

**Sediment Quality Guideline Development in Canada**

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**Abstract**

This paper is intended to stimulate a comparison of different national approaches to environmental quality guideline development. The process of sediment quality guideline development for application to Canadian marine and freshwater regimes is outlined. Reference is made to the purposes and potential applications of sediment quality guidelines in a national context. These guidelines are required to be consistent with national environmental quality objectives and with international agreements to which Canada is a party, such as the London Convention 1972. Various observations on the scientific basis for environmental quality guidelines are also made.

**Le développement des lignes directrices applicables aux sédiments au Canada**

**Résumé**

Cet article vise à encourager une évaluation comparative des approches au développement des directives applicables à la qualité de l'environnement. On y esquisse la méthode de développement des lignes directrices applicables aux sédiments en régimes marines et d'eau douce au Canada. On y fait référence spéciale aux buts et aux usages possibles des lignes directrices applicables aux sédiments dans un contexte national. Ces lignes directrices doivent être compatibles avec les objectifs de protection de l'environnement et aussi avec les conventions internationales dont le Canada est partie contractante, par exemple la Convention de Londres, 1972. On y présente aussi quelques observations sur les fondements scientifiques des lignes directrices applicables à la qualité de l'environnement.

**Introduction**

Chemical contamination of sediments may affect activities such as dredging, dredge material disposal, aquaculture, swimming, habitat, fishing and shoreline rehabilitation. In addition, through the processes of desorption and resuspension, contaminated sediments can act as significant sources of contaminants in areas in which other sources have been reduced. To assess the significance of sedimentary contamination in a uniform and scientifically systematic manner, environmental managers require guidelines for judging the acceptability of measured contaminant levels in the context of the suitability of environmental conditions for specific uses and amenities.

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The "Montreal Guidelines", developed under the auspices of the United Nations Environment Programme, provide a global framework for the protection of marine ecosystems against the effects of contaminants derived from land-based sources. These guidelines, which were adopted, in principle, by Canada in 1985, outline control strategies required to protect, preserve, and enhance the quality of the marine environment.

In a national context, the Canadian Environmental Protection Act (CEPA) of June, 1988, provides the national authority for the conservation and protection of the Canadian environment. The formulation of marine environmental quality (MEQ) guidelines is part of the functions and duties described in the Act.

In Canada, there exist no nationally recognized, ecotoxicologically-based, guidelines for marine sediments. Numerical limits for the acceptability of materials to be dumped at sea have been defined for mercury and cadmium under Part VI of CEPA which embodies the previous Ocean Dumping Control Act - legislation promulgated pursuant to Canada's Contracting Party status under the Convention on the Prevention of Marine Pollution from the Dumping of Wastes and Other Matter, London 1972 (known as the London Convention 1972).

In 1990, The Canadian Department of the Environment (Environment Canada) initiated a programme to develop sediment quality guidelines for application to marine and freshwater areas of Canada. *Guidelines* are defined by Environment Canada as numerical concentrations or narrative statements recommended to support and maintain designated uses of the marine environment. For example, no harmful effects on [specified in-fauna] will result if the maximum concentration of [specified chemical element] remains below  $x \text{ mg.kg}^{-1}$  in surficial [nature (i.e., grain-size distribution) specified] sediment.

As a first step in the process of developing SQGs, Environment Canada evaluated guidelines established in other jurisdictions that might offer potential for application in Canada. It also conducted an evaluation of approaches used for guideline development (see Appendix) that have previously been reviewed by Chapman (1989) and Persaud *et al* (1989). All of these various approaches have advantages and drawbacks but in order to select the most appropriate common approach, it is first essential to determine the objectives and purposes of sediment quality guidelines for the jurisdiction in which they are to be defined. All of these various approaches have advantages and drawbacks but in order to select the most appropriate common approach it is first essential to determine the objectives and purposes of sediment quality guidelines for the jurisdiction in which they are to be defined.

### **Objectives and Purposes of Canadian Sediment Quality Guidelines**

The following reflects the types of initial considerations that are essential for the selection of methods for defining sediment quality guidelines in a Canadian context. It is axiomatic that similar *a priori* considerations would be needed for defining guidelines for any other environmental matrix.

#### **Definitions**

*Sediment quality guidelines* (SQGs) constitute a national benchmark relating to the quality of sediments in the context of adverse effects on human health, aquatic organisms, other wildlife, and legitimate uses of the aquatic environment. This guideline, or benchmark, denotes sediment quality in terms of the concentrations of specific substances that are

deemed to provide adequate protection of human and animal health and legitimate uses of the aquatic environment.

The term *sediments*, in the present context, means the bottom particulate deposits in aquatic environments (rivers, streams, lakes and marine waters). Bottom sediments comprise particulate material of various sizes, shapes, mineralogy and composition derived from various internal and external sources. Sediments may be relict or of recent deposition. The predominant sources of recently-deposited particulate material are terrigenous, biogenic, authigenic, marine and extra-terrestrial. Terrigenous material is derived from weathering processes, including wave action, and may be transported through water (including ice) or the atmosphere. Biogenic material includes the skeletal remains of plants and animals. Authigenic material is formed as particulate precipitates from water as a consequence of biogeochemical processes. Extra-terrestrial matter is derived from the continuous rain of meteoric material descending through the atmosphere. The factors controlling particle remobilization, transport and deposition include particle size, shape, and density and the flow, turbulence, density, and viscosity characteristics of the carrying medium.

### Applications of Sediment Quality Guidelines

Sediment quality guidelines will be applied to the following:

**CEPA Part VI:** Denotes levels of specific substances at, or below, which sediments are deemed generically acceptable for open water disposal without recourse to special measures (e.g., capping or treatment).

**Environmental Assessment:** Denotes levels of substances at, or below, which concerns regarding the health and productivity of the aquatic environment or significant risks to human health are unwarranted.

**Remediation:** Denotes levels of substances at, or below, which remediation of the sedimentary environment is unjustified.

### Interpretation of Meaning

**Implications of Values Exceeding Guidelines:** Concentrations of substances exceeding the SQG values would be deemed potentially unsuitable for the protection of the environment and human health and would impose a need for further testing to assess the degree to which adverse effects might ensue. In the first instance, such additional testing would require evaluations of risks to human health and testing for biological effects on representative indigenous organisms. Thus, the SQG corresponds to a screening ('no effects') level below which no further mitigation or assessment would be required and above which further evaluations of the hazards, and potential damage and risks, would be necessary.

**Generic Aspects of SQGs:** SQGs are generic in nature and are for national application as screening levels. It is implicit that SQGs are levels at which acceptability is inherently and universally (nationally) acceptable and relate to contaminant concentrations that are not of concern. It is recognized that SQGs may be somewhat lower than values that will be regarded as acceptable in site-specific or regional circumstances following specific assessments of local conditions, legitimate uses of amenities, effects on organisms, and potential effects on exposed human populations have been made.

## Normalization for the Natural Incidence of Substances

In order for SQGs to meet these generic requirements, allowance has to be made for the incidence of wholly natural inorganic and organic substances in sediments. It is clearly untenable to ignore such natural contributions to sediment quality when the primary concern is the degree to which the composition of sediments may have been modified or augmented by anthropogenic activities.

### The Approach

The approach to setting guidelines is to first establish the range of the natural incidence of naturally-occurring substances, such as trace elements and natural organic compounds, and the levels of artificial organics arising from ubiquitous contamination of the environment. These values are then used as a foundation for invoking assessment of the effects of substances when they are present at higher concentrations. This latter assessment is based on toxicological information available from a wide variety of sources.

### Establishing the Natural Levels of Natural Substances

Chemicals in sediments are partitioned among three major phases: detrital and non-detrital particulate and pore-water. The detrital particulate phase comprises material locked up in sedimentary minerals that can be regarded as unexchangeable on short geological time-scales. The non-detrital particulate phase comprises material adsorbed to the external surfaces of sediment particles, associated with iron oxide grain coatings, carbonates, sulphides, and organic matter. The pore water phase contains substances in solution, and in colloidal form. The interstitial water of sediments is generally in some stage of re-equilibration to the sedimentary material. The partitioning between non-detrital particulate and pore-water phases is dependent upon salinity, pH, redox, porosity, microbial activity and the hydrodynamics of the overlying water.

The mineralogy and grain-size distribution of sedimentary detrital minerals determines most of the natural abundance and distribution of chemical elements in crystalline sediments. Most of the natural concentrations of elements are associated, included, and/or structurally combined with a limited number of detrital aluminosilicate minerals such as micas, pyroxenes, amphiboles and secondary clay minerals. In most cases, concentrations increase with decreasing grain-size, an effect that can be normalized (compensated for) in the comparison of the concentrations of elements in sediments. Such normalizations can be based on a number of naturally-occurring elements but, for Canadian applications, lithium (Loring, 1990) would appear to be the most appropriate.

For redox positive sediments, the element/lithium ratio is a suitable major criterion upon which to characterize normality. Relationships between chemical elements and lithium are typically of the form  $Y = ax + b$  (i.e., linear) (see Figures) but the constants (b) can be significant because elements can be at measurable levels in coarse materials, such as sands, that may be virtually devoid of lithium. Both the slopes (a) and the constants (b) of these relationships vary among locations but the uniformity and ubiquity of such relationships offers a mechanism of defining reasonable upper limits to the natural occurrence of elements in marine sediments. This approach would also implicitly take account of the enrichment in oxidized surface sediments resulting from the mobilization of elements that become solubilized under reducing conditions (e.g., iron and manganese). An additional factor needs to be introduced to account

for the presence of elements associated with the organic fraction of the sediments (e.g., mercury and cadmium) but this needs only to be invoked at organic carbon concentrations exceeding 2% or 3%. The expression defining the normal concentrations of elements in sediments would then be of the form:

$$C_i = a + xC_{Li} + (|y| + y)/2$$

where

$$y = (C_{TOC} - 0.03)$$

and

TOC = Total Organic Carbon and a is a constant

This would then define reasonable upper limits to the presence of elements in sediments irrespective of their mineralogical composition and grain-size distributions.

In reducing sediments there are different relationships between the forms of elements present with shifts towards reduced forms such as sulphides. Elements that are solubilized under reducing conditions (e.g., Fe and Mn) will migrate to oxidized layers where they will tend to be reprecipitated. This results in a reduction in the concentration of such elements in reduced sediments. However, there are no *a priori* reasons why the same basis for defining upper levels for the normal natural occurrence of elements should not be applicable.

Data for the presence of natural and artificial organic substances from essentially natural sediments far from local and regional sources of contaminants can be used as a guide to defining the acceptable levels of these substances. Account must be taken of the presence of total organic matter in the sediments and, accordingly, a reasonable method of proceeding to define either the normal levels of naturally-occurring organic substances or the levels of artificial organics that have ubiquitously contaminated the environment is to express ratios of these substances to total organic matter (expressed as total organic carbon) in remote sediments. Again, a factor of 2 would seem a reasonable way of allowing for variations in levels in relation to total organic matter subject to the proviso that the upper values so defined lie below no-effect levels from a toxicological perspective.

#### Application of Toxicology

Once the natural levels of substances and the levels of ubiquitous contaminants have been defined as described above, it would be appropriate to: (1) judge the relationship between these levels and No Effect Levels (NOELs) from toxicological perspectives; and (2) define at what levels guidelines should be set that would have the effect of requiring more detailed toxicological evaluation for values in excess of guideline levels. Because the toxicological information required will not be comprehensive for all chemicals or for all sediment matrices, default sediment quality guidelines should be those defined by the previous evaluation of natural levels (for naturally-occurring substances) and the levels of ubiquitous contamination (for artificial substances). Nevertheless, where useful information exists regarding the levels at which substances result in either no effect or a likelihood of biological effects, this should be used to draw comparisons. Such comparisons need, however, to be made with care. In the first instance the toxicological information should apply to conditions and sediment matrices that are similar to the environmental situation for which the comparison is being made. Second, the toxicological information should, wherever possible, relate to organisms that are known to be indigenous to the environmental sediments to which the comparison is being made.

A possible mechanism of dealing with cases in which toxicological information relating to indigenous organisms and specific sediment types is unavailable, we would advocate the use of an equilibrium partitioning approach based on the combination of marine water quality guidelines and appropriate partition (or distribution) coefficients. For inorganic substances, the partition coefficients would be the sediment-water partition coefficient  $k_p$ , which is a measure of the particle reactivity of substances. This coefficient will not be a constant (see, for example, Santschi, 1984) but it will probably be sufficient to account primarily for its variation with salinity for these purposes. For organically-associated contaminants the octanol-water partition coefficient ( $k_{ow}$ ) should suffice when considered in relation to the organic carbon levels in aquatic matrices.

### Summary

We have described here the nature and intended applications of sediment quality guidelines in Canada and presented an possible approach to their definition for national purposes. We would welcome comments and criticisms of this paper, particularly the approach we outline. Furthermore, we would like to solicit information on similar developments in other countries on the formulation of environmental quality guidelines in the hope that improved consistency and uniformity would be of benefit in international forums.

### References

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## Appendix

The following approaches, used in other jurisdictions for environmental quality guideline development, have been evaluated for potential application in Canada:

1. Sediment background;

In this approach, sediment contaminant concentrations at a site are compared with those at a site deemed representative of background (i.e., relatively uncontaminated) conditions.

2. Spiked-sediment toxicity;

This approach relies on empirically-generated information on the response of test organisms to specific contaminants under laboratory conditions.

3. Water quality guidelines applied to interstitial water;

This approach applies water quality guidelines directly to sediment pore waters;

4. Interstitial water toxicity;

This involves guidelines based on the toxicity of sediment pore waters.

5. Equilibrium partitioning;

This approach uses water quality guidelines and sediment-water partition (or distribution) coefficients ( $k_d$ 's).

6. Tissue residue;

This method applies limits for tissue concentrations of contaminants coupled with biological concentration factors relative to water and sediment-water partition coefficients.

7. Benthic community structure;

This method involves assessments of benthic community structure in relation to sediment characteristics (nature and composition).

8. Screening level concentration;

The screening level concentration is an estimate of the highest concentration of a contaminant that can be tolerated by a pre-defined number of in-faunal species.

9. Sediment quality triad;

This approach is based on the combination of sediment chemistry, sediment bioassays, and *in situ* biological effects.

10. Apparent effects threshold;

This approach is based on relationships between measured concentrations of a contaminant in sediments and observed biological effects, principally on benthic organisms. The purpose is to define contaminant concentrations at which significant biological effects do not occur.

11. Sediment assessment strategy recommended by the International Joint Commission (IJC);

The basis of this approach is an assumption that contaminated sediments are of concern only if they are exerting a stress on biological systems or if toxic substances are being bioaccumulated.

12. National Status and Trends Program data base.

This approach is based on that of Long and Morgan (1990) in which existing information on a variety of effects-based methods is assessed for concordance among chemical and biological data and professional judgement made in selecting a guideline value.