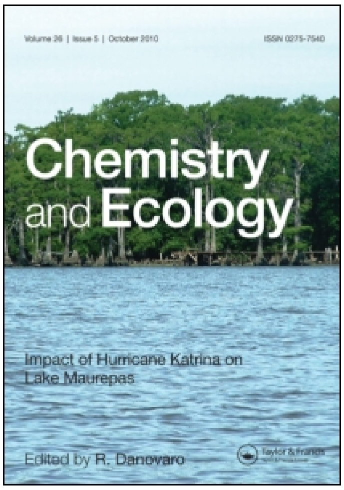

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THE APPLICATION OF A TIERED TESTING APPROACH TO THE MANAGEMENT OF DREDGED SEDIMENTS FOR DISPOSAL AT SEA IN CANADA

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Canada, and other signatories to the *London Convention 1972* on the prevention of marine pollution by dumping, are preparing to ratify a *1996 Protocol* to this convention. Among the improvements to this international agreement, is a new process for the Assessment of Waste and Other Matter, which is to be adopted by signatory parties. The process includes a step in which material considered potentially acceptable for sea disposal must be characterized by chemical, physical and biological properties. Canada's interpretation and intended implementation of this characterization step is presented for the assessment of dredged sediments. This tiered testing approach involves using chemical screening limits for contaminants, and biological testing when screening levels are exceeded. Dredged material containing specified substances (*e.g.*, cadmium, mercury, PAHs, PCBs, *etc.*) below or at screening levels would generally be considered of little environmental concern for disposal at sea. Wastes above the screening levels would require more detailed assessment before their suitability for disposal at sea could be determined.

Keywords: London Convention 1972; *1996 Protocol*; disposal at sea; sediment assessment; bioassessment

INTRODUCTION

Environment Canada regulates disposal at sea and meets its international obligations on the prevention of marine pollution by dumping under the *London Convention 1972* (LC72) (IMO, 1982) by

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means of the *Canadian Environmental Protection* Act (CEPA, 1988, Part VI) and the *Ocean Dumping Regulations* (ODR, 1988). As a signatory to the LC72, Canada, and more than 76 other member states agree to adhere to the pollution prevention principles in the treaty, to enforce them under national law and to report annually to the Convention on disposal and monitoring activities. The 1996 Protocol to the Convention introduces, among other improvements, a new process for the Assessment of Wastes and Other Matter. To ratify the *1996 Protocol*, Canada must eventually amend CEPA to include the process and it must find ways to interpret and implement its various components in policy and regulation. The focus of this paper will be on Canada's decisions regarding one of the components in this waste assessment framework; the waste characterization component.

The process for the Assessment of Wastes and Other Matter (Fig. 1) begins with a list of wastes generally considered suitable for disposal. Those wastes not listed, are rejected. The majority of waste considered for sea disposal is dredged material.

The process then requires an examination of the alternatives to disposal at sea and of other uses of the material, including waste reduction, recycling and re-use. Wastes are rejected unless ocean disposal is the environmentally preferable and practical alternative.

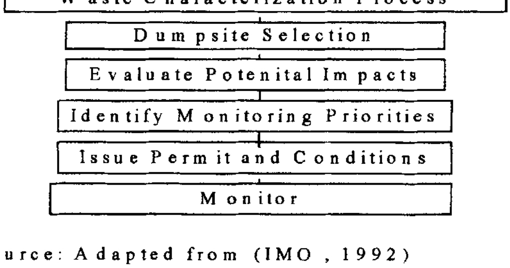


FIGURE 1 Process for the Assessment of Wastes and Other Matter.

For suitable wastes, an assessment of their chemical, physical and biological properties must then be undertaken. This is called the waste characterization stage of the assessment and is the focus of this paper. Only after the waste has been characterized, and found suitable, can an adequate risk assessment be made, allowing selection of a disposal site, and setting permit and monitoring needs (IMO, 1997).

THE PROCESS FOR WASTE CHARACTERIZATION

The 1996 *Protocol* charges each party to develop a "National Action List" to provide a mechanism for screening candidate wastes on the basis of their potential effects on human health and the marine environment. Parties agreed that priority should be given to controlling toxic, persistent and bioaccumulative substances from anthropogenic sources (IMO, 1997).

From 1976–1991, Canada used primarily chemical screening limits in its waste characterization process. Other countries, notably the USA, have used chemical and biological testing (PSDDA, 1989; USEPA, 1991). Beginning in 1991, with a six year Ocean Disposal Action Plan, Canada began refining its waste characterization process to introduce "effects-based" chemical guidelines and to develop a battery of bioassays to further assess toxicity, persistence and bioaccumulation. The resulting tiered approach is described below.

Tier 1

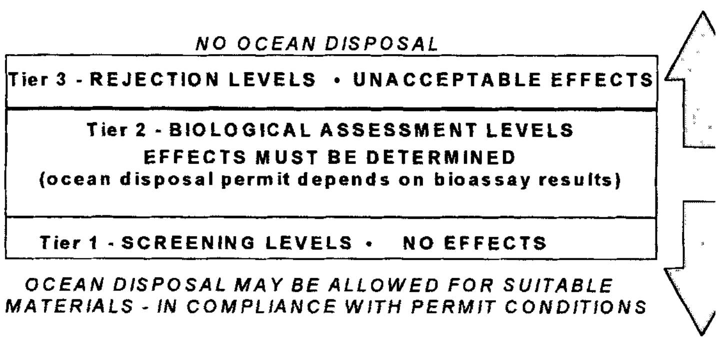
The first tier is a chemical screening level. Wastes (sediments or excavation spoils) intended for ocean disposal are analysed for contaminants of concern which include cadmium, mercury, PAHs, PCBs and other contaminants identified as a result of reviewing site history and nearby sources of pollution (Environment Canada, 1995b). These parameters are treated as chemical "indicators" of pollution and will likely be compared to a set of Canadian Sediment Quality Guidelines (SQGs), which are being developed by Environment Canada and reviewed and recommended by the Canadian Council of Ministers of the Environment (Environment Canada, 1994b; CCME, 1995; Bewers *et al.*, 1998). These are biological-effects based guidelines which denote chemical concentrations at or below which adverse biological effects are not expected (MacDonald *et al.*, 1992). Fisheries and Oceans Canada is also slated to develop marine environmental quality guidelines, which may prove useful as screening levels for the programme in the future. Levels above the chosen screening criteria would trigger further investigations of sediment quality, including biological assessments and, where geochemical information warrants it, an evaluation of natural background concentrations of substances at the site.

Tier 2

Tier 2 involves biological assessment. Bioassays and bioaccumulation tests have been developed to examine lethal and sub-lethal chronic effects and are required if the above mentioned screening limits are exceeded. If the substance passes the proposed biological tests, open water disposal could be considered. If the sediment fails the bioassays, disposal at sea would not be permitted.

Tier 3

Rejection levels will eventually be developed with the experience gained using bioassays. These will represent a third tier and result in numerical levels or biological response levels as appropriate. No ocean disposal would be allowed above rejection levels.



Source: Adapted from (Environment Canada, 1994c)

FIGURE 2 Tiered testing approach.

STATUS

Sediment Quality Guidelines – Status and Future

The procedures used in deriving Canadian SQGs are described in a *Protocol for the Derivation of Canadian Sediment Quality Guidelines for the Protection Aquatic Life* (CCME, 1995). Individual guidelines are developed using a weight of evidence approach and are based on the available scientific information on the biological effects of the sediment-associated chemical. Almost all of these guidelines are likely to be "interim" rather than "full" guidelines in recognition of the type of information on which they are based and of the need to consider site-specific conditions during their implementation. That is, a weight of evidence approach relies on evaluating *associations* between chemical concentrations and biological effects in sediments, rather than on establishing *cause-effect* relationships. Site-specific conditions may influence the bioavailability chemicals in sediments and the expression of adverse biological effects (Environment Canada, 1994c). Interim guidelines for cadmium ($0.7\,mg\,kg^{-1}$) and mercury ($0.13\,mg\,kg^{-1}$) have been completed and several others are nearing completion (Environment Canada, 1997a, b, c). Table I gives an indication of guideline values for mercury in other jurisdictions (CCME, 1994). Similar tables have been constructed for other guideline variables.

Bioassessment

The development of the battery of bioassays began in 1991, with an assessment of the types of tests and end-points which would be useful to assess sediments with respect to the concerns of toxicity and bioaccumulation. Both lethal and sub-lethal end-points were included to assess long and short term effects. Wherever possible, whole sediment tests using Canadian species were chosen to approximate local field conditions and responses (Bousfield, 1990; Arenicola Marine, 1992; Beak, 1992). Chosen tests were compared with those used in other jurisdictions and vetted through the Intergovernmental Aquatic Toxicity Group, a body of Federal and Provincial toxicology experts. Laboratory and field validation were undertaken (EVS, 1991a, b, c; McLeay *et al.*, 1991, 1993; Beak, 1992; Porebski *et al.*, 1998).

TABLE I Marine sediment quality guidelines for mercury from other jurisdictions

Jurisdiction	*Approach*	*Guideline (mg/kg d)*	*Rationale*	*Reference*
United States	EqPA	0.01	EPA chronic marine	Layman *et al.*, 1987
Florida	WEA	0.13	Threshold effect level (TEL)	MacDonald, 1994
United States	EqPA	0.15	EPA acute marine threshold	Layman *et al.*, 1987
Burrard Inlet, BC	SQO	0.15	Sediment quality objectives	Swain and Nijman, 1991
United States	WEA	0.15	Effects range low (ERL)	Long *et al.*, 1995
Puget Sound, WA	AETA	0.21	PDSDA screening level concentration	USACOE, 1988
Netherlands	EqPA	0.3	Target value – Multifunctional sediment quality value, Ministry of Housing	
Spatial Planning and the Environment, 1994 Washington	AETA	0.41	Sediment quality standard	Washington Department of Environment, 1991
Netherlands	EqPA	0.5	Limit value – ecotoxicological risk value	Ministry of Housing, Spatial Planning and the Environment, 1994
California	AETA	0.51	California AET values	Becker *et al.*, 1990
United States	WEA	0.71	Effects range median (ERM)	Long *et al.*, 1995
Canada		0.75	Includes mercury compounds; in the solid phase of a waste	Ocean Dumping Regulations, 1988
United States	EqPA	0.8	EPA chronic marine threshold; not corrected for organic carbon	Bolton *et al.*, 1985
California,	AETA	1.2	California AET values	Becker *et al.*, 1990
Florida,	WEA	0.7	Probable effects level (PEL)	MacDonald, 1994
Canada		1.5	Includes mercury compounds; in the liquid phase of a waste	Ocean Dumping Regulations, 1988
Puget Sound, Wa	AETA	2.1	PSDDA maximum level criteria	USACOE, 1988
Netherlands	EqPA	10	Intervention value – exceedence indicates serious pollution	Ministry of Housing, Spatial Planning and the Environment, 1994

Round robin testing and determination of species tolerance levels to factors such as particle size range, ammonia, organic carbon and others, is going on to help understand and limit the effects of these "non-contaminants" on test results (Yee *et al.*, 1992; Doe and Wade, 1992; Tay *et al.*, 1998). Figure 3 outlines the basic process for test development. At least two years of research and review has gone into each test protocol. Supporting guidance has also been commissioned on collection and handling of sediment (EC, 1994d), test precision with reference toxicants (EC, 1995c), statistics and interpretation (in preparation). An additional year is usually needed to refine the general protocol into a formal reference method suitable for regulatory use.

Four toxicity tests and a bioaccumulation test are in the current battery for disposal at sea assessments in Canada. All tests, with the exception of the polychaete test, are now available for use. Additional research is underway to refine interpretative guidance for these tests (Porebski *et al.*, 1998). Development of the reference methods began in 1997 and the first method on amphipods is expected in 1998.

Amphipod Test

This is a 10 day survival test (acute test) in whole sediment, on sediment burrowing marine and estuarine amphipods. The test compares percent survival in test sediments with clean reference or control sediments. A total of seven Canadian native species were selected

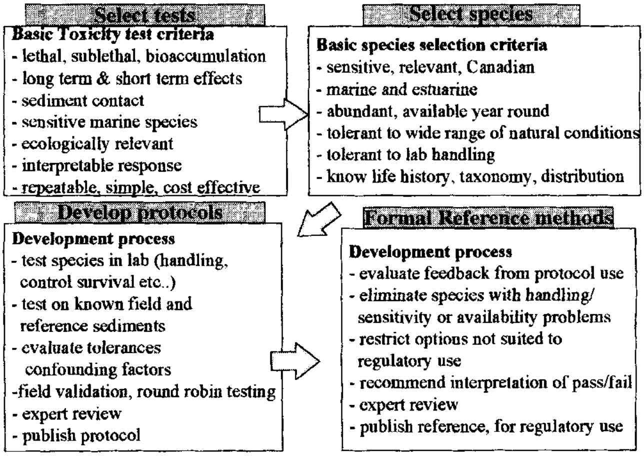


FIGURE 3 Biological test development.

from Atlantic, Pacific and northern waters, in both marine and estuarine environments. To date, selected species for regulatory use are; *Amphiporeia virginiana*, *Eohaustorius estuarius*, *Eohaustorius washingtonianus* and *Rhepoxynius abronius*. The species were selected for their ecological relevance, sensitivity, availability and ease of handling in the laboratory. A test protocol outlining how the test should be performed with each species has been published, and a training video is available (Environment Canada, 1992a). The standard reference method, taking into account information on tolerances to various physical factors and natural toxicants and defined interpretation criteria is expected in 1998.

Echinoid Test

This is a sub-lethal marine toxicity test using gametes obtained from sea urchins or sand dollars, which measures success of fertilization in undiluted pore water (extracted from test sediment), as compared with a control water. The assay usually takes only 20 minutes and is thought to be among the most sensitive of marine sub-lethal toxicity tests (Environment Canada, 1992b). The current protocol lists suitable species as the green sea urchin (*Strongylocentrotus droebachiensis*), the Pacific sea urchin (*S. purpuratus*), the eccentric sand dollar (*Dendraster excentricus*), the Atlantic purple sea urchin (*Arabacia punctulata*) and the white sea urchin (*Lytechinus pictus*) (Environment Canada, 1992b). A standard reference method will now be derived. Consideration of confounding factors must also be completed as well as a final evaluation of which of the above species would be suitable for year-round regulatory use.

Photoluminescent Bacteria Test

This is a test of light production by a strain of bacteria (*Vibrio fisheri* also known as *Photobacterium phosphoreum*). The bacterium emits light, as the result of normal metabolic processes and light reduction when exposed to a contaminated sediment or pore water, is taken as a measure of toxicity (Environment Canada, 1992c). The test can be done using pore water, elutriates or in solid phase sediment. The solid phase test is favoured for regulatory use in sediment assessment.

A test protocol has been published (Environment Canada, 1992c). A standard reference method will now be derived for regulatory use. Consideration of confounding factors must also be completed.

Polychaete Test

This is a 14 day sub-lethal growth and survival test, using deposit-feeding, tube dwelling, polychaete worms in whole sediment. The end-point of interest to the programme, will compare final individual mean dry weight of worms from test sediments, with that obtained from reference or control sediments. A draft protocol has been produced using *Polydora cornuta* or *Boccardia proboscidea*. These species are found in Canadian Atlantic and Pacific waters respectively. Culturing and testing trials have been used (Pocklington *et al.*, 1995; McLeay *et al.*, 1997).

Bioaccumulation Test

This test was developed by the U.S. Environmental Protection Agency (USEPA, 1993). It involves measuring accumulated contaminants in the tissue of bivalves or marine worms after a 28 day exposure to whole, field-collected sediments. Test sediments are compared to control or reference sediments. Among selected species are the marine bivalves *Macoma nasuta* and *M. balthica* and a marine worm *Nereis virens*. The USA protocol is judged to be acceptable for use until a Canadian protocol is approved.

Evaluation of Biological Test Results

The following hierarchy of interim interpretation guidance applies to the biological test results:

1. The substance proposed for disposal at sea contains substances in excess of screening (regulated or guideline) levels and passes all biological tests. This substance *can be considered acceptable for open water disposal.*
2. The substance proposed for disposal at sea contains substances in excess of screening (regulated or guideline) levels and passes the

acute toxicity test, but fails one sub-lethal or bioaccumulation test. *Capping or confined aquatic disposal may be acceptable.*

3. The substance proposed for disposal at sea contains substances in excess of screening (regulated or guideline) levels and either fails the acute test or two or more additional tests including sub-lethal tests and the bioaccumulation test. *This material will not be permitted for disposal at sea.* The material may be treated to reduce contamination and then may be re-tested for disposal at sea.

USING THE TIERED TESTING SCHEME

Since 1994, when Environment Canada began allowing the use of bioassays to test sediments with contaminants in excess of screening levels, several clients have used the battery system. One west coast client, proposed disposal at sea of sediments with cadmium levels ranging from 1.26 $mg\,kg^{-1}$ to 3.01 $mg\,kg^{-1}$ (ASL, 1994). All levels were in excess of the regulated screening level of 0.6 $mg\,kg^{-1}$. The required battery of bioassays was performed by the applicant. Materials were not found to cause lethal, sub-lethal or bioaccumulative effects according to the interim pass/fail criteria developed by the programme. The client received a permit for disposal at sea (Sullivan, 1994).

The pass/fail criteria were based on experience gained by the department with the tests and criteria used for similar tests in other jurisdictions (Tay *et al.*, 1998; PSDDA, 1989). The criteria are shown in Figure 4.

In a second application on the west coast, PAHs were elevated above the screening level of 2.5 $mg\,kg^{-1}$ and ranged from 3.0 $mg\,kg^{-1}$ to 5.1 $mg\,kg^{-1}$ (Beak, 1995). Lethal effects were not observed but failures were seen in the echinoid fertilization test at all test stations and in four of the six stations for the photoluminescent bacteria test, indicating a potential for sub-lethal effects. Four of six of the stations also showed bioaccumulation. This application did not receive an ocean disposal permit (Beak, 1995).

CONSIDERATIONS ON USING TIERED TESTING

In the above case, it could be argued that failure in the echinoid and bacterial tests were due to total ammonia (16–28 $ug\,g^{-1}$, but only

TEST	FAILS IF...
Bivalve bioaccumulation test	Significant difference from reference/control *
Amphipod acute test	A ***decrease in survival of at least 20%*** is observed between the test sediment and a clean sediment used as a reference. *
Photoluminescent bacteria solid-phase test	Five minute ***IC50 is less than 1000 mg/kg***.
Echinoid test	A ***decrease in fertilization of at least 25%*** is observed between the test sediment and control water. *

* The observed difference must be statistically significant.

Source: Adapted from (Porebski *et al.*, 1998)

FIGURE 4 Interim pass/fail criteria.

$9.1\,\mathrm{ug\,g^{-1}}$ in the chosen reference sediment) and hydrogen sulphide ($21-1020\,\mathrm{ug\,g^{-1}}$, but less than $14\,\mathrm{ug^{-1}}$ in the reference), in the sediment, rather than the PAHs, which were identified as the parameters of concern (Beak, 1995). These levels of ammonia and sulphide had been found to cause toxicity in marine invertebrates (Burgess *et al.*, 1993).

In addition, whereas the old approach of using fixed bulk chemical values for pass/fail criteria was often thought to be overly conservative, the tiered testing approach does not give clients as clear an indication of whether they are likely to pass or fail before the tests are run, because of the integrative nature of the bioassays. The bioassay tests are expensive ($5,000–$10,000 (Canada) per battery sample), and even though passing has the potential to save much greater amounts, though avoiding costly land disposal, spending $20,000 to $100,000 for tests with an uncertain result has likely been a factor in limiting the continued use of these tests by clients to date (Environment Canada, 1996b).

Confounding Factors

Whereas the cost of the testing will likely continue to be high in the near term, and the very nature of using bioassays precludes achieving a completely predictable response to any natural field sediment, Environment Canada has taken steps to improve the understanding of organism responses to various factors and the interpretation of the tests, in order to increase the confidence in their use as environmental management tools.

Initially, it was thought that confounding factors, including particle size, total organic carbon, ammonia, sulphide and others, could be fully accounted for and addressed by comparing the test sediments to a reference sediment, which had similar geochemical properties to the test sediment, but lacked the chemical contamination. Indeed many of the bioassays are interpreted by their percentage difference from a reference sediment. In practice, finding suitable reference sediments, which match for all the desired parameters, but remain uncontaminated, has proven to be challenging (Environment Canada, 1996a). In some instances, one or more of the bioassays failed in supposedly clean reference sediments (Beak, 1995; Environment Canada, 1996a). This may have been due to unmeasured contaminants (*e.g.*, the number of chemicals measured remains limited), an inexact match with the test sediment, or because the test organisms were unsuitable to that particular sediment type and condition. Further research on the location, testing and establishment of suitable reference sites is needed.

In parallel, increased awareness of the potential for factors (other than contaminants) to cause toxic effects in bioassays has triggered research by Environment Canada to understand better, and control for, the effects of ammonia, sulphide and particle size (Tay *et al.*, 1998). Additional factors, including total organic carbon and Eh (sediment oxidation–reduction potential) may also need to be further evaluated.

Ammonia can arise from both natural and anthropogenic sources and can be formed in sediment during handling and storage. A review of literature suggested that measurement methods, and the correlation between ammonia and the measured toxicity of bacterial, amphipod and echinoid tests varied from one study to another (Tay *et al.*, 1998), with some finding a clear link (Bay *et al.*, 1995), and others finding no, or limited, correlation (Ankely *et al.*, 1990; Carr *et al.*, 1996; Baily *et al.*, 1995; Porebski *et al.*, 1998). Environment Canada research did find correlations between ammonia and the bacterial assay, two species in the amphipod assays and with the echinoid assays. In all cases, however, the ammonia levels in the available test samples were below levels known to cause toxicity in marine organisms, suggesting other factors were responsible for the observed toxicity effects (Tay *et al.*, 1998). Research over the next few years will more clearly establish, on a species by species basis, tolerance ranges for ammonia in sediment or pore water. These ranges will appear in each final reference method, to help regulators assess whether ammonia toxicity needs to be considered in the assessment of the bioassay results.

Under anoxic conditions, sulphur is reduced to hydrogen sulphide becoming highly toxic, and this toxicity is known to increase with temperature, and with decreasing pH and dissolved oxygen. At present, there is limited literature explaining the relationship between sediment sulphide and toxicity end-points (Tay *et al.*, 1998). Environment Canada research found a correlation between bioassay response and sulphide in the bacterial test, but not in the amphipod or echinoid tests. Insufficient data on species tolerance ranges to sulphides was available to assess the significance of these relationships (Tay *et al.*, 1988). As with ammonia, research is ongoing to define better species tolerances to sulphides. Reference methods should reflect these ranges.

The fact that certain amphipods are not able to tolerate either very fine or very coarse grain sizes has been documented (PSDDA, 1989; Lamberson *et al.*, 1992; USEPA, 1994). Problems with the photoluminescent bacteria test in fine sediments are also explained in the literature as a result of bacteria being lost in the filtering process step of the method because of their adhesion to small sediment particles (Tay *et al.*, 1998; Green *et al.*, 1992). The echinoid test is conducted in pore water and is not affected by particle size. Based on Environment Canada research, the degree of sensitivity to particle size among four Canadian amphipod species was ranked as follows: *E. washingtonianus* > *R. abronius* > *E. estuarius* = *A. virginiana*. Environment Canada research on the bacteria showed that particle size effects were more pronounced at the coarse end of the size spectrum and that the effects were less pronounced when fines were more than 40% (Tay *et al.*, 1998). The reference method for amphipods will require that the species selected to for toxicity assessment be within its particle size tolerance range for that sediment. The present interim pass/fail criteria for the bacterial test, uses a fixed number (1000 mg kg^{-1}, for a 5 minute EC50) which appears to account for most particle size variability (Tay *et al.*, 1998). However, the researchers suggest a higher criterion may be needed to test sediment containing < 40% fines. The reference method will need to address this relationship.

CONCLUSION

The tiered testing approach presented here seems to be a workable interpretation of the waste characterization step of the 1996 *Protocol* to the LC72. Development work undertaken since 1991, has provided a "tool box" of Canadian chemical and biological methods, with which to assess marine and estuarine sediments destined for ocean disposal. Basing disposal site monitoring on a similar tiered testing scheme, will allow for comparison of benchmarks in the continuing evaluation of long term effects after disposal has taken place.

Despite these efforts, however, several practical aspects remain to be addressed before the process is formally integrated into a regulatory approach. The completion of the sediment quality guidelines, or screening levels is needed. Refinement of the interpretation and use limitations of the bioassay battery, will need to include defining species by species tolerance levels to various confounding factors such as particle size, ammonia and sulphide. The location and better definition of reference sites will also be needed to aid with interpretation of the bioassays.

The cost effectiveness and predictability of results, using the tiered testing scheme, will continue to be important to the clients using the system and will likely receive greater attention as Environment Canada adopts more of a cost recovery approach to assessment and monitoring for disposal at sea.

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