Chapter 3

A Framework for Assessing Site-Specific Sediment Quality Conditions in Florida

3.0 Introduction

The numerical sediment quality assessment guidelines (SQAGs) recommended in Volume 1 (MacDonald 1994) provide a strong technical basis for assessing sediment quality in Florida. These guidelines explicitly address the uncertainty associated with the sediment quality assessment process by identifying ranges of contaminant concentrations instead of absolute values. In addition, the probability of observing adverse biological effects within these ranges has been calculated in Volume 1 to provide further guidance on the use of these management tools. Nonetheless, the possibility of arriving at erroneous conclusions still exists if the SQAGs are used in isolation. For this reason, an evaluation framework has been developed to assist potential SQAG users in the implementation of sediment quality assessments.

The purpose of this Chapter is to provide a framework for using SQAGs and related tools. This framework identifies the essential considerations that should be addressed in conducting site-specific sediment quality assessment programs and is comprised of the following steps (Figure 1) :

(i) Collect Historical Land and Water Use Information;

(ii) Collect and Evaluate Existing Sediment Chemistry Data;

(iii) Collect Supplemental Sediment Chemistry Data;

(iv) Evaluate the Origin of Sediment-Associated Contaminants;

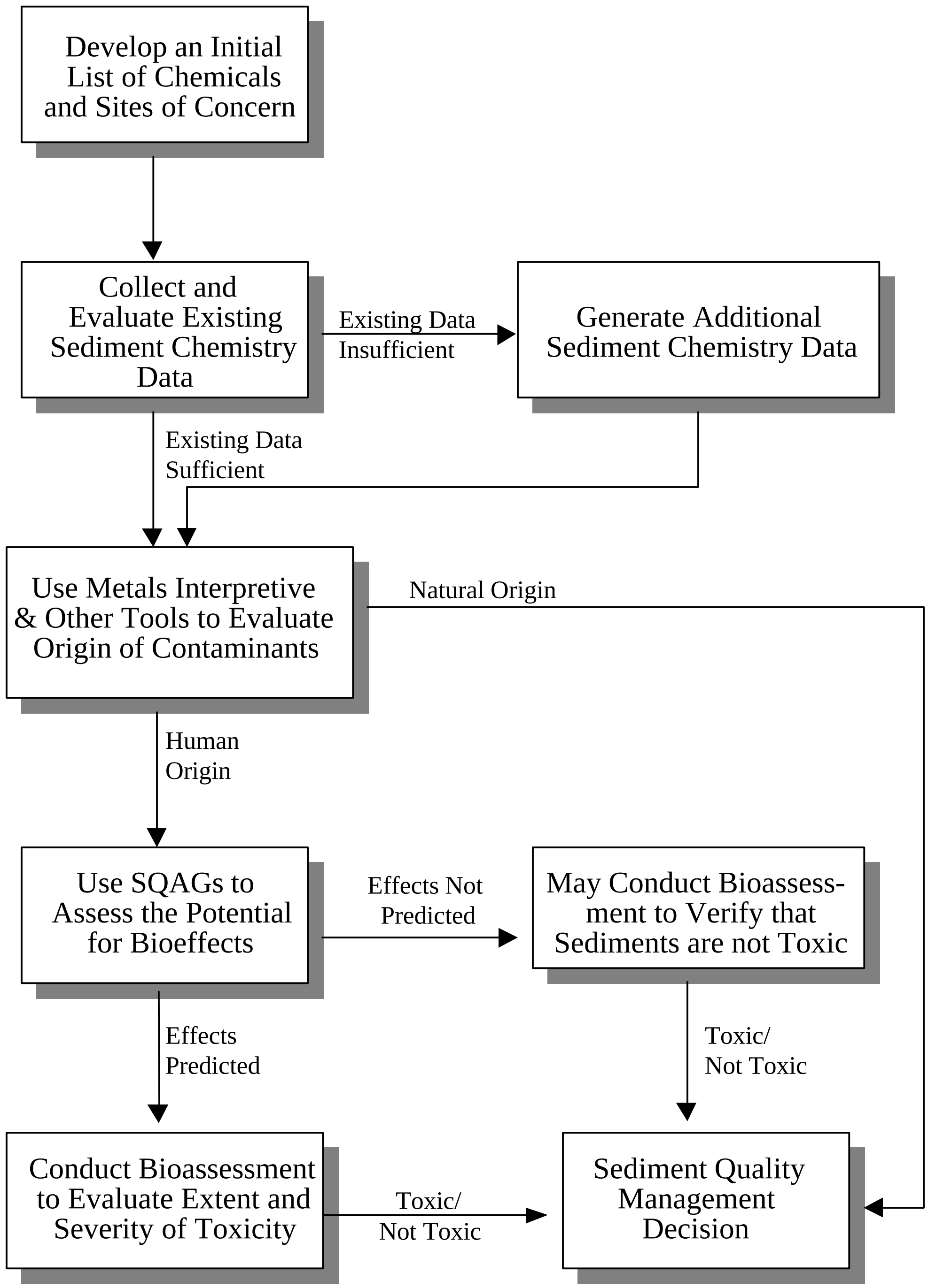
(v) Conduct Preliminary Assessment of the Potential for Biological Effects of Sediment-Associated Contaminants;

(vi) Conduct Biological Assessment of Sediment Quality; and,

(vii) Implement Management of Sediment Quality.

The recommended framework is designed to provide a consistent approach to assessing sediment quality in marine and estuarine areas. A similar approach could be used in freshwater ecosystems, once freshwater SQAGs become available. However, the framework is not intended to replace accepted sediment testing protocols, such as those developed for

Figure 1. Framework for conducting site-specific assessments of sediment quality conditions in Florida.



the ocean disposal of dredged material. Instead, it is intended to provide general guidance to support the sediment quality assessment process. Each component of the recommended framework is discussed in the following sections.

3.1 Collect Historical Land and Water Use Information

The first phase of a site-specific sediment quality assessment involves the collection and review of pertinent information on the site under consideration. Information is required on the types of industries and businesses that operate or have operated in the area, on the location of wastewater treatment plants, on land use patterns in upland areas, on stormwater drainage systems, on residential developments, and on other historic and ongoing activities within the area. These data provide a basis for identifying possible sources of contaminants to aquatic ecosystems. Information on the chemical composition of wastewater effluent discharges, the types of contaminants likely to be associated with non-point sources, and the physical/chemical properties (e.g., K_{ow}, K_{oc}, solubility, persistence, etc.) of those substances provides a basis for developing an initial list of chemical concerns at the site.

In addition to information on contaminant sources, information should also be collected that helps to define environmental management goals at the site (if these have not already been established). Environmental management goals in estuarine and marine systems may be based on protection of the ecosystem as a whole, maintenance of viable populations of sportfish species, protection of human health (e.g., swimmable and fishable), and/or a variety of other considerations (e.g., regional stormwater management, industrial development). As such, information on existing and future uses of the site provide a basis for making decisions regarding the nature and extent of the investigations that should be conducted at the site. Mudroch and McKnight (1991), Baudo and Muntau (1990) and MacDonald (1989) provide detailed descriptions of the information that should be collected and discuss how these data may be used to assess ambient environmental quality.

3.2 Collect and Evaluate Existing Sediment Chemistry Data

Collection and evaluation of existing sediment chemistry data are critical components of the site-specific sediment quality assessment process. In Florida, sediment chemistry and other relevant data are generated under various environmental programs and the data should be assembled to support a preliminary assessment of sediment quality at the site under consideration. It is essential that these data be fully evaluated to determine their applicability in the sediment quality assessment process. This evaluation should cover the overall quality of the data set and the degree to which the data are thought to represent current conditions at the entire site under consideration.

Concerns regarding data quality may be resolved by evaluating the quality assurance/quality control measures that were implemented during collection, transport, and analysis of sediment samples. A number of conventions have now been established which provide guidance on the field aspects of sediment sampling programs (ASTM 1994a; EPA and ACE 1991). While a diversity of analytical procedures have been developed to quantify concentrations of contaminants in sediments, a number of standard methods have been recommended (for example by EPA and ACE 1991; ASTM 1994a). However, it is essential that total digestion techniques (using strong acids, such as hydrofluoric acid) be applied to samples for metal analysis. Novel analytical procedures may be appropriate in certain circumstances and should be evaluated using the accuracy and precision data for the technique (i.e., the results of analyses performed on standard reference materials, and split and spiked sediment samples). Analytical detection limits are also highly relevant to assessing potential biological effects at the site. The suitability of the detection limits may be assessed by comparing them to the SQAGs (specifically, the TEL) developed for that substance.

In addition to reliable sediment chemistry data, assessment of sediment quality also requires information that adequately represents the contemporary environmental conditions at the site under consideration. Therefore, the age of the chemistry data is a central question with respect to determining the applicability of the data. Natural degradative processes in the environment and sedimentation can lead to reductions in the concentrations of sediment-associated organic contaminants over time (Mosello and Calderoni 1990). Major hydrological events (such as severe storms) may result in the transport of sediments, while industrial developments and/or regulatory activities may alter the sources and composition of contaminants released into the environment. Thus, it is important that assessments of sediment quality be undertaken with the most recent data available.

In addition to temporal variability, the chemistry of bed sediments is known to vary significantly on a spatial basis (FDEP 1994; Long *et al.* 1991; Mah *et al.* 1989). Therefore, any single sample is likely to represent only a small proportion of the geographic area in which it was collected. For this reason, data from a number of stations are required to provide a representative picture of sediment quality conditions at the site, with the actual number of stations required dependent on the size of the area under consideration, the concentrations of sediment-associated contaminants, and the variability of contaminant concentrations (including spatial variability in surficial sediments and at depth).

Another important factor to consider in evaluating the applicability of existing sediment quality data is the list of variables that were analyzed. It is important that the list of analytes reflects existing and historical contaminant sources from land and water use activities in the area. In harbors, for example, variables such as pentachlorophenol (which is used as a preservative for pilings), tributyltin (which is used in antifouling paints for ships), copper and zinc (which are used in antifouling paints for pleasure craft) should be measured. Similarly, highly elevated concentrations of polycyclic aromatic hydrocarbons (PAHs) and lead are often associated with urban stormwater discharges. In agricultural areas, persistent pesticides and nutrients (including the toxic compounds of nitrogen) should be considered in sediment quality assessments. The SQAGs should be applied carefully when chemistry data are lacking on one or more substances that have a high potential for occurring in sediments.

If the results of the data evaluation process indicate that the sediment chemistry data are acceptable, it is possible to conduct a preliminary assessment of the potential for biological effects and an evaluation of the probable origin of sediment-associated contaminants. However, if the sediment chemistry data are considered to be of unacceptable quality or are not considered to adequately represent the site, additional sediment chemistry data may be required to complete the preliminary assessment.

3.3 Collect Supplemental Sediment Chemistry Data

The third stage in the sediment quality assessment process involves the generation of supplemental sediment chemistry data. Additional testing of sediments may be required when existing data are of insufficient quality or quantity to support the assessment of sediment quality at a site. The identification of chemical concerns conducted in Step 1 provides a defensible means of identifying a list of potential analytes for inclusion in the sediment quality monitoring program.

Sampling programs should be designed to delineate spatial variability (horizontal and vertical) in sediment contamination, and explicitly identify the quality assurance/quality control measures that will be implemented. The need to characterize temporal variability (time-series coring) also should be considered. Collection, handing, and storage of sediment samples should follow established protocols (e.g., ASTM 1994a). Analytical methods and detection limits should be appropriate for the substances under consideration. Implementation of a focused, well-designed monitoring program will ensure that the resultant sediment chemistry data will support a defensible sediment quality assessment.

3.4 Evaluate Natural vs. Anthropogenic Sources of Sediment-Associated Contaminants

Sediment chemistry data are essential for evaluating sediment quality conditions in Florida coastal waters. However, interpretation of environmental metals data is made difficult by the fact that absolute metal concentrations in coastal sediments are influenced by a variety of factors, including sediment mineralogy, grain size, organic content, and anthropogenic enrichment (Schropp and Windom 1988). This combination of factors results in metal levels that can vary over several orders of magnitude at **uncontaminated** sites in Florida (Schropp *et al.* 1990). Therefore, it is important to consider the natural background levels of sediment-associated metals when conducting sediment quality assessments.

In the past, determining whether estuarine and coastal sediments were anthropogenically-enriched with metals was a difficult process requiring comprehensive, site-specific assessments. However, the FDEP (Schropp and Windom 1988; Schropp *et al.* 1990) has developed a practical approach for assessing metals contamination in coastal sediments. This procedure relies on normalization of metal concentrations to a reference element. In the case of Florida, normalization of metal concentrations to concentrations of aluminum in estuarine sediments provided the most promising method of comparing metal levels on a regional basis. However, normalization using lithium and other reference elements has been used in other regions and may be applicable to Florida, as well (Loring 1991).

Florida Department of Environmental Protection's development of the metals interpretive tool was relatively straightforward. Briefly, data on sediment metal concentrations were collected from roughly 100 estuarine sites chosen for their remoteness from known or potential sources of metals contamination. Total metal concentrations (using "total digestion" procedures) were determined in these samples. Simple linear regressions of each of seven metals on aluminum were performed on log-transformed data and 95% prediction limits were calculated. Significant correlations were obtained for arsenic, cadmium, chromium, copper, lead, nickel, and zinc. The regression lines and prediction limits were then plotted. These plots form the technical basis for interpreting data on the concentrations of metals in sediments, such that anthropogenic enrichment would be suspected at sites with metal concentrations that exceeded the upper 95% prediction limit (for one or more substances). The application of this procedure using data from various areas (e.g., Tampa Bay, Schropp *et al.* 1989; Louisiana, Pardue *et al.* 1992) has supported the effectiveness and utility of this interpretive tool.

Mercury data were also collected from uncontaminated estuarine sediments; however, FDEP does not have confidence that mercury enrichment can be identified through its relationship with aluminum. To deal with mercury, the maximum mercury value in the "clean" data set was identified and is assumed to be typical of natural sediments. Anthropogenic enrichment of mercury concentrations is suspected when this maximum value is exceeded.

The metals interpretive tool provides an effective means of identifying sites that are anthropogenically enriched with metals. While no equivalent tool exists for evaluating the origin of many organic substances, a considerable number of organic contaminants are released into the environment only as a result of human activities. Therefore, the development of a comparable interpretive tool may not be as critical as it was for metals. Substances that fall into this category include chlorophenols (and related compounds), polychlorinated biphenyls (PCBs), pesticides, dioxins and furans, phthalates, and a host of other compounds. However, a variety of PAHs may occur in coastal sediments as a result of natural processes. While several methods have been proposed to establish the probable origin of this class of contaminants (such as calculating the ratios of the concentrations of some hydrocarbons or groups of hydrocarbons to distinguish between storm runoff, oil spills, and other sources), these techniques require further refinement before they can be used routinely in sediment quality assessments.

3.5 Conduct Preliminary Assessment of the Potential for Biological Effects of Sediment-Associated Contaminants

Sediment chemistry data alone do not provide an adequate basis for assessing the hazards posed by sediment-associated contaminants to aquatic organisms. Interpretive tools are also required to determine if sediment-associated contaminants are present at concentrations which could, potentially, impair the designated uses of the aquatic environment. In this respect, the SQAGs provide a scientifically defensible basis for evaluating the potential effects of sediment-associated contaminants on aquatic organisms.

In Florida, SQAGs are used to define three ranges of contaminant concentrations (MacDonald, 1994 Volume 1). The *probable effects* range is defined as the range of concentrations of a specific contaminant in sediment within which biological effects are usually or always observed (probable effects range ≥ PEL). Sediments with concentrations of contaminants within the probable effects range are considered to represent ***significant and immediate hazards*** to exposed organisms. Sites with concentrations of one or more contaminants that fall within the probable effects range should be considered to be the highest priority for implementing sediment quality management options. However, direct biological assessment is required at these sites to determine the nature and extent of effects that could be manifested. In the future, it may be possible to refine the assessment of the hazards associated with exceedances of PELs by considering both the number and magnitude of these exceedances.

The *possible effects* range is defined as the range of concentrations of a specific contaminant in sediment within which the expression of adverse biological effects is uncertain and is likely to be dependent on such factors as the bioavailability, which may influence the toxicity of the substance (TEL < possible effects range < PEL). Sediment-associated contaminants are considered to represent ***potential*** hazards to exposed organisms when concentrations fall within this range. Sediments with concentrations of contaminants within this range require further assessment to determine the biological significance of the contamination. In general, further assessment would be supported by a suite of biological tests designed to evaluate the biological significance of sediment-associated contaminants to key species of aquatic biota.

The *minimal effects* range is defined as the range of concentrations of a specific contaminant in sediment within which biological effects are rarely or never observed (no effects range ≤ TEL). Sediments with concentrations of contaminants within the no effects range are considered to be of ***acceptable quality***. In general, further investigations of sediment quality conditions would be considered to be of relatively low priority for sediments in which contaminant concentrations fall within the no effects range. However, biological testing may be required to validate the results of the preliminary assessment of the potential for adverse biological effects (particularly in sediments with low levels of TOC, AVS, and/or other variables that could influence the bioavailability of sediment-associated contaminants). In addition, biological testing would be warranted if the site is suspected to contain contaminants that were not measured or for which SQAGs were not available. For example, high levels of ammonia could trigger biological responses at sites nearby wastewater treatment plant outfalls, though the levels of other contaminants appear to be acceptable when compared with the SQAGs.

While numerical, effects-based sediment quality assessment guidelines provide essential information for evaluating the potential effects of sediment-associated metals, they should not be used alone to evaluate the quality of marine and estuarine sediments. Assessments of sediment quality also should include evaluation of the degree of anthropogenic enrichment. Using this approach, metals concentrations would be considered to be a serious concern when they exceed the biological effects-based guidelines and they are anthropogenically enriched.

The importance of using the effects-based guidelines and the metals interpretive tool together is demonstrated by evaluating Florida sediment chemistry data. In this example, data on levels of sediment-associated lead from two geochemically distinct systems, Biscayne Bay and Apalachicola Bay, are examined to illustrate the integrated sediment quality assessment framework. A summary of the available data (FDEP 1994) on the levels of sediment-associated lead in the vicinity of Miami is provided in Figure 2 (Biscayne Bay data are presented in order of increasing concentration and assigned sample numbers from 1 to 108). Evaluation of these data using the effects-based SQAGs suggest that approximately 19% of the samples fall within the probable effects range of concentrations (i.e., exceed the PEL of 112 mg/kg), while another 19% of the samples fall within the possible effects range (i.e., between the TEL of 30 mg/kg and the PEL). Therefore, comparison of sediment chemistry data with the numerical SQAGs suggests that there is a relatively high probability of observing adverse biological effects in the sediments collected from the Miami area. Further evaluation of these data using the metals interpretive tool (Figure 3) demonstrates that many sediments from this area are anthropogenically-enriched with lead, with roughly 90% of the samples exceeding the 95% prediction limits established for 'clean' sites. Concordance between the effects-based tool and the geochemically-based tool suggests that the Biscayne Bay area should be considered to be of relatively high priority for conducting further investigations to evaluate sediment toxicity.

In Apalachicola Bay, roughly 13% of the samples collected in the Florida coastal contaminants survey (FDEP 1994) had levels of lead that exceeded the TEL of 30 mg/kg (Figure 4; Apalachicola Bay data are presented in order of increasing concentration and assigned sample numbers from 1 to 29). Comparison of the ambient levels of lead in Apalachicola Bay with the SQAGs suggests that there is a possibility of observing adverse biological effects at several sites in this system. However, further evaluation of these data

Figure 2. Concentrations of lead in sediments in Biscayne Bay.

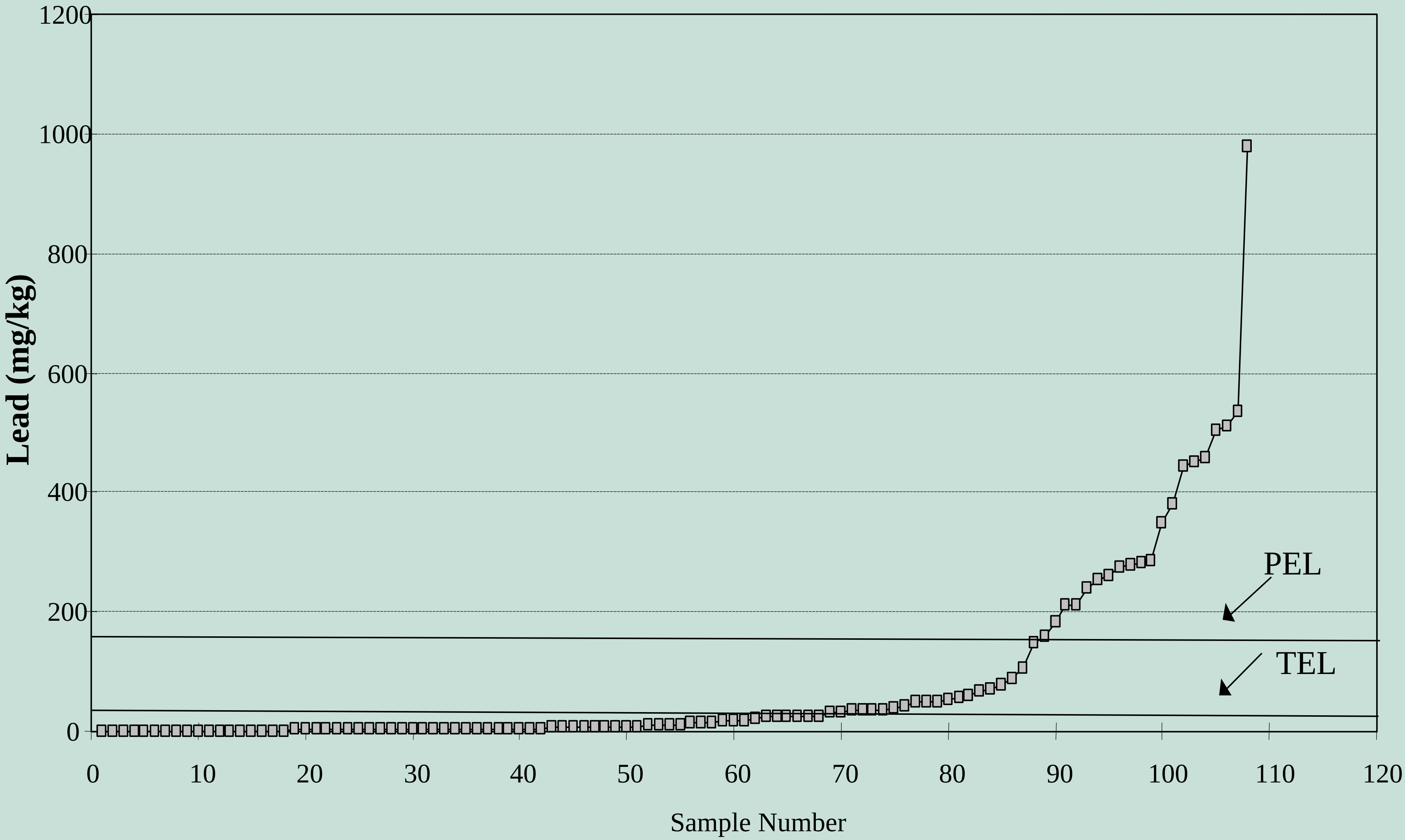


Figure 3. Aluminum normalized concentrations of lead in Biscayne Bay sediments.

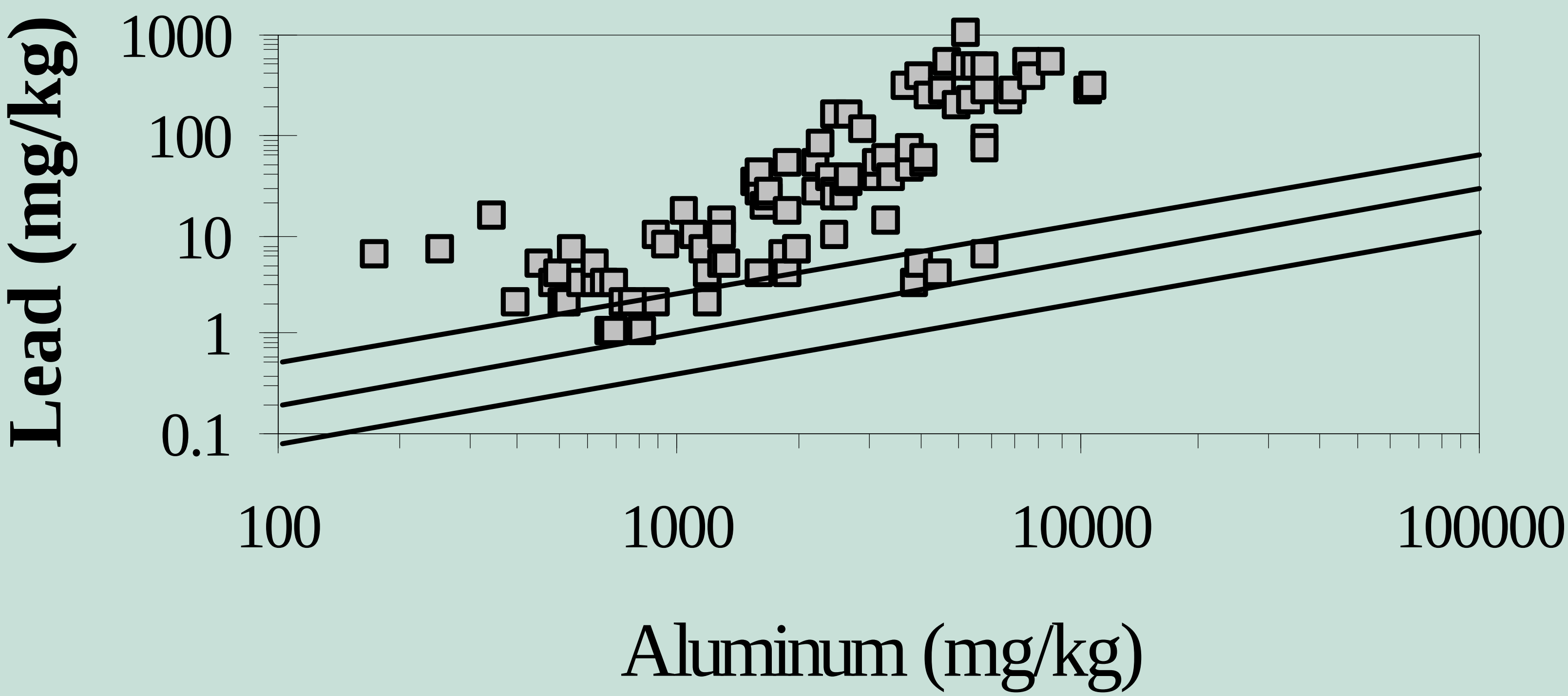
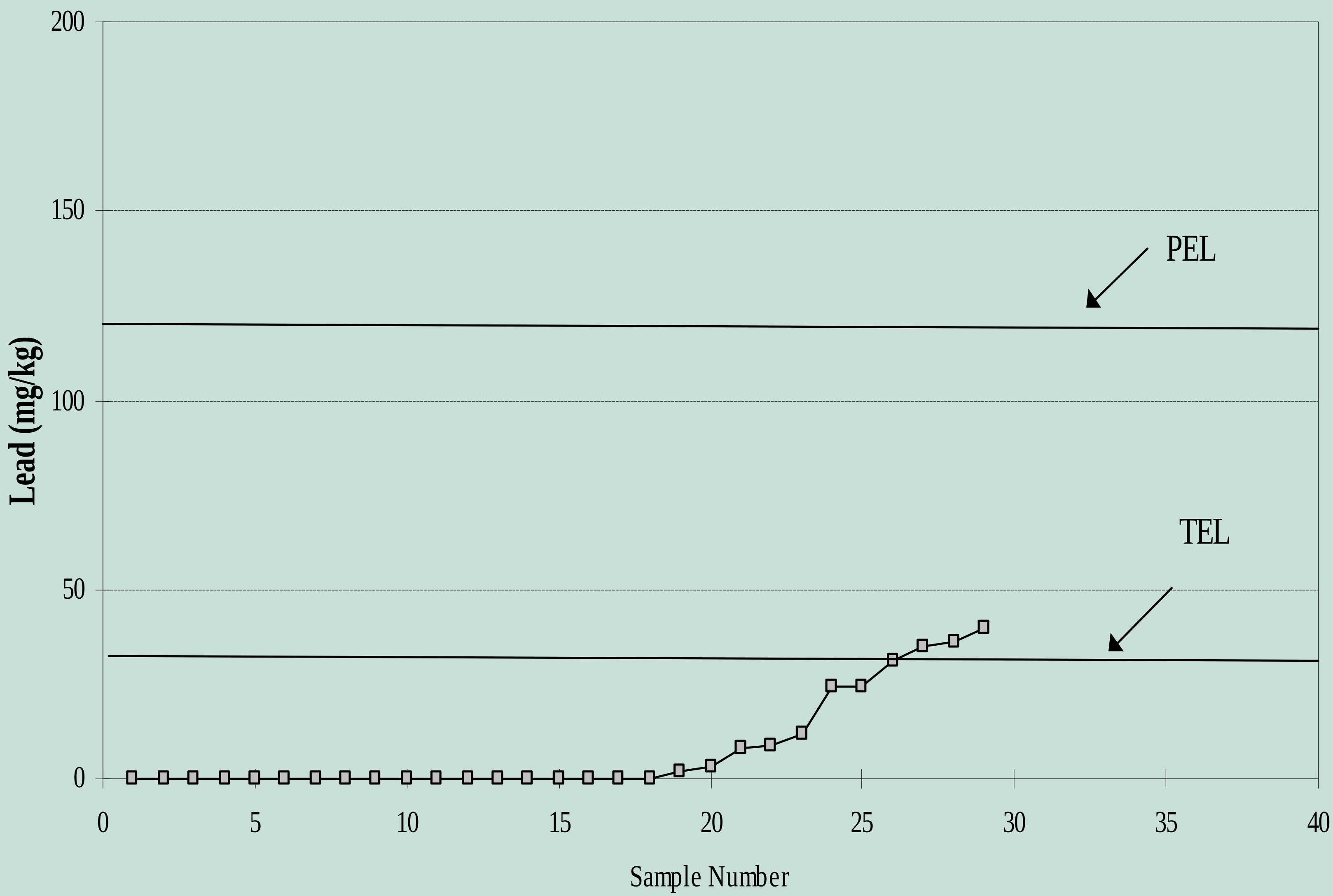


Figure 4. Concentratons of lead in sediments in Apalachicola Bay.



using the metals interpretive tool indicates that aluminum-normalized lead levels in Apalachicola Bay sediments are similar to those measured in 'clean' sediments in Florida (Figure 5). Therefore, while the effects-based tool predicts that adverse effects could, possibly, be observed at some sites due to elevated levels of lead, the metals interpretive tool clearly demonstrates that lead concentrations in Apalachicola Bay are naturally-occurring. As such, sediment-associated lead should not be considered to be a high priority for conducting further investigations to evaluate the extent of sediment toxicity. These examples emphasize the importance of using these assessment tools together to conduct reliable evaluations of sediment quality in Florida coastal waters.

3.6 Conduct Biological Assessment of Sediment Quality

At present, the nature and extent of available information on the effects of sediment-associated contaminants is such that there is often significant uncertainty associated with predictions of the biological significance of elevated concentrations of contaminants in bed sediments (i.e., the SQAGs do not support the establishment of cause and effect relationships). Therefore, biological testing is required to provide reliable information regarding the toxicity of bed sediments (generally a suite of biological tests is required) and to confirm the results of the preliminary sediment quality assessment.

Biological testing is required to support three distinct aspects of the sediment quality assessment process in Florida. First, biological testing may be required to assess the toxicity of sediments at sites where the concentrations of one or more contaminants fall within the probable and possible effects ranges. Second, biological testing may be required to assess the toxicity of sediments likely to contain unmeasured substances. In addition, ancillary biological testing is required to determine if there are systematic differences between the toxicity (as affected by bioavailability and other factors) of a substance in sediments represented in the database compared to that in Florida sediments. In some cases, the results of this biological testing will indicate a need for site-specific SQAGs to assess the potential effects of sediment-associated contaminants.

A number of tests have been developed to evaluate the biological significance of sediment contamination. These tests may be as simple as short-term bioassays involving a single contaminant using a single species, or as complex as microcosm studies in which the long-term effects of mixtures of contaminants on ecosystem dynamics are investigated. In addition, tests may be designed to assess the toxicity of whole sediments (solid phase), suspended sediments, elutriates, sediment extracts, or pore water. The organisms that are routinely tested include microorganisms, algae, aquatic macrophytes, invertebrates, and fish.

Whole sediment bioassays and pore water tests are the most relevant for assessing the effects of contaminants that are associated with bottom sediments. The ASTM presently has

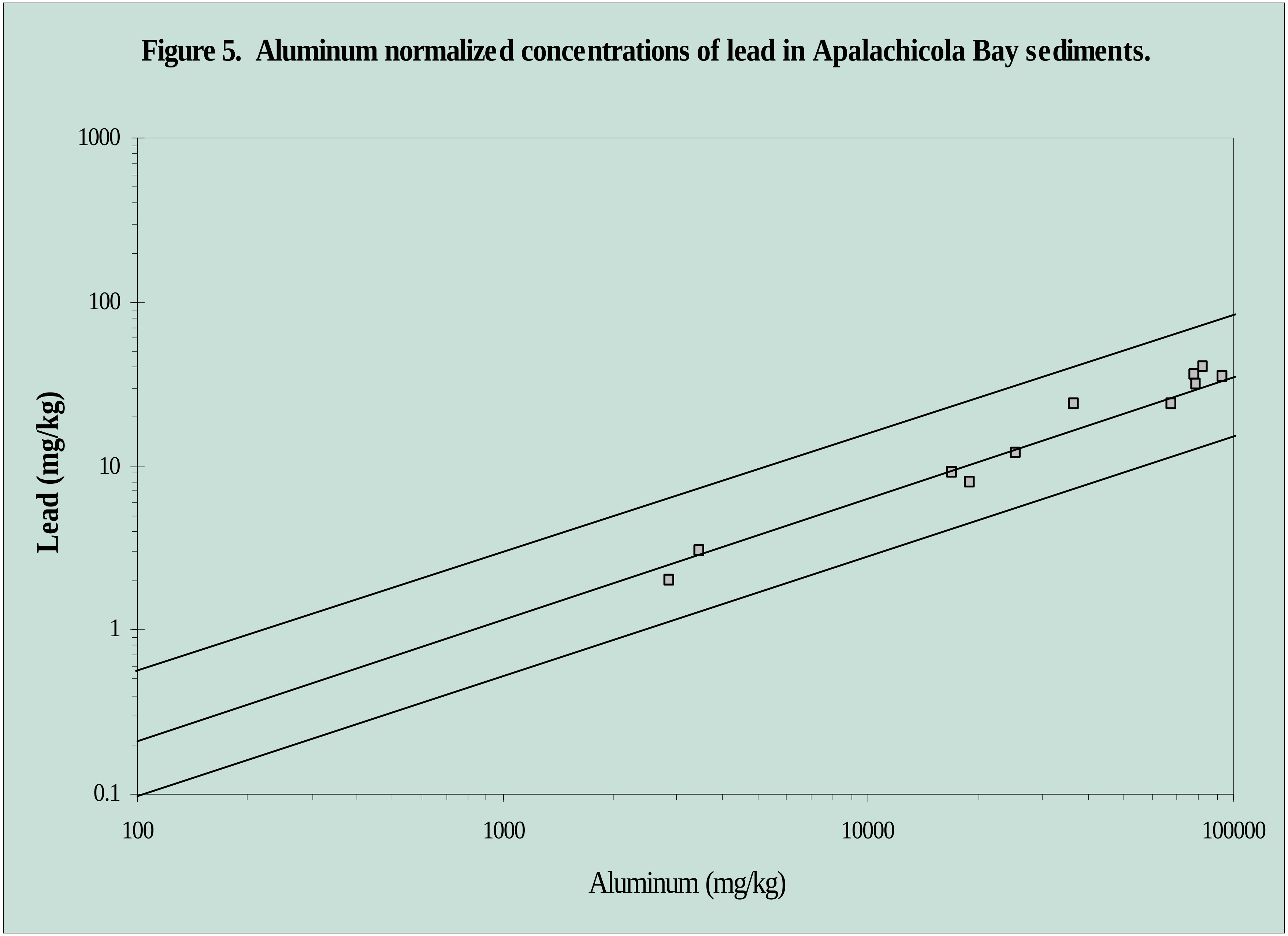


Figure 5. Aluminum normalized concentrations of lead in Apalachicola Bay sediments.
1000
100
10
1
0.1
Lead (mg/kg)
100
1000
10000
100000
Aluminum (mg/kg)

developed and approved four whole sediment tests for assessing the toxicity of marine and estuarine sediments. These tests (which are ten days in duration) are designed to assess the acute toxicity of sediment-associated contaminants on five species of amphipods (*Rhepoxynius abronius, Eohaustorius estuarius, Ampelisca abdita, Grandidierella japonica* and *Leptocheirus plumulosus*; ASTM 1993). These bioassays may be modified to assess toxicity to other benthic invertebrate species that occur in estuarine and marine environments, including other amphipods, other crustaceans, polychaetes, and bivalves (ASTM 1994a). In addition, procedures for conducting sediment toxicity tests with polychaetes and echinoderms are currently under consideration by the ASTM (Ingersoll 1991), and should be approved this year (C. Ingersoll. National Biological Survey. Columbia, Missouri. Personal communication).

In addition to whole sediment toxicity tests, various procedures are available for assessing the potential for adverse effects on aquatic organisms due to the resuspension of sediments or partitioning of contaminants into water (i.e., using elutriates or pore water). Perhaps the most sensitive and frequently used of these is the bacterial luminescence test (Microtox; Burton and Stemmer 1988; Schiewe *et al.* 1985); however, the environmental relevance of this test is not fully established. Tests using algae, invertebrates, and fish also have been employed to assess the toxicity of the suspended and/or aqueous phases. While no standard methods have yet been approved by the ASTM, a document on the use of oyster and echinoderm embryos and larvae in sediment toxicity testing of marine sediments (including elutriates, pore water or whole sediment) is currently in preparation (Ingersoll 1991). These latter tests, which are often conducted on pore water samples, provide very sensitive tools for assessing sediment toxicity. In addition, formal procedures for conducting water column bioassays and bioaccumulation tests have been recommended by the EPA and ACE (1991) and Lee *et al.* (1989), and a document on sediment resuspension testing is under development by ASTM (1994b).

While requirements for biological tests differ between applications, sediment toxicity tests should follow the general protocols established and approved by the ASTM. These protocols may be modified to assess toxicity to resident species, over longer time periods (i.e., to address chronic toxicity), or for different endpoints; however, the basic principles of these protocols should be followed. When ASTM methods do not exist or do not apply, the procedures used should be carefully documented to ensure that the experimental design can be evaluated and repeated by independent investigators. In addition, it is important to utilize tests that have been used in similar applications.

Other types of biological information may also be used in the sediment quality assessment process. For example, comparison of biological indicators (such as the diversity and abundance of benthic invertebrate communities) at test sites and appropriate reference sites (i.e., sites with similar depth, salinity, particle size distribution, TOC) provides a means of assessing the relative toxicity of test sediments. Various statistical procedures may be used to help identify the contaminants that are associated with observed biological effects when adequate sediment chemistry data are available. In this respect, the PELs represent reliable tools for identifying the substances that have a high likelihood of being associated with the observed biological effects. In addition, spiked-sediment bioassays may be used to establish cause and effect relationships for specific substances or mixtures of contaminants. Furthermore, tests to evaluate the toxicity of pore water provide information which may be used to identify the toxic elements of contaminated sediments (i.e., using toxicity identification evaluation procedures; Ankley and Thomas 1992). Information on levels of contaminants in aquatic biota and on bioaccumulation may help determine the significance of contaminant levels in sediments relative to the protection of human health and the health of wildlife that consume aquatic organisms.

3.7 Implement Management of Sediment Quality

The ultimate objective of the sediment quality assessment process is to provide information that supports the management of environmental quality. The management decisions that are ultimately made will depend on various factors, including the nature and severity of the contamination, the potential for exposure of aquatic organisms, the management goals for the site, the availability of remediation technology, the costs associated with remediation, and public expectations. Integration of information on these factors will enable managers and others to make defensible decisions regarding remediation, abating existing pollution sources, preventing increased contaminant loadings, or simply monitoring trends in environmental contamination.

A number of sediment quality management decisions are possible, based on consideration of available information from the environmental assessment. At some sites, evaluation of the available information will indicate that no additional action is warranted. At other sites, monitoring for assessment of trends in sediment quality may be required. At sites that are seriously contaminated, some remedial action may be necessary to achieve environmental management goals. These remedial actions could include removal and treatment of toxic materials, isolation (or capping) of contaminated sediments, implementation of source control measures, or no action at all (i.e., permit natural degradative and sedimentation processes to mitigate contaminant effects). An overview of the techniques that are available for cleaning up contaminated sediments is presented by Sullivan and Bixby (1989).