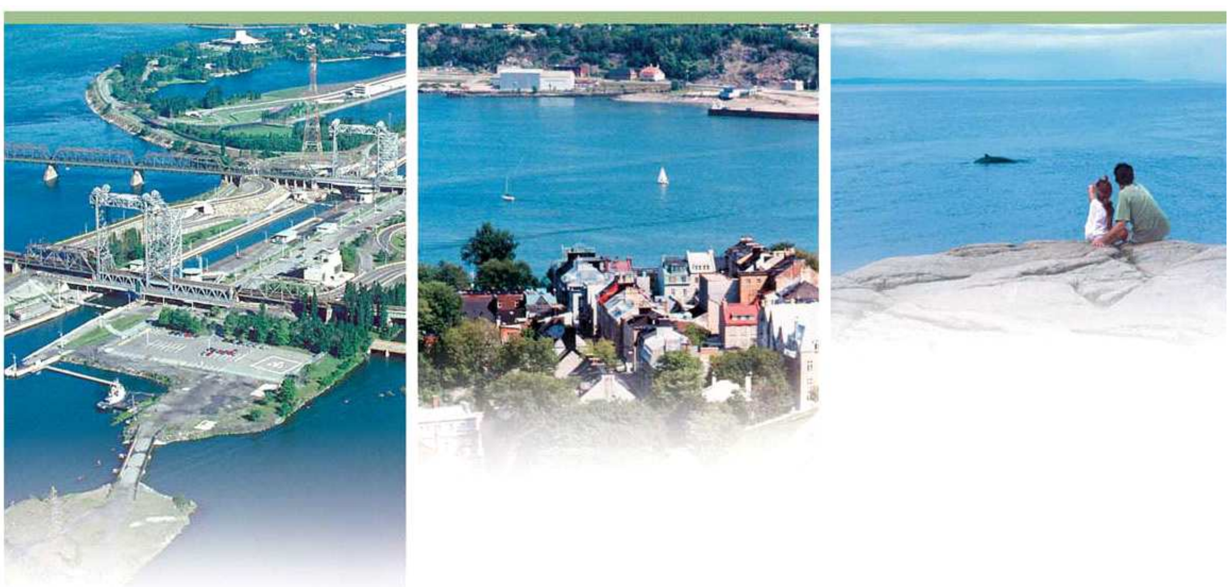
St. Lawrence Plan
For a Sustainable Development

Criteria for the Assessment of Sediment Quality in Quebec and Application Frameworks: Prevention, Dredging and Remediation

Environment Canada
and
Ministère du Développement durable,
de l'Environnement et des Parcs du Québec



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For more information on the development of the criteria for the assessment of sediment quality in Quebec:

The task group has also produced a document entitled *Reference Document – Criteria for the Assessment of Sediment Quality in Quebec and Application Frameworks: Prevention, Dredging and Remediation* (Environment Canada and Ministère du Développement durable, de l’Environnement et des Parcs du Québec, 2006). This document provides a more detailed account of the procedure used in reviewing sediment quality criteria and contains all of the information compiled during the review process.

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Message from the Co-chairs of the Navigation Consensus-building Committee

On behalf of all the members of the Navigation Consensus-building Committee (NCC), we salute the sustained and rigorous work of the group of experts from Environment Canada and the Ministère du Développement durable, de l'Environnement et des Parcs du Québec who took part in the production of this document.

This highly complex task was performed in a genuine spirit of cooperation, with the aim of realizing this important project, which is a part of the Sustainable Navigation Strategy.

The NCC is proud to have supported the production of this document. We are confident that these new sediment quality criteria will contribute to enhancing the St. Lawrence River for the benefit of future generations.

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The task group would also like to thank all those who contributed in any way to the production of this document.

Foreword

The present document replaces the publication entitled *Interim Criteria for Quality Assessment of St. Lawrence River Sediment* (SLC and MENVIQ 1992). The new sediment quality criteria may be updated as changes are made in the scientific information on which they are based.

This publication was produced jointly by Environment Canada and the Ministère du Développement durable, de l'Environnement et des Parcs du Québec, with the support of the Navigation Consensus-building Committee.

Problems in applying the interim sediment quality criteria, notably because of the naturally high concentrations of certain metals in the St. Lawrence, were reported in the 1990s. With the publication of the Canadian Sediment Quality Guidelines by the Canadian Council of Ministers of the Environment (CCME 1995; 1999) and the availability of new data on many substances of concern in the St. Lawrence, sediment management authorities saw the need for a review of the interim criteria adopted in 1992. A workshop held in 1996 (PWGSC 1996) brought together various stakeholders involved in dredging and sediment management, and led to the preparation of a study report (Belles-Iles and Savard 2000). This was followed by a second workshop in 2000 aimed at developing a work plan for reviewing the sediment quality criteria. Some of the resulting recommendations (WGIMDS 2001) were adopted by the Working Group on the Integrated Management of Dredging and Sediments.

The development and improvement of sediment quality assessment tools were among the recommendations made (WGIMDS 2004) with a view to reducing the scientific uncertainty associated with dredging activities. The WGIMDS recognized the need to (1) review and revise the sediment quality criteria in order to consider the specific characteristics of the St. Lawrence and the knowledge acquired since the publication of the interim criteria in 1992; (2) complete the development of complementary assessment tools that are needed by all stakeholders and that are essential for increasing knowledge of sediment quality and of the potential effects of sediments on aquatic organisms; and (3) develop a decision-analysis approach to provide a more rigorous procedural framework permitting more consistent and equitable handling of issues and situations.

This document presents the results of the review of the interim sediment quality assessment criteria. This exercise has resulted in the adoption of new sediment quality criteria, which are described herein and replace the criteria established in 1992. Sediment quality assessment criteria constitute a screening tool for assessing the chemical contamination of sediments. Additional sediment management tools, including an ecotoxicological assessment process, are currently under development. This document takes account of the complementary nature of these various tools. The guidelines and recommendations for applying the sediment quality criteria provide for the use of other suitable analytical tools as well. The new criteria for the assessment of sediment quality in Quebec are based on the approach of the Canadian Council of Ministers of the Environment (CCME 1995). In all, five thresholds have been adopted: two threshold values developed by the CCME (1999) and three additional criteria derived using the same database and method, in order to meet sediment management needs specific to Quebec.

For the assessment of sediment quality, the criteria are used in conjunction with the natural and ambient concentrations in sediments at the site under study. Recent samples collected in the fluvial section of the St. Lawrence were used to determine the natural and ambient concentrations present in the pre-industrial sediments and postglacial clays in this sector.

Sediment management in Quebec involves three distinct contexts: prevention of sediment contamination; management of dredged sediments; and remediation of contaminated aquatic sites. Guidelines and recommendations for the application of sediment quality criteria are provided for each of these management contexts.

A more detailed description of the criteria review process, together with all the information compiled during this exercise, is provided in the reference document (EC and MDDEP 2006).

Abstract

This document presents the results of a review of the sediment quality criteria adopted in Quebec in 1992. It describes the new quality criteria adopted by Environment Canada and the Quebec Ministère du Développement durable, de l'Environnement et des Parcs, as well as the process leading to their development. The document also contains unpublished information on the natural and ambient concentrations of various substances in the sediments of the St. Lawrence River. Guidelines and recommendations for interpreting and applying the quality criteria are also presented.

Following an assessment of new data and of sediment quality guidelines developed by other jurisdictions, it was concluded that the interim criteria published in 1992 should be replaced with new quality criteria based on the approach of the Canadian Council of Ministers of the Environment (CCME). In selecting the methodological approach, the task group took into consideration aspects such as data completeness and updating of the CCME's toxicological database, together with the availability of data on freshwater, marine and estuarine environments.

To protect aquatic life, the CCME has derived two reference values for some 30 substances in freshwater and marine sediments: a threshold effect level (TEL) and a probable effect level (PEL). These two values have been adopted for the assessment of sediment quality in Quebec, and three other levels were derived to define all of the intervention levels needed for sediment management in Quebec under a diversity of contexts. The three new sediment quality criteria were defined using the CCME database and a calculation method similar to the one used to determine the TEL and the PEL. They are (1) the rare effect level (REL), (2) the occasional effect level (OEL), and (3) the frequent effect level (FEL).

This set of criteria constitutes a screening tool for assessing the degree of contamination of sediment. Employed in conjunction with natural background levels, these quality criteria can prevent the contamination of sites that are sensitive to inputs of anthropogenic contaminants. The criteria can also be combined with other assessment tools, such as toxicity tests and biological field studies, to determine the most appropriate management method for dredged material based on its degree of contamination. The sediment quality criteria can also serve as indicators of the remedial measures required at contaminated sites and help to define restoration objectives.

Résumé

Ce document présente les résultats de la révision des critères pour l’évaluation de la qualité des sédiments au Québec adoptés en 1992. Au cœur de ce rapport, sont décrits les nouveaux critères de qualité retenus par Environnement Canada et le ministère du Développement durable, de l’Environnement et des Parcs du Québec ainsi que la démarche qui a conduit à leur détermination. S’y trouvent également des informations pertinentes, et dans certains cas inédites, sur les teneurs naturelles et ambiantes de diverses substances présentes dans les sédiments du Saint-Laurent. Des directives et des recommandations pour l’interprétation et l’application des critères de qualité y sont également présentées.

Il a été estimé, après évaluation des nouvelles données disponibles et du développement de critères de qualité par d’autres juridictions, qu’il y avait avantage à remplacer les critères publiés en 1992 par des critères de qualité basés sur l’approche développée par le Conseil canadien des ministres de l’environnement (CCME). L’exhaustivité et la mise à jour potentielle de la banque de données toxicologiques du CCME de même que la disponibilité de données pour les milieux d’eau douce et pour les milieux marins et estuariens ont été des facteurs déterminants dans le choix de l’approche méthodologique.

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Abbreviations

BEDS: Biological Effects Database for Sediments

CCME: Canadian Council of Ministers of the Environment

FEL: frequent effect level

OEL: occasional effect level

PEL: probable effect level

REL: rare effect level

TEL: threshold effect level

Chapter 1

Selection of the Approach to Derive the Sediment Quality Criteria

After evaluating the new data resulting from the development of sediment quality guidelines in other Canadian jurisdictions and elsewhere, the task group mandated with reviewing the interim sediment quality criteria concluded that it would be better to replace the criteria published in 1992 with new sediment quality criteria based on the approach adopted by the Canadian Council of Ministers of the Environment (CCME 1995) to derive its Canadian Sediment Quality Guidelines.

The task group considered the fact that the database used to calculate the Canadian guidelines, the CCME's Biological Effects Database for Sediments, contains a vast amount of data, including data from the Ontario Ministry of the Environment (Jaagumagi 1990a; 1990b), which were used in determining the interim criteria for the assessment of sediment quality in the St. Lawrence in 1992.

The team also considered that the CCME database is likely to be updated regularly, because the protocol for the derivation of Canadian Sediment Quality Guidelines provides for the incorporation of data obtained from spiked-sediment toxicity tests. The group was also sensitive to the fact that the Canadian guidelines establish separate values for freshwater, marine and estuarine environments.

Finally, the task group concluded that the CCME approach also has the advantage of ensuring greater harmonization with provinces that are already using the Canadian guidelines, and greater consistency with Environment Canada's Disposal at Sea Program.

Chapter 2

Development of the Sediment Quality Criteria

The criteria for the assessment of sediment quality in Quebec incorporate the Canadian Sediment Quality Guidelines along with three additional values derived using the same database and an approach similar to that used by the Canadian Council of Ministers of the Environment (CCME).

2.1 The CCME Approach: A Modified Version of the National Status and Trends Program Approach

In 1995, the Canadian Council of Ministers of the Environment (CCME) developed the Protocol for the Derivation of Canadian Sediment Quality Guidelines for the Protection of Aquatic Life. The protocol provides for the use of two complementary approaches to establish links between concentrations of chemicals in sediments and observed effects in benthic and pelagic organisms. At present, only one of these two approaches, a slightly modified version of the National Status and Trends Program (NSTP), is being used to derive the national sediment quality guidelines. The second approach, which centres on spiked-sediment toxicity testing, cannot be used owing to the paucity of data for this type of testing. This is why the CCME has issued interim sediment quality guidelines (CCME 2001a).

The National Status and Trends Program (NSTP) database was created by the National Oceanic and Atmospheric Administration (NOAA) in 1990. Long and Morgan (1990) compiled information from it on the biological effects of sediment-associated contaminants. At the request of Environment Canada, this database was reviewed and expanded by adding new data obtained from other sites or by dealing with additional chemicals or new observations of biological effects. This expanded database, now called the Biological Effects Database for Sediments (BEDS), was used in developing the Canadian Sediment Quality Guidelines (SQGs). BEDS contains various types of data that can be used to establish links between the concentration of a given chemical and the presence or absence of a biological effect. These data come from field studies (species abundance and richness of benthic communities, toxic effects on living organisms, especially on growth, reproduction and survival), spiked-sediment toxicity tests, and equilibrium partitioning models. BEDS also includes sediment quality assessment criteria adopted by other jurisdictions.

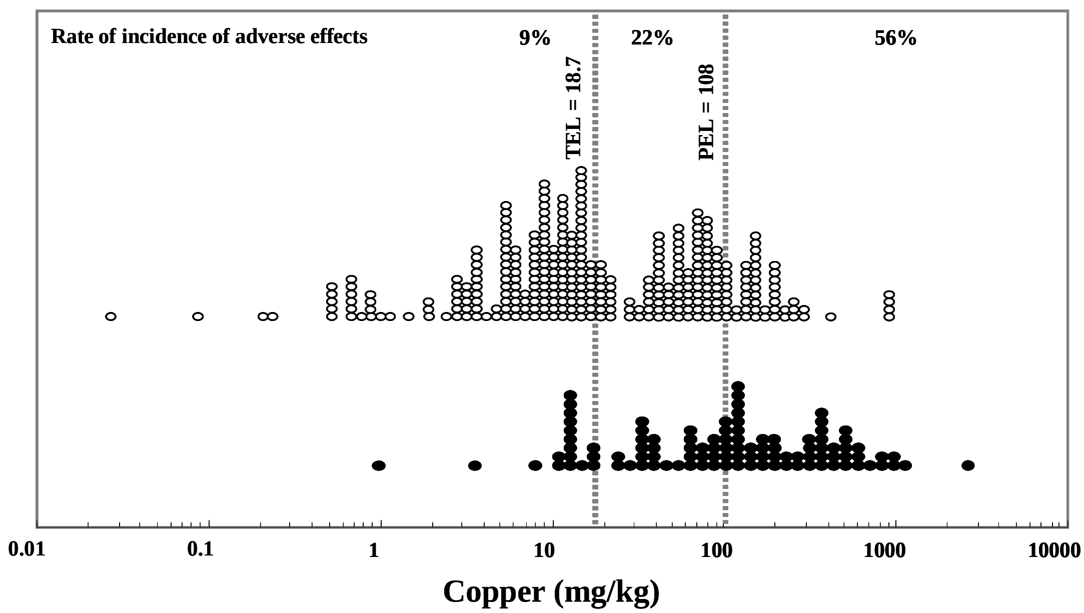
During the construction of BEDS, the acceptability of data was screened using stringent requirements of reliability and accuracy with respect to the experimental design, test protocols, analytical methods and statistical procedures used in each candidate study. Only the data deemed acceptable were incorporated into the corresponding record in BEDS, which includes details on the measured chemical concentration, study location, type of analysis or approach, test duration, the end-point measured, the species and life stage tested, the evidence of observed effects and the study reference. When available, information on sediment characteristics (particle grain-size distribution, total organic carbon, acid volatile sulphide, etc.) and the overlying water column was also compiled. Data in which observed biological effects can be linked to the measured chemical concentration in sediment are called “effect data.” In contrast, data for which no biological effect is observed or data in which there is little or no concordance between the chemical concentrations and the observed biological effects are called “no-effect data.” About 10% of the data in BEDS is derived from Canadian studies while the rest of the research was done in the United States (D. D. MacDonald, personal communication).

For the derivation of the Sediment Quality Guidelines, the CCME opted to use MacDonald’s modified version (1993) of the original NSTP approach (Long and Morgan 1990). In the modified approach, unlike the original one, information is compiled separately for freshwater and marine sediments. The data are divided into two sets: the “effect” data set and the “no-effect” data set. No-effect data are included in this procedure because they are considered to provide relevant information for defining the relationship between contaminating substances and biotic responses (MacDonald 1994). A minimum amount of data must be available to provide the “weight of evidence” supporting the association between concentrations of chemicals in sediments and biological effects, and hence to ensure adequate protection of aquatic species. The database must comprise at least 20 “effect” entries and 20 “no-effect” entries for each chemical under study. When this requirement is met, two reference values are established. The first value defines the **threshold effect level** (TEL) and the second the **probable effect level** (PEL).

Three ranges of chemical concentrations are defined for the TEL and the PEL: (1) the lowest range of concentrations, within which adverse effects are rarely observed; (2) the possible effects range, between the TEL and the PEL, within which adverse effects are occasionally observed; and (3) the probable effects range, within which adverse biological effects are frequently observed. The definition of these ranges is based on the premise that the probability of toxic effects resulting from exposure to a given chemical increases with the concentration of that substance in sediments. Figure 1 gives an example of the distribution of effect data and no-effect data according to ascending chemical concentrations.

In order to ensure that the TEL and the PEL obtained for each chemical identify ranges in chemical concentrations that satisfy their narrative definitions, the incidence of adverse effects is calculated for each range of concentrations (CCME 2002a). The incidence of adverse effects is determined by calculating the percentage represented by the number of effect data entries relative to the entire data set (effect data + no-effect data) present in a given range of concentrations (Figure 1). For most substances, the incidence of adverse effects is 10% or less for the range of concentrations below the TEL (biological effects are rarely observed), satisfying the narrative definition of the TEL. For the range of concentrations above the PEL (biological effects are frequently observed), the incidence of adverse effects varies considerably among chemicals, and is sometimes lower than 50%, especially for freshwater sediments (CCME 2002a). The low incidence of adverse effects observed for a number of substances in this range indicates that the degree of correspondence between the values obtained for the PEL and the narrative definition of the PEL (concentration above which adverse effects are usually observed) is occasionally somewhat weaker than in the case of the TEL.

To address these various uncertainties (e.g. failure to satisfy the narrative definition of the TEL), the CCME protocol provides that a safety factor may be applied to the two threshold values obtained (CCME 1995, Appendix C). This is done in the case of dioxins and furans (PCDD/PCDF)[1]. The current threshold effect level constitutes the Interim Sediment Quality Guideline (ISQG). In some cases where the National Status and Trends Program (NSTP) approach cannot be used owing to a lack of data, the CCME may either use sediment quality criteria established by other jurisdictions (as was done for Arochlor 1254 and toxaphene) or use the equilibrium partioning method (as was done for nonylphenol).



Source: Adapted from CCME 1999.

Figure 1 Distribution of copper concentrations in marine and estuarine sediments associated with adverse biological effects (●) and no adverse biological effects (o)

2.2 The Quebec Approach: The CCME Approach with Additional Reference Values

It was decided that the CCME's two reference values, namely the TEL and the PEL, should be adopted as criteria for sediment quality assessment in Quebec. However, because these two values alone are insufficient to address all of the different sediment management contexts in Quebec, three additional reference values have been added to cover all of the management needs associated with the following three contexts:

[1] In deriving Interim Sediment Quality Guidelines for dioxins and furans, a safety factor of 10 was applied to the TEL and the PEL because a significant proportion of observations (79%) did not correspond with the narrative definition of the TEL, with concentrations being lower than the TEL in Canadian sediments, and because of uncertainty related to the bioaccumulation and biomagnification of dioxins and furans.

a) **Prevention of sediment contamination from industrial discharges**:

To prevent sediment contamination resulting from industrial-source discharges into a watercourse, the quality criteria are supported by chemical analyses which make it possible to monitor the status of vulnerable sites and provide advance warning of incipient contamination. Monitoring may be initiated even before the TEL is reached. A new threshold that is even lower than the TEL has been derived: the **rare effect concentration** (REL).

The REL and the TEL are the two signposts for preventing contamination.

b) **Management of dredged sediment**:

Open-water disposal of dredged sediment is prohibited except where the material presents no threat to aquatic biota. A contamination threshold needs to be identified beyond which toxicity testing is mandatory. Since past experience has shown that most toxicity tests are not very sensitive to low levels of contamination, a value higher than the TEL, but lower than the PEL, has been calculated in order to derive a new reference value. The **occasional effect concentration** (OEL) is the concentration above which adverse effects are anticipated in many benthic species.

In addition, to facilitate the management of dredged sediment, it is necessary to determine a sufficiently high threshold of contamination above which open-water disposal is prohibited, without the need for additional analyses. Since the PEL is not a high enough threshold for this type of decision, a new reference value has been derived: the **frequent effect concentration** (FEL), or the concentration above which adverse effects are anticipated for the majority of benthic species.

The OEL and the FEL are the two threshold values governing the management of dredged sediment disposal.

c) **Remediation of contaminated aquatic sites**

The decision to remediate a contaminated site is generally made after an in-depth analysis concludes that the advantages of restoring the site outweigh the disadvantages. While exceedance of the PEL signals the need to undertake such studies, a higher reference value (i.e. the FEL), indicates that the site should be remediated and that feasibility studies should therefore be undertaken.

The PEL and the FEL are the two threshold values that can be used to provide guidance for remediation decisions.

These three new reference values are designed to be used in conjunction with the TEL and the PEL established by the CCME, bringing to five the number of reference values used for sediment management in Quebec. Nonetheless, only two reference values are used in each of the three sediment management contexts described in this document. It is therefore necessary to determine the context in which the situation under study applies in order to select the requisite quality criteria. The frameworks for managing and applying quality criteria for the three contexts are detailed in sections 5.2, 5.3 and 5.4, and illustrated in Table 5.

2.3 Derivation of the Five Sediment Quality Criteria

In establishing the Canadian Guidelines (CCME 1999), the threshold effect level (TEL) and the probable effect level (PEL) were calculated by taking the geometric mean of two values: one derived from the effect data set and the other from the no-effect data set. For consistency, the three additional reference values—the rare effect level (REL), the occasional effect level (OEL), and the frequent effect level (FEL)—were defined using BEDS data and a calculation method similar to that used for the TEL and the PEL. The five sediment quality criteria values are obtained using the following formulas:

$$\mathbf{REL} = \sqrt{(E_{15} \times NE_{15})}$$

$$\mathbf{TEL} = \sqrt{(E_{15} \times NE_{50})}$$

$$\mathbf{OEL} = \sqrt{(E_{50} \times NE_{50})}$$

$$\mathbf{PEL} = \sqrt{(E_{50} \times NE_{85})}$$

$$\mathbf{FEL} = \sqrt{(E_{85} \times NE_{85})}$$

Where E_{15}: 15th percentile of the effect data set
E_{50}: 50th percentile of the effect data set
E_{85}: 85th percentile of the effect data set
NE_{15}: 15th percentile of the no-effect data set
NE_{50}: 50th percentile of the no-effect data set
NE_{85}: 85th percentile of the no-effect data set

The five quality criteria values calculated for over 30 substances in freshwater sediments and marine sediments are presented in tables 1 and 2, respectively.

2.4 Derivation of a Reference Value for Nickel

In the St. Lawrence River, nickel is generally associated with postglacial clays; the dispersion of these clays leads to the enrichment of the sediments of the river bed. Nickel is sometimes one of the main contaminants present in sediments, and as such it is among the substances routinely analysed during sediment quality studies (Section 5.1). It is therefore important to have reference values that can be used to estimate the degree of toxicity associated with the nickel concentrations measured in sediments.

Since the CCME has not established a TEL or a PEL for nickel and the BEDS database cannot be used to calculate the REL, the OEL or the FEL, the possibility of adopting values established by other jurisdictions, on an interim basis, was considered. However, given the specific nature of the nickel situation in the St. Lawrence River, it seemed more appropriate to establish a threshold value to guide decisions on the management of dredged material (Section 4.1) using known natural concentrations in the St. Lawrence. Consequently, only an OEL has been calculated for freshwater sediments; it is based on the geometric mean (47 mg/kg) (Table 1) of the natural concentration in pre-industrial sediments (29 mg/kg) and the natural concentration in postglacial clays (75 mg/kg) (Table 3).

This value is comparable to the values advanced by other jurisdictions that determine concentrations above which adverse effects are likely to be observed (e.g. the PEL). According to MacDonald et al. (2000), these values range from 33 to 75 mg/kg for freshwater sediments.

Table 1 Criteria for the assessment of freshwater sediment quality

Group	Substance	Concentrations (mg/kg)[a,b] REL	TEL	OEL	PEL	FEL
Metals and metalloids	Arsenic	4.1	5.9	7.6	17	23
	Cadmium	0.33	0.60	1.7	3.5	12
	Chromium	25	37	57	90	120
	Copper	22	36	63	200	700
	Lead	25	35	52	91	150
	Mercury*	0.094	0.17	0.25	0.49	0.87
	Nickel	ND	ND	47	ND	ND
	Zinc	80	120	170	310	770
Organic compounds	Total polychlorinated biphenyls (PCBs)*	0.025	0.034	0.079	0.28	0.78
	Nonylphenol and its ethoxylates [c]	ND	1.4	ND	ND	ND
	PCDD/PCDF (ng tox eq/kg)* [d]	0.27	0.85	10	22	36
Polycyclic aromatic hydrocarbons	Acenaphthene [e]	0.003 7	0.006 7	0.021	0.089	0.94
	Acenaphthylene [e]	0.003 3	0.005 9	0.030	0.13	0.34
	Anthracene [e]	0.016	0.047	0.11	0.24	1.1
	Benzo[a]anthracene	0.014	0.032	0.12	0.39	0.76
	Benzo[a]pyrene	0.011	0.032	0.15	0.78	3.2
	Chrysene	0.026	0.057	0.24	0.86	1.6
	Dibenzo[a,h]anthracene [e]	0.003 3	0.006 2	0.043	0.14	0.20
	Fluoranthene	0.047	0.11	0.45	2.4	4.9
	Fluorene [e]	0.010	0.021	0.061	0.14	1.2
	2-Methylnaphthalene [e]	0.016	0.020	0.063	0.20	0.38
	Naphthalene [e]	0.017	0.035	0.12	0.39	1.2
	Phenanthrene	0.025	0.042	0.13	0.52	1.1
	Pyrene	0.029	0.053	0.23	0.88	1.5
Organochlorine pesticides	Chlordane	0.001 5	0.004 5	0.006 7	0.008 9	0.015
	DDD* [f]	0.000 35	0.003 5	0.008 5	0.008 5	0.015
	DDE* [g]	0.000 25	0.001 4	0.002 6	0.006 8	0.019
	DDT* [e, h]	0.000 33	0.001 2	0.003 8	0.004 8	0.010
	Dieldrin*	0.000 44	0.002 9	0.003 9	0.006 7	0.017
	Endrin	0.000 63	0.002 7	0.036	0.062	0.33
	Heptachlor epoxide	0.000 26	0.000 60	0.002 7	0.002 7	0.004 0
	Lindane	0.000 22	0.000 94	0.001 4	0.001 4	0.011
	Toxaphene* [i]	ND	0.000 10	ND	ND	ND

REL: rare effect level; TEL: threshold effect level; OEL: occasional effect level; PEL: probable effect level; FEL: frequent effect level

* For these persistent, bioaccumulative and toxic substances (SLV 2000 1999), bioaccumulation effects may be observed in aquatic, avian and terrestrial consumers at various trophic levels. These effects are not taken into consideration in the quality criteria presented here. Information on this subject is presented in Section 3.1 and in point 2 of Section 5.2.

[a] The values have been rounded to two significant digits. The shaded columns contain the CCME values and the non-shaded columns the additional reference values.

[b] All the values are expressed as milligrams per kilogram (mg/kg) of dry sediment, except for the PCDD/PCDF values, which are expressed as nanograms per kilogram (ng tox eq/kg).

[c] Value determined by the CCME (2002b) using the equilibrium partitioning method and assuming a total organic carbon (TOC) level of 1%. The calculation is based on toxicity equivalency factors (Appendix 1).

[d] PCDD/PCDF: Polychlorinated dibenzo-p-dioxins/polychlorinated dibenzofurans; values are expressed in toxicity equivalency units (1). In accordance with the CCME protocol, the initial values obtained during the calculation of quality criteria were divided by a safety factor of 10.

[e] The values calculated for marine sediments were adopted by default.

[f] DDD: 2,2-bis(p-chlorophenyl)-1,1-dichloroethane or dichlorodiphenyldichloroethane. This criterion applies to the sum of the p,p' and o,p' isomers.

[g] DDE: 1,1-dichloro-2,2,bis(p-chlorophenyl)ethylene or dichlorodiphenyldichloroethylene. This criterion applies to the sum of p,p' and o,p' isomers.

[h] DDT: 2,2-bis(p-chlorophenyl)-1,1,1-trichloroethane or dichlorodiphenyltrichloroethane. This criterion applies to the sum of the p,p' and o,p' isomers.

[i] New York State Department of Environmental Conservation (1994) value adopted by the CCME (2002c). The value was derived by using the equilibrium partitioning method and assuming a total organic carbon (TOC) level of 1%.

ND: Not determined.

Table 2 Criteria for the assessment of marine sediment quality

Group	Substance	REL	TEL	OEL	PEL	FEL
				(mg/kg) [a, b]		
Metals and metalloids	Arsenic	4.3	7.2	19	42	150
	Cadmium	0.32	0.67	2.1	4.2	7.2
	Chromium	30	52	96	160	290
	Copper	11	19	42	110	230
	Lead	18	30	54	110	180
	Mercury*	0.051	0.13	0.29	0.70	1.4
	Nickel	ND	ND	ND	ND	ND
	Zinc	70	120	180	270	430
Organic compounds	Total polychlorinated biphenyls (PCBs)*	0.012	0.022	0.059	0.19	0.49
	Nonylphenol and its ethoxylates [c]	ND	1	ND	ND	ND
	PCDD/PCDF (ng tox eq/kg)* [d, h]	0.27	0.85	10	22	36
Polycyclic aromatic hydrocarbons	Acenaphthene	0.003 7	0.006 7	0.021	0.089	0.94
	Acenaphthylene	0.003 3	0.005 9	0.031	0.13	0.34
	Anthracene	0.016	0.047	0.11	0.24	1.1
	Benzo[a]anthracene	0.027	0.075	0.28	0.69	1.9
	Benzo[a]pyrene	0.034	0.089	0.23	0.76	1.7
	Chrysene	0.037	0.11	0.30	0.85	2.2
	Dibenzo[a,h]anthracene	0.003 3	0.006 2	0.043	0.14	0.20
	Fluoranthene	0.027	0.11	0.50	1.5	4.2
	Fluorene	0.010	0.021	0.061	0.14	1.2
	2-Methylnaphthalene	0.016	0.020	0.063	0.20	0.38
	Naphthalene	0.017	0.035	0.12	0.39	1.2
	Phenanthrene	0.023	0.087	0.25	0.54	2.1
	Pyrene	0.041	0.15	0.42	1.4	3.8
Organochlorine pesticides	Chlordane	0.000 92	0.002 3	0.003 3	0.004 8	0.016
	DDD* [e]	0.000 63	0.001 2	0.004 0	0.007 8	0.028
	DDE* [f]	0.000 79	0.002 1	0.074	0.37	0.56
	DDT* [g]	0.000 33	0.001 2	0.003 8	0.004 8	0.010
	Dieldrin*	0.000 38	0.000 71	0.002 0	0.004 3	0.006 0
	Endrin [h]	0.000 63	0.002 7	0.036	0.062	0.33
	Heptachlor epoxide [h]	0.000 26	0.000 60	0.002 7	0.002 7	0.004 0
	Lindane	0.000 22	0.000 32	0.000 51	0.000 99	0.001 9
	Toxaphene* [i]	ND	0.000 10	ND	ND	ND

* For these persistent, bioaccumulative and toxic substances (SLV 2000 1999), bioaccumulation effects may be observed in aquatic, avian and terrestrial consumers at various trophic levels. These effects are not taken into consideration in the quality criteria presented here. Information on this subject is presented in Section 3.1 and in point 2 of Section 5.2.

[a] The values have been rounded to two significant digits. The shaded columns contain the CCME values and the non-shaded columns the additional reference values.

[b] All values are expressed as milligrams per kilogram (mg/kg) of dry sediment, except for the PCDD/PCDF values, which are expressed as nanograms per kilogram (ng tox eq/kg).

[c] Value determined by the CCME (2002b) using the equilibrium partitioning method and assuming a total organic carbon (TOC) level of 1%. The calculation is based on toxicity equivalency factors (Appendix 1).

[d] PCDD/PCDF: Polychlorinated dibenzo-p-dioxins/polychlorinated dibenzofurans; values are expressed in toxicity equivalency units (1). In accordance with the CCME protocol, the initial values obtained during the calculation of quality criteria were divided by a safety factor of 10.

[e] DDD: 2,2-bis(p-chlorophenyl)-1,1-dichloroethane or dichlorodiphenyldichloroethane. This criterion applies to the sum of p,p’ and o,p’ isomers.

[f] DDE: 1,1-dichloro-2,2,bis(p-chlorophenyl)ethylene or dichlorodiphenyldichloroethylene. This criterion applies to the sum of the p,p’ and o,p’ isomers.

[g] DDT: 2,2-bis(p-chlorophenyl)-1,1,1-trichloroethane or dichlorodiphenyltrichloroethane. This criterion applies to the sum of the p,p’ and o,p’ isomers.

[h] The values calculated for freshwater sediments were adopted by default.

[i] New York State Department of Environmental Conservation (1994) value adopted by the CCME (2002c). The value was derived by using the equilibrium partitioning method and assuming a total organic carbon (TOC) level of 1%.

ND: Not determined.

Scope and Limitations of the Sediment Quality Criteria

3.1 Scientific Scope of the Quality Criteria

Sediment quality criteria (SQC) constitute one of the tools currently available for assessing sediment quality. They are used to assess the chemical contamination of sediments and define appropriate management thresholds according to the degree of contamination. Other tools, such as toxicity tests and biological field studies, can also be used to assess sediment quality and the effects of sediment contamination on aquatic organisms. Each of these tools provides specific information, and it is often necessary to use several of them to obtain complementary information for analysing the situation in greater depth.

TOOL	SCOPE	LIMITATIONS
Chemical quality criteria specific to each substance	• Cover a wide range of species and effects for a particular contaminant. • Identify substances of concern. • Guide mitigation measures since one or more substances are identified. • Help to determine management thresholds (e.g. remediation threshold, restrictions on open-water disposal). • Can be used to prevent contamination at a specific site. • Take bioavailability of contaminants partially into account since many data come from the environment. • Inexpensive when the number of contaminants to be analysed is low.	• Consider only known contaminants selected for analysis. • Do not take into account the bioavailability of the contaminants specific to the sediment under study. • Do not take into account bioaccumulation and contamination of organisms for human consumption or piscivorous wildlife. • Do not systematically incorporate the combined toxic effects of several substances. • Costs can be high if the number of contaminants to be analysed is high.
Sediment toxicity tests	• Simultaneously incorporate the toxic effects of a number of substances. • Also measure the effects of unknown contaminants. • Measure the effects of contaminants for which there are no chemical criteria. • Take account of the bioavailability of the sediment contaminants under study. • Measure the actual toxicity of the sediments tested. • Can take bioaccumulation into account and prevent the contamination of organisms.	• Represent a limited toxicological pattern (only a few species and a few effects are tested). • Do not provide direct guidance for mitigation measures, such as treatment technologies, since they do not identify the substance(s) involved. • Do not provide information on the cause of the contamination.
Biological field studies	• Measure the effects present in the environment. • Incorporate long-term effects and identify trends over time. • Incorporate the effects of all sources, including unknown sources. • Incorporate the effects of all other possible stresses (e.g. degradation of the physical environment, parasitism) in addition to those associated with toxic contaminants.	• Do not assess short-term effects. • Do not identify a single cause for the observed effect. • Do not always distinguish between sources. • Effects are measured only after they have occurred (not preventive). • Large budgets are required to obtain a good level of discrimination.

The limitations of SQC as a sediment quality assessment tool are described below.

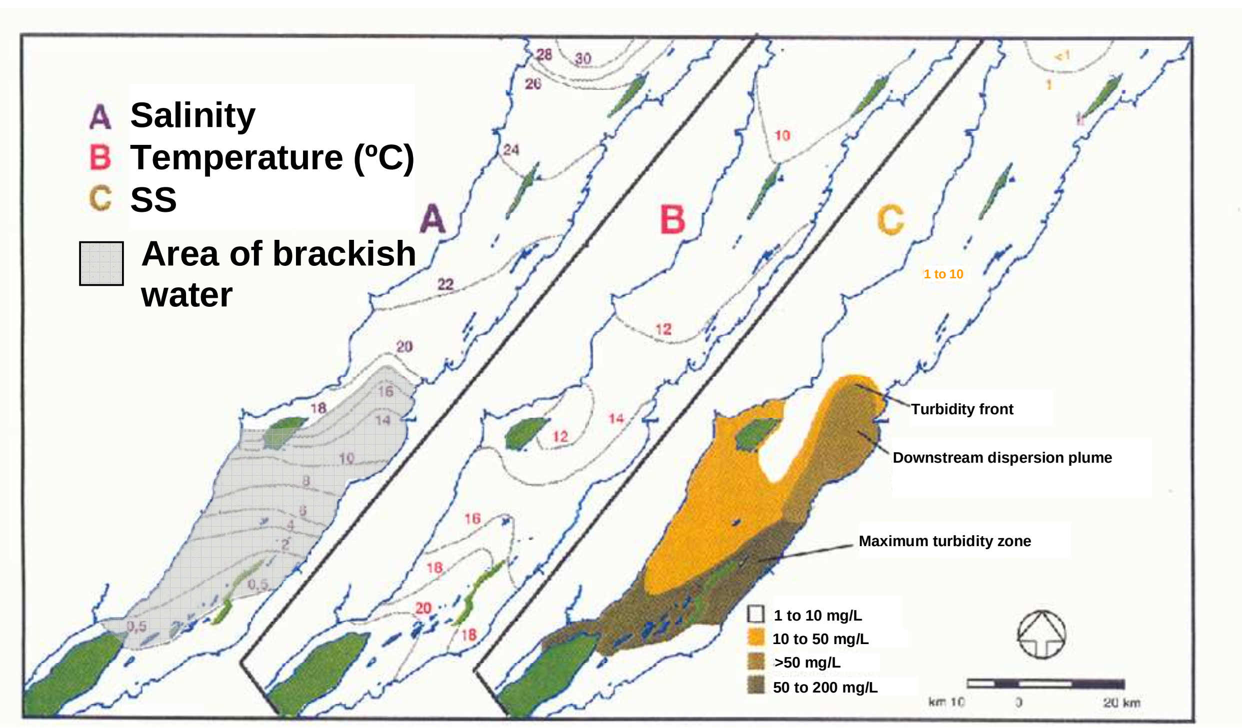
- The quality criteria described in this document are intended to protect aquatic life from the toxic effects of chemicals. Such substances can also have aesthetic, organoleptic and physical effects on the quality of the environment or on aquatic organisms. When well documented, these effects may be considered on a case-by-case basis.
- Sediments that meet chemical quality criteria are generally of good quality. However, the absence of toxic substances does not mean that an aquatic ecosystem is free from disturbances. Other potential disturbances include habitat loss, dredged material disposal, and a significant increase in the concentration of suspended solids (SS). Considerations related to maintaining the health of an ecosystem in order to protect aquatic life and human health, a specific use of the site in question or the need to protect vulnerable or threatened species may entail the adoption of specific mitigation measures or additional actions.
- At no time should the SQC be considered implicit approval to allow a site to degrade until it reaches the adopted threshold values.
- The quality criteria presented here do not address the issues of bioaccumulation or biomagnification in the food chain. Some highly bioaccumulative substances may not have any direct effect on benthic organisms that are continuously exposed to very small doses of those substances. The organisms nonetheless accumulate the substances in their tissues and pass on concentrated amounts of the chemicals to predators that feed on them. In general, the data underpinning the quality criteria in this document stem from observed effects in benthic organisms or pelagic larval stages, rather than in organisms representing different levels of the food chain. It is therefore probable that, in the case of highly bioaccumulative substances, these quality criteria cannot be used to prevent the contamination of organisms that will be eaten by species higher up the food chain (benthivorous and piscivorous organisms, avian fauna, terrestrial fauna and humans). There is a need to use other tools, such as bioaccumulation tests, in some assessments of sediment quality. In addition, the CCME has developed Canadian tissue residue guidelines aimed at protecting wildlife species that consume aquatic biota (CCME 2001b); the guidelines apply to several highly bioaccumulative substances including polychlorinated biphenyls, dichlorodiphenyltrichloroethane, methylmercury, polychlorinated dioxins and furans and toxaphene. To round out the assessment of contamination at a given site, the tissue residue guidelines can be used in conjunction with the sediment quality criteria described in this document.
- Although the quality criteria were derived on a case-by-case basis for individual substances, the additive, synergistic or antagonistic effects of a number of substances are taken into account to a certain extent, because the data used for the calculations come from sediments typically contaminated with several chemicals. Nonetheless, the combinations of substances vary from site to site, and the prevailing conditions at a given site may differ considerably from those represented by the quality criteria. Toxicity tests done on sensitive species using the sediments collected at a given site can help to identify the interactive effects of several chemicals. To identify site-specific problems more effectively, factors affecting the bioavailability of chemicals can be taken into consideration (Section 3.3).

3.2 Geographic Limitations of the Sediment Quality Criteria

Given that the quality criteria were established using data from a variety of sources, they can be used to assess sediment quality in any body of water in Quebec in conjunction with background (natural) or regional ambient levels (Chapter 4).

The quality criteria for freshwater sediments and those for marine sediments can be applied to three sections of the St. Lawrence River, as described below.

- The St. Lawrence River receives only freshwater inflows in the area extending from the outlet of the Great Lakes to the eastern tip of Île d'Orléans. The criteria for freshwater sediments apply to this part of the St. Lawrence, which comprises the fluvial section (from the outlet of the Great Lakes to downstream of Lake Saint-Pierre) and the fluvial estuary (from downstream of Lake Saint-Pierre to the eastern tip of Île d'Orléans).
- The upstream part of the upper estuary, which is characterized by a mixture of salt and fresh water, extends from the eastern tip of Île d'Orléans to Île aux Coudres. Salinity varies along a longitudinal gradient between < 1‰ at Île d'Orléans and 15‰ at Île aux Coudres (Ouellet and Cerceau 1976; Gagnon et al. 1998; Leclerc 2000) (Figure 2). Although the ichthyofauna of the brackish water characterizing this sector is dominated by freshwater species, a number of diadromous and marine species are present as well (Leclerc 2000). In order to protect all of the species that occur in this section, the strictest quality criteria for both freshwater and marine sediments should be used for every substance analysed.



Sources: Taken from Gagnon et al. (1998). Adapted from Lavoie and Beaulieu (1971), Bousfield et al. (1975), Greisman and Ingram (1977), Gagnon et al. (1983), and Fortier and Gagné (1990) for salinity; adapted from Vigeant (1984) for temperature; adapted from Soucy et al. (1976) and d'Anglejan (1981) for suspended solids.

Figure 2 Salinity, temperature and SS gradients in the St. Lawrence upper estuary

- Downstream of Île aux Coudres, salinity increases rapidly, attaining 27‰ at the mouth of the Saguenay River. Marine sediment quality criteria are used for the entire zone encompassing the lower part of the upper estuary (from Île aux Coudres to the Saguenay), the saltwater estuary (from the Saguenay to Anticosti Island), and the Gulf of St. Lawrence.

3.3 Physico-chemical Limitations of the Quality Criteria

3.3.1 Sediment particle grain size

Quality criteria developed using data for sediments with a highly variable particle grain-size distribution can be applied to all types of sediments, except sediment with grains larger than 2 mm. Given the wide range of particle sizes in the sediment used for the derivation of quality criteria, it would be inappropriate to normalize the results of chemical analyses based on sediment particle size distribution. Particle size analysis of sediments is performed primarily to assess sediment dynamics at a study site.

3.3.2 Adjustment of chemical results based on the concentration of total organic carbon in the sediment sample

Although the total organic carbon (TOC) in sediment can reduce the bioavailability of nonpolar organic substances and thus lower their toxicity to benthic organisms, the data used to establish the sediment quality criteria are insufficient to quantify or predict the effect of this parameter on contaminant toxicity (CCME 1995). Consequently, the criteria for polycyclic aromatic hydrocarbons (PAHs) and other organic compounds, with the exception of toxaphene and nonylphenol, should not be adjusted based on the level of TOC. Considering that the TELs for toxaphene and nonylphenol and its ethoxylates were calculated using a TOC of 1% in sediments, the quality criterion value can be corrected by multiplying the TEL by the TOC of the sample, up to a maximum TOC value of 10%.

3.3.3 Factors affecting contaminant bioavailability and toxicity for aquatic organisms

In addition to particle size distribution and total organic carbon, other factors such as redox conditions and pH, as well as the presence of acid volatile sulphide (AVS) and iron or manganese oxides, are known to affect the bioavailability and toxicity of chemicals for aquatic organisms. Although all of these characteristics are incorporated into the sediment quality criteria, since they are based on data compiled from a variety of environments, it may be useful to give greater consideration to specific factors at a given site, even if the data available at present do not allow correction factors to be established to adjust the quality criteria for the parameters listed below.

Factors affecting the bioavailability and toxicity of contaminants for aquatic organisms

Redox conditions and pH: A decrease in pH and an increase in redox potential in the ambient environment can release the metals bound to sediments, increasing their bioavailability and their potential to cause adverse effects in benthic organisms. The main metals and metalloids known to be affected by redox conditions and pH are arsenic, cadmium, chromium, mercury, lead and zinc.

Acid volatile sulphide (AVS): AVS affects the toxicity of cationic trace metals since these metals can form complexes with sulphide. They then become less bioavailable and therefore less toxic for aquatic organisms. The main substances known to be affected by AVS are cadmium, copper, mercury and zinc.

Presence of iron oxides and/or manganese oxides: The metals present in the sediments can be strongly bound to iron oxide and manganese oxide particles. The main substances known to be affected by the presence of iron oxides and/or manganese oxides are arsenic, chromium, lead and zinc.

Chapter 4

Determination of Natural and Ambient Levels

A concentration is said to be "natural" when the sediment has not undergone any anthropogenic chemical alteration or modification. In practical terms, natural concentrations are those measured in pre-industrial sediments.

The "ambient" concentration is a value that characterizes the distribution of levels of a chemical element or chemical compound in the surficial sediments of a region. The source of these chemicals may be natural and/or anthropogenic, and their presence is the result of diffuse enrichment, affecting the entire region, rather than a localized or point source contamination generated by a local source.

During the quality criteria review process, the values corresponding to natural and ambient concentrations were determined only for regions for which data on natural levels could be obtained from statistical studies.

4.1 Natural Levels

Two types of sediment in the St. Lawrence River are characterized by natural concentrations. The first type is the postglacial clays that were deposited in the Champlain Sea over 8000 years ago. These sediments can be identified on the basis of their physical and chemical properties (Appendix 2). The second type consists of more recent sediments dating back to the pre-industrial era (before 1920) that formed thin deposits on the beds of fluvial lakes. Most of the pre-industrial sediment data relate to sediments that accumulated in permanent deposition zones in the fluvial section, the fluvial estuary and the Laurentian Channel in the Gulf of St. Lawrence. These data do not permit individual characterization of the fluvial lakes or of specific sections of the St. Lawrence.

Sediment samples collected in the St. Lawrence between 1999 and 2001 can be used to determine the natural levels in the zone encompassing the fluvial section and the fluvial estuary. In these sectors, core samples of postglacial clays and pre-industrial sediments were obtained, processed separately and analysed for 27 inorganic substances. In addition, 22 polycyclic aromatic hydrocarbons (PAHs) were analysed in the pre-industrial sediments (Saulnier and Gagnon 2006).

For the determination of natural levels, the 90th percentile of the data was adopted in order to minimize the effect of potential outliers and to characterize the highest possible natural levels by excluding improperly analysed samples.

Table 3 presents the total extractable concentrations[2] for metals other than mercury and the total concentrations for mercury and PAHs[3]. These values can be used as the natural levels for the

[2] The total extractable concentration of a metal is the concentration measured after aqua regia (HNO_3 and HCl) extraction without dissolving the silica matrix (CEAEQ 2006).

entire fluvial section and the fluvial estuary. Note that the chromium, copper, nickel and zinc levels are higher in postglacial clays than in pre-industrial sediments, owing to differences in the mineralogy and in the sources of the materials that make up the sediment matrix (Saulnier and Gagnon 2003).

Available data on the natural levels of substances in the sediments of the St. Lawrence estuary and gulf relate to very fine-grained sediments collected at depths of up to 300 m in the middle of the Laurentian Channel, between the mouth of the Saguenay River and Cabot Strait (Gobeil 1991; 2000). This type of sediment is generally not representative of the sediments likely to be dredged along the coast. The data are presented as total concentrations in Appendix 3 for information purposes only and they apply solely to the Laurentian Channel. Since no statistical studies have been done to determine the natural levels in the sediments of coastal zones in the estuary and gulf (areas where dredging and other activities are likely to be undertaken), no value has been defined for these sectors.

4.2 Ambient Levels

The data on ambient levels of substances in the fluvial section of the St. Lawrence were collected between 1999 and 2003 from surficial sediment sampling stations laid out in a systematic grid pattern in the different fluvial lakes. In all, 249 sediment samples were analysed for metals, metalloids and PAHs (Pelletier and Lepage 2002; Pelletier 2006).

The ambient concentrations (Table 4) correspond to the 75th percentile of the data and thus exclude samples from zones potentially affected by local contamination or samples affected by analytical errors. The use of this percentile ensures that the metal analysis results are total concentrations (as in the case of natural levels) rather than total extractable concentrations[4].

As in the case of natural-level data, the ambient-level data available for the St. Lawrence estuary and gulf correspond to sediments collected in the middle of the Laurentian Channel (Gobeil 1991; 2000) and they are not representative of coastal zones where dredging is likely to be undertaken. Therefore, these data are presented in Appendix 3 for information purposes only and they apply solely to the Laurentian Channel. As in the case of natural levels in the Laurentian Channel, the values correspond to total concentrations.

[3] The total concentration of a metal is the concentration measured after complete extraction of the sample, including the silica matrix, using hydrofluoric acid (HF) or perchloric acid ($HClO_4$) (CEAEQ 2006).

[4] The total concentrations of the metals present in St. Lawrence sediments are generally 10% higher than the total extractable concentrations (C. Gagnon, personal communication).

Table 3 Natural levels of substances in sediments from the fluvial section and the fluvial estuary of the St. Lawrence

Group	Substance[a]	Concentrations (mg/kg)[b]	
		Pre-industrial sediment	Postglacial clays
Metals and metalloids[c]	Aluminum	23 000	48 000
	Arsenic	**6.6**	**8.0**
	Barium	150	350
	Beryllium	0.82	2.1
	Cadmium	**0.20**	**0.20**
	Calcium	15 000	29 000
	Chromium	**60**	**150**
	Cobalt	13	27
	Copper	**19**	**54**
	Gallium	8.7	19
	Iron	30 000	56 000
	Lanthanum	37	56
	Lead	**13**	**16**
	Lithium	22	72
	Magnesium	10 000	25 000
	Manganese	550	1 100
	Mercury	**0.083**	**0.021**
	Nickel	**29**	**75**
	Phosphorus	960	1 100
	Potassium	6 100	14 000
	Rubidium	39	99
	Sodium	850	2 200
	Strontium	59	110
	Thallium	0.16	0.36
	Uranium	1.1	1.7
	Vanadium	73	120
	Zinc	**86**	**150**
PAHs	**Acenaphthene**	**0.0070**	-
	Acenaphthylene	**< 0.0020**	-
	Anthracene	**0.036**	-
	1,2-Benzanthracene-7,12-dimethyl	< 0.002	-
	Benzo[*a*]anthracene	**0.020**	-
	Benzo[b+j+k]fluoranthene	0.14	-
	Benzo[ghi]perylene	0.059	-
	Benzo[c]phenanthrene	< 0.0020	-
	Benzo[a]pyrene	**0.062**	-
	Chrysene	**0.075**	-
	Dibenzo[a,h]anthracene	**0.011**	-
	Dibenzo[a,h]pyrene	< 0.0040	-
	Dibenzo[a,i]pyrene	< 0.0050	-
	Dibenzo[a,l]pyrene	< 0.0030	-
	Fluoranthene	**0.13**	-
	Fluorene	**0.020**	-
	Indeno[1,2,3-cd]pyrene	0.062	-
	3-Methylcholanthrene	< 0.0050	-
	2-Methylnaphthene	**0.020**	-
	Naphthalene	**0.019**	-
	Phenanthrene	**0.10**	-
	Pyrene	**0.15**	-
Other parameter	Total organic carbon (%)	1.3	0.61

Source: Saulnier and Gagnon 2003.

a Substances in bold are those for which one or more quality criteria have been derived (Table 1).

b The values have been rounded to two significant digits.

c The values correspond to total extractable concentrations (extraction using a mixture of nitric acid and hydrochloric acid, also known as *aqua regia*) for all metals except mercury. The mercury values represent the total concentration.

Table 4 Ambient levels of substances in sediments in the St. Lawrence fluvial lakes

Group	Substance[a]	Concentrations (mg/kg)[b]		
		Lake Saint-François	**Lake Saint-Louis**	**Lake Saint-Pierre**
Metals and metalloids[c]	Aluminum	58 000	70 000	71 000
	Antimony	0.50	0.50	0.20
	Arsenic	**5.0**	**7.0**	**2.0**
	Barium	630	720	820
	Beryllium	1.5	1.8	1.8
	Bismuth	< 0.10	0.20	< 0.10
	Cadmium	**0.80**	**1.0**	**0.40**
	Calcium	52 000	37 000	24 000
	Chromium	**52**	**93**	**66**
	Cobalt	9.6	20	13
	Copper	**27**	**41**	**24**
	Gallium	15	20	17
	Iron	26 000	47 000	34 000
	Lanthanum	29	58	36
	Lead	**25**	**38**	**19**
	Lithium	19	35	21
	Magnesium	15 000	17 000	12 000
	Manganese	560	1 100	720
	Mercury	**0.15**	**0.19**	**0.044**
	Molybdenum	0.90	1.1	0.70
	Nickel	**28**	**20**	**26**
	Phosphorus	1 100	1 300	1 000
	Potassium	20 000	23 000	22 000
	Rubidium	66	100	68
	Sodium	18 000	17 000	24 000
	Strontium	330	320	400
	Thallium	0.44	0.61	0.38
	Uranium	1.7	2.3	1.5
	Vanadium	58	97	78
	Zinc	**120**	**220**	**100**
Organic compounds	**Total PCBs**[d]	**0.12**	**0.069**	**0.034**
PAHs	**Acenaphthene**	**< 0.0050**	**< 0.020**	**< 0.0050**
	Acenaphthylene	**0.0088**	**< 0.020**	**0.0068**
	Anthracene	**0.020**	**< 0.020**	**0.010**
	Benzo[a]anthracene	**0.039**	**< 0.020**	**0.021**
	Benzo[a]pyrene	**0.040**	**< 0.010**	**0.023**
	Chrysene	**0.048**	**< 0.020**	**0.026**
	Dibenzo[a,h]anthracene	**0.010**	**0.0075**	**0.0040**
	Fluoranthene	**0.069**	**< 0.010**	**0.045**
	Fluorene	**0.0090**	**< 0.020**	**0.0050**
	2-Methylnaphthalene	**0.0073**	**< 0.030**	**< 0.004**
	Naphthalene	**< 0.010**	**< 0.040**	**0.010**
	Phenanthrene	**0.029**	**< 0.020**	**0.023**
	Pyrene	**0.058**	**< 0.010**	**0.037**
Other parameter	Total organic carbon (%)	3.2	3.2	0.81

Source: M. Pelletier, personal communication.

[a] The substances in bold are those for which quality criteria have been derived (Table 1). No quality criteria have been defined for the other substances.

[b] The values have been rounded to two significant digits.

[b] The values are total concentrations (measured after complete extraction of the sample, including the silica matrix, using hydrofluoric acid [HF] or perchloric acid [$HClO_4$]).

[d] The values of total polychlorinated biphenyls represent concentrations calculated for the sum of the PCB homologues.

Chapter 5

Application of Sediment Quality Criteria

5.1 Physico-chemical Characterization of Sediment

1. Sediment sampling must be done in accordance with the *Sediment Sampling Guide for Dredging and Marine Engineering Projects in the St. Lawrence River* (Environment Canada 2002b; 2002c).
2. During characterization of the study site, sediments can be segregated by delimiting homogeneous contamination zones. These can then be managed separately based on their degree of contamination.
3. Physico-chemical analyses must be done in accordance with the *Guide de caractérisation physico-chimique des sédiments* (CEAEQ, in preparation). It goes without saying that the detection limits must be lower than the quality criteria.
4. The analytical parameters that must be routinely considered in all sediment quality assessment projects are listed in the table below. Only major contaminants usually present in sediments are shown. However, this list is not restrictive and, depending on the specific conditions at the site or project, the manager may add one or more substances to the list. For example, in an agricultural area, it may be advisable to test for pesticides; in a sector affected by an industrial effluent, it may be advisable to analyse the substances likely to be present in the effluent and to bind to the particles.

Analytical parameters selected for routine assessment of sediment quality*

– Metals and metalloids (arsenic, cadmium, chromium, copper, mercury, nickel, lead, zinc)
– Polycyclic aromatic hydrocarbons (PAHs) (detailed list in Appendix 5)
– Polychlorinated biphenyls (PCBs) (approach described in Appendix 4)
– Grain size distribution
– Total organic carbon (TOC)
– Petroleum hydrocarbons (C_{10}–C_{50})

* No sediment quality criteria are available for some of these parameters at present. Analyses are nonetheless required to facilitate interpretation of other results and/or to ensure that the sediments meet soil quality criteria (Beaulieu et al. 1999).

5. All the chemical analysis results must be presented on a dry weight basis and the certificates of analysis provided, along with the complete characterization reports, and include information on the quality control aspects.
6. For the metals, with the exception of mercury, the quality criteria apply to the total extractable concentrations obtained by hot extraction of the sediments using a mixture of

nitric acid and hydrochloric acid (HCl/HNO_3). This method measures the theoretically bioavailable metal fraction and not the residual metals (i.e. metals contained in the sediment matrix). The total extractable concentration of mercury, which is the basis of the quality criterion, can be determined either through extraction of the sediments with strong acids (nitric, sulphuric and hydrochloric) in an oxidizing environment or through thermal and chemical decomposition in a combustion furnace. This difference in extraction approach stems from the analytical considerations specific to mercury.

7. The concentration of total PCBs in sediments must be measured using a method that adequately considers the actual profile of the PCBs in the sediments under study. The recommended method is *Détermination des biphényles polychlorés; méthode par congénère* (CEAEQ 2003) (Appendix 4). It is also strongly recommended that the individual concentrations of the 41 congeners and of the homologue groups, in addition to the total concentration, be indicated in the PCB analysis reports. When toxic effects similar to those associated with dioxins and furans are suspected because of the possible presence of large quantities of planar and coplanar PCBs in the sediments, the analytical approach chosen must also be capable of measuring both the concentrations of total PCBs and the concentrations of the 12 congeners for which 2,3,7,8-TCDD toxicity equivalency factors (TEFs) have been calculated for fish (Appendix 4).

8. In the case of dioxins and furans, the quality criteria are expressed in toxic equivalents (TE) calculated using the TEFs determined by the World Health Organization (van den Berg et al. 1998) for fish (Appendix 1). When the measured concentrations are expressed using TEFs that are different from those of the WHO, the total concentration of dioxins and furans should be recalculated using the equivalency factors provided in Appendix 1.

9. In the case of nonylphenol and its ethoxylates, the quality criteria are expressed as toxic equivalents calculated using the toxicity equivalency factors (TEFs) determined by Servos et al. (2000) and adapted by Environment Canada (2002a) (Appendix 1). When the measured concentrations are expressed using toxicity equivalency factors different from those of Servos et al. (2000), the total concentration of nonylphenol and its ethoxylates should be recalculated using the equivalency factors in Appendix 1.

10. The quality criteria for toxaphene and for nonylphenol and its ethoxylates were calculated assuming a total organic carbon (TOC) level of 1%. These values can be corrected by multiplying the value of the quality criterion by the TOC percentage in the sediment sample to be assessed, up to a maximum value of 10%. The criteria calculated for the other organic compounds must not be adjusted based on the TOC content (Section 3.3.2).

11. For each of the three management contexts, the quality criteria define three classes of contamination (Table 5). The presence of a single substance that exceeds the quality criterion is sufficient for sediments to be attributed the highest class of contamination. Sediments containing substances belonging to both class 1 and class 2 are therefore considered as belonging to class 2.

    Dredged material requiring disposal should be managed according to the class to which it belongs and with respect for the principle of not contributing to the deterioration of the receiving environment. Thus, class 2 sediments may be laid over class 2 or class 3 sediments, but not over class 1 sediment.

5.2 Application of Quality Criteria for the Prevention of Sediment Contamination

To prevent contamination of sediments by new inputs of contaminants to a body of water (e.g. industrial or urban discharges), the rare effect level (REL) and the threshold effect level (TEL) are the threshold values used to determine the management framework (Table 5).

1. When, for all substances analysed, the concentration is lower than or equal to the REL (class 1), no action is required as the sediments are considered to have no impact on the environment.
2. However, mercury, PCBs, chlorinated dioxins and furans, dieldrin, DDT (+DDD+DDE) and toxaphene are substances targeted for virtual elimination[5]. These persistent, bioaccumulative and toxic substances (PBTS), even when not directly toxic to the species exposed, accumulate in the environment, migrate and contaminate all the compartments (water, sediments, tissues), and eventually have deleterious effects on species that have not been tested (e.g. beluga whales, humans, terrestrial fauna and piscivorous fauna). Measures must be adopted to avert any new additions of these substances to the environment and to prevent their spread, even if no quality criterion is exceeded.
3. When, for one or more substances, the concentration is higher than the REL but lower than or equal to the TEL (class 2), the probability that the sediments will have an impact on the environment is low. However, monitoring measures may be implemented in order to keep track of any changes in the situation over time. If an increase in levels is observed, it may be necessary to conduct investigations to identify the source of contamination and assess the environmental impact.
4. When, for one or more substances, the concentration is higher than the TEL (class 3), the probability of observing adverse effects on benthic organisms increases with the concentrations measured. If the concentration measured is also higher than the natural concentration or the ambient level, the sources of contamination must be identified and, if necessary, action targeting the parties responsible taken in order to stop the contamination. To prevent new inputs of contaminants, additional measures may be planned for any new facility likely to produce discharges that could lead to an increase in concentrations above the TEL or above the natural levels in zones of sediment deposition downstream, and sometimes even upstream[6], of the discharge point.

5.3 Application of Quality Criteria for the Management of Dredged Sediment

The occasional effect level (OEL) and the frequent effect level (FEL) are the threshold values used to determine the management framework for dredged sediment (Table 5).

[5] Virtual elimination refers either to the total elimination of persistent, bioaccumulative and toxic substances in the environment or to the suppression of the effects of these substances on the environment and the ecosystem (SLV 2000 1999).

[6] In the St. Lawrence River, reversals in current direction can result in contaminants being found upstream of the point of discharge.

Table 5 Overview of the three application frameworks for sediment quality criteria in Quebec

<table>
<tr><th>Quality criteria</th><th></th><th>Prevention of sediment contamination caused by industrial discharges</th><th>Management of sediments resulting from dredging operations*</th><th>Remediation of contaminated sites</th></tr>
<tr><td></td><td rowspan="3">Biological effects frequently observed**</td><td rowspan="7">The probability of detecting adverse effects increases with the concentrations measured. Examine the problem: carry out investigations to identify the source or sources of contamination and take action targeting the parties responsible in order to prevent an increase in contamination or new inputs of contaminants.</td><td>The probability of detecting adverse biological effects is very high. Open-water disposal is prohibited. The sediments must be treated or safely contained.</td><td>Sediment contamination is considered a serious problem. Identify the sources and take action targeting the parties responsible, if applicable, in order to eliminate inputs of contaminants. Site remediation is desirable. Biological assessments should be carried out to determine the feasibility of a remediation process, set the priorities for action and identify the environmental gains. The remediation target is the OEL or the ambient concentration.</td></tr>
<tr><td>5. FEL
$\sqrt{(E_{85} \times NE_{85})}$</td><td></td><td></td></tr>
<tr><td></td><td rowspan="3">The probability of detecting adverse biological effects is relatively high and increases with the concentration. Open-water disposal can only be considered a valid option if toxicity tests demonstrate that the sediments will not adversely affect the receiving environment and if the disposal does not contribute to the deterioration of the receiving environment.</td><td>Identify the sources and take action targeting the parties responsible, if applicable, in order to eliminate inputs of contaminants. Environmental studies may be necessary to supplement the evaluation of the contamination, assess the risk and determine the remediation requirements. The remediation target is the OEL or the ambient concentration.</td></tr>
<tr><td>4. PEL
$\sqrt{(E_{50} \times NE_{85})}$</td><td></td><td></td></tr>
<tr><td></td><td rowspan="3">Biological effects occasionally observed**</td><td rowspan="7">Although adverse biological effects may be anticipated, the level of contamination alone does not justify initiation of site remediation</td></tr>
<tr><td>3. OEL
$\sqrt{(E_{50} \times NE_{50})}$</td><td></td></tr>
<tr><td></td><td rowspan="5">The probability of detecting adverse biological effects is relatively low. The sediments can be disposed of in open water or may be used for other purposes, provided the disposal does not contribute to the deterioration of the receiving environment.</td></tr>
<tr><td>2. TEL
$\sqrt{(E_{15} \times NE_{50})}$</td><td></td><td></td></tr>
<tr><td></td><td rowspan="3">Biological effects rarely observed**</td><td>The probability that the sediments will have an impact on the environment is low. Monitoring measures may be instituted in order to verify any changes in the situation over time.</td></tr>
<tr><td>1. REL
$\sqrt{(E_{15} \times NE_{15})}$</td><td></td></tr>
<tr><td></td><td>The sediments are considered not to have an impact. No action is required, except in the case where there is a risk that persistent, bioaccumulative toxic substances discharged in water bodies will accumulate in sediments and in the tissues of organisms.</td></tr>
</table>

Class 1 Class 2 Class 3

REL: rare effect level; TEL: threshold effect level; OEL: occasional effect level; PEL: probable effect level; FEL: frequent effect level.

* Management of dredged sediment: The sediment management option that is chosen must be the one with the least impact on the environment and economically feasible, regardless of the degree of sediment contamination. When studying options, consideration should be given to beneficial use of sediments in terrestrial or aquatic environments.

** According to CCME (1995).

1. The option chosen for the management of dredged material must be the one that entails the least impact on the environment, while also being economically feasible, whatever the level of sediment contamination. The disposal of dredged material must not contribute to the deterioration of the receiving environment. During dredging operations or the disposal of dredged material, measures must be taken to minimize any increase in the concentration of suspended solids. In addition, when studying management options, possibilities for the beneficial use of sediments in terrestrial or aquatic environments must be considered. Disposal and the beneficial use of sediments in terrestrial environments are governed by the Soil Protection and Contaminated Sites Rehabilitation Policy (Beaulieu et al. 1999), as well as by the applicable legislative and regulatory framework.

2. When, for all the substances analysed, the concentration is lower than or equal to the OEL (class 1), the probability of observing adverse biological effects is relatively low. The sediments can therefore be disposed of in open water or used for other purposes, provided that their disposal does not contribute to the deterioration of the receiving environment (physical impacts of sediment).

3. When the concentration of a contaminant is higher than the OEL but lower than or equal to the FEL (class 2), the probability of observing adverse biological effects is relatively high and increases with the concentration. Open-water disposal of dredged sediments can be considered a valid management option only where proper toxicity tests have demonstrated that the sediments will not adversely affect the receiving environment. Managers must also ensure that the disposal does not contribute to the deterioration of the receiving environment. Proper characterization of the disposal site is required, for instance, prior to authorization of open-water disposal. The concentrations in dredged material must be lower than or equal to the levels measured in sediments at the disposal site. Lastly, steps should also be taken to ensure that the chosen disposal site minimizes the adverse impacts on the environment and on related activities.

4. When the concentration of a substance is greater than the FEL (class 3), the probability of observing adverse biological effects is very high, and open-water disposal of dredged material is prohibited. The sediments must instead be treated or safely contained.

5.4 Application of Quality Criteria for the Management and Remediation of Contaminated Sites

For contaminated site remediation, the probable effect level (PEL) and frequent effect level (FEL) are the threshold values used to determine the management framework (Table 5).

1. When, for all contaminants, the concentration is lower than the PEL (class 1), there is no need to initiate a remediation process, unless development projects or dredging work is planned at the site or such a process is required by management considerations other than the protection of aquatic life.

2. When the concentration of a contaminant is higher than the PEL but lower than or equal to the FEL (class 2), the advisability of undertaking a remediation process should be determined. Other measures, such as toxicity tests and biological field studies, may be necessary to supplement the analysis of the contamination and assess the risk associated with the contaminated sediments. Taking action to eliminate the sources must be considered.

3. When the concentration of a contaminant exceeds the FEL (class 3), sediment contamination is considered a serious problem. Actions must be taken to eliminate the sources of contamination. Remediation of the site is desirable. Biological assessments should be carried out to determine the feasibility of a remediation process, set priorities for action, and identify the environmental gains.
4. Generally, the OEL or, depending on the case, the ambient concentration (Section 5.5) is the remediation level to be attained. However, the remediation target may also be determined on a case-by-case basis, using appropriate supplemental studies. Determining the remediation threshold may require (1) an analysis of sediment toxicity (using toxicity tests); (2) determination of the ambient or natural concentrations in sediment, as applicable; (3) an analysis of the risk to human health and to the environment; (4) determination of the volume of contaminated sediments; and (5) an analysis of the technical and economic feasibility of the various remediation scenarios considered.

5.5 Consideration of Natural and Ambient Levels

1. The quality criteria can be used in combination with the natural levels measured at a given site. When the quality criterion for a chemical substance is lower than the natural concentration for a given area, the quality criterion then takes the place of the natural concentration, except in the case of the frequent effect level (FEL). Table 3 provides values considered as representative of the natural levels in the fluvial section of the St. Lawrence. However, these values apply only to the fluvial section. If there are no data for a given sector or watercourse, the natural concentrations for one or more contaminants can be determined by analysing representative samples from the area under study (see point 6, below).
2. As indicated in point 1 of this section, the natural concentrations measured in postglacial clays (Table 3) can be used, provided that the sediments being characterized have been identified as postglacial clays. It is therefore necessary to demonstrate that the sediments concerned have the characteristics of postglacial clays (Appendix 2).
3. In the case of chromium, the natural concentrations in the postglacial clays (Table 3) in the fluvial section of the St. Lawrence can be higher than the FEL. In the context of managing dredged material, when the measured concentration of chromium exceeds the FEL, this then becomes the threshold level triggering toxicity tests, provided that the sediments have been identified as postglacial clays (Appendix 2).
4. The natural pre-industrial concentration can be considered as a concentration that is usually tolerated by benthic organisms living in those conditions. In a prevention context, if there are no criteria for a given substance, the natural pre-industrial level, if properly determined for the area under study, can be used as the threshold effect level (TEL).
5. During remediation of contaminated sites, the ambient concentrations can be used to determine the remediation target to be attained.
6. If, for management purposes, the natural or ambient concentrations must be determined for a specific area, the number of samples collected must be sufficient to ensure that they are fairly representative of the environment. The sampling plan must cover a large enough area to ensure that the samples are representative of local or regional concentrations in areas not influenced by a point source of contamination. The number of samples required can vary

with the size of the study area; however, at least ten samples must be analysed. The 75th percentile of the distribution of values should be used to determine the maximum ambient or natural levels[7]. In the characterization reports, the work done and the results obtained must be clearly described so that the representativeness of the values chosen to determine the ambient and/or natural concentrations can be assessed.

[7] The 75th percentile of the value distribution was selected as a precautionary measure in situations where a small number of samples are likely to be collected.

Chapter 6

Conclusion

The sediment quality criteria are now in effect in Quebec and must be applied to all projects requiring an assessment of sediment quality at sites in the province. The use of these criteria will provide a means of ensuring that the recommended threshold values meet management needs. It will therefore be important to verify that the occasional effect level (OEL) is indeed an adequate threshold value for triggering toxicity tests. This will require the analysis of a large number of toxicity test results.

Other tools will complement and/or validate the sediment quality criteria. For instance, the development of an ecotoxicological assessment approach, which is currently the subject of a joint federal/provincial study, addresses such issues as the analysis of the predictive capability of various assessment tools, including toxicity tests, biological field studies and quality criteria. The results of this study will help to validate the accuracy of the quality criteria in determining the management thresholds identified for each of the three management contexts.

Advances in our understanding of natural concentrations in the pre-industrial sediments and postglacial clays of the St. Lawrence (Saulnier and Gagnon 2003; 2006) allow the quality criteria to be applied in a way that also takes into account the specific geological characteristics of the St. Lawrence. As well, the information available on ambient levels of substances in the fluvial lakes of the St. Lawrence (Pelletier and Lepage 2002; Pelletier 2003, unpublished data) makes it possible to set realistic remediation objectives for contaminated sites.

Further knowledge acquisition is essential to our increased understanding of the effects of contaminants on the aquatic environment and for enhancing sediment quality assessment. It will also be important to document the contribution of coplanar PCBs to the dioxin- and furan-type toxicity that affects benthic organisms. In addition, quality criteria need to be developed for new emerging substances, such as polybromodiphenylethers (PBDE) and endocrine disruptors, and toxicity tests proper to them are required.

At this stage, the structure of the sediment management process in Quebec has been strengthened as a result of the review process and the adoption of new sediment quality criteria. New research and development work, such as the creation of an ecotoxicological assessment process, will undoubtedly support the continued acquisition of knowledge and management tools in the area of dredging and sediments. Also, more information on the natural and ambient levels of substances in the marine environment is required to better take account of the particularities of this environment in the sediment management process.

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Appendices

Appendix 1 Toxicity Equivalency Factors (TEFs)

Chemical	**TEF**
2,3,7,8-TCDD *	1
1,2,3,7,8-PCDD *	1
1,2,3,4,7,8-HCDD *	0.5
1,2,3,6,7,8-HCDD *	0.01
1,2,3,7,8,9-HCDD *	0.01
1,2,3,4,6,7,8-HCDD *	0.001
OCDD *	0.0001
2,3,7,8- TCDF *	0.05
1,2,3,7,8-PCDF *	0.05
2,3,4,7,8-PCDF *	0.5
1,2,3,4,7,8-HCDF *	0.1
1,2,3,6,7,8-HCDF *	0.1
1,2,3,7,8,9-HCDF *	0.1
2,3,4,6,7,8-HCDF *	0.1
1,2,3,4,6,7,8-HCDF *	0.01
1,2,3,4,7,8,9- HCDF *	0.01
OCDF *	0.0001
Nonylphenol (NP) **	1
Nonylphenol ethoxylate (NP*n*EO; $1 \leq n \leq 8$) **	0.5
Nonylphenol ethoxylate (NP*n* EO; $n \geq 9$) **	0.005
Nonylphenol ethoxycarboxylate (NP1EC) **	0.005
Nonylphenol ethoxycarboxylate (NP2EC) **	0.005
Octylphenol (OP) **	1
Octylphenol ethoxylate (OP*n*EO; $1 \leq n \leq 8$) **	0.5
Octylphenol ethoxylate (OP*n*EO; $n \geq 9$) **	0.005
Octylphenol ethoxycarboxylate (OP1EC) **	0.005
Octylphenol ethoxycarboxylate (OP2EC) **	0.005

* WHO (van den Berg et al. 1998) TEFs for congeners of dioxins and furans (PCDD/PCDF) in fish.
** TEFs for nonylphenol and its ethoxylates adapted from Servos et al. (2000) by Environment Canada (2002a).

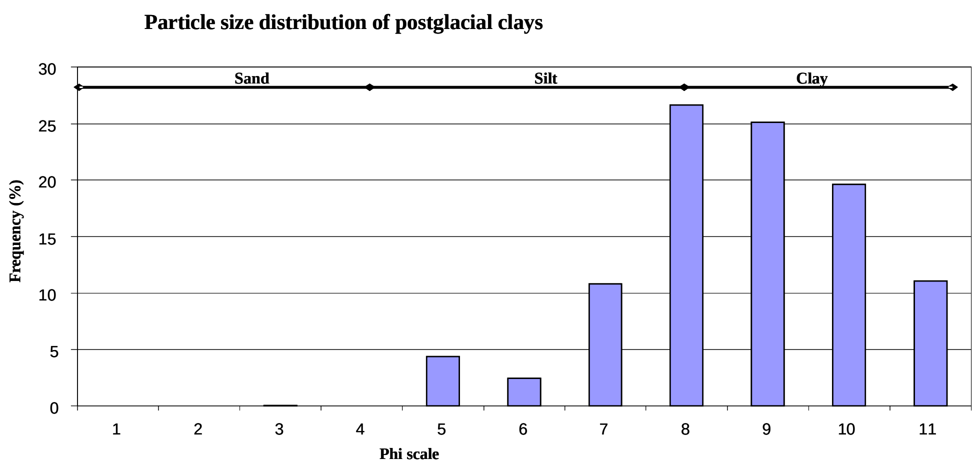
Appendix 2 Identifying the Characteristics of Postglacial Clays

The clay deposits of the Champlain Sea are not part of the recent sedimentary deposits of the St. Lawrence River. They were laid down far earlier in a marine context that differs completely from the current fluvial context. However, because of bottom and bank erosion, and inputs from the tributaries that follow, in part, a sinuous flow pattern over these clay deposits, they contribute significantly to the supply of fine particles in recent sediments (Pelletier and Lepage 2002).

The following are some of the physical and chemical properties used to differentiate postglacial clay from pre-industrial sediments and from recent sediments:

- Postglacial clay is bluish-grey in colour, very cohesive, frequently bedded and does not erode easily. The clay is generally compact to plastic, with black flecks and/or varves [8] (Lavoie and Pelletier 2003).

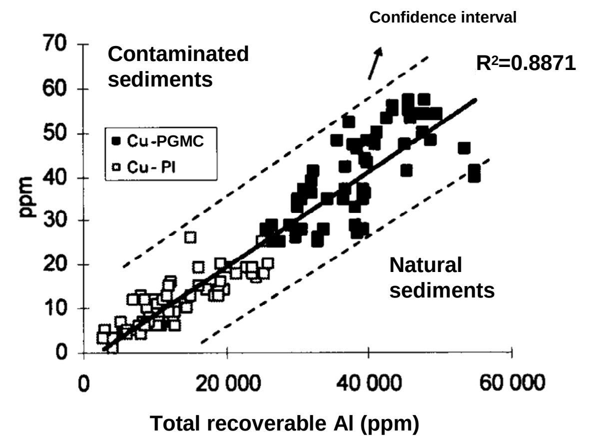
- The particle size distribution of postglacial clay includes a high percentage of fine silts and clays.



Source: Adapted from Lavoie and Pelletier 2003.

[8] Seasonal patterned lacustrine deposit from a proglacial lake. Each varve is an annual deposit composed of a layer of light-coloured material, low in organic matter, deposited by inflows of sediment-laden meltwater in the spring and summer, and a dark layer, rich in organic matter, deposited in the fall and early winter (OLF 2002).

- The clay generally contains 0 to 0.5% organic carbon, 0.5% to 1.0% carbonate and, finally, 75% to 90% pelite (Pelletier and Long 1990).
- The aluminum concentration is higher in postglacial clays than in pre-industrial sediments and the mineral composition of postglacial clays differs from that of recent sediments (Saulnier and Gagnon 2003 and 2006).



Mineral fractions (% weight)	Postglacial marine clays[1]	Pre-industrial sediments of the St. Lawrence[2]
Quartz	13.5	50-70
Feldspars	24	20-30
Mica	17	<1
Clay minerals	24	Trace
Amphiboles	6.5	2-3
Pyroxenes	<1	<1
Carbonates	7	---
Oxides	1.5	1-3
Iron sulphides	2.25	Trace
Accessory minerals	Trace	Trace
Organic matter	0.1-2.0	0.01-2.6[3]

1 Lepage and Richard (unpublished).
2 Loring 1976.
3 Saulnier and Gagnon (2006).

Cu-PGMC: copper concentrations in postglacial marine clays

Cu-PI: copper concentrations in pre-industrial sediments

- The microfauna in the postglacial clay is typical of the saltwater and cold-water lake environments formed during deglaciation (Lavoie and Pelletier 2003).

Appendix 3 Upper Limits of Natural and Ambient Levels in the Laurentian Channel, Expressed in Total Concentrations

	Natural levels (mg/kg)		Ambient levels (mg/kg)	
Substance	**Estuary**	**Gulf**	**Estuary**	**Gulf**
Arsenic	5	5		15
Cadmium	0.2	0.35	0.13	0.2
Chromium	100		120	
Copper	16	30	25	30
Lead	15	20	30	30
Mercury	0.02	0.02	0.15	0.07
Nickel	50	55	50	55
Silver	0.05	0.07	0.15	0.07
Zinc	110	110	150	120

Note : The data are derived from studies by Gobeil (1991; 2000). The sampling dates vary from station to station but generally extend from 1987 to 1996.

Appendix 4 Recommended Approach for the Analysis of Polychlorinated Biphenyls (PCBs)

The toxicological data from the Biological Effects Database for Sediments (BEDS), used to calculate the quality criteria for PCBs, were taken from various studies and a number of analytical methods were most likely used to determine the PCB concentrations (Environment Canada 1999). In this context, the selection of an analytical approach for determining total PCBs and for comparing them to the quality criteria presented in this document must be based on considerations of analytical accuracy. Furthermore, both Environment Canada and the Quebec Ministère du Développement durable, de l'Environnement et des Parcs recommend that total PCBs be determined using a method based on the measurement of an assortment of congeners representative of what is typically observed in environmental samples and on the sum of the concentrations of the various homologue groups of PCBs.

Consequently, it was decided to select an analytical approach for total PCBs based on the analysis of 41 congeners (Table A4.1), i.e. the CEAEQ's "congener method": *Détermination des biphényles polychlorés; méthode par congénère* (CEAEQ 2003). In fact, compared to the analytical approach for total PCBs based on the quantification of Arochlor mixtures, the approach based on the quantification of congeners and homologue groups is more accurate, especially when the Arochlor patterns are altered, as is almost always the case in situations of sediment contamination. In addition, most laboratories that provide PCB analysis services in Quebec already use this new approach for quantifying total PCBs.

Moreover, since some PCB congeners produce toxic effects similar to those associated with dioxins and furans, in certain situations, the 12 PCB congeners for which 2,3,7,8-TCDD toxicity equivalency factors (TEFs) are available (Table A4.2) should be analysed. In these cases, the analytical approach selected for PCBs must be capable of determining both the concentrations of total PCBs and the individual concentrations of the 12 congeners with TEF. A high-resolution PCB quantification method must then be used, such as the CEAEQ's (2001) *Détermination des biphényles polychlorés (congénères), dosage par chromatographie en phase gazeuse couplée à un spectromètre de masse à haute résolution*. However, a slight modification must be made to the step of fractionation on an alumina column in order to separately determine total PCBs and the 12 congeners with TEFs. Additional information on this subject can be found in the CEAEQ's method for analysing chlorinated dioxins and furans (CEAEQ 2002).

After correction based on their respective TEFs, the analytic results for these 12 PCB congeners will be compared to the quality criteria for dioxins and furans, while the analytic results for total PCBs will be compared to the quality criteria for total PCBs.

Table A4.1 List of the 41 PCB congeners analysed using the congener method

Homologue group	Congener		2,3,7,8-TCDD TEF
	IUPAC No.	Substitution position	
Trichlorobiphenyls	17	2,2',4-PCB	
	18	2,2',5-PCB	
	28	2,4,4'-PCB	
	31	2,4',5-PCB	
	33	2',3,4-PCB	
Tetrachlorobiphenyls	44	2,2',3,5'-PCB	
	49	2,2',4,5'-PCB	
	52	2,2',5,5'-PCB	
	70	2,3',4',5-PCB	
	74	2,4,4',5-PCB	
Pentachlorobiphenyls	82	2,2',3,3',4-PCB	
	87	2,2',3,4,5'-PCB	
	95	2,2',3,5',6-PCB	
	99	2,2',4,4',5-PCB	
	101	2,2',4,5,5'-PCB	
	105	2,3,3',4,4'-PCB	X
	110	2,3,3',4',6-PCB	
	118	2,3',4,4',5-PCB	X
Hexachlorobiphenyls	128	2,2',3,3',4,4'-PCB	
	132	2,2',3,3',4,6'-PCB	
	138	2,2',3,4,4',5'-PCB	
	149	2,2',3,4',5',6-PCB	
	151	2,2',3,5,5',6-PCB	
	153	2,2',4,4',5,5'-PCB	
	156	2,3,3',4,4',5-PCB	X
	158	2,3,3',4,4',6-PCB	
	169	3,3',4,4',5,5'-PCB	X
Heptachlorobiphenyls	170	2,2',3,3',4,4',5-PCB	
	171	2,2',3,3',4,4',6-PCB	
	177	2,2',3,3',4',5,6-PCB	
	180	2,2',3,4,4',5,5'-PCB	
	183	2,2',3,4,4',5',6-PCB	
	187	2,2',3,4',5,5',6-PCB	
	191	2,3,3',4,4',5',6-PCB	
Octachlorobiphenyls	194	2,2',3,3',4,4',5,5'-PCB	
	195	2,2',3,3',4,4',5,6-PCB	
	199	2,2',3,3',4,5,5',6'-PCB	
	205	2,3,3',4,4',5,5',6-PCB	
Nonachlorobiphenyls	206	2,2',3,3',4,4',5,5',6-PCB	
	208	2,2',3,3',4,5,5',6,6'-PCB	
Decachlorobiphenyl	209	2,2',3,3',4,4',5,5',6,6'-PCB	

Source: CEAEQ 2003.

Table A4.2 Toxicity equivalency factors (TEFs) for the PCB congeners generating toxic effects similar to those associated with dioxins and furans

PCB congeners	**TEFs for fish***
Non-ortho (planar):	
PCB-77	0.0001
PCB-81	0.0005
PCB-126	0.005
PCB-169	0.000 05
Mono-ortho (coplanar):	
PCB-105	< 0.000 005
PCB-114	< 0.000 005
PCB-118	< 0.000 005
PCB-123	< 0.000 005
PCB-156	< 0.000 005
PCB-157	< 0.000 005
PCB-167	< 0.000 005
PCB-189	< 0.000 005

*Data taken from van der Berg et al. 1998.

Appendix 5 List of Polycyclic Aromatic Hydrocarbons (PAHs) to be Routinely Analysed

PAH	**Quality criteria (tables 1 and 2)**
Acenaphthene	X
Acenaphthylene	X
Anthracene	X
Benzo[a]anthracene	X
Benzo[b]fluoranthene	
Benzo[j]fluoranthene	
Benzo[k]fluoranthene	
Benzo[c]phenanthrene	
Benzo[g,h,i]perylene	
Benzo[a]pyrene	X
Benzo[e]pyrene	
Chrysene	X
Dibenzo[a,h]anthracene	X
Dibenzo[a,h]pyrene	
Dibenzo[a,i]pyrene	
Dibenzo[a,l]pyrene	
7,12-Dimethylbenzo[a]anthracene	
1,3-Dimethylnaphthalene	
Fluoranthene	X
Fluorene	X
Indeno[1,2,3-cd]pyrene	
3-Methylcholanthrene	
1-Methylnaphthalene	
2-Methylnaphthalene	X
Naphthalene	X
Phenanthrene	X
Pyrene	X
2,3,5-Trimethylnaphthalene	