sediment contamination, identifying the need for remedial actions, and establishing remediation targets at contaminated sites in British Columbia. These criteria should be used in conjunction with the requirements of the Special Waste Regulation (SWR; BC 1988). Sediments with COPC concentrations in excess of the levels specified in the SWR must be removed to the extent feasible and disposed of in accordance with the provisions of the SWR. In addition, in accordance with the provisions of the CSR, sediments containing certain types of substances (e.g., non-aqueous phase liquid; NAPL) must also be removed to the extent feasible and disposed of in an appropriate manner.

10.0 REFERENCES

Adams WJ, Kimerle RA, and RG Mosher. 1985. Aquatic safety assessment of chemicals sorbed to sediments. In: Cardwell RD, Purdy R, and RC Bahner, editors. Aquatic toxicology and hazard assessment: Seventh symposium. Philadelphia (PA): ASTM. ASTM STP 854. p 429–453.

Ankley GT, Lodge K, Call DJ, Balcer MD, Brooke LT, Cook PM, Kreis Jr RJ, Carlson AR, Johnson RD, Niemi GJ, and others. 1992. Integrated assessment of contaminated sediments in the lower Fox River and Green Bay, Wisconsin. *Ecotoxicol Environ Saf* 23:46–63.

BC. 1988. *Waste Management Act*: Special Waste Regulation. B.C. Reg. 63/88. Victoria, British Columbia.

BC. 1996. *Waste Management Act.* Updated to November 2, 1999. RS Chap. 482. Victoria, British Columbia.

BC. 1997. *Waste Management Act*: Contaminated Sites Regulation. Updated to November 12,1999. B.C. Reg. 375/96. Victoria, British Columbia.

BC. 2002. Second stage amendments. Contaminated Sites Regulation. February 1, 2002 .B.C. Reg. 375/96, Victoria, British Columbia.

BCE (BC Environment). 1998. A compendium of working water quality guidelines for British Columbia: 1998 edition. Water Quality Section. Water Management Branch. Environment and Resource Management Department. Victoria, British Columbia

Carr, RS, Nipper, M, Adams, WJ, Berry, WJ, Burton Jr, GA, Ho, K, MacDonald, D, Scroggins, R, and PV Winger, 2001. Summary of a SETAC technical workshop: Pore-water toxicity testing: Biological, chemical, and ecological considerations with a review of methods and applications, and recommendations for future areas of research. Summary of the SETAC Workshop on Pore-water Toxicity Testing: Biological, Chemical, and Ecological Considerations with a Review of Methods and Applications, and Recommendations for Future Areas of Research; 18–22 March 2000; Pensacola, FL. Society of Environmental Toxicology and Chemistry (SETAC). Pensacola, FL. 38 p.

Carr RS. 1998. Marine and estuarine porewater toxicity testing. In: Wells PG, Lee K, and C Blaise, editors. Microscale testing in aquatic toxicology: Advances, techniques, and practice. Boca Raton (FL): CRC Press. p 523–538.

Carr RS and DC Chapman , 1995. Comparison of methods for conducting marine and estuarine sediment porewater toxicity tests: Extraction, storage, and handling techniques. *Arch Environ Contam Toxicol* 28:69–77.

Carr RS, Williams JW, and CTB Fragata. 1989. Development and evaluation of a novel marine sediment porewater toxicity test with the polychaete *Dinophilus gyrociliatus*. *Environ Toxicol Chem* 8:533–543.

CCME (Canadian Council of Ministers of the Environment). 1995. Protocol for the derivation of Canadian sediment quality guidelines for the protection of aquatic life. Prepared by the Technical Secretariat of the CCME Task Group on Water Quality Guidelines. Ottawa, Canada.

CCME (Canadian Council of Ministers of the Environment). 1998. Canadian sediment quality guidelines for the protection of aquatic life. Prepared by the Technical Secretariat of the CCME Task Group on Water Quality Guidelines. Ottawa, Canada.

CCME (Canadian Council of Ministers of the Environment). 2001. Canadian tissue residue guidelines for the protection of wildlife consumers of aquatic biota - Update. Prepared by the Technical Secretariat of the CCME Task Group on Water Quality Guidelines. Ottawa, Canada.

Crane JL, MacDonald DD, Ingersoll CG, Smorong DE, Lindskoog RA, Severn CG, Berger TA, and LJ Field. 2000. Development of a framework for evaluating numerical sediment quality targets and sediment contamination in the St. Louis River Area of Concern. EPA-905-R-00-008. Great Lakes National Program Office, United States Environmental Protection Agency, Chicago, Illinois

Di Toro DM, Zarba CS, Hansen DJ, Berry WJ, Swartz RC, Cowan CE, Pavlou SP, Allen HE, Thomas NA, and PR Paquin. 1991. Technical basis for establishing sediment quality criteria for nonionic organic chemicals using equilibrium partitioning. *Environ Toxicol Chem* 10:1541–1583.

Edmunds WM, and AH Bath. 1976. Centrifuge extraction and chemical analysis of interstitial waters. *Environ Sci Technol* 10:467–472.

Environment Canada. 1997. Canadian sediment quality guidelines for toxaphene. Guidelines and Standards Division. Hull, Quebec.

Fairey, R, Long, ER, Roberts, CA, Anderson, BS, Phillips, BM, Hunt, JW, Puckett, HR and CJ Wilson. 2001. An evaluation of methods for calculating mean sediment quality guideline quotients as indicators of contamination and acute toxicity to amphipods by chemical mixtures. *Environ Toxicol Chem* 20:2276-2286.

Field, LJ, MacDonald, DD, Norton, SB, Ingersoll, CG, Severn, CG, Smorong, D and R Lindskoog. 2002. Predicting amphipod toxicity from sediment chemistry using logistic regression models *Environ Toxicol Chem* (In press).

Field, LJ, MacDonald, DD, Norton, SB, Severn, CG and CG Ingersoll. 1999. Evaluating sediment chemistry and toxicity data using logistic regression modelling. *Environ Toxicol Chem* 18:1311-1327.

Hesslin RH. 1976. An in situ sampler for close interval pore water studies. *Limnol Oceanogr* 21:912–914.

Hooten RL, and RS Carr. 1998. Development and application of a marine sediment porewater toxicity test using *Ulva fasciata* and *U. lactuca* zoospores.*Environ Toxicol Chem* 17:932–940.

Ingersoll, CG, Haverland, PS, Brunson, EL, Canfield, JT, Dwyer, FJ, Henke, CE, Kemble, NE, Mount, DR, and RG Fox. 1996. Calculation and evaluation of sediment effect concentrations for the amphipod *Hyalella azteca* and the midge *Chironomus riparius*. Journal Great Lakes Research 22(3):602-623.

Ingersoll CG, Dillon, T, and RG Biddinger (*eds*.). 1997. Ecological risk assessment of contaminated sediment. SETAC Press, Pensacola, FL. 389 pp.

Ingersoll CG, MacDonald DD, Wang N, Crane JL, Field LJ, Haverland, PS, Kemble NE, Lindskoog RA, Severn C, and DE Smorong, 2001. Predictions of sediment toxicity using consensus-based freshwater sediment quality guidelines. *Arch Environ Contam Toxicol* 41:8-21

Ingersoll, CG and DD MacDonald. 2002. A Guidance Manual to Support the Assessment of Contaminated Sediments in Freshwater, Estuarine and Marine Ecosystems, *Volume 3 – Interpretation of the Results of Sediment Quality Investigations* – Draft. Prepared for the US Environmental Protection Agency Great Lakes National Program Office Chicago, Illinois and the Environmental Management Branch. B.C. Ministry of Water, Land and Air Protection, Victoria, British Columbia.

Jahnke RA. 1988. A simple, reliable, and inexpensive pore-water sampler. *Limnol Oceanogr* 33:483–487.

Long, ER and LG Morgan. 1991. The potential for biological effects of sediment-sorbed contaminants tested in the National Status and Trends Program. NOAA Technical Memorandum NOS OMA 52. National Oceanic and Atmospheric Administration. Seattle, Washington. 175 pp + appendices.

Long, ER and DD MacDonald. 1998. Recommended uses of empirically derived sediment quality guidelines for marine and estuarine ecosystems. *Human and Ecological Risk Assessment* 4(5):1019-1039.

Long, ER, LJ Field, and DD MacDonald. 1998. Predicting toxicity in marine sediments with numerical sediment quality guidelines. *Environ Toxicol Chem* 17(4):714-727.

Long, ER, MacDonald DD, Severn, CG and CB Hong. 2000. Classifying probabilities of acute toxicity in marine sediments with emperically derived sediment quality guidelines. *Environ Toxicol Chem* 19:2598-2601.

MacDonald DD, Ingersoll CG, and TA Berger. 2000. Development and evaluation of consensus-based sediment quality guidelines for freshwater ecosystems. *Arch Environ Contam Toxicol* 39:20-31

MacDonald, DD. 2001. Development and evaluation of numerical sediment quality criteria for sediment contaminated sites in British Columbia: A retrospective. Prepared for Contaminated Sites Remediation and Assessment Section, Ministry of Water, Land and Air Protection. November, 2001.

MacDonald, DD and CG Ingersoll, 2002a. A Guidance Manual to Support the Assessment of Contaminated Sediments in Freshwater, Estuarine and Marine Ecosystems, *Volume 1 – An Ecosystem-base Framework for Assessing and Managing Contaminated Sediments* – Draft. Prepared for the US Environmental Protection Agency Great Lakes National Program Office Chicago, Illinois and the Environmental Management Branch. B.C. Ministry of Water, Land and Air Protection, Victoria, British Columbia.

MacDonald, DD and CG Ingersoll, 2002b. A Guidance Manual to Support the Assessment of Contaminated Sediments in Freshwater, Estuarine and Marine Ecosystems, *Volume 2 – Design and implementation of Sediment Quality Investigations* – Draft. Prepared for the US Environmental Protection Agency Great Lakes National Program Office Chicago, Illinois and the Environmental Management Branch. B.C. Ministry of Water, Land and Air Protection, Victoria, British Columbia.

Macfarlane, MW and DD MacDonald, 1999. Draft- *Criteria for Managing Contaminated Sediment in British Columbia.* B.C. Ministry of Environment, Lands and Parks, Pollution Prevention and Remediation Branch, Victoria, British Columbia.

Ministry of Environment, Lands and Parks (MELP). 1998. Recommended guidance and checklist for Tier 1 ecological risk assessment of contaminated sites in British Columbia. Prepared by Landis, W.G., A.J. Markiewicz, V. Wilson, A. Fairbrother, and G. Mann. Prepared for Industrial Wastes and Hazardous Contaminants Branch. Victoria, British Columbia.

Ministry of Water, Land and Air Protection. 2002. Technical Guidance X-18, Nonscheduled Toxic Substances - Internal Draft. Environmental Management Branch, Victoria, British Columbia.

Munawar, M and G Dave *(eds.)*. Ecovision World Monograph Series. SPB Academic Publishing. Amsterdam, The Netherlands.

NYSDEC (New York State Department of Environmental Conservation). 1994. Technical guidance for screening contaminated sediments. Division of Fish and Wildlife. Division of Marine Resources. New York. 36 pp.

Presley BJ, Brooks RR, and HM Kappel. 1967. A simple squeezer for removal of interstitial water from ocean sediments. *J Mar Res* 25:355–362.

Singleton, HJ 1995. Water quality criteria for particulate matter. Water Quality Branch. Ministry of Environment. Victoria, British Columbia.

USEPA (United States Environmental Protection Agency). 1989. Risk Assessment Guidance for Superfund volume I, Human Health Evaluation Manual (Part A) Interim Final. EPA/540/1-89/002 Office of Emergency and Remedial Response, Washington, District of Columbia.

USEPA (United States Environmental Protection Agency), 1993. Technical basis for deriving sediment quality criteria for nonionic organic contaminants for the protection of benthic organisms by using equilibrium partitioning. EPA-822-R-93-011 Office of Water, Washington District of Columbia

USEPA (United States Environmental Protection Agency). 2000. Prediction of sediment toxicity using consensus-based freshwater sediment quality guidelines. EPA 905-R-00-007. Great Lakes National Program Office, Chicago, Illinois

WDOE (Washington Department of Ecology). 1991. Sediment management standards. *Washington Administrative Code.* Olympia WA.USA.

Winger PV and PJ Lasier, 1991. A vacuum-operated pore-water extractor for estuarine and freshwater sediments. *Arch Environ Contam Toxicol* 21:321–324.

SCHEDULE 1. GLOSSARY OF TERMS AND ACRONYMS

AVS	Acid volatile sulfide. Reactive solid-phase sulfide fraction that can be extracted by cold hydrochloric acid. AVS appears to be one of the factors that influences the bioavailability of divalent metals.
BCE	British Columbia Environment (Ministry of Environment, Lands and Parks).
Benthic Organisms	The species, including both infaunal and epibenthic species, that utilize habitats in or on the sediments located at the bottom of streams, lakes, oceans, or other aquatic systems.
BIEAP	Burrard Inlet Environmental Action Program.
Bioaccumulation	The net accumulation of a substance by an organism as a result of uptake from all environmental sources.
Bulk Sediment	Sediment and associated pore-water which have had minimal manipulation.
CCME	Canadian Council of Ministers of the Environment.
Contaminant	Substance that is present at elevated levels in sediment or pore-water as a result of human activities.
Contaminated Sediment	Sediment containing chemical substances at concentrations that pose a known or potential threat to human health or the environment (i.e., in excess of the criteria presented in Tables 1 and 2).
COPCs	Contaminants of potential concern.
CSR	Contaminated Site Regulation.
DSI	Detailed Site investigation.
EC	Effects Concentration. A statistically or graphically estimated concentration that is expected to produce one or more specific effects in of a group of organisms under specified conditions.
EC_{20}	20% Effects Concentration
EC_{50}	50% Effects Concentration
ERA	Ecological Risk Assessment The process that evaluates the likelihood that adverse ecological effects may occur or are occurring as a result of exposure to one or more stressors.

Ecosystem	The biotic community and abiotic environment within a specified location in space and time.
Epibenthic Species	Organisms that live primarily on the surface of the sediment.
Exposure	Co-occurrence of or contact between a stressor and an ecological component (i.e., receptor).
FREMP	Fraser River Estuary Management Program.
Habitat	The environment in which receptors are found. Receptors may live exclusively within a single type of habitat or may use several types of habitats.
Infaunal Species	Organisms that live primarily within the sediment matrix.
PAH	Polycyclic aromatic hydrocarbons.
PCB	Polychlorinated biphenyl.
PEC	Probable effect concentration.
PEL	Probable effect level.
Pore-water	Water occupying space between sediment particles.
PSI	Preliminary site investigation.
QAP	Quality assurance plan.
Receptor	An organism or group of organisms that are or have the potential to be exposed to and adversely affected by a stressor.
Remediation Targets	The conditions that should be met in sediments following remediation to achieve the desired sediment management goals. Remediation targets are typically expressed as the concentrations of contaminants of potential concern in bulk sediments and/or pore-water. However, narrative remediation targets may also be established at sites with contaminated sediments (e.g., sediments should not adversely affect amphipod survival, growth, or reproduction, as measured in 42-d toxicity tests).
Responsible person	Means a person described in section 26.5 of the Waste Management Act (Supplement).
Risk	The probability or likelihood that an adverse effect will occur.
SAP	Sampling and analysis plan.
SEC	Severe effect concentration.

Sediment	Particulate matter which usually lies below water. For the purpose of applying the criteria, sediments are intended to include to soft, aqueous, sedimentary deposits that are comprised primarily of fine-grained particles (i.e., < 6.35 mm). Sediments are not intended to include other materials, such as gravel, cobble, boulders, logs, wood fibre, hog fuel, slag, paint chips, asphalt, or coal tar.
Sediment Hot Spot	Location where one or more contaminants of potential concern is present at concentrations in excess of the sediment quality criteria.
SedQC	Sediment quality criteria.
SedQC-Q	Sediment quality criteria quotient
$SedQC_{SCS}$	Sediment quality criteria for sensitive contaminated sites.
$SedQC_{TCS}$	Sediment quality criteria for typical contaminated sites.
SEM	Simultaneous extractable metals.
Source	An anthropogenic input or activity that releases or creates a stressor in the environment.
SQAL	Sediment quality advisory level; based on the equilibrium partitioning models.
SQG	Sediment quality guideline.
SQT	Sediment quality threshold
Stressor	Any physical, chemical, or biological component of an ecosystem which can induce an adverse response in a receptor.
SWR	Special Waste Regulation.
TEL	Threshold effect level.
TEQ	Toxic equivalents.
TIE	Toxicity identification evaluation.
TOC	Total organic carbon.
TRC	Tissue residue criteria.

SCHEDULE 2. FACTORS FOR CONSIDERATION IN THE APPLICATION OF THE CRITERIA FOR SENSITIVE CONTAMINATED SITES (SQC_{SCS})

Areas to Which the SQC_{SCS} Should be Applied Include:

- Areas, sites or reaches which support red and blue listed plants and animal species, or nests designated under the *Wildlife Act*.
- Habitats used by endangered or threatened species, or Species of Special Concern under the *Species at Risk Act*.
- Watercourses, wetlands, forested riparian areas, mudflats and intertidal zones that are important to preservation of fish and wildlife.
- Reaches of aquatic habitats that are important to fish spawning or serve as important rearing habitat for fish.
- Reaches of aquatic environments encompassing, and/or bordering habitat compensation or restoration sites, or other areas that are intended or designed to create, restore or enhance biological or habitat features.
- Areas of unique habitat that are identified in federal, provincial or municipal landuse plans.
- Reaches of the aquatic environment that exist within federal and provincial marine parks, Federal and provincial parks, or ecological reserves.
- Areas and aquatic habitat included within provincial Wildlife Management Areas.
- Areas covered under conservation agreements and areas designated as "Environmentally Sensitive" in municipal landuse plans or strategies.

Marinas, docks, wharves and associated infrastructure located within these areas may be assessed making use of the SQC_{TCS} criteria limits. To make use of the SQC_{TCS} in these circumstances, the proponents must present information to support their proposal to the appropriate agencies. This information should include:

- **the identification of existing resources in the area;**
- **the identification of offsite contaminant sources; and**
- **the measures taken to eliminate onsite sources of contamination.**

TABLE 1 GENERIC SEDIMENT QUALITY CRITERIA[1, 2]

COLUMN I	COLUMN II	COLUMN III	COLUMN IV	COLUMN V
	FRESH WATER[3]		MARINE and ESTUARINE WATER[4]	
Substance	Sensitive Contaminated Sites ($SedQC_{SCS}$)	Typical Contaminated Sites ($SedQ_{TCS}$)	Sensitive Contaminated Sites ($SedQC_{SCS}$)	Typical Contaminated Sites ($SedQC_{TCS}$)
Inorganic Substances				
arsenic	12 000	20 000	25 000	50 000
cadmium	2 100	4 200	2 400	5 040
chromium	64 000	110 000	110 000	190 000
copper	120 000	240 000	65 000	130 000
lead	63 000	110 000	70 000	134 000
mercury	330	580	420	840
zinc	220 000	380 000	200 000	330 000
Polychlorinated Biphenyls (PCBs)				
Total PCBs	156	332	105	230
Polycyclic Aromatic Hydrocarbons (PAHs)				
Low Molecular Weight PAHs (LMW-PAHs)				
acenaphthene	48	110	48	110
acenaphthylene	67	150	67	150
anthracene	150	290	150	290
fluorene	83	170	83	170
naphthalene	210	470	210	470
2-methylnaphthalene	110	240	110	240
phenanthrene	310	620	320	650
High Molecular Weight PAHs (HMW-PAHs)				
benz(a)anthracene	210	460	380	830
benzo(a)pyrene	410	940	430	920
chrysene	460	1 030	480	1 020
dibenz(a,h)anthracene	71	160	71	160
fluoranthene	1 230	2 830	800	1 790
pyrene	460	1 050	780	1 680
TOTAL PAHS[5]	9 230	20 200	9230	20 400
Pesticides				
chlordane	6.7	11	3.5	5.7
dieldrin	4.8	8.0	2.5	5.2
Sum DDT	3.0	5.7	3.0	5.7
Sum DDE	4.1	8.1	188	450

COLUMN I	COLUMN II	COLUMN III	COLUMN IV	COLUMN V
	FRESH WATER[3]		MARINE and ESTUARINE WATER[4]	
Substance	**Sensitive Contaminated Sites ($SedQC_{SCS}$)**	**Typical Contaminated Sites ($SedQ_{TCS}$)**	**Sensitive Contaminated Sites ($SedQC_{SCS}$)**	**Typical Contaminated Sites ($SedQC_{TCS}$)**
Sum DDD	6.0	10	4.5	9.4
lindane (gamma-bhc)	1.2	1.7	0.65	1.2
endrin	33	75	33	75
heptachlor epoxide	1.7	3.3	1.7	3.3
Chlorinated Phenols				
pentachlorophenol	400[6]	800[6]	360[7]	690[7]
Polychlorinated Dioxins and Furans (PCDDs and PCDFs)				
2,3,7,8-TCDD TEQs	0.013	0.026	0.013	0.026

Footnotes

1. All values are in ug/kg Dry Weight (DW) unless otherwise stated. Substances must be analyzed using methods specified in protocols approved under section 53 of the Contaminated Sites Regulation or alternate methods acceptable to the director.

2. Criteria are for total substance concentrations.

3. Standard to protect freshwater aquatic life.

4. Standard to protect marine and/or estuarine aquatic life.

5. Total PAHs includes:

1-methylnaphthalene
1-methylphenanthrene
2,6-dimethylnaphthalene
2,3, 5-trimethylnaphthalene
2-methylnaphthalene
acenaphthene
acenaphthylene
anthracene
benz(a)anthracene
benzo(a)pyrene
benzo(e)pyrene
benzo(b)fluoranthene
benzo(ghi)perylene
benzo(k)fluoranthene
chrysene
dibenz(a,h)anthracene
fluorene
fluoranthene
indeno(1,2,3-c,d)pyrene
naphthalene
perylene
phenanthrene
pyrene

1. Adopted from New York Department of Environmental Conservation, 1994.

2. Adopted from Washington Department of Ecology, 1991.

TABLE 2 TISSUE RESIDUE CRITERIA FOR BIOACCUMULATIVE SUBSTANCES [1, 2, 3, 4]

COLUMN I		COLUMN II
Substance		**Tissue Residue Criteria**
Organic Mercury		
methyl mercury		33
Polychlorinated Biphenyls (PCBs)		
total PCBs	mammalian	0.79 ng/TEQ[5] /kg
	avian	2.4 ng TEQ[5] /kg
PESTICIDES		
DDD[6]		14
DDE[6]		14
DDT[6]		14
Polychlorinated Dioxins and Furans (PCDDs and PCDFs)		
2,3,7,8-TCDD TEQs	mammalian	0.71 ng/TEQ[5] /kg
	avian	4.75 ng TEQ[5] /kg

Footnotes

1. All values are in ug/kg unless otherwise stated. Substances must be analyzed using methods specified in protocols approved under section 53 of the Contaminated Sites Regulation or alternate methods acceptable to the director.

2. All values are expressed in terms of wet weight (WW).

3. Standards are for total substance concentrations.

4. All values adopted from the Canadian Council of Ministers of Environment (CCME) 2001.

5. Expressed as Toxic Equivalent Unit (TEQ) based on World Health 1998 TEF values for fish

6. TRC is for total DDT, which is equal to DDD+DDE+DDT (CCME, 2001).