Development and Evaluation of Numerical Sediment Quality Assessment Guidelines for Florida Inland Waters

Technical Report

Prepared for:

Florida Department of Environmental Protection
Twin Towers Office Building
2600 Blair Stone Road
Tallahassee, Florida 32399-2400

Prepared – January 2003 – by:

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United States Geological Survey
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List of Acronyms

:g/kg OC	micrograms per kilogram organic carbon
%OC	percent organic carbon
AETA	Apparent Effects Threshold Approach
AVS	acid volatile sulfide
BEDS	Biological Effects Database for Sediments
BEHP	bis(2-ethyl hexyl)phthalate
BSAFs	sediment-to-biota bioaccumulation factors
CA	Consensus Approach
COPCs	chemicals of potential concern
CWA	Clean Water Act
-d	- day
DQOs	data quality objectives
DW	dry weight
ELA	Effects Level Approach
EqPA	Equilibrium Partitioning Approach
ERA	Effects Range Approach
ERL	effects range-low
ERM	effects range-median
ESGs	equilibrium-based sediment guidelines
FCVs	final chronic values
FDEP	Florida Department of Environmental Protection
FGS	Florida Geological Survey
f_{oc}	fraction organic carbon
HCB	hexachlorobenzene
HCBC	hexachlorobutadiene
HCH	hexachlorocyclohexane
K_{oc}	partition coefficient for sediment organic carbon
K_{ow}	octanol-water partition coefficient
Kp	partition coefficients
LELs	Lowest effects levels
LRMA	Logistic Regression Modeling Approach
"Mean-MPP (or)"	mean-metals or PAHs or PCBs
MESL	MacDonald Environmental Sciences Ltd.
METs	moderate effects threshold
NECs	no effect concentrations or
NPDES	National Pollutant Discharge Elimination System
OC pesticides	organochlorine pesticides
PAETs	probable AETs
PAHs	polycyclic aromatic hydrocarbons
PCBs	polychlorinated biphenyls
PCDDs	polychlorinated dibenzo-*p*-dioxins
PCDFs	polychlorinated dibenzofurans

PEC-Qs	PEC-quotients
PECs	probable effect concentrations
PEL	probable effects level
PEL-HA	probable effects level-*Hyalella azteca*
SECs	sediment effect concentrations
SELs	severe effects levels
SEM	simultaneously extracted metals
SLC	screening level concentration
SLCA	Screening Level Concentration Approach
SQAG-Qs	SQAG-quotients
SQAGs	sediment quality guidelines
SQALs	sediment quality advisory levels
SQGs	sediment quality guidelines
SQROs	Sediment quality remediation objectives
SSLC	species screening level concentration
SVOCs	semi-volatile organic chemicals
T_{10}	10 percent probability of observing sediment toxicity
T_{50}	50 percent probability of observing sediment toxicity
T_{90}	90 percent probability of observing sediment toxicity
TECs	threshold effect concentrations
TEL	threshold effects level
TEL-HA	threshold effects level-*Hyalella azteca*
TETs	toxic effects threshold
TMDL	total maximum daily load
TOC	total organic carbon
TRA	tissue residue approach
TRA	Tissue residue approach
TRGs	tissue residue guidelines
TRGs	tissue residue guidelines
USEPA	United States Environmental Protection Agency
USFDA Action Levels	United States Food and Drug Administration Action Levels
USGS	United States Geological Survey
WS	whole sediment

Executive Summary

In response to the need for guidance on the assessment of sediment quality conditions in freshwater ecosystems, Florida Department of Environmental Protection (FDEP) and its partners launched the ***Freshwater Sediment Quality Assessment Initiative*** in early 2000. This initiative, which is being implemented cooperatively by FDEP, United States Geological Survey (USGS), United States Environmental Protection Agency (USEPA), county governments, and water management districts (see Acknowledgments for a list of cooperators), consists of three main elements, including:

- Formulation of an integrated framework for planning, designing, implementing, and interpreting the results of sediment quality investigations;
- Development of an interpretive tool for assessing metal enrichment in freshwater sediments; and,
- Establishment of numerical, sediment quality assessment guidelines (SQAGs) for assessing the potential for adverse biological effects associated with exposure to contaminated sediments.

Together, these three elements of the overall ***Freshwater Sediment Quality Assessment Initiative*** are intended to provide FDEP staff and others with the guidance needed to conduct sediment quality assessments and to support defensible sediment management decisions.

This report, which addresses the third element of the initiative, describes the development and evaluation of numerical SQAGs that are intended to support the assessments of sediment quality conditions in Florida inland waters, including effects-based SQAGs and bioaccumulation-based SQAGs. The effects-based SQAGs are intended to provide a means of determining the concentrations of sediment-associated contaminants that are unlikely to be associated with adverse biological effects and those that are likely to be associated with sediment toxicity or other adverse effects on sediment-dwelling organisms. By comparison, the bioaccumulation-based SQAGs are intended to identify the concentrations of sediment-associated contaminants that are unlikely to be associated with adverse effects on aquatic-dependent wildlife and/or human health.

To support the identification of interests and needs related to the assessment of contaminated sediments in Florida inland waters, FDEP convened a workshop in 2000 (MacDonald 2000). Based on input provided by workshop participants, the potential for adverse effects on sediment-dwelling organisms, aquatic-dependent wildlife, and human health represent the principal concern relative to contaminated sediments. In addition to identifying sediment quality issues and concerns, workshop participants also identified the toxic and bioaccumulative chemicals of potential concern (COPCs) for which numerical SQAGs are required to support sediment quality assessments in the state. Metals, polycyclic aromatic hydrocarbons (PAHs), polychlorinated biphenyls (PCBs), chlorinated benzenes, phthalates, triazine herbicides, organophosphate pesticides, organochlorine pesticides (OC pesticides), and toxaphene were identified as the highest priority toxic substances that partition into sediments. The bioaccumulative substances of greatest concern included mercury, PAHs, PCBs, chlorinated benzenes, polychlorinated dibenzo-*p*-dioxins (PCDDs) and polychlorinated dibenzofurans (PCDFs), and OC pesticides.

A total of eight distinct approaches were reviewed and evaluated to support the establishment of numerical SQAGs for Florida inland waters. Both empirical and theoretical approaches were considered to support the derivation of numerical SQAGs for the protection of sediment-dwelling organisms, including: screening level concentration approach (SLCA); effects range approach (ERA); effects level approach (ELA); apparent effects threshold approach (AETA); equilibrium partitioning approach (EqPA); logistic regression modeling approach (LRMA); and, consensus approach (CA). Based on the results of this evaluation, it was recommended that guidelines developed using the consensus-based approach [i.e., the threshold effect concentrations (TECs) and probable effect concentrations (PECs)] be adopted as preliminary effects-based SQAGs for Florida inland waters (MacDonald *et al.* 2000a). For those substances for which consensus-based guidelines were not available, it was recommended that guidelines derived using other effects-based approaches be evaluated to select SQAGs that could be used on an interim basis in Florida. The tissue residue approach (TRA) was considered to be the most relevant method for deriving numerical SQAGs for the protection of wildlife and human health (i.e., for substances that bioaccumulate in the food web).

The evaluations that have been conducted to date demonstrate that the consensus-based guidelines provide reliable and predictive tools for assessing sediment quality conditions

(MacDonald *et al.* 2000a; Crane *et al.* 2000; USEPA 2000a; Ingersoll *et al.* 2001). While these results generate a high level of confidence in the consensus-based guidelines, a further evaluation of the predictive ability of these guidelines was conducted to assess their relevance in the southeastern portion of the United States. To support this evaluation, matching sediment chemistry and sediment toxicity data were assembled from diverse studies conducted throughout USEPA Regions III, IV, and VI. For each of the samples represented in the project database, mean PEC-quotients (PEC-Qs) were calculated. Subsequently, the incidence of toxicity (i.e., to amphipods, *Hyalella azteca*, and midges, *Chironomus tentans* and *Chironomus riparius*) within ranges of mean PEC-Qs was calculated and compared to the results obtained using the information contained in the national database (USEPA 2000a). Additionally, concentration-response relationships were developed using the regional database and compared to the relationships developed for the same test organisms and endpoints using the data contained in the national database. The results of these evaluations showed that systematic differences in the toxicity of sediment-associated COPCs (as expressed using mean PEC-Qs) do not exist between the regional and national data sets. Therefore, it was concluded that consensus-based guidelines are likely to represent relevant tools for assessing sediment quality conditions in Florida and should be adopted as the effects-based SQAGs.

Together, the effects-based and bioaccumulation-based SQAGs describe the conditions that need to be maintained in freshwater ecosystems to protect sediment-dwelling organisms, aquatic-dependent wildlife, and human health against the adverse effects associated with exposure to contaminated sediments. Using the recommended approach, effects-based SQAGs were recommended for a total of 29 COPCs in Florida inland waters. Interim SQAGs were recommended for another 20 COPCs, based on the effects-based guidelines that have been promulgated in other jurisdictions. Bioaccumulation-based SQAGs for the protection of aquatic-dependent wildlife were recommended for 11 COPCs, while SQAGs for the protection of human health were recommended for 52 COPCs in the state. Because it was not possible to establish SQAGs for all of the COPCs that were identified by workshop participants, narrative SQAGs were also recommended to support assessments of sediment quality conditions.

The numerical SQAGs are intended to provide science-based tools for assessing sediment quality conditions in Florida's freshwater ecosystems. To assist potential users of these tools, the recommended applications of the SQAGs were also described in this report. In total, five principal program applications were identified for the SQAGs, including: supporting monitoring and assessment initiatives; assessing and managing contaminated sites; restoring wetland habitats; assessing ecological risks; and, supporting environmental regulation programs. Although the potential uses of the SQAGs were explicitly described, it is important to note that the SQAGs should be used together with other assessment tools to support comprehensive assessments of sediment quality conditions. MacDonald and Ingersoll (2002a; 2002b) and Ingersoll and MacDonald (2002) describe the ecosystem-based framework for designing, conducting, and interpreting the results of sediment quality investigations.

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Chapter 1 Introduction

1.0 Background

Traditionally, management of aquatic resources in Florida has focused primarily on water quality. However, the importance of sediments in terms of determining the fate and effects of a wide variety of chemicals of potential concerns (COPCs) has become more apparent in recent years (MacDonald *et al.* 1996; Ingersoll *et al.* 1997). In addition to providing habitats for many organisms, sediments are important because many toxic substances that are found at only trace levels in water can accumulate to elevated levels in sediments. As such, sediments serve both as reservoirs and potential sources of COPCs to the water column. Sediment-associated COPCs have the potential to cause direct effects on sediment-dwelling organisms and to adversely affect wildlife and human health when these substances accumulate in the food web. Therefore, information on sediment quality conditions is essential for evaluating the overall status of freshwater ecosystems.

Florida Department of Environmental Protection (FDEP) plays a lead role in the assessment and management of aquatic resources in the state. To meet its responsibilities in terms of managing Florida's unique freshwater ecosystems, FDEP has developed a number of programs that enable it to effectively protect water quality and ensure proper waste management. Many of these programs have components that necessitate the assessment and management of sediment quality conditions, including:

- Watershed Monitoring;
- Environmental Resource Permitting;
- Everglades Ecosystem Restoration;
- Industrial Wastewater;
- Mine Reclamation;
- Nonpoint Source/Stormwater;
- Solid and Hazardous Waste;

- State Lands;
- Surface Water;
- Total Maximum Daily Loads; and,
- Waste Cleanup.

In response to the need for guidance on the assessment of sediment quality conditions in freshwater ecosystems, FDEP and its partners launched the ***Freshwater Sediment Quality Assessment Initiative*** in early 2000 (Appendix 1). This initiative, which is being implemented cooperatively by FDEP, United States Geological Survey (USGS), United States Environmental Protection Agency (USEPA), county governments, and water management districts, consists of three main elements, including:

- Formulation of an integrated framework for planning, designing, implementing, and interpreting the results of sediment quality investigations;
- Development of an interpretive tool for assessing metal enrichment in freshwater sediments; and,
- Establishment of numerical sediment quality assessment guidelines (SQAGs) for assessing the potential for adverse biological effects associated with exposure to contaminated sediments.

Together, these three elements of the overall ***Freshwater Sediment Quality Assessment Initiative*** are intended to provide FDEP staff and others with the guidance that is needed to conduct sediment quality assessments and to support defensible sediment management decisions.

1.1 Formulation of an Ecosystem-Based Framework for Assessing Contaminated Sediments

The first element of the ***Freshwater Sediment Quality Assessment Initiative*** involves the development of an integrated framework for assessing sediment quality conditions in Florida inland waters. In response to the need for such a framework, FDEP has formulated detailed guidance of the assessment of contaminated sediments. The resultant three-volume guidance manual provides:

- An ecosystem-based framework for assessing and managing contaminated sediments (Volume I; MacDonald and Ingersoll 2002a);
- Recommended procedures for designing and implementing sediment quality investigations (Volume II; MacDonald and Ingersoll 2002b); and,
- Recommended procedures for interpreting the results of sediment quality investigations (Volume III; Ingersoll and MacDonald 2002).

The first volume of the guidance manual, *An Ecosystem-based Framework for Assessing and Managing Contaminated Sediments in Freshwater Ecosystems* (MacDonald and Ingersoll 2002a), describes the five step process that is recommended to support the assessment and management of sediment quality conditions (i.e., relative to sediment-dwelling organisms, aquatic-dependent wildlife, and human health). Importantly, the document provides an overview of the framework for ecosystem-based sediment quality assessment and management. The recommended procedures for identifying sediment quality issues and concerns and compiling the existing knowledge base are also described. Furthermore, the recommended procedures for establishing ecosystem goals, ecosystem health objectives, and sediment management objectives are presented. Finally, methods for selecting ecosystem health indicators, metrics, and targets for assessing contaminated sediments are described. Together, this guidance is intended to support planning activities related to contaminated sediment assessments, such that the resultant data are likely to support sediment management decisions at the site under investigation.

The second volume of the series, *Design and Implementation of Sediment Quality Investigations* (MacDonald and Ingersoll 2002b), describes the recommended procedures for designing and implementing sediment quality assessment programs. More specifically, Volume II provides an overview of the recommended framework for assessing and managing sediment quality conditions. In addition, Volume II presents the recommended procedures for conducting preliminary and detailed site investigations to assess sediment quality conditions. Furthermore, the factors that need to be considered in the development of sampling and analysis plans for assessing contaminated sediments are described.

Supplemental guidance on the design of sediment sampling programs, on the evaluation of sediment quality data, and on the management of contaminated sediments is provided. The types and objectives of sediment quality assessments that are commonly conducted in freshwater ecosystems are also described.

The third volume in the series, *Interpretation of the Results of Sediment Quality Investigations* (Ingersoll and MacDonald 2002), describes the four types of information that are commonly used to assess contaminated sediments, including whole-sediment and pore-water chemistry data, whole-sediment toxicity data, benthic invertebrate community structure data, and bioaccumulation data. Some of the other tools that can be used to support assessments of sediment quality conditions are also described (e.g., fish health assessments). The information compiled on each of the tools includes: descriptions of its applications, advantages, and limitations; discussions on the availability of standard methods, evaluations of data quality and methodological uncertainty; interpretation of the associated data; and, recommendations to guide its use. Furthermore, guidance is provided on the interpretation of data on multiple indicators of sediment quality conditions. Together, the information provided in the three volume series is intended to further support the design and implementation of focused sediment quality assessment programs.

1.2 Development of a Metals Interpretive Tool

The development of an interpretive tool for assessing metal enrichment in Florida freshwater sediments was identified as a high priority element of the ***Freshwater Sediment Quality Assessment Initiative***. The metals interpretive tool is intended to provide users with a simple way to account for the natural variability of metal concentrations in Florida's freshwater ecosystems and to determine whether a sediment is enriched by metals. To support the development of such a tool, FDEP and its partners collected samples of lake, stream, and spring sediments at numerous uncontaminated sites throughout north and central Florida. In each of these sediment samples, the concentrations of metals were determined. Subsequently, the resultant data were evaluated and used to develop a metals interpretive tool for freshwater sediments.

The data on the concentrations of trace metals and candidate reference elements (i.e., aluminum, iron, magnesium) in uncontaminated lake, stream, and spring sediments were analyzed to support the development of a metals interpretive tool. A simple statistical approach was used to evaluate the data on metals concentrations, including assessment of the normality of the metals concentration data, identification and removal of outliers, and determination of relationships between each metal and candidate normalizers. More specifically, linear regressions and 95% prediction limits were used to describe the relationships between the concentrations of trace metals and candidate normalizers. The resultant 95% prediction limits establish the expected range of natural variation of metal concentrations in uncontaminated freshwater sediments (Carvalho and Schropp 2002).

Application of the freshwater metals interpretive tool is relatively straightforward. Specifically, users can compare the concentrations of metals in freshwater sediments at a new site (i.e., one that was not included in the database that was compiled to develop the metals interpretive tool) to the metal-reference element relationships that were established for uncontaminated sediments to determine if measured levels fall within the expected natural ranges. Metal enrichment is suspected when the measured concentrations of trace metals exceed the upper 95% prediction limits for uncontaminated sediments. The development and applications of the metals interpretive tool is described in a technical report prepared by Carvalho and Schropp (2002).

1.3 Establishment of Sediment Quality Assessment Guidelines

The third element of the ***Freshwater Sediment Quality Assessment Initiative*** involves the development and evaluation of numerical SQAGs for Florida inland waters, including effects-based SQAGs and bioaccumulation-based SQAGs. The effects-based SQAGs are intended to provide a means of determining the concentrations of sediment-associated contaminants that are unlikely to be associated with adverse biological effects and those that are likely to be associated with sediment toxicity or other adverse effects on sediment-dwelling organisms. By comparison, the bioaccumulation-based SQAGs are intended to identify the concentrations of sediment-associated contaminants that are unlikely to be associated with adverse effects on aquatic-dependent wildlife or human health.

The purpose of this report is to describe the process that was used to develop and evaluate SQAGs for freshwater ecosystems in Florida. More specifically, this report was prepared to provide background information on the assessment of contaminated sediments, to describe the approach to the establishment of numerical SQAGs, to evaluate the predictive ability of the SQAGs, and to recommend effects-based and bioaccumulation-based SQAGs for assessing sediment quality conditions in freshwater ecosystems. This report is also intended to provide a summary of program applications for the SQAGs and a series of recommendations for supporting assessments of sediment quality conditions in Florida [Note: In this report, the tools that have been developed in other jurisdictions for assessing the effects of contaminated sediments on sediment-dwelling organisms, aquatic-dependent wildlife, and human health are termed sediment quality guidelines (SQGs), while those that have been developed or recommended for use in Florida are termed SQAGs].

Chapter 2 Interests and Needs Related to the Assessment of Contaminated Sediments in Florida Inland Waters

2.0 Introduction

Concerns relative to the management of aquatic resources in freshwater systems have traditionally focused primarily on water quality. As such, early aquatic resource management efforts were often directed at assuring the potability of surface water or groundwater sources. Subsequently (i.e., with the authorization of the Clean Water Act; CWA), the scope of these management initiatives expanded to include protection of instream (i.e., fish and aquatic life), agricultural, industrial, and recreational water uses. While initiatives undertaken pursuant to the CWA have unquestionably improved the quality of the nation's waters, a growing body of evidence indicates that management efforts directed solely at the attainment of goals for surface water quality are unlikely to provide adequate protection for the designated uses of aquatic ecosystems.

In recent years, concerns relative to the health and vitality of aquatic ecosystems have begun to reemerge. One of the principal reasons for this is that many toxic and bioaccumulative chemicals (such as metals, polycyclic aromatic hydrocarbons - PAHs, polychlorinated biphenyls - PCBs, chlorophenols, and organochlorine pesticides - OC pesticides), which are found in only trace amounts in water, can accumulate to elevated levels in sediments. Some of these pollutants, such as OC pesticides and PCBs, were released into the environment some time ago. Although the use of many of these substances has been banned in the United States for nearly 30 years, these chemicals continue to persist in the environment. Other COPCs continue to enter our waters from industrial and municipal discharges, urban and agricultural runoff, and atmospheric deposition from remote sources. Due to their physical and chemical properties, many of these substances tend to accumulate in sediments. In addition to providing sinks for many chemicals, sediments can also serve as potential sources of pollutants to the water column (i.e., when conditions change in the receiving water system; such as during periods of anoxia or after severe storms).

This chapter of the report is intended to provide background information relevant to the assessment of contaminated sediments in Florida inland waters. More specifically, this chapter includes discussions on the role of sediments in freshwater ecosystems and on the principal sediment quality issues and concerns in the state. Additionally, the main reasons that information on sediment quality conditions are being collected in Florida are described (i.e., based on the input that was provided by stakeholders at a workshop that was convened by FDEP in 2000; MacDonald 2000). Furthermore, the principal COPCs in Florida inland waters are identified.

2.1 Role of Sediments in Freshwater Ecosystems

The particulate materials that lie below the water in ponds, lakes, springs, streams, rivers, and other aquatic systems are called sediments (ASTM 2001a). Sediments represent essential elements of aquatic ecosystems because they support both autotrophic and heterotrophic organisms. Autotrophic (which means self-nourishing) organisms are those that are able to synthesize food from simple inorganic substances (e.g., carbon dioxide, nitrogen, and phosphorus) and the sun's energy. Green plants, such as algae, bryophytes (e.g., mosses and liverworts), and aquatic macrophytes (e.g., sedges, reeds, and pond weed), are the main autotrophic organisms in freshwater ecosystems. In contrast, heterotrophic (which means other-nourishing) organisms utilize, transform, and decompose the materials that are synthesized by autotrophic organisms (i.e., by consuming or decomposing autotrophic and other heterotrophic organisms). Some of the important heterotrophic organisms that can be present in aquatic ecosystems include bacteria, epibenthic and infaunal invertebrates, fish, amphibians, and reptiles. Birds and mammals can also represent important heterotrophic components of aquatic and aquatic-dependent food webs (i.e., through the consumption of aquatic organisms).

Sediments support the production of aquatic organisms in several ways. For example, hard-bottom sediments, which are characteristic of faster-flowing streams and are comprised largely of gravels, cobbles, and boulders, provide stable substrates to which periphyton (i.e., the algae that grows on rocks) can attach and grow. Soft sediments, which are common in ponds, lakes, and slower-flowing sections of rivers and streams, are comprised largely of sand, silt, and clay (i.e., fine sediment). Such sediments provide substrates in which aquatic macrophytes can root and grow. The nutrients that are present in such sediments can also nourish aquatic macrophytes. By providing habitats and nutrients for aquatic plants, sediments support autotrophic production (i.e., the production of green plants) in aquatic systems. Sediments can also support prolific bacterial and meiobenthic communities, the latter including protozoans, nematodes, rotifers, benthic cladocerans, copepods, and other organisms. Bacteria represent important elements of aquatic ecosystems because they decompose organic matter (e.g., the organisms that die and accumulate on the surface of the sediment, as well as anthropogenically-derived organic chemicals) and, in so doing, release nutrients to the water column and increase bacterial biomass. Bacteria represent the primary heterotrophic producers in aquatic ecosystems, upon which many meiobenthic organisms depend. The role that sediments play in supporting primary productivity (both autotrophic and heterotrophic) is essential because green plants and bacteria represent the foundation of food webs upon which all other aquatic organisms depend (i.e., they are consumed by many other aquatic species).

In addition to their role in supporting primary productivity, sediments also provide essential habitats for many sediment-dwelling invertebrates and benthic fish. Some of these invertebrate species live on the sediments (termed epibenthic species), while others live in the sediments (termed infaunal species). Both epibenthic and infaunal invertebrate species consume the plants, bacteria, and other organisms that are associated with the sediments. Invertebrates represent important elements of aquatic ecosystems because they are consumed by a wide range of wildlife species, including amphibians, reptiles, fish, birds, and mammals. For example, virtually all fish species consume aquatic invertebrates during all or a portion of their life cycle. In addition, many birds (e.g., dippers, sand pipers, and swallows) consume aquatic invertebrates. Similarly, aquatic invertebrates represent important food sources for both amphibians (e.g., frogs and salamanders) and reptiles (e.g., turtles and snakes). Therefore, sediments are of critical importance to many wildlife species due to the role that they play in terms of the production of aquatic invertebrates.

Importantly, sediments can also provide habitats for many wildlife species during portions of their life cycle. For example, a variety of fish species utilize sediments for spawning and incubation of their eggs and larvae. In addition, juvenile fish often find refuge from predators in sediments and/or in the aquatic vegetation that is supported by the sediments. Furthermore, many amphibian species burrow into the sediments in the fall and remain there throughout the winter months, such that sediments provide important overwintering habitats.

Therefore, sediments play a variety of essential roles in terms of maintaining the structure (i.e., assemblage of organisms in the system) and function (i.e., the processes that occur in the system) of aquatic ecosystems.

2.2 Sediment Quality Issues and Concerns

Considering the important roles that they play, it is apparent that sediments represent essential elements of freshwater ecosystems. Yet, the available information on sediment quality conditions indicate that sediments throughout the United States, including Florida, are contaminated by a wide range of toxic and bioaccumulative substances, including metals, PAHs, PCBs, OC pesticides, a variety of semi-volatile organic chemicals (SVOCs), polychlorinated dibenzo-*p*-dioxins (PCDDs) and polychlorinated dibenzofurans (PCDFs; USEPA 1997). The nature and extent of such sediment contamination depends on a variety of factors, such as the types of sources of COPCs that are present in the system under investigation, the loadings of COPCs from the various sources, proximity to sources, and the fate of the COPCs once they are released into the aquatic system.

Contaminated sediments represent an important environmental concern for several reasons. First, contaminated sediments have frequently been demonstrated to be toxic to sediment-dwelling organisms and fish. As such, exposure to contaminated sediments can result in decreased survival, reduced growth or impaired reproduction in benthic invertebrates and fish. Additionally, certain COPCs in the sediments are taken up by benthic organisms through a process called bioaccumulation. When larger animals feed on these contaminated prey species, the pollutants are taken into their bodies and are passed along to other animals in the food web in a process called biomagnification. As a result of the effects of toxic and bioaccumulative substances, benthic organisms, fish, birds, and mammals can be adversely affected by contaminated sediments (Ingersoll *et al.* 1997; MacDonald *et al.* 2002a; 2002b).

Contaminated sediments can also adversely affect human health and the human uses of aquatic ecosystems. First, human health can be adversely affected due to direct exposure to contaminated sediments during wading or swimming in affected waterbodies. Consumption of contaminated fish and shellfish also poses a risk to human health. Human use of aquatic ecosystems can also be compromised by the presence of contaminated sediments through reductions in the abundance of food or sportfish species or due to the imposition of fish consumption advisories (i.e., when fish or shellfish tissues are found to contain unacceptable levels of bioaccumulative substances). As such, contaminated sediments in freshwater ecosystems pose potential hazards to sediment-dwelling organisms (i.e., epibenthic and infaunal invertebrate species), aquatic-dependent wildlife species (i.e., fish, amphibians, reptiles, birds, and mammals), and human health (Ingersoll *et al.* 1997).

2.3 Reasons for Collecting Information on Sediment Quality Conditions

Information on sediment quality conditions is of fundamental importance in the management of natural resources. To help focus the ***Freshwater Sediment Quality Assessment Initiative***, FDEP conducted a multi-stakeholder workshop in early 2000 to identify interests and needs related to sediment quality assessment and management (MacDonald 2000). Workshop participants were asked to describe why sediment quality data are currently being collected in Florida. In addition, information was solicited on how such data are currently being used to support management decisions in the state. Based on the responses that were provided by workshop participants, it is apparent that the primary reasons for conducting sediment quality assessments in Florida include:

- To support broad assessments of environment conditions. The watershed assessments that are currently being conducted throughout the state provide a good example of such broad environmental assessments. Information on sediment quality conditions is needed to evaluate the effects of contaminated sediments on aquatic organisms, wildlife, and human health;

- To support the identification and assessment of sites with contaminated sediments. In this context, information on sediment quality conditions is needed to determine if a site is contaminated, to identify COPCs, and to assess the areal extent of contamination;

- To evaluate the status and trends in environmental conditions. Information on sediment quality conditions is needed to determine if water bodies are currently supporting designated uses and to determine if conditions are improving or worsening over time;

- To support ecological risk assessments. Information on sediment quality conditions is needed to evaluate the risks posed by contaminated sediments to aquatic and terrestrial receptors. Such information is also required to evaluate various risk management options;

- To assess the efficacy of point or non-point source pollution control efforts. Information on sediment quality conditions is needed to determine if environmental conditions are improving as a result of the management initiatives that are being implemented to reduce inputs of COPCs into aquatic ecosystems;

- To assess the cumulative environmental effects of multiple facilities in an area. Information on sediment quality conditions is needed to determine if sufficient assimilative capacity exists to support additional facilities in a particular water body and to evaluate various options for siting new facilities;

- To evaluate the feasibility of restoring wetland habitats. Information on sediment quality conditions is needed to determine if wetland sediments, post-restoration, are likely to support the designated uses of the aquatic ecosystem. This information is also needed to support the design of wetland restoration projects; and,

- To assess the environmental impacts of various anthropogenic activities. Information on sediment quality conditions is needed to conduct comprehensive assessments of the effects of anthropogenic activities, particularly those that result in releases of toxic or bioaccumulative substances to surface waters.

2.4 Chemicals of Potential Concern

Identification of COPCs represents an essential element of the overall SQAGs derivation process. In the context of this report, COPCs are defined as those substances that are released in freshwater ecosystems as a result of human activities (including those originating from both point and non-point sources) and have the potential to adversely affect the uses of aquatic ecosystems (e.g., aquatic life, recreation and aesthetics). It is important to establish the COPCs in Florida inland waters because such information, when considered in conjunction with data on the environmental fate and persistence of these chemicals, provides a basis for identifying the substances that are likely to partition into sediments (i.e., the sediment-associated COPCs). The toxic and bioaccumulative COPCs that are likely to occur in Florida freshwater sediments are considered to be the highest priority for establishing numerical SQAGs.

A variety of methods could be used to identify the sediment-associated COPCs in Florida inland waters. To expedite this process, FDEP convened a multi-stakeholder workshop in early 2000 to identify the substances that were most likely to occur at levels that could compromise the beneficial uses of freshwater ecosystems (MacDonald 2000). Based on the input that was provided by workshop participants, the highest priority substances for establishing numerical SQAGs included:

Toxic Substances that Partition into Sediments:

- Metals (arsenic, barium, beryllium, boron, cadmium, chromium, cobalt, copper, lead, mercury, nickel, silver, strontium, titanium, and zinc);
- Polycyclic aromatic hydrocarbons (PAHs; acenaphthene, acenaphthylene, anthracene, fluorene, 2-methylnaphthalene, naphthalene, phenanthrene, benz[a]anthracene, benzo(a)pyrene, chrysene, dibenz[a,h]anthracene, fluoranthene, pyrene, total PAHs, and other PAHs);
- Polychlorinated biphenyls (PCBs);
- Chlorinated benzenes [hexachlorobenzene (HCB), hexachlorobutadienes (HCBD), and degradation products];
- Phthalates [e.g., bis(2-ethyl hexyl)phthalate (BEHP)];

- Triazine herbicides (e.g., atrazine);
- Organophosphate pesticides (e.g., diazinon);
- Organochlorine pesticides [(OC pesticides) aldrin, chlordane; dieldrin, DDTs, endrin, heptachlor, heptachlor epoxide, lindane]; and,
- Toxaphene.

Bioaccumulative Substances that Partition into Sediments:

- Metals (mercury);
- PAHs (acenaphthene, acenaphthylene, anthracene, fluorene, 2-methylnaphthalene, naphthalene, phenanthrene, benz[a]anthracene, benzo(a)pyrene, chrysene, dibenz[a,h]anthracene, fluoranthene, pyrene, total PAHs, and other PAHs);
- PCBs;
- Polychlorinated dibenzo-*p*-dioxins (PCDDs) and polychlorinated dibenzofurans (PCDFs);
- Chlorinated benzenes (HCB, HCBD, and degradation products); and,
- OC pesticides (aldrin, chlordane; dieldrin, DDTs, endrin, heptachlor, heptachlor epoxide, lindane).

Chapter 3 Approaches for Establishing Numerical Sediment Quality Assessment Guidelines for Freshwater Ecosystems

3.0 Introduction

Numerical sediment quality guidelines (including sediment quality criteria, sediment quality objectives, and sediment quality standards) have been developed by various jurisdictions in North America for both freshwater and marine ecosystems. Such guidelines have been used in numerous applications, including designing monitoring programs, interpreting historical data, evaluating the need for detailed sediment quality assessments, assessing the quality of prospective dredged materials, conducting remedial investigations and ecological risk assessments, and developing sediment quality remediation objectives (SQROs; Long and MacDonald 1998). Numerical SQGs have also been used by many scientists and administrators to identify COPCs in aquatic ecosystems and to rank areas of concern on a regional or national basis (e.g., USEPA 1997). It is apparent, therefore, that numerical SQGs represent useful tools for assessing the quality of freshwater and marine sediments (MacDonald *et al.* 1992; USEPA 1992; Adams *et al.* 1992; USEPA 1996; Ingersoll *et al.* 1996; Smith *et al.* 1996; USEPA 1997; Ingersoll *et al.* 1997).

Florida has been a leader in the development and implementation of numerical SQGs. In 1994, the FDEP published sediment quality assessment guidelines (SQAGs; so termed to distinguish them from the SQGs that have been developed in other jurisdictions) for Florida coastal waters (MacDonald 1994; MacDonald *et al.* 1996). These SQAGs were derived using the effects level approach, which represents a modification of the weight-of-evidence approach that was developed under NOAA's National Status and Trends Program for deriving empirically-based SQGs (Long and Morgan 1991). Using the effects level approach, two SQAGs were derived for each chemical substance, including a threshold effects level (TEL) and a probable effects level (PEL). These SQAGs defined three ranges of contaminant concentrations, including a minimal effects range, a possible effects range, and a probable effects range. Numerical SQAGs were established for 34 priority substances in marine and estuarine waters, including trace metals, PAHs, PCBs, and OC pesticides. These SQAGs have provided useful tools for assessing sediment quality conditions in marine and estuarine ecosystems within the state and elsewhere in North America.

In recent years, FDEP, USGS, Florida Geological Survey, USEPA, Dade County, South Florida Management District, and several other organizations have been collecting sediment chemistry data in freshwater ecosystems throughout the state. The results of these monitoring programs will provide valuable information on the concentrations of sediment-associated contaminants throughout the state. However, interpretation of these data will require reliable tools for determining if measured concentrations of COPCs exceed background levels and/or if such levels are likely to be associated with adverse biological effects. The interpretive tool that was recently developed for assessing metal enrichment in Florida freshwater sediments provides a basis for identifying sediments in which metal concentrations exceed background levels (Carvalho and Schropp 2002). However, numerical SQAGs are still required to support assessments of the potential for biological effects associated with sediment contamination.

This chapter is intended to provide the information needed to support the selection of the most relevant approach or approaches for establishing numerical SQAGs for Florida inland waters. To that end, the existing approaches to the derivation of numerical SQGs and their uses are described. Additionally, each of these approaches are critically evaluated to determine their strengths and limitations. Based on the results of that evaluation, an approach for establishing effects-based SQAGs for Florida inland waters is recommended. Similarly, an approach for establishing SQAGs for bioaccumulative substances is selected.

3.1 Review and Evaluation of Existing Approaches to the Derivation of Numerical Sediment Quality Guidelines

A number of jurisdictions throughout North America have developed numerical SQGs for freshwater and/or marine ecosystems. The SQGs that are currently being used in North America have been developed using a variety of approaches, including both empirical and theoretical approaches. Both empirical and theoretical approaches were considered to support the derivation of numerical SQAGs for the protection of sediment-dwelling organisms, including:

- Screening Level Concentration Approach (SLCA);
- Effects Range Approach (ERA);
- Effects Level Approach (ELA);
- Apparent Effects Threshold Approach (AETA);
- Equilibrium Partitioning Approach (EqPA);
- Logistic Regression Modeling Approach (LRMA); and,
- Consensus Approach (CA).

The tissue residue approach (TRA) was considered to be the primary method for deriving numerical sediment quality objectives for the protection of wildlife and human health (i.e., for substances that bioaccumulate in the food web). The following sections of this report provide brief descriptions of each of these approaches. The strengths and limitations of these approaches are summarized in Table 3.1.

3.1.1 Screening Level Concentration Approach

The SLCA is a biological effects-based approach for deriving SQGs for the protection of benthic organisms. This approach utilizes matching biological and chemical data collected in field surveys to calculate a screening level concentration (SLC; Neff *et al*. 1986). The SLC is an estimate of the highest concentration of a substance that can be tolerated by a pre-defined proportion of benthic infaunal species.

The SLC is calculated using a database that contains information on the concentrations of COPCs in sediments and on the co-occurrence of benthic organisms in the same sediments. For each benthic organism for which adequate data are available, a species screening level concentration (SSLC) is calculated. The SSLC is determined by plotting the frequency distribution of the COPC concentrations over all of the sites at which the species occurs (information from at least ten sites is required to calculate a SSLC). The 90th percentile of this distribution is taken as the SSLC for the species being investigated. The SSLCs for all of the species for which adequate data are available are then compiled as a frequency distribution to determine the concentration that can be tolerated by a specific proportion of the species (i.e., the 5th percentile of the distribution would provide a SLC that should be tolerated by 95% of the species). This concentration is termed the SLC of the contaminant.

A number of jurisdictions have used the SLCA to derive numerical SQGs. For example, Neff *et al.* (1986) developed freshwater SLCs for a variety of chemical substances, primarily using data from the Great Lakes. Similarly, the Quebec Ministry of the Environment used the SLCA for deriving two SQGs for each COPC in the St. Lawrence River, including a minimal effect threshold (MET) and a toxic effect threshold (TET; EC and MENVIQ 1992). The MET was calculated as the 15th percentile of the SSLCs, while the TET was calculated as the 90th percentile of the SSLC distribution for each substance. Therefore, the MET and TET are considered to provide protection for 85% and 10% of the species represented in the database, respectively. Furthermore, Environment Ontario developed a lowest effect level (LEL) and severe effect level (SEL) for various chemical substances using this approach (Persaud *et al.* 1993).

3.1.2 Effects Range Approach

The ERA to the derivation of SQGs was formulated to provide informal tools for assessing the potential for various COPCs tested in the National Status and Trends Program (NSTP) to be associated with adverse effects on sediment-dwelling organisms (Long and Morgan 1991). The SQGs derivation process involves several steps, including acquisition of candidate data sets, review and evaluation of data sets, compilation of acceptable data into a project database, and data analysis (including guideline derivation).

In the first step of the process, candidate data sets were identified using bibliographic database searches and communications with investigators active in the sediment assessment field. Following their retrieval, candidate data sets were reviewed and evaluated to determine their applicability for incorporation into the database (MacDonald *et al.* 1996). This evaluation was designed to determine the overall applicability of the data set, the methods that were used, the endpoints that were measured, and the degree of concordance between the chemical and biological data. The data which met the evaluation criteria were incorporated into the project database.

Information from several types of investigations were incorporated into the project database, including spiked-sediment toxicity tests, field studies conducted in the United States, and initiatives directed at the formulation of numerical SQGs. All of the information contained in the database was weighted equally, regardless of the method that was used in the investigation. Individual entries in the database consisted of the concentration of the COPC, the location of the study, the species tested and endpoint measured, and an indication of whether or not there was concordance between the observed effect and the concentrations of a specific chemical [i.e., no effect (NE), no or small gradient (NG or SG), no concordance (NC), or a "hit" (*), which indicated that an effect was measured in association with elevated sediment chemistry]. Data from non-toxic or unaffected samples were assumed to represent background conditions. Data which showed no concordance between chemical and biological variables were included in the database, but were not used to calculate the SQGs [i.e., only the effects data (i.e., hits) were used to calculate the SQGs].

Simple analytical procedures were used to derive numerical SQGs using the information that was compiled in the database. First, the data for which a biological effect was observed in association with elevated chemical concentrations (i.e., hits) were sorted in ascending order of concentration. Next, the 10^{th} and 50^{th} percentile concentrations for each compound were determined. The effects range-low (ERL; 10^{th} percentile value) represents a lower threshold value, below which adverse effects on sensitive life stages and/or species occurred only infrequently. The effects range-median (ERM; 50^{th} percentile value) represents a second threshold value, above which adverse effects were frequently observed.

Using the ERA, Long and Morgan (1991) and Long *et al.* (1995) derived two types of informal SQGs (i.e., ERL and ERM) for use in the NSTP. The database that was used by Long and Morgan (1991) to derive the SQGs consisted of data from freshwater, estuarine, and marine ecosystems. Ingersoll *et al.* (1996) used a similar approach to derive ERLs (15^{th} percentile of the effects data set) and ERMs (50^{th} percentile of the effects data set) for assessing sediments from various freshwater locations in the United States. Similarly, MacDonald (1997) applied the ERA to regionally-collected field data to derive site-specific sediment effect concentrations (SECs) for PCBs and DDTs in the Southern California Bight.

3.1.3 Effects Level Approach

The ELA is closely related to the ERA described above. However, the ELA is supported by an expanded version of the database that was used to derive the effects ranges (Long and Morgan 1991). The expanded database contains matching sediment chemistry and biological effects data from spiked-sediment toxicity tests and from field studies conducted throughout North America (including both effects and no effects data). The expanded database also contains SQGs derived using various approaches. The information contained in the expanded database was evaluated and classified using the same selection criteria that were used to compile the original NSTP database.

In the ELA, the underlying information in the database was used to derive two types of SQGs, including threshold effect levels (TELs) and probable effect levels (PELs). The TEL, which is calculated as the geometric mean of the 15th percentile of the effects data set and the 50th percentile of the no effects data set, represents the chemical concentration below which adverse effects are expected to occur infrequently. The PEL represents a second threshold value, above which adverse effects are expected to be frequently observed. The PEL is calculated as the geometric mean of the 50th percentile of the effects data set and the 85th percentile of the no effects data set.

The ELA was applied to the expanded database [i.e., Biological Effects Database for Sediments (BEDS)] to derive numerical SQGs (i.e., TELs and PELs) for Florida coastal waters (MacDonald *et al.* 1996). Similarly, Ingersoll *et al.* (1996) applied this approach to the results of freshwater toxicity tests on amphipods and midges to derive SQGs for assessing sediment quality conditions in freshwater systems. Furthermore, Smith *et al.* (1996) and CCME (1999) used the ELA to derive TELs and PELs for freshwater and marine systems in Canada.

3.1.4 Apparent Effects Threshold Approach

The AETA to the development of SQGs was developed for use in the Puget Sound area of Washington State (Tetra Tech Inc. 1986). The AETA is based on empirically-defined relationships between measured concentrations of COPCs in sediments and observed biological effects. This approach is intended to define the concentration of a COPC in sediment above which significant ($p \leq 0.05$) biological effects are *always* observed. These biological effects include, but are not limited to, toxicity to benthic and/or water column species (as measured using sediment toxicity tests), changes in the abundance of various benthic species, and changes in benthic community structure. The AET values can be based on dry weight-normalized COPC concentrations or total organic carbon (TOC)-normalized concentrations for organic substances (Barrick *et al*. 1988; WDOE 1990). The guidance manual to support the assessment of contaminated sediments in freshwater ecosystems provides more information on normalizing procedures (MacDonald and Ingersoll 2002a; 2002b; Ingersoll and MacDonald 2002).

The state of Washington has used AET values to establish sediment quality standards and minimum clean-up levels for a variety of COPCs in the state (WDOE 1990). Cubbage *et al.* (1997) refined this approach to support the development of probable AETs (PAETs) using matching sediment chemistry and toxicity data for freshwater sediments from the state of Washington. Ingersoll *et al.* (1996) utilized a similar approach to develop freshwater AETs (termed no effect concentrations or NECs in that study) using the results of toxicity tests and chemical analyses conducted on sediments from various freshwater locations in the United States.

3.1.5 Equilibrium Partitioning Approach

The water-sediment EqPA is based on the premise that the distribution of COPCs among the two principal compartments in the sediment matrix (i.e., sediment solids and interstitial water) is predictable based on their physical and chemical properties, assuming that continuous equilibrium exchange between sediment and interstitial water occurs. This approach has been supported by the results of spiked-sediment toxicity tests, which indicate that positive correlations exist between the biological effects observed and the concentrations of COPCs measured in the interstitial water (Di Toro *et al.* 1991; Berry *et al.* 1996; Hansen *et al.* 1996).

In the EqPA, water quality criteria developed for the protection of freshwater or marine organisms are used to support the SQGs derivation process. As such, the water quality criteria formulated for the protection of water column species are assumed to be applicable to benthic organisms (Di Toro *et al*. 1991). The SQGs are calculated using the appropriate water quality criteria [usually the final chronic values (FCVs) or equivalent values; USEPA 1998; 1999a] in conjunction with the sediment/water partition coefficients (Kp) for the specific COPCs. The FCV is derived from the species mean chronic values that have been calculated from published toxicity data and is intended to protect 95% of aquatic species. The calculation procedure for non-ionic organic substances is as follows:

$$\mathbf{SQG = Kp \bullet FCV}$$

where:

SQG	=	Sediment quality guideline (in ∶g/kg);
Kp	=	Partition coefficient for the chemical (in L/kg); and,
FCV	=	Final chronic value (in ∶g/L).

The Kp is a function of the partition coefficient for sediment organic carbon (K_{oc}) of the substance under consideration and the amount of organic carbon in the sediment under investigation (f_{oc}; where $Kp = K_{oc} \bullet f_{oc}$; Di Toro *et al.* 1991). The K_{oc} for non-ionic substances can be calculated from its octanol-water partition coefficient (K_{ow}; Di Toro *et al.* 1991). The f_{oc} is the decimal equivalent of the percent organic carbon in the sediment (i.e., $f_{oc} = 0.01$ if TOC = 1%).

The EqPA has been used to derive numerical SQGs in several jurisdictions. For example, USEPA (1997) reported organic carbon-normalized SQGs (termed equilibrium-based sediment guidelines; ESGs) for a variety of non-polar organic substances. In addition, draft ESGs have been developed for endrin, dieldrin, and metal mixtures (S. Ireland. United States Environmental Protection Agency. Washington, District of Columbia. Personal communication). The SQGs for divalent cationic metals [i.e., simultaneously extracted metals (SEM)] are applied using data on the levels of acid volatile sulfide (AVS) in sediments (i.e., metals are thought to contribute to sediment toxicity only when SEM concentrations exceed AVS concentrations by a factor of five or more; Hansen *et al.* 1996; USEPA 1997). New York State Department of Environmental Conservation also developed SQGs for the protection of aquatic life using the EqPA (NYSDEC 1999).

3.1.6 Logistic Regression Modeling Approach

In the LRMA, numerical SQGs are derived from the results of field studies conducted to assess sediment quality conditions. The first step of the SQGs derivation process involves the collection, evaluation, and compilation of matching sediment chemistry and toxicity data from a wide variety of sites in North America. Next, the information compiled in the project database is retrieved on a substance-by-substance basis, with the data from individual sediment samples sorted in order of ascending concentration. For each sediment sample, the ascending data table provides information on the concentration of the COPC under consideration (on either a dry weight- or organic carbon-normalized basis) and the results of the toxicity test (i.e., toxic or not toxic) for each endpoint (e.g., 10-d survival of amphipods; Field *et al.* 1999).

In the next step of the process, the data contained in the ascending data tables are screened to minimize the potential for including samples in which the selected COPC did not contribute substantially to the observed toxicity. In this analysis, the chemical concentration in each toxic sample is compared to the mean concentration in the non-toxic samples from the same study and geographic area. The toxic samples with concentrations of the selected COPC that are less than or equal to the average concentration of that chemical in the non-toxic samples are not used in further analyses of the data (i.e., it was highly unlikely that the COPC substantially contributed to sediment toxicity in such samples; Field *et al.* 2002).

In the final step of the analysis, the screened data are used to develop logistic regression models, which express the relationship between the concentration of the selected COPC and the probability of observing toxicity. In its simplest form, logistic models can be described using the following equation (Field *et al.* 1999):

$$\boldsymbol{p = e^{B0+B1(x)} / (1 + e^{B0+B1(x)})}$$

where:

p	=	probability of observing a toxic effect;
B0	=	intercept parameter;
B1	=	slope parameter; and,
x	=	concentration or log concentration of the chemical.

Using a preliminary database consisting of the results of 10-d toxicity tests with marine amphipods, Field *et al*. (1999) derived logistic regression models for seven chemical substances to illustrate the methodology. More specifically, these investigators calculated T_{10}, T_{50}, and T_{90} values for four metals (lead, mercury, nickel and zinc), two PAHs (fluoranthene and phenanthrene), and total PCBs. These values represent the chemical concentrations that correspond to a 10%, 50%, and 90% probability of observing sediment toxicity. In addition to supporting the derivation of specific T-values, this method can be used to determine the concentration of a COPC that corresponds to any probability of observing toxicity. Therefore, a sediment manager can identify an acceptable probability of observing sediment toxicity at a site (e.g., 25%) and determine the corresponding chemical concentrations (e.g., T_{25} value). The calculated value can then be used as the SQG for the site. While the existing data from 10-d toxicity tests with marine amphipods (endpoint: survival) support the development of logistic models for 37 substances (Field *et al.* 2002), insufficient data are currently available to derive reliable logistic models for any freshwater invertebrate species or toxicity test endpoint (Crane *et al.* 2000).

3.1.7 Consensus Approach

In the CA, consensus-based SQGs are derived from the existing SQGs that have been established for the protection of sediment-dwelling organisms. Derivation of numerical SQGs using the CA involves a four-step process. In a first step, the SQGs that have been derived by various investigators for assessing the quality of freshwater sediments are collected and collated. Next, the SQGs obtained from all sources are evaluated to determine their applicability to the derivation of consensus-based SQGs. The selection criteria that are applied are intended to evaluate the transparency of the derivation methods, the degree to which the SQGs are effects-based, and the uniqueness of the SQGs.

The effects-based SQGs that meet these selection criteria are then grouped to facilitate the derivation of consensus-based sediment effect concentrations (SECs; Swartz 1999). Specifically, the SQGs for the protection of sediment-dwelling organisms are grouped into two categories according to their original narrative intent, including threshold effect concentrations (TECs) and probable effect concentrations (PECs). The TECs are intended to identify COPC concentrations below which harmful effects on sediment-dwelling organisms are unlikely to be observed. Examples of TECs include threshold effect levels

(TELs; Smith *et al.* 1996; Ingersoll *et al.* 1996), effect range low values (ERLs; Long and Morgan 1991; Ingersoll *et al.* 1996), and lowest effect levels (LELs; Persaud *et al.* 1993). The PECs are intended to identify COPC concentrations above which harmful effects on sediment-dwelling organisms are likely to be frequently or always observed (MacDonald *et al.* 1996; Swartz 1999). Examples of PECs include probable effect levels (PELs; Smith *et al.* 1996; Ingersoll *et al.* 1996), effect range median values (ERMs; Long and Morgan 1991; Ingersoll *et al.* 1996); and severe effect levels (SELs; Persaud *et al.* 1993).

Following classification of the existing SQGs, consensus-based TECs are calculated by determining the geometric mean of the SQGs that are included in this category. Likewise, consensus-based PECs are calculated by determining the geometric mean of the PEC-type values. The geometric mean, rather than the arithmetic mean, is calculated because it provides an estimate of central tendency that is not unduly affected by outliers and because the SQGs may not be normally distributed. Consensus-based TECs or PECs are calculated only if three or more published SQGs are available for a chemical substance or group of substances (MacDonald *et al.* 2000a).

The CA has been used to derive numerical SQGs for a variety of chemical substances and media types. For example, Swartz (1999) derived consensus-based SQGs for PAHs in marine ecosystems. Using a similar approach, MacDonald *et al.* (2000b) derived SQGs for total PCBs in freshwater and marine sediments. Ingersoll and MacDonald (1999) and MacDonald *et al.* (2000a) developed consensus-based SQGs for metals, PAHs, PCBs, and several pesticides in freshwater sediments. As the term implies, consensus-based SECs are intended to reflect the agreement among the various SQGs by providing an estimate of their central tendency. Consensus-based SECs are, therefore, considered to provide a unifying synthesis of the existing SQGs, reflect causal rather than correlative effects, and account for the effects of contaminant mixtures in sediment (Swartz 1999; MacDonald *et al.* 2000a; MacDonald *et al.* 2000b). The predictive ability of the consensus-based SECs were evaluated by MacDonald *et al.* (2000a; 2000b; 2001), Kemble *et al.* (2000), USEPA (2000a), and Ingersoll *et al.* (2001).

3.1.8 Tissue Residue Approach

The TRA (which is also known as the biota-water-sediment EqPA) for deriving numerical SQGs was developed to address concerns regarding the bioaccumulation of sediment-associated COPCs in aquatic and aquatic-dependent food webs. The TRA is used to estimate the levels of individual chemicals or classes of chemicals in sediments that are unlikely to result in unacceptable tissue residues (i.e., levels in excess of the concentrations recommended to protect aquatic-dependent wildlife and/or human health; Cook *et al.* 1992).

Derivation of numerical SQGs using the TRA involves several steps. As a first step, the COPCs for which SQGs are to be derived are selected based on their potential to accumulate in aquatic food webs (e.g., based on their K_{ow}). Next, numerical tissue residue guidelines (TRGs) are identified for these COPCs. While most of the available TRGs are intended to provide protection for human health (e.g., Food and Drug Administration Action Levels; USEPA 1989), it is also important to obtain TRGs that are explicitly designed to protect piscivorous wildlife species. Following the selection of TRGs, sediment-to-biota bioaccumulation factors (BSAFs) are determined for each COPC. Such BSAFs can be determined from the results of bioaccumulation assessments, from matching sediment chemistry and tissue residue data (i.e., from the results of field studies), or from the results of bioaccumulation models. Numerical SQGs are subsequently derived using the equation (WDOH 1995):

$$\mathbf{SQG = TRG \div BSAF}$$

Numerical SQGs can also be developed using information on the K_{ow} of a substance and its corresponding bioaccumulation-based WQC (NYSDEC 1999).

The applicability of the TRA is supported by data which demonstrate that declines in DDT residues in fish and birds (since its use was banned) are strongly correlated with declining concentrations of this substance in surficial sediments in the Great Lakes and Southern California Bight. This approach has been used in Lake Ontario to derive numerical SQGs for 2,3,7,8 tetrachlorodibenzo-*p*-dioxin on the basis of fish tissue residues (Endicott *et al*. 1989; Cook *et al*. 1989). In addition, the New York State Department of Environmental Conservation has developed numerical SQGs for the protection of wildlife and human health using this approach (NYSDEC 1999). Human health-based SQGs have also been established in Washington State by the Washington State Department of Health (WDOH 1995; 1996).

3.2 Recommended Strategy for Establishing Sediment Quality Assessment Guidelines for Florida Inland Waters

A total of seven approaches to the derivation of numerical SQGs for the protection of sediment-dwelling organisms were described in the preceding sections of this chapter. Crane *et al.* (2000) evaluated these approaches and determined that each approach has certain strengths and limitations that influence their applicability for deriving numerical SQGs (Table 3.1). Based on the results of that review, it is apparent that no single approach can be used to establish numerical SQGs for all water uses. Therefore, it may be necessary to employ a strategy for establishing SQAGs for Florida coastal waters that involves the use of multiple approaches.

3.2.1 Recommended Approach for Establishing Effects-Based Sediment Quality Assessment Guidelines

To help guide the selection of an approach for deriving effects-based SQAGs for Florida coastal waters, MacDonald (1994) identified a number of criteria for evaluating individual approaches. At that time, the primary factors that needed to be considered in the selection of an approach for deriving SQAGs included practicality, cost-effectiveness, scientific defensibility, and broad applicability to assessments of sediment quality conditions. In the context of that evaluation, an approach was considered to be practical if it supported the development of numerical SQAGs and was feasible to implement in the near-term. Cost-effectiveness was evaluated based on the estimated costs associated with implementation of the approach and the requirement for new data to support the approach. The scientific defensibility of each candidate approach was determined by evaluating its potential to: consider the bioavailability of COPCs; establish cause and effect relationships; incorporate biological effects data, especially from the southeast; and, apply to the classes of COPCs and chemical mixtures that occur in Florida. Amenability to field validation was also considered to be a key factor for evaluating scientific defensibility. Finally, candidate approaches were considered to be broadly applicable if the resultant SQAGs could be used in the sediment quality assessment and management initiatives that are being conducted in the state. Although these selection criteria were established some time ago, they are still relevant for evaluating candidate approaches for deriving numerical SQAGs for Florida inland waters.

Among the candidate approaches to the derivation of effects-based SQAGs, the SLCA is the least amenable to application in Florida. One of the principal impediments to its application is the dearth of matching sediment chemistry and benthic invertebrate community structure data for freshwater ecosystems. Additionally, this approach does not consider the bioavailability of sediment-associated COPCs, cannot be used to establish dose-response relationships, and does not provide a weight of evidence for assessing sediment quality conditions (i.e., because it utilizes benthos data only; Table 3.2). Because benthic invertebrate community structure can be affected by factors other than the concentrations of sediment-associated COPCs, the SLCA is likely to be of little assistance in conducting ecological risk assessments or supporting regulatory decisions at contaminated sites.

The ERA, ELA, and AETA are all empirically-based approaches that rely on analyses of matching sediment chemistry and biological effects data to support the derivation of numerical SQAGs. All three approaches scored highly in the evaluation (Table 3.2); however, all three were limited by their inability to define dose-response relationships and by the extent to which the existing guidelines derived using these approaches incorporate data from the southeast. The AETA was further limited because insufficient regional data are currently available to support the derivation of SQAGs. None of the three approaches fully account for the factors that can influence the bioavailability of sediment-associated COPCs.

The EqPA scored highly for many of the selection criteria that were used to evaluate candidate approaches for deriving numerical SQAGs. In terms of practicality, cost-effectiveness, and applicability, the EqPA was the highest rated approach (Table 3.2). However, this approach does not consider data from the southeast, does not yield SQGs for individual metals, does not provide a weight of evidence for assessing sediment quality conditions, does not consider the effects of mixtures of COPCs (with the exception of the E PAH model; Swartz *et al.* 1995), and the approach is not particularly amenable to field validation (i.e., data from sites which contain complex mixtures of COPCs cannot be used to field validate the resultant SQAGs).

Among the seven effects-based approaches that were evaluated, the LRMA had the second highest overall assessment score (Table 3.2). More specifically, the LRMA scored highly in the cost-effectiveness, scientific defensibility, and applicability categories. The principal limitation of this approach is that insufficient data are currently available to support the development of reliable logistic models for most COPCs in freshwater sediments (Crane *et al.* 2000). In addition, the approach does not support the development of dose-response relationships. Furthermore, insufficient data from the southeast are available to support the development of reliable regional logistic models.

Of the approaches that were evaluated, the CA appears to be the most applicable for establishing effects-based SQAGs for Florida inland waters. Based on the results of the evaluation, the CA is both practical and cost-effective for deriving numerical SQAGs. While it does not consider the factors thought to influence the bioavailability of sediment-associated contaminants, the results of several investigations demonstrate that dry weight-normalized guidelines predict the presence and absence of sediment toxicity as well or better than guidelines that are normalized to TOC or account for binding of metals by AVS (Ingersoll *et al.* 1996; Long *et al.* 1998a). Although regional data were not used in the derivation of the guidelines, such data have been assembled to the extent possible to support an evaluation of the predictive ability of the guidelines in freshwater sediments from the southeastern portion of the United States. Hence, the two principal limitations of the approach have been mitigated. Furthermore, the consensus-based SECs are considered to provide a unifying synthesis of the existing guidelines, reflect causal rather than correlative effects, and account for the effects of COPC mixtures (Swartz 1999; MacDonald *et al.* 2000a; 2000b; 2001). Therefore, the consensus-based SECs are likely to provide powerful tools for assessing sediment quality conditions in Florida inland waters and are recommended for establishing effects-based SQAGs. The results of the evaluation of the predictive ability of the SECs will provide a basis for identifying any refinements that are need to increase their applicability to the southeastern portion of the United States.

Consensus-based guidelines are not available for all of the COPCs that occur in Florida inland waters (MacDonald 2000). Nevertheless, sediment quality assessors in the state require science-based tools to support the assessment and management of sediments that have been contaminated by substances for which consensus-based guidelines are not available. For this reason, it is recommended that the guidelines from other jurisdictions be reviewed and evaluated to identify SQAGs that can be used on an interim basis in Florida. More specifically, it is recommended that the effects-based guidelines that are most consistent with the narrative intent of the SQAGs be adopted for use as interim SQAGs in Florida.

3.2.2 Recommended Approach for Establishing Bioaccumulation-Based Sediment Quality Assessment Guidelines

Sediment-associated COPCs have the potential to adversely affect wildlife species in several ways. First, certain wildlife species can be exposed directly to contaminated sediments through dermal contact (e.g., demersal fish species, such as catfish) or through ingestion (e.g., bottom-feeding fish species or birds that consume sediment-dwelling organisms), potentially resulting in direct toxicity. In addition, many wildlife species may be exposed to sediment-associated COPCs as a result of food web transfers and associated bioaccumulation. The accumulation of toxic substances in the tissues of these species can result in decreased growth, impaired reproduction, reduced survival, or other harmful effects. Finally, sediment-associated COPCs can be toxic to sediment-dwelling organisms and, in so doing, result in decreased abundance of food organisms.

Bioaccumulation-based guidelines represent important tools for conducting sediment quality assessments for several reasons. First and foremost, unlike the effects-based SQAGs described in the previous section, the bioaccumulation-based guidelines explicitly consider the potential for bioaccumulation and effects on higher trophic levels in the food web. That is, the bioaccumulation-based guidelines provide a basis for interpreting sediment chemistry data in terms of the potential for harmful effects on wildlife. Because there were a limited number of bioaccumulation-based guidelines and the methods for evaluating the reliability of these guidelines are not readily available, it is recommended that the existing guidelines for the protection of wildlife (NYSDEC 1999; MacDonald 1994) be adopted directly as interim bioaccumulation-based SQAGs for Florida inland waters (Table 5.2). Importantly, these interim SQAGs should be used in conjunction with tissue chemistry data and applicable tissue residue guidelines (TRGs; such as Newell *et al.* 1987; USEPA 1989) to confirm that contaminated sediments pose a hazard to mammalian and/or avian wildlife species.

Bioaccumulation-based SQAGs are also needed to evaluate the potential effects of contaminated sediments on human health. For the same reasons that were cited for the bioaccumulation-based guidelines for protecting aquatic-dependent wildlife, it is recommended that the existing guidelines for the protection of human health (e.g., NYSDEC 1999; WDOH 1995; 1996) be adopted directly as interim SQAGs for Florida inland waters. For those substances for which guidelines are available from two or more jurisdictions, the lower of the applicable guidelines should be adopted as the interim SQAGs. These interim SQAGs should be applied in conjunction with tissue residue data and applicable TRGs (e.g., USFDA Action Levels; USEPA 1989) to confirm that contaminated sediments are posing an unacceptable risk to human health.

Chapter 4 Evaluation of the Predictive Ability of Effects-Based Sediment Quality Assessment Guidelines

4.0 Introduction

Effects-based SQAGs are required to support the assessment and management of contaminated sediments in Florida inland waters. The approaches recommended in Chapter 3 provide a basis for cost-effectively establishing such effects-based SQAGs. Based on the results of a preliminary evaluation, MacDonald *et al.* (2000a) concluded that the consensus-based sediment effect concentrations (SECs; which were derived using the approach recommended for establishing effects-based SQAGs for freshwater ecosystems in Florida) provide a reliable basis for assessing sediment quality conditions in freshwater ecosystems. Subsequently, USEPA (2000a) and Ingersoll *et al.* (2001) conducted a further evaluation of these assessment tools using a more robust database and concluded the consensus-based SECs can be used to accurately predict the presence and absence of sediment toxicity on both regional and national bases. The results of these evaluations suggest that the consensus-based SECs are likely to be applicable for assessing sediment quality conditions in Florida inland waters.

Despite the results of the earlier evaluations, the relevance of these SQAGs for assessing sediment quality conditions in the southeast needs to be demonstrated to provide users with a high level of confidence in these tools. For this reason, the consensus-based SECs that were derived by MacDonald *et al.* (2000a) were further evaluated to determine their applicability in Florida and elsewhere in the southeastern portion of the United States. More specifically, the ability of the SQAGs to correctly predict the presence and absence of sediment toxicity, based on sediment chemistry data alone, was evaluated (i.e., the predictive ability of the SQAGs).

This chapter describes the strategy that was used to evaluate the predictive ability of the freshwater SQAGs. More specifically, this chapter describes the efforts that were made to acquire matching sediment chemistry and toxicity data from Florida and elsewhere in the southeastern portion of the United States. In addition, the methods that were used to review and evaluate each of the candidate data sets are described. Furthermore, the procedures that were used to compile the highest quality data sets into a regional sediment toxicity database are described. Finally, the methods that were used to evaluate the predictive ability of the SQAGs and the results of that evaluation are presented.

4.1 Acquisition of Candidate Data Sets

An extensive search of the scientific literature was conducted by the FDEP and MacDonald Environmental Sciences Ltd. (MESL) to acquire matching sediment chemistry and bioeffects data from the southeastern portion of the United States. In the context of this report, the southeast is considered to be comprised of the geographic area within USEPA Region IV (i.e., Florida, Georgia, Alabama, Mississippi, North Carolina, South Carolina, Kentucky and Tennessee). To support the predictive ability evaluation, an effort was made to acquire all of the relevant information on the concentrations of COPCs (i.e., trace metals, PCBs, PAHs, certain OC pesticides, such as chlordane and DDTs, and several other classes of organic COPCs, such as PCDDs and PCDFs) in sediments from the southeast and the associated data on the effects of those sediments to sediment-dwelling organisms (i.e., including the results of sediment toxicity tests and benthic invertebrate community assessments). The process that was used to identify and acquire candidate data sets included:

- Accessing the information contained in MESL's database on the effects of sediment-sorbed COPCs on aquatic organisms (i.e., BEDS);
- Conducting on-line searches of a number of bibliographic databases to obtain recently published articles from peer-reviewed journals;
- Reviewing recent volumes of peer-reviewed journals that routinely publish papers on the effects of sediment-associated COPCs to access recently published data (e.g., *Chemosphere, Environmental Toxicology and Chemistry*; *Water, Air, and Soil Pollution*; *Archives of Environmental Contamination and Toxicology*; *Environmental Science and Technology*; *Ecotoxicology*, etc.); and,

- Contacting various practitioners in the sediment quality assessment field, by either letter or phone, to obtain published and unpublished data sets relevant to this project.

Although data acquisition efforts were initially focused exclusively on the southeast, early results indicated that it was unlikely that the required information would be obtained from USEPA Region IV alone. For this reason, the geographic scope of the target area was expanded to include USEPA Region III and VI. The second challenge that arose during the data acquisition process was the lack of consistency among benthic invertebrate community assessments (e.g., a variety of indices had been used to assess the status of benthic invertebrate communities). As such, it was difficult to identify sediment quality metrics relative to the benthic invertebrate community that could be applied consistently across a number of data sets. For this reason, data acquisition efforts were further focused on obtaining matching sediment chemistry and sediment toxicity data. By making these adjustments to the data acquisition strategy, it was possible to obtain sufficient data (i.e., ≥50 samples for each toxicity test considered: e.g., 28- to 42-d survival or growth of amphipods) to support evaluation of the preliminary SQAGs (i.e., the consensus-based SECs).

4.2 Review and Evaluation of Candidate Data Sets

All data sets and associated documents retrieved during the course of this study were critically evaluated to determine their scientific and technical validity. To support this evaluation, a set of selection criteria were developed in cooperation with the Science Advisory Group on Sediment Quality Assessment (Appendix 2). These selection criteria provided a means of consistently evaluating methods used in each study, including procedures used to collect, handle, and transport sediment samples, protocols that were applied to conduct sediment toxicity tests, methods that were used to determine the concentrations of COPCs in sediments, and the statistical tests that were applied to the study results. In many cases, additional communications with investigators and/or professional judgement were needed to determine if the selection criteria had been satisfied.

4.3 Development of a Regional Sediment Toxicity Database

The data sets that met the selection criteria were incorporated into spreadsheets (in MS Excel format) or directly into the project database (in MS Access format), printed, and verified against the original data sources (i.e., number-for-number). Overall, application of these quality assurance procedures were intended to ensure that only high quality and fully verified data were incorporated into the project database. Additional quality assurance procedures were undertaken to verify that translation problems had not occurred when data were incorporated into the project database (i.e., roughly 10% of the data entries were compared to the original data sources). Finally, the project manager conducted a quality assurance review of the database.

All matching sediment chemistry and toxicity data that met the screening criteria were incorporated into the project database on a per sample basis. Each record in the resultant database included the citation, a brief description of the study area (i.e., by waterbody and reach), a description of the sampling locations (including georeferencing data, if available), information on the toxicity tests that were conducted (including species tested, endpoint measured, test duration, etc.), type of material tested (i.e., whole sediment, pore water, or elutriate), the TOC concentrations (if reported), and the chemical concentrations (expressed on a dry weight basis). Other supporting data, such as SEM concentrations, AVS, particle size distributions, and water temperature, were also included in the individual data records, as available.

Using the selection criteria identified in Appendix 2, a total of 38 freshwater data sets from USEPA Regions III, IV, and VI were incorporated into the regional database. The assembled database includes data on a large number of samples with a broad range of concentrations and many different bioassay endpoints. A list of the data sets that were incorporated into the project database, including geographic area sampled, number of samples, and bibliographic citation, is provided in Table 4.1. These data sets provided information on the toxicity of whole-sediment samples to the following species: the amphipod, *Hyalella azteca* or *Leptocheirus plumulosus* (endpoints: survival, growth, and reproduction); the midge, *Chironomus tentans* (endpoints: survival and growth); the cladocerans (i.e., water fleas), *Daphnia magna* or *Ceriodaphnia dubia* (endpoints: survival and reproduction); the clam, *Corbicula fluminea* (endpoint: survival); flathead minnow, *Pimephales promelas* (endpoint: survival); and the bacterium, *Vibrio fisheri* (Microtox; endpoint: bioluminescence).

Additionally, the results of pore-water toxicity tests on the following species were incorporated into the regional database: the amphipod, *Hyalella azteca* (endpoint: survival); the cladoceran, *Daphnia magna* (endpoint: survival); steelhead trout, *Oncorhynchus mykiss* (endpoint: survival); and the bacterium, *Vibrio fisheri* (endpoint: bioluminescence).

Although matching sediment chemistry and toxicity data were available on various species and toxicity test endpoints, only a subset of these data were selected for evaluating the predictive ability of the preliminary SQAGs. More specifically, the results of the following toxicity tests were used in the predictive ability evaluation (Table 4.2):

- 10-d whole-sediment toxicity tests with the amphipod, *Hyalella azteca* (endpoints: survival; and, survival or growth);
- 28- to 42-d whole-sediment toxicity tests with the amphipod, *Hyalella azteca* (endpoints: survival; and, survival or growth);
- 10-d whole-sediment toxicity tests with the midge, *Chironomus tentans* (endpoints: survival or growth); and,
- Overall toxicity (i.e., the results of any of the above whole-sediment toxicity tests).

These toxicity test results were selected for use in the evaluation of the preliminary SQAGs for several reasons. First, 10-d and 28- to 42-d tests with amphipods and 10-d tests with midges are standard toxicity tests, for which a large quantity of data are currently available nationally. As such, the results of tests conducted with sediment samples from Florida and elsewhere in the southeast can be readily compared to the results of tests conducted elsewhere in the United States. In this respect, the results of tests compiled in the regional database can be compared to the concentration (i.e., mean PEC-Q) - response (i.e., percent incidence of toxicity) relationships that were developed using a larger database (USEPA 2000a; Ingersoll *et al*. 2001). Importantly, the results of these whole-sediment toxicity tests represent the most robust data sets in the regional database. Individual samples were designated as toxic or not toxic based on a statistically significant reduction in survival or growth relative to a control or reference sediment.

To support subsequent interpretation of the sediment chemistry data, the total concentrations of several chemical classes were determined for each sediment sample. Specifically, the concentrations of total PAHs were calculated by summing the concentrations of up to 13 individual PAHs, including acenaphthene, acenaphthylene, anthracene, fluorene, 2-methylnaphthalene, naphthalene, phenanthrene, benz[a]anthracene, dibenz[a,h]anthracene, benzo(a)pyrene, chrysene, fluoranthene, and pyrene. For PCBs, the concentrations of total PCBs were determined using various procedures, depending on how the data were reported in the original study. If only the concentrations of total PCBs was reported in the study, then those values were used directly. If the concentrations of various Aroclors (e.g., Aroclor 1242, Aroclor 1248) were reported, then the concentrations of the various Aroclors were summed to determine the concentration of total PCBs. When the concentrations of individual congeners were reported, these values were summed to determine total PCB concentrations. An evaluation conducted by the CCME (1999) indicated that all three procedures for estimating the concentration of tPCB yielded roughly equivalent results. For DDTs, the concentrations of p,p'-DDD and o,p'-DDD, p,p'-DDE and o,p'-DDE, and p,p'-DDT and o,p'-DDT were summed to calculate the concentrations of sum DDD, sum DDE, and sum DDT, respectively. Total DDTs was calculated by summing the concentrations of sum DDD, sum DDE, and sum DDT. Finally, the concentrations of chlordane were determined by summing the concentrations of alpha- and gamma-chlordane isomers. If only the concentrations of total chlordane were reported in the study, then those values were used directly. In calculating the total concentrations of the various chemical classes, less than detection limit values were assigned a value of one-half of the detection, except when the detection limit was greater than the consensus-based PEC (or an alternate sediment quality guideline if a PEC was not available; MacDonald *et al.* 2000a). In this latter case, the less than detection limit value was not used in the calculation of the total concentration of the substance or in the calculation of mean PEC-Qs.

4.4 Evaluation of the Effects-Based Sediment Quality Assessment Guidelines

Based on the results of the evaluation presented in Chapter 3, the consensus-based SECs (i.e., TECs and PECs) that were derived by MacDonald *et al.* (2000a) are recommended as preliminary SQAGs for Florida inland waters. The underlying guidelines that were used to derive the consensus-based TECs and PECs are described in Table 4.3, and listed in Tables 4.4 and 4.5, respectively (MacDonald *et al.* 2000a).

Previous evaluations of numerical SQGs have typically focused on determining their reliability and predictive ability. The results of evaluations of reliability provide the information needed to determine if the SQAGs for individual substances are consistent with their stated narrative intent. For example, the consensus-based TECs are intended to define the concentrations of sediment-associated contaminants below which adverse effects on sediment-dwelling organisms are likely to occur only infrequently. By determining the incidence of toxicity (i.e., number of toxic samples divided by the total number of samples) in sediment samples in which the concentrations of the selected substance (e.g., cadmium) is below the TEC, it is possible to determine the reliability of the associated SQAG. MacDonald *et al.* (2000a; 2000b; 2001) applied these procedures to evaluate the reliability of the consensus-based TECs and PECs for freshwater ecosystems and concluded that the SECs for most chemicals provided a reliable basis for classifying sediment samples as toxic and not toxic (Tables 4.6, 4.7, and 4.8; MacDonald *et al.* 2000a). The matching sediment chemistry and toxicity data that were used in this evaluation were largely independent of the underlying guidelines that were used to develop the SECs [i.e., a portion of the data used to evaluate predictive ability had been used to derive the TELs/PELs and TEL-*Hyalella azteca* (HAs)/PEL-HAs; however, none of these data had been used to derive the lowest effects level/severe effects level (LELs/SELs), moderate effects threshold/toxic effects threshold (METs/TETs), ERLs/ERMs, or sediment quality advisory levels (SQALs); Table 4.3].

While the SECs for the individual chemical substances provide reliable tools for assessing sediment quality conditions (MacDonald *et al.* 2000a), the predictive ability of these SQGs should be enhanced when the SQAGs are used together in assessments of sediment quality (i.e., because in-place sediments usually contain complete mixtures of COPCs; MacDonald *et al.* 2000a). In addition, it would be helpful to consider the magnitude of the exceedances of the SQAGs in such assessments. In response to the need for enhanced assessment tools, Long *et al.* (1998b) developed a procedure for evaluating the biological significance of COPC mixtures in marine and estuarine sediments through the application of mean SQAG-quotients (SQAG-Qs; which were calculated as the arithmetic mean of the SQAG-Q that was calculated for each measured substance, where SQAG-Q = concentration of a substance divided by the SQAG for that substance). Subsequently, USEPA (2000a) and Ingersoll *et al.* (2001) evaluated 11 difference procedures for calculated mean SQAG-Qs and concluded that the *"Mean-MPP (or)"* procedure for calculating mean PEC-Qs yielded the most robust (i.e., included the largest number of samples) and reliable (i.e., concordance between sediment chemistry and toxicity) results for freshwater sediments. Therefore, the analyses of the predictive ability were conducted for mean PEC-Qs that were calculated using the *"Mean-MPP (or)"* procedure (USEPA 2000a; Ingersoll *et al.* (2001). Using this procedure, mean PEC-Qs were determined for each sediment sample in the database by calculating the arithmetic mean of the mean PEC-Q for metals, the PEC-Q for total PAHs, and/or the PEC-Q for total PCBs.

4.5 Predictive Ability of the Effects-Based Sediment Quality Assessment Guidelines

In this evaluation, the predictive ability of the preliminary SQAGs was evaluated in two ways. First, the incidence of sediment toxicity within relevant ranges of mean PEC-Qs was calculated using the information contained in the regional database and compared to the incidence of biological effects that was observed for sediments collected at sites located throughout the United States (Table 4.9; USEPA 2000a and Ingersoll *et al.* 2001). More specifically, the incidence of toxicity for each of the selected toxicity tests was determined for the following categories of mean PEC-Qs: <0.1, 0.1 to <0.5, 0.5 to <1.0, 1.0 to <5.0, ≥1.0, and ≥5.0. These ranges are the same as those used in the USEPA (2000a) evaluation of the predictive ability of the consensus-based PECs. The regional data were considered to be consistent with the national data if the incidence of toxicity within ranges of mean PEC-Qs was within 10% of that determined for the national database.

The predictive ability of the preliminary SQAGs was also evaluated by deriving concentration-response relationships from the information contained in the regional database. More specifically, the relationship between mean PEC-Qs (concentration) and incidence of toxicity (response) was evaluated by fitting logistic regression models to summarized data for each toxicity test endpoint (i.e., using SigmaPlot 2000, Version 6.00). More specifically, the underlying sediment chemistry and toxicity data were sorted by increasing mean PEC-Q and compiled in groups of 10 to 50 samples, depending on the number of samples available for each endpoint (i.e., to yield a minimum of 10 groups of samples). For each group of samples, which are termed concentration intervals, the geometric mean of the mean PEC-Q and the incidence of toxicity were calculated. These summarized data were then plotted and used to generate the logistic regression models for each toxicity test endpoint. The correlation coefficient (r^2) and level of significance (p) were then determined for each model. Subsequently, the regional concentration-response relationships were compared to the concentration-response curves generated by USEPA (2000a) using the results of 10- to 14-d toxicity tests with *Hyalella azteca*, 28- to 42-d toxicity tests with *Hyalella azteca*, and 10- to 14-d toxicity tests with *Chironomus spp*. The regional data were considered to be consistent with the national data if the regional dose-response curve generally fell within the 95% prediction limits for the relationship that was generated using the information contained in the national database.

The results of this evaluation of predictive ability indicate that the preliminary SQAGs are likely to provide a reliable basis for assessing effects on sediment-dwelling organisms in Florida and elsewhere in the southeast portion of the United States. For the 10-d whole-sediment toxicity tests with *Hyalella azteca* (n=522 samples), the incidence of sediment toxicity (i.e., as measured using data on amphipod survival or amphipod survival or growth; Table 4.10) increased consistently and markedly with increasing COPC concentrations (i.e., as indicated by mean PEC-Qs). At mean PEC-Qs of <0.1, the incidence of acute toxicity (i.e., survival or growth) to amphipods was low (i.e., 13%; n=116). The incidence of sediment toxicity increased to 18% (n=385) at mean PEC-Qs of 0.1 to 1.0. Higher mean PEC-Qs were associated with a higher incidence of acute toxicity to amphipods (i.e., 48% for mean PEC-Qs of $\geq$1.0, n=21; and, 100% for mean PEC-Qs of $\geq$5.0, n=3). By comparison, the incidence of acute toxicity to amphipods (i.e., based on the results of 10- to 14-d whole-sediment toxicity tests with *Hyalella azteca*) in the national database was 18% for mean PEC-Qs of <0.1 (n=147), 20% for mean PEC-Qs of 0.1 to <1.0 (n=361), 54% for mean PEC-Qs of $\geq$1.0 (n=162), and 71% for mean PEC-Qs of $\geq$5.0 (n=70; USEPA 2000a). Hence, the incidence of acute toxicity to amphipods in the regional and national databases generally agreed within 10% within the various concentration intervals (i.e., for 5 of 6 concentration intervals; Tables 4.9 and 4.10). Importantly, the concentration-response curve generated using the matching sediment chemistry and toxicity data from the regional database fell within the 95% prediction limits for the dose-response relationship that was generated using the information contained in the national database (Figures 4.1 and 4.2). Therefore, it is concluded that systematic differences between the regional and national databases are not apparent when data on the acute toxicity of freshwater sediments to amphipods is evaluated.

A substantial quantity of data from 28- to 42-d whole-sediment toxicity tests with the amphipod, *Hyalella azteca*, are available to evaluate the predictive ability of the preliminary SQAGs (n = 174 samples). Considering either survival or growth, the incidence of chronic sediment toxicity was low (i.e., 13%; n=53) at low mean PEC-Qs (i.e., <0.1; Table 4.10). The incidence of chronic toxicity was higher (i.e., 30%; n=110) at mean PEC-Qs of 0.1 to <1.0. Amphipod survival or growth was significantly reduced in 45% of the sediment samples with mean PEC-Qs of ≥1.0 (n=11). By comparison, the incidence of chronic toxicity to amphipods in the national database was 10% (n=63), 30% (n=66), and 97% (n=31) at mean PEC-Qs of <0.1, 0.1 to 1.0, and ≥1.0, respectively (Table 4.9). These results, combined with the concentration-response curves for survival and survival or growth of amphipods (Figures 4.3 and 4.4), suggest that there may be differences between the regional and national data sets. Specifically, amphipod survival appears to be reduced at lower levels of contamination in sediments from the southeast than is the case for sediments from elsewhere in the United States (Figure 4.3; Table 4.11). However, when survival or growth is considered, the reverse may be true, particularly at elevated mean PEC-Qs (i.e., >1.0; Figure 4.4). Therefore, it is not unreasonable to conclude that the differences between the national and regional concentration-response relationships are minor when chronic toxicity to amphipods is considered.

The results of acute toxicity tests (i.e., 10-d) with midges were also used to evaluate the predictive ability of the preliminary SQAGs. The results of this evaluation indicated that the incidence of toxicity (i.e., survival or growth) to midges was relatively low (i.e., 23%; n=26) in sediments with mean PEC-Qs of <0.1 (Table 4.10). At mean PEC-Qs of 0.1 to 1.0, the incidence of sediment toxicity decreased to 11% (n=103). The incidence of toxicity was higher (i.e., 75%; n=4) in sediments with mean PEC-Qs of ≥1.0. By comparison, the incidence of acute toxicity to midges (i.e., based on the results of 10- to 14-d whole-sediment toxicity tests with the survival and growth endpoints) in the national database was 20% for mean PEC-Qs of <0.1 (n=121), 21% for mean PEC-Qs of 0.1 to <1.0 (n=376), and 52% for mean PEC-Qs of ≥1.0 (n=132; USEPA 2000a). Hence, the incidence of toxicity to midges in the regional and national databases generally agreed within 10% for the three concentration intervals, with the largest differences observed for the highest concentration interval (Table 4.10). The incidence of acute toxicity was not well correlated with COPC concentrations (as indicated by mean PEC-Qs) in the regional database, as evidenced by the lower correlation coefficient ($r^2 = 0.42$; p=0.07) compared to the national database ($r^2 = 0.56$; p=<0.0001; Table 4.11; Figure 4.5). Therefore, it would be difficult to conclude that systematic differences in the toxicity of freshwater sediments to midges exist between the regional and national databases.

Overall toxicity can be evaluated by considering the results of the selected toxicity tests conducted on a sediment sample. In this analysis, sediment samples found to be toxic in one or more of the toxicity tests were designated as toxic for overall toxicity. Using this designation, 18% (n=150) of the sediment samples with mean PEC-Qs of <0.1 were toxic to one or more of the organisms tested and endpoints measured (Table 4.10). By comparison, the incidence of sediment toxicity was 21% (n=467) in the samples with mean PEC-Qs of 0.1 to <1.0. The incidence of toxicity was higher in sediment samples in which the mean PEC-Q was ≥1.0 (i.e., 42%; n=26) and ≥5.0 (75%; n=4). As such, the overall toxicity of sediment samples generally increases with increasing levels of sediment contamination (as indicated by mean PEC-Qs).

In summary, the available data on the toxicity of sediment samples from Florida and elsewhere in the southeast portion of the United States indicate that the preliminary SQAGs can be used to accurately classify sediment samples as toxic and not toxic using sediment chemistry data alone. Because systematic differences were not observed in the toxicity of regionally-collected or nationally-collected sediment samples to amphipods or midges, it is reasonable to conclude that the concentration-response relationships that were developed using the national database apply to Florida. Based on those nationally-derived concentration-response relationships, the probability of observing chronic toxicity to amphipods is 50% at a mean PEC-Q of 0.63 (USEPA 2000a). Because sediment-dwelling organisms are likely to be exposed to contaminated sediments for extended periods of time (i.e., >28-d), benthic invertebrate communities are likely to be adversely affected when exposed to sediments in which the chronic toxicity threshold is exceeded. Therefore, it is likely that adverse effects on sediment-dwelling organisms would occur frequently in sediments from Florida inland waters when this level of sediment contamination (i.e., mean PEC-Q of 0.63) is exceeded. In contrast, the probability of observing chronic toxicity is low (i.e., <10%) at mean PEC-Qs of <0.1. Sediment-dwelling organisms would be provided with a high level of protection in sediments with these chemical characteristics.

Chapter 5 Recommended Sediment Quality Assessment Guidelines for Florida Inland Waters

5.0 Introduction

Through the Water Resource Management Program, FDEP has the primary responsibility for protecting the quality of Florida's rivers, lakes, and wetlands. To support water management initiatives within the state, FDEP has identified designated water uses, promulgated numerical water quality standards to protect those uses, and established an antidegradation policy to protect high quality waters. Such water quality standards provide an effective basis for managing water quality conditions in Florida.

In addition to water quality standards, integrated management of aquatic ecosystems requires a basis for assessing and managing aquatic-dependant resources, including sediment quality condition. For this reason, FDEP has identified SQAGs as an important tool for assessing the quality of aquatic habitats. This chapter presents the SQAGs that are recommended for assessing sediment quality conditions in Florida inland waters. The SQAGs describe the conditions that need to be maintained to ensure that sediment-dwelling organisms, aquatic-dependent wildlife, or human health are not adversely affected by the presence of toxic and/or bioaccumulative substances in sediments. Numerical SQAGs have been recommended for COPCs when sufficient information was available to do so. Because it was not possible to recommend numerical SQAGs for many of the COPCs in Florida inland waters (see Chapter 2), narrative SQAGs have also been recommended to support assessments of sediment quality conditions.

5.1 Narrative Sediment Quality Assessment Guidelines

Although it is desirable to establish numerical SQAGs for all of the COPCs that occur or are likely to occur in Florida inland waters, recommendation of such SQAGs is limited by the availability of guidelines from other jurisdictions and/or by the availability of suitable toxicological information for certain substances. For this reason, it is necessary to recommend narrative SQAGs that can be used to assess sediment quality conditions within the state. In addition, procedures for evaluating compliance with the narrative SQAGs are needed.

5.1.1 Toxic Substances

A number of toxic substances have been identified as COPCs in Florida inland waters. For many of these substances, sufficient toxicological data exist to recommend numerical SQAGs (see Section 5.2.1). However, limitations on the availability of information preclude the derivation of numerical SQAGs for other COPCs. For this reason, the following narrative SQAG is recommended to support the assessment of sediment quality conditions in the state:

> *Toxic substances should not occur in shoreline or bottom sediments, either singly or in combination, at concentrations that adversely affect, or can reasonably be expected to adversely affect, biological resources (i.e., sediment-dwelling organisms, fish, amphibians, and reptiles).*

In the context of this report, an adverse effect on a biological resource is considered to have occurred if one or more of the following adverse changes in viability have been observed, or are likely to occur, in response to exposure to one or more COPCs: death, disease, behavior abnormalities, cancer, genetic mutations, physiological malformations, or physical deformities (USDOI 1996).

Compliance with the above narrative SQAG cannot be measured directly. For this reason, it is necessary to establish a number of indicators of sediment quality conditions. The following are recommended as the primary indicators for assessing adverse effects on sediment dwelling organisms: sediment chemistry and sediment toxicity (MacDonald *et al.* 2002a). Secondary indicators of sediment quality conditions include benthic invertebrate community structure, tissue chemistry, and physical habitat characteristics. Relative to sediment chemistry, the recommended numerical SQAGs presented in Section 5.2.1 identify the concentrations of COPCs that are unlikely to cause or substantially contribute to sediment toxicity (i.e., TECs) and those that are sufficient to cause or substantially contribute to sediment toxicity (i.e., PECs). The chemical mixture model (i.e., as expressed in terms of mean PEC-Qs) provides a means of estimating the probability of observing chronic toxicity to amphipods in sediments with various chemical characteristics.

In addition to applying sediment chemistry data, compliance with the narrative SQAG can also be evaluated using sediment toxicity data. In this context, the 28-d whole-sediment toxicity tests with the amphipod, *Hyalella azteca* (endpoints: survival and growth) is recommended as the primary basis for assessing compliance with the narrative SQAG relative to sediment-dwelling organisms. Using this test, sediments are considered to be toxic to sediment-dwelling organisms if the measured response of the test organisms exposed to sediments from an assessment area is significantly different from the response that is observed in an appropriately selected control or reference sediment (ASTM 2001a; Ingersoll *et al.* 2002).

5.1.2 Bioaccumulative Substances

In addition to causing toxicity to sediment-dwelling organisms, many of the COPCs in Florida can accumulate in the tissues of aquatic organisms and, in so doing, pose a hazard to aquatic-dependent wildlife and/or human health. While numerical SQAGs have been recommended for a number of these substances (see Section 5.2.2), such SQAGs are not available for several other bioaccumulative COPCs. For this reason, the following narrative SQAG is recommended to support the assessment of sediment quality conditions in the state:

> *Bioaccumulative substances should not occur in shoreline or bottom sediments, either singly or in combination, at concentrations that adversely affect, or can reasonably be expected to adversely affect, aquatic-dependent wildlife or human health.*

In the context of this report, adverse effects on aquatic-dependent wildlife and/or human health are considered to have occurred if one or more of the following adverse changes in viability have been observed, or are likely to occur, in response to exposure to one or more COPCs: death, disease, behavior abnormalities, cancer, genetic mutations, physiological malformations, or physical deformities (USDOI 1996). Issuance of fish consumption advisories is also considered to represent an adverse effect on human health (i.e., an impairment of the beneficial uses of the aquatic ecosystem).

Compliance with the above narrative SQAG cannot be measured directly. For this reason, it is necessary to establish a number of indicators of injury to biological resources. The following indicators are recommended for assessing injury to sediment dwelling organisms: sediment chemistry and tissue chemistry (MacDonald *et al.* 2002b). With respect to sediment chemistry, the recommended numerical SQAGs presented in Section 5.2.2 identify the concentrations of COPCs in sediments that are sufficient to cause or substantially contribute to adverse effects on aquatic-dependent wildlife and human health.

While sediment chemistry data provide relevant information for assessing the potential for bioaccumulation of sediment-associated contaminants in the tissues of aquatic organisms, confirmation of risks to aquatic-dependent wildlife and human health necessitates the collection of tissue residue data. More specifically, compliance with the narrative SQAG should be evaluated by comparing the levels of bioaccumulative COPCs in the tissues of aquatic organisms to numerical TRGs for the protection of piscivorus wildlife (Newell *et al.* 1987) and/or for the protection of human health (e.g., Food and Drug Administration action levels and tolerance levels; USEPA 1989).

5.2 Numerical Sediment Quality Assessment Guidelines

The narrative statements presented in Section 5.1 describe the level of protection that FDEP intends to afford ecological and human receptors through the application of SQAGs. While such narrative SQAGs clearly define the use protection goals for freshwater ecosystems in Florida, numerical SQAGs are also needed to support sediment management initiatives in the state.

5.2.1 Effects-Based Sediment Quality Assessment Guidelines

In accordance with the recommended approach (Section 3.2), the consensus-based TECs and PECs were identified as preliminary SQAGs for Florida inland waters. In total, preliminary effects-based SQAGs were recommended for 29 COPCs in the state (MacDonald *et al.* 2000a). The results of the reliability evaluations indicate that the consensus-based TECs and PECs can be used to establish reliable, effects-based SQAGs for Florida inland waters. More specifically, the TECs identify the concentrations of sediment-associated COPCs below which adverse effects on sediment-dwelling organisms are unlikely to occur (i.e., false negative rates are typically < 25% using the TECs; i.e., incorrectly identifying sediment samples as not toxic when they are actually toxic to one or more species; MacDonald *et al.* 2000a). In addition, the PECs identify the concentrations of sediment-associated COPCs above which adverse effects on sediment-dwelling organisms are likely to occur (i.e., false positive rates are typically < 25% using the PECs; i.e., incorrectly identifying sediment samples as toxic when they are actually not toxic; MacDonald *et al.* 2000a). A lower incidence of toxicity was reported at concentrations above the PEC for heptachlor epoxide, while no data were available for evaluating the reliability of the PEC for endrin. Because the preliminary SQAGs provide a reliable basis to classifying sediments as toxic to sediment-dwelling organisms, they are recommended as effects-based SQAGs for assessing sediment quality conditions in Florida. The TEC-type and PEC-type guidelines from other jurisdictions that are recommended as interim SQAGs are also included in Table 5.1.

While the preliminary effects-based SQAGs for individual COPCs provide reliable tools for assessing sediment quality conditions, predictive ability is enhanced when the SQAGs are used together to assess sediment quality conditions. USEPA (2000a) recommended the use of mean PEC-Qs to facilitate the assessment of sediments with mixtures of COPCs (i.e., metals, PCBs, and/or PAHs). Based on the results of the USEPA (2000a) evaluation, the probability of observing sediment toxicity is 10% and 50% at mean PEC-Qs of 0.12 and 0.63, respectively. The results of the predictive ability evaluation conducted in this study indicated that the relationships between concentration (i.e., mean PEC-Qs) and response (i.e., incidence of toxicity) generated using the national database and the regional database are similar (i.e., the logistic regression curve for the regional database largely falls within the 95% prediction limits for the national database).

The results of the predictive ability evaluations indicate that the chemical mixture models that utilize the consensus-based PECs can be used to accurately assess the presence and absence of sediment toxicity in Florida inland waters and elsewhere in the southeast. In sediments that contain mixtures of contaminants, mean PEC-Qs of 0.12 and 0.63 are recommended as SQAGs for assessing sediments with mixtures of COPCs. The probability of observing chronic toxicity to sediment-dwelling organisms (i.e., the amphipod, *Hyalella azteca*) is <10% below a mean PEC-Q of 0.12 and >50% above a mean PEC-Q of 0.63.

5.2.2 Bioaccumulation-Based Sediment Quality Assessment Guidelines

The bioaccumulation-based SQGs that were derived by New York State Department of Environmental Conservation (NYSDEC 1999) are recommended as interim bioaccumulation-based SQAGs for the protection of aquatic-dependent wildlife (Table 5.2). As insufficient data are available to evaluate the reliability of these SQAGs in Florida or elsewhere in the southeastern portion of the United States, it is recommended that collection of the requisite data to evaluate the bioaccumulation-based SQAGs be identified as a priority. The types of information that would support such an evaluation include the results of standard 28-d bioaccumulation tests with the oligochaete, *Lumbriculus variegatus* (i.e., ASTM 2001b), matching sediment chemistry and tissues residue data for field-collected sediments and infaunal invertebrate species, and relevant bioaccumulation/food web models (i.e., to estimate the transfer of COPCs to aquatic-dependent wildlife).

The bioaccumulation-based SQGs that were derived by New York State Department of Environmental Conservation (NYSDEC 1999) and the Washington State Department of Health (WDOH 1995; 1996) are recommended as interim bioaccumulation-based SQAGs for the protection of human health (Table 5.2). For each bioaccumulative COPC, the lower of the guidelines reported by these two jurisdictions was selected as the interim SQAG for the protection of human health.

Chapter 6 Applications of the Numerical Sediment Quality Assessment Guidelines

6.0 Introduction

In Florida, there are a variety of environmental programs and program activities that necessitate the collection and interpretation of information on sediment quality conditions. The numerical SQAGs that were recommended in Chapter 5 of this report are likely to support many of these activities by providing a basis for interpreting sediment chemistry data relative to the potential for observing adverse effects on sediment-dwelling organisms, aquatic-dependent wildlife, and/or human health. This chapter provides an overview of the potential uses of effects-based and bioaccumulation-based SQAGs in a variety of program applications in Florida. More specifically, the following sections of this report briefly discuss how the SQAGs can be used in:

- Monitoring and assessment initiatives;
- Assessment and management of contaminated sites;
- Restoration of wetland habitats;
- Assessment of ecological risks; and,
- Environmental regulation programs.

Although the potential uses of SQAGs are explicitly described, it is important to note that the SQAGs should be used along with other sediment quality assessment tools, such as the Florida metals interpretative tool (Carvalho and Schropp 2002) and sediment toxicity tests (ASTM 2001a; USEPA 2000b), within an integrated framework to support decisions regarding the management of contaminated sediments. Such a framework for assessing contaminated sediments is provided in the companion documents to this report (MacDonald and Ingersoll 2002a; 2002b; Ingersoll and MacDonald 2002).

6.1 Monitoring and Assessment Initiatives

Ambient environmental monitoring represents an essential element of virtually all programs that are focused on the assessment and management of environmental conditions. Without the data that are generated in such monitoring programs, the information needed to support environmental management decisions would be unavailable. Some of the specific applications of the SQAGs in monitoring and assessment initiatives in Florida include: supporting the design of monitoring programs; interpreting the results of monitoring programs; identifying COPCs and areas of concern; and, evaluating sediment quality conditions in stormwater ponds.

6.1.1 Designing Environmental Monitoring Programs

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 monitoring, etc.), limitations on available resources dictate that they must be conducted in an effective and efficient manner. 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.

The numerical SQAGs contribute to the design of environmental monitoring programs in several ways. First, comparison of existing sediment chemistry data to 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 utilized to identify COPCs within an area of concern. By considering the potential sources of these substances, it may be possible to further identify priority sites for investigation. The SQAGs can also assist in monitoring program design by establishing target detection limits for each substance (e.g., <0.5 x TEC; MacDonald and Ingersoll 2002b). Determination of the detection limits that are needed to support further interpretations of sediment chemistry data should help to avoid many of the difficulties that have resulted from the use of standard, yet inappropriate, analytical methods.

6.1.2 Interpreting Environmental Monitoring Data

Ambient monitoring of freshwater ecosystems in Florida is primarily focused on the assessment of water quality conditions. However, it is likely that sediment quality monitoring activities will intensify in the future. Numerical SQAGs are likely to support ambient monitoring initiatives by assisting in identification of issues and concerns relative to sediment quality conditions, the design of sampling programs, and interpretation of the resultant data.

The numerical SQAGs provide consistent tools for evaluating spatial patterns in chemical contamination. More specifically, the SQAGs can be used to compare and rank sediment quality conditions among sites located within an area of concern (Long and MacDonald 1998). If a stratified random sampling design is used in the monitoring program, then the SQAGs provide a basis for calculating the spatial extent of potentially toxic sediments. In the areas of greatest concern, further investigations would typically be implemented to explicitly identify the sources of COPCs, assess the areal extent and severity of sediment toxicity, evaluate the potential for bioaccumulation, and/or determine the need for source control measures or other remedial measures. The SQAGs can also be used to evaluate the success of any regulatory actions that are implemented at the site (Macfarlane and MacDonald 2002).

While previous guidance has cautioned against using the SQAGs as stand alone decision-making tools, the results of recent evaluations of reliability and predictive ability substantially increase the level of confidence that can be placed in the SQAGs. In the national database, for example, there is a low probability (i.e., 8%) of observing sediment toxicity in sediments with mean PEC-Qs below 0.1 (i.e., based on the results of 28- to 42-day toxicity tests with amphipods; USEPA 2000a). In contrast, the probability of observing sediment toxicity is relatively higher at mean PEC-Qs of 0.5 to 1.0 (56%) and >1.0 (97%; USEPA 2000a). Therefore, the PECs can also be used directly to support certain sediment management decisions (e.g., to implement source control measures, to conduct sediment remediation, etc.). These tools are particularly efficient for evaluating sediment quality conditions at relatively small sites, where the costs of further investigations could approach or exceed the costs of implementing the remedial measures (MacDonald and Ingersoll 2002a; 2002b; Ingersoll and MacDonald 2002).

6.1.3 Identifying Chemicals of Potential Concern

As previously discussed, many substances that are present at only trace levels in water can accumulate to elevated levels in sediments. The effects-based and bioaccumulation-based SQAGs provide a basis for identifying the substances that occur in sediments at concentrations that pose a potential hazard to sediment-dwelling organisms, aquatic-dependent wildlife, and/or human health. More specifically, the numerical SQAGs can be used to identify, rank, and prioritize COPCs in freshwater sediments. In this application, the concentration of each chemical substance can be compared to the corresponding SQAG. Those substances that occur at concentrations below the TECs should be considered to be of low priority relative to the potential for effects on sediment-dwelling organisms. Those substances that occur at concentrations above the TEC but below the PEC should be considered to be of moderate concern, while those that are present at concentrations in excess of the PECs should be considered to be of relatively high concern (Long and MacDonald 1998).

The relative priority that should be assigned to each chemical can be determined by evaluating the magnitude and frequency of exceedance of the SQAGs. Chemicals that frequently exceed the PECs and/or those that exceed the PECs by a large margin should be viewed as the chemicals of greatest concern (Long and MacDonald 1998). In conducting such assessments, it is also important to remember that certain chemicals can be present in relatively unavailable forms (such as slag, paint chips, tar, etc.). Therefore, it is not a 100% certainty that samples with chemical concentrations in excess of the PECs will actually be toxic to sediment-dwelling organisms. Additionally, the reliability of the SQAGs should be considered when conducting evaluations of chemicals of concern, with the greatest weight assigned to those SQAGs which have been shown to be highly or moderately reliable (MacDonald *et al.* 2000a; Ingersoll *et al.* 1996; 2001)

The degree of confidence that can be placed in determinations of COPCs can be increased by collecting ancillary sediment quality information. Specifically, data on regional background concentrations of sediment-associated COPCs (e.g., metals) can be used to identify substances of relatively low concern with respect to anthropogenic activities (i.e., those that occur at or below background levels). In Florida, an interpretive tool has been developed for assessing metal enrichment in freshwater sediments (Carvalho and Schropp 2002). Using this tool, the metals that exceed the SQAGs and the upper limit of background conditions (i.e., 95% prediction limit) should be considered to be the highest priority for further investigations. Data from toxicity tests can also be used to support the identification of COPCs. In particular, matching sediment chemistry and sediment toxicity data provide a basis for evaluating the degree of concordance between the concentrations of specific COPCs and measured adverse effects (i.e., using correlation analyses and regression plots; Carr *et al.* 1996). Those substances that are present at elevated concentrations (i.e., as indicated by exceedances of the PECs) in toxic samples should be identified as the chemicals of greatest concern (Long and MacDonald 1998). Those chemicals that are not positively correlated to the results of the toxicity tests should be viewed as relatively lower priority.

For bioaccumulative substances, the SQAGs also provide an important basis for identifying COPCs. In this case, the results of laboratory bioaccumulation tests (e.g., using the oligochaete, *Lumbriculus variegatus*) and/or tissue residue analyses conducted on field-collected samples of benthic organisms can be used to validate that bioaccumulative COPCs are present in bioavailable forms.

6.1.4 Identifying Areas of Concern

The numerical SQAGs can be used to identify areas of potential concern with respect to the potential for observing adverse biological effects. In this application, the concentrations of sediment-associated COPCs should be compared to the corresponding SQAGs. Sediments in which none of the measured chemical concentrations exceed the TECs should be considered to have the lowest potential for adversely affecting sediment-dwelling organisms and could be considered as reference areas (Long and Wilson 1997). However, the potential for unmeasured substances to be present at levels of toxicological concern can not be dismissed without evaluating detailed information on land and water uses within the water body or the results of toxicity tests. Those sediments which have concentrations of one of more COPCs between the TECs and PECs should be considered to be of moderate priority, while those sediments with COPC concentrations in excess of one or more PECs should be considered to be of relatively high concern (Long and MacDonald 1998). Once again, the magnitude and frequency of exceedances of the PECs provide a basis for assigned relative priority to areas of concern with respect to contaminated sediments. The bioaccumulation-based SQAGs can also be used in this way to help identify areas of potential concern.

Sediment chemistry and associated data from sediment coring and profiling studies can be used to determine the timing and progression of sediment contamination within a site. The metals interpretive tool (Carvalho and Schropp 2002) is likely to be particularly useful in this application because it provides a means of identifying sediments in which metals have been enriched as a result of human activities. Data from such studies can also be used to identify natural background levels. In turn, the SQAGs can be used to determine the levels of sediment-associated contaminants that pose a potential hazard to ecological receptors.

6.1.5 Identifying Sources of Chemicals of Potential Concern

In addition to assessing status and trends in sediment quality conditions, environmental monitoring programs can provide important information for identifying sources of COPCs. In this context, the SQAGs can be used to identify areas in which sediment quality conditions have degraded to such a point that contaminated sediments pose hazards to sediment-dwelling organisms, aquatic-dependent wildlife, and/or human health. By applying overlay mapping techniques, it is possible to identify the sources of COPCs that are most likely affecting sediment quality conditions. In addition, the significance of atmospheric deposition of COPCs can be evaluated by applying the metals interpretive tools and the SQAGs together to identify areas (i.e., that are not influenced by point sources or other non-point sources of COPCs) in which anthropogenic enrichment has occurred and sediment quality conditions pose a potential hazard to ecological receptors or human health.

6.1.6 Supporting Watershed Assessments

In Florida, watershed assessments are conducted periodically to evaluate the status and trends of freshwater ecosystems. Such assessments, which are conducted in five year cycles, are currently focused on evaluating water quality conditions (i.e., primarily conventional variables, bacteriological characteristics conditions, and nutrient levels) in groundwater, streams, and lakes in the state, as well as the status of various biological indicators of ecosystem health. In the future, the scope of such assessments could be expanded to include evaluations of sediment quality conditions. Numerical SQAGs are likely to support such assessments by providing a basis for assessing the potential for contaminated sediments to be adversely affecting sediment-dwelling organisms, aquatic-dependent wildlife, and/or human health.

6.1.7 Evaluating Stormwater Ponds

Stormwater ponds represent important elements of the overall water management program in Florida. These facilities support water quality management initiatives by collecting stormwater during precipitation events and promoting the settling of suspended sediments. In this way, stormwater ponds reduce loadings of COPCs to surface waters from non-point sources. However, such ponds tend to fill-in as sediments and other materials are deposited in the ponds. The numerical SQAGs can support assessments of stormwater ponds by providing effects-based and bioaccumulation-based tools for evaluating the hazards posed by contaminated sediments to sediment-dwelling organisms, aquatic-dependent wildlife, and/or human health. In addition, the SQAGs can be used in the selection of disposal options for materials that are removed from such ponds.

6.2 Assessment and Management of Contaminated Sites

Historic land and water use activities have resulted in releases of toxic and/or bioaccumulative substances at a number of sites in the state. In some cases, the nature, magnitude, and extent of such releases have resulted in significant contamination of environmental media, including water, sediment, and biota. At such sites, it is often necessary to evaluate hazards posed by contaminated sediments to ecological receptors and/or human health. The results of such assessments provide a basis for evaluating the various options for managing these sites. Some of the specific activities that are conducted to assess and manage contaminated sites in Florida are briefly described in the following sections.

6.2.1 Undertaking Enforcement Actions and Clean-ups

In Florida, sediment quality assessment tools are needed to support a variety of enforcement actions and clean-ups at contaminated sites. Such actions may be initiated by the Hazardous Waste Sections of County governments, the FDEP's Bureau of Waste Clean-up (as coordinated through FDEP's district offices), or by natural resource trustees (i.e., FDEP, NOAA, USFWS). In such actions, the numerical SQAGs are needed to determine if sediments are contaminated, to identify COPCs, to assess the areal extent of contamination, and to support the establishment of target clean-up levels (i.e., sediment quality remediation objectives; sediment quality remediation objectives; SQROs).

Sediment quality remediation objectives represent an essential component of the contaminated sediment remediation process because they establish target clean-up levels for a site. Sediment quality issues are rarely entirely the responsibility 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 SQROs is important because they provide a common yardstick against which the success of a range of sediment management initiatives can be measured.

Numerical SQAGs can be used in several ways to support the derivation of SQROs. Specifically, SQAGs are useful because they provide a means of establishing SQROs that fulfill the narrative use protection or use restoration goals for the site. For example, SQROs could be set at the TECs and/or mean PEC-Q of 0.1 if the site management goal is to provide a high level of protection for sediment-dwelling organisms. Alternatively, the SQROs could be set at the PECs or a mean PEC-Q of 0.6 if the immediate goal for the site is to reduce the potential for acute toxicity and permit natural recovery processes to further reduce COPC concentrations and associated risks to ecological receptors. In addition, the SQAGs and associated evaluations of predictive ability provide information that may be used to evaluate the costs and benefits associated with various remediation options.

6.2.2 Reclaiming Phosphate Mines

In both northern and central Florida, phosphate mining has affected large tracts of land. In recent years, substantial effort has been directed at the development and implementation of strategies for reclaiming affected lands following the completion of mining activities. Because phosphate-bearing rock contains a number of metals (i.e., at levels that are elevated relative to other soils in Florida), there is a potential for wetlands that are constructed as part of mine reclamation initiatives to be contaminated by metals. The numerical SQAGs can be used to evaluate the significance of sediment-associated metals and establishing target clean-up levels at phosphate mines, should remedial measures be required.

6.3 Restoration of Wetland Habitats

In Florida, wetland habitats represent an essential components of freshwater ecosystems. Wetlands provide a number of ecological services in the state. For example, wetlands perform a number of functions which contribute to the enhancement of the quality of water and provide "safety" functions (e.g., flood control) which have substantial economic value. Wetland habitats support numerous wildlife species (such as fish, birds, and mammals) by providing food sources, protective cover, and habitats for reproduction. Wetlands also support recreational and aesthetic water uses, and in so doing generate a range of economic benefits for the state. Because wetland restoration initiatives provide a basis for restoring these beneficial water uses, a number of state programs rely of the restoration of wetland habitats to achieve their long-term environmental management objectives. Some of the potential uses of the SQAGs in wetland restoration activities are described in the following sections.

6.3.1 Restoring Agricultural Land

In recent years, restoration of agricultural lands has been initiated at a number of locations in the state. Such restoration projects commonly involve the flooding of agricultural land to restore native wetland habitats. In this application, the SQAGs can be used to determine if adverse effects on sediment-dwelling organisms are likely to occur after the land has been flooded. In addition, bioaccumulation-based SQAGs can be used to assess the potential for effects on wildlife and/or human health that could occur after reclamation activities have been completed. As such, the SQAGs support assessments of the costs and benefits of candidate agricultural land restoration projects.

6.3.2 Assessing State Liability

In Florida, private lands are periodically purchased to support a number of state program objectives, such as habitat protection and habitat restoration. Some of these private lands have been contaminated as a result of various land use activities (e.g., agricultural operations, industrial activities, land filling, etc.). In this application, the numerical SQAGs can be used to identify the presence of contaminated sediments and, in so doing, assist in the assessment of the state's potential liability (i.e., clean-up costs) if the lands are purchased.

6.3.3 Restoring the Everglades

Restoring water flows has been a central component of the Everglades restoration initiative. In certain locations, however, successful restoration of aquatic habitats will also necessitate restoration of sediment quality conditions (e.g., in agricultural areas in which historic pesticide use may be a concern). In this case, the numerical SQAGs can be used to identify contaminated sediments. In addition, the SQAGs can be used to establish restoration objectives in terms of sediment quality conditions.

6.4 Assessment of Risks to Ecological Receptors

Risk assessment is the process of assigning magnitudes and probabilities to the adverse effects that may be associated with environmental contamination or other hazards. Ecological risk assessment (ERA) is an evolving process that is designed to provide science-based guidance for managing environmental quality, particularly at contaminated sites. Until recently, appropriate scientific information was not available for assessing the ecological risks that were associated with contaminated sediments. However, a panel of environmental chemists and toxicologists recently concluded that there is sufficient certainty associated with SQAGs to recommend their use in ecological risk assessments (Ingersoll *et al.* 1997).

The numerical SQAGs can contribute directly to several stages of the ecological risk assessment process, including problem formulation, effects assessment, and risk characterization. During problem formulation, background information and preliminary sampling data are used to identify the problem and define issues that need to be addressed at sediment contaminated sites (Chapman *et al.* 1997). At the problem formulation stage, SQAGs can be used in conjunction with existing sediment chemistry data to identify the COPCs and areas of concern with respect to sediment contamination (Long and MacDonald 1998; MacDonald *et al.* 2001). In turn, this information can be used to scope out the nature and extent of the problem and to identify probable sources of sediment contamination at the site. In addition, the SQAGs provide a consistent basis for identifying appropriate reference areas that can be used in subsequent assessments of the sediment contaminated site (Menzie 1997). Furthermore, the underlying data used to derive the SQAGs provide a scientific basis for identifying appropriate assessment endpoints (i.e., receptors and ecosystem functions to be protected) and measurement endpoints (i.e., metrics for the assessment endpoints) that can be used at subsequent stages of the assessment.

Numerical SQAGs represent effective tools that can be used to assess the effects of sediment-associated contaminants (i.e., during the effects assessment of the ERA). The goal of the effects assessment is to provide information on the toxicity or other effects that are likely to occur as a result of the sediment contamination. In this application, the SQAGs and associated chemical mixture models provide an effective basis for describing how sediment toxicity is likely to change with changing COPC concentrations (MacDonald *et al.* 1996; Ingersoll *et al.* 1996; MacDonald *et al.* 2000a; Ingersoll *et al.* 2001). The applicability of the SQAGs in effects assessments is increased when used in conjunction with other tools that facilitate determinations of background concentrations of contaminants, sediment toxicity, bioaccumulation, and effects on *in situ* benthic macroinvertebrates (Chapman *et al.* 1997).

The primary purpose of the risk characterization stage of an ERA is to estimate the nature and extent of the risks associated with exposure to contaminated sediment and to evaluate the level of uncertainty associated with that estimate (Chapman *et al.* 1997). The SQAGs are particularly useful at this stage of the process because they provide a quantitative basis for evaluating the potential for observing adverse effects associated with exposure to contaminated sediments, for determining the spatial extent of unacceptable levels of sediment contamination (i.e., sediments that exceed prescribed limits of risk to sediment-dwelling organisms), and for estimating the uncertainty in the risk determinations (i.e., the potential for Type I and Type II errors). Importantly, calculation of the frequency of exceedance of the PECs and mean PEC-Qs for individual sediment samples enables risk assessors to estimate the probability that contaminated sediments will be toxic to sediment-dwelling organisms (Long and MacDonald 1998; USEPA 2000a; Ingersoll *et al.* 2001). These procedures facilitate determination of the cumulative effects of COPCs arising from multiple sources (i.e., in addition to the contaminated site) and evaluation of the potential for off-site impacts when appropriate sediment chemistry data are available. The uncertainty associated with the application of the SQAGs at this stage of the ERA can be effectively reduced by using the SQAGs in conjunction with other assessment tools, such as results of toxicity tests and/or benthic invertebrate community assessments.

6.5 Environmental Regulation

In Florida, as in other jurisdictions, decisions regarding the management of natural resources are intended to assure their long-term sustainability and to optimize the benefits that accrue to the residents of the state. Achieving these goals is dependent on development and implementation of environmental regulations that effectively manage human activities that have the potential to adversely affect aquatic resources. While regulations are in place to regulate the discharge of industrial and municipal effluents and the disposal of solid wastes, hazardous wastes, and dredged materials, such regulations are not necessarily protective of sediment quality conditions (i.e., they are usually focused on protecting water quality conditions). Some potential uses of the SQAGs in these environmental regulation processes are described in the following sections.

6.5.1 Evaluating Dredged Materials

A variety of dredge and fill activities are undertaken in the state to support the beneficial uses of Florida inland waters (e.g., navigational dredging, beach nourishment). Such activities are typically authorized under FDEP's Environmental Resource Permitting Program.

Although the inland testing manual provides explicit guidance on the assessment of dredged materials for open water disposal (USEPA and USACE 1998), the numerical SQAGs complement this guidance by providing relevant tools to support such tiered assessments. In this application, the numerical SQAGs can be used to determine if dredged materials are likely to be toxic to sediment-dwelling organisms and, hence, support the evaluation of various disposal options. More specifically, these tools can be used to identify dredged materials that require special handling and careful disposal. Conversely, the numerical SQAGs and the metals interpretive tool can be used to identify sediments that are unlikely to pose significant hazards to aquatic organisms and, hence, could be used for a variety of beneficial uses (e.g., beach nourishment, etc.).

6.5.2 Evaluating Solid Wastes

There are a variety of solids wastes (e.g., sewage sludge, wood wastes, composted materials, and other debris) that require evaluation prior to selecting appropriate disposal or re-use options. However, the SQAGs recommended in this report are intended to apply directly to aqueous sediments. As such, their application for assessing other materials is uncertain. Therefore, the SQAGs should be used with caution in these types of applications.

6.5.3 Evaluating Total Maximum Daily Loadings

Under direction from USEPA, FDEP is now required to conduct total maximum daily loading (TMDL) assessments for all water bodies in the state. For each substance of concern, a TMDL must be determined that specifies the total amount of the substance that can be discharged into a water body from all sources without adversely affecting designated uses. As contaminated sediments can adversely affect the designated uses of surface waters, sediment contamination must be considered in the development of TMDLs. Desorption from sediments also represents a potential source of certain COPCs to overlying waters, which must be considered in the TMDL calculations. The numerical SQAGs can be used to help identify the locations where beneficial uses are not being maintained due to the accumulation of COPCs in sediments. In addition, the SQAGs could be used to assist in the establishment of TMDLs for these water bodies.

6.5.4 Evaluating National Pollutant Discharge Elimination System Permits

In Florida, the discharge of water and wastewater to receiving water systems is authorized by FDEP through the issuance of permits under the National Pollutant Discharge Elimination System (NPDES). Historically, the discharge limits for various COPCs that are specified in such permits have been established using ambient water quality criteria, in conjunction with other related information. The water quality criteria identify the concentrations of water-borne COPCs that should not be exceeded in receiving waters, post-mixing, to protect the designated uses of the water body. In this application, the numerical SQAGs can be used to determine if sediments have been contaminated as a result of permitted discharges (and/or other inputs of contaminants). In this way, it may be possible to evaluate the efficacy of NPDES permits in terms of protecting the uses of receiving water systems.

6.5.5 Assessing the Effects of Aquatic Weed Control Programs

Proliferation of aquatic weeds is a serious problem in many water bodies in Florida. Frequently, copper-based compounds are applied to these systems to control such nuisance organisms. The numerical SQAGs can be used, in conjunction with ambient monitoring data, to identify the herbicide application rates that are likely to result in acceptable or problematic levels of copper in freshwater sediments. This information could then be utilized to refine aquatic weed control strategies in the state.

Chapter 7 Summary and Recommendations

7.0 Introduction

In response to the need for guidance on the assessment of sediment quality conditions in freshwater ecosystems, FDEP and its partners launched the ***Freshwater Sediment Quality Assessment Initiative*** in early 2000. This initiative, which is being implemented cooperatively by FDEP, USGS, USEPA, county governments, and water management districts (see Acknowledgments for a list of cooperators), consists of three main elements, including:

- Formulation of an integrated framework for planning, designing, implementing, and interpreting the results of sediment quality investigations;
- Development of an interpretive tool for assessing metal enrichment in freshwater sediments; and,
- Establishment of numerical SQAGs for assessing the potential for adverse biological effects associated with exposure to contaminated sediments.

Together, these three elements of the overall ***Freshwater Sediment Quality Assessment Initiative*** are intended to provide FDEP staff and others with the guidance needed to conduct sediment quality assessment, and to support defensible sediment management decisions. This report, which addresses the third element of the initiative, describes the development and evaluation of numerical SQAGs that are intended to support assessments of sediment quality conditions in Florida inland waters. This chapter of the report provides a summary of the results of the project and offers a series of recommendations to support the assessment and management of contaminated sediments in the state.

7.1 Summary

The third element of the ***Freshwater Sediment Quality Assessment Initiative*** involves the development and evaluation of numerical SQAGs for Florida inland waters, including effects-based SQAGs and bioaccumulation-based SQAGs. The effects-based SQAGs are intended to provide a basis for determining the concentrations of sediment-associated COPCs that are unlikely to be associated with adverse biological effects and those that are likely to be associated with sediment toxicity or other adverse effects on sediment-dwelling organisms. By comparison, the bioaccumulation-based SQAGs are intended to identify the concentrations of sediment-associated COPCs that are unlikely to be associated with adverse effects on aquatic-dependent wildlife or human health.

To support the identification of interests and needs related to the assessment of contaminated sediments in Florida inland waters, FDEP convened a workshop in 2000 (MacDonald 2000). Based on input provided by workshop participants, the potential for adverse effects on sediment-dwelling organisms, aquatic-dependent wildlife, and human health represents the principal concern relative to contaminated sediments. In addition to identifying sediment quality issues and concerns, workshop participants also identified the toxic and bioaccumulative COPCs for which numerical SQAGs are required to support sediment quality assessments in the state. Metals, PAHs, PCBs, chlorinated benzenes, phthalates, triazine herbicides, organophosphate pesticides, OC pesticides, and toxaphene were identified as the highest priority toxic substances that partition into sediments. The bioaccumulative substances of greatest concern included mercury, PAHs, PCBs, chlorinated benzenes, PCDDs and PCDFs, and OC pesticides.

A total of eight distinct approaches were reviewed and evaluated to support the establishment of numerical SQAGs for Florida inland waters. Both empirical and theoretical approaches were considered to support the derivation of numerical SQAGs for the protection of sediment-dwelling organisms, including SLCA, ERA, ELA, AETA, EqPA, LRMA, and CA. Based on the results of this evaluation, it was recommended that guidelines developed using the CA (i.e., the TECs and PECs) be adopted as preliminary effects-based SQAGs for Florida inland waters (MacDonald *et al.* 2000a). For those substances for which consensus-based guidelines were not available, it was recommended that guidelines derived using other effects-based approaches be evaluated to select SQAGs that could be used on an interim basis in Florida. The TRA was considered to be the most relevant method for deriving numerical SQAGs for the protection of wildlife and human health (i.e., for substances that bioaccumulate in the food web).

The evaluations that have been conducted to date demonstrate that the consensus-based guidelines provide reliable and predictive tools for assessing sediment quality conditions (MacDonald *et al.* 2000a; Crane *et al.* 2000; USEPA 2000a; Ingersoll *et al.* 2001). While these results generate a high level of confidence in the consensus-based guidelines, a further evaluation of the predictive ability of these guidelines was conducted to assess their relevance in the southeastern portion of the United States. To support this evaluation, matching sediment chemistry and sediment toxicity data were assembled from diverse studies conducted throughout USEPA Regions III, IV, and VI. For each of the samples represented in the project database, mean PEC-Qs were calculated. Subsequently, the incidence of toxicity (i.e., to amphipods, *Hyalella azteca*, and midges, *Chironomus tentans* and *Chironomus riparius*) within ranges of mean PEC-Qs was calculated and compared to the results obtained using the information contained in the national database (USEPA 2000a). Additionally, concentration-response relationships were developed using the regional database and compared to the relationships developed for the same test organisms and endpoints using the data contained in the national database. The results of these evaluations showed that systematic differences in the toxicity of sediment-associated COPCs (as expressed using mean PEC-Qs) do not exist between the regional and national data sets. Therefore, it was concluded that consensus-based guidelines are likely to represent relevant tools for assessing sediment quality conditions in Florida and should be adopted as the effects-based SQAGs.

Together, the effects-based and bioaccumulation-based SQAGs describe the conditions that need to be maintained in freshwater ecosystems to protect sediment-dwelling organisms, aquatic-dependent wildlife, and human health against the adverse effects associated with exposure to contaminated sediments. Using the recommended approach, effects-based SQAGs were recommended for a total of 29 COPCs in Florida inland waters. Interim SQAGs were recommended for another 20 COPCs, based on the effects-based guidelines that have been promulgated in other jurisdictions. Bioaccumulation-based SQAGs for the protection of aquatic-dependent wildlife were recommended for 11 COPCs, while SQAGs for the protection of human health were recommended for 52 COPCs in the state. Because it was not possible to establish SQAGs for all of the COPCs that were identified by workshop participants, narrative SQAGs were also recommended to support assessments of sediment quality conditions.

The numerical SQAGs are intended to provide science-based tools for assessing sediment quality conditions in Florida's freshwater ecosystems. To assist potential users of these tools, the recommended applications of the SQAGs were also described in this report. In total, five principal program applications were identified for the SQAGs, including: supporting monitoring and assessment initiatives; assessing and managing contaminated sites; restoring wetland habitats; assessing ecological risks; and, supporting environmental regulation programs. Although the potential uses of the SQAGs were explicitly described, it is important to note that the SQAGs should be used together with other assessment tools to support comprehensive assessments of sediment quality conditions. MacDonald and Ingersoll (2002a; 2002b) and Ingersoll and MacDonald (2002) describe the ecosystem-based framework for designing, conducting, and interpreting the results of sediment quality investigations.

7.2 Recommendations

This report was prepared to provide background information on the assessment of contaminated sediments, to describe the recommended approach to the establishment of numerical SQAGs, to evaluate the predictive ability of the SQAGs, and to present the recommended effects-based and bioaccumulation-based SQAGs for assessing sediment quality conditions in freshwater ecosystems. Additionally, a summary of the recommended program applications of the SQAGs was provided in this report. The following recommendations are offered to identify the strategic actions that should be taken to improve the assessment and management of contaminated sediments in Florida inland waters.

7.2.1 Refinement of the Tools for Assessing Sediment Quality Conditions

The ***Freshwater Sediment Quality Assessment Initiative*** was undertaken to develop tools to support assessments of sediment quality conditions in freshwater ecosystems. In response to the need for science-based assessment tools, FDEP developed an interpretive tool for assessing metal enrichment in Florida freshwater sediments (Carvalho and Schropp 2002). In addition, effects-based and bioaccumulation-based SQAGs have been developed to support evaluations of the potential for effects on sediment-dwelling organisms, aquatic-dependent wildlife, and human health associated with exposure to contaminated sediments (this report). While these tools are likely to meet the state's immediate requirements, further development of such tools is recommended to ensure that FDEP and its partners can meet emerging challenges associated with the assessment and management of contaminated sediments. More specifically, the following activities are recommended:

- Develop SQAGs for the protection of sediment-dwelling organisms for those substances for which neither consensus-based guidelines nor guidelines from other jurisdictions are currently available;
- Refine the chemical mixture model (i.e., mean PEC-Qs) such that it better incorporates the substances of greatest concern in Florida inland waters;
- Evaluate the extent to which the effects-based SQAGs provide the desired level of protection for *in situ* benthic macroinvertebrate communities;
- Develop bioaccumulation-based SQAGs for the protection of aquatic-dependent wildlife for those substances for which guidelines from other jurisdictions are not currently available;
- Develop bioaccumulation-based SQAGs for the protection of human health for those substances for which guidelines from other jurisdictions are not currently available; and,
- Conduct an evaluation of the reliability of the bioaccumulation-based SQAGs in Florida and elsewhere in the southeastern portion of the United States.

7.2.2 Evaluation of the Ecosystem-Based Framework for Assessing and Managing Sediment Quality Conditions

In response to the need for guidance on the assessment and management of contaminated sediments, FDEP developed an integrated framework for assessing sediment quality conditions in Florida inland waters. The three volume guidance manual provides an ecosystem-based framework for assessing and managing contaminated sediments, detailed guidance on the design and implementation of sediment quality investigations, and advice on the interpretation of the results of sediment quality investigations (MacDonald and Ingersoll 2002a; 2002b; Ingersoll and MacDonald 2002). Although the guidance manual was designed to meet the needs that were identified by workshop participants (MacDonald 2000), it would be helpful to have users identify any refinements needed to better enable them to address their program requirements. Therefore, it is recommended that the guidance manual be broadly distributed to potential users within the state. The recipients should be asked to review and evaluate the guidance manual relative to their needs and identify any refinements that would increase its applicability.

7.2.3 Improvement of Monitoring and Assessment Initiatives

Participants at the workshop that was convened in 2000 developed a number of recommendations that would improve the monitoring and assessment of sediment quality conditions in the state (MacDonald 2000). As these recommendations were not addressed in the first three elements of the ***Freshwater Sediment Quality Assessment Initiative***, the recommendations that were offered by workshop participants are reproduced here to make sure that they are considered in the next phase of the initiative:

- Identify potential sources of existing sediment quality data;
- Compile the existing data on sediment quality conditions on a watershed by watershed basis and evaluate the resultant data using appropriate assessment tools;
- Develop an understanding of the importance of the microbial community to ecological health and the fate of sediment-associated COPCs;
- Document the levels of metals in phosphate rock and phosphatic sediments; and,

- Evaluate sediment quality conditions in areas where fish consumption advisories (e.g., due to mercury contamination) have been issued to determine if there are sediment-related issues that need to be addressed.

7.2.4 Development of Strategies for Managing Contaminated Sediments

Sediment management initiatives are currently being conducted under a number of federal, state, county, and local government programs in Florida. Participants at the interests and needs workshop that was convened in 2000 identified several high priority activities that should be undertaken to support the management of contaminated sediments, including remedial action planning (MacDonald 2000). These recommendations are reproduced here to ensure that they are considered in the next phase of the initiative:

- Conduct a review of disposal options for contaminated sediments (including those that contain metals and organic contaminants), focusing on lessons learned in other jurisdictions;
- Develop a strategy for disposing of contaminated sediments from stormwater ponds; and,
- Investigate the possibility of establishing sediment quality standards for the state.

7.2.5 Development of Outreach and Partnership Building Programs

In the southeastern portion of the United States, there are a relatively large number of initiatives that are directed at the assessment and management of contaminated sediments. Development of a regional strategy for assessing and managing contaminated sediments is likely to increase the effectiveness of government programs and encourage greater support for sediment management initiatives (i.e., to coordinate the various initiatives). Some of the specific recommendations for outreach and partnership building that were offered by participants at the interests and needs workshop (MacDonald 2000) include:

- Develop partnerships with other organizations that are actively involved in the assessment and management of contaminated sediments, including the U.S. Army Corps of Engineers, water management districts, county governments, and other natural resource trustees;
- Highlight key sediment-related issues to help people understand them and to increase their priority relative to other environmental management issues;
- Explore the potential for securing funding under Section 319 of the CWA to conduct a statewide assessment of sediment quality conditions;
- Evaluate the potential for conducting monitoring programs under Section 305b of the CWA and encourage USEPA to get more involved in this area;
- Encourage other USEPA Region IV states to cooperate in the refinement of frameworks and tools for assessing sediment quality conditions; and,
- Report the progress that is being made on sediment-related initiatives to senior management in FDEP on a regular basis.

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Tables

Table 3.1. Summary of the strengths and limitations of existing approaches for deriving numerical sediment quality assessment guidelines (adapted from Crane *et al.* 2000).

Approach	Strengths	Limitations
Screening Level Concentration Approach	* Based on biological effects data. * Sufficient data to derive SQGs are generally available for many chemicals. * Suitable for all classes of chemicals and most types of sediments. * Accounts for the effects of mixtures of contaminants.	* Not possible to establish cause and effect relationships. * Large database of matching sediment chemistry and benthic data is required. * Chemistry and benthic data are rarely strictly matching (i.e., generated from splits of a homogenized sediment sample). * Bioavailability is not considered.
Effects Range Approach	* Based on biological effects data. * Many types of biological effects data are considered. * Suitable for all classes of chemicals and most types of sediments. * Provides a weight of evidence. * Provides data summaries for evaluating sediment quality. * Accounts for the effects of mixtures of contaminants.	* Large database of matching sediment chemistry and biological effects data is required. * Not possible to establish cause and effect relationships. * Bioavailability is not considered. * Does not consider the potential for bioaccumulation.
Effects Level Approach	* Based on biological effects data. * Many types of biological effects data are considered. * Suitable for all classes of chemicals and most types of sediments. * Provides a weight of evidence. * Provides data summaries for evaluating sediment quality. * Accounts for the effects of mixtures of contaminants.	* Large database of matching sediment chemistry and biological effects data is required. * Not possible to establish cause and effect relationships. * Bioavailability is not considered. * Does not consider the potential for bioaccumulation.

Table 3.1. Summary of the strengths and limitations of existing approaches for deriving numerical sediment quality assessment guidelines (adapted from Crane *et al.* 2000).

Approach	Strengths	Limitations
Apparent Effects Threshold Approach	* Based on biological effects data. * Several types of biological effects data are considered. * Considers effects on benthic invertebrate community structure. * Suitable for all classes of chemicals and most types of sediments. * Accounts for the effects of mixtures of contaminants	* Extensive site-specific database is required. * Not possible to establish cause and effect relationships. * Risk of under-protection of resource. * Bioavailability is not considered. * Does not consider the potential for bioaccumulation.
Equilibrium Partitioning Approach	* Based on biological effects. * Suitable for many classes of chemicals and most types of sediments. * Bioavailability is considered. * Supports cause and effect evaluations.	* Water quality criteria are not available for certain * *In situ* sediments are rarely at equilibrium. * Further field validation is needed. * Guidelines for single chemicals do not account for effects. of mixtures of contaminants. * Risk of under-protection of resource. * Does not consider the potential for bioaccumulation.
Logistic Regression Modelling Approach	* Based on sediment toxicity test results. * Suitable for all classes of chemicals and most types of sediments. * Provides SQGs that are associated with a specific probability of observing sediment toxicity. * Provides SQGs that are species and endpoint specific. * Factors that influence bioavailability can be considered. * SQGs can be derived that correspond to specific management goals (e.g., 20% probability of observing sediment toxicity).	* Large database of matching sediment chemistry and biological effects data is required. * Insufficient data are available for most freshwater receptors. * Not possible to establish cause and effect relationships. * Bioavailability is not considered. * Does not consider the potential for bioaccumulation.

Table 3.1. Summary of the strengths and limitations of existing approaches for deriving numerical sediment quality assessment guidelines (adapted from Crane *et al.* 2000).

Approach	Strengths	Limitations
Consensus-Based Sediment Quality Guidelines Approach	* Provides a unifying synthesis of the existing sediment quality guidelines. * Reflects causal rather than correlative effects. * Accounts for the effects of contaminant mixtures in sediments. * Predictive ability in freshwater sediments has been demonstrated.	* Bioavailability is not considered. * Does not consider the potential for bioaccumulation.
Tissue Residue Approach	* Bioaccumulation is considered. * A protocol for the derivation of tissue residue guidelines is available. * Numerical SQGs can be derived if biota-sediment accumulation factors are available.	* Tissue residue guidelines for wildlife are not yet available for most chemicals. * Wildlife may be exposed to contaminants from multiple sites.

SQGs = sediment quality guidelines.

Table 3.2. Evaluation of candidate approaches for deriving sediment quality assessment guidelines for Florida inland waters (adapted from MacDonald 1994).

Evaluation Criteria	SLCA	ERA	ELA	AETA	EqPA	LRMA	CA
Practicality							
Supports development of numerical SQAGs?	2	2	2	2	2	2	2
Feasible to implement in the near term?	0	2	2	0	2	0	2
Cost Effectiveness							
Inexpensive to implement?	2	2	2	2	2	2	2
Does not requires generation of new data?	0	2	2	0	2	1	2
Scientific Defensibility							
Considers bioavailability?	0	0	0	1	2	2	0
Provides cause and effect relationships?	0	0	0	0	2	0	1
Based on biological effects data?	2	2	2	2	2	2	2
Considers data from southeast?	0	0	0	0	0	0	0
Provides weight of evidence?	0	2	2	2	0	1	2
Supports definition of ranges of concentrations rather than absolute assessment values	2	2	2	2	1	2	2
Considers effects of mixtures of contaminants?	2	2	2	2	0	2	2
Amenable to field validation?	2	2	2	2	0	2	2
Applicable to all classes of chemicals?	2	2	2	2	1	2	2
Applicability							
Supports monitoring programs?	2	2	2	2	2	2	2
Supports identification of COPCs?	2	2	2	2	2	2	2
Supports identification of sites of potential concern?	2	2	2	2	2	2	2
Supports ecological risk assessments?	0	1	1	1	2	2	2
Supports pollution control efforts?	2	2	2	2	2	2	2

Table 3.2. Evaluation of candidate approaches for deriving sediment quality assessment guidelines for Florida inland waters (adapted from MacDonald 1994).

Evaluation Criteria	SLCA	ERA	ELA	AETA	EqPA	LRMA	CA
Applicability (continued)							
Supports wetland restoration projects?	1	1	1	1	2	1	1
Supports hazardous waste site clean-ups?	0	1	1	1	2	2	2
Supports regulatory decisions?	0	1	1	2	2	2	2
Overall assessment score	23	32	32	30	32	33	36

Note: Scores of 2, 1, or 0 were assigned if the approach fully, somewhat, or doesn't satisfy the criterion, respectively.
SQAGs = sediment quality assessment guidelines; COPCs = contaminants of potential concern.
SLCA = screening level concentration approach; ERA = effects range approach; ELA = effects level approach; AETA = apparent effects threshold approach;
EqPA = equilibrium partitioning approach; LRMA = logistic regression modelling approach; CA = consensus-based approach.

Table 4.1. Listing of matching sediment chemistry and toxicity data sets compiled in the regional database.

Location	Sampling Date	n	Whole Sediment Toxicity Tests Conducted	Sediment Chemistry Analyses Conducted	Reference
USEPA Region 3					
Chesapeake Bay, Delaware Bay, Anacostia River, DE, MD, NJ, PA, VA, DC	1990	34	10-d *Hyalella azteca* (S)	Butyltins, TOC, grainsize, metals, PAHs	Weisberg *et al.* (1990)
Chester-Sassafras watershed *(Bohemia River, Corsica River),* MD	1991	10	28-d *Hyalella azteca* (S, G)	Butyltins, TOC, grainsize, metals, PAHs, AVS, SEM	McGee *et al.* (1995)
Middle Potomac-Anacostia-Occoquan watershed *(Anacostia River, Potomac River),* DC	1993	11	10-d *Hyalella azteca*	Chlorinated benzenes, AVS, grainsize, TOC, metals, PAHs, PCBs, pesticides	USFWS (1997)
Middle Potomac-Anacostia-Occoquan watershed *(Anacostia River, Kingman Lake, Potomac River),* DC	1993	5	10-d *Hyalella azteca* (S)	TOC, grainsize, metals, PCBs, OC pesticides	Eignor (1994)
Chester-Sassafras, Gunpowder-Patapsco watersheds *(Corsica River, Curtis Creek),* MD	1993[1]	5	10-d *Hyalella azteca* (S)	Grainsize, metals	McGee *et al.* (1993)
Middle Potomac-Anacostia-Occoquan watershed *(Anacostia River, Kingman Lake, Potomac River),* DC	1994[1]	15	28-d *Hyalella azteca* (S, G)	AVS, grainsize, TOC, metals, PAHs, PCBs, OC pesticides	Velinsky *et al.* (1994)
Brandywine-Christina watershed *(Christina River, Churchmans Marsh, Newport Marsh, Nonesuch Creek)* , DE	1995	39	10-d *Hyalella azteca* (S)	AVS, SEM, grainsize, TOC, metals, PAHs, PCBs, pesticides	Olinger (1996)

Table 4.1. Listing of matching sediment chemistry and toxicity data sets compiled in the regional database.

Location	Sampling Date	n	Whole Sediment Toxicity Tests Conducted	Sediment Chemistry Analyses Conducted	Reference
USEPA Region 3 (cont.)					
Powell watershed *(Ely Creek)*, VA	1997	18	10-d *Chironomus tentans* (S, G)	Metals	Cherry *et al.* (2001)
Brandywine-Christina watershed *(Army Creek)*, DE	1999, 2000	12 12	10-d *Chironomus tentans* (S, G) 10-d *Hyalella azteca* (S, G)	Phthalates, TOC, metals, PAHs, pesticides	USEPA (1999b)
Middle Potomac-Anacostia-Occoquan watershed *(Anacostia River Estuary)*, DC	2000	20 20	10-d *Chironomus tentans* (S, G) 10-d *Hyalella azteca* (S, G)	TOC, grainsize, metals, PAHs, PCBs, OC pesticides	Fisher *et al.* (2001)
USEPA Region 4					
Lower Mississippi River, Ogeechee River, IL, LA, MS, TN, GA	1994, 1995	45	10-d *Hyalella azteca* (S)	AVS, TOC, metals, PAHs, PCBs, pesticides	Winger and Lasier (1998)
Everglades watershed *(Homestead Air Force Base)*, FL	1995, 1996	88	10-d *Hyalella azteca* (S)	Butyltins, chlorinated benzenes, TOC, metals, PAHs, PCBs, pesticides	Hefty (1998)
Pensacola Bay watershed *(Lagoon between Santa Rosa Island and the Santa Rosa Sound)*, FL	1996	4	10-d *Hyalella azteca* (S)	Chlorinated benzenes, metals, PCBs, pesticides	Lewis *et al.* (2000)
Lower Savannah watershed *(Lower Savannah River)*, GA, SC	1996, 1997	48	10-d *Hyalella azteca* (S)	AVS, SEM, TOC, grainsize, metals	Winger *et al.* (2000)

Table 4.1. Listing of matching sediment chemistry and toxicity data sets compiled in the regional database.

Location	Sampling Date	n	Whole Sediment Toxicity Tests Conducted	Sediment Chemistry Analyses Conducted	Reference
USEPA Region 4 (cont.)					
Bayou De Chien-Mayfield, Highland-Pigeon, Lower Green, Pond, Tradewater watersheds *(Bayou de Chien, Casey Creek, Highland Creek, Panther Creek, Pond River, Tradewater River),* KY	1997	6	10-d *Hyalella azteca* (S)	Chlorinated benzenes, TOC, metals, PCBs, pesticides	Roth *et al.* (1998a)
Barren, Tradewater watersheds *(Gasper River, Greasy Creek),* KY	1998	4	10-d *Hyalella azteca* (S)	Chlorinated benzenes, phthalates, phenols, ethers, metals, PAHs, PCBs, pesticides	Roth *et al.* (1998b)
Chipola watershed *(Sapp Battery Site),* FL	1998	11 11	10-d *Chironomus tentans* (S, G) 10-d *Hyalella azteca* (S, G)	Metals, grainsize, TOC	ARCADIS Geraghty & Miller (1998a; 1998b); New England Bioassay, Inc. (1998)
Upper Cumberland watershed *(Cane Creek),* KY	1998	2	10-d *Hyalella azteca* (S)	Chlorinated benzenes, chlorophenols, metals, PCBs, pesticides	Commonwealth of Kentucky (1999a)
Lower Oconee watershed *(Oconee River),* GA	1998	12	28-d *Hyalella azteca* (S, G)	Chlorinated benzenes, TOC, grainsize, metals, PAHs, PCBs, pesticides, AVS, SEM	Lasier *et al.* (2001)
Rolling Fork, Upper Green watersheds *(Salt Lick Creek, Billy Creek),* KY	1998, 1999	4	10-d *Hyalella azteca* (S)	Chlorinated benzenes, TOC, metals, PCBs, pesticides	Commonwealth of Kentucky (2000c)

Table 4.1. Listing of matching sediment chemistry and toxicity data sets compiled in the regional database.

Location	Sampling Date	n	Whole Sediment Toxicity Tests Conducted	Sediment Chemistry Analyses Conducted	Reference
USEPA Region 4 (cont.)					
Lower Kentucky, Silver-Little Kentucky watersheds, KY	1999	5	10-d WS *Hyalella azteca* (S)	Chlorinated benzenes, phthalates, phenols, ethers, PAHs, PCBs, pesticides	Commonwealth of Kentucky (1999b)
Upper Cumberland watershed, KY	2000	5	10-d *Hyalella azteca* (S)	Chlorinated benzenes, phthalates, phenols, ethers, AVS, SEM, metals, PAHs, PCBs, pesticides	Commonwealth of Kentucky (2000a)
Upper Cumberland watershed, KY	2000	4	10-d *Hyalella azteca* (S)	Chlorinated benzenes, phthalates, phenols, ethers, AVS, SEM, metals, PAHs, PCBs, pesticides	Commonwealth of Kentucky (2000b)
USEPA Region 6					
Trinity River Basin *(East Fork, Elm Fork, Trinity River),* TX	1989[1]	72 36	10-d *Chironomus tentans* (S) 10-d *Hyalella azteca* (S)	TOC, metals, pesticides	Dickson *et al.* (1989)
Trinity River, TX, Mobile Bay, AL, Tabbs Bay, TX	1996[1]	5 10 4 5	10-d *Hyalella azteca* (S) 28-d *Hyalella azteca* (S) 28-d *Hyalella azteca* (G) 32-d *Hyalella azteca* (S)	TOC, grainsize, AVS, SEM, metals, PAHs	USEPA (1996)
Lower Calcasieu watershed *(Calcasieu River),* LA	1996, 1997	15	10-d *Hyalella azteca* (S, G)	Chlorinated benzenes, phthalates, phenols, ethers, TOC, grainsize, metals, PAHs, OC pesticides, AVS, SEM	McLaren/Hart Environmental Engineering (1997)

Table 4.1. Listing of matching sediment chemistry and toxicity data sets compiled in the regional database.

Location	Sampling Date	n	Whole Sediment Toxicity Tests Conducted	Sediment Chemistry Analyses Conducted	Reference
USEPA Region 6 (cont.)					
West Galveston Bay watershed *(Swan Lake salt marsh)*, TX	1997	2	10-d *Hyalella azteca* (S, G)	Chlorinated benzenes, phthalates, phenols, ethers, grainsize, TOC, metals, PAHs, PCBs, pesticides	Charters *et al.* (1998)
Austin-Travis Lakes, Gunpowder-Patapsco, Rio Grande watersheds *(Eliza Pool, Canal Creek, Rio Grande River)*, TX	1998[1]	13 13 13	28-d *Hyalella azteca* (S, G) 35-d *Hyalella azteca* (S) 42-d *Hyalella azteca* (S, G)	TOC, grainsize, AVS, SEM, PAHs	Ingersoll *et al.* (1998)
Lower Calcasieu watershed *(Calcasieu River)*, LA	2000	100 99 100 99	10-d *Hyalella azteca* (S) 10-d *Hyalella azteca* (G) 28-d *Hyalella azteca* (S) 28-d *Hyalella azteca* (G)	Chlorinated benzenes, phthalates, phenols, ethers, metals, PAHs, PCBs, OC pesticides, AVS, SEM, TOC, dioxins, furans	CDM and MESL (2002)
Lower Calcasieu watershed *(Calcasieu River)*, LA	2000	12	10-d *Hyalella azteca* (S)	Chlorinated benzenes, phthalates, phenols, ethers, metals, PAHs, PCBs, pesticides	Entrix, Inc. (2001)
Austin-Travis Lakes watershed *(Barton Creek, Wells Branch Creek)*, TX	2000	9	28-d *Hyalella azteca* (S, G)	Grainsize, metals, PAHs	Ingersoll *et al.* (2001)

d = day; n = number of samples; S = survival; G = growth; TOC = total organic carbon; PAHs = polycyclic aromatic hydrocarbons; PCBs = polychlorinated biphenyls; AVS = acid volatile sulfides; SEM = simultaneously extracted metals; OC = organochlorine.
[1]Sampling date unknown, report date used.

Table 4.2. Summary of the whole-sediment toxicity data used to evaluate the predictive ability of the preliminary sediment quality assessment guidelines for Florida inland waters.

Species Tested	**Common Name**	**Duration of Exposure (WS)**	**Endpoint Measured**	**Number of Samples**	**Number of Toxic Samples (%)**
Hyalella azteca	Amphipod	10-d	Growth	159	16 (10%)
Hyalella azteca	Amphipod	10-d	Survival	522	88 (17%)
		10-d	Survival or Growth	522	96 (18%)
Hyalella azteca	Amphipod	28-d	Growth	162	18 (11%)
Hyalella azteca	Amphipod	28-d	Survival	169	30 (18%)
Hyalella azteca	Amphipod	32-d	Survival	5	0 (0%)
Hyalella azteca	Amphipod	35-d	Survival	13	0 (0%)
Hyalella azteca	Amphipod	42-d	Growth	13	1 (8%)
Hyalella azteca	Amphipod	42-d	Survival	13	0 (0%)
		28- to 42-d	Survival or Growth	174	45 (26%)
Chironomus tentans	Midge	10-d	Growth	61	8 (13%)
Chironomus tentans	Midge	10-d	Survival	133	12 (9%)
		10-d	Survival or Growth	133	20 (15%)
All tests combined	Amphipod or Midge	10- to 42-d	Survival or Growth	643	137 (21%)

WS = whole sediment; -d = -day.

Table 4.3. Descriptions of the published freshwater SQGs that were used to derive numerical sediment effect concentration (from MacDonald *et al.* 2000a).

Type of SQG	Acronym	Approach	Description	Reference
Threshold Effect Concentration - SQGs				
Lowest Effect Level	LEL	SLCA	Sediments are considered to be clean to marginally polluted at concentrations below the LELs. Adverse effects on the majority of sediment-dwelling organisms are not expected below this concentration.	Persaud *et al.* 1993
Threshold Effect Level	TEL	WEA	Represents the concentration below which adverse effects are expected to occur only rarely.	Smith *et al.* 1996
Effects Range - Low	ERL	WEA	Represents the chemical concentration below which adverse effects would be only rarely observed.	Long and Morgan 1991
Threshold Effect Level for *Hyalella azteca* in 28-day tests	TEL-HA28	WEA	Represents the concentration below which adverse effects on survival or growth of the amphipod, *Hyalella azteca*, are expected to occur only rarely (in 28-day tests).	USEPA 1996; Ingersoll *et al.* 1996
Minimal Effect Threshold	MET	SLCA	Sediments are considered to be clean to marginally polluted at concentrations below the METs. Adverse effects on the majority of sediment-dwelling organisms are not expected below this concentration.	EC and MENVIQ 1992
Chronic Equilibrium Partitioning Threshold	SQAL	EqPA	Represents the concentration in sediments that is predicted to be associated with concentrations in the interstitial water below a chronic water quality criterion. Adverse effects on sediment-dwelling organisms are predicted to occur only rarely below this concentration.	Bolton *et al.* 1985; Zarba 1992; USEPA 1997

Table 4.3. Descriptions of the published freshwater SQGs that were used to derive numerical sediment effect concentration (from MacDonald *et al.* 2000a).

Type of SQG	Acronym	Approach	Description	Reference
Probable Effect Concentration - SQGs				
Severe Effect Level	SEL	SLCA	Sediments are considered to be heavily polluted at concentrations above the SELs. Adverse effects on the majority of sediment-dwelling organisms are expected when this concentration is exceeded.	Persaud *et al.* 1993
Probable Effects Level	PEL	WEA	Represents the concentration above which adverse effects are expected to occur frequently.	Smith *et al.* 1996
Effects Range - Median	ERM	WEA	Represents the chemical concentration above which adverse effects would frequently occur.	Long and Morgan 1991
Probable Effects Level for *Hyalella azteca* in 28-day tests	PEL-HA28	WEA	Represents the concentration above which adverse effects on survival or growth of the amphipod, *Hyalella* azteca, are expected to occur frequently in 28-day tests.	USEPA 1996; Ingersoll *et al.* 1996
Toxic Effect Threshold	TET	SLCA	Sediments are considered to be heavily polluted at concentrations above the TETs. Adverse effects on sediment-dwelling organisms are expected when this concentration is exceeded.	EC and MENVIQ 1992

SQGs = sediment quality guidelines; LEL = lowest observed effect level; SLCA = screening level concentration approach; WEA = weight of evidence approach;
ERL = effects range low; TEL = threshold effect level; MET = minimal effects threshold; SQAL = sediment quality advisory level;
EqPA = equilibrium partitioning approach; SEL = severe effect level; PEL = probable effect level; ERM = effects range median; TET = toxic effect threshold.
HA28 = *Hyalella azteca* 28 day test.

Table 4.4. Sediment quality guidelines that reflect threshold effect concentrations (TECs; i.e., below which harmful effects are unlikely to be observed; from MacDonald *et al.* 2000a).

Substance	*Threshold Effect Concentrations*						
	TEL	**LEL**	**MET**	**ERL**	**TEL-HA28**	**SQAL**	**Consensus-Based TEC**
Metals (in mg/kg DW)							
Arsenic	5.9	6	7	33	11	NG	9.79
Cadmium	0.596	0.6	0.9	5	0.58	NG	0.99
Chromium	37.3	26	55	80	36	NG	43.4
Copper	35.7	16	28	70	28	NG	31.6
Lead	35	31	42	35	37	NG	35.8
Mercury	0.174	0.2	0.2	0.15	NG	NG	0.18
Nickel	18	16	35	30	20	NG	22.7
Zinc	123	120	150	120	98	NG	121
Polycyclic Aromatic Hydrocarbons (PAHs; in µg/kg DW)							
Anthracene	NG	220	NG	85	10	NG	57.2
Fluorene	NG	190	NG	35	10	540	77.4
Naphthalene	NG	NG	400	340	15	470	176
Phenanthrene	41.9	560	400	225	19	1800	204
Benz[a]anthracene	31.7	320	400	230	16	NG	108
Benzo(a)pyrene	31.9	370	500	400	32	NG	150
Chrysene	57.1	340	600	400	27	NG	166
Dibenz[a,h]anthracene	NG	60	NG	60	10	NG	33.0
Fluoranthene	111	750	600	600	31	6200	423
Pyrene	53	490	700	350	44	NG	195
Total PAHs	NG	4000	NG	4000	260	NG	1610

Table 4.4. Sediment quality guidelines that reflect threshold effect concentrations (TECs; i.e., below which harmful effects are unlikely to be observed; from MacDonald *et al.* 2000a).

Substance	*Threshold Effect Concentrations*						
	TEL	**LEL**	**MET**	**ERL**	**TEL-HA28**	**SQAL**	**Consensus-Based TEC**
Polychlorinated Biphenyls (PCBs; in µg/kg DW)							
Total PCBs	34.1	70	200	50	32	NG	59.8
Organochlorine Pesticides (in µg/kg DW)							
Chlordane	4.5	7	7	0.5	NG	NG	3.24
Dieldrin	2.85	2	2	0.02	NG	110	1.90
Sum DDD	3.54	8	10	2	NG	NG	4.88
Sum DDE	1.42	5	7	2	NG	NG	3.16
Sum DDT	NG	8	9	1	NG	NG	4.16
Total DDTs	7	7	NG	3	NG	NG	5.28
Endrin	2.67	3	8	0.02	NG	42	2.22
Heptachlor epoxide	0.6	5	5	NG	NG	NG	2.47
Lindane (gamma-BHC)	0.94	3	3	NG	NG	3.7	2.37

TEC = Threshold effect concentration (from MacDonald *et al.* 2000a).
TEL = Threshold effect level; dry weight (Smith *et al.* 1996).
LEL = Lowest effect level, dry weight (Persaud *et al.* 1993).
MET = Minimal effect threshold; dry weight (EC and MENVIQ 1992).
ERL = Effects range low; dry weight (Long and Morgan 1991).
TEL-HA28 = Threshold effect level for *Hyalella azteca* ; 28 day test; dry weight (USEPA 1996).
SQAL = Sediment quality advisory levels; dry weight at 1% OC (USEPA 1997).
NG = No guideline; DW = dry weight.

Table 4.5. Sediment quality guidelines that reflect probable effect concentrations (PECs; i.e., above which harmful effects are likely to be observed; from MacDonald *et al.* 2000a).

Substance	*Probable Effect Concentrations*					
	PEL	**SEL**	**TET**	**ERM**	**PEL-HA28**	**Consensus-Based PEC**
Metals (in mg/kg DW)						
Arsenic	17	33	17	85	48	33.0
Cadmium	3.53	10	3	9	3.2	4.98
Chromium	90	110	100	145	120	111
Copper	197	110	86	390	100	149
Lead	91.3	250	170	110	82	128
Mercury	0.486	2	1	1.3	NG	1.06
Nickel	36	75	61	50	33	48.6
Zinc	315	820	540	270	540	459
Polycyclic Aromatic Hydrocarbons (PAHs; in µg/kg DW)						
Anthracene	NG	3700	NG	960	170	845
Fluorene	NG	1600	NG	640	150	536
Naphthalene	NG	NG	600	2100	140	561
Phenanthrene	515	9500	800	1380	410	1170
Benz[a]anthracene	385	14800	500	1600	280	1050
Benzo(a)pyrene	782	14400	700	2500	320	1450
Chrysene	862	4600	800	2800	410	1290
Fluoranthene	2355	10200	2000	3600	320	2230
Pyrene	875	8500	1000	2200	490	1520
Total PAHs	NG	100000	NG	35000	3400	22800
Polychlorinated Biphenyls (PCBs; in µg/kg DW)						
Total PCBs	277	5300	1000	400	240	676

Table 4.5. Sediment quality guidelines that reflect probable effect concentrations (PECs; i.e., above which harmful effects are likely to be observed; from MacDonald *et al.* 2000a).

Substance	*Probable Effect Concentrations*					
	PEL	**SEL**	**TET**	**ERM**	**PEL-HA28**	**Consensus-Based PEC**
Organochlorine Pesticides (in µg/kg DW)						
Chlordane	8.9	60	30	6	NG	17.6
Dieldrin	6.67	910	300	8	NG	61.8
Sum DDD	8.51	60	60	20	NG	28.0
Sum DDE	6.75	190	50	15	NG	31.3
Sum DDT	NG	710	50	7	NG	62.9
Total DDTs	4450	120	NG	350	NG	572
Endrin	62.4	1300	500	45	NG	207
Heptachlor Epoxide	2.74	50	30	NG	NG	16.0
Lindane (gamma-BHC)	1.38	10	9	NG	NG	4.99

PECs = probable effect concentrations (from MacDonald *et al.* 2000a)
PEL = Probable effect level; dry weight (Smith *et al.* 1996).
SEL = Severe effect level, dry weight (Persaud *et al.* 1993).
TET = Toxic effect threshold; dry weight (EC and MENVIQ 1992).
ERM = Effects range median; dry weight (Long and Morgan 1991).
PEL-HA28 = Probable effect level for *Hyalella azteca* ; 28-day test; dry weight (USEPA 1996).
NG = No guideline; DW = dry weight.

Table 4.6. Reliability of the consensus-based threshold effect concentrations (TECs) in freshwater sediments (from MacDonald *et al.* 2000a).

Substance	Number of Samples	Number of Samples Predicted to be Not Toxic	Number of Samples Observed to be Not Toxic	Percentage of Samples Correctly Predicted to be Not Toxic
Metals				
Arsenic	150	58	43	74.1
Cadmium	347	102	82	80.4
Chromium	347	132	95	72.0
Copper	347	158	130	82.3
Lead	347	152	124	81.6
Mercury	79	35	12	34.3
Nickel	347	184	133	72.3
Zinc	347	163	133	81.6
Polycyclic Aromatic Hydrocarbons (PAHs)				
Anthracene	129	75	62	82.7
Fluorene	129	93	66	71.0
Naphthalene	139	85	64	75.3
Phenanthrene	139	79	65	82.3
Benz[a]anthracene	139	76	63	82.9
Benzo(a)pyrene	139	81	66	81.5
Chrysene	139	80	64	80.0
Dibenz[a,h]anthracene	98	77	56	72.7
Fluoranthene	139	96	72	75.0
Pyrene	139	78	62	79.5
Total PAHs	167	81	66	81.5
Polychlorinated Biphenyls (PCBs)				
Total PCBs	120	27	24	88.9
Organochlorine Pesticides				
Chlordane	193	101	86	85.1
Dieldrin	180	109	91	83.5
Sum DDD	168	101	81	80.2
Sum DDE	180	105	86	81.9
Sum DDT	96	100	77	77.0
Total DDT	110	92	76	82.6
Endrin	170	126	89	70.6
Heptachlor Epoxide	138	90	74	82.2
Lindane	180	121	87	71.9

Table 4.7. Reliability of the consensus-based probable effect concentrations (PECs) in freshwater sediments (from MacDonald *et al.* 2000a).

Substance	Number of Samples	Number of Samples Predicted to be Toxic	Number of Samples Observed to be Toxic	Percentage of Samples Correctly Predicted to be Toxic
Metals				
Arsenic	150	26	20	76.9
Cadmium	347	126	118	93.7
Chromium	347	109	100	91.7
Copper	347	110	101	91.8
Lead	347	125	112	89.6
Mercury	79	4	4	100
Nickel	347	96	87	90.6
Zinc	347	120	108	90.0
Polycyclic Aromatic Hydrocarbons (PAHs)				
Anthracene	129	13	13	100
Fluorene	129	13	13	100
Naphthalene	139	26	24	92.3
Phenanthrene	139	25	25	100
Benz[a]anthracene	139	20	20	100
Benzo(a)pyrene	139	24	24	100
Chrysene	139	24	23	95.8
Fluoranthene	139	15	15	100
Pyrene	139	28	27	96.4
Total PAHs	167	20	20	100
Polychlorinated Biphenyls (PCBs)				
Total PCBs	120	51	42	82.3
Organochlorine Pesticides				
Chlordane	193	37	27	73.0
Dieldrin	180	10	10	100
Sum DDD	168	6	5	83.3
Sum DDE	180	30	29	96.7
Sum DDT	96	12	11	91.7
Total DDT	110	10	10	100
Endrin	170	0	0	NA
Heptachlor Epoxide	138	8	3	37.5
Lindane	180	17	14	82.4

NA = Not applicable

Table 4.8. Incidence of toxicity within ranges of contaminant concentrations defined by the sediment quality guidelines (SQGs; from MacDonald *et al.* 2000a)

Substance	Number of Samples Evaluated	Incidence of Toxicity (number of samples in parenthesis)		
		≤TEC	TEC-PEC	>PEC
Metals				
Arsenic	150	25.9% (15 of 58)	57.6% (38 of 66)	76.9% (20 of 26)
Cadmium	347	19.6% (20 of 102)	44.6% (29 of 65)	93.7% (118 of 126)
Chromium	347	28% (37 of 132)	64.4% (38 of 59)	91.7% (100 of 109)
Copper	347	17.7% (28 of 158)	64.0% (48 of 75)	91.8% (101 of 110)
Lead	347	18.4% (28 of 152)	53.6% (37 of 69)	89.6% (112 of 125)
Mercury	79	65.7% (23 of 35)	70.0% (28 of 40)	100% (4 of 4)
Nickel	347	27.7% (51 of 184)	62.7% (32 of 51)	90.6% (87 of 96)
Zinc	347	18.4% (30 of 163)	60.9% (39 of 64)	90.0% (108 of 120)
Polycyclic Aromatic Hydrocarbons (PAHs)				
Anthracene	129	17.3% (13 of 75)	92.9% (26 of 28)	100% (13 of 13)
Fluorene	129	29% (27 of 93)	85.7% (12 of 14)	100% (13 of 13)
Naphthalene	139	24.7% (21 of 85)	94.1% (16 of 17)	92.3% (24 of 26)
Phenanthrene	139	17.7% (14 of 79)	88.2% (30 of 34)	100% (25 of 25)
Benz[a]anthracene	139	17.1% (13 of 76)	70% (14 of 20)	100% (20 of 20)
Benzo(a)pyrene	139	18.5% (15 of 81)	75.7% (28 of 37)	100% (24 of 24)
Chrysene	139	20% (16 of 80)	68.1% (32 of 47)	95.8% (23 of 24)
Fluoranthene	139	25% (24 of 96)	82.5% (33 of 40)	100% (15 of 15)
Pyrene	139	20.5% (16 of 78)	63.0% (29 of 46)	96.4% (27 of 28)
Total PAHs	167	18.5% (15 of 81)	65.1% (43 of 66)	100% (20 of 20)
Polychlorinated Biphenyls (PCBs)				
Total PCBs	120	11.1% (3 of 27)	31.0% (9 of 29)	82.3% (42 of 51)
Organochlorine Pesticides				
Chlordane	193	14.9% (15 of 101)	75.0% (15 of 20)	73.0% (27 of 37)
Dieldrin	180	16.5% (18 of 109)	95.2% (20 of 21)	100% (10 of 10)
Sum DDD	168	19.8% (20 of 101)	33.3% (1 of 3)	83.3% (5 of 6)
Sum DDE	180	18.1% (19 of 105)	33.3% (1 of 3)	96.7% (29 of 30)
Sum DDT	96	23% (23 of 100)	0.0% (0 of 1)	91.7% (11 of 12)
Total DDT	110	17.4% (16 of 92)	100% (23 of 23)	100% (10 of 10)
Endrin	170	29.4% (37 of 126)	40.0% (4 of 10)	NA% (0 of 0)
Heptachlor Epoxide	138	17.8% (16 of 90)	85.0% (17 of 20)	37.5% (3 of 8)
Lindane	180	28.1% (34 of 121)	65.9% (29 of 44)	82.4% (14 of 17)

NA = not applicable; TEC = threshold effect concentration; PEC = probable effect concentration.

Table 4.9. Incidence of sediment toxicity within ranges of mean PEC-Qs for sediments collected throughout the United States (from USEPA 2000a).

Toxicity Test	Endpoint	n	Incidence of Toxicity (number of samples in parentheses)					
			<0.1	**0.1 to <0.5**	**0.5 to <1.0**	**1.0 to <5.0**	**≥1.0**	**≥5.0**
10- to 14-day tests with amphipods *(Hyalella azteca)*	Survival or growth	670	18% (26 of 147)	16% (46 of 288)	37% (27 of 73)	41% (38 of 92)	54% (87 of 162)	71% (50 of 70)
28- to 42-day tests with amphipods *(Hyalella azteca)*	Survival or growth	160	10% (6 of 63)	13% (5 of 39)	56% (15 of 27)	NC	97% (30 of 31)	NC
10- to 14-day tests with midges *(Chironomus tentans or Chironomus riparius)*	Survival or growth	629	20% (24 of 121)	17% (53 of 313)	43% (27 of 63)	43% (38 of 88)	52% (69 of 132)	68% (30 of 44)

n = number of samples; NC = not calculated.

Table 4.10. Incidence of sediment toxicity within ranges of mean PEC-Qs for sediments from Florida and elsewhere in the southeastern portion of the United States.

Toxicity Test - Endpoint	n	Avg mean Q	Incidence of Toxicity (number of samples in parentheses)					
			<0.1	0.1 to <0.5	0.5 to <1.0	1.0 to <5.0	≥1.0	≥5.0
10-d *Hyalella azteca* survival	522	0.379	13% (15 of 116)	15% (51 of 339)	30% (14 of 46)	33% (6 of 18)	38% (8 of 21)	67% (2 of 3)
10-d *Hyalella azteca* survival or growth	522	0.379	13% (15 of 116)	16% (54 of 339)	37% (17 of 46)	39% (7 of 18)	48% (10 of 21)	100% (3 of 3)
28-42-d *Hyalella azteca* survival	174	0.549	8% (4 of 53)	13% (11 of 87)	43% (10 of 23)	38% (3 of 8)	45% (5 of 11)	67% (2 of 3)
28-42-d *Hyalella azteca* survival or growth	174	0.549	13% (7 of 53)	24% (21 of 87)	52% (12 of 23)	38% (3 of 8)	45% (5 of 11)	67% (2 of 3)
10-d *Chironomus tentans* survival	133	0.391	19% (5 of 26)	7% (7 of 94)	0% (0 of 9)	0% (0 of 3)	0% (0 of 4)	0% (0 of 1)
10-d *Chironomus tentans* survival or growth	133	0.391	23% (6 of 26)	9% (8 of 94)	33% (3 of 9)	67% (2 of 3)	75% (3 of 4)	100% (1 of 1)
Overall Toxicity	643	0.381	18% (27 of 150)	18% (73 of 406)	43% (26 of 61)	36% (8 of 22)	42% (11 of 26)	75% (3 of 4)

n = number of samples; PEC-Q = probable effects concentration quotient.

Table 4.11. Comparison of concentration-response relationships using matching sediment chemistry and biological effects data from the regional and national databases.

Endpoint Measured	n	Sediment Quality Targets (expressed as mean PEC-Qs[1])		
		P_{20}	P_{50}	Logistic Model Parameters[2]
Chronic toxicity to amphipods (endpoint: survival)				
Regional database	174	0.299	1.82	a = 76.9819; b = -0.9205; x_0 = 0.9310 (r^2 = 0.79; p = <0.001)
National database[3]	160	0.647	3.03	a = 309.0814; b = -0.6643; x_0 = 36.0700 (r^2 = 0.79; p = <0.0001)
Chronic toxicity to amphipods (endpoint: survival or growth)				
Regional database	174	0.136	0.781	a = 61.7734; b = -1.2463; x_0 = 0.2450 (r^2 = 0.78; p = <0.05)
National database[3]	160	0.220	0.628	a = 111.7462; b = -1.2496; x_0 = 0.7438 (r^2 = 0.93; p = <0.0001)
Acute toxicity to amphipods (endpoint: survival)				
Regional database	522	0.362	NA[4]	a = 633.7739; b = -0.4810; x_0 = 447.2264 (r^2 = 0.71; p = <0.05)
National database[3]	670	0.336	4.46	a = 122.2927; b = -0.4890; x_0 = 9.4722 (r^2 = 0.77; p = <0.0001)
Acute toxicity to amphipods (endpoint: survival or growth)				
Regional database	174	0.302	NA[4]	a = 1020.4246; b = -0.5518; x_0 = 361.9784 (r^2 = 0.82; p = <0.005)
National database[3]	670	0.225	3.38	a = 113.4909; b = -0.4811; x_0 = 5.5553 (r^2 = 0.71; p = <0.0001)
Chronic toxicity to midges (endpoint: survival or growth)				
Regional database	133	0.496	1.12	a = 8404.0068; b = -1.1309; x_0 = 103.2892 (r^2 = 0.42; p = 0.07)
National database[3]	632	0.187	3.52	a = 99.4883; b = -0.4736; x_0 = 3.4422 (r^2 = 0.56; p = <0.0001)

[1]PEL-Q = probable effect concentration quotient from MacDonald *et al.* (2000a).

[2]Logistic Model Equation: $y = a/[1+(x/x_0)^b]$

[3]From USEPA (2000a) and Ingersoll *et al.* (2001).

[4]NA = not applicable; concentration-response data did not support calculation of the P value.

Table 5.1. Sediment quality assessment guidelines for the protection of sediment-dwelling organisms in Florida.

Substance	Sediment Quality Assessment Guideline		Source
	TEC	PEC	
Metals (in mg/kg DW)			
Arsenic	9.8	33	MacDonald *et al.* (2000a)
Barium	20	60	USEPA (1977)
Beryllium	NG	NG	
Boron	NG	NG	
Cadmium	1.0	5.0	MacDonald *et al.* (2000a)
Chromium	43	110	MacDonald *et al.* (2000a)
Cobalt	50	NG	Persaud *et al*. (1993)
Copper	32	150	MacDonald *et al.* (2000a)
Lead	36	130	MacDonald *et al.* (2000a)
Mercury	0.18	1.1	MacDonald *et al.* (2000a)
Nickel	23	49	MacDonald *et al.* (2000a)
Silver	1.0	2.2	NYSDEC (1999)
Strontium	NG	NG	
Titanium	NG	NG	
Zinc	120	460	MacDonald *et al.* (2000a)
Zircon	NG	NG	
Polycyclic Aromatic Hydrocarbons (PAHs; in µg/kg DW)			
Acenaphthene	6.7	89	CCME (1999)
Acenaphthylene	5.9	130	CCME (1999)
Anthracene	57	850	MacDonald *et al.* (2000a)
Fluorene	77	540	MacDonald *et al.* (2000a)
Naphthalene	180	560	MacDonald *et al.* (2000a)
Phenanthrene	200	1200	MacDonald *et al.* (2000a)
Benz[a]anthracene	110	1100	MacDonald *et al.* (2000a)
Benzo(a)pyrene	150	1500	MacDonald *et al.* (2000a)
Chrysene	170	1300	MacDonald *et al.* (2000a)
Dibenz[a,h]anthracene	33	140	MacDonald *et al.* (2000a)/CCME (1999)
Fluoranthene	420	2200	MacDonald *et al.* (2000a)
Pyrene	200	1500	MacDonald *et al.* (2000a)
Total PAHs	1600	23000	MacDonald *et al.* (2000a)

Table 5.1. Sediment quality assessment guidelines for the protection of sediment-dwelling organisms in Florida.

Substance	Sediment Quality Assessment Guideline TEC	PEC	Source
Polychlorinated Biphenyls (PCBs; in µg/kg DW)			
Total PCBs	60	680	MacDonald *et al.* (2000a)
Chlorinated Benzenes (in µg/kg DW)			
Hexachlorobenzene (HCB)	20	240	Persaud *et al*. (1993)
Hexachlorobutadiene (HCBD)	55	550	NYSDEC (1999)
Phthalates (in µg/kg DW)			
Bis(2-ethylhexyl)phthalate	180	2600	MacDonald *et al.* (1996)
Dimethyl Phthalate	NG	NG	
Diethyl Phthalate	630	NG	USEPA (1997)
Di-n-butyl Phthalate	NG	43	Cubbage *et al.* (1997)
Organochlorine Pesticides (in µg/kg DW)			
Chlordane	3.2	18	MacDonald *et al.* (2000a)
Dieldrin	1.9	62	MacDonald *et al.* (2000a)
Sum DDD	4.9	28	MacDonald *et al.* (2000a)
Sum DDE	3.2	31	MacDonald *et al.* (2000a)
Sum DDT	4.2	63	MacDonald *et al.* (2000a)
Total DDTs	5.3	570	MacDonald *et al.* (2000a)
Endrin	2.2	210	MacDonald *et al.* (2000a)
Heptachlor Epoxide	2.5	16	MacDonald *et al.* (2000a)
Lindane (gamma-BHC)	2.4	5.0	MacDonald *et al.* (2000a)
Organophosphate Pesticides (in µg/kg DW)			
Azinphos-ethyl	0.018	NG	Stortelder *et al.* (1989)
Azinphos-methyl	0.062	NG	Stortelder *et al.* (1989)
Diazinon	0.38	NG	Stortelder *et al.* (1989)
Ethion	NG	NG	
Malathion	0.67	NG	USEPA (1997)
Methidathion	NG	NG	
Phosmet	NG	NG	
Phosphamidon	NG	NG	
Phoxim	0.060	NG	Stortelder *et al.* (1989)
Pyrazophos	0.015	NG	Stortelder *et al.* (1989)

Table 5.1. Sediment quality assessment guidelines for the protection of sediment-dwelling organisms in Florida.

Substance	Sediment Quality Assessment Guideline		Source
	TEC	PEC	
Other Pesticides (in µg/kg DW)			
Toxaphene	0.10	32	NYSDEC (1999)
Triazine Herbicides (in µg/kg DW)			
Atrazine	0.30	NG	Stortelder *et al.* (1989)
Cyanazine	NG	NG	
Simazine	0.34	NG	Stortelder *et al.* (1989)

DW = dry weight; NG = no guideline.

Table 5.2. Sediment quality assessment guidelines for the protection of aquatic-dependent wildlife and human health in Florida.

Chemicals of Concern	Wildlife-Based SQAGs[1]	Source	Human Health-Based SQAGs[2]	Source
Metals (mg/kg DW)				
Lead	NG		NG	
Mercury	NG		NG	
Polycyclic Aromatic Hydrocarbons (µg/kg OC)				
Acenapthene	NG		NG	
Acenaphthylene	NG		NG	
Anthracene	NG		NG	
Fluorene	NG		NG	
2-methylnaphthalene	NG		NG	
Naphthalene	NG		NG	
Phenanthrene	NG		NG	
Benz[a]anthracene	NG		69	WDOH (1995; 1996)
Benzo(b)fluoranthene	NG		69	WDOH (1995; 1996)
Benzo(k)fluoranthene	NG		69	WDOH (1995; 1996)
Benzo(a)pyrene	NG		69	WDOH (1995; 1996)
Chrysene	NG		44	WDOH (1995; 1996)
Dibenz[a,h]anthracene	NG		69	WDOH (1995; 1996)
Fluoranthene	NG		NG	
Indeno(1,2,3-cd)pyrene	NG		69	WDOH (1995; 1996)
Pyrene	NG		NG	
Total PAHs	NG		NG	

Table 5.2. Sediment quality assessment guidelines for the protection of aquatic-dependent wildlife and human health in Florida.

Chemicals of Concern	Wildlife-Based SQAGs[1]	Source	Human Health-Based SQAGs[2]	Source
Polychlorinated Biphenyls (µg/kg OC)				
Aroclor 1016	NG		4.9	WDOH (1995; 1996)
Aroclor 1242	NG		1.7	WDOH (1995; 1996)
Aroclor 1248	NG		1.7	WDOH (1995; 1996)
Aroclor 1254	NG		1.7	WDOH (1995; 1996)
Aroclor 1260	NG		1.7	WDOH (1995; 1996)
Total PCBs	1400	NYSDEC (1999)	NG	
Chlorinated Benzenes (µg/kg OC)				
Hexachlorobenzene (HCB)	12000	NYSDEC (1999)	310	WDOH (1995; 1996)
Hexachlorobutadiene (HCBD)	4000	NYSDEC (1999)	8100	WDOH (1995; 1996)
Phthalates (µg/kg OC)				
Bis(2-ethyl hexyl)phthalate	NG		36000	WDOH (1995; 1996)
Chlorophenols (µg/kg OC)				
Pentachlorophenol	NG		4200	WDOH (1995; 1996)
Pesticides (µg/kg OC)				
Aldrin	NG		0.13	WDOH (1995; 1996)
Aldrin + Dieldrin	770	NYSDEC (1999)	NG	NYSDEC (1999)
Chlordane	6	NYSDEC (1999)	1.7	WDOH (1995; 1996)
Dieldrin	NG		0.14	WDOH (1995; 1996)
p,p-DDD	NG		9.1	WDOH (1995; 1996)
p,p-DDE	NG		5.5	WDOH (1995; 1996)

Table 5.2. **Sediment quality assessment guidelines for the protection of aquatic-dependent wildlife and human health in Florida.**

Chemicals of Concern	Wildlife-Based SQAGs[1]	Source	Human Health-Based SQAGs[2]	Source
Pesticides (µg/kg OC; con't.)				
p,p-DDT	NG		6.5	WDOH (1995; 1996)
Total DDT	1000	NYSDEC (1999)	10	NYSDEC (1999)
Endosulfan	NG		36000	WDOH (1995; 1996)
Endrin	800	NYSDEC (1999)	550	WDOH (1995; 1996)
Heptachlor	NG		1.3	WDOH (1995; 1996)
Heptachlor epoxide	NG		0.65	WDOH (1995; 1996)
Heptachlor + heptachlor epoxide	30	NYSDEC (1999)	0.80	NYSDEC (1999)
Alpha-hexachlorocyclohexane (HCH)[3]	NG		0.94	WDOH (1995; 1996)
Beta-HCH[3]	NG		3.2	WDOH (1995; 1996)
Technical-HCH[3]	1500	NYSDEC (1999)	3.3	WDOH (1995; 1996)
Lindane (gamma-HCH)[3]	NG		4.6	WDOH (1995; 1996)
Mirex	3700	NYSDEC (1999)	70	NYSDEC (1999)
Toxaphene	NG		20	NYSDEC (1999)
Dioxins (µg/kg OC)				
1,2,3,4,6,7,8-Heptachlorodibenzo-p-dioxin	NG		12	WDOH (1995; 1996)
1,2,3,4,6,7,8-Heptachlorodibenzofuran	NG		12	WDOH (1995; 1996)
1,2,3,4,7,8,9-Heptachlorodibenzofuran	NG		12	WDOH (1995; 1996)
1,2,3,4,7,8-Hexachlorodibenzo-p-dioxin	NG		0.046	WDOH (1995; 1996)
1,2,3,4,7,8-Hexachlorodibenzofuran	NG		0.046	WDOH (1995; 1996)
1,2,3,6,7,8-Hexachlorodibenzo-p-dioxin	NG		0.046	WDOH (1995; 1996)
1,2,3,6,7,8-Hexachlorodibenzofuran	NG		0.046	WDOH (1995; 1996)
1,2,3,7,8,9-Hexachlorodibenzo-p-dioxin	NG		0.046	WDOH (1995; 1996)

Table 5.2. Sediment quality assessment guidelines for the protection of aquatic-dependent wildlife and human health in Florida.

Chemicals of Concern	Wildlife-Based SQAGs[1]	Source	Human Health-Based SQAGs[2]	Source
Dioxins (µg/kg OC; con't.)				
1,2,3,7,8,9-Hexachlorodibenzofuran	NG		0.046	WDOH (1995; 1996)
1,2,3,7,8-Pentachlorodibenzo-p-dioxin	NG		0.0092	WDOH (1995; 1996)
1,2,3,7,8-Pentachlorodibenzofuran	NG		0.026	WDOH (1995; 1996)
2,3,4,6,7,8-Hexachlorodibenzofuran	NG		0.046	WDOH (1995; 1996)
2,3,4,7,8-Pentachlorodibenzofuran	NG		0.0031	WDOH (1995; 1996)
2,3,7,8-Tetrachlorodibenzo-p-dioxin	0.2	NYSDEC (1999)	0.00015	WDOH (1995; 1996)
2,3,7,8-Tetrachlorodibenzofuran	NG		0.013	WDOH (1995; 1996)
Octachlorodibenzodioxin	NG		120	WDOH (1995; 1996)
Octachlorodibenzofuran	NG		120	WDOH (1995; 1996)

OC = organic carbon; NG = no guideline is available; SQGs = sediment quality guidelines; DW = dry weight; OC = organic carbon.

[1]Source: NYSDEC 1999

[2]Source: WDOH 1995; 1996 (*if no guideline was available from this source, the NYSDEC 1999 guidelines were used)

[3]The wildlife-based SQGs for hexachlorocyclohexane (HCH) are for the sum of all HCH isomers, including alpha - HCH, beta-HCH and gamma-HCH.

Figures

Figure 4.1. Relationship between the geometric mean of mean PEC-Qs and the incidence of acute toxicity to amphipods (endpoints: survival only) in the national (10- to 14-day toxicity tests) and regional (10-day toxicity tests) databases.

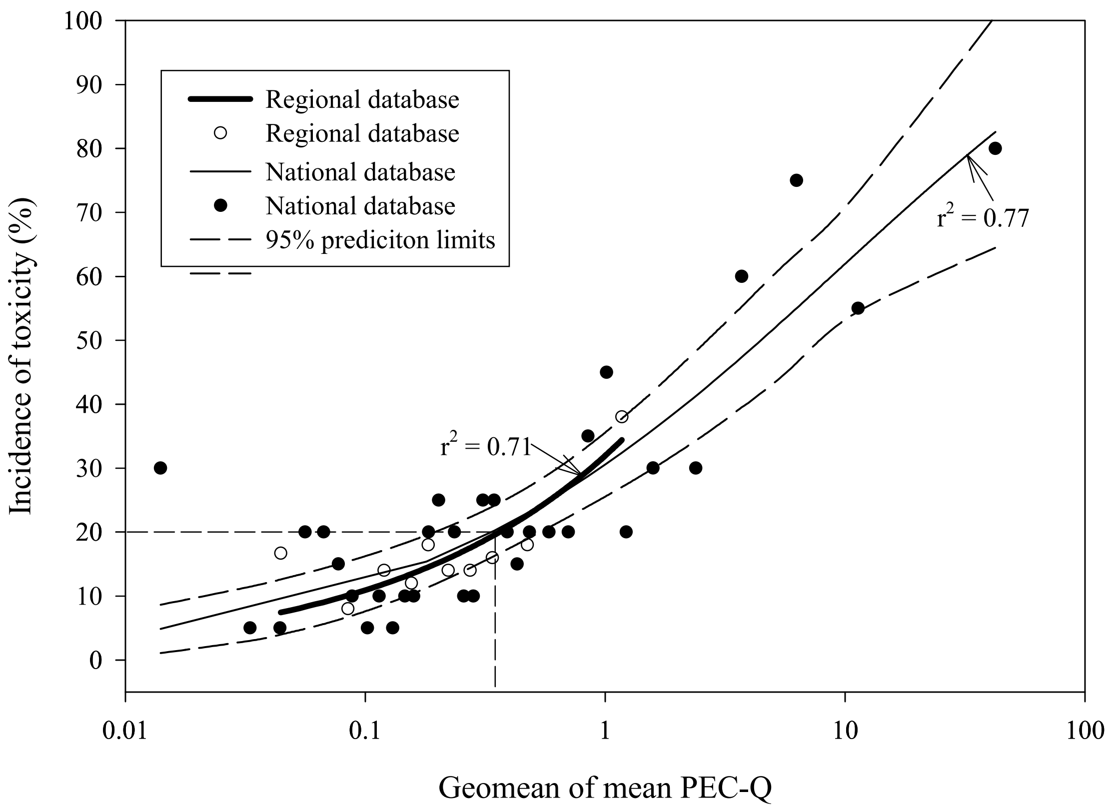


Figure 4.2. Relationship between the geometric mean of mean PEC-Qs and the incidence of acute toxicity to amphipods (endpoints: survival or growth) in the national (10- to 14-day toxicity tests) and regional (10-day toxicity tests) databases.

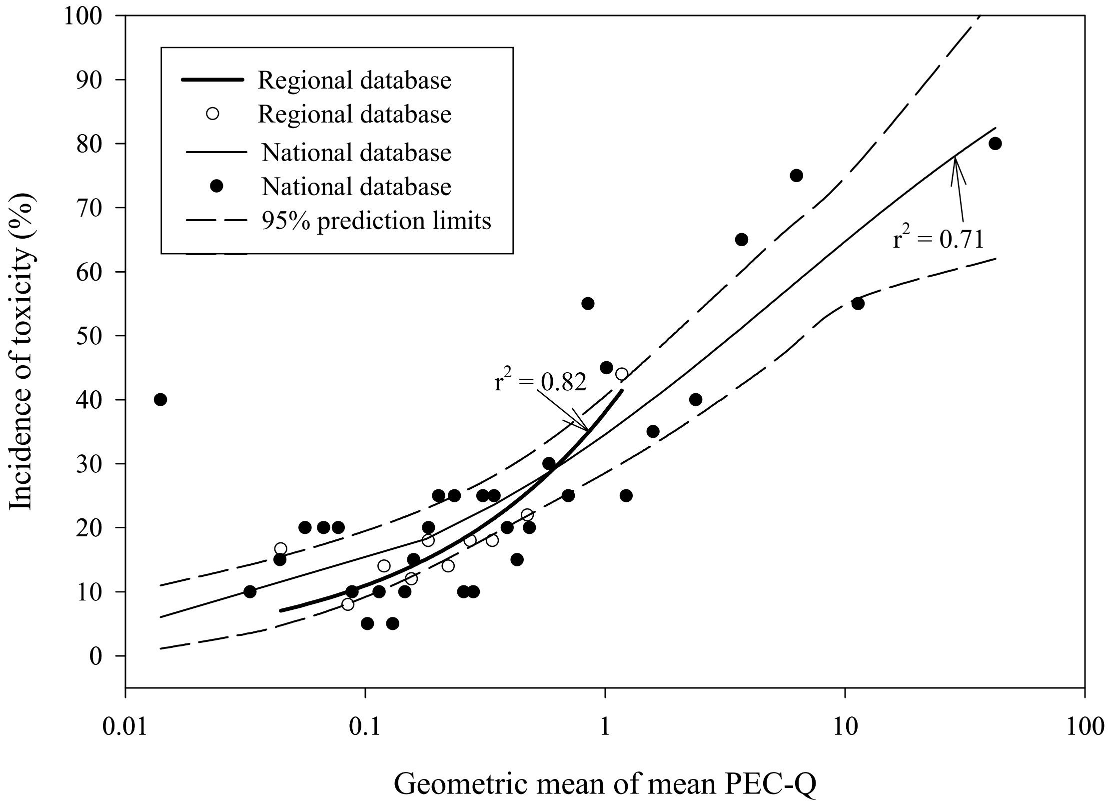


Figure 4.3. Relationship between the geometric mean of mean PEC-Qs and the incidence of chronic toxicity to amphipods (endpoints: survival only) in the national (28- to 42-day toxicity tests) and regional (28- to 42-day toxicity tests; n = 174, grouped by 15) databases.

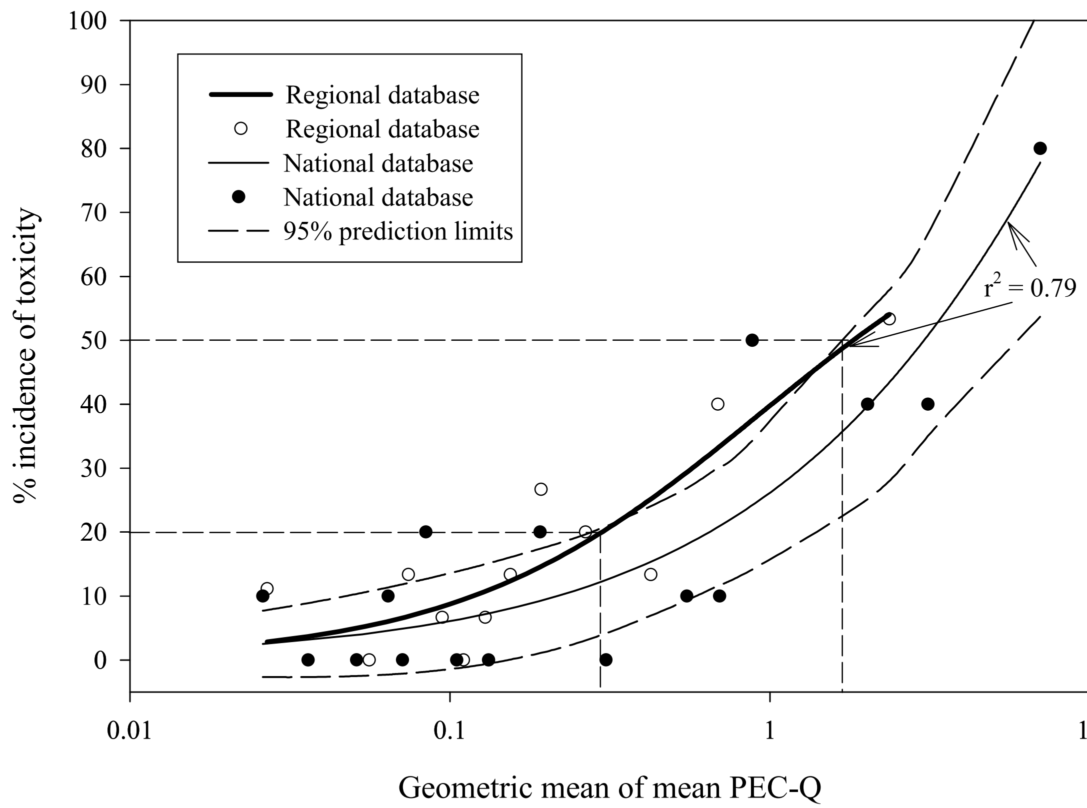


Figure 4.4. Relationship between the geometric mean of mean PEC-Qs and the incidence of chronic toxicity to amphipods (endpoints: survival or growth) in the national (28- to 42 day toxicity tests) and regional (28- to 42-day toxicity tests) databases.

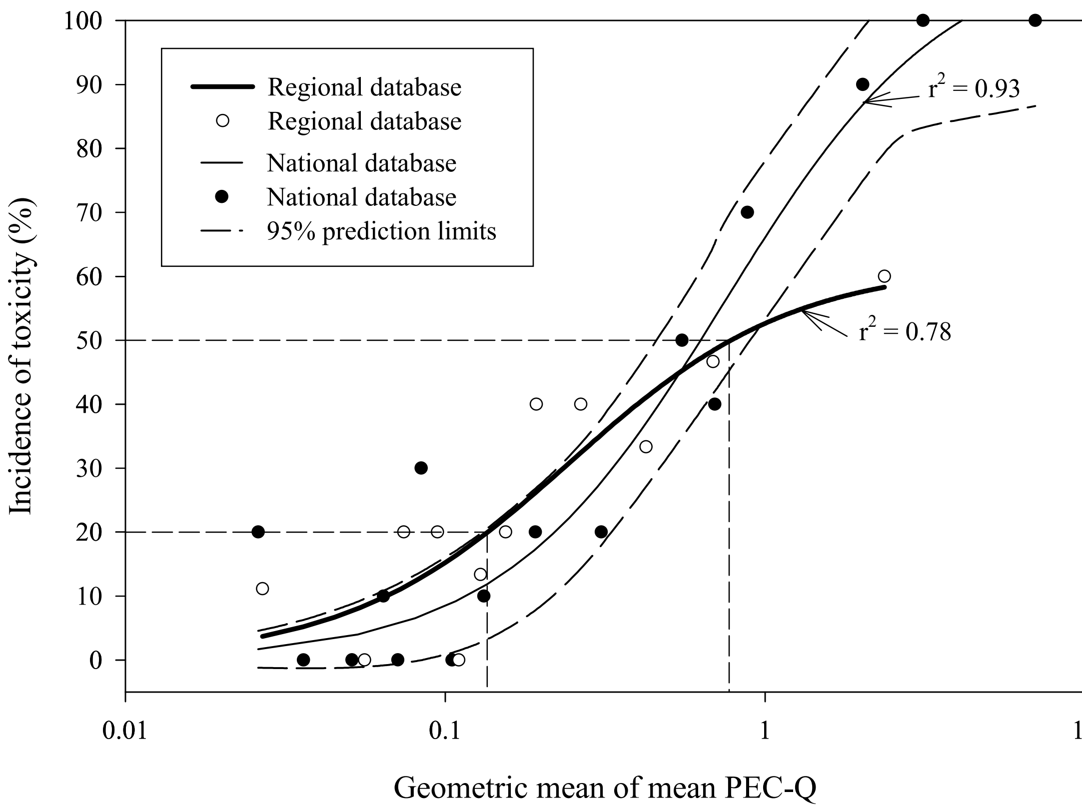
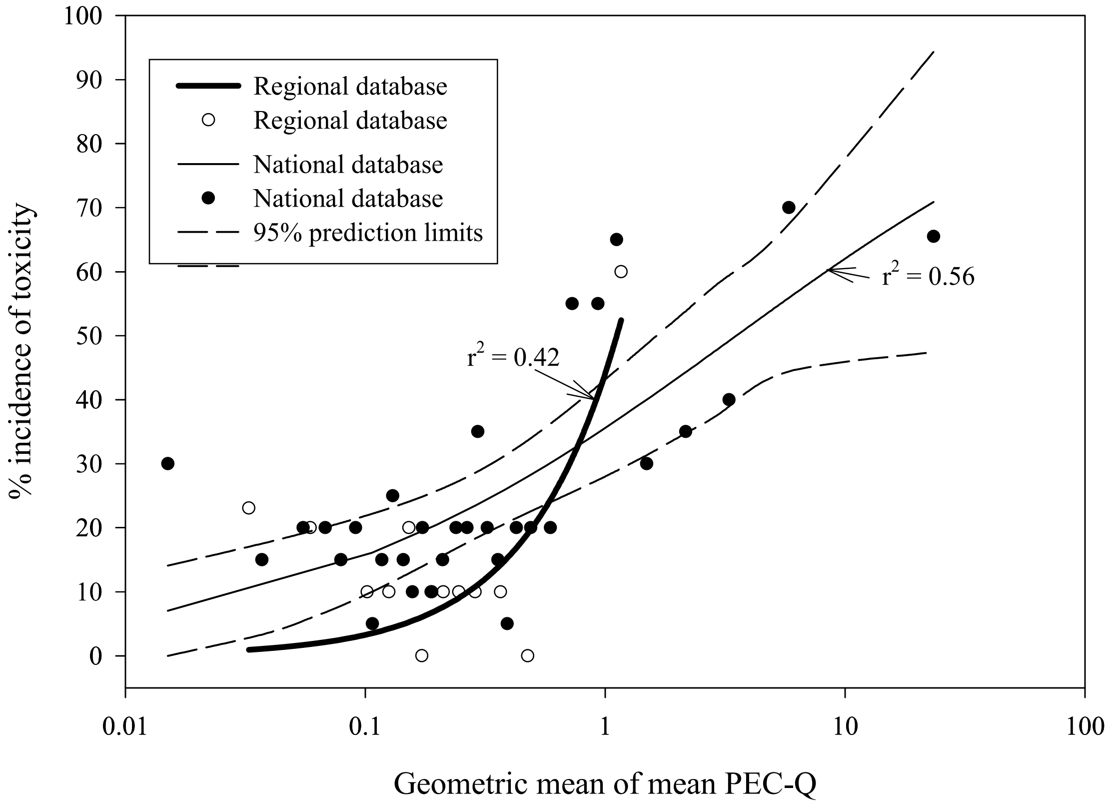


Figure 4.5. Relationship between the geometric mean of mean PEC-Qs and the incidence of acute toxicity to midges (endpoints: survival or growth), in the national (10- to 14-d Chironomus spp. toxicity tests) and regional (10-day toxicity tests) databases.



Appendices

Appendix 1 Freshwater Sediment Quality Assessment Initiative: Project Overview

A1.0 Introduction and Background

Historic and, to a lesser extent, ongoing land and water use activities, have caused aquatic sediments in many locations throughout Florida to become contaminated with a variety of toxic and bioaccumulative substances. These contaminants include trace metals, PAHs, PCBs, PCDDs and PCDFs, chlorinated pesticides (e.g., DDTs and toxaphene), and other industrial and agricultural chemicals. The presence of contaminated sediments in freshwater, estuarine, and marine ecosystems has the potential to adversely affect aquatic organisms, aquatic-dependent wildlife species, and human health. For this reason, the assessment, management, and remediation of contaminated sediments has been identified as a priority for the water assessment initiative and waste management sections of the FDEP.

In recognition of the need to support sediment management activities throughout the state, FDEP initiated its first major sediment-related initiative in the early 1980's. This initiative, which was implemented under the Coastal Zone Management Program, consisted of four main elements. First, FDEP conducted a broad survey of sediment quality conditions in near-shore marine and estuarine habitats along the Atlantic and Gulf coasts. Next, the resultant data from relatively uncontaminated sites were used to develop a practical approach for assessing metals contamination in coastal sediments which relied on the normalization of metal concentrations to a reference element (i.e., the metals interpretive tool; Schropp and Windom 1988; Schropp *et al.* 1990). Subsequently, effects-based SQAGs were developed which provide a scientifically-defensible basis for evaluating the potential effects of sediment-associated contaminants on aquatic organisms (MacDonald 1994; MacDonald *et al.* 1996). Finally, a framework for assessing sediment quality conditions in marine and estuarine ecosystems was developed to provide agency staff and others with guidance on how the various tools should be applied together to support sediment management decisions (MacDonald 1994). These assessment tools and the assessment framework are currently being used in a wide variety of applications, both in Florida and elsewhere in North America.

While the existing guidance documents provide administrators, managers, and scientists with the tools that are needed to effectively manage marine and estuarine sediments in Florida, companion tools for assessing freshwater sediments are not currently available in the state. For this reason, FDEP has identified the development of guidance on the assessment of freshwater sediments as a high priority. This guidance has been developed as part of the ***Freshwater Sediment Quality Assessment Initiative***.

A1.1 Freshwater Sediment Quality Assessment Initiative

Traditionally, the management of aquatic resources in Florida has focused primarily on water quality. However, the importance of sediments in terms of determining the fate and effects of a wide variety of contaminants has become more apparent in recent years. In addition to providing habitat for many organisms, sediments are important because many toxic substances found at only trace levels in water can accumulate to elevated levels in sediments. As such, sediments serve both as reservoirs and potential sources of contaminants to the water column. Sediment-associated contaminants have the potential to cause direct effects on sediment-dwelling organisms and to adversely affect wildlife and human health when these substances accumulate in the food web. Therefore, information on sediment quality conditions is essential for evaluating the overall status of freshwater ecosystems.

The FDEP plays a lead role in the assessment and management of aquatic resources in the state. To meet its responsibilities in terms of managing Florida's unique freshwater ecosystems, FDEP has developed a number of programs that enable it to effectively protect water quality and ensure proper waste management. Many of these programs have components that necessitate the assessment and management of sediment quality conditions, including:

- Watershed Monitoring;
- Environmental Resource Permitting;
- Everglades Ecosystem Restoration;
- Domestic and Industrial Wastewater;

- Mine Reclamation;
- Nonpoint Source/Stormwater;
- Solid and Hazardous Waste;
- State Lands; and,
- Waste Cleanup.

A1.2 Implementation Plan

Successful completion of the ***Freshwater Sediment Quality Assessment Initiative*** necessitated the development and implementation of an effective project management strategy. In recognition of the need for broad stakeholder involvement and inter-agency cooperation, FDEP developed a detailed implementation plan that consists of the following elements:

- Identify the project components and develop a preliminary implementation plan;
- Convene an interests and needs workshop on the assessment of freshwater sediments;
- Prepare and distribute a workshop summary report to workshop participants;
- Build an effective inter-agency Steering Committee to guide the project through the implementation phase;
- Solicit additional advice from stakeholders on an as needed basis;
- Prepare periodic progress reports for FDEP's senior managers and stakeholders;
- Prepare and distribute draft guidance documents to stakeholders;
- Incorporate comments and finalize guidance documents; and,
- Convene a series a workshops for FDEP district staff and others to explain the applications of the tools that are described in the guidance documents.

A1.3 Development of a Metals Interpretive Tool

Sediment chemistry data are essential for evaluating sediment quality conditions in freshwater ecosystems. However, interpretation of data on the concentrations of sediment-associated metals is challenging because such measurements are influenced by a variety of factors, including sediment mineralogy, grain size, organic content, and anthropogenic enrichment. This combination of factors results in metals levels that can vary two to three orders of magnitude at uncontaminated sites in Florida. Therefore, it is important to consider the natural background levels of sediment-associated metals when conducting sediment quality assessments.

In Florida, assessment of the probable origin of metals in freshwater sediments is supported by a metals interpretive tool. Development of the metals interpretive tool for freshwater sediments followed the same procedures that were used to formulate the companion tool for marine and estuarine sediments (Schropp *et al.* 1990). In the first step of this process, existing data on the concentrations of sediment-associated metals at several hundred uncontaminated sites in the state were obtained, evaluated, and compiled in electronic database format. Florida Department of Environmental Protection, Florida Geological Survey (FGS), and USEPA represented the primary sources of these data. Next, a statistical test were applied to the data for each metal to determine if the data were normally distributed. For those metals that had normally distributed data, simple linear regressions of each metal and an appropriate geochemical normalizer were performed (using log-transformed data) and the 95% prediction limits were calculated for each regression equation. The regression plots provide the basis for interpreting new data on the concentrations of metals in sediments, such that anthropogenic enrichment of metal levels is indicated at sites with metals concentrations exceeding the upper 95% prediction limit (for one or more substances).

A1.4 Derivation and Evaluation of Sediment Quality Assessment Guidelines

Sediment chemistry data alone do not provide an adequate basis for assessing the hazards posed by sediment-associated contaminants to aquatic organisms. In addition, interpretive tools are 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, effects-based SQAGs are needed to provide a scientifically defensible basis for evaluating the potential effects of sediment-associated contaminants on aquatic organisms.

Numerical SQAGs for freshwater ecosystems were developed using the same general approach that was used to derive the SQAGs for Florida's coastal waters (MacDonald 1994). First, matching sediment chemistry and biological effects data from Florida and elsewhere in the southeast (i.e., Region IV) were acquired from a variety of sources. Next, each candidate data set were reviewed and critically evaluated to determine its scientific and technical validity. Data sets that were deemed to be acceptable were compiled in electronic database format and verified against the original data source. Subsequently, numerical SQAGs for each chemical of concern were developed using the consensus approach (MacDonald *et al.* 2000a). Finally, the SQAGs were evaluated to determine if they provide a reliable basis for predicting the presence and absence of adverse biological effects in Florida and the southeastern portion of the United States.

A1.5 Formulation of an Integrated Framework for Assessing Freshwater Sediments

Numerical SQAGs provide benchmarks for evaluating the potential effects of sediment-associated contaminants on aquatic organisms. While numerical SQAGs provide essential tools for assessing the quality of freshwater sediments, decisions regarding the management of contaminated sediments should not be made based on exceedances of the SQAGs alone.

Instead, the SQAGs should be used within an integrated framework which supports a more comprehensive assessment of sediment quality conditions.

The integrated framework identifies the steps that should be taken to conduct comprehensive assessments of sediment quality conditions in freshwater ecosystems. In addition, the integrated framework provides detailed guidance on each of the steps in the assessment process, including the following:

- Collection of historical land and water use information;
- Identification of contaminants and areas of concern;
- Collection and evaluation of existing sediment chemistry data;
- Collection of supplemental sediment chemistry data;
- Assessment of the potential for biological effects of sediment-associated contaminants;
- Evaluation of the probable origin of sediment-associated contaminants;
- Collection of additional biological effects data;
- Evaluation of the nature, severity, and areal extent of contamination;
- Development and implementation of a remedial action plan; and,
- Evaluation of the efficacy of remedial measures.

The recommended framework will be designed to provide a consistent approach to assessing sediment quality in freshwater ecosystems. However, the framework will not replace accepted sediment testing protocols, such as developed for the ocean disposal of dredged material. Instead, it is intended to provide general guidance to support the sediment quality assessment process.

Appendix 2 Criteria for Evaluating Candidate Data Sets

A2.0 Introduction

In recent years, the Great Lakes National Program Office (USEPA), United States Geological Survey, National Oceanic and Administration, Minnesota Pollution Control Agency, Florida Department of Environmental Protection, British Columbia Ministry of Water, Air, and Land Protection, MacDonald Environmental Sciences Ltd., and EVS Consultants have been developing a database of matching sediment chemistry and sediment toxicity data to support evaluations of the predictive ability of numerical SQAGs in the Great Lakes Basin and elsewhere in North America (Field *et al.* 1999; USEPA 2000a; Crane *et al.* 2000). In addition, various project-specific databases have been developed to facilitate access to and analysis of data sets to support natural resource damage assessments and ecological risk assessments at sites with contaminated sediments (MacDonald and Ingersoll 2000; MacDonald *et al.* 2000a; Crane *et al.* 2000; MacDonald *et al.* 2001b; 2001c; Ingersoll *et al.* 2001). The goal of these initiatives was to collect and collate the highest quality data sets for assessing sediment quality conditions at contaminated sites and evaluating numerical SQAGs. To assure that the data used in these assessments met the associated data quality objectives (DQOs), all of the candidate data sets were critically evaluated before inclusion in the database. However, the screening process was also designed to be flexible to assure that professional judgement could also be used when necessary in the evaluation process. In this way, it was possible to include as many data sets as possible and, subsequently, use them to the extent that the data quality and quantity dictate.

The following criteria for evaluating candidate data sets were established in consultation with an *ad hoc* Science Advisory Group on Sediment Quality Assessment (which is comprised of representatives of federal, provincial, and state government agencies, consulting firms, and non-governmental organizations located throughout North America and elsewhere worldwide). These criteria are reproduced here because they provide useful guidance on the evaluation of data that have been generated to support sediment quality assessments. In addition, these criteria can be used to support the design of sediment sampling and analysis plans, and associated quality assurance project plans (see Volume II).

A2.1 Criteria for Evaluating Whole-sediment, Pore-water, and Tissue Chemistry

Data on the chemical composition of whole sediments, pore water, and biological tissues are of fundamental importance in assessments of sediment quality conditions. For this reason, it is essential to ensure that high quality data are generated and used to support such sediment quality assessments. In this respect, data from individual studies are considered to be acceptable if:

- Samples were collected from any sediment horizon (samples representing surficial sediments are most appropriate for assessing effects on sediment-dwelling organisms and other receptors, while samples of sub-surface sediments are appropriate for assessing potential effects on sediment-dwelling organisms and other receptors, should these sediments become exposed; ASTM 2001a; ASTM 2001d; USEPA 2000b);
- Appropriate procedures were used for collecting, handling, and storing sediments (e.g., ASTM 2001b; 2001c; USEPA 2001) and samples of other media types;
- The concentrations of a variety of all COPCs were measured in samples;
- Appropriate analytical methods were used to generate chemistry data. The methods that are considered to be appropriate included USEPA approved methods, other standardized methods (e.g., ASTM methods, SW-846 methods), or methods that have been demonstrated to be equivalent or superior to standard methods; and,
- Data quality objectives were met. The criteria that are used to evaluate data quality included:

    (i) the investigator indicated that DQOs had been met;

    (ii) analytical detection limits were reported and lower than the PECs (however, detection limits < TEC are preferred);

    (iii) accuracy and precision of the chemistry data were reported and within acceptable ranges for the method;

    (iv) sample contamination was not noted (i.e., analytes were not detected at unacceptable concentrations in method blanks); and,

(v) the results of a detailed independent review indicated that the data were acceptable and/or professional judgement indicated that the data set was likely to be of sufficient quality to be used in the assessment (i.e., in conjunction with author communications and/or other investigations).

A2.2 Criteria for Evaluating Biological Effects Data

Data on the effects of contaminated sediments on sediment-dwelling organisms and other aquatic species provide important information for evaluating the severity and extent of sediment contamination. Data from individual studies are considered to be acceptable for this purpose if:

- Appropriate procedures were used for collecting, handling, and storing sediments (e.g., ASTM 2001b; USEPA 2000b; 2001); Sediments were not frozen before toxicity tests were initiated (ASTM 2001a; 2001e);
- The responses in the negative control and/or reference groups were within accepted limits (i.e., ASTM 2001a; 2001c; 2001d; 2001e; 2001f; 2001g; USEPA 2000a);
- Adequate environmental conditions were maintained in the test chambers during toxicity testing (i.e., ASTM 2001a; 2001d; USEPA 2000a);
- The endpoint(s) measured were ecologically-relevant (i.e., likely to influence the organism's viability in the field) or indicative of ecologically-relevant endpoints; and,
- Appropriate procedures were used to conduct bioaccumulation tests (ASTM 2001c).

Additional guidance is presented in USEPA (1994) for evaluating the quality of benthic community data generated as part of a sediment quality assessment. These criteria include collection of replicate samples, resorting at least 10% of the samples, and independent checks of taxonomic identification of specimens. Guidance is presented in USEPA (2000c) and in Schmidt *et al.* (2000) for evaluating the quality of fish health and fish community data.

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