Approach to the Assessment of Sediment Quality in Florida Coastal Waters

Volume 2 - Application of the Sediment Quality Assessment Guidelines

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November 1994

Executive Summary

In Florida, conservation and protection of natural resources has been identified as a high priority environmental management goal. Realization of this goal requires protection of living resources and their habitats in estuarine, nearshore, and marine ecosystems. In the last decade, there has been a significant increase in the level of scientific understanding (and public recognition) of the important role sediments play in the functioning of coastal ecosystems. In addition to providing important habitats for aquatic organisms, sediments play a critical role in determining the fate and effects of environmental contaminants. Hence, sediment quality issues and concerns are becoming more important in the management of natural resources.

Recent monitoring data indicate that concentrations of various contaminants are present at elevated levels at a number of locations in Florida coastal sediments. While these chemical data provide essential information on the nature and areal extent of contamination, they provide neither a direct measure of adverse biological effects nor an indication of the potential for such effects. Therefore, effects-based SQAGs have been developed to evaluate the potential for biological effects associated with sediment-sorbed contaminants and to provide assistance in managing coastal resources. The primary uses of these SQAGs have been identified in this document. In addition, a framework for using the SQAGs in conjunction with other assessment tools has been presented.

The metals interpretive tool (Schropp and Windom 1988) and the preliminary SQAGs were used to conduct an initial assessment to determine the nature, extent, and severity of contamination in Florida coastal sediments. The degree of anthropogenic enrichment and the potential for adverse biological effects associated with measured levels of sediment-sorbed contaminants were used as indices of contamination. Data contained in the Florida Department of Environmental Protection coastal sediment chemistry database were used to identify priority areas and priority substances with respect to sediment contamination. The results of this evaluation are considered to be preliminary due to various limitations, including the dearth of data from certain areas, the lack of information on many organic chemicals, and the age of some chemical data (i.e., they may not reflect present conditions). This type of assessment should be repeated when the limitations have been addressed.

The initial assessment screened information from 21 coastal areas. The vicinity of Miami, Jacksonville, Tampa Bay, Pensacola, and Panama City were identified as the highest priority areas in terms of the extent and severity of sediment contamination. As surveys have recently been ccompleted in Tampa Bay and Pensacola Bay, the highest priority areas for new studies are Biscayne Bay and the St. Johns River. The contaminants of greatest concern in Florida sediment included lead, mercury, benzo(a)pyrene, pyrene, acenaphthene, benz(a)anthracene, chrysene, fluoranthene, and phenanthrene.

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ACKNOWLEDGEMENTS

It would be difficult to explicitly acknowledge all of the persons who contributed to the production of this document. However, the author would like to gratefully acknowledge those persons who made very substantial contributions to its preparation. Data and other pertinent information on the biological effects of sediment-sorbed contaminants was supplied by over 140 investigators across North America, including those from research institutes, universities, consulting firms, and state, provincial, and federal agencies. Each of these people deserve a special acknowledgement and the author's most sincere thanks. Preparation of this report would not have been possible without the expert guidance and advice provided throughout the course of this study by the Florida Department of Environmental Protection's Science Advisory Group on Assessing Sediment Quality. This group was comprised of Ed Long (National Oceanic and Atmospheric Administration), Chris Ingersoll, Pam Haverland, Scott Carr (National Biological Survey), Herb Windom (Skidaway Institute of Oceanography), Steve Schropp (Taylor Engineering, Inc.), Fred Calder, Gail Sloane, and Thomas Seal (Florida Department of Environmental Protection). Sherri Smith, Michael Wong (Environment Canada), and Graham Lewis (North West Florida Water Management District) also provided useful input on the derivation and use of sediment quality guidelines. A number of external reviewers provided insightful and substantive comments on the January 1993 draft of this document and their efforts are greatly appreciated. In addition, the author would like to thank M.L. Haines, B.L. Charlish, K. Brydges, B. Moore, and M. Popadynec (MacDonald Environmental Sciences Limited) for their significant contributions to the preparation of this document.

This project was supported by the Florida Department of Environmental Protection with funds made available through the National Oceanic and Atmospheric Administration under the Coastal Zone Management Act of 1972, as amended.

Chapter 1

Introduction

Contaminated sediments have been identified in marine and estuarine ecosystems throughout the United States (Bolton *et al.* 1985). The highest levels of sediment-associated contaminants have been measured in coastal areas that are influenced by point sources of pollution, primarily from municipal and industrial sources (NOAA 1990). However, high and biologically significant concentrations of many substances have also been observed in coastal areas that are mainly affected by non-point pollution sources, usually in the vicinity of urban and agricultural developments (O'Connor 1990). As Florida coastal waters may be affected by both point and non-point sources of pollution, there is a significant potential for degradation of environmental quality in these ecosystems.

Over the past 10 years, Florida Department of Environmental Protection (FDEP 1994) and others (e.g., Delfino *et al.* 1991; Long and Morgan 1990; Long *et al.* 1991) have collected a substantial quantity of information on the chemical composition of Florida sediments. Examination of these data indicates that numerous areas in Florida are contaminated by metals (such as chromium, copper, lead, silver, and mercury) and organic substances (such as polycyclic aromatic hydrocarbons and pesticides). However, sediment chemistry data alone are not adequate for identifying or managing potential sediment quality problems in the state. For this reason, FDEP has implemented a program to develop and evaluate tools that support the efficient and effective assessment of sediment quality.

The numerical sediment quality assessment guidelines (SQAGs) developed for Florida coastal waters using the weight of evidence approach are reported in the companion Volume 1 (MacDonald 1994). An evaluation of the overall reliability of the SQAGs also was conducted in Volume 1 to provide potential users of the tools with general guidance on using the guidelines. However, potential SQAG users also require further instructions on the appropriate uses and limitations of these sediment management tools (Sediment Quality Subcommittee 1992). For this reason, guidance in this document is provided to assist potential users in applying the SQAGs and other relevant sediment quality assessment tools.

The purpose of this report is to clearly identify the intended uses of the SQAGs and to list the applications that are considered to be inappropriate. In addition, a general framework for assessing the significance of sediment-associated contaminants is presented. Numerical SQAGs are an integral component of this framework, as they provide a basis for assessing the ***potential*** effects of sediment-associated contaminants (MacDonald 1994). A metals interpretive tool (Schropp and Windom 1988; Schropp *et al.* 1990) and various bioassessment tools (i.e., toxicity and bioaccumulation tests; benthic invertebrate community assessments) are also included in this framework because they provide essential information for evaluating sediment quality. Finally, this document reports the results of a preliminary assessment of sediment quality in Florida coastal waters, which may be used as a basis for identifying priority contaminants and priority areas for further investigation.

Chapter 2

Potential Applications of the Recommended Sediment Quality Assessment Guidelines

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2.0 Introduction

Contaminated sediments can be associated with a diverse array of adverse effects on aquatic organisms, including the plants and animals that live in, on, or near bed sediments. Numerical sediment quality assessment guidelines (SQAGs) may be used to identify and designate sediments that have high, moderate, and low probabilities of being associated with adverse effects on aquatic organisms. This feature of the SQAGs makes them useful in a range of management applications, including:

- interpreting sediment chemistry data;
- designing monitoring programs;
- supporting regulatory decisions;
- conducting risk assessments at contaminated sites;
- developing remediation objectives for contaminated sites; and,
- developing sediment quality objectives.

Each of these applications are briefly discussed in the following sections. In addition, the inappropriate uses of the guidelines are identified and discussed. Potential users of the SQAGs are encouraged to review the advantages and limitations of the weight of evidence approach used to derive the guidelines, as well as the results of the evaluation of the guidelines presented in MacDonald (1994).

2.1 Data Interpretation

Over the past decade, sediment chemistry data have been collected at a wide range of sites for many purposes. By themselves, these data may be used to assess the status and trends in environmental quality; however, they do not provide a basis for determining if the concentrations of contaminants represent potential hazards to aquatic organisms. Numerical

SQAGs contribute to the sediment quality assessment process by providing practical assessment tools or 'scientific yardsticks' against which the biological importance of sediment chemistry data can be assessed. In this context, SQAGs may be used as screening tools to identify areas and contaminants of concern on site-specific, regional, or national bases. To illustrate this process, an initial assessment of the potential for biological effects associated with measured concentrations of contaminants in Florida coastal waters is presented in Chapter 4 of this document.

As part of this study, two SQAGs were recommended for each contaminant of concern in Florida coastal waters, if sufficient data were available to support their development. Specifically, threshold effect levels (TELs) were formulated to define concentrations of contaminants below which biological effects are not expected. Likewise, probable effect levels (PELs) for each substance were developed to define ranges of concentrations above which biological effects are likely. When contaminant concentrations exceed one or more PELs, sediment samples are predicted to be toxic. Further investigations, including bioassessment, should be considered to be a high priority at sites with multiple exceedances of the PELs. Similarly, investigations into the sources and possible control measures should be conducted when the concentrations of individual contaminants exceed the PELs at multiple sites. Between the TELs and the PELs adverse biological effects are possible; however, further investigations are required to evaluate the actual nature and severity of these effects. The SQAGs provide the scientific information necessary to interpret the potential biological implications of contaminated sediments and, hence, a basis for focussing further investigations and identifying the need for remedial measures. The SQAGs also provide a basis for interpreting relationships between sediment chemistry and biological effects. In this application, the contaminants that are most likely to be associated with observed biological responses (e.g., acute toxicity) are those that exceed the PELs. Those substances which do not exceed the PELs are less likely to be one of the causative factors in the observed response, even if they are significantly correlated with toxicity. More detailed investigations of the contaminants that are associated most strongly with biological effects would require use of toxicity identification evaluation (TIE) procedures (Ankley and Thomas 1992).

2.2 Monitoring Program Design

Monitoring is an integral component of environmental surveillance programs. While such programs may be undertaken for a number of reasons (e.g., trend assessment, impact assessment, compliance, etc.), limitations on available resources dictate that they must be effective and efficient. For this reason, it is important for sediment quality monitoring programs to be well-focused and to provide the type of information that is necessary to manage contaminated sediments.

Numerical SQAGs support the design of environmental monitoring programs in several ways. First, comparison of existing sediment chemistry data with the SQAGs provides a systematic basis for identifying high priority areas for implementing monitoring activities. Second, when used in conjunction with existing sediment chemistry data, the SQAGs may be used to identify priority contaminants within an area of concern. By considering the potential sources of these contaminants, it may be possible to further identify priority sites for investigation. Lastly, the SQAGs assist in monitoring program design by identifying the required detection limits for each substance (e.g., TEL ÷ 2). Determination of the detection limits required for further interpretation of the data should help to avoid many of the difficulties that have resulted from the use of standard, yet inappropriate, analytical methods.

2.3 Support for Regulatory Decisions

Generally, SQAGs alone would not be used to make decisions on the management of contaminated sediments. However, the SQAGs are effective tools for identifying the need for site-specific investigations to support regulatory decisions, including source control and other remedial measures. In this context, SQAGs may be used to assess existing sediment chemistry data from contaminated sites and to identify substances of concern. Typically, further investigations would then be implemented to identify contaminant sources, assess the areal extent and severity of the contamination, evaluate potential source control measures, and determine the need for other remedial measures. The SQAGs would also be used to evaluate the success of any regulatory actions that are implemented at the site.

2.4 Ecological Risk Assessment

Ecological risk assessment is the process that evaluates the likelihood that adverse ecological effects may occur or are occurring as a result of exposure to one or more stressors (EPA 1992). By estimating the probabilities of observing adverse biological effects under a variety of exposure scenarios, ecological risk assessment strives to provide science-based guidance for managing environmental quality, particularly at contaminated sites. While the Society of Environmental Toxicology and Chemistry (SETAC) is currently in the process of developing procedures for assessing the risks associated with contaminated sediments, such methods are not yet available. In addition, the scientific information required to support ecological risk assessment has not been available in a summarized form. However, the SQAGs contribute directly to the ecological risk assessment process because they define three ranges of contaminant concentrations that are rarely, sometimes, and usually associated with adverse biological effects. Moreover, the supporting documentation (MacDonald *et al.* 1994) can be used to calculate the percent incidence (or probability) of adverse effects within each of these ranges (Long *et al.* In press). Furthermore, the evaluation of the predictability of the SQAGs (presented in MacDonald 1994) provides a basis for assigning probabilities to the adverse effects that may be associated with contaminant concentrations that exceed the recommended guidelines. Hence, the SQAGs should form an integral part of ecological risk assessments that are conducted at sites with contaminated sediments in Florida.

2.5 Development of Sediment Quality Remediation Objectives

While the majority of coastal sites in Florida are likely to be relatively uncontaminated, high and biologically-significant concentrations of certain substances in sediments may be present in the vicinity of major urban and/or industrial developments. At these sites, further investigations would be required to evaluate the extent, severity, and effects of sediment-associated contaminants. When the results of focused environmental assessments indicate that aquatic habitats are seriously degraded, remediation may be required to restore the designated water uses at the site and achieve long-term water management goals.

Sediment quality remediation objectives are an essential component of the remediation process because they help establish the target clean-up levels for a site. In this context, SQAGs are useful because they provide the basic scientific information required to formulate site-specific remediation objectives. In addition, the SQAGs provide information that help evaluate the costs and benefits associated with various remediation options. However, the SQAGs should not be used directly as target clean-up levels at contaminated sites. Procedures for deriving site-specific remediation objectives have been recommended by MacDonald and Sobolewski (1993), and these could be employed on an interim basis in the state.

2.6 Development of Sediment Quality Objectives

Sediment quality issues are rarely entirely the province of one agency or one level of government. For this reason, it may be necessary to establish agreements between various levels of government to define their respective responsibilities with respect to the prevention, assessment, and remediation of sediment contamination. Multi-jurisdictional agreements may include accords on a number of issues; however, establishment of site-specific sediment quality objectives is important because they provide a common yardstick against which the success of a range of environmental management activities can be measured. In this context, sediment quality objectives are defined as numerical concentrations of sediment-associated contaminants which have been established to support and protect aquatic life at a specific site (MacDonald and Sobolewski 1993).

Numerical SQAGs contribute significantly to the objectives development process because they provide basic scientific information on the biological effects of sediment-associated contaminants. As such, the SQAGs may be used as the technical basis for establishing site-specific sediment quality objectives. It is important to note, however, that these guidelines should not be regarded as blanket values for regional sediment quality. Variations in environmental conditions throughout the state could affect sediment quality in different ways and, hence, necessitate the modification of the guidelines to reflect local conditions. While no specific guidance on the derivation of site-specific sediment quality objectives for Florida coastal waters is available, MacDonald and Sobolewski (1993) provide some general instructions that may help address this issue.

2.7 Inappropriate Uses of the Sediment Quality Assessment Guidelines

While the recommended SQAGs are likely to have a number of important uses in Florida and elsewhere, they have certain limitations that should be recognized. First, the SQAGs should not be used as mandatory target clean-up levels, or standards, at contaminated sites (e.g., Superfund sites) unless additional site-specific studies are conducted (Sediment Quality Subcommittee 1992). However, the SQAGs and the supporting documentation may be used, in conjunction with other information, as a technical basis for establishing target clean-up levels. MacDonald and Sobolewski (1993) provide explicit guidance on the derivation of site-specific sediment quality remediation objectives for contaminated sites in Canada. It is likely that these recommendations would apply in other areas, including Florida coastal waters.

The recommended SQAGs are not intended to define uniform values for sediment quality on a state-wide basis. That is, the SQAGs should not be used as sediment quality criteria. In certain areas, local conditions may influence the applicability of the guidelines. For example, high background levels of certain trace metals (e.g., lead) have been reported in Apalachicola Bay. Some of the samples collected from this area exceed the threshold effect level (TEL) for lead, even though there is no evidence of significant anthropogenic enrichment (FDEP 1994; see Section 3.4). Therefore, it would not be appropriate to evaluate sediment quality in Apalachicola Bay using the recommended TEL for lead by itself. This example illustrates the importance of using the SQAGs in conjunction with other tools (such as the metals interpretive tool and various bioassessment tools) for conducting sediment quality assessments.

Various organizations have expressed concerns regarding the potential use of the SQAGs as criteria for the disposal of dredged material. It is important for potential users to remember that the SQAGs are not intended to be used as pass/fail criteria for dredged disposal analysis, nor are they intended to replace formal assessment protocols developed by federal agencies (EPA and ACE 1991). Nonetheless, the SQAGs may provide useful information for evaluating the quality of dredged material and could be utilized as part of the dredged disposal analysis process, subject to approval by the responsible agencies.

The SQAGs are not intended to replace the water quality criteria that are used in various state programs. However, the SQAGs do provide useful information for evaluating the effectiveness of certain regulatory programs. For example, more stringent regulations may be required at sites where water quality criteria (WQC) have been established, ambient monitoring data indicate compliance with the WQC, and the SQAGs have been exceeded. This situation could occur because water quality regulations generally do not consider the potential for contamination of bed sediments. Consideration of both sediment quality and water quality will increase the probability that the beneficial uses of aquatic ecosystems are adequately protected.

Lastly, it is important to note that SQAGs developed using the weight of evidence do not provide a basis for identifying the substance or substances that **caused** an effect in field-collected samples. Instead, the SQAGs define contaminant concentrations that are unlikely or usually **associated** with adverse effects. Exceedance of the PEL for a certain substance indicates that the chemical may be, in part, responsible for the observed effects; however, confirmation of the role of individual chemicals which occur in complex mixtures in sediment toxicity requires the use of toxicity identification evaluation procedures (Ankley and Thomas 1992). Alternatively, toxicity tests using sediments that have been spiked with individual chemicals or contaminant mixtures may be conducted to establish dose-response relationships (Lamberson and Swartz 1992). Once the cause(s) of sediment toxicity has been identified, better decisions can be made regarding sediment management.

Chapter 3

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

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3.0 Introduction

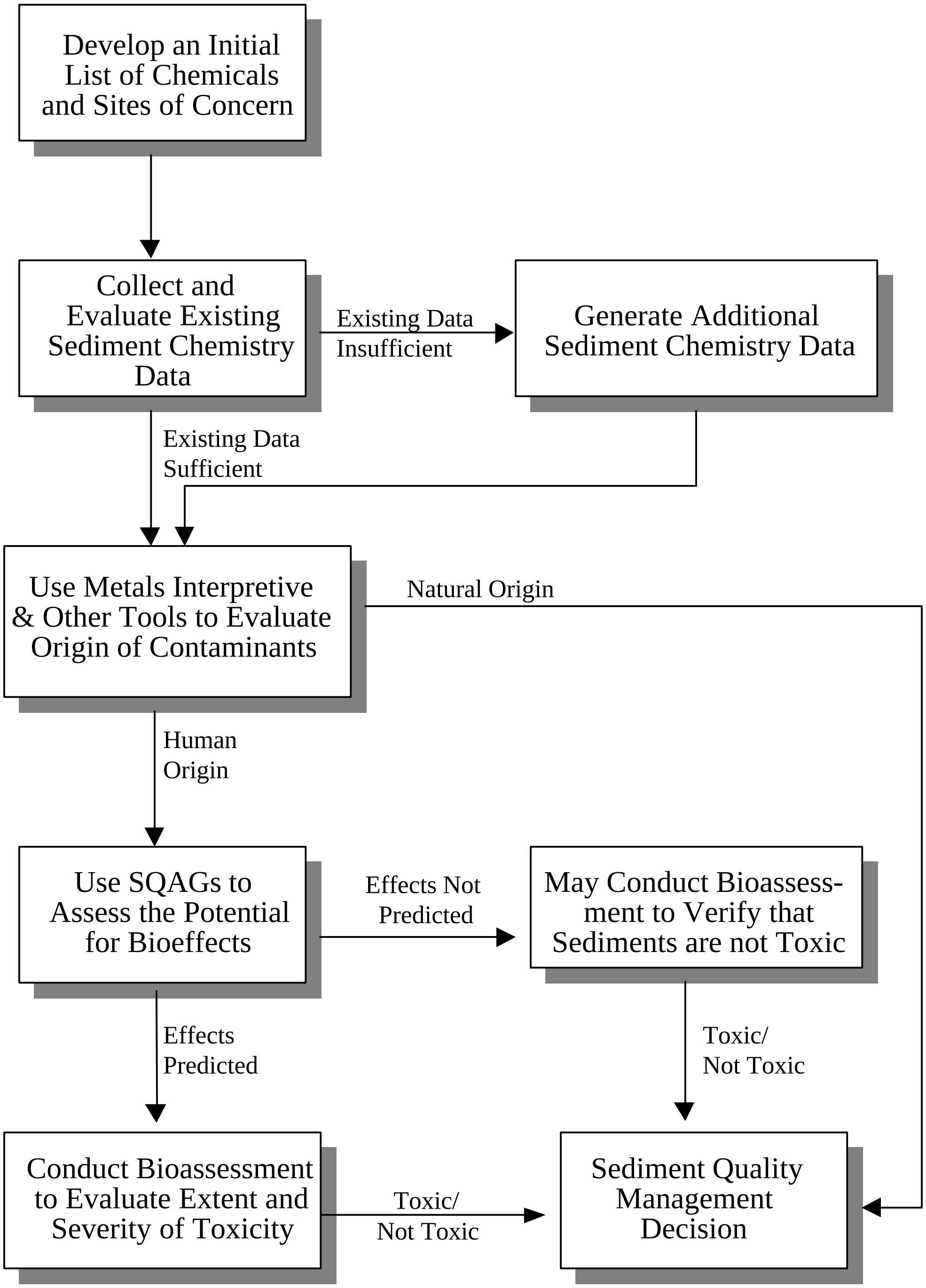
The numerical sediment quality assessment guidelines (SQAGs) recommended in Volume 1 (MacDonald 1994) provide a strong technical basis for assessing sediment quality in Florida. These guidelines explicitly address the uncertainty associated with the sediment quality assessment process by identifying 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

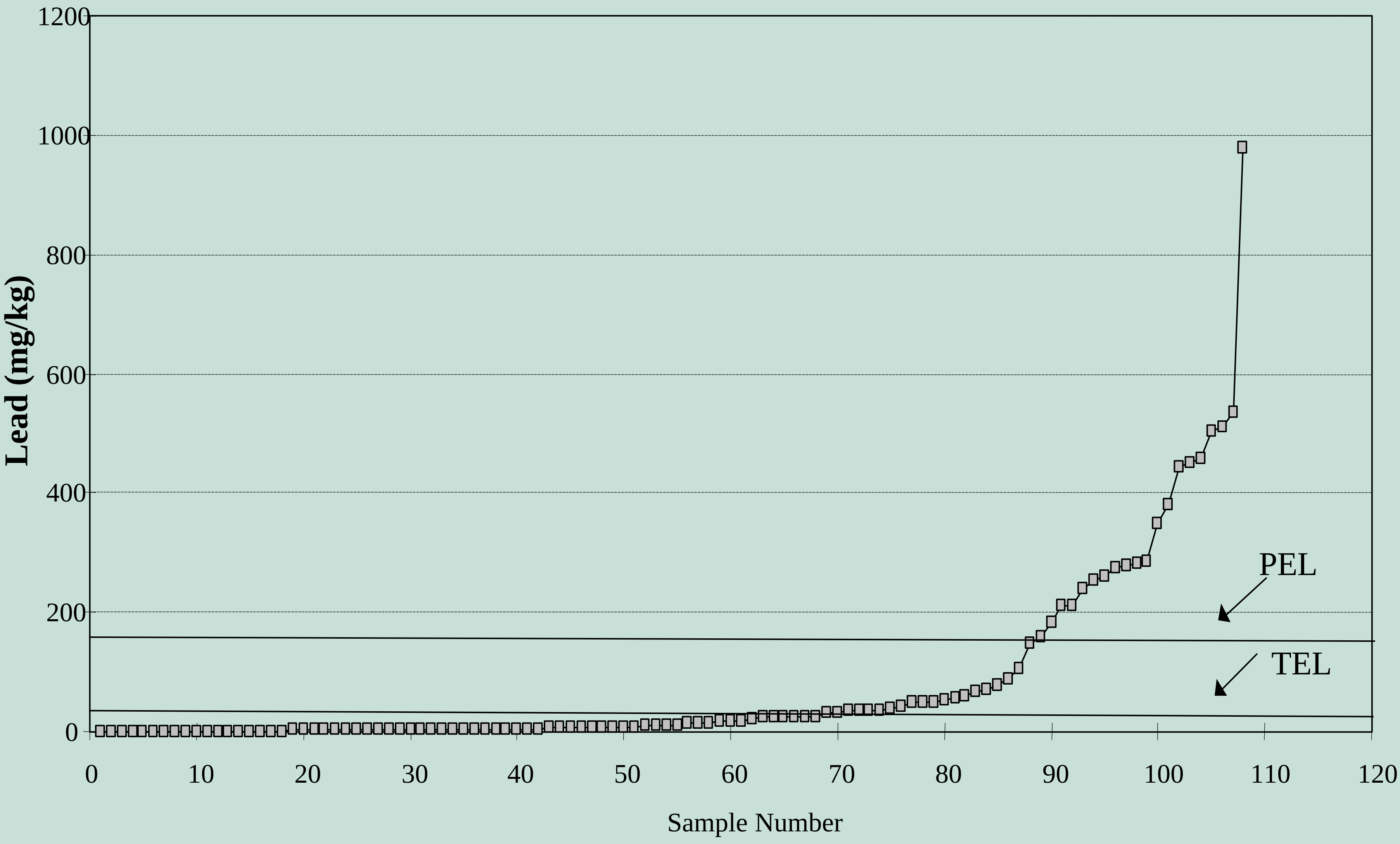


Figure 2. Concentrations of lead in sediments in Biscayne Bay.

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

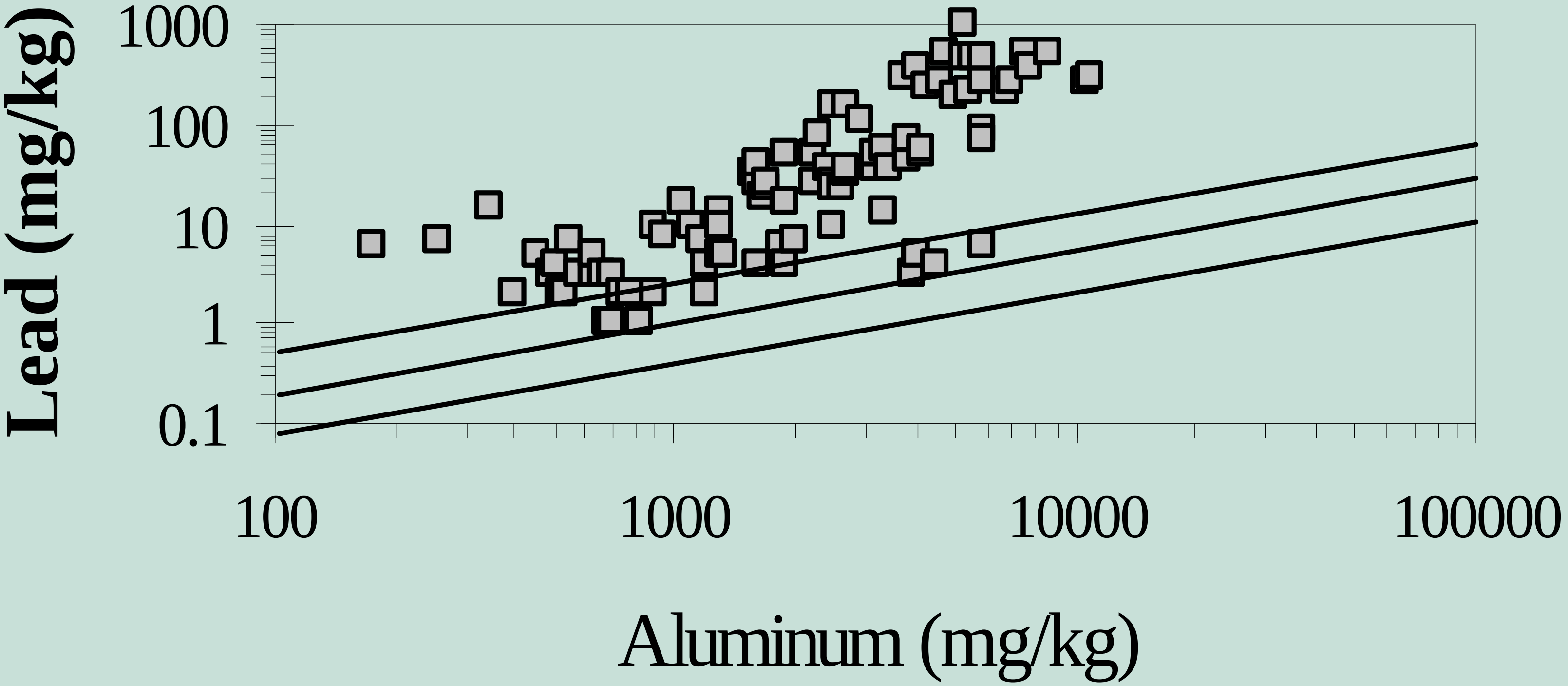
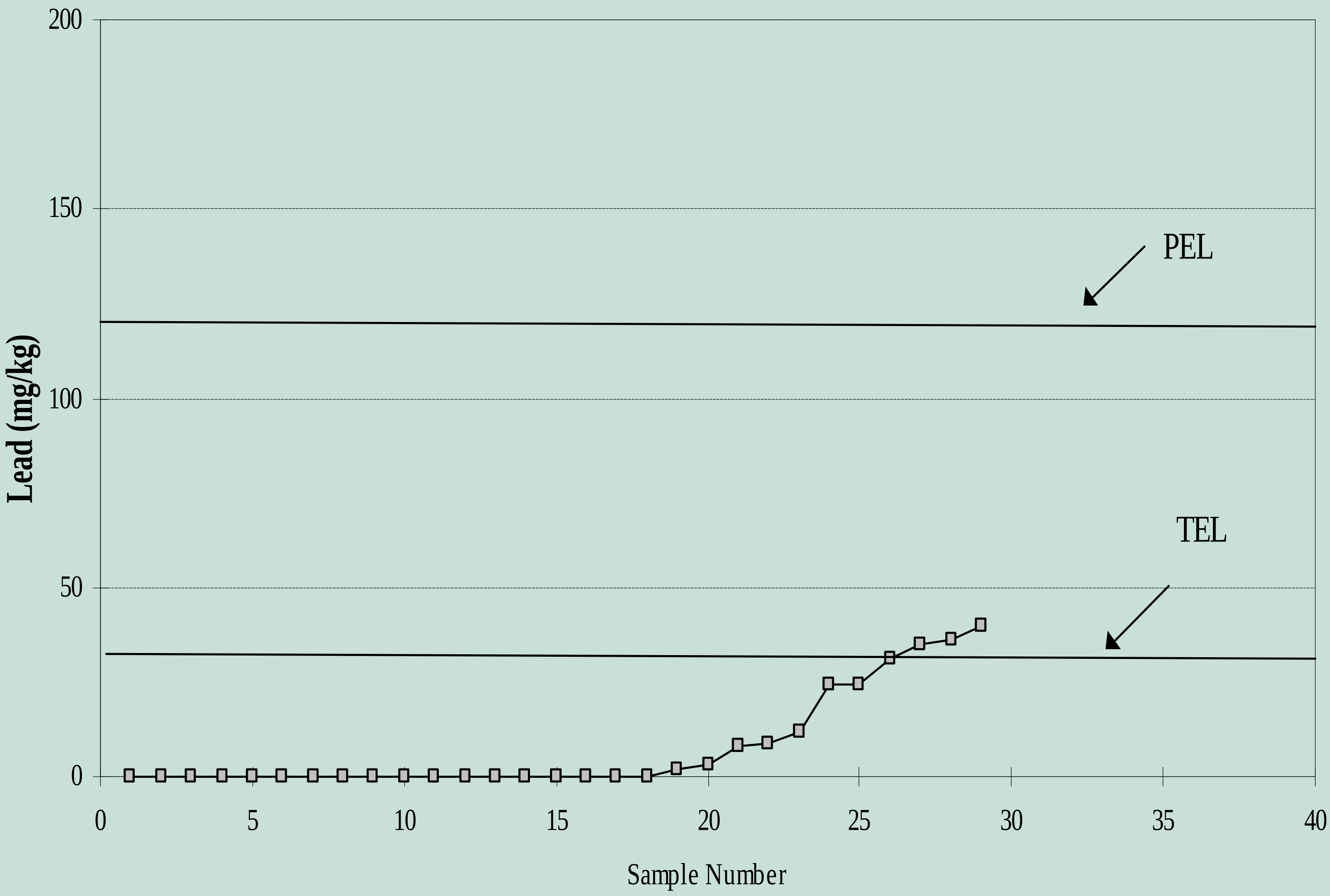


Figure 4. Concentratons of lead in sediments in Apalachicola Bay.



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

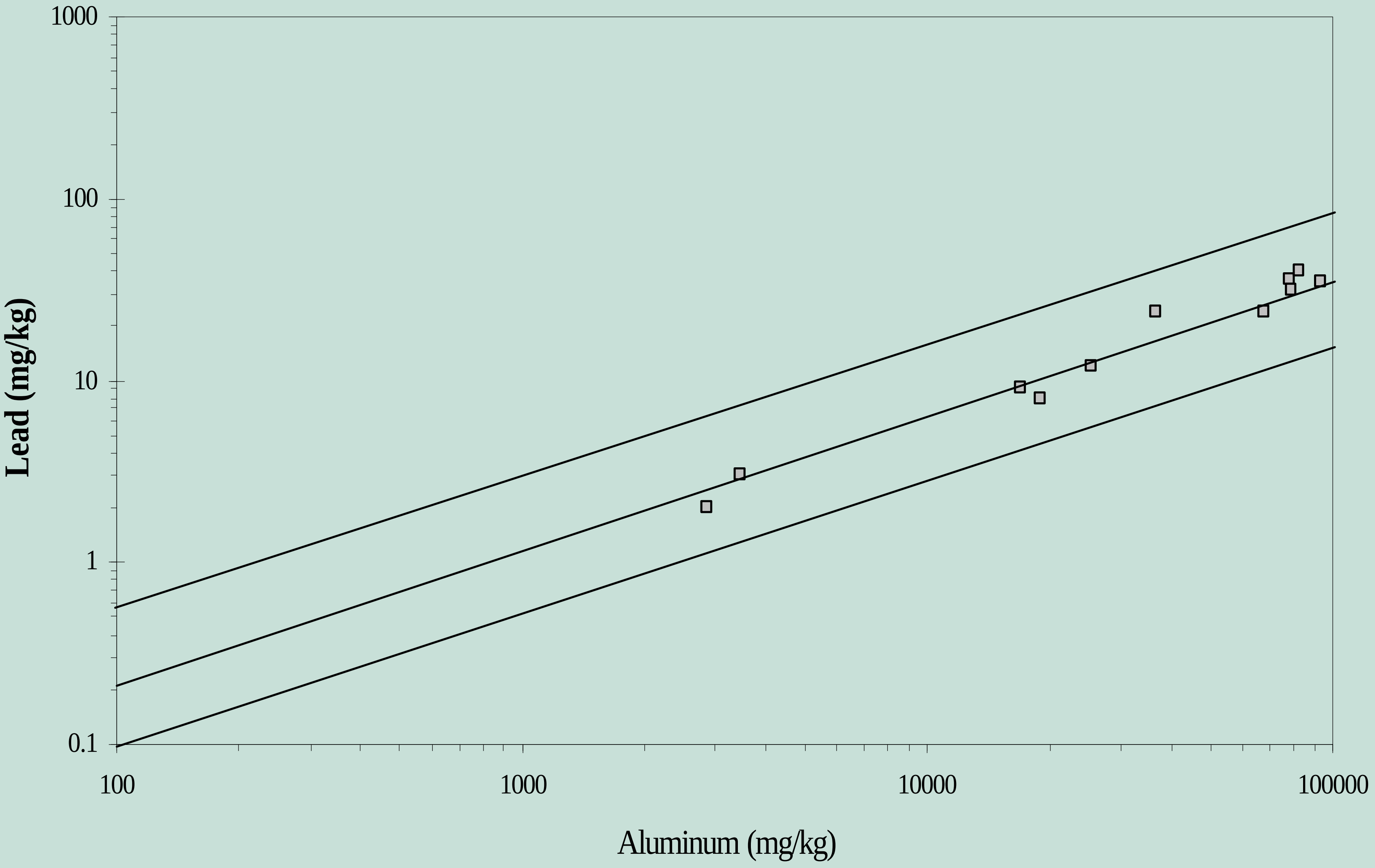
At present, the nature and extent of available information on the effects of sediment-associated contaminants is such that there is often significant uncertainty associated with predictions of the biological significance of elevated concentrations of contaminants in bed sediments (i.e., the SQAGs do 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.



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).

Chapter 4

An Initial Assessment of the Potential for Biological Effects of Sediment-Associated Contaminants in Florida Coastal Waters

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4.0 Introduction

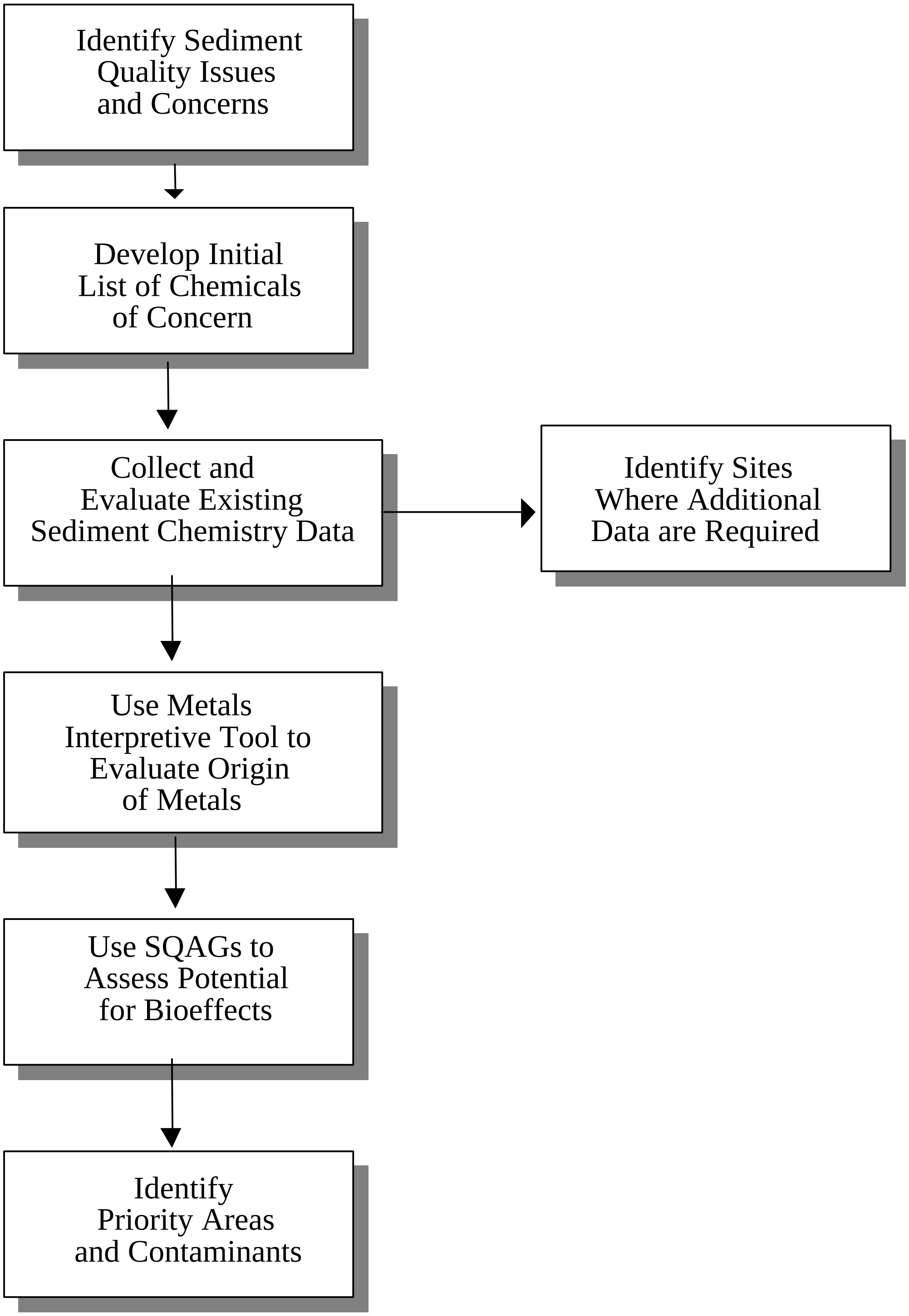
This Chapter presents an initial assessment of the potential for biological effects of sediment-associated contaminants, using Florida Department of Environmental Protection (FDEP) coastal sediment chemistry data and the sediment quality assessment guidelines (SQAGs) recommended in Volume 1 (MacDonald 1994). Although preliminary, this assessment helps focus sediment management efforts by identifying priority contaminants and priority sites with respect to the potential for adverse biological effects. The exercise also illustrates how an identification of sediment quality concerns conducted on a regional scale would help direct limited resources to yield the greatest environmental benefits.

This initial regional assessment of sediment quality consists of several parts. In Volume 1, regional sediment quality issues and concerns were identified by reviewing potential sources of contaminants in the state. Priority substances with respect to sediment contamination were subsequently identified by compiling relevant data from several sources. Next, numerical SQAGs were derived preferentially for preliminary substances of concern in Florida sediments. This chapter carries the derivation of SQAGs forward by compiling a database containing sediment chemistry data for Florida coastal waters, and comparing sediment chemistry data with the metals interpretive tool (Schropp and Windom 1988) and the SQAGs (Figure 6).

4.1 Identification of Regional Sediment Quality Issues and Concerns

In Florida, sediment quality issues and concerns are primarily associated with direct and non-point (diffuse) source discharges of contaminants from urban and suburban areas into coastal waters. These inputs include effluent discharges from wastewater treatment plants, stormwater runoff, and a variety of related sources. In addition, industrial facilities have the potential to release significant quantities of contaminants into estuarine and marine systems.

Figure 6. Framework for conducting preliminary regional sediment quality assessment of Florida coastal waters.



Furthermore, intensive agricultural operations have the potential to contribute pesticides and fertilizers to aquatic ecosystems. Other possible sources of contaminants into Florida coastal waters include leachates from landfills, dredging operations, and the operation of boat repair and moorage facilities. Each of these potential sources of contaminants was considered in identifying substances for this preliminary evaluation. A discussion of sediment quality issues and concerns, and anthropogenic influences in Florida is provided in MacDonald (1994), while a list of substances likely to be associated with coastal sediments is provided in Table 1.

4.2 Development of a Database on Sediment Chemistry in Florida

Over the past 10 years, the FDEP has conducted coastal sediment contaminant surveys in various regions throughout the state. This information has now been assembled into a database (the Florida coastal sediment contaminants database; FDEP 1994) in dBase IV^{TM} format. This database contains information on approximately 700 stations located in estuarine and nearshore marine areas throughout Florida. While most of these stations are located in the vicinity of cities and their satellite communities, roughly 17% of the stations are located in pristine areas for the purpose of identifying natural background conditions.

There are over 11,000 miles of tidal shoreline in Florida, and the database is not representative of the full extent of the state's coastal conditions. The Florida coastal sediment contaminants database has focused on metals due to the prevalence of anthropogenic activities that generate metals-enriched wastes. The metals most commonly measured in the survey include aluminum, cadmium, chromium, copper, nickel, lead, mercury, and zinc. Typically, two samples have been collected and analyzed at each station. Organic substances are also represented in the database at a limited number of stations. In general, sampling for organic substances was conducted when land use activities suggested that there would be a high probability of detecting these substances in sediments.

4.3 Evaluate the Probable Origin of Sediment-Associated Metals

The metals interpretive tool (Schropp and Windom 1988; Schropp *et al.* 1989; Schropp *et al.* 1990) provides a reliable basis for evaluating the probable origin of sediment-associated metals. To identify the areas in which the concentrations of sediment-associated metals have been enriched anthropogenically, the metals interpretive tool was applied to the existing sediment chemistry data. In this evaluation, the preliminary areas of greatest concern were identified as those with the greatest frequency of metals concentrations that exceeded the 95% prediction limits. Similarly, the highest priority metals, with respect to anthropogenic enrichment were identified as those that frequently exceeded their respective 95% prediction limits. Pooled data for a number of sampling stations and sampling dates were used to

Table 1. Preliminary identification of chemicals of concern in Florida coastal waters.

Substance	Reference/Rationale
Metals	
Arsenic	Long et al. (1991); FDEP (1994).
Cadmium	Long et al. (1991); FDEP (1994).
Chromium	Long and Morgan (1990); Long et al. (1991); FDEP (1994).
Copper	Used in aquatic herbicides/found in fish; Long et al. (1991); Trefry et al. (1983); Leslie (1990); FDEP (1994).
Lead	Long and Morgan (1990); Long et al. (1991); FDEP (1994).
Mercury	Long and Morgan (1990); Long et al. (1991); FDEP (1994).
Nickel	Long et al. (1991); FDEP (1994).
Silver	Long and Morgan (1990); FDEP (1994).
Tributyltin	Used as an antifoulant on ships.
Zinc	Long and Morgan (1990); Long et al. (1991); FDEP (1994).
Polycyclic Aromatic Hydrocarbons (PAHs)	
Acenaphthene	Delfino et al. (1991); FDEP (1994).
Acenaphthylene	Delfino et al. (1991); FDEP (1994).
Anthracene	Long and Morgan (1990); Delfino et al. (1991); FDEP (1994).
Benz(a)anthracene	Long and Morgan (1990); Delfino et al. (1991); FDEP (1994).
Benzo(a)pyrene	Long and Morgan (1990); Delfino et al. (1991); FDEP (1994).
Chrysene	Long and Morgan (1990); Delfino et al. (1991); FDEP (1994).
Dibenzo(a,h)anthracene	Long and Morgan (1990); Delfino et al. (1991); FDEP (1994).
Fluorene	Long and Morgan (1990); Delfino et al. (1991); FDEP (1994).
Fluoranthene	FDEP (1994).
Napthalene	Long and Morgan (1990); Delfino et al. (1991); FDEP (1994).
2-methylnapthalene	Long and Morgan (1990).
Phenanthrene	Long and Morgan (1990); Delfino et al. (1991); FDEP (1994).
Pyrene	Long and Morgan (1990); Delfino et al. (1991); FDEP (1994).
Total PAHs	Long and Morgan (1990); Long et al. (1991); FDEP (1994).
Polychlorinated Biphenyls (PCBs)	
Total PCBs	Long and Morgan (1990); Long et al. (1991); Delfino et al. (1991); FDEP (1994).

Table 1. Preliminary identification of chemicals of concern in Florida coastal waters (continued).

Substance	Reference/Rationale
Pesticides	
Aldrin/Dieldrin	Long and Morgan (1990); Long et al. (1991); FDEP (1994).
Azinphos-methyl (guthio	Organophosphorous insecticide (Kow > 10,000?)
Chlordane	Long and Morgan (1990); Long et al. (1991); FDEP (1994).
Chlorothalonil	Chlorophenyl fungicide (Kow = 20,000)
Chlorpyrifos	Organophosphorous insecticide (Kow > 50,000)
DDT and metabolites	Long and Morgan (1990); Long et al. (1991); FDEP (1994); Delfino et al. (1991).
Disulfoton	Organophosphorous insecticide (Kow > 10,000)
Endosulfan	Delfino et al. (1991); FDEP (1994).
Endrin	Organochlorine insecticide (Kow > 10,000?); FDEP (1994).
Heptachlor	Organochlorine insecticide (Kow > 10,000?); FDEP (1994).
Heptachlor epoxide	Organochlorine insecticide (Kow > 10,000?); FDEP (1994).
Lindane (gamma-BHC)	Organochlorine insecticide (Kow > 10,000?); FDEP (1994).
Mirex	Organochlorine insecticide (Kow > 10,000?); FDEP (1994).
Phorate	Organophosphorous insecticide (Kow > 10,000?).
Quintozene (PCNB)	Chlorophenyl fungicide (Kow = 10,000).
Toxaphene (alpha-BHC)	Organochlorine insecticide; FDEP (1994).
Trifluralin	Dinitroanaline herbicide (Kow > 200,000); FDEP (1994).
Chlorinated Organic Compounds	
2,3,7,8-T4CDD	Pulp and paper industry.
2,3,7,8-T4CDF	Pulp and paper industry
Pentachlorophenol	Delfino et al. (1991); FDEP (1994).
Phthalates	
Bis(2-ethylhexyl)phthala	Delfino et al. (1991).
Dimethyl phthalate	Delfino et al. (1991).
Di-n-butylphthalate	Delfino et al. (1991).

* Kow = Octanol-water partition coefficient which provides an indication of the hydrophobicity of a substance; Criteria for selection of pesticides: Kow > 5,000.

evaluate the extent of anthropogenic metals enrichment within each geographic area. It was not possible to evaluate enrichment of any of the organic contaminants measured in Florida coastal waters.

4.4 Derivation of Numerical Sediment Quality Assessment Guidelines

Effects-based SQAGs provide a basis for assessing the potential for biological effects associated with various concentrations of contaminants. In Florida, threshold (TELs) and probable effects levels (PELs) have been recommended for 34 substances or groups of substances (MacDonald 1994). These guidelines define three ranges of contaminant concentrations: a probable effects range; a possible effects range; and, a minimal effects range. The procedure used to derive these guidelines is presented in MacDonald (1994), while the uses of the SQAGs are described in Chapters 2 and 3 of this document.

4.4.1 Preliminary Areas of Concern

In the FDEP coastal contaminants database, measurements of metals levels were organized into 20 general geographic areas to facilitate this evaluation (Figure 7). While this database provides important information for evaluating sediment quality in Florida coastal waters, its broad applicability is limited by the number of samples that have been collected in certain areas. For example, fewer than ten sites have been sampled in the Jupiter, Ft. Lauderdale, and Florida Keys areas. Nonetheless, it is apparent that metals concentrations have been significantly enriched in many areas of the state.

On the Atlantic coast (Table 2), the highest frequency of exceedances of the 95% prediction limits for metals occurred in the vicinity of Miami. Cadmium, chromium, copper, lead, mercury and zinc were all anthropogenically-enriched at a large proportion of the sites sampled. Almost three-quarters of the sites had lead to aluminum enrichment ratios of greater than one, with ratios of greater than 100 observed at certain sites. Significant anthropogenic enrichment of metals was also apparent in the Jacksonville and West Palm Beach areas.

In the Gulf of Mexico (Table 3), coastal sediments in the vicinity of Tampa and Pensacola had the highest frequency of exceedances of the 95% prediction limits of the eight metals considered. The concentrations of cadmium, copper, chromium, lead, mercury, and zinc were all enriched in these areas. In Tampa Bay, more than a third of the sites had cadmium to aluminum enrichment ratios of greater than one. In Pensacola Bay, more than 20% of the sites sampled had zinc to aluminum enrichment ratios of greater than one, which indicates that a relatively high proportion of the sites have anthropogenically-enriched levels of zinc.

Figure 7. Florida Department of Environmental Protection coastal survey area map.

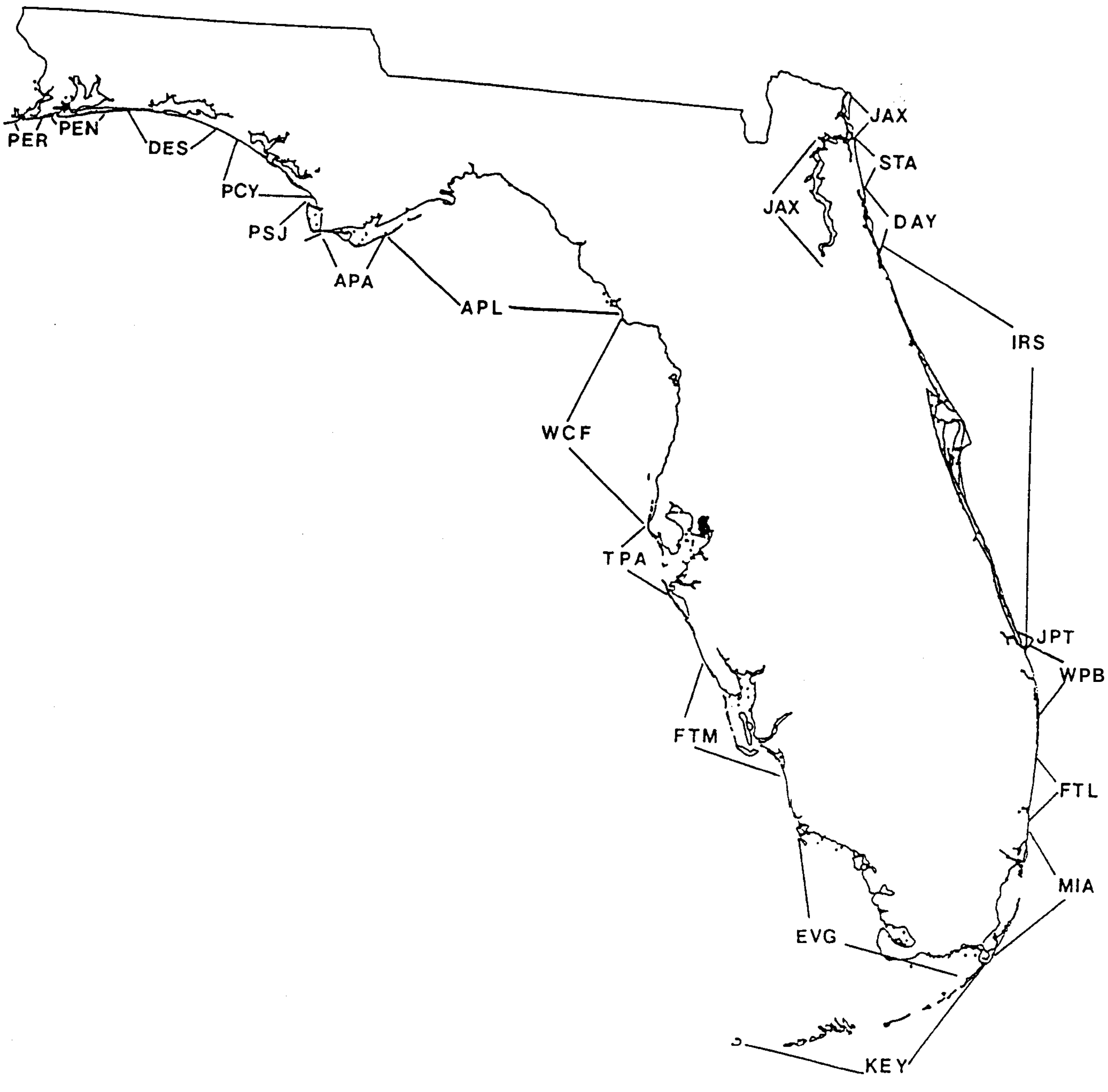


Table 2. Evaluation of anthropogenic-enrichment of metals levels for each Atlantic coast sampling area.

	Number of Exceedances of the 95% Prediction Limits									
Substance	JAX	STA	DAY	IRS	JPT	WPB	FTL	MIA	KEY	Total
Metals										
Arsenic	0	0	0	0	0	0	0	**4**	0	**4**
Cadmium	**15**	0	**4**	**8**	0	**2**	0	**48**	**1**	**78**
Chromium	**2**	0	0	**2**	0	**2**	0	**51**	0	**57**
Copper	**10**	**3**	**6**	**8**	0	**8**	**4**	**48**	0	**87**
Lead	**27**	0	**2**	**6**	0	**26**	**5**	**78**	**1**	**145**
Mercury	**25**	**1**	0	**9**	0	**6**	**2**	**55**	**2**	**100**
Nickel	**2**	0	0	0	0	**1**	0	**1**	0	**4**
Silver	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**0**
Zinc	**27**	0	0	**6**	0	**23**	**5**	**20**	**2**	**83**
Number of Samples	68	37	31	86	7	27	5	110	4	558

Place names indicate the general coastal vicinity of sampling station locations.
JAX = Jacksonville; STA = St. Augustine; DAY = Daytona Beach; IRS = Indian River; JPT = Jupiter; WPB = West Palm Beach; FTL = Ft. Lauderdale; MIA = Miami; KEY = Florida Keys.

Table 3. Evaluation of anthropogenic-enrichment of metals levels for each Gulf coast sampling area.

	Number of Exceedances of the 95% Prediction Limit											
Substance	EVG	FTM	TPA	WCF	APL	APA	SJB	PCY	DES	PEN	PER	Total
Metals												
Arsenic	0	0	**1**	**1**	0	0	0	0	0	**1**	0	**3**
Cadmium	0	**4**	**51**	**8**	0	**1**	**2**	**2**	**1**	**7**	**1**	**77**
Chromium	0	**1**	**17**	**6**	0	0	0	0	0	**7**	**2**	**33**
Copper	0	**3**	**14**	**11**	0	0	**1**	**1**	**1**	**4**	0	**35**
Lead	**3**	**2**	**38**	**7**	0	0	**1**	**1**	**1**	**11**	**1**	**65**
Mercury	0	**4**	**32**	**1**	0	0	**7**	**2**	0	**12**	**2**	**60**
Nickel	0	0	**4**	**1**	0	0	0	0	0	0	0	**5**
Silver	-	-	-	-	-	-	-	-	-	-	-	-
Zinc	0	**3**	**31**	**6**	0	**1**	**1**	**1**	**1**	**18**	**3**	**65**
Number of Samples	96	67	141	30	56	30	22	39	20	79	17	597

Place names indicate the general coastal vicinity of sampling station locations.
EVG = Everglades; FTM = Ft. Mayers; TPA = Tampa Bay; WCF = West Central Florida; APL = Apalachee Bay; APA = Apalachichola Bay; STJ = St. Josephs Bay; PCY = Panama City; DES = Destin; PEN = Pensacola Bay; PER = Perido Bay.

4.4.2 Preliminary Metals of Concern

The results of this evaluation indicate that anthropogenic-enrichment of metals levels occurs relatively frequently in Florida coastal sediments. Of the substances considered, lead was identified as the metal of greatest concern. Mercury to aluminum ratios of greater than one were observed at a total of 210 sites, with the majority of these sites located in the Atlantic coast (145 of 210). Somewhat lower frequencies of exceedance of the 95% prediction limits were observed for cadmium (155), mercury (160), and zinc (148). Once again, the highest frequency of metals enrichment was observed on the Atlantic coast. In contrast, the metals to aluminum ratios for arsenic and nickel rarely exceeded one, indicating that these metals represent minor concerns with respect to sediment contamination. Chromium and copper were enriched at 90 and 122 sites, respectively. For these two metals, the highest frequency of enrichment was observed on the Atlantic coast.

4.5 Assessment of the Potential for Biological Effects of Sediment-Associated Contaminants

The existing sediment chemistry data were used in conjunction with the recommended SQAGs to conduct an initial assessment of the potential for adverse biological effects in Florida coastal sediments. This assessment was conducted by screening the FDEP coastal sediment chemistry database (FDEP 1994) using the SQAGs. In this way, the sites with contaminant concentrations that exceeded the probable effects level and the threshold effects level, respectively, could be readily identified. The highest priority areas with respect to sediment contamination were identified as those with the greatest frequency of contaminant concentrations within the probable effects ranges. The highest priority substances with respect to sediment contamination were identified as those that frequently occurred at concentrations within the probable effects ranges. For metals, the areas and contaminants of greatest concern were those that had concentrations that were known to be anthropogenically enriched and that were likely to be associated with biological effects. Pooled data for a number of sampling stations and sampling dates were used to assess sediment quality within each geographic area.

4.5.1 Areas of Concern in Florida Coastal Waters

Chemical measurements in the FDEP database were organized into 20 general geographic areas in this initial assessment of sediment quality (Figure 7). Although evaluation of the database provides insight into sediment quality conditions at sites within these areas, this initial assessment is constrained by data limitations for some areas. For example, data on levels of metals were available for less than ten sites in the Jupiter, Ft. Lauderdale and Florida Keys areas. Even more severe limitations on the data were apparent when PAHs, PCBs, pesticides and other organic contaminants were considered (see Tables 4-7). In spite of these limitations, it is apparent that sediment quality represents a significant environmental concern in a number of locations within the state.

On the Atlantic coast (Table 4), coastal sediments in the vicinity of Miami had the highest frequency of contaminant concentrations within the **probable** effects ranges. Copper, lead, mercury, silver zinc, phenanthrene, chrysene, pyrene and total PCBs were all present at concentrations that are considered to represent significant hazards to aquatic organisms. In addition, several PAHs were present at levels in excess of their respective PELs in the Jacksonville and Daytona Beach areas; these included benz(a)anthracene, fluoranthene, phenanthrene, and pyrene. Concentrations of several metals also fell within the probable effects range in the Jacksonville and Indian River areas.

All of the Atlantic coastal areas surveyed, with the exception of the Jupiter area, had concentrations of one or more contaminants that fell within the **possible** effects range (Table 5). The greatest number of exceedances were observed in the Miami area, reflecting both the degree of contamination and the total number of samples collected within the area. Metals appear to represent the greatest hazard to aquatic organisms on the Atlantic coast of Florida; however, PAHs and PCBs have also been detected at levels of concern in many areas. Elevated levels of two DDT degradation products (i.e., DDD and DDE) were recorded in the Ft. Lauderdale area. The total number of samples and the number of exceedances of the SQAGs for each area on the Atlantic coast are presented in Tables 4 and 5.

Coastal sediments in the Gulf of Mexico appeared to be somewhat less contaminated than sediments on the Atlantic coast of Florida (Table 6). The greatest frequency of exceedance within the **probable** effects range occurred in Tampa Bay, with arsenic, cadmium, copper, chromium, lead, and zinc being the principal contaminants of concern in this area. Several other sampling programs have indicated that PAHs and pesticides are present at levels of concern in Tampa Bay, however (Long and Morgan 1990; E. Long. NOAA. Seattle, Washington. Personal communication). Elevated levels of several metals (i.e., ≥ PEL) have also been observed in Pensacola Bay and the Panama City area. Pensacola Bay also had multiple exceedances of the SQAGs for several PAHs, including benz(a)anthracene, fluoranthene, and pyrene. While concentrations of organic contaminants rarely fell within the probable effects ranges along the Gulf coast, this region has been only infrequently sampled for this class of analytes.

All of the areas surveyed along the Gulf coast had concentrations of four or more contaminants that fell within the **possible** effects ranges (Table 7). The greatest number of observations within the possible effects ranges occurred in Tampa Bay; this reflects the level of sampling effort that has been directed at this area, as well as the level of contamination. The other main areas of concern in terms of metals contamination are Pensacola Bay, Panama

Table 4. Number of samples that fall within the probable effects range (i.e., >= PEL) of contaminant concentrations for each Atlantic coast sampling area.

	Number of Observations Within the Probable Effects Range									
Substance	JAX	STA	DAY	IRS	JPT	WPB	FTL	MIA	KEY	Total
Metals										
Arsenic	**2**	**1**	0	0	0	0	0	0	0	**3**
Cadmium	0	0	0	0	0	0	0	**2**	0	**2**
Chromium	**1**	0	0	**1**	0	0	0	**2**	0	**4**
Copper	0	0	0	0	0	0	0	**14**	0	**14**
Lead	0	0	0	0	0	0	0	**21**	0	**21**
Mercury	**1**	0	0	**4**	0	**1**	**1**	**29**	0	**36**
Nickel	**1**	0	0	0	0	0	0	0	0	**1**
Silver	**3**	0	0	**3**	0	0	0	**11**	0	**17**
Zinc	0	0	0	0	0	0	0	**9**	0	**9**
Number of Samples	68	37	31	86	7	27	5	110	4	375
Polycyclic Aromatic Hydrocarbons (PAHs)										
Acenaphthene	**9**	0	0	0	0	0	0	**1**	0	**10**
Acenaphthylene	**1**	0	0	0	0	0	0	**1**	0	**2**
Anthracene	**1**	0	0	0	0	0	0	**3**	0	**4**
Benz(a)anthracene	0	0	0	0	0	0	**1**	**7**	0	**8**
Benzo(a)pyrene	**4**	0	0	0	0	0	0	**5**	0	**9**
Chrysene	0	0	0	0	0	0	0	**15**	0	**15**
Dibenzo(a,h)anthracene	**1**	0	0	0	0	**1**	0	0	0	**2**
Fluoranthene	**3**	0	**3**	0	0	0	0	**9**	0	**15**
Fluorene	**2**	0	0	0	0	0	0	0	0	**2**
2-methylnaphthalene	0	0	0	0	0	0	0	0	0	**0**
Naphthalene	0	0	0	0	0	0	0	**2**	0	**2**
Phenanthrene	**2**	0	**4**	0	0	0	0	**10**	0	**16**
Pyrene	**4**	0	**1**	0	0	0	0	**10**	0	**15**
Number of Samples	34	2	6	7	0	6	4	66	0	125

Table 4. Number of samples that fall within the probable effects range (i.e., >= PEL) of contaminant concentrations for each Atlantic coast sampling area (continued).

	Number of Observations Within the Probable Effects Range									
Substance	JAX	STA	DAY	IRS	JPT	WPB	FTL	MIA	KEY	Total
Pesticides										
Aldrin	NG	NG	NG	NG	NG	NG	NG	NG	NG	NG
Azinophosmethyl (Guthion)	NG	NG	NG	NG	NG	NG	NG	NG	NG	NG
Chlordane	**2**	0	0	0	0	0	0	**3**	0	**5**
Chlorthalonil	NG	NG	NG	NG	NG	NG	NG	NG	NG	NG
Chlorpyrifos	NG	NG	NG	NG	NG	NG	NG	NG	NG	NG
p,p'-DDD	0	0	0	0	0	0	**1**	0	0	**1**
p,p'-DDE	0	0	0	0	0	0	0	0	0	**0**
p,p'-DDT	0	0	0	0	0	0	**1**	**3**	0	**4**
Dieldrin	0	0	0	0	0	0	0	0	0	**0**
Disulfoton	NG	NG	NG	NG	NG	NG	NG	NG	NG	NG
Endosulfan	NG	NG	NG	NG	NG	NG	NG	NG	NG	NG
Heptachlor	NG	NG	NG	NG	NG	NG	NG	NG	NG	NG
Heptachlor epoxide	NG	NG	NG	NG	NG	NG	NG	NG	NG	NG
Lindane (gamma-BHC)	0	0	0	0	0	0	0	0	0	**0**
Phorate	NG	NG	NG	NG	NG	NG	NG	NG	NG	NG
Quintozene (PCNB)	NG	NG	NG	NG	NG	NG	NG	NG	NG	NG
Toxaphene (alpha-BHC)	NG	NG	NG	NG	NG	NG	NG	NG	NG	NG
Trifluralin	NG	NG	NG	NG	NG	NG	NG	NG	NG	NG
Number of Samples	47	3	6	21	0	11	5	78	0	171
Polychlorinated Biphenyls (PCBs)										
Total PCBs	0	0	0	0	0	0	0	**7**	0	**7**
Number of Samples	47	3	6	21	0	11	5	78	0	171

NG = no guideline; insufficient data to derive sediment assessment quality guidelines.
Place names indicate the general coastal vicinity of sampling station locations.
JAX = Jacksonville; STA = St. Augustine; DAY = Daytona Beach; IRS = Indian River; JPT = Jupiter; WPB = West Palm Beach; FTL = Ft. Lauderdale; MIA = Miami; KEY = Florida Keys.

Table 5. Number of samples that fall within the possible effects range (i.e., > TEL and < PEL) of contaminant concentrations for each Atlantic coast sampling area.

	Number of Observations Within the Possible Effects Range									
Substance	JAX	STA	DAY	IRS	JPT	WPB	FTL	MIA	KEY	Total
Metals										
Arsenic	**17**	**14**	**9**	**8**	0	**2**	0	**16**	0	**66**
Cadmium	**15**	0	**2**	**13**	0	**1**	0	**26**	0	**57**
Chromium	**7**	**8**	**1**	**14**	0	0	0	**31**	0	**61**
Copper	**27**	**9**	**12**	**23**	0	**1**	**2**	**23**	0	**97**
Lead	**22**	0	**1**	**12**	0	**2**	**2**	**19**	0	**58**
Mercury	**33**	**1**	**6**	**15**	0	**6**	**1**	**32**	**4**	**98**
Nickel	**7**	**5**	0	**7**	0	**1**	0	**1**	0	**21**
Silver	**2**	0	0	**2**	0	0	0	**6**	0	**10**
Zinc	**9**	0	**1**	**8**	0	0	0	**10**	0	**28**
Number of Samples	68	37	31	86	7	27	5	110	4	375
Polycyclic Aromatic Hydrocarbons (PAHs)										
Acenaphthene	**3**	0	0	0	0	0	0	0	0	**3**
Acenaphthylene	**1**	0	0	0	0	0	0	0	0	**1**
Anthracene	**6**	0	0	0	0	**1**	**2**	**4**	0	**13**
Benz(a)anthracene	0	0	0	0	0	0	0	0	0	**0**
Benzo(a)pyrene	**4**	0	0	0	0	**3**	**1**	**9**	0	**17**
Chrysene	**7**	0	0	0	0	0	**1**	**6**	0	**14**
Dibenzo(a,h)anthracene	0	0	0	0	0	0	0	0	0	**0**
Fluoranthene	**16**	**2**	**3**	0	0	**6**	**1**	**25**	0	**53**
Fluorene	**2**	0	0	0	0	0	**1**	0	0	**3**
2-methylnaphthalene	0	0	0	0	0	**1**	0	0	0	**1**
Naphthalene	**6**	0	0	0	0	**1**	0	0	0	**7**
Phenanthrene	**1**	**2**	**2**	0	0	0	0	**5**	0	**10**
Pyrene	**12**	0	**2**	0	0	**3**	**2**	**19**	0	**38**
Number of Samples	34	2	6	7	0	6	4	66	0	125

Table 5. Number of samples that fall within the possible effects range (i.e., > TEL and < PEL) of contaminant concentrations for each Atlantic coast sampling area (continued).

	Number of Observations Within the Possible Effects Range									
Substance	JAX	STA	DAY	IRS	JPT	WPB	FTL	MIA	KEY	Total
Pesticides										
Aldrin	NG	NG	NG	NG	NG	NG	NG	NG	NG	NG
Azinophosmethyl (Guthion)	NG	NG	NG	NG	NG	NG	NG	NG	NG	NG
Chlordane	0	0	0	0	0	0	0	0	0	**0**
Chlorthalonil	NG	NG	NG	NG	NG	NG	NG	NG	NG	NG
Chlorpyrifos	NG	NG	NG	NG	NG	NG	NG	NG	NG	NG
p,p'-DDD	0	0	0	0	0	0	**2**	0	0	**2**
p,p'-DDE	0	0	0	0	0	0	**3**	0	0	**3**
p,p'-DDT	0	0	0	0	0	0	0	0	0	**0**
Dieldrin	0	0	0	0	0	0	0	0	0	**0**
Disulfoton	NG	NG	NG	NG	NG	NG	NG	NG	NG	NG
Endosulfan	NG	NG	NG	NG	NG	NG	NG	NG	NG	NG
Heptachlor	NG	NG	NG	NG	NG	NG	NG	NG	NG	NG
Heptachlor epoxide	NG	NG	NG	NG	NG	NG	NG	NG	NG	NG
Lindane (gamma-BHC)	0	0	0	0	0	0	0	0	0	**0**
Phorate	NG	NG	NG	NG	NG	NG	NG	NG	NG	NG
Quintozene (PCNB)	NG	NG	NG	NG	NG	NG	NG	NG	NG	NG
Toxaphene (alpha-BHC)	NG	NG	NG	NG	NG	NG	NG	NG	NG	NG
Trifluralin	NG	NG	NG	NG	NG	NG	NG	NG	NG	NG
Number of Samples	47	3	6	21	0	11	5	78	0	171
Polychlorinated Biphenyls (PCBs)										
Total PCBs	**2**	0	**4**	0	0	0	0	**6**	0	**12**
Number of Samples	47	3	6	21	0	11	5	78	0	171

NG = no guideline; insufficient data to derive sediment quality assessment guidelines.
Place names indicate the general coastal vicinity of sampling station locations.
JAX = Jacksonville; STA = St. Augustine; DAY = Daytona Beach; IRS = Indian River; JPT = Jupiter; WPB = West Palm Beach; FTL = Ft. Lauderdale; MIA = Miami; KEY = Florida Keys.

Table 6. Number of samples that fall within the probable effects range (i.e., >= PEL) of contaminant concentrations for each Gulf coast sampling area.

	Number of Observations Within the Probable Effects Range											
Substance	EVG	FTM	TPA	WCF	APL	APA	SJB	PCY	DES	PEN	PER	Total
Metals												
Arsenic	0	0	**9**	**1**	0	**1**	0	0	0	**1**	0	**12**
Cadmium	0	0	**2**	0	0	0	0	0	0	**1**	0	**3**
Chromium	0	**1**	**13**	**1**	0	0	0	0	0	**8**	**2**	**25**
Copper	0	0	**3**	**1**	0	0	0	**2**	0	**1**	0	**7**
Lead	0	0	**7**	0	0	0	0	0	0	**2**	0	**9**
Mercury	0	0	**6**	**1**	0	0	**1**	**1**	0	**4**	0	**13**
Nickel	0	0	**1**	0	0	0	0	0	0	0	0	**1**
Silver	0	0	0	0	**1**	0	0	0	**1**	0	0	**2**
Zinc	0	0	**4**	0	0	0	0	0	0	**4**	0	**8**
Number of Samples	96	67	141	30	56	30	22	39	20	79	17	597
Polycyclic Aromatic Hydrocarbons (PAHs)												
Acenaphthene	0	0	0	0	0	0	0	0	0	**1**	**1**	**2**
Acenaphthylene	0	0	0	0	0	0	0	0	0	0	0	**0**
Anthracene	0	0	0	0	0	0	0	0	0	**1**	0	**1**
Benz(a)anthracene	0	0	0	0	0	0	0	0	0	**5**	0	**5**
Benzo(a)pyrene	0	0	0	0	0	0	0	0	0	**2**	**1**	**3**
Chrysene	0	0	0	0	0	0	0	0	0	0	0	**0**
Dibenzo(a,h)anthracene	0	0	0	0	0	0	0	0	0	0	0	**0**
Fluoranthene	0	0	0	0	0	0	0	0	0	**3**	0	**3**
Fluorene	0	0	0	0	0	0	0	0	0	0	0	**0**
2-methylnaphthalene	0	0	0	0	0	0	0	0	0	0	0	**0**
Naphthalene	0	0	0	0	0	0	0	0	0	0	0	**0**
Phenanthrene	0	0	0	0	0	0	0	0	0	**2**	0	**2**
Pyrene	0	0	0	0	0	0	0	0	**1**	**7**	**2**	**10**
Number of Samples	3	12	11	0	0	0	0	0	3	29	9	67

Table 6. Number of samples that fall within the probable effects range (i.e., >= PEL) of contaminant concentrations for each Gulf coast sampling area (continued).

Substance	Number of Observations Within the Probable Effects Range											
	EVG	FTM	TPA	WCF	APL	APA	SJB	PCY	DES	PEN	PER	Total
Pesticides												
Aldrin	NG	NG	NG	NG	NG	NG	NG	NG	NG	NG	NG	NG
Azinophosmethyl (Guthion)	NG	NG	NG	NG	NG	NG	NG	NG	NG	NG	NG	NG
Chlordane	0	0	0	0	0	0	0	0	0	**1**	0	**1**
Chlorthalonil	NG	NG	NG	NG	NG	NG	NG	NG	NG	NG	NG	NG
Chlorpyrifos	NG	NG	NG	NG	NG	NG	NG	NG	NG	NG	NG	NG
p,p'-DDD	0	0	0	0	0	0	0	0	0	0	0	**0**
p,p'-DDE	0	0	0	0	0	0	0	0	0	0	0	**0**
p,p'-DDT	0	0	0	0	0	0	0	0	0	0	0	**0**
Dieldrin	0	0	0	0	0	0	0	0	0	0	0	**0**
Disulfoton	NG	NG	NG	NG	NG	NG	NG	NG	NG	NG	NG	NG
Endosulfan	NG	NG	NG	NG	NG	NG	NG	NG	NG	NG	NG	NG
Heptachlor	NG	NG	NG	NG	NG	NG	NG	NG	NG	NG	NG	NG
Heptachlor epoxide	NG	NG	NG	NG	NG	NG	NG	NG	NG	NG	NG	NG
Lindane (gamma-BHC)	0	0	0	0	0	0	0	0	0	0	0	**0**
Phorate	NG	NG	NG	NG	NG	NG	NG	NG	NG	NG	NG	NG
Quintozene (PCNB)	NG	NG	NG	NG	NG	NG	NG	NG	NG	NG	NG	NG
Toxaphene (alpha-BHC)	NG	NG	NG	NG	NG	NG	NG	NG	NG	NG	NG	NG
Trifluralin	NG	NG	NG	NG	NG	NG	NG	NG	NG	NG	NG	NG
Number of Samples	3	8	24	0	0	0	5	3	3	29	7	82
Polychlorinated Biphenyls (PCBs)												
Total PCBs	0	0	0	0	0	0	0	0	0	0	0	**0**
Number of Samples	3	8	24	0	0	0	5	3	3	29	7	82

NG = no guideline; insufficient data to derive sediment quality assesment guidelines.

Place names indicate the general coastal vicinity of sampling station locations.

EVG = Everglades; FTM = Ft. Mayers; TPA = Tampa Bay; WCF = West Central Florida; APL = Apalachee Bay; APA = Apalachichola Bay; STJ = St. Josephs Bay; PCY = Panama City; DES = Destin; PEN = Pensacola Bay; PER = Perido Bay.

Table 7. Number of samples that fall within the possible effects range (i.e., > TEL and < PEL) of contaminant concentrations for each Gulf coast sampling area.

	Number of Observations Within the Possible Effects Range											
Substance	EVG	FTM	TPA	WCF	APL	APA	SJB	PCY	DES	PEN	PER	Total
Metals												
Arsenic	**7**	**1**	**16**	**3**	**6**	**7**	**5**	**11**	**4**	**20**	**8**	**88**
Cadmium	0	**3**	**51**	**4**	**2**	0	**3**	**3**	**1**	**6**	**2**	**75**
Chromium	**1**	**1**	**35**	**8**	**2**	**5**	**7**	**10**	**4**	**20**	**2**	**95**
Copper	**1**	**3**	**33**	**10**	0	**5**	**5**	**4**	**3**	**16**	**3**	**83**
Lead	0	**2**	**26**	**1**	0	**4**	**3**	**5**	**3**	**9**	**2**	**55**
Mercury	**2**	**6**	**43**	**5**	**3**	0	**6**	**5**	**1**	**15**	**3**	**89**
Nickel	**1**	0	**20**	**2**	0	**6**	**5**	**7**	**2**	**4**	**2**	**49**
Silver	0	0	**14**	0	0	0	0	**6**	**1**	0	0	**21**
Zinc	0	**1**	**18**	**1**	0	0	0	**1**	**1**	**14**	**1**	**37**
Total Number of Samples	96	67	141	30	56	30	22	39	20	79	17	597
Polycyclic Aromatic Hydrocarbons (PAHs)												
Acenaphthene	0	0	0	0	0	0	0	0	0	0	0	**0**
Acenaphthylene	0	0	0	0	0	0	0	0	0	0	0	**0**
Anthracene	0	0	0	0	0	0	0	0	0	**4**	0	**4**
Benz(a)anthracene	0	0	0	0	0	0	0	0	0	0	0	**0**
Benzo(a)pyrene	0	0	0	0	0	0	0	0	0	**12**	**2**	**14**
Chrysene	0	0	0	0	0	0	0	0	0	**1**	**5**	**6**
Dibenzo(a,h)anthracene	0	0	0	0	0	0	0	0	0	0	0	**0**
Fluoranthene	0	0	0	0	0	0	0	0	0	**10**	**4**	**14**
Fluorene	0	0	0	0	0	0	0	0	0	0	0	**0**
2-methylnaphthalene	0	0	0	0	0	0	0	0	0	0	0	**0**
Naphthalene	0	0	0	0	0	0	0	0	0	**1**	**1**	**2**
Phenanthrene	0	0	0	0	0	0	0	0	0	**8**	**2**	**10**
Pyrene	0	0	0	0	0	0	0	0	0	**10**	**4**	**14**
Total Number of Samples	3	12	11	0	0	0	0	0	3	29	9	67

Table 7. Number of samples that fall within the possible effects range (i.e., > TEL and < PEL) of contaminant concentrations for each Gulf coast sampling area (continued).

	Number of Observations Within the Possible Effects Range											
Substance	EVG	FTM	TPA	WCF	APL	APA	SJB	PCY	DES	PEN	PER	Total
Pesticides												
Aldrin	NG	NG	NG	NG	NG	NG	NG	NG	NG	NG	NG	NG
Azinophosmethyl (Guthion)	NG	NG	NG	NG	NG	NG	NG	NG	NG	NG	NG	NG
Chlordane	0	0	0	0	0	0	0	0	0	0	0	**0**
Chlorthalonil	NG	NG	NG	NG	NG	NG	NG	NG	NG	NG	NG	NG
Chlorpyrifos	NG	NG	NG	NG	NG	NG	NG	NG	NG	NG	NG	NG
p,p'-DDD	0	0	0	0	0	0	0	0	0	0	0	**0**
p,p'-DDE	0	0	0	0	0	0	0	0	0	0	0	**0**
p,p'-DDT	0	0	0	0	0	0	0	0	0	**2**	0	**2**
Dieldrin	0	0	0	0	0	0	0	0	0	0	0	**0**
Disulfoton	NG	NG	NG	NG	NG	NG	NG	NG	NG	NG	NG	NG
Endosulfan	NG	NG	NG	NG	NG	NG	NG	NG	NG	NG	NG	NG
Heptachlor	NG	NG	NG	NG	NG	NG	NG	NG	NG	NG	NG	NG
Heptachlor epoxide	NG	NG	NG	NG	NG	NG	NG	NG	NG	NG	NG	NG
Lindane (gamma-BHC)	0	0	0	0	0	0	0	0	0	0	0	**0**
Phorate	NG	NG	NG	NG	NG	NG	NG	NG	NG	NG	NG	NG
Quintozene (PCNB)	NG	NG	NG	NG	NG	NG	NG	NG	NG	NG	NG	NG
Toxaphene (alpha-BHC)	NG	NG	NG	NG	NG	NG	NG	NG	NG	NG	NG	NG
Trifluralin	NG	NG	NG	NG	NG	NG	NG	NG	NG	NG	NG	NG
Total Number of Samples	3	8	24	0	0	0	5	3	3	29	7	82
Polychlorinated Biphenyls (PCBs)												
Total PCBs	0	**2**	0	0	0	0	0	0	0	**6**	0	**8**
Total Number of Samples	3	8	24	0	0	0	5	3	3	29	7	82

NG = no guideline; insufficient data to derive sediment quality assessment guidelines.

Place names indicate the general coastal vicinity of sampling station locations.

EVG = Everglades; FTM = Ft. Mayers; TPA = Tampa Bay; WCF = West Central Florida; APL = Apalachee Bay; APA = Apalachichola Bay; STJ = St. Josephs Bay; PCY = Panama City; DES = Destin; PEN = Pensacola Bay; PER = Perido Bay.

City, Perdido Bay, and West Central Florida. Elevated levels of PAHs and PCBs were also observed in Pensacola Bay and Perdido Bay. Significantly more sampling effort is required to fully evaluate contamination of coastal sediments by organic substances in the Gulf of Mexico region of Florida. The total number of samples and the number of exceedances of the SQAGs for each area on the Gulf coast are presented in Tables 6 and 7.

4.5.2 Contaminants of Concern in Florida Coastal Waters

The contaminants of greatest concern in Florida coastal waters were identified by screening the data in the FDEP (1994) coastal sediment chemistry database with the SQAGs recommended by MacDonald (1994). For each substance, the percent of the total number of samples that had concentrations that fell within the probable (i.e., ≥ PEL) and possible (i.e., ≥ TEL and < PEL) effects ranges was calculated. Contaminants with concentrations that equalled or exceeded the PEL in many samples (i.e., 5%) were considered to be of greatest concern. The contaminants which had a high incidence (i.e., ≥ 10%) of concentrations within the possible effects range and one or more exceedance of the PEL were considered to be of somewhat lower priority (Table 8).

On the Atlantic coast, lead, mercury, acenaphthene, benz(a)anthracene, benzo(a)pyrene, chrysene, fluoranthene, phenanthrene, and pyrene were considered to be the highest priority contaminants. In general, the PAHs had the highest percent incidence of concentrations within the probable effects range. Arsenic, cadmium, chromium, copper, and anthracene were also considered to be contaminants of concern, albeit of lower priority than the substances listed above.

Elevated levels of toxic substances were somewhat less common on the Gulf coast of Florida than on the Atlantic coast. Only two substances had a high incidence of concentrations within the probable effects range, benz(a)anthracene and pyrene. The lower priority contaminants of concern included arsenic, cadmium, chromium, copper, mercury, chrysene, fluoranthene, phenanthrene, and total PCBs. It was not possible to evaluate the relative importance of the 17 preliminary contaminants of concern (see MacDonald 1994) for which SQAGs were not available.

4.6 Summary

The initial assessment of the potential for observing adverse biological effects has been conducted to identify areas and contaminants of concern in Florida coastal sediments. The results of this evaluation suggest that the areas in the vicinity of Miami, Jacksonville, Tampa, and Pensacola should be considered to be the highest priority for conducting further

Table 8. Percent of sediment quality samples with contaminant concentrations that exceed the sediment quality assessment guidelines.

Substance	Atlantic Coast >= PEL (%)	Atlantic Coast >=TEL; <PEL (%)	Gulf Coast >= PEL (%)	Gulf Coast >=TEL; <PEL (%)
Metals				
Arsenic	0.8	17.6	2	14.7
Cadmium	0.5	15.2	0.5	12.6
Chromium	1	16.3	4.2	15.9
Copper	3.7	25.9	1.1	13.9
Lead	5.6	15.5	1.5	9.2
Mercury	9.6	26.1	2.2	14.9
Nickel	0.3	5.6	0.2	8.2
Silver	4.5	2.7	0.3	3.5
Zinc	2.4	7.5	1.3	6.2
Polycyclic Aromatic Hydrocarbons (PAHs)				
Acenaphthene	8	2.4	3	0
Acenaphthylene	1.6	0.8	0	0
Anthracene	3.2	10.4	1.5	6
Benz(a)anthracene	6.4	0	8.9	0
Benzo(a)pyrene	7.2	13.6	4.5	20.9
Chrysene	12	11.2	0	23.9
Dibenzo(a,h)anthracene	1.6	0	0	0
Fluoranthene	12	42.4	4.5	20.9
Fluorene	1.6	2.4	0	0
2-methylnaphthalene	0	0.8	0	0
Naphthalene	1.6	5.6	0	3
Phenanthrene	12.8	8	3	14.9
Pyrene	12	30.4	14.9	20.9

Table 8. Percent of sediment quality samples with contaminant concentrations that exceed the sediment quality assessment guidelines (continued).

Substance	Atlantic Coast		Gulf Coast	
	>= PEL (%)	>=TEL; <PEL (%)	>= PEL (%)	>=TEL; <PEL (%)
Pesticides				
Chlordane	2.9	0	1.3	0
p,p'-DDD	0.6	1.2	0	0
p,p'-DDE	0	1.8	0	0
p,p'-DDT	2.3	0	0	2.5
Total DDE	0	0	0	0
Lindane (gamma-BHC)				
Polychlorinated Biphenyls (PCBs)				
Total PCBs	4.1	8.2	0	10

PEL = Probable Effect Level; TEL = Threshold Effect Level investigations, including bioassessments. As surveys have recently been completed in Tampa Bay and Pensacola Bay, the highest priority areas for new studies are Biscayne Bay and the St. Johns River. Overall, benzo(a)pyrene and pyrene are considered to be the highest priority contaminants; however, lead, mercury, acenaphthene, benz(a)anthracene, chrysene, fluoranthene, and phenanthrene are important on the Atlantic coast. Interestingly, the levels of arsenic at several sites exceed the PELs, yet are not anthropogenically-enriched.

While this initial assessment of sediment quality provides an indication of the potential for biological effects of sediment-associated contaminants, these results should not be used, by themselves, to make management decisions regarding sediment quality. Several limitations of this assessment are identified to emphasize this point. The sediment chemistry database used in this assessment has broad coverage; however, the data on many analytes are limited. As such, several of the constituents that are likely to be found in Florida sediments were not measured in the FDEP surveys. Much of the data on levels of organic contaminants is relatively old (greater than 5 years old) and, therefore, of questionable value with respect to reflecting present conditions. In addition, the extent to which the available data accurately reflect the spatial variability in sediment quality conditions is largely unknown. For these reasons, comparable data collected by others such as the EPA Environmental Monitoring and Assessment Program (EMAP), Delfino *et al.* (1991), and by NOAA (NSTP) should be evaluated to provide a more comprehensive assessment of sediment quality.

For metals, the results of the assessment of the potential for biological effects must be considered in light of the evaluation of the probable origin of these substances. In general, there was a high degree of agreement between the evaluations conducted using the SQAGs and the metals interpretive tool. Significant anthropogenic-enrichment was observed in association with exceedance of the PELs for most chemicals and at most sites. Therefore, the results of the evaluation of areas of concern and contaminants of concern conducted using the PELs can be considered to be reliable. However, poor concordance between the two evaluations was observed for arsenic. Only two of the 15 sites with arsenic concentrations greater than the PEL were anthropogenically enriched. Therefore, arsenic should not be considered as a contaminant of high concern in Florida. In addition, high background levels of several metals in West Central Florida and nearby Panama City are indicated by the exceedances of PELs, but not the 95% prediction limits. Therefore, these areas should not be considered to be high priority areas of concern, based on metal concentrations alone.

Chapter 5

Recommendations

5.1 Recommendations

The following recommendations are offered to assist the FDEP in identifying priorities for supporting the application of the SQAGs. General recommendations for improving the technical soundness of the SQAGs are identified in Volume 1 (MacDonald 1994).

5.1.1 Applications of the Sediment Quality Assessment Guidelines

The recommended SQAGs represent powerful tools for assessing sediment quality in a number of applications in Florida. However, further guidance is required to define the role of the SQAGs in several, high priority applications. Specifically, a detailed Users Manual is required to describe how the SQAGs should be used in various state programs. In addition, guidance is needed on the derivation of site-specific sediment quality remediation objectives (i.e., target cleanup levels) at contaminated sites. Furthermore, procedures for conducting ecological risk assessments at sites with contaminated sediments should be developed. Lastly, seminars or workshops to provide assistance to SQAG users should be conducted to ensure that these management tools are used appropriately in Florida.

5.1.2 Site-Specific Assessment of Sediment Quality

The recommended approach for assessing sediment quality in Florida is based on the identification of three ranges of contaminant concentrations: the minimal effects range; the possible effects range; and, the probable effects range. This approach was selected to explicitly account for uncertainties associated with evaluating the available data linking contaminant concentrations with adverse biological effects. When contaminant concentrations fall within the probable effects range at a particular site, there is a high probability that adverse biological effects will be observed. These sites should be given highest priority for further investigations.

Effects-based SQAGs should not be used alone to make contaminated sediment management decisions. Ancillary tools, such as the FDEP metals interpretive tool (Schropp and Windom 1988), should be used to determine the probable origin of sediment-associated contaminants. In addition, uncertainty regarding the potential for biological effects of sediment-associated contaminants at specific locations should be addressed by implementing appropriate biological investigations. These tools, when used together, will provide an efficient and effective basis for making contaminated sediment management decisions.

5.1.3 Regional Assessment of Sediment Quality

The initial assessment of Florida coastal sediments provides a basis for identifying priority areas and contaminants for consideration in further investigations. However, the initial assessment is considered to be preliminary because it is based on data generated in FDEP coastal contaminants surveys, which have several limitations. First, insufficient data were available to conduct a reliable assessment in many areas of the state. Second, only limited data are available on levels of organic contaminants in most areas of Florida. Third, much of the available data on levels of metals and organic contaminants are several years old and may not accurately reflect present conditions. Nonetheless, this assessment emphasizes the urgent need to conduct further investigations, including biological tests, in the vicinity of Miami. Additional surveys may also be needed in the Jacksonville and West Palm Beach areas to assess sediment quality and evaluate the predictability of the SQAGs.

A list of priority contaminants in coastal sediments was developed from existing sediment quality data and information on land and water use patterns in Florida. However, insufficient information currently exists to determine the distribution of many of these contaminants in Florida sediments. Therefore, an expanded suite of analytes (to reflect contaminant inputs) should be incorporated into site-specific sediment quality monitoring programs. Such programs should be expanded to include the persistent pesticides that are used or have been used in an area, as well as the specific industrial chemicals that are present in wastewater effluents.

As mentioned elsewhere in this document, SQAGs alone are not adequate to reliably predict biological effects in contaminated sediments. At some sites, unmeasured contaminants may represent significant concerns with respect to evaluating potential biological effects. This is especially true when available sediment chemistry data do not adequately reflect the likely sources of contaminants. In these situations, additional chemical and biological testing may be required to resolve uncertainties over the potential for biological effects. In addition, further field studies are required to evaluate the applicability of the SQAGs for arsenic, which are exceeded in a number of sites that are not anthropogenically-enriched.

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