GUIDELINES FOR THE PROTECTION AND MANAGEMENT OF AQUATIC SEDIMENT QUALITY IN ONTARIO

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GUIDELINES FOR THE PROTECTION AND MANAGEMENT OF AQUATIC SEDIMENT QUALITY IN ONTARIO

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The background

Contaminated sediment has been singled out as a major environmental problem. The concern is that persistent toxic substances - poisonous substances that take a long time to break down - in the sediment will accumulate in carp, catfish and other bottom-dwelling fish as well as in the bottom-dwelling organisms, such as worms and midges, that live in the sediments. These contaminants may be transferred to fish either because they have fed on the organisms or come into contact with the sediments. These chemicals may be transferred again to wildlife, birds and people who eat the fish. This process, by which organisms can accumulate levels of persistent chemicals higher than in sediments or water, is called biomagnification.

The source

The primary source of contaminants in sediments is toxic chemicals from industrial and municipal discharges of waste water. The runoff from cities, towns and agricultural areas may also contribute to the problem. Other sources include:

- Lakefilling or the practice of creating more land by building up the shoreline with rubble, bricks, stones, concrete and loose earth may also add to the problem unless the fill is free of contaminants.

- Chemicals in factory emissions which, attaching themselves to particles of dust or droplets of water, fall back to the earth in the form of dust, rain, sleet, hail or snow.

The response

The ministry has several programs in place which, either directly or indirectly, tackle the problem of contaminated sediment.

- <u>The Municipal Industrial Strategy for Abatement (MISA)</u> - The aim of the program is to reduce drastically the discharges of toxic chemicals from industry and municipalities either by improving treatment plants or by changing industrial processes so that toxic chemicals are no longer needed.

- <u>The Remedial Action Plan (RAP) Program</u> - The aim of the program is to help clean up the 17 Areas of Concern in Ontario identified by the International Joint Commission as being badly contaminated. The RAP teams have identified contaminated sediment as one of the factors contributing to poor water quality and living conditions for the sediment dwelling organisms - also known as the benthic community.

- <u>Operation Lifelines and the Beaches Improvement Program</u> - The aim of these programs is to help municipalities improve storm water management and reduce the amount of runoff from cities and towns.

- <u>Fill Quality Guidelines for Lakefilling in Ontario</u> - The aim of the guidelines is to protect the quality of the aquatic habitat. The guidelines regulate the quality of fill used, based on the Provincial Sediment Quality Guidelines and the Provincial Water Quality

Objectives/Guidelines.

The Sediment Quality Guidelines

The purpose of the Sediment Quality Guidelines is to protect the aquatic environment by setting safe levels for metals, nutrients (substances which promote the growth of algae) and organic compounds.

The guidelines replace the ministry's 1976 Open Water Disposal Guidelines. Those guidelines originally were developed to determine whether or not dredged material was suitable for disposal in open water. Over time their use was expanded to include all aspects of sediment assessment.

The guidelines are designed to help environmental managers - ministry officials and environmental consultants - make decisions on a whole range of issues that affect the quality of sediment. For example, the guidelines will be used by RAP teams to determine which sediments are contaminated and how to manage the problem most effectively.

How the guidelines work

The guidelines establish three levels of effect - No Effect Level, Lowest Effect Level and Severe Effect Level. The Lowest Effect level and Severe Effect Level are based on the long-term effects which the contaminants may have on the sediment-dwelling organisms. The No Effect Level is based on levels of chemicals which are so low that no contaminants are passed through the food chain.

The levels of effect are designed to help environmental managers determine:

- when sediment may be considered clean;
- what levels of contamination are acceptable for short periods of time while the source of the contamination is being controlled and cleanup plans are being developed;
- what levels of contamination are considered severe enough to consider the possibility of either removing the sediment or covering it with a layer or two of cleaner sediment. This is called capping.

The three levels of effect are:

- **The No Effect Level:** This is the level at which the chemicals in the sediment do not affect fish or the sediment-dwelling organisms. At this level no transfer of chemicals through the food chain and no effect on water quality is expected.

  Sediment that has a No Effect Level rating is considered clean and no management decisions are required. Furthermore, it may be placed in rivers and lakes provided it does not physically affect the fish habitat or existing water uses - for example a water intake pipe.

- The Lowest Effect Level: This indicates a level of contamination which has no effect on the majority of the sediment-dwelling organisms. The sediment is dean to marginally polluted.

  Dredged sediments containing concentrations of organic contaminants - PCBs or pesticides, for example - that fall between the No Effect Level and the Lowest Effect Level may not be disposed of in an area where the sediment at the proposed disposal site has been rated at the No Effect Level or better.

  Contamination in sediment that exceeds the Lowest Effect Level may require further testing and a management plan.

- The Severe Effect Level: At this level, the sediment is considered heavily polluted and likely to affect the health of sediment-dwelling organisms. If the level of contamination exceeds the Severe Effect Level then testing is required to determine whether or not the sediment is acutely toxic.

  At the Severe Effect Level a management plan may be required. The plan may include controlling the source of the contamination and removing the sediment.

For more copies of the new Provincial Sediment Quality Guidelines, please contact the Ministry of the Environment, Public Information Centre, 135 St. Clair Ave. W., Toronto, Ont. M4V 1P5, (416) 323-4321.

FOREWORD

The guidelines provided in this document were developed for use in evaluating sediments throughout Ontario, and replace the Open Water Disposal Guidelines (published by the Ministry in 1976) currently used for sediment evaluation. The Provincial Sediment Quality Guidelines (PSQGs) are intended to provide guidance during decision-making in relation to sediment issues, ranging from prevention to remedial action.

The document provides a background to the PSQG development, the PSQGs, the application of the guidelines to sediment evaluation and the protocol used in establishing the guidelines. Companion volumes to the document (Jaagumagi 1992a, 1992b) provide more details on the actual derivation of the numeric values for various parameters.

SECTION 1

BACKGROUND.

Contaminated sediment has been singled out as a major environmental concern in many areas of Ontario, especially the Great Lakes (IJC 1985). Persistent toxic substances that have accumulated in bottom sediments from industrial, municipal and non-point sources are a threat to the survival of bottom-dwelling (benthic) organisms and their consumers, and can also impair the quality of the surrounding water.

Sediments contaminated by such substances have become a critical problem for environmental managers. In order to deal effectively with sediment contamination problems, managers need to know at what levels contaminants pose no risk to sediment-dwelling organisms as well as other water uses, and at what levels contaminants are detrimental to aquatic biota. At present, management decisions are seriously hampered due to a lack of criteria whereby acceptable and unacceptable levels of contaminants in sediments can be defined. A definition of sediment contamination needs to be developed before strategies for the management of contaminated sediments can be implemented.

Routine evaluation of the significance of contaminants in sediments is currently a difficult task because of the lack of adequate guidelines. The Open-Water Disposal Guidelines, developed during the early 1970's (Persaud & Wilkins 1976), were not designed to address the significance of contaminants in *in situ* sediment but were designed exclusively for the evaluation of dredged material for open-water disposal and only incidentally provide general guidance on environmental protection.

The need for biological effects-based guidelines for the evaluation of sediment is well recognized. Current sediment related issues are much broader than those identified in the early 1970's and knowledge based on information accumulated over the last decade or so requires that strategies be developed to manage sediment. Guidelines for the evaluation of sediment must provide the basis for determining when sediments are considered clean, what levels of contamination are acceptable in the short-term, and when contamination is severe enough to warrant significant remedial action.

The Provincial Sediment Quality Guidelines described in this document are a set of numerical guidelines developed for the protection of aquatic biological resources. These biologically based guidelines have been derived to protect those organisms that are directly impacted by contaminated sediment, namely the sediment-dwelling (benthic) species. To protect against biomagnification of contaminants through the food chain from sediment contaminant sources, as well as other water quality concerns (e.g., recreational uses), the Ministry has relied on Provincial Water Quality Objectives / Provincial Water Quality Guidelines (PWQO/PWQGs) as the basis for deriving sediment values that ensure these objectives and guidelines are not exceeded as a result of sediment contamination. The derivation of the PWQO/PWQGs is explained in detail in OMOE (1990).

The Sediment Quality Guidelines tabled in the document have been designed such that they are consistent with the goals and policies for the management of surface waters that the Ministry has detailed in its handbook, Water Management: Goals, Policies, Objectives and Implementation Procedures of the Ministry of the Environment (MOE, 1984).

SECTION 2

SEDIMENT QUALITY GUIDELINES

The essence of the guideline levels and their significance are provided below. The guidelines as set out define three levels of ecotoxic effects and are based on the chronic, long term effects of contaminants on benthic organisms. These levels are:

1. A No Effect Level at which no toxic effects have been observed on aquatic organisms. This is the level at which no biomagnification through the food chain is expected. Other water quality and use guidelines will also be met at this level.

2. A Lowest Effect Level indicating a level of sediment contamination that can be tolerated by the majority of benthic organisms.

3. A Severe Effect Level indicating the level at which pronounced disturbance of the sediment-dwelling community can be expected. This is the sediment concentration of a compound that would be detrimental to the majority of benthic species.

Guideline Levels and Their Significance

Guideline Level	Sediment Quality	Potential Impact
	Grossly Polluted	
Severe Effect Level	/ /	Will significantly affect use of sediment by benthic organisms.
	Marginally- Significantly Polluted	Will affect sediment use by some benthic organisms.
Lowest Effect Level	/ / / / / / / / / / / / / / /	
	Clean - Marginally Polluted	Potential to affect some sensitive water uses.
No Effect Level	/ / / / / / / / / / / / / / /	
	Clean	No impact on water quality water uses or benthic organisms anticipated.

Details on these levels, and the protocols used in developing the guidelines are provided in section 4 of this document.

The No Effect and Lowest Effect guidelines compare closely with the lowest or no effect levels determined through a review of sediment toxicity bioassays by National Oceanic and Atmospheric Administration (NOAA) (Long and Morgan, 1990)

As is discussed in Section 4.4, it is not currently possible to calculate a No Effect value for all parameters. Where this is the case for the metals, an interim value based on the lower of the background or Lowest Effect Levels will be used as a lower practical limit for management decisions. For the organics, the background values in Table 5 define the lower practical limit for management decisions.

Table 1: Provincial Sediment Quality Guidelines for Metals and Nutrients.
(values in µg/g (ppm) dry weight unless otherwise noted).

METALS	No Effect Level	Lowest Effect Level	Severe Effect Level
Arsenic	-	6	33
Cadmium	-	0.6	10
Chromium	-	26	110
Copper	-	16	110
Iron (%)	-	2	4
Lead	-	31	250
Manganese	-	460	1100
Mercury	-	0.2	2
Nickel	-	16	75
Zinc	-	120	820
NUTRIENTS			
TOC (%)	-	1	10
TKN	-	550	4800
TP	-	600	2000

* - values less than 10 have been rounded to 1 significant digit. Values greater than 10 have been rounded to two significant digits except for round numbers which remain unchanged (e.g., 400).

- - denotes insufficient data/no suitable method.

TOC - Total Organic Carbon TKN - Total Kjeldahl Nitrogen TP - Total Phosphorus

(June 1992)

Table 2a: Provincial Sediment Quality Guidelines for PCBs and Organochlorine Pesticides. (values [a] in pg/g (ppm) dry weight unless otherwise noted).

Compound	No Effect Level	Lowest Effect Level	Severe Effect Level (µg/g organic carbon)*
Aldrin	-	0.002	8
BHC	-	0.003	1.2
α-BHC	-	0.006	10
β-BHC	-	0.005	21
γ-BHC	0.0002	(0.003)[b]	(1)[c]
Chlordane	0.005	0.007	6
DDT(total)		0.007	12
o,p+ p,p-DDT	-	0.008	71
p,p-DDD	-	0.008	6
p,p-DDE	-	0.005	19
Dieldrin	0.0006	0.002	91
Endrin	0.0005	0.003	130
HCB	0.01	0.02	24
Heptachlor	0.0003	-	-
H. epoxide	-	0.005[b]	5[c]
Mirex	-	0.007	130
PCB (total)	0.01	0.07	530
PCB 1254[d]	-	(0.06)[b]	(34)[c]
PCB 1248[d]	-	(0.03)[b]	(150)[c]
PCB 1016[d]	-	(0.007)[b]	(53)[c]
PCB 1260[d]	-	(0.005)[b]	(24)[c]

Lowest Effect Levels and Severe Effect Levels are based on the 5th and 95th percentiles respectively of the Screening Level Concentration (SLC) (see Section 42.4) except where noted otherwise.

( ) Denotes tentative guidelines

[a] Values less than 10 have been rounded to 1 significant digit. Values greater than 10 have been rounded to 2 significant digits except for round numbers which remain unchanged.

[b] 10% SLC.
[c] 90% SLC.
[d] Analyses for PCB Arochlors are not mandatory unless specifically requested by MOE.
\- Insufficient data to calculate guideline.

* Numbers in this column are to be converted to bulk sediment values by multiplying by the actual TOC concentration of the sediments (to a maximum of 10%), e.g. analysis of a sediment sample gave a PCB value of 30 ppm and a TOC of 5%. The value for PCB in the Severe Effects column is first converted to a bulk sediment value for a sediment with 5% TOC by multiplying 530 x 0.05 = 26.5 ppm as the Severe Effect Level guidelines for that sediment. The measured value of 30 ppm is then compared with this bulk sediment value and is found to exceed the guideline.

(March 1993)

Table 2b: Provincial Sediment Quality Guidelines for Polycyclic Aromatic Hydrocarbons. (values in µg/g (ppm) dry weight unless otherwise noted).

Compound	No Effect Level	Lowest Effect Level	Severe Effect Level (µg/g organic carbon)*
Anthracene	-	0.220	370
Benz[a]anthracene	-	0.320	1,480
Benzo[k]fluoranthene	-	0.240	1,340
Benzo[a]pyrene	-	0.370	1,440
Benzo[g,h,i]perylene	-	0.170	320
Chrysene	-	0.340	460
Dibenzo[a,h]anthracene	-	0.060	130
Fluoranthene	-	0.750	1,020
Fluorene	-	0.190	160
Indeno[1,2,3-cd]pyrene	-	0.200	320
Phenanthrene	-	0.560	950
Pyrene	-	0.490	850
PAH (total)	-	4	10,000

(Guidelines could not be calculated for Acenaphthene, Acenaphthylene, Benzo[b]fluorene and Naphthalene due to insufficient data. These will be calculated when sufficient data is available.)

Lowest Effect Levels and Severe Effect Levels are based on the 5^{th} and 95^{th} percentiles respectively of the Screening Level Concentration (SLC) (see Section 4.2.4) except where noted otherwise.

- Insufficient data to calculate guideline.

* Numbers in this column are to be converted to bulk sediment values by multiplying by the actual TOC concentration of the sediments (to a maximum of 10%), e.g. analysis of a sediment sample gave a B[a]P value of 30 ppm and a TOC of 5%. The value for B[a]P in the Severe Effects column is first converted to a bulk sediment value for a sediment with 5% TOC by multiplying 1443 x 0.05 = 72 ppm as the Severe Effect Level guideline for that sediment. The measured value of 30 ppm is then compared with this bulk sediment value and is found to not exceed the guideline.

PAH (total) is the sum of 16 PAH compounds: Acenaphthene, Acenaphthylene, Anthracene, Benzo[k]fluoranthene, Benzo[b]fluorene, Benzo[a]anthracene, Benzo[a]pyrene, Benzo[g,h,i]perylene, Chrysene, Dibenzo[a,h]anthracene, Fluoranthene, Fluorene, Indeno[1,2,3-cd]pyrene, Naphthalene, Phenanthrene and Pyrene.

(March 1993)

Table 3: Additional Parameters.

Parameters carried over from the Open Water Disposal Guidelines.

Oil and Grease	0.15%
Cyanide	0.1 ppm
Ammonia	100 ppm
Cobalt	50 ppm
Silver	0.5 ppm

Routine testing for these parameters would not be required but may be requested on a case-specific basis. (June 1992)

SECTION 3

APPLICATION OF THE SEDIMENT QUALITY GUIDELINES

The Provincial Sediment Quality Guidelines (PSQGs) shown in Tables 1 and 2 supersede the Open-Water Disposal Guidelines and will provide the basis for all sediment (or potential lakefill materials to be placed in water) evaluations in Ontario. The guidelines pertain mainly to activities within the aquatic environment and adherence to them is not to be construed as exemption from the requirements of other guidelines, policies, or regulations of this Ministry or other agencies (e.g., the placement of contaminated sediment at an upland site or facility will be subject to the requirements of the Ministry's Waste Management Regulations). The PSQGs will be used in making decisions on a number of sediment-related issues ranging from prevention of sediment contamination to remedial action for contaminated sediment. Issues to be addressed include, but are not limited to, the following:

- Determination of fill quality for lakefilling associated with shoreline development programs.
- Evaluation of sediment quality.
- Determination of appropriate action with regard to sediment clean-up in areas with historic sediment contamination such as IJC Areas of Concern as well as other *areas* of potential impact.
- Determination of the suitability of dredged material for open-water disposal.
- Establishing the chemical suitability of substrate material for the restoration of benthic habitat.
- Determination of the appropriate degree of sediment clean-up as a result of chemical spills or unauthorized discharge.

3.1 THE EVALUATION PROCESS

Initial evaluation of bottom sediment or fill material is conducted by comparing the chemical concentrations of the material to the appropriate parameter values listed in Tables 1 and 2a, and where required Tables 4 and 5, based on the conditions described in section 3.1.1. Chemical analysis for compounds listed in Table 2b will be performed where specifically requested by MOE or where there is reason to suspect contamination by PAH compounds. Provincial Sediment Quality Guidelines could not be calculated for the parameters in Table 3. Since these parameters can be of concern in protecting aquatic biological resources, the Open Water Disposal Guidelines will continue to be used though chemical analysis for these parameters will be performed only where specifically requested by MOE. The Open Water Disposal Guidelines are equivalent to the Lowest Effect Level in terms of management decisions.

3.1.1 General Conditions Governing Evaluation

(a) Material will be tested by bulk sediment analyses and results reported on a dry weight basis (MOE Analytical Methods (MOE 1983) or MOE approved equivalent analytical procedures to be used).

(b) For the purposes of sediment or fill quality evaluation, actual analytical results reported by the performing laboratory must be provided. However, in comparing the results with the parameter values in the guidelines the results will be rounded as follows: if the reported value is less than ten, it will be rounded to one significant digit. Values greater than 10 will be rounded to two significant digits. Round numbers remain unchanged.

e.g.	Reported Value	Rounded Value
<10	1.78	2
	0.0364	0.04
	0.0052	0.005
>10	10.827	11
	128.4	130

(c) If all parameter values for a given material are <u>at or below</u> the No Effect Level Guidelines, that material passes the guideline and it is anticipated that the material will have no adverse chemical effects on aquatic life or water quality.

(d) If a single parameter value for a given material, based on a sampling program, <u>exceeds</u> the No Effect Level Guideline but is below the Lowest Effect Level Guideline, the material fails the No Effect Level Guidelines and would be considered as having a negligible potential to impair the aquatic environment.

(e) If a single parameter value for a given material, based on a sampling program, is <u>at or above</u> the Lowest Effect Level Guidelines, that material fails the guideline and it is anticipated that such material may have an adverse effect on some benthic biological resources. If all values <u>are below</u> the Lowest Effect Level Guidelines, no significant effects on benthic biological resources are anticipated.

(f) If any single parameter value for a given material, as determined by a sampling program, is <u>at or above</u> the Severe Effect Level Guideline, that material is considered <u>highly contaminated</u> and will likely have a significant effect on benthic biological resources.

(g) The Ministry recognizes that in an area as geologically diverse as Ontario, local natural sediment levels of the metals may vary considerably and in certain areas, such as wetlands, the organic matter content and nutrient levels may be naturally high.

METALS: In areas where local background levels are above the Lowest Effect Level, the local background level will form the practical lower limit for management decisions. In some waterbodies surficial sediments upstream of all discharges may be acceptable for calculation of background values. Where it cannot be shown that such

Table 4: Background Levels for the Metals.

Metal	Background ($\mu g/g$)
Arsenic	4.2
Cadmium	1.1
Chromium	31
Copper	25
Iron (%)	3.12
Lead	23
Manganese	400
Mercury	0.10
Nickel	31
Zinc	65

Values are based on analyses of Great Lakes pre-colonial sediment horizon. (June 1992)

Table 5: Background Sediment Concentrations* of Organic Compounds.

Compound	Background ($\mu g/g$ dry wt.)
Aldrin	0.001
α-BHC	0.001
β-BHC	0.001
γ-BHC	0.001
Chlordane	0.001
DDT (total)	0.010
o,p+ p,p DDT	0.005
p,p-DDD	0.002
p,p-DDE	0.003
Dieldrin	0.001
Endrin	0.001
HCB	0.001
Heptachlor	0.001
Heptachlor epoxide	0.001
Mirex	0.001
PCB (total)	0.020

* Values are based on the highest of the Lake Huron or Lake Superior mean surficial sediment concentrations.

(June 1992)

areas are unaffected by local discharges, the pre-colonial sediment horizon is used. Site specific background for metals is calculated as the mean of 5 replicate samples from surficial sediment that has not been directly affected by man's activities or from the 'pre-colonial' sediment horizon. The calculations are described in Section 4 of this document. Alternatively, the mean background values for the Great Lakes Basin as presented in Table 4 may be used.

NUTRIENTS: Areas of high natural organic matter content, such as marshes and other types of wetlands, can be readily distinguished from those resulting from anthropogenic sources. In such cases, for the nutrients listed in Table 1, the local background would serve as the practical lower limit for management action.

(h) It is also recognized that long-range sources such as atmospheric deposition have contributed to accumulation of organic compounds in areas remote from any specific source. Therefore, in those areas where specific sources cannot be determined, the practical lower limit for management action is the Upper Great Lakes deep basin surficial sediment concentration. These have been defined for a number of organic compounds and are presented in Table 5.

3.2 SPECIFIC APPLICATIONS

3.2.1 Placement of Fill Directly into a Water-course

Fill refers to any type of solid material, other than those defined as inert (i.e., chemically clean) under MOE's Waste Management Guidelines described in Regulation 309 of the Environmental Protection Act, used in shoreline or nearshore development programs generally referred to as lakefilling.

As a minimum, chemical analyses shall be carried out for the Mandatory Parameters listed in the Fill Quality Guidelines (Hayton *et al.* 1992). In addition, chemical analysis may be required for some or all of the parameters in Tables 1, 2 and 3 on a site-specific basis.

Fill material equal to, or better than, the No Effect Level Guidelines can be used without restriction in a watercourse.

The conditions governing fill that exceed the No Effect Level are outlined in MOE's guidelines on lakefilling (Hayton *et al* 1992).

3.2.2 Areas of Potential Concern

When sediment quality in an area consistently exceeds the Lowest Effect Level Guideline, subject to the conditions in 3.1.1.(g) above, that area shall be considered as an area of potential concern, and the actions outlined below shall apply. The sediment evaluation procedure is shown in Figure 2.

In areas where contaminants in sediment are at or above the Lowest Effect Level, steps should be taken to *control all point and non point contaminant sources* to the area. Consideration will be given to the provisions governing areas of high mineralization and atmospheric deposition as outlined in section 3.1.1.(g) and (h).

Application of Provincial Sediment Quality Guidelines to Sediment Assessment.

The sediment evaluation procedure described below outlines in detail the procedure in Figure 2.

1. The sediment concentrations for all parameters, based on a sampling program, are compared to the PSQGs. The concentrations of each parameter are compared to each of the guideline levels.

1a. If sediment analysis shows that the concentration of that parameter is below the No Effect Level, the sediment can be considered as clean and no further management decisions are required.

2. If the sediment concentration of a parameter exceeds the No Effect Level but is below the Lowest Effect Level then no further management decisions are needed. However, for the purposes of dredged material disposal, sediment at this level cannot be disposed of in an area where existing sediment concentrations are below the No Effect Level.

3. If the sediment concentration exceeds the

Lowest Effect Level, then the concentration is compared with the local background values for that parameter. Background values can be derived from physically contiguous areas that are unaffected by point-source discharges, or if these do not exist, then from the "pre-colonial" sediment horizon. The latter would represent background levels in existence before European colonization of the area and is generally considered as the area below the *Ambrosia* pollen horizon. In those instances where local values are not available, the concentration may be compared to the background values listed in Tables 4 and 5. These are based on values from the Great Lakes and may not be applicable to inland sites.

3a. If the sediment concentration is below the natural background then no further management decisions need to be considered.

3b. If the sediment concentration also exceeds the local background value, then the next step is to determine whether the sediment poses a threat to aquatic life, and if so, the severity of this effect. Since the range of sediment concentrations that falls between the Lowest Effect Level and the Severe Effect Level is in most cases very large, it is necessary to distinguish between situations where a parameter may exceed the Lowest Effect Level only slightly, from one where the levels are close to the Severe Effect Level. The biological effects in such cases would be expected to differ widely. A number of biological assessment techniques would be expected to be used in such an assessment. These should encompass laboratory and field-based measures on both individual toxic effects as well as "ecosystem" measures. The types and complexity of analyses will differ according to the specific characteristics (sediment type, contaminant) of each site.

3c. Assessment of the biological effects in turn permits management decisions to be made on the need and potential effectiveness of the available remedial options including source control and sediment remediation. This step will include consideration of the environmental effects and will also incorporate the socioeconomic impacts of both the sediment contamination and the remedial options. This step would be expected to proceed in most cases with considerable public involvement.

3d. The final choices made would involve source control and either the implementation of remedial action or a decision to leave and monitor. The basis for choosing the latter may be a lack of environmental effects or may be based on socio-economic considerations. In some situations leaving contaminated material in place is also an accepted and effective remedial option and may be less environmentally damaging. Where biological effects were found to be present but a decision has been made to leave the material in place, or where this is the accepted remedial action, monitoring may be required along with consideration of other actions that may be needed to restrict public exposure.

4. If the concentration of the contaminant in the sediment exceeds the Severe Effect Level then the sediment bioassay described in section 3.2.3, designed to assess whether the sediment is acutely toxic, is required.

4a. If on the basis of these tests the sediment has not been found to be acutely toxic, then the assessment procedure as described in steps 3b through 3d above are to be followed.

4b. Where the sediment has been found to be acutely toxic on the basis of the bioassay tests, it is necessary to evaluate source control and all remedial options, including leaving the material in place. In some cases, management decisions may involve the implementation of interim remedial action.

In areas where contaminants in sediment are at or above the Severe Effect Level, the sediment is deemed to be highly contaminated and measures in addition to source control may be required to dean up the sediment. Such measures should be determined on the basis of the biological tests outlined below. If the sediment fails either of the tests, *in situ* remedial action is warranted. If the sediment passes both tests, efforts should be directed towards point and non-point source control. *In situ* clean-up must not be a substitute for source control. The sediment evaluation procedure is outlined in Figure 2.

Biological Tests

The following acute lethality *test*, or an equivalent test approved by MOE, will be carried out to determine the need for *in situ* sediment remedial action. Details on the following tests are provided in Bedard *et al.* (1992).

Sediment Bioassay Protocol

The experiments are run as static whole-sediment beaker tests, using two types of aquatic biota: 3-4 month old fathead minnows, *Pimephales promelas* (to assess effects of contaminated sediment on water column organisms) and 3-4 month old reared nymphs of the burrowing mayfly, *Hexagenia limbata* (to assess effects of contaminated sediment on a sediment-dwelling organism). The organisms are placed in jars (2 litre) with dechlorinated water and sediment (4:1 ratio) for a 10-day exposure period. At the end of the experiment, percent mortality is calculated.

Selection of Controls

Controls are very important and necessary for proper interpretation of bioassay results. Two types of control sediments are selected for the Sediment Bioassay Protocol and these are:

- Sediments in which test organisms are cultured.
- Control site from study location, upstream or removed from the pollution sources being assessed but as similar as possible in composition.

Data Interpretation

Data interpretation involves comparing bioassay results from test sediments to results from:

- replicate test sediments to address variability among replicates
- control sediments that organisms were cultured in
- upstream control sediments or sediments removed from pollution sources being assessed.

Statistically significant ($P < 0.05$) differences between test and control sediments for the various endpoints indicate that test sediments have negatively impacted the biota. Control mortality is monitored and must not exceed 15% for the validation of test results.

3.2.3 Dredged Material Disposal

Dredged material refers to any material removed from the bottom of a watercourse as a result of capital or maintenance dredging, remedial action or spills clean-up. The conditions outlined below relate only to material being considered for disposal in open water and does not include material to be placed within Confined Disposal Facilities (CDFs). Analyses will be performed for all parameters listed in Tables 1 and 2, unless previous data suggest the absence of certain parameters. In addition, chemical analysis may be required for some or all of the parameters in Table 3.

A. Disposal in Areas With Sediment Quality Equal to or Better Than the No Effect Level Guidelines.

The dredged material to be disposed of must not exceed the No Effect Level Guidelines.

B. Disposal in Areas With Sediment Quality Exceeding *the* No Effect Level Guidelines.

The dredged material to be disposed of in such areas must be below the Lowest Effect Level Guidelines, subject to the conditions described in 3.1.1.(g). Detailed application of these guidelines is described below and is shown in Figure 3.

Sediment Evaluation for Dredged Material Disposal

Dredge material disposal in open water requires that both the material to be removed as well as the material in the disposal area be analyzed. Each parameter is compared to the PSQG levels. In practice, the material is matched to the disposal area, which in turn will be classified into one of three groups.

Group 1

1a. The concentrations of contaminants in sediments in the disposal area are below the No Effect Level. If the concentrations in the dredged material are also below the No Effect Level the material is suitable for disposal at this site.

1b. If the concentrations in the dredged sediments are above the No Effect Level then this material is not suitable for disposal at this site, since this would result in contamination of a dean site with sediment of a lesser quality. However, if the concentrations in the dredged material are below the Lowest Effect Level, it may be suitable for disposal at another site where existing sediment concentrations are above the No Effect Level.

1c. Material that exceeds the Lowest Effect Level for any parameter is not suitable for open water disposal at this site.

Group 2

2a. The sediments in the disposal area are above the No Effect Level but still below the Lowest Effect Level. If the concentrations in the dredged material are below the No Effect Level then the material is suitable for open water disposal at this site.

2b. Similarly, if the dredged material is above the No Effect Level but below the Lowest Effect Level, the material is also suitable for disposal at this site. Material that exceeds the Lowest Effect Level is not suitable for open water disposal at this site.

Group 3

3a. If the sediments in the disposal area are contaminated to above the Lowest Effect Level, material that is below the Lowest Effect Level is suitable for open water disposal at this site.

3b. Material that exceeds the Lowest Effect Level for organic compounds and mercury is not suitable for open water disposal. Material that exceeds the Lowest Effect Level for metals other than mercury is suitable for open water disposal under certain conditions. If the material is at or below the Great Lakes background (as defined in Table 4) and does not exceed ambient sediment levels then the material is suitable for open water disposal at this site.

3.2.4 Spills Clean-up

In areas where ambient or background sediment levels of the substance(s) spilled are below the No Effect Level, the clean-up level will, as a minimum, be to the No Effect Level. IS the ambient sediment levels for that watercourse are above the No Effect Level, then cleanup will be, as a minimum, to the local ambient level. To clean up beyond the ambient level would be of no lasting benefit due to the long-term migration and cycling of sediment within the ecosystem.

SECTION 4

PROTOCOL FOR SETTING SEDIMENT QUALITY GUIDELINES

4.1 RATIONALE FOR SETTING SEDIMENT QUALITY GUIDELINES

In developing guidelines to provide adequate protection for biological resources, the Ministry has attempted to ensure that the methods employed consider the full range of natural processes governing the fate and distribution of contaminants in the natural environment. Since benthic organisms respond to a variety of stress-inducing factors they are, in essence, integrators of all the physical, chemical and biological phenomena being experienced in their environment and these organisms should form the basis of any method used in setting sediment guidelines.

Because individual species may respond differently to stress-inducing factors it is very difficult to study a specific organism (eg. a sensitive species) with the hope of developing guidelines that will protect the rest of the community. Sensitivity to chemical contaminants has not been fully evaluated for different benthic organisms and most sediment bioassay work has been concerned mainly with a few selected species (eg. the mayfly *Hexagenia).* While the mayfly has traditionally been used as a "sensitive" indicator organism for factors such as low dissolved oxygen, its sensitivity relative to other benthic organisms has not been dearly established for chemical contaminants. Therefore, in developing PSQGs, the Ministry has not relied on single-species data.

Similarly, a method that relies heavily on those species that are known to be extremely tolerant of contaminants in sediment cannot result in guidelines that will adequately protect less tolerant members of the aquatic community. It has been demonstrated that some populations can adapt to varying levels of environmental contamination with increasing tolerance to these contaminants occurring in succeeding generations. This can present difficulty in laboratory studies of reared populations since these may lack the genetic diversity found in natural populations and responses may not be consistent with those observable under field conditions.

Another concern in relation to placing heavy reliance on laboratory data stems from the fact that in most situations contaminants in sediments exist as mixtures of various substances. Laboratory tests have been geared towards examining the effects of single substances and laboratory data can be difficult to apply to field situations.

In developing the protocol for setting Sediment Quality Guidelines, the ministry considered a number of different approaches developed by state and federal agencies in North America that employed various degrees of biological assessment. The various suggestions for the development of Sediment Quality Guidelines can be summarized in five approaches as possible means of setting sediment quality guidelines. At present, no single approach can adequately account for all the factors that operate in natural sediments and each of the five approaches has positive attributes as well as limitations with regard to the development of biologically based guidelines. The rationale used in setting Sediment Quality Guidelines includes a number of considerations which are detailed below. These considerations provided the basis for selecting the best method or combination of methods for Sediment Quality Development.

1. Sediment Quality Guidelines should consider a range of contaminant concentrations that is wide enough to determine the level at which ecotoxic effects become noticeable. This can be achieved most effectively by looking at a large number of organisms under the widest possible range of contaminant exposure. Only then can the appropriate ecotoxic level be adequately determined. A restricted range may result in the setting of guidelines that are not reflective of actual ecotoxic effects on organisms and as such may be overprotective. This is especially important where the range of effects used may not cover the entire tolerance range of the species in question.

2. PSQGs should be based on cause-effect relationships between a specific contaminant and benthic organisms since it is necessary to demonstrate that at a certain concentration a contaminant results in adverse effects on benthic organisms.

3. PSQGs should account for contaminant effects in a multi-contaminant medium. Since contaminated sediments usually consist of mixtures of substances, the presence of a number of different contaminants, any or all of which may affect the response of the organisms to the contaminant being investigated must be considered. Since combinations of contaminants may evoke different responses than those occurring singly (through either synergistic or antagonistic effects) these effects must be accounted for as well. A PSQG method must incorporate this feature into the derivation of a number for specific contaminants.

4. PSQGs should consider chronic effects of contaminants on aquatic biota since these can affect the long term viability of aquatic organism populations. Methods that consider only acute effects do not offer adequate protection, since sediment concentrations reflect long-term conditions and are not subject to the extreme temporal variability of water column contaminant concentrations.

5. The PSQGs should be capable of incorporating and accounting for the range of environmental factors that could have a bearing on the presence or absence of organisms in a given area. Contaminant behaviour and organisms' well-being are

governed by a variety of natural physical, chemical and biological processes. If these processes are not accounted for in a PSQG method then the resulting guidelines will be unrealistic. For example, organisms may be absent from a given area not because of the level of contaminants but because of unsuitable habitat, low dissolved oxygen, or interspecific competition. In formulating a guideline it is essential that these factors be considered along with the chemical data. If they are not considered, the numerical value obtained would not necessarily be protective of aquatic species. This will also reduce the need for site-specific guidelines, since a full range of environmental conditions will have been covered.

4.2 APPROACHES TO SEDIMENT QUALITY GUIDELINE DEVELOPMENT.

As part of the sediment guideline development process, the Ministry has carried out an extensive literature review of possible approaches to the development of sediment guidelines. This effort has resulted in the selection of five potential approaches for this purpose. These are:

1. Sediment Background Approach
2. Equilibrium Partitioning Approach (Water - Sediment and Biota - Water - Sediment Partitioning)
3. Apparent Effects Threshold Approach
4. Screening Level Concentration Approach
5. Spiked Bioassay Approach

The five approaches are discussed below and additional details can be found in the pertinent literature cited for each method.

4.2.1 Sediment Background Approach

In the Background Approach, sediment contaminant concentrations are compared to concentrations from reference background sites where contaminant levels are deemed to be acceptable (OMOE 1987, 1988). Using the Background Approach, levels are set according to a "suitable" reference site or "acceptable" level of contamination. A suitable reference site may be one where sediments are deemed to be relatively unaffected by anthropogenic inputs. Alternatively a suitable reference site may be derived through sediment profiles. In the latter, the pre-industrial sediment horizon, as determined through techniques such as palynology, could be used to determine background levels.

The basis of the Background method is the implicit assumption that concentrations above these background values have an adverse effect on aquatic organisms.

For the purposes of PSQG development a "pre-industrial" standard could be adopted only for metals. The strictly anthropogenic (man-made) organic contaminants, for which background levels should theoretically be zero, would require adoption of a contemporary surficial sediment standard, based on a suitable reference site.

Advantages:

The data requirements of the Background Approach are minimal in that the method requires only measurement of the chemical concentrations of contaminants in sediments. As such it can be used with the existing data, thus minimizing the need for additional data collection.

The method does not require quantitative toxicological data and avoids the need to seek mechanistic chemical explanations for contaminant behaviour or biological effects.

Background limits have advantages from an enforcement perspective since the Background Approach does provide an indication of the chemical concentration for metals that is expected to occur naturally. While it is possible that biological effects may occur in some species at metal concentrations indistinguishable from non-anthropogenic background, it is difficult to justify enforcement of a standard that has never been realized in nature. Thus background levels for metals can provide a practical lower limit for management decisions. For organic contaminants, which are largely anthropogenic, background should theoretically be zero. In most areas, however, contaminants have found their way into sediment and a contemporary benchmark based on current average concentrations for a suitable reference area may provide the practical lower limit for enforcement.

There is at present an adequate database for developing sediment guidelines for several contaminants using the Background Approach.

Limitations:

Since the Background Approach relies only on the chemical concentration of contaminants in sediments it has no biological basis. Because biological effects data are not considered, cause-effect relationships between sediment contaminant levels and sediment-dwelling organisms cannot be determined.

The exclusive use of chemical data implies that sediment characteristics have no influence on the resultant biological effects, but rather that chemical concentrations alone are responsible for the observed effects. However, sediment characteristics (i.e., grain size, organic content, dissolved oxygen levels) have been shown to be major factors affecting benthic community composition.

Implicit in the method is the assumption that the chemicals present are in their biologically available forms. The method therefore, makes no allowance for the occurrence of different chemical species with differing biological availability and toxicity.

A further limitation of this approach is that background levels tend to be highly site-specific. They therefore require the designation of a reference site, which itself is likely to be highly subjective.

4.2.2 Equilibrium Partitioning Approaches

Phase partitioning of organic compounds has been used to describe the distribution of certain organic compounds in aquatic compartments. Partitioning, like adsorption, is one of the processes by which organic compounds can be sorbed to sediments. A major difference however, is that partitioning is solubility dependent and therefore, reversible (i.e. equilibrium) partitioning of non-polar organic compounds is a function of their solubility in water. The very insoluble compounds, as a result, partition strongly to sediment with only very minor amounts in water. These compounds tend to have high partition coefficients, as measured by the octanol-water partition coefficient, K_{OW}. The K_{OW} is the ratio of the amount of the compound that is soluble in an organic solvent such as octanol relative to the amount soluble in water.

The partitioning approaches have been extensively investigated by the U.S. EPA (Pavlou & Weston 1984). A basic assumption of this approach is that the distribution of contaminants among different compartments in sediment is controlled in a predictable manner by a continuous equilibrium exchange among sediment solids and the interstitial water. Partitioning to these two phases can therefore be calculated by the quantity of sorbent in the sediment, for which organic carbon is the primary sorbent, and the partition coefficient K_{OC}. K_{OC} values, which can be estimated from K_{OW}, are normalized to sediment organic content.

The EP approaches also assume that interstitial water is the primary route of organism exposure to contaminants in sediments. Therefore, this approach assumes that only the amount of contaminant partitioning to the water is of interest, the amounts partitioning to the sediments being considered as unavailable.

Using this approach, contaminant-specific partition coefficients are determined (generally expressed in terms of organic carbon content of sediment) and used to predict the distribution of the contaminant between sediment and interstitial water. It must be pointed out that this approach can only be used for contaminants that partition between environmental phases. Contaminants that do not partition appreciably into sediment organic matter, and those whose chemical behaviour is highly unpredictable, such as the metals, cannot be considered using the partitioning approach.

Under the EP approach, a generic (i.e. equally applicable to all sites) organic carbon-normalized partition coefficient K_{OC} is developed and is then multiplied by an existing PWQO/G to derive a sediment guideline. In essence, the distribution coefficients for the non-polar organics are used to establish the chemical concentration in the sediments that, at equilibrium, will not exceed PWQO/Gs in the interstitial water.

Sediment Quality Guidelines based on the equilibrium partitioning of organics can be calculated in a number of ways, depending on the type of data available.

1. Water - Sediment Equilibrium Partitioning Approach

   The water - sediment partitioning approach is a generic partitioning method which derives a sediment quality guideline from the partitioning of a chemical to the water and the sediment solid phases. There is sufficient evidence to show that sediment organic carbon is the primary environmental factor influencing partitioning (Di Toro *et al.* 1985 in OMOE 1988). The partition coefficient K_d is normalized for organic content and an organic carbon-normalized sediment-water partition coefficient is derived (K_{OC}). This can either be derived empirically, or calculated from the octanol-water partition coefficient. The partition coefficient is then multiplied by a water quality criterion (such as a PWQO) to derive a sediment quality guideline.

2. Biota - Water - Sediment Equilibrium Partitioning Approach

   The Biota - Water - Sediment Partitioning Approach is a generic partitioning method which derives a sediment guideline from an existing tissue residue criterion. It is a two step approach utilising a generic water - biota bioconcentration factor (BCF) to relate the tissue criterion to a corresponding water concentration. For bioaccumulable substances this relationship determines the tissue-water concentration level (TWCL). The TWCL is the value that must not be exceeded in water in order to prevent exceedance of the tissue residue criteria from which the TWCL was derived. The TWCL, therefore, is equivalent to a water-quality criterion. Following this step the approach is similar to that described for the water - sediment approach with the TWCL used in place of the water quality criterion.

Advantages:

Generic Partitioning Approaches are biologically based to the extent that existing water or tissue criteria are biologically based and, therefore, provide more defensible guidelines than the Background Approach. Since they make use of the virtual no-effect levels determined from existing Provincial Water Quality Objectives and Guidelines (PWQO/Gs) the sediment guidelines derived through generic partitioning approaches can be considered no-effect levels for the protection of those end-uses the water quality guidelines were designed to achieve.

The partitioning approach relies on an existing toxicological rationale which has been established during the development of the water quality criterion being used. Thus, a new toxicological evaluation is not required provided that the water quality criterion has been derived to protect those benthic organisms which are exposed to the interstitial water. However, a corresponding limitation to the approach is its applicability only to chemicals which have water quality criteria. Moreover, if the water and sediment criteria are meant to protect different organisms then an assumption is made that the two sets of organisms are of equal sensitivity to given levels of contaminants.

Limitations:

The basic assumption that availability of an organic compound to aquatic organisms is controlled by the amounts partitioning to the water ignores both the sediments and food chain effects as potential sources. It has not yet been proven that the interstitial water is the only significant route of exposure and for the highly hydrophobic compounds (those with high K_{OW}), all of these sources may be significant routes of exposure.

Tissue residue criteria are generally based on human health considerations and human food consumption patterns. Therefore, the tissue residue criteria apply to human food organisms such as fish, rather than benthic organisms. Similarly, the BCF applies to fish, and the water concentration (TWCL) thus derived applies to the water column in which the fish lives. This approach is limited by the substantial gap that exists between the water column compartment and the interstitial water compartment that is assumed to be in equilibrium with the sediments.

The reduction in contaminant concentration from the interstitial water to the water column compartment is likely to be highly site-specific depending on local-circulation.

Current use of the Partitioning Approach is limited to those contaminants that exhibit predictable partitioning behaviour. Since the partitioning of metals in sediments is highly unpredictable (e.g., sediment-water partition coefficients for metals can span a wide range of values differing by orders of magnitude depending on such factors as redox potential, pH, dissolved oxygen and organic matter content of the sediment) and polar organics generally do not partition into sediment, the partitioning approaches are considered applicable only to non-polar organic compounds.

The scientific validity of a sediment guideline obtained through the partitioning approaches relies heavily on the accuracy of the partitioning coefficients (K_{OC}) used. The published values for partition coefficients obtained by different authors can differ by an order of magnitude. This presents great difficulty in choosing a representative value for use in guideline development work and unless a standard approach is used it will be difficult to obtain consistent or compatible guidelines using the EP approach.

At present the EP approach cannot account for all the forms a contaminant can exist in and all the possible sediment constituents it can partition to. This is currently a drawback to the EP approach since the various forms of a contaminant have their own toxicity and partitioning characteristics. Several species of a contaminant may be bioavailable and toxic, but often their concentrations are more or less linearly dependent on the concentration of a single species. While it has been possible to establish that one species correlates with the observed toxic effects for the non-polar organics, this has not been possible for the metals or the polar organics. The partitioning approach does not work for metals or polar organics due to the multiplicity of adsorption mechanisms these undergo. It is not even clear which sediment components are controlling partitioning.

4.23 <u>Apparent Effects Threshold Approach (AET)</u>

The AET, as developed by Tetra Tech (1986) is a statistically based approach that attempts to establish quantitative relationships between individual sediment contaminants and observed biological effects. The biological effects can be both field measured effects such as changes in benthic community structure and laboratory measured effects through the use of sediment bioassays. The basis of this technique is to find the sediment concentration of a contaminant above which significant biological effects are always observed. These effects can be any or all of a number of different types, such as chronic or acute toxicity, changes in community composition, and bioaccumulation and are considered in conjunction with the measured sediment contaminant levels. Inherent in the approach is the assumption that observed effects above this level of contamination are specifically related to the contaminant of interest, while below this level any effects observed could be due to other contaminants.

Advantages:

The AET Approach is effects based and therefore more defensible than the partitioning approaches in relation to the protection of benthic organisms. The method assumes a direct cause-effect relationship between sediment concentrations of a contaminant and the occurrence of significant biological effects.

Unlike the partitioning approach the AET makes no assumptions regarding contaminant availability from the various environmental compartments. Therefore the effects on biota can be due to contaminants available through both adsorption from sediments and interstitial water and through absorption from ingested matter.

Limitations:

The method is unable to separate the biological effects that may be due to a combination of contaminants.

While assuming a cause-effect relationship, the method cannot dearly demonstrate a cause-effect relationship for any single contaminant. Thus, while definite ecotoxic effects can be established, these cannot be attributed to any one chemical contaminant.

In using the AET approach care must be exercised in selecting the species of organism to be used and the particular type of effects (endpoints) to be considered. If the data used consist of mixed species and endpoints, the least sensitive of these , will always predominate and the guidelines derived may not protect other more sensitive species. For example, if the data base for a particular contaminant contains data on acute toxicity to tubificid oligochaetes, then the AET will be designed to protect against acute toxicity to tubificids. It will not protect species that are more sensitive nor will it provide protection against chronic effects.

For most practical purposes this method requires chronic toxicity data since results from the existing database indicate guidelines tend to be higher than those calculated by other means, in some cases by an order of magnitude. This is usually due to the use of acute toxicity data which needs a correction factor to adjust to chronic toxicity. The development of a chronic toxicity database (i.e, one based on reproductive effects and effects on the most sensitive life stages) itself requires a very extensive set of information which at present does not exist in a 'standardized form. In order to obtain such information, considerable laboratory testing will have to be carried out. In addition, for data from different investigators to be useful, consistency in procedures and definition of endpoints will be necessary. To this end, results from single investigators are the most effective for attaining consistent results.

In practice, guidelines generated by the AET approach are likely to be underprotective since this method determines the contaminant level above which biological effects are always expected. Biological effects, however, can be and are observed at chemical concentrations lower than these values, though these effects may not occur in all samples.

The AET method is applicable for all types of contaminants, making use of both laboratory tests on sediments (spiked sediments) and field data. In laboratory tests, of field-collected sediments it may not be possible, to separate the effects of mixtures of chemicals. If spiked sediments are used, only single contaminant or known (specific) mixtures can be used and therefore this method suffers from some of the same limitations as the Spiked Bioassay method (discussed below). In using field collected sediments in conjunction with other field data (e.g. community composition), it is not possible to separate the effects of mixtures of contaminants and this method suffers' from the limitations affecting the SLC method.

4.2.4 The Screening Level Concentration Approach (SLC)

The SLC, like the AET, is an effects based approach applicable mainly to benthic organisms. The SLC approach uses field data on the co-occurrence in sediments of benthic infaunal species and different concentrations of contaminants. The SLC is an estimate of the highest concentration of a contaminant that can be tolerated by a specific proportion of benthic species. In its original derivation and application, the 95^{th} percentile was used.

The SLC, as developed by Neff *et al* (1986), is calculated through a two step process. First, for a large number of species (at least ten for each chemical) a species SLC (SSLC) is calculated by plotting the frequency distribution of the contaminant concentrations over all sites (at least ten) where the species is present. The 90^{th} percentile of this distribution is then taken as the SSLC for that species. The 90th percentile was chosen to provide a more conservative estimate of the SSLC. Extreme sediment concentrations may be an aspect of specific sediment characteristics resulting in low biological availability relative to the sediment concentration. By choosing the 90^{th} percentile, these values are excluded. In the second step, the SSLCs for each species are plotted as a frequency distribution and the 5^{th} percentile is interpolated from this distribution. This is the SLC and represents the concentration which 95% of the species can tolerate.

A basic assumption in the method is that the data cover the full tolerance range of each species. This assumption requires that a large range of chemical concentrations be sampled in each case (at least two orders of magnitude) since an SLC will be generated whether or not this assumption is true. This is important though sometimes difficult to verify. The difficulty lies in the fact that the full tolerance range of most species is not known.

Sediment contaminant concentrations for the non-polar organics are normalized to TOC content of the sediments. Since these compounds generally partition strongly to organic matter, the normalized concentration should more closely represent contaminant availability to benthic organisms. For metals and polar organics, bulk sediment concentrations are used since the best normalization procedures for representation of metal availability are as yet unresolved.

Advantages:

Since the SLC approach does not make any assumptions about the absence of a species and considers only those species present, the SLC approach does not require *a priori* assumptions concerning cause-effect relationships between sediment contaminant concentrations and the presence or absence of benthic species. As no relationship is assumed it is not necessary to take into account the wide variety of environmental factors that affect benthic communities, such as substrate type, temperature and depth.

However, valid a *posteriori* inferences can be drawn from this type of analysis regarding the range of sediment contaminant concentrations that can be tolerated by the sediment infauna since field data on the co-occurrence of benthic infaunal species and sediment contaminant concentrations are used.

However, since the SLC Approach uses field data on the co-occurrence in the field of contaminants and benthic species, the environmental factors acting on the species distribution are already integrated into the data-set and the response determined is a measure of both the environmental factors and the contaminant levels. It also integrates changes in chronic responses such as reproduction/ fecundity and sensitive life-stages, since it is a cumulative measure of effects. In addition, it integrates into the biological response any synergistic or additive effects from multiple contaminants as they would occur in natural sediments. Because of this, the SLC approach overcomes the difficulties of applying bioassay data to field situations, and the lack of uncertainty associated with partition coefficients.

While it was originally developed primarily for *use* with non-polar organics (using TOC normalization) it is also appropriate for metals and polar organics as well since it can be used with or without TOC normalization.

At present the size of the database has determined that the SLC level be set at the 5^{th} percentile of the SLC frequency distribution. However, as the database continues to expand it should be possible to reliably calculate the 1st percentile (Le. the level of a contaminant that 99% of the species present can tolerate). The precision of the SLC is directly related to the size of the database and the range of variability of the various factors within the database. Therefore great care must be taken to include data taken over the full range of conditions since a database skewed to either lightly or heavily contaminated areas will yield guidelines that are either too conservative (overprotective) or do not provide adequate protection for aquatic life (underprotective).

Limitations:

The major limitation of the SLC approach is the difficulty in determining a direct cause-effect relationship between any one contaminant and the benthic biota, since very rarely is a single contaminant present in natural situations. Therefore, the effects observed are related to the entire mixture of chemicals.

The range and distribution of contaminant concentrations and the particular species used to generate them can significantly affect the calculation of the SLC value. The use of only low values of contaminant concentration may not encompass the entire tolerance range of the species and the concentration would be below the level that would adversely affect the distribution of that species. In such situations, an SLC would still be generated but the value would be conservative and unrealistic. This can be overcome by ensuring that the database include values from heavily contaminated areas.

The SLC is also sensitive to the species used in the database. Unlike the Partitioning approach, the SLC does not make any assumptions regarding the possible routes of effect from aquatic contaminants, all possible modes of exposure are taken into account. Since contaminant availability from the sediments may differ in relation to the feeding habits of the organisms used, the proportion of species from each of the feeding groups will determine the shape of the SLC curve. This can also be overcome by limiting the database to those organisms living in or feeding on the sediment.

4.2.5 Spiked Bioassay Approach

In this approach, dose-response relationships are determined by exposing test organisms, under controlled laboratory conditions, to sediments that have been spiked with known amounts of contaminants (OMOE 1987, 1988). Sediment quality guideline values can then be determined using the sediment bioassay data in a manner similar to that in which aqueous bioassays are used to establish water quality criteria. Where chronic toxicity data are not available, an approximation can be obtained by using acute toxicity endpoints that have been adjusted downwards by a factor of ten to obtain a chronic protection level and then applying a suitable safety factor.

Advantages:

The major advantage of this approach is that a direct cause-effect relationship can be determined, at least under laboratory conditions, for a specific chemical or combination of chemicals for any species of organism.

Limitations:

Despite this advantage, limitations exist that, at present, preclude the use of this method for setting guidelines. Techniques have not been standardized for spiking sediments and differences in methods/techniques can strongly influence the results. In addition, laboratory bioassays performed under controlled conditions may not be directly applicable to field situations where conditions may vary considerably from those encountered in the laboratory. In order to derive realistic guidelines from the Bioassay Approach efforts will have to be made to test different sediments with various chemical mixtures in differing proportions and using different organisms, as would exist in field situations.

4.3 Summary Evaluations of the Various Approaches to PSQG Development

As pointed out earlier, the major objectives in the development of sediment quality guidelines are to provide protection to aquatic organisms and ensure water quality protection, as well as guidance in decision-making related to abatement efforts and remedial action. As such they are intended to be both proactive and reactive in application. The primary basis for such decisions is the protection of biological resources against the lethal and sublethal effects of contaminated sediment.

The biological resources that could potentially be impacted by contaminants in sediment span a wide range. These include organisms that could be impacted directly, namely the benthic species that live in or feed on the sediment, and water column organisms that could sorb contaminants released from the sediment to water and/or through the consumption of benthic organisms; and those impacted indirectly such as non-aquatic consumers (humans and wildlife) of top aquatic predators such as fish.

In reviewing the five approaches to setting sediment guidelines, it is apparent that each approach has certain merits as well as limitations.

The Background Approach while larking a biological basis, does provide a good indication of the levels at which metals are expected to occur naturally and thus provides a realistic lower limit for guideline development.

The partitioning approaches to sediment guideline development use existing criteria such as a water quality or tissue residue criteria which can be considered as virtual no-effect values. The resulting sediment guidelines can therefore also be considered as virtual no-effect values for the protection of water column organisms from sediment-bound contaminants.

The partitioning approach is attractive because it is capable of providing a measure of contaminant availability from sediments with a minimum of data. Due to the incorporation of various safety factors in the generation of PWQOs, this approach is able to provide an estimate of the no-effect level of a contaminant in sediments. How protective this value may be depends on the sediment organisms, the size of the safety factor, and the type of sediment. The approach is limited by its assumption of a single route of exposure for aquatic organisms and its restriction to the non-polar organics.

The AET approach appears best suited to discriminating between contaminated and uncontaminated areas within a site, since the data used tend to be highly site specific. As a result, any guidelines derived will also *be* site-specific. The major limitation lies in the assumption of a cause-effect relationship that the methods proves unable to demonstrate. There is also a paucity of chronic effects data suitable for AET applications, particularly if consistency in level of protection (i.e. single species and endpoint) is desired. Therefore, the AET approach is judged less acceptable than the other effects-based approaches.

The SLC approach has an advantage in that no cause-effect relationships are assumed and therefore, it does not need to account for all of the natural environmental factors that can affect organisms. The effects of these are already integrated into the data. The effects of multi-contaminant interactions are also factored into the data set used in the calculations and, with a sufficiently large database, the effects of other contaminants can be minimized.

The SLC approach would be less defensible on a theoretical basis than the Spiked Bioassay Approach if the data bases for the two approaches were comparable. It has been found, however, that relevant information from bioassays is considerably lacking, especially in relation to the impacts of chemical mixtures on benthic populations. Due to the paucity of Spiked Bioassay data, it is difficult to achieve consistency in the level of protection (i.e. a variety of species and endpoints must be considered). The problem could be rectified with further chronic data acquisition, particularly if standard spiking techniques were adopted. In practice, the methodology has not been standardized and variations in experimental protocol can greatly influence the results. The ability to transpose laboratory derived results to natural situations is also questionable.

Since there is presently a significant lack of adequate data for use in the development of sediment quality guidelines using the spiked bioassay approach, the SLC approach offers the best means of developing sediment quality guidelines for the protection of the benthic community. This is especially true since there already exists a good database for the Great Lakes Region.

In accordance with the merits and limitations of the various approaches to sediment guideline development, their use can be summarized as follows:

- Partitioning approaches have been used to develop virtual no-effect levels for the protection of water quality and uses, and health risks associated with humans and wildlife through the consumption of fish. These can be used to set sediment contaminant levels that are also protective of these same uses.

- The effects-based approaches (AET, SLC and Bioassay) are being used to develop guidelines for the protection of benthic organisms. Based on the existing information base, only the SLC approach is of immediate use in the development of sediment quality guidelines.

- The Background Approach has been used to establish levels where adequate data do not exist for application of any of the other methods or where the methods used are inappropriate for the type of compound. In addition, background levels provide a practical lower limit for management decisions.

As sediment bioassay techniques are refined and standardized it may be necessary to revise the protocol to accommodate these techniques as well, though it is unlikely that these will ever supplant field based approaches such as the SLC, since some field verification of laboratory results will always be necessary.

4.4 CALCULATION OF SEDIMENT QUALITY GUIDELINES

The calculation of specific guideline values for the three levels of guidelines referred to in Section 2 are described in detail below.

4.4.1 THE NO EFFECT LEVEL

Since this is intended as the level at which contaminants in sediments do not present a threat to water quality and uses, benthic biota, wildlife or human health, the parameter values used in deriving the No Effect Levels must be the most stringent criteria.

The No Effect Level is principally designed to protect against biomagnification through the food chain. Since these effects are most often observed with the nonpolar organics, this guideline level is not applicable to most of the trace metals.

The partitioning approaches are used to set these guidelines since, with appropriate safety factors PWQOs/Gs are designed to protect against biomagnification of contaminants through the food chain, as well as all water quality uses and organisms.

At present, reliable partition coefficients can only be derived for the nonpolar organics, since only these compounds undergo predictable partitioning behaviour in sediments. No Effect Level Guidelines cannot be calculated for metals and polar organics.

Non-Polar Organics

The No Effect Level for non-polar organics is obtained through a chemical equilibrium partitioning approach using PWQOs.

The calculations for each criterion are as follows: A PWQO/G value is multiplied by an organic carbon-normalized sediment-water partition coefficient, K_{OC}. Normalization was recommended by Pavlou and Weston (1984) and OMOE (1988) since sediment organic carbon has been found to be the primary environmental factor influencing partitioning.

A PSQG is then derived through the equation:

$$SQG = K_{OC} \times PWQO/G$$

where PSQG is the sediment quality guideline normalized to the sediment organic carbon content (TOC). This is converted to a bulk sediment basis by assuming a 1% TOC concentration. A 1% level for sediment organic carbon is used for converting to a bulk sediment basis, since calculations using the SLC approach have shown that this is the lowest effect level of organic carbon in the sediment. A bulk sediment calculation based on the actual organic carbon content of the sediment has been avoided for this reason.

The organic carbon-normalized partition coefficient is calculated from either an experimentally derived sediment-water partition coefficient:

$$K_{sed} = \frac{[X]_{sed} / O.C.}{[X]_{iw}}$$

where $[X]_{sed}$ is the concentration of compound X in the sediment (as mass of X/mass of organic carbon) and $[X]_{iw}$ is the concentration of the compound in the interstitial water (as gm/L) (Pavlou 1987), or it can be reasonably accurately derived from the octanol-water partition coefficient according to the formula developed by Di Toro *et al.* (1985)(in OMOE 1988).

$$\log_{10} K_{OC} = 0.00028 + 0.983 \log_{10}(K_{OW})$$

The K_{OW} value used is derived by taking the geometric mean of the available K_{OW} values.

Both measured and calculated K_{OW} values can be used to derive a K_{OC} and a number of values are required to estimate the K_{OW} used.

K_{OC} values should be calculated from laboratory derived sediment - water partition coefficients whenever possible, rather than from values derived from the octanol-water partition coefficient (K_{OW}).

Since the No Effect Level Guidelines make use of the PWQO/Gs which employ safety factors to ensure conservative levels, it is anticipated that the sediment guidelines derived from these will be conservative as well. While the distribution of non-polar organics in the pre-colonial sediment horizon should technically be zero, it is recognized that a certain amount of sediment contamination has occurred from remote sources through atmospheric inputs. Since guidelines set below these background levels would be impractical, the background levels must form the lower limits of any sediment quality guidelines. To this end, Background levels for the non-polar organics are provided in this document for comparative purposes. These are based on the average of the upper Great Lakes, deep basin surficial (top 5 cm) sediment concentrations, or in some cases, on concentrations in bluff materials. It is expected that where the No Effect Level guidelines derived by the partitioning method fall below these background levels, the background levels will provide the practical lower limit for management purposes.

The deep basin surficial sediment concentrations from the Upper Great Lakes can be considered as representative of atmospheric inputs of the persistent (generally nonpolar) organics. Table 5 gives the background levels for those compounds for which upper Great Lakes level have been calculated, and these can be considered as normal background levels for management purposes. This is not to be construed as a tacit acceptance of this level of contamination, but merely recognizes the ubiquitous distribution of these contaminants.

4.4.2 THE LOWEST EFFECT LEVEL

The Lowest Effect Level is the level at which actual ecotoxic effects become apparent. It is derived using field-based data on the co-occurrence of sediment concentrations and benthic species. The Screening Level Concentration method described in the previous section is used for all types of contaminants.

The calculation of the SLC is a two step process and is calculated separately for each parameter. In the first step, for each parameter the individual SLCs (termed Species SLCs) are calculated for each of the benthic species. The sediment concentrations at all locations at which that species was present are plotted in order of increasing concentration (Figure 1a). From this plot, the 90th percentile of this concentration distribution is determined. The 90th percentile was chosen to provide a conservative estimate of the tolerance range for that species. This would serve to eliminate extremes in concentrations that may be due to specific and unusual sediment characteristics. The 90th percentile is that locus below which 90 percent of the sediment concentrations fall.

In the second step, the 90th percentiles for all of the species present are plotted, also in order of increasing concentration (Figure 1b). From this plot, the 5th percentile and the 95th percentile are calculated. These represent the concentrations below which 5 percent and 95 percent of the concentrations fall.

1. <u>Metals, Nutrients, and Polar Organics.</u>

   Calculate the 5th percentile of the SLC based on bulk-chemistry sediment data. Since the guidelines are derived for province-wide application, the locations used should span a wide range of geographical areas within Ontario of varying sediment concentrations of the contaminant. It is important to ensure that both high sediment concentrations as well as low concentrations are used in the data set to ensure the result is not biased towards one end or the other, since this could bias the resulting SSLC. A minimum of 10 observations would be required to calculate a SSLC for any one species. This relatively low minimum has been chosen so as not to exclude less common species, or more importantly, the more sensitive species that may not be present at the more contaminated sites and thus may not be represented at the majority of sites. A minimum of 20 SSLCs (i.e. 20 species) would be required for calculation of an SLC.

2. <u>Non-polar Organics</u>

   Calculate the SLC as above, but using contaminant concentrations normalized to the organic carbon content of the sediments (i.e. mass of contaminant/mass of organic carbon as expressed by TOC).

   The organic carbon normalized sediment contaminant concentrations are converted back to a bulk sediment concentration assuming a 1% TOC. A limit of 1% TOC has been imposed on the calculation since calculations using the SLC approach have shown that this is the lowest effect level of organic carbon in the sediment.

The Ministry also recognizes that certain parameters addressed in these guidelines, such as the trace metals, occur naturally in aquatic environments. In an area as geologically diverse as Ontario, natural sediment levels can vary considerably from one region of the province to another as a result of differences in local geology. Therefore, the Ministry realizes that certain sites will naturally exceed the Lowest Effect Level. In such cases, the local background levels, based on the pre-colonial sediment horizon, will form the practical lower limit for management decisions as described in the Implementation Section of this document.

Calculation of Site-Specific Background:

> The mean of 5 surficial sediment samples (top 5 cm) taken from an *area* contiguous to the area under investigation, but unaffected by any current or historical point source inputs.
>
> or:
>
> The mean of 5 samples taken by a sediment core from the pre-colonial sediment horizon. The pre-colonial horizon is generally determined as the sediment below the *Ambrosia* sediment horizon. Except in areas of high sedimentation, such as river mouths, this can be estimated as that sediment lying below the 10 cm sediment depth.

4.43 THE SEVERE EFFECT LEVEL

This level represents contaminant levels in sediments that could potentially eliminate most of the benthic organisms. It is obtained by calculating the 95th percentile of the SLC (the level below which 95% of all SSLCs fall).

1. <u>Metals. Nutrients, and Polar Organics</u>

   Calculate the 95th percentile of all SSLCs using the bulk chemistry values.

2. <u>Non-nolar Organics</u>

   Calculate the SLC as for the metals, but normalizing the data to the organic carbon content (TOC) of the sediments. The TOC-normalized SLC is then converted to a bulk sediment value at the time of application to a specific site, based on the actual TOC concentration of the sediments at that site (to a maximum of 10%, the 95% SLC guideline for TOC (Table 1)).

The selected guidelines are inferred values, based on available data and are subject to revision as new data become available. Subsequent revisions will follow the same logical selection process, though using an expanded data base.

4.5 DATA REQUIREMENTS

A PWQO or PWQG is required for setting levels according to the partitioning approach. In order to maintain consistency between sediment and water quality guidelines, levels set by other agencies will not be used.

At least three estimates of partitioning coefficients would be required to set a guideline using the partitioning approach. Guidelines based on fewer than the minimum number of estimates would be regarded as tentative.

The range of contaminant concentrations for the SLC calculations should span at least two orders of magnitude and include data from both heavily contaminated areas and relatively clean areas. Data from dean areas are needed to ensure that sensitive . species are included in the SLC calculation, while heavily contaminated areas are needed to ensure that the full tolerance range of all the species is covered.

The database for the SLC calculations should be based on primarily benthic infaunal species and should minimize the reliance on epibenthic species. A minimum of 75% benthic infaunal species would be required to ensure that the observed effects are from sediment associated contaminants and not from water column effects.

Consistency in the species data used has to be ensured. This requires checking the data for synonymies, unusual species distributions, and level of identification. The minimum acceptable taxonomic level would be the genus, provided that species level identifications were also included in the data set from which the information was derived. Data using only generic level identifications could not be used.

The SLC database must include a large range of areas sampled in order to minimize the effects of unmeasured but co-varying contaminants. Since these are unlikely to occur in the same relation at all other areas, the effects of other contaminants can be reduced or excluded if a sufficiently large number of different areas are included.

A minimum of 10 observations are required to calculate an SSLC. A minimum of 20 SSLCs are required to calculated an SLC. This low number has been chosen so as not to exclude the less common or more sensitive species that may not be present at more highly contaminated sites.

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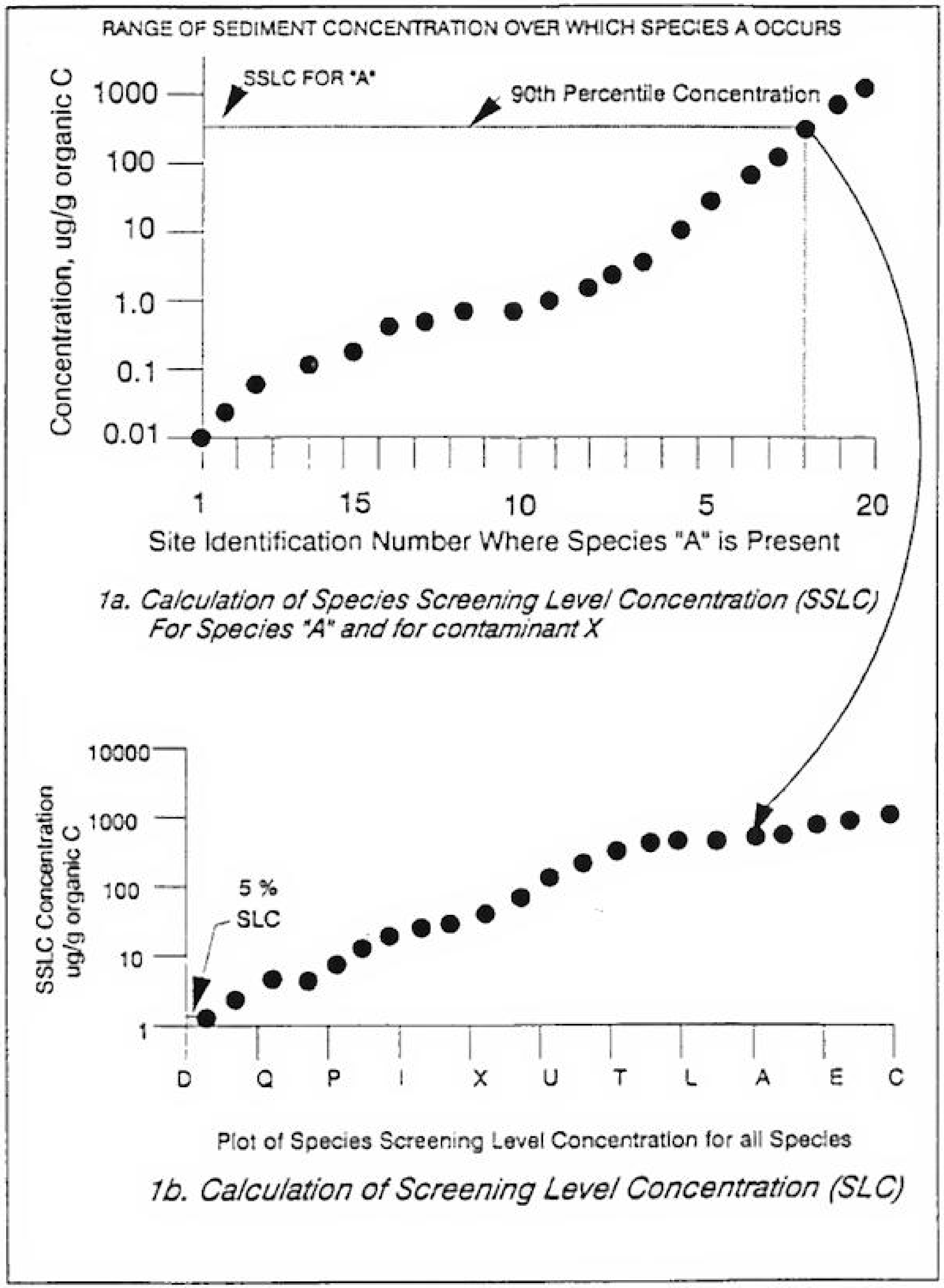

Figure 1: Screening Level Concentration Calculation.

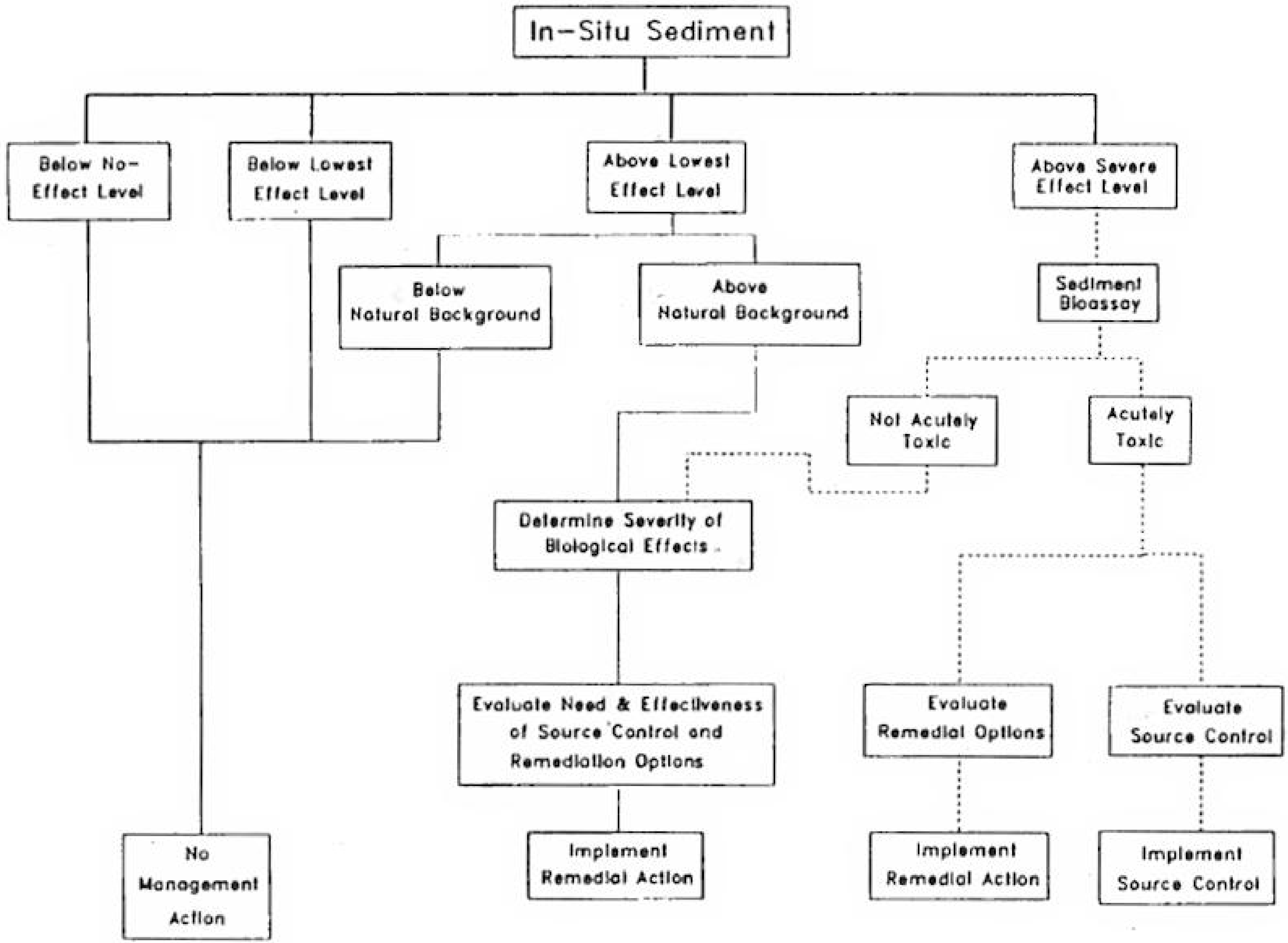

Figure 2: Application of Provincial Sediment Quality Guidelines to Sediment Assessment.

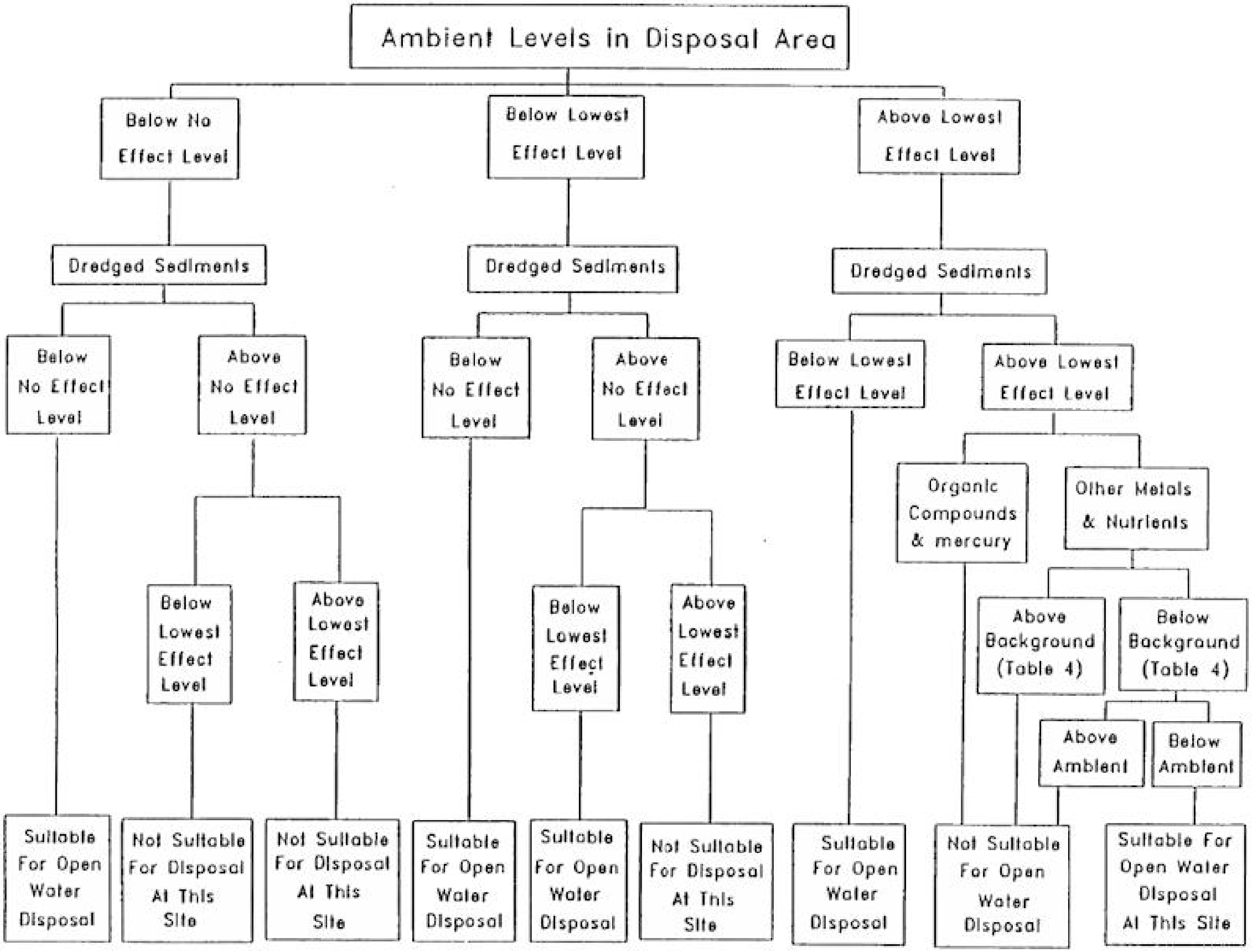

Figure 3: Application of Provincial Sediment Quality Guidelines to Dredging Activities.