Cover Pages in Separate File - specific to three clients
Called Volume I Cover Pages

ML DON'T FORGET TO CHANGE PRINTER TO ACROBAT THEN GENERATE

TOC PRIOR TO PRINTING PDF

Table of Contents

List of Tables

List of Figures

Executive Summary

Traditionally, concerns relative to the management of aquatic resources in freshwater ecosystems have 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, 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 in the past twenty years have unquestionably improved water quality conditions, a growing body of evidence indicates that management efforts directed solely at the attainment of surface water quality may not provide an adequate basis for protecting the designated uses of aquatic ecosystems.

In recent years, concerns relative to the health and vitality of aquatic ecosystems have begun to reemerge in North America. 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, organochlorine pesticides (OC pesticides), and polybrominated diphenyl ethers]; 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 long ago. The use of many of these substances has been banned in North America for more than 30 years; nevertheless, these chemicals continue to persist in the environment. Other contaminants enter our waters every day 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 when conditions change in the receiving water system (e.g., during periods of anoxia, after severe storms).

Information from a variety of sources indicates that sediments throughout North America 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), and polychlorinated dibenzo-*p*-dioxins and furans (PCDDs and PCDFs). For example, contaminated sediments pose a major risk to the beneficial uses of aquatic ecosystems throughout the Great Lakes basin, including 43 areas of concern (AOCs) identified by the International Joint Commission. The imposition of fish consumption advisories has adversely affected commercial, sport, and food fisheries in many areas. In addition, degradation of the benthic community and other factors have adversely affected fish and wildlife populations. Furthermore, fish in many of these areas have been observed to have higher levels of tumors and other abnormalities than fish from reference areas. Contaminated sediments have also threatened the viability of many commercial ports through the imposition of restrictions on dredging of navigational channels and disposal of dredged materials. Overall, contaminated sediments have been linked to 11 of the 14 beneficial use impairments that have been documented at the Great Lakes AOCs. Such use impairments have also been observed elsewhere in Canada and the United States.

In response to the concerns raised regarding contaminated sediments, responsible authorities throughout North America have launched programs to support the assessment, management, and remediation of contaminated sediments. The information generated under these programs provide important guidance for designing and implementing investigations at sites with contaminated sediments. In addition, guidance has been developed under various sediment-related programs to support the collection and interpretation of sediment quality data. While such guidance has unquestionably advanced the field of sediment quality assessments, the users of the individual guidance documents have expressed a need to consolidate this information into an integrated ecosystem-based framework for assessing and managing sediment quality in freshwater ecosystems (i.e., as specified under the Great Lakes Water Quality Agreement). Practitioners in this field have also indicated the need for additional guidance on the applications of the various tools that support sediment quality assessments. Furthermore, the need for additional guidance on the design of sediment quality monitoring programs and on the interpretation of the resultant data has been identified.

This guidance manual, which comprises a three-volume series, is not intended to supplant the existing guidance on sediment quality assessment. Rather, this guidance manual is intended to further support the design and implementation of assessments of sediment quality conditions by:

- Presenting an ecosystem-based framework for assessing and managing contaminated sediments (Volume I);
- Describing the recommended procedures for designing and implementing sediment quality investigations (Volume II); and,
- Describing the recommended procedures for interpreting the results of sediment quality investigations (Volume III).

The first volume of the guidance manual, ***An Ecosystem-Based Framework for Assessing and Managing Contaminated Sediments in the Freshwater Ecosystems***, 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 (Chapter 2). In addition, the recommended procedures for identifying sediment quality issues and concerns and compiling the existing knowledge base are described (Chapter 3). Furthermore, the recommended procedures for establishing ecosystem goals, ecosystem health objectives, and sediment management objectives are presented (Chapter 4). Finally, methods for selecting ecosystem health indicators, metrics, and targets for assessing contaminated sediments are described (Chapter 5). 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. More detailed information on these and other topics related to the assessment and management of contaminated sediments can be found in the publications that are listed in the bibliography (Appendix 2).

The second volume of the series, ***Design and Implementation of Sediment Quality Investigations***, 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 process is presented in this document (Chapter 2). In addition, this volume describes the recommended procedures for conducting preliminary and detailed site investigations to assess sediment quality conditions (Chapters 3 and 4). Furthermore, the factors that need to be considered in the development of sampling and analysis plans for assessing contaminated sediments are described (Chapter 5). Supplemental guidance on the design of sediment sampling programs, on the evaluation of sediment quality data, and on the management of contaminated sediment is provided in the Appendices to this volume. The appendices of this document also describe the types and objectives of sediment quality assessments that are commonly conducted in freshwater ecosystems.

The third volume in the series, ***Interpretation of the Results of Sediment Quality Investigations***, describes the four types of information that are commonly used to assess contaminated sediments, including sediment and pore water chemistry data (Chapter 2), sediment toxicity data (Chapter 3), benthic invertebrate community structure data (Chapter 4), and bioaccumulation data (Chapter 5). Some of the other tools that can be used to support assessments of sediment quality conditions are also briefly described (e.g., fish health assessments; Chapter 6). The information compiled on each of the tools includes:

descriptions of its applications, advantages, and limitations; discussions on the availability of standard methods, the evaluation of data quality, methodological uncertainty, and the interpretation of associated data; and, recommendations to guide the use of each of these individual indicators of sediment quality conditions. Furthermore, guidance is provided on the interpretation of data on multiple indicators of sediment quality conditions (Chapter 7). Together, the information provided in the three-volume series is intended to further support the design and implementation of focused sediment quality assessment programs.

List of Acronyms

%	percent
µg	microgram
µg/kg	micrograms per kilogram
µg/L	micrograms per liter
µmol/g	micromoles per gram
AET	apparent effects threshold
AETA	Apparent Effects Threshold Approach
Al	aluminum
ANOVA	analysis of variance
AOC	Area of Concern
APHA	American Public Health Association
ARCS Program	Assessment and Remediation of Contaminated Sediments Program
ASTM	American Society for Testing and Materials
AVS	acid volatile sulfides
BCE	British Columbia Environment
BCWMA	British Columbia Waste Management Act
BEST	biomonitoring of environmental status and trends
BSAF	biota-sediment bioaccumulation factor
CA	Consensus Approach
CAC	citizens advisory committee
CCME	Canadian Council of Ministers of the Environment
CCREM	Canadian Council of Resource and Environment Ministers
CDF	confined disposal facility
CEPA	Canadian Environmental Protection Act
CERCLA	Comprehensive Environmental Response, Compensation, and Liability Act
CERCLIS	Comprehensive Environmental Response, Compensation, and Liability Information System
CI	confidence interval
CLP	Contract Laboratory Program
COC	contaminant of concern
COPC	chemical of potential concern
CRLD	contract required detection limit
CSO	combined sewer overflow
CSR	Contaminated Sites Regulation
CWA	Clean Water Act
-d	- days
DDT	dichlorodiphenyl-trichloroethane
DDTs	*p,p*'-DDT, *o,p*'-DDT, *p,p*'-DDE, *o,p*'-DDE, *p,p*'-DDD, *o,p*'-DDD, and any metabolite or degradation product
DELT	deformities, fin erosion, lesions, and tumors
DL	detection limit

DM	dredged material
DO	dissolved oxygen
DOE	Department of the Environment
DOI	Department of the Interior
DQO	data quality objective
DSI	detailed site investigation
DW	dry weight
EC	Environment Canada
EC_{50}	median effective concentration affecting 50 percent of the test organisms
EEC	European Economic Community
ELA	Effects Level Approach
EMAP	Environmental Monitoring and Assessment Program
EPT	Ephemeroptera, Plecoptera, Trichoptera (i.e., mayflies, stoneflies, caddisflies)
EqPA	Equilibrium Partitioning Approach
ERL	effects range low
ERM	effects range median
EROD	ethoxyresorufin-*O*-deethylase
ESG	equilibrium-partitioning sediment quality guidelines
FCV	final chronic values
FD	factual determinations
FIFRA	Federal Insecticide, Rodenticide and Fungicide Act
gamma-BHC	gamma-hexachlorocyclohexane (lindane)
GFAA	graphite furnace atomic absorption
GIS	geographic information system
-h	- hours
H_2S	hydrogen sulfide
HC	Health Canada
Hcl	hydrochloric acid
IBI	Index of biotic integrity
IC_{50}	median inhibition concentration affecting 50 percent of test organisms
ICP	inductively coupled plasma-atomic emission spectrometry
ID	insufficient data
IDEM	Indiana Department of Environmental Management
IJC	International Joint Commission
IWB	index of well-being
K_{oc}	organic carbon partition coefficients
K_{ow}	octanol-water partition coefficients
Kp	sediment/water partition coefficients
LC_{50}	median lethal concentration affecting 50 percent of the test organism
LCS/LCSDs	laboratory control sample/laboratory control sample duplicates
Li	lithium
LMP	lakewide management plan
LOD	limit of detection
LOEC	lowest observed effect concentration
LRMA	Logistic Regression Modeling Approach

mean PEC-Q	mean probable effect concentration quotient
MESL	MacDonald Environmental Sciences Ltd.
MET	minimal effect threshold
mg/kg	milligrams per kilogram
mg/L	milligrams per liter
mgs	milligrams
mIBI	macroinvertebrate index of biotic integrity
-min	- minutes
mm	millimeter
mm	millimeters
MPRSA	Marine Protection, Research, and Sanctuaries Act
MS/MSDs	matrix spike/matrix spike duplicates
MSD	minimum significant difference
n	number of samples
NAWQA	National Water Quality Assessment
NEPA	National Environmental Policy Act
NG	no guideline available
NH_3	unionized ammonia
NH_4^+	ionized ammonia
NOAA	National Oceanic and Atmospheric Administration
NOEC	no observed effect concentration
NPDES	National Pollutant Discharge and Elimination System
NPL	National Priorities List
NPO	nonpolar organics
NR	not reported
NRDA	natural resource damage assessment
NSQS	National Sediment Quality Survey
NSTP	National Status and Trends Program
NT	not toxic
NYSDEC	New York State Department of Environmental Conservation
OC	organic carbon
OC pesticides	organochlorine pesticides
OECD	Organization of Economic Cooperation and Development
OEPA	Ohio Environmental Protection Agency
OERR	Office of Emergency and Remedial Response
OPA	Oil Pollution Act
OPTTS	Office of Prevention, Pesticides, and Toxic Substances
OSW	Office of Solid Waste
OW	The Office of Water
PAET	probable apparent effects threshold
PAHs	polycyclic aromatic hydrocarbons
PARCC	precision, accuracy, representativeness, completeness, and comparability
PCBs	polychlorinated biphenyls
PCDDs	polychlorinated dibenzo-*p*-dioxins
PCDFs	polychlorinated dibenzofurans
PCS	permit compliance system

PEC	probable effect concentration (consensus-based)
PEC-Q	probable effect concentration quotient
PEL	probable effect level
PEL-HA28	probable effect level for *Hyalella azteca*; 28-day test
PQL	protection quantification limit
PSDDA	Puget Sound Dredged Disposal Analysis
PSEP	Puget Sound Estuary Program
PSI	preliminary site investigation
QA/QC	quality assurance/quality control
QAPP	quality assurance project plan
QHEI	qualitative habitat evaluation index
RAP	remedial action plan
RCRA	Resource Conservation and Recovery Act
REF	reference sediment
RPD	relative percent difference
RRH	rapidly rendered harmless
RSD	relative standard deviation
SAB	Science Advisory Board
SAG	Science Advisory Group
SAP	sampling and analysis plan
SEC	sediment effect concentration
SEL	severe effect level
SEM	simultaneously extracted metals
SEM - AVS	simultaneously extracted metal minus acid volatile sulfides
SETAC	Society of Environmental Toxicology and Chemistry
SLCA	Screening Level Concentration Approach
SMS	sediment management standards
SOD	sediment oxygen demand
SPMD	semipermeable membrane device
SQAL	sediment quality advisory levels
SQC	sediment quality criteria
SQG	sediment quality guideline
SQRO	sediment quality remediation objectives
SQS	sediment quality standard
SSLC	species screening level concentration
SSZ	sediment sampling zone
STP	sewage treatment plant
SVOC	semivolatile organic compound
SVOC	semi-volatile organic chemical
T	toxic
TEC	threshold effect concentration
TEL	threshold effect level
TEL-HA28	threshold effect level for *Hyalella azteca*; 28 day test
TET	toxic effect threshold
TIE	toxicity identification evaluation
TMDL	total maximum daily load

TOC	total organic carbon
tPAH	total polycyclic aromatic hydrocarbons
TRA	Tissue Residue Approach
TRG	tissue residue guideline
TRV	toxicity reference values
TSCA	Toxic Substances Control Act
USACE	United States Army Corps of Engineers
USDOI	United States Department of the Interior
USEPA	United States Environmental Protection Agency
USFWS	United States Fish and Wildlife Service
USGS	United States Geological Survey
VOC	volatile organic compound
WDOE	Washington Department of Ecology
WMA	Waste Management Act
WQC	water quality criteria
WQS	water quality standards
WW	wet weight

Glossary of Terms

Acute toxicity – The response of an organism to short-term exposure to a chemical substance. Lethality is the response that is most commonly measured in acute toxicity tests.

Acute toxicity threshold – The concentration of a substance above which adverse effects are likely to be observed in short-term toxicity tests.

Altered benthic invertebrate community – An assemblage of benthic invertebrates that has characteristics (i.e., mIBI score, abundance of EPT taxa) that are outside the normal range that has been observed at uncontaminated reference sites.

Aquatic ecosystem – All the living and nonliving material interacting within an aquatic system (e.g., pond, lake, river, ocean).

Aquatic invertebrates – Animals without backbones that utilize habitats in freshwater, estuaries, or marine systems.

Aquatic organisms – The species that utilize habitats within aquatic ecosystems (e.g., aquatic plants, invertebrates, fish, amphibians and reptiles).

Benthic invertebrate community – The assemblage of various species of sediment-dwelling organisms that are found within an aquatic ecosystem.

Bioaccumulation – The net accumulation of a substance by an organism as a result of uptake from all environmental sources.

Bioaccumulation-based sediment quality guidelines (SQGs) – Sediment quality guidelines that are established to protect fish, aquatic-dependent wildlife, and human health against effects that are associated with the bioaccumulation of contaminants in sediment-dwelling organisms and subsequent food web transfer.

Bioaccumulative substances – The chemicals that tend to accumulate in the tissues of aquatic and terrestrial organisms.

Bioavailability – Degree to which a chemical can be absorbed by and/or interact with an organism.

Bioconcentration – The accumulation of a chemical in the tissues of an organism as a result of direct exposure to the surrounding medium (e.g., water; i.e., it does not include food web transfer).

Biomagnification – The accumulation of a chemical in the tissues of an organism as a result of food web transfer.

Chemical benchmark – Guidelines for water or sediment quality which define the concentration of contaminants that are associated with low or high probabilities of observing harmful biological effects, depending on the narrative intent.

Chemical of potential concern – A substance that has the potential to adversely affect surface water or biological resources.

Chronic toxicity – The response of an organism to long-term exposure to a chemical substance. Among others, the responses that are often measured in chronic toxicity tests include lethality, decreased growth, and impaired reproduction.

Chronic toxicity threshold – The concentration of a substance above which adverse effects are likely to be observed in long-term toxicity tests.

Congener – A member of a group of chemicals with similar chemical structures (e.g., PCDDs generally refers to a group of 75 congeners that consist of two benzene rings connected to each other by two oxygen bridges).

Consensus-based probable effect concentrations (PECs) – The PECs that were developed from published sediment quality guidelines and identify contaminant concentrations above which adverse biological effects are likely to occur.

Consensus-based threshold effect concentrations (TECs) – The TECs that were developed from published sediment quality guidelines and identify contaminant concentrations below which adverse biological effects are unlikely to occur.

Contaminants of concern (COC) – The substances that occur in environmental media at levels that pose a risk to ecological receptors or human health.

Contaminated sediment – Sediment that contains chemical substances at concentrations that could potentially harm sediment-dwelling organisms, wildlife, or human health.

Conventional variables – A number of variables that are commonly measured in water and/or sediment quality assessments, including water hardness, conductivity, total organic carbon (TOC), sediment oxygen demand (SOD), unionized ammonia (NH_3), temperature, dissolved oxygen (DO), pH, alkalinity

Core sampler – A device that is used to collect both surficial and sub-surface sediment samples by driving a hollow corer into the sediments.

Degradation – A breakdown of a molecule into smaller molecules or atoms.

DELT abnormalities – A number of variables that are measured to assess fish health, including deformities, fin erosion, lesions, and tumors.

Diagenesis – The sum of the physical and chemical changes that take place in sediments after its initial deposition (before they become consolidated into rocks, excluding all metamorphic changes).

Discharge – discharge of oil as defined in Section 311(a)(2) o f the Clean Water Act, and includes, but is not limited to, any spilling, leaking, pumping, pouring, emitting, emptying, or dumping of oil.

Ecosystem – All the living (e.g., plants, animals, and humans) and nonliving (rocks, sediments, soil, water, and air) material interacting within a specified location in time and space.

Ecosystem-based management – An approach that integrates the management of natural landscapes, ecological processes, physical and biological components, and human activities to maintain or enhance the integrity of an ecosystem. This approach places equal emphasis on concerns related to the environment, the economy, and the community (also called the ecosystem approach).

Ecosystem goals – Are broad management goals which describe the long-term vision that has been established for the ecosystem.

Ecosystem metrics – Identify quantifiable attributes of the indicators and defines acceptable ranges, or targets, for these variables.

Ecosystem objectives – Are developed for the various components of the ecosystem to clarify the scope and intent of the ecosystem goals. These objectives should include target schedules for being achieved.

Endpoint – A measured response of a receptor to a stressor. An endpoint can be measured in a toxicity test or in a field survey.

Epibenthic organisms – The organisms that live on the surface of sediments.

Exposure – Co-occurrence of or contact between a stressor (e.g., chemical substance) and an ecological component (e.g., aquatic organism).

Grab (Dredge) samplers – A device that is used to collect surficial sediments through a scooping mechanism (e.g. petite ponar dredge).

Hazardous substance – hazardous substance as defined in Section 101(14) of CERCLA.

Index of biotic integrity (IBI) – A parameter that is used to evaluate the status of fish communities. The IBI integrates information on species composition (i.e., total number of species, types of species, percent sensitive species, and percent tolerant species), on trophic composition (i.e., percent omnivores, percent insectivores, and percent pioneer species), and on fish condition.

Infaunal organisms – The organisms that live in sediments.

Injury – a measurable adverse change, either long or short-term, in the chemical or physical quality or the viability of a natural resource resulting either directly or indirectly from exposure to a discharge of oil or release of a hazardous substance, or exposure to a product of reactions resulting from the discharge to oil or release of a hazardous substance. As used in this part, injury encompasses the phrases “injury”, “destruction”, and “loss”. Injury definitions applicable to specific resources are provided in Section 11.62 of this part (this definition is from the Department of the Interior Natural Resource Damage Assessment Regulations).

Macroinvertebrate index of biotic integrity (mIBI) – The mIBI was used to provide information on the overall structure of benthic invertebrate communities. The scoring criteria for this metric includes such variables as number of taxa, percent dominant taxa, relative abundance of EPT taxa, and abundance of chironomids.

Mean probable effect concentration-quotient (PEC-Q) – A measure of the overall level of chemical contamination in a sediment, which is calculated by averaging the individual quotients for select chemicals of interest..

Natural resources – land, fish, wildlife, biota, air, water, ground water, drinking water supplies, and other such resources belonging to, managed by, held in trust by, appertaining to, or otherwise controlled by the federal government (including the resources of the fishery conservation zone established by the Magnuson Fishery Conservation and Management Act of 1976), State or local government, or any foreign government and Indian tribe. These natural resource have been categorized into the following five groups: surface water resources, ground water resources, air resources, geologic resources, and biological resources.

Natural resources damage assessment – the process of collecting, compiling, and analyzing information, statistics, or data through prescribed methodologies to determine damages for injuries to natural resources as set forth in this part.

Neoplastic – Refers to abnormal new growth.

Oil – oil as defined in Section 311(a)(1) of the Clean Water Act, of any kind or in any form, including, but not limited to, petroleum, fuel oil, sludge, oil refuse, and oil mixed with wastes other that dredged spoil.

Piscivorus wildlife species – The wildlife species that consume fish as part of all of their diets (e.g., herons, kingfishers, otter, osprey, and mink).

Population – An aggregate of individual of a species within a specified location in time and space.

Pore water – The water that occupies the spaces between sediment particles.

Probable effect concentration (PEC) – Concentration of a chemical in sediment above which adverse biological effects are likely to occur.

Probable effect concentration-quotient (PEC-Q) – A PEC-Q is a measure of the level of chemical contamination in sediment relative to a sediment quality guideline, and is calculated by dividing the measured concentration of a substance in a sediment sample by the corresponding PEC.

Receptor – A plant or animal that may be exposed to a stressor.

Release – A release of a hazardous substance as defined in Section 101(22) of CERCLA.

Sediment – Particulate material that usually lies below water.

Sediment-associated contaminants – Contaminants that are present in sediments, including whole sediments or pore water.

Sediment chemistry data – Information on the concentrations of chemical substances in whole sediments or pore water.

Sediment-dwelling organisms – The organisms that live in, on, or near bottom sediments, including both epibenthic and infaunal species.

Sediment injury – The presence of conditions that have injured or are sufficient to injure sediment-dwelling organisms, wildlife, or human health.

Sediment quality guideline – Chemical benchmark that is intended to define the concentration of sediment-associated contaminants that is associated with a high or a low probability of observing harmful biological effects or unacceptable levels of bioaccumulation, depending on its purpose and narrative intent.

Sediment quality targets – Chemical or biological benchmarks for assessing the status of each metric.

Simultaneously extracted metals (SEM) – Divalent metals - commonly cadmium, copper, lead, mercury, nickel, and zinc - that form less soluble sulfides than does iron or manganese and are solubilized during the acidification step (0.5m HCl for 1 hour) used in the determination of acid volatile sulfides in sediments.

Stressor – Physical, chemical, or biological entities that can induce adverse effects on ecological receptors or human health.

Surface water resources – The waters of North America, including the sediments suspended in water or lying on the bank, bed, or shoreline and sediments in or transported through coastal and marine areas. This term does not include ground water or water or sediments in ponds, lakes, or reservoirs designed for waste treatment under the Resource Conservation and Recovery Act of 1976 (RCRA), 42 U.S.C. 6901-6987 or the Clean Water Act, and applicable regulations.

Threshold effect concentration (TEC) – Concentration of a chemical in sediment below which adverse biological effects are unlikely to occur.

Tissue – A group of cells, along with the associated intercellular substances, which perform the same function within a multicellular organism.

Tissue residue guideline (TRG) – Chemical benchmark that is intended to define the concentration of a substance in the tissues of fish or invertebrates that will protect fish-eating wildlife against effects that are associated with dietary exposure to hazardous substances.

Trophic level – A portion of the food web at which groups of animals have similar feeding strategies.

Trustee – Any Federal natural resources management agency designated in the National Contingency Plan and any State agency designated by the Governor of each State, pursuant to Section 107(f)(2)(B) of CERCLA, that may prosecute claims for damages under Section 107(f) or 111(b) of CERCLA; or any Indian tribe, that may commence an action under Section 126(d) of CERCLA.

Wildlife – The fish, reptiles, amphibians, birds, and mammals that are associated with aquatic ecosystems.

Whole sediment – Sediment and associated pore water.

Acknowledgments

The authors would like to acknowledge the efforts of a number of individuals who contributed to the preparation of '*A Guidance Manual to Support the Assessment of Contaminated Sediments in Freshwater Ecosystems*'. First, we would like to thank the members of the Science Advisory Group on Sediment Quality Assessment for their insight and guidance on the need for and elements of this Guidance Manual. We would also like to thank the instructors of the various short courses on sediment quality assessment for providing access to instructional materials that provided a conceptual basis for many of the sections included in the Guidance Manual. Furthermore, we would like to express our sincerest appreciation to the members of the project Steering Committee for providing oversight and excellent review comments on previous drafts of this report. The Steering Committee consisted of the following individuals:

Tom Balduf (Ohio Environmental Protection Agency)
Peter Landrum (National Oceanic and Atmospheric Administration)
Judy Crane (Minnesota Pollution Control Agency)
Scott Cieniawski (United States Environmental Protection Agency)
Karen Woodfield (New York State Department of Environmental Conservation)
Bonnie Eleder (United States Environmental Protection Agency)
Roger Jones (Michigan Department of Environmental Quality)
John Estenik (Ohio Environmental Protection Agency)
Walter Berry (United States Environmental Protection Agency)
Scott Ireland (United States Environmental Protection Agency)
Demaree Collier (United States Environmental Protection Agency)
Marc Tuchman (United States Environmental Protection Agency)
Frank Estabrooks (New York State Department of Environmental Conservation)
Jay Field (National Oceanic and Atmospheric Administration)
Lee Liebenstein (Wisconsin Department of Natural Resources)
Jan Miller (United States Army Corps of Engineers)
T.J. Miller (United States Fish and Wildlife Service)
Dave Mount (United States Environmental Protection Agency)
Gail Sloane (Florida Department of Environmental Protection Agency)
Eric Stern (United States Environmental Protection Agency)
William Creal (Michigan Department of Environmental Quality)
Kelly Burch (Pennsylvania Department of Environmental Protection)
Mike MacFarlane (British Columbia Ministry of Water, Air and Land Protection)

Finally, timely review comments on the final draft of the Guidance Manual were provided by Scott Cieniawski, Demaree Collier, Marc Tuchman, Jay Field, Judy Crane, and Mike MacFarlane. Development of this Guidance Manual was supported in part by the United States Environmental Protection Agency's Great Lakes National Program Office through the grant "Development of a Guidance Manual for Sediment Assessment", Grant Number GL995632-01, awarded to the Sustainable Fisheries Foundation. Additional funding to support the preparation of this report was provided by the Florida Department of Environmental Protection and the British Columbia Ministry of Water, Air and Land Protection. This report has been reviewed in accordance with United States Environmental Protection Agency, United States Geological Survey, and Sustainable Fisheries Foundation policies.

Chapter 1. Introduction

1.0 Background

Traditionally, concerns relative to the management of aquatic resources in freshwater ecosystems have 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, 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 in the past twenty years have unquestionably improved water quality conditions, a growing body of evidence indicates that management efforts directed solely at the attainment of surface water quality may not provide an adequate basis for protecting the designated uses of aquatic ecosystems.

In recent years, concerns relative to the health and vitality of aquatic ecosystems have begun to reemerge in North America. 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, organochlorine pesticides (OC pesticides), and polybrominated diphenyl ethers], 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 long ago. The use of many of these substances has been banned in North America for 30 years or more; nevertheless, these chemicals continue to persist in the environment. Other contaminants enter our waters every day 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 when conditions change in the receiving water system (e.g., during periods of anoxia, after severe storms).

1.1 Sediment Quality Issues and Concerns

Sediments represent essential elements of freshwater ecosystems. Nevertheless, the available information on sediment quality conditions indicates that sediments throughout North America 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), and polychlorinated dibenzo-*p*-dioxins and furans (PCDDs and PCDFs; IJC 1988; USEPA 1997a; 2000a). Contaminated sediment has been identified as a source of ecological impacts throughout North America. In the Great Lakes basin, for example, sediment quality issues and concerns are apparent at 42 of the 43 areas of concern (AOCs) that have been identified by the International Joint Commission (Table 1.1; IJC 1988). In British Columbia, such issues and concerns have been identified in the lower Fraser and lower Columbia River systems (MESL 1997; MacFarlane 1997; Mah *et al.* 1989). Such issues have also emerged in Florida, in some cases raising concerns about human health and aquatic-dependent wildlife (MacDonald 2000).

Contaminated sediments represent an important environmental concern for several reasons. First, contaminated sediments have 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 sediment-associated contaminants (termed bioaccumulative substances) 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 call biomagnification. As a result, benthic organisms, fish, birds, and mammals can be adversely affected by contaminated sediments. Contaminated sediments can also compromise human health due to direct exposure when wading, swimming, or through the consumption of contaminated fish and shellfish. Human uses 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. 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.

While contaminated sediment does not represent a specific use impairment, a variety of beneficial use impairments have been documented in association with contaminated sediments. For example, the imposition of fish consumption advisories (i.e., resulting from the bioaccumulation of sediment-associated contaminants) has adversely affected commercial, sport, and food fisheries in many areas. In addition, degradation of the benthic community (i.e., resulting from direct exposure to contaminated sediments) and other factors have contributed to the impairment of fish and wildlife populations. Furthermore, fish from areas with contaminated sediments have been observed to have higher incidences of tumors and other abnormalities than fish from reference areas (i.e., due to exposure to carcinogenic and teratogenic substances that accumulate in sediments). Contaminated sediments have also threatened the viability of many commercial ports through the imposition of restrictions on dredging of navigational channels and disposal of dredged materials (IJC 1997). A summary of use impairments and how they can be affected by contaminated sediments is presented in Table 1.2.

1.2 Purpose of the Report

In response to the concerns that have been raised regarding sediment quality conditions, the United States Environmental Protection Agency (USEPA) launched the Assessment and Remediation of Contaminated Sediments (ARCS) Program in 1987 to support the assessment and management of contaminated sediments in the Great Lakes basin. Likewise, Florida Department of Environmental Protection and British Columbia Ministry of Environment, Lands, and Parks spearheaded initiatives in the early 1990's to support sediment assessment and management (MacDonald 1994a; MacDonald 1994b; BCE 1997;

MacDonald and MacFarlane 1999). The information generated under these programs provides important guidance for designing and implementing investigations at sites with contaminated sediments (e.g., USEPA 1994; MacDonald 1994b). In addition, guidance has been developed under various other sediment-related programs to support the collection and interpretation of sediment quality data (e.g., Reynoldson *et al.* 2000; Ingersoll *et al.* 1997; USEPA-USACE 1998; ASTM 2001a; USEPA 2000b; Krantzberg *et al.* 2001). While these guidance documents have unquestionably advanced the field of sediment quality assessment, the users of these individual guidance documents have expressed a need to consolidate this information into an integrated ecosystem-based framework for assessing and managing sediment quality in freshwater ecosystems.

This guidance manual, which comprises a three-volume series, is not intended to supplant the existing guidance documents on sediment quality assessment (e.g., USEPA 1994; Reynoldson *et al.* 2000; USEPA-USACE 1998; USEPA 2000b; ASTM 2001a; Krantzberg *et al.* 2001). Rather, this guidance manual is intended to further support the design and implementation of assessments of sediment quality conditions by:

- Presenting an ecosystem-based framework for assessing and managing contaminated sediments (Volume I);
- Describing the recommended procedures for designing and implementing sediment quality investigations (Volume II); and,
- Describing the recommended procedures for interpreting the results of sediment quality investigations (Volume III).

The first volume of the guidance manual, ***An Ecosystem-Based Framework for Assessing and Managing Contaminated Sediments in Freshwater Ecosystems***, 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 (Chapter 2). The recommended procedures for identifying sediment quality issues and concerns and compiling the existing knowledge base are also described (Chapter 3). Furthermore, the recommended procedures for establishing ecosystem goals, ecosystem health objectives, and sediment management objectives are presented (Chapter 4). Finally, methods for selecting ecosystem health indicators, metrics, and targets for assessing contaminated sediments are described (Chapter 5). 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***, 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 (Chapter 2). In addition, Volume II describes the recommended procedures for conducting preliminary and detailed site investigations to assess sediment quality conditions (Chapters 3 and 4). Furthermore, the factors that need to be considered in the development of sampling and analysis plans for assessing contaminated sediments are described (Chapter 5). Supplemental guidance on the design of sediment sampling programs, on the evaluation of sediment quality data, and on the management of contaminated sediment is provided in the Appendices to Volume II. The types and objectives of sediment quality assessments that are commonly conducted in freshwater ecosystems are also described in the appendices of this volume.

The third volume in the series, ***Interpretation of the Results of Sediment Quality Investigations***, describes the four types of information that are commonly used to assess contaminated sediments, including sediment and pore water chemistry data (Chapter 2), sediment toxicity data (Chapter 3), benthic invertebrate community structure data (Chapter 4), and bioaccumulation data (Chapter 5). Some of the other tools that can be used to support assessments of sediment quality conditions are also described (e.g., fish health assessments; Chapter 6). The information compiled on each of the tools includes: descriptions of its applications, advantages, and limitations; discussions on the availability of standard methods, the evaluation of data quality, methodological uncertainty, and the interpretation of associated data; and, recommendations to guide its use. Furthermore, guidance is provided on the interpretation of data on multiple indicators of sediment quality conditions (Chapter 7). Together, the information provided in the three-volume series is intended to further support the design and implementation of focused sediment quality assessment programs.

Chapter 2. An Overview of the Framework for Ecosystem-Based Sediment Quality Assessment and Management

2.0 Introduction

Jurisdictions throughout North America are transitioning toward the implementation of comprehensive ecosystem-based approaches to address concerns related to environmental quality conditions (IJC 1997). However, little guidance is currently available on how to assess and manage contaminated sediments within the context of the ecosystem as a whole. The following sections of Volume I are intended to provide an overview of the ecosystem approach, to present a framework for implementing ecosystem-based management, and to describe the steps that are involved in integrating sediment quality assessment and management into the ecosystem management process.

2.1 Defining the Ecosystem Approach

The ecosystem approach to planning, research and management is the most recent phase in an historical succession of approaches to environmental management. Previously, humans were considered to be separate from the environment in which they lived. This *egocentric approach* viewed the external environment only in terms of human uses. However, overwhelming evidence from many sources indicates that human activities can have significant and far-reaching impacts on the environment and on the humans who reside in these systems. Therefore, there is a need for a more holistic approach to environmental management, in which humans are considered as integral components of the ecosystem. The ecosystem approach provides this progressive perspective by integrating the *egocentric view* that characterized earlier management approaches, with an *ecocentric view* that considers the broader implications of human activities.

The primary distinction between the environmental and ecosystem approaches is whether the system under consideration is external to (in the environmental approach) or contains (in the ecosystem approach) the human population in the study area (Vallentyne and Beeton 1988). The conventional concept of the environment is like that of a *house* - external and detached; in contrast, ecosystem implies *home* - something that we feel part of and see ourselves in, even when we are not there (Christie *et al.* 1986). The change from the environmental approach to the ecosystem approach necessitates a change in the view of the environment from a political or people-oriented context to an ecosystem-oriented context (Vallentyne and Beeton 1988). The essence of the ecosystem approach is that humans are considered to be integral components of the ecosystem rather than being viewed as separate from their environment (Christie *et al.* 1986).

The ecosystem approach is not a new concept and it does not hinge on any one program, definition, or course of action. It is a way thinking and a way of doing things (RCFTW 1992). Adopting an ecosystem approach means viewing the basic components of an ecosystem (i.e., air, water, land, and biota) and its functions in a broad context, which effectively integrates environmental, social, and economic interests into a decision-making framework that embraces the concept of sustainability (Figure 2.1; CCME 1996). Importantly, the ecosystem approach recognizes human activities, rather than natural resources, need to be managed if we are to achieve our long-term goal of sustainability. The identifying characteristics of the ecosystem approach include (Vallentyne and Hamilton 1987):

- A synthesis of integrated knowledge on the ecosystem;
- A holistic perspective of interrelating systems at different levels of integration; and,
- Actions that are ecological, anticipatory, and ethical.

This expanded view then shapes the planning, research, and management decisions pertaining to the ecosystem. Selected definitions of the ecosystem approach for managing human activities are presented in Table 2.1.

2.2 Benefits of the Ecosystem Approach

The ecosystem approach is superior to the approaches to environmental management used previously (i.e., ecosystemic, piecemeal, and environmental approaches) for a number of reasons. First, the ecosystem approach provides a basis for the long-term protection of natural resources, including threatened and endangered species. In the past, management decisions were typically made with a short-term vision (i.e., within a single political mandate). In contrast, the ecosystem approach necessitates a long-term view of the ecosystem (i.e., evaluating the influence of decisions over a period of seven generations), which necessarily considers the welfare of its biotic components. Hence, management decisions are more likely to be consistent with sustainable development goals. A comparison of the four approaches to resolving anthropogenic ecological challenges is presented in Table 2.2.

Second, the ecosystem approach provides an effective framework for evaluating the real costs and benefits of developmental proposals and remedial alternatives. Previously, decisions regarding the development of industrial and municipal projects were heavily weighted toward financial benefits and job creation. Likewise, decisions regarding the restoration of contaminated sites were made principally based on costs and political considerations. Neither the long-term impacts of contamination and other stressors nor the sustainability of the resources upon which they depended were fully considered. In contrast, implementation of the ecosystem approach encourages the consideration of the long-term effects of human activities in the assessment process. Therefore, management decisions are less likely to be made based solely on political considerations, such as near-term job creation.

The ecosystem approach also enhances the multiple use of natural resources. In the past, governments have often allocated natural resources for the exclusive use of single industrial interests. Implementation of the ecosystem approach ensures that all stakeholders have an opportunity to participate in the establishment of management goals for the ecosystem. This process makes it more difficult for governments to make political decisions that benefit special interest groups, at the expense of other beneficial uses of natural resources.

Research and monitoring activities are essential elements of any environmental management program. The ecosystem approach provides a basis for focusing these activities by establishing very clear management goals for the ecosystem. Therefore, research and monitoring activities are driven by the needs of the program (to determine if the management goals are being met), rather than by the interests of individual scientists or by political expediency. In this way, the ecosystem approach provides a mechanism for integrating science and management.

One of the most important benefits of the ecosystem approach is that it directly involves the public in decision-making processes. Specifically, this approach provides a forum for public input at a non-technical level (i.e., during the establishment of management goals and ecosystem health objectives), which is both effective and non-threatening. The detailed technical issues are then left to those who are charged with the management of these ecosystems. The framework for implementing the approach also provides a means of holding managers accountable for the decisions that they make.

Traditionally, environmental impact assessments have not consistently provided reliable information for evaluating the effects of anthropogenic developments on the ecosystem. In the ecosystem approach, however, the functional relationships between human activities, changes to the physical and chemical environment, and alterations in the biological components of the ecosystem are established *before* making important management decisions. Therefore, management decisions are more likely to be consistent with the long-term goals established and subsequent monitoring activities can focus on the ecosystem components that are most likely to be affected.

The ecosystem approach also facilitates the restoration of damaged and degraded natural resources. By explicitly identifying the long-term impacts of degraded ecosystems on designated land and water uses, this approach more clearly delineates the benefits of restoration and remedial measures. Therefore, limited resources can be focused on restoration projects that are likely to yield the greatest benefits to the ecosystem as a whole. In recognition of the substantial benefits associated with its use, this holistic approach to the management of human activities is being applied in a number of areas throughout North America. For example, the Tampa Bay Estuary Program and its partners have adopted an ecosystem-based approach to assessing and managing contaminated sediments in Tampa Bay (MacDonald 1995; 1997; 1999). Likewise, the ecosystem approach has been adopted under the Great Lakes Water Quality Agreement and is currently being applied in several Great Lakes Areas of Concern (AOCs), such as the St. Louis River AOC (Crane *et al.* 2000) and the Indiana Harbor AOC (MacDonald and Ingersoll 2000).

2.3 A Framework for Implementing Ecosystem-Based Management

Implementation of the ecosystem approach requires a framework in which to develop and implement environmental assessment and management initiatives. This framework consists of five main steps, including (Environment Canada 1996; CCME 1996; Figure 2.2):

- Collate the existing ecosystem knowledge base and identify and assess the issues;
- Develop and articulate ecosystem health goals and objectives;
- Select ecosystem health indicators;

- Conduct directed research and monitoring; and,
- Make informed decisions on the assessment, conservation, protection, and restoration of natural resources.

The first step in the framework is intended to provide all participants in the process with a common understanding of the key issues and the existing knowledge base for the ecosystem under investigation. While various types of information are collected, reviewed, evaluated, and collated at this stage of the process, emphasis is placed on assembling the available information on historic land and resource use patterns, on the structure, function, and status of the ecosystem, and on the socioeconomic factors that can influence environmental management decisions. Both contemporary scientific data and traditional knowledge are sought to provide as complete an understanding as possible on the ecosystem. The information assembled at this stage of the process should be readily accessible to all participants in the process (i.e., by completing and distributing a state of the knowledge report summary report, preparing and making available a detailed technical report, and disseminating the underlying data). Chapter 3 of Volume I provides guidance on the identification of sediment quality issues and concerns.

In the second step of the process, participants cooperatively develop a series of broad ecosystem goals and more specific ecosystem health objectives (e.g., sediment management objectives) to articulate the long-term vision for the ecosystem. The ecosystem goals are based on the participants' common understanding of the ecosystem knowledge base and reflect the importance of the ecosystem to the community and to other stakeholder groups. A set of *ecosystem health objectives* are also formulated at this stage of the process to clarify the scope and intent of the ecosystem goals. Societal values are reflected in the goals and objectives by ensuring that competing resource users are involved in their development. It is important that each of the ecosystem health objectives includes a target schedule for being achieved to help participants prioritize their programs and activities. Importantly, the designated uses of the aquatic ecosystem that require protection and/or restoration emerge directly from the goals and objectives that are established by stakeholders. The designated uses of aquatic ecosystems that are relevant for assessing and managing contaminated sediments are discussed in Appendix 3 of Volume I. Information on the establishment of ecosystem goals, ecosystem health objectives, and sediment management objectives is presented in Chapter 4 of Volume I.

The third step of the ecosystem management framework involves the selection of a suite of ecosystem health indicators, which provide an effective basis for measuring the level of attainment of the goals and objectives. Initially, a broad suite of candidate indicators of ecosystem health are identified and evaluated to determine their applicability. Typically, selection criteria are established and applied on *a priori* basis to provide a consistent means of identifying the indicators that are most relevant to the assessment and/or management initiative. Each of the selected ecosystem health indicators must be supported by specific metrics and targets, which identify the acceptable range for each of the variables that will be measured in the monitoring program (Figure 2.3). If all of the measured attributes or metrics fall within acceptable ranges for all of the indicators, then the ecosystem as a whole is considered to be healthy and vital. Guidance on the selection of ecosystem health indicators for assessing the effects of contaminated sediments on sediment-dwelling organisms, aquatic-dependent wildlife, and human health is provided in Chapters 5 of Volume I.

In the fourth step of the process, environmental monitoring and directed research are undertaken to evaluate the status of the ecosystem and to fill any data gaps that have been identified. In this application, the term monitoring is used to describe a wide range of activities that are focused on assessing the health of the ecosystem under consideration. Such monitoring could be implemented under a broad array of environmental assessment programs (e.g., National Status and Trends Program, Environmental Monitoring and Assessment Program) or conducted to address site-specific concerns regarding environmental quality conditions (e.g., natural resource damage assessments, ecological risk assessments, human health risk assessments; see Appendix 1 of Volume II). Directed research activities may be needed to address priority data gaps for the ecosystem under consideration. Evaluation of the adequacy of the knowledge base provides a basis for identifying data gaps, including those associated with the application of the ecosystem health indicators chosen (i.e., to establish baseline conditions) or with the existing knowledge base. The results of monitoring activities (i.e., to assess the status of each indicator) provide the information needed to determine if the ecosystem goals and objectives are being met, to revise the metrics and targets, and to refine the monitoring program design.

Overall, the framework for implementing ecosystem-based management is intended to support informed decision-making. That is, the ecosystem goals and ecosystem health objectives establish the priorities that need to be reflected in decisions regarding the conservation of natural resources, protection of the environment, and socioeconomic development. As a final step in the process, the information on the status of the ecosystem health indicators is used by decision-makers to evaluate the efficacy of their management activities and to refine their approaches, if necessary. Successful adoption of this framework requires a strong commitment from all stakeholders and a willingness to explore new decision-making processes (Environment Canada 1996).

Chapter 3. Identification of Sediment Quality Issues and Concerns

3.0 Introduction

The first step in the ecosystem-based management process involves the collation of the existing information on the ecosystem under investigation. In this step of the process, both contemporary scientific data and traditional knowledge are compiled to obtain a detailed understanding of the ecosystem. More specifically, information is compiled on:

- The structure, function, and status of the ecosystem;
- Historic land and resource use patterns; and,
- The socioeconomic characteristics of the study area.

This information provides stakeholders with an understanding of key ecosystem attributes and, hence, a basis for developing a common vision for the future (which is articulated in terms of ecosystem goals and ecosystem health objectives; see Chapter 4 of Volume I). In addition to supporting the development of ecosystem goals and objectives, collation of the existing knowledge base is essential for identifying the sediment quality issues and concerns that need to be addressed in the ecosystem management process. Some of the questions that are commonly raised during this stage of the process include:

- Are the sediments contaminated by toxic and/or bioaccumulative substances?
- Are contaminated sediments impairing the beneficial uses of the aquatic ecosystem? If so, which uses are being impaired?
- Which substances are causing or substantially contributing to beneficial use impairment?

- Who is responsible for the release of those substances?
- What is the areal extent of sediment contamination?
- Where are the hot spots located?
- What actions are needed to restore the beneficial uses of the aquatic ecosystem?

The identification and assessment of issues and concerns relative to contaminated sediments requires detailed information on the site and the larger ecosystem under investigation. More specifically, information is needed on historic and current uses of the site, on regional land use patterns, on the characteristics of effluent and stormwater discharges in the vicinity of the site, and local hydrological conditions. Subsequent integration of information provides an informed basis for identifying sediment quality issues and concerns. In turn, such information is essential for designing and implementing sediment quality assessments that explicitly address project objectives (see Chapter 2 of Volume II for more information on the recommended framework for assessing and managing contaminated sediments).

3.1 Historic and Current Uses of the Site

The potential for sediment contamination is influenced by the historic and current uses of the site under investigation. Because there is a low probability of release of toxic or bioaccumulative substances from urban parks and residential lands, the potential for sediment contamination is likely to be relatively low at such sites. In contrast, releases of anthropogenically-derived substances are more likely to occur in the vicinity of agricultural lands and those used for commercial activities. Industrial activities have the highest potential to release toxic and/or bioaccumulative substances and, in so doing, result in the contamination of sediments. A listing of the activities that have a relatively high potential for releasing hazardous substances into the environment is provided in Table 3.1 (BCE 1997).

The nature of the activities conducted at a site determines which substances may have been released into the environment. For example, releases of metals into aquatic ecosystems are commonly associated with mining, milling and related activities. Likewise, metal smelting, processing, or finishing industries can release metals into the environment. Oil and natural gas drilling, production, processing, retailing, and distribution can result in the release of a variety of petroleum hydrocarbons and related substances into the environment, such as alkanes, alkenes, polycyclic aromatic hydrocarbons, phenols, metals, benzene, toluene, ethylene, and xylene (MacDonald 1989). Wood preservation, pulp and paper, and related industries can result in releases of chlorophenols, chloroguaiacols, chlorocatechols, chlorovertatrols, chloroanisoles, PCDD, PCDF, resin acids, metals, and other substances (MacDonald 1989). Chemical manufacturing and related activities can result in the release of a wide variety of contaminants, depending on the nature of the operation (Curry *et al.* 1997). Information on the uses of the site under investigation (including any spill data that are available) provides a basis for developing a preliminary list of substances that have potentially been released into the environment in the immediate vicinity of the site (i.e., chemicals of potential concern; COPCs).

3.2 Regional Land Use Patterns

In addition to information on historic and current uses of the site under investigation, evaluation of sediment quality issues and concerns also requires information on regional land patterns. More specifically, information is needed on the types of industries and businesses that operate or have operated in the region (i.e., within the watershed of interest), on the location of wastewater treatment plants, on land use patterns in upland areas, on stormwater drainage systems, on residential developments, and on other historic, ongoing, and potential activities within the area. These types of information can be obtained from a variety of sources, including federal, state, and provincial regulatory agencies, municipal governments, First Nations/Tribal organizations, planning commissions, public utility districts, watershed councils, and other non-governmental organizations. These data provide a basis for identifying potential sources of contaminants to aquatic ecosystems. In turn, information on potential contaminant sources provides a basis for identifying the substances that may have been released into aquatic ecosystems nearby the site under investigation. These substances can then be added to the preliminary list of COPCs.

3.3 Characteristics of Effluent and Stormwater Discharges

Information on the location, volumes, and chemical characteristics of effluent and stormwater discharges that are located at and nearby the site under investigation provides important data for validating the preliminary list of COPCs. In the United States, such information is available from National Pollution Discharge and Elimination System (NPDES) records [i.e., the Permit Compliance System (PCS) database]. Information on the nature and location of facilities that are subject to regulation under the Resource Conservation and Recovery Act (i.e., facilities at which hazardous wastes are generated, transported, stored, or disposed of) is also available from the PCS database. Likewise, information on the location, volume, and chemical characteristics of municipal wastewater treatment plant discharges is also available in the PCS database. This database can be accessed from the USEPA web page:

(http://www.epa.gov/r5water/npdestek/npdpretreatmentpcs.htm).

In Canada, the appropriate responsible authority within each province or territory should be contacted for data on the characteristics of effluent and stormwater discharges.

It is important to remember that the PCS and similar databases do not provide comprehensive information on the characteristics of effluents that are discharged into receiving water systems. For this reason, other information on the types of contaminants that are typically released into the environment in association with specific land use activities should also be used to identify COPCs at the site (see Section 3.1 of Volume I; Table 3.1).

3.4 Identification of Sediment-Associated Chemicals of Potential Concern

When used together, the information on historic and current uses of the site, on regional land use patterns, on the characteristics of effluent and stormwater discharges in the vicinity of the site provides a basis for identifying the preliminary COPCs at a site. However, further refinement of this list requires data on the physical/chemical properties of each of those substances. More specifically, information should be compiled on the octanol-water partition coefficients (K_{ow}), organic carbon partition coefficients (K_{oc}), and solubilities of the preliminary COPCs. Substances with moderate to high log K_{ow} or log K_{oc} values (i.e., > 3.5) and/or those that are sparingly soluble in water are the most likely to accumulate in sediments. The preliminary COPCs that have a high potential for accumulating in sediments should be identified as the sediment-associated COPCs at the site.

In addition to information on the sources and fate of environmental contaminants, historical sediment chemistry data provide a basis for identifying sediment-associated COPCs. However, evaluating the relevance and quality of historic data before using it in this application is important. For example, historical data sets may include only a limited suite of chemical analytes, which restricts their use for identifying COPCs. In addition, the applicability of the sediment chemistry data may be further restricted by high analytical detection limits and/or poor recoveries of target analytes from sediments. Furthermore, spatial coverage of the study area may not include the areas that are most likely to have contaminated sediments. Due to these potential limitations, historical data sets should be used with caution for eliminating substances from the list of COPCs for a site. However, substances that have been measured in sediments at concentrations in excess of threshold effect concentrations (TECs) or similar sediment quality guidelines (SQGs) should be identified as COPCs (see Chapter 2 of Volume III).

3.5 Identification of Areas of Potential Concern

The information that was assembled to support the identification of COPCs also provides a relevant basis for identifying areas of potential concern within a study area. More specifically, information on the historic and current uses of the site, on regional land use patterns, on the locations of effluent and stormwater discharges provides a basis for identifying the areas of potential concern at the site (i.e., areas that potentially have contaminated sediments). In addition, information on local hydrological conditions should be considered when evaluating the potential for sediment contamination at a site. For example, accumulation of contaminated sediments is unlikely to be a concern in fast-moving reaches of river systems with coarse-grained sediments (i.e., local sediment transport zones). However, contaminated sediments are likely to accumulate in the slower moving reaches of river systems, in lakes, in harbors, and near-shore coastal areas (i.e., local sediment deposition zones with fine-grained sediments). The results of previous reconnaissance surveys, historic dredging records, bathymetric charts, and site visits provide a basis for determining if local sediment deposition zones are likely to occur in the vicinity of the site under investigation.

Historical sediment chemistry data can also be used to identify areas of potential concern relative to sediment contamination. However, the application of such data for this purpose can be limited for a number of reasons (see Section 2.2 of Volume II for a description of the potential limitations of historical sediment chemistry data). Therefore, such historical sediment chemistry and related data should be used with care for identifying areas of potential concern.

3.6 Identification of Sediment Quality Issues and Concerns

Investigations of sediment quality conditions are frequently conducted to obtain the information needed to support environmental management decisions related to a site or a water body. Such investigations are often conducted to determine if sediments are contaminated, if contaminated sediments are impairing beneficial uses, and management actions are needed to restore the beneficial uses of the aquatic ecosystem. Sediment quality investigations may also be undertaken to evaluate the areal extent of contamination, to identify sediment hot spots, and to determine who is responsible for the cleaning-up the site, if necessary.

Designing sediment quality assessment programs that provide the information needed to resolve these questions requires an understanding of the sediment quality issues and concerns at the site under consideration. More specifically, investigators need to know if sediments are potentially contaminated and, if so, which substances are likely to be associated with sediments. Classification of these substances in terms of their potential toxicity and their potential for bioaccumulating provides a basis for identifying which groups of receptors are most likely to be exposed to sediment-associated contaminants (e.g., sediment-dwelling organisms, fish, aquatic-dependant wildlife, humans). Examination of the available information on the fate and effects of the COPCs provides a means of further identifying receptors at risk at the site. Integration of the information on COPCs, areas of potential concern, and receptors at risk facilitates the identification of sediment quality issues and concerns for the site under consideration. In turn, this information enables investigators to determine if further investigations (i.e., preliminary and/or detailed site investigations) are needed to assess sediment quality conditions (see Volume II for more information on the design of sediment quality investigations). In addition, this information can be used to develop an assessment plan that will provide the data needed to evaluate the risks associated with exposure to contaminated sediments.

Chapter 4. Procedures for Establishing Ecosystem Goals and Sediment Management Objectives for Assessing and Managing Contaminated Sediments

4.0 Introduction

Ecosystem goals and ecosystem health objectives represent key elements of the framework for implementing ecosystem-based management (see Chapter 2 of Volume I). Ecosystem goals are broad narrative statements that describe the desired future state of the ecosystem (Bertram and Reynoldson 1992). Ecosystem health objectives are narrative statements that clarify the scope and intent of the ecosystem goals by defining the desired condition of the ecosystem in terms of specific ecological characteristics and uses (CCME 1996). Ecosystem goals and ecosystem health objectives are established to provide the guidance needed to focus management decisions on the maintenance of important ecosystem functions (Environment Canada 1996).

Ecosystem goals and ecosystem health objectives can be established using a variety of approaches. However, the most effective ecosystem goals and ecosystem health objectives are developed using a cooperative visioning process that includes all interested stakeholder groups. In general, this process involves five main steps, including:

- Defining the ecosystem;
- Defining the human community (i.e., stakeholder groups) that needs to be involved in the visioning process;
- Disseminating information on the ecosystem (i.e., issues and concerns; existing ecosystem knowledge base, that was compiled during the first step of the framework; see Chapter 3 of Volume I);
- Convening workshops to develop a long-term vision for the ecosystem; and,

- Translating the vision into ecosystem goals and ecosystem health objectives (and associated sediment management objectives).

Each of these steps is briefly described in the following sections of this chapter.

4.1 Defining the Ecosystem

The term "ecosystem" has a number of definitions. For example, one of the earliest definitions of ecosystem is "the community of living organisms and the physical factors forming their environment, such as water, land, and air" (Stoddart 1965). Some of the other early definitions of this term include: "a collection of all organisms and environments in a single location" (McNaughton and Wolf 1979); "an organizational unit, including one or more living entities, through which there is a transfer and processing of energy and matter" (Evans 1956); and, "a collection of interacting components and their interactions, that includes ecological or biological components" (Odum 1983). More recent definitions of the term are generally consistent with the earlier definitions, except that they include specific reference to humans as integral components of the biological community and emphasize the flexible nature of ecosystem spatial boundaries (Environment Canada 1996). A selection of contemporary definitions of the term "ecosystem" is provided in Table 4.1 (Environment Canada 1996).

In evaluating the definitions of the term "ecosystem" that have been advanced by various investigators and organizations, Environment Canada (1996) identified a number of key insights that are relevant to defining the geographic scope of an ecosystem, as follows:

- Sustained life is a property of ecosystems, not species. Individual species cannot survive indefinitely on their own. The smallest unit of the biosphere that can support life over the long term is an ecosystem.

- Ecosystems are open systems of matter and energy (composition) in various combinations (structures) that change over time (function). Ecosystems undergo continuous change in response to pressures from component populations (human or otherwise) and the changing physical environment.

- Everything in an ecosystem is related to everything else. These interrelationships underline another important characteristic of an ecosystem - it is more than the sum of its parts.

- People are an important part or ecosystems. As noted above, sustained life is a property of systems, not individual species. This implies the necessity of maintaining the health and integrity of natural systems to ensure our own survival.

- Ecosystems possess various spatial and temporal scales. The choice of scale depends on the problem to be addressed or the human activities being managed.

- Any ecosystem is open to "outside" influences (Allen *et al.* 1991). Consideration of outside influences complicates efforts to predict or model cause and effect relationships and highlights the need for flexibility and adaptability.

Defining the geographic scope of the ecosystem under consideration represents an essential step in the development of ecosystem goals and ecosystem health objectives. However, this step can be complicated because ecosystems do not have clearly defined boundaries. Air, water, earth, plants and animal move and can affect several different ecosystems (Grant 1997). Nevertheless, ecosystems can be operationally defined by considering such factors as the unifying ecological characteristics of the ecosystem, the practicality of ecosystem boundaries relative to the issues and concerns that have been identified, and distribution of human populations (Grant 1997). In many cases, ecosystem boundaries can be established using watershed boundaries; this approach is particularly relevant for initiatives that are primarily focused on the assessment and management of aquatic resources.

4.2 Identifying Key Stakeholder Groups

Identification of key stakeholder groups, which is often termed the human community of interest, is of critical importance for developing ecosystem goals and ecosystem health objectives. A community of interest can be defined as a group of individuals and organizations that participate in common practices, depend on one another, make decisions together, and commit themselves to the group's well-being over the long-term (Grant 1997). It is important to identify the members of the human community of interest relative to the ecosystem because these stakeholders need to participate in the development of ecosystem goals and ecosystem health objectives, and in the subsequent steps in the ecosystem management process. The members of the community of interest may be defined by identifying who is likely to be affected by the health of the ecosystem and who is willing to actively plan for and work toward a sustainable, healthy ecosystem. For example, Citizens Advisory Committees (CACs) have been established at many Great Lakes AOCs to represent the various stakeholder groups and to guide the management of aquatic resources.

4.3 Disseminating Information on the Ecosystem

The first step in the ecosystem management process is to define the issues and concerns and to compile the existing knowledge base on the ecosystem. The existing knowledge base is the collection of scientific, traditional, and folk knowledge about the ecosystem. To be effective, the existing knowledge base should:

- Provide information on the current status of the ecosystem;
- Include information on the environment, economy, and society;
- Provide historical reference points for determining what can be achieved in the ecosystem;

- Facilitate scientific predictions regarding future trends and state limits on scientific certainty;
- Provide a mechanism for updating the knowledge base as new information becomes available; and,
- Be updated regularly with new information. Importantly, the existing knowledge base needs to be broadly accessible to everyone with an interest in the ecosystem.

Broad dissemination of the information contained with the existing knowledge base is essential for ensuring that all participants in the ecosystem management process have a common understanding of the original (i.e., prior to European contact) and current state of the ecosystem. In this way, discussions regarding the possible future state of the ecosystem can fully consider the benefits that the ecosystem has historically delivered, as well as the benefits that the ecosystem is currently delivering. Dissemination of this information can be undertaken in a number of ways, including distribution of paper reports, videos, maps and fact sheets, development of interactive internet sites, delivery of slide shows, scientific papers, and other presentations at workshops and/or community meetings, and releases of news stories in the media. One of the keys to effective communication regarding the status of the ecosystem is to ensure that the language used is understandable to all of the members of the community of interest (i.e., minimize the use of technical jargon).

4.4 Convening Multi-Stakeholder Workshops

The visioning process gives the stakeholders an opportunity to describe the desired future state of the ecosystem. It is of fundamental importance to the ecosystem management process because it provides a mechanism for diverse interest groups to define their common interests and, in so doing, lays the groundwork for working together to achieve their common goals.

Multi-stakeholder workshops and community meetings represent primary means of conducting this visioning process. Typically, these workshops and meetings are organized so as to enable participants to access key elements of the existing knowledge base (i.e., through presentations and hand-outs). Then, various workshop techniques (e.g., guided imagery, image recollection, small group discussions, group presentations) can be used to identify the elements of their vision for the future. Then, workshop participants are asked to identify the common elements of their shared vision for a healthy ecosystem (i.e., the vision elements to which most or all stakeholders can agree).

4.5 Translating the Long-Term Vision into Ecosystem Goals and Ecosystem Health Objectives

The final step in the visioning process is to translate the long-term vision developed by workshop participants into clearly stated ecosystem goals and ecosystem health objectives. In the Great Lakes ecosystem, for example, stakeholders generally share a common vision for aquatic habitats, which could be stated as follows (IJC 1991):

- Self-maintenance or self-sustainability of the ecological systems;
- Sustained use of the ecosystem for economic or other societal purposes; and,
- Sustained development to ensure human welfare.

These broad vision elements provide a basis for developing ecosystem goals that provide guidance for managing human activities in a manner that assures the long-term sustainability of aquatic ecosystems. With these three concepts in mind, the Ecosystem Objectives Work Group (1992) developed ecosystem goals and objectives for Lake Ontario (Table 4.2). Similarly, the Lake Superior Working Group (1993) developed ecosystem objectives for Lake Superior that defined the desired future state for the ecosystem (Table 4.3). These, and other examples (see MacDonald 1999; Crane *et al.* 2000), provide a relevant basis for defining an ecosystem goal for managing aquatic ecosystems that applies broadly to freshwater ecosystems and can be modified for use in specific areas, as follows:

> *To protect, sustain, and, where necessary, restore healthy, functioning aquatic ecosystems that are capable of supporting current and future uses.*

While this long-term management goal effectively articulates the long-term vision for the management of aquatic ecosystems, it is too general to effectively guide management decisions at sites with contaminated sediments. To be useful, ecosystem goals must be further clarified and refined to establish *ecosystem health objectives* (Harris *et al.* 1987). In turn, the ecosystem health objectives support the identification of indicators and metrics that provide direct information for specifically assessing the health and integrity of the ecosystem.

Habitats that support the production of fish and wildlife are of fundamental importance for maintaining the uses of aquatic ecosystems. While sites with contaminated sediments typically cover relatively small geographic areas within larger aquatic ecosystems (e.g., watersheds), they have the potential to substantially influence conditions within the larger management unit. For this reason, it is essential that sediment management decisions support the long-term goals that have been established for the ecosystem, as a whole. In recognition of the importance of aquatic habitats, the following ecosystem health objectives are recommended to provide guidance on the protection and restoration of aquatic ecosystems:

> *Maintain and/or restore sediment quality conditions such that the health of benthic communities is protected and, where necessary, restored.*

> *Maintain and/or restore sediment quality conditions such that the health of fish populations is protected and, where necessary, restored.*

Maintain and/or restore sediment quality conditions such that the health of aquatic-dependent wildlife populations is protected and, where necessary, restored.

Maintain and/or restore sediment quality conditions such that human health is protected and the human uses of the aquatic ecosystem are, where necessary, restored.

These objectives explicitly recognize that there are multiple uses of aquatic ecosystems that can be affected by sediment quality conditions and, hence, need to be considered in the assessment, management, and remediation of contaminated sediments. Importantly, these objectives also recognize that biotic receptors can be exposed to sediment-associated contaminants in three ways, including direct exposure to *in situ* sediments and pore water (including processing of sediments by sediment-dwelling organisms), through transfer of sediment-associated contaminants into the water column, and through the consumption of contaminated food organisms. Therefore, sediment management strategies must consider these three exposure routes, if the designated uses of aquatic ecosystems are to be protected, maintained, and restored.

A description of the designated water uses that could potentially exist at sites with contaminated sediments are identified in Appendix 3 of Volume I. Because various water bodies may have different designated uses, the ecosystem health objectives may not apply uniformly at all sites with contaminated sediments. In addition, different use designations may be applied to specific areas within a single watershed, depending on the receptors that are present, ambient environmental conditions, and several other factors. Therefore, some of the ecosystem health objectives may apply to certain areas of the watershed, while others objectives may apply to other areas. Because all of the subsequent steps in the ecosystem-based management process flow directly from the ecosystem goals and objectives that have been established, the importance of this step in the process cannot be over emphasized.

4.6 Establishing Sediment Management Objectives

The ecosystem goals and ecosystem health objectives developed in the previous stage of the process describe the desired state of the ecosystem under consideration. Such goals and objectives represent indispensable tools for managing human activities that have the potential to affect the quality of aquatic ecosystems. However, more specific guidance is also needed to support the management of sites with contaminated sediments. For this reason, it is recommended that sediment management objectives be established for sites known or suspected to have sediments that are contaminated with toxic and/or bioaccumulative substances at levels that could adversely affect the beneficial uses of the aquatic ecosystem.

Sediment management objectives may be defined as narrative statements that describe the desired future sediment quality conditions at a site (i.e., as opposed to the entire aquatic ecosystem). To be useful, the sediment management objectives must reflect the ecosystem health objectives and be expressed in terms of specific ecological functions. For example, maintenance and/or restoration of sediment quality conditions to protect and/or restore benthic communities has been recommended as an ecosystem health objective for aquatic ecosystems. The corresponding sediment management objectives for a site with contaminated sediments could be:

- *Maintain and/or restore sediment quality conditions such that sediments do not adversely affect the survival, growth, or reproduction of sediment-dwelling organisms (as indicated by the results of long-term toxicity tests);*
- *Maintain and/or restore sediment quality conditions such that sediments are not contaminated at levels that would adversely affect the survival, growth, or reproduction of sediment-dwelling organisms (as indicated by sediment chemistry data for COPCs);*

- *Maintain and/or restore sediment quality conditions such that sediments do not adversely affect the structure of benthic macroinvertebrate communities (as indicated by the results of benthic surveys); and,*
- *Maintain and/or restore sediment quality conditions such that sediments are not contaminated at levels that would result in the accumulation of contaminants in the tissues of aquatic organisms to levels that would adversely affect aquatic-dependent wildlife or human health.*

For sites that are being investigated under CERCLA, guidance for conducting ecological risk assessments (USEPA 1997b; 1998) and natural resource damage assessments (DOI regulations; 43 Code of Federal Regulations Part 11) provides an effective basis for establishing sediment management objectives that are consistent with programmatic needs (Appendix 1 in Volume II). Sediment management objectives have also been established for contaminated sites that are being investigated under the CSR of the B.C. Waste Management Act (MacDonald *et al.* 2001). Establishment of such sediment management objectives on an *a priori* basis is important because they can guide the development and evaluation of remedial alternatives at sites that are found to have degraded sediment quality conditions.

Chapter 5. Selection of Ecosystem Health Indicators, Metrics and Targets for Assessing the Effects of Contaminated Sediments on Sediment-Dwelling Organisms, Aquatic Dependent Wildlife, and Human Health

5.0 Introduction

The ecosystem goals developed cooperatively by interested stakeholder groups describe the desired state of an ecosystem (Bertram and Reynoldson 1992). Ecosystem health objectives further clarify these goals by expressing them in terms of the ecological characteristics and human uses of the ecosystem. Such ecosystem goals and ecosystem health objectives provide a basis for establishing sediment management objectives and ecosystem health indicators that guide the assessment and management of contaminated sediments in freshwater ecosystems. Adherence to this ecosystem-based approach enhances the likelihood that any sediment management activities that are undertaken at sites with contaminated sediments will be consistent with, and support, the broader management initiatives that have been established for the ecosystem. This chapter provides guidance on the selection of ecosystem health indicators, metrics, and targets to support the assessment and management of contaminated sediments. Additional information on the selection of indicators, metrics, and targets is provided in Volume III.

5.1 Identification of Candidate Ecosystem Health Indicators

In the environment, a variety of plant and animal species (i.e., receptors) can be exposed to physical, chemical, and/or biological stressors. Each of these stressors has the potential to affect the status of the ecological receptors and, in so doing, influence the structure and/or function of plant and animal communities in the ecosystem. In turn, such interactions between stressors, particularly those that are anthropogenically induced, and receptors have the potential to influence the health of the aquatic ecosystems, including the associated beneficial uses by humans.

Ecosystem health, as defined by the ecosystem goals and ecosystem health objectives, cannot be measured directly (Environment Canada 1996). For this reason, establishing a suite of ecosystem health indicators to support the evaluation of the status and trends of the ecosystem as a whole is necessary. An ecosystem health indicator is any characteristic of the environment that, when measured, provides accurate and precise information on the structure and/or function of the ecosystem. For example, sediment toxicity may be selected as an indicator of the extent to which sediments are likely to support healthy and self-sustaining populations of benthic macroinvertebrates. Such indicators can provide a basis for measuring attainment of the long-term goals and objectives for the ecosystem and for identifying any undesirable changes that have occurred or are likely to occur to the ecosystem. To be effective, however, ecosystem health indicators need to be accompanied by appropriate metrics and quantitative targets. A metric may be defined as any measurable characteristic of an ecosystem health indicator (e.g., survival of amphipods, *Hyalella azteca*, in 28-d toxicity tests), while a target defines the desirable range of a specific metric (e.g., not statistically different from the control response). The relationship between ecosystem goals, ecosystem health objectives, ecosystem health indicators, metrics, and targets, within the context of the ecosystem approach to environmental management, is illustrated in Figures 2.3 and 5.1.

The identification of candidate ecosystem health indicators represents an important step in the ecosystem-based management process. Candidate ecosystem health indicators encompass all of the ecosystem components and functions that could be used to provide information on the health of the ecosystem as a whole (i.e., to track progress toward the ecosystem goals and ecosystem health objectives). The existing knowledge base that was compiled as the first step of the process provides a summary of what is known about the structure and function of the ecosystem under investigation. As such, the existing knowledge base provides an effective basis for identifying candidate ecosystem health indicators for the system under investigation. In cases where the existing knowledge basis is limited, information on similar ecosystems may be useful for identifying candidate ecosystem health indicators. The suite of indicators that are ultimately selected for assessing ecosystem health will be drawn from the candidate ecosystem health indicators that are identified at this stage of the process.

5.2 Evaluation of Candidate Ecosystem Health Indicators

While detailed information on the status of each of the physical, chemical, and biological components of the environment would provide comprehensive information on ecosystem structure and function, collecting such data on every component of the ecosystem is neither practical nor feasible. For this reason, focusing assessment activities on the candidate indicators that provide the most useful information for assessing ecosystem health is necessary. In the case on contaminated sediment assessment, it is particularly important to focus on those indicators that have been demonstrated to provide reliable information on the effects of contaminated sediments on the structure and function of the aquatic ecosystem.

A number of approaches have been used to evaluate candidate ecosystem health indicators. For example, the International Joint Commission has developed a framework for evaluating and selecting biological indicators of ecosystem health (IJC 1991). This framework provides detailed guidance on the development of ecosystem goals, on the identification of physicochemical, biological, and sociological indicators of ecosystem health, and on the establishment of monitoring programs to assess attainment of these goals. Likewise, Environment Canada has proposed a national framework for developing biological indicators for evaluating ecosystem health, as well as specific guidance on their application (Environment Canada 1993; 1996; 1997; CCME 1996). Both of these frameworks indicate that identification of the purpose of the resultant monitoring data is a central consideration in the selection of ecosystem health indicators. The IJC (1991) recognized five distinct purposes for which environmental data are collected, including:

- Assessment - evaluating the current status of the environment to determine its adequacy for supporting specific uses (i.e., fish and aquatic life). That is, monitoring the attainment of the ecosystem health objectives;
- Trends - documenting changes in environmental conditions over time. That is, monitoring the degradation, maintenance, and/or rehabilitation of the ecosystem under consideration;
- Early warning - providing an early warning that hazardous conditions exist before they result in significant impacts on sensitive and/or important components of the ecosystem;
- Diagnostic - identifying the nature of any hazardous conditions that may exist (i.e., the specific causes of ecosystem degradation) in order to develop and implement appropriate management actions to mitigate against adverse impacts; and,
- Linkages - demonstrating the linkages between indicators to improve the effectiveness and efficiency of monitoring programs and to reinforce the need to make environmentally sound management decisions.

Identification of the ultimate purpose of the monitoring data is important because no single indicator will be universally applicable in every application. For this reason, selecting a suite of indicators that most directly addresses the requirements of the monitoring program is necessary. To support evaluations of the relevance of candidate ecosystem health indicators, Ryder and Edwards (1985) and the IJC (1991) identified a number of desirable characteristics of candidate indicators, including:

- Biologically relevant: candidate indicators must be important for maintaining a balanced community and indicative of other, unmeasured biological indicators;

- Sensitive: candidate indicators should exhibit graded responses to environmental stresses, should not be tolerant of environmental changes, and should not exhibit high natural variability;
- Measurable: candidate indicators should have operational definitions and determination of their status should be supported by procedures for which it is possible to document the accuracy and precision of the measurements (easy to measure);
- Cost-effective: candidate indicators should be relatively inexpensive to measure and provide the maximum amount of information per unit effort;
- Supported by historical data: sufficient scientific data and/or traditional knowledge should be available to support the determination of natural variability, trends, and targets for the ecosystem metrics;
- Non-destructive: collection of the required data on the candidate indicators should not result in changes in the structure and/or function of the ecosystem, or on the status of individual species;
- Of the appropriate scale: candidate indicators should be applicable for determining the status to the ecosystem as a whole, not only to limited geographic areas within the ecosystem; and,
- Non-redundant: candidate indicators should provide unique information on the status of the ecosystem.
- Socially relevant: candidate indicators should be of obvious value to, and be observable by, stakeholders or be predictive of an indicator that has these attributes;
- Interpretable: candidate indicators should provide information that supports evaluations of the status of the ecosystem and the associated human uses of the ecosystem (acceptable ranges or targets should be definable);
- Anticipatory: candidate indicators should be capable of providing an indication that environmental degradation is occurring before serious harm has occurred;

- Timely: candidate indicators should provide information quickly enough to support the initiation of effective management actions before significant and lasting effects on the ecosystem have occurred;
- Broadly applicable: candidate indicators should be responsive to many stressors and be applicable to a broad range of sites;
- Diagnostic: candidate indicators should facilitate the identification of the particular stressor that is causing the problem;
- Continuity: candidate indicators should facilitate assessments of environmental conditions over time; and,
- Integrative: candidate indicators should provide information on the status of many unmeasured indicators.

Application of this system for evaluating candidate indicators involves two main steps. First, the reasons for collecting monitoring data need to be explicitly identified from the five potential purposes listed earlier in Section 5.2 of Volume I (assessment, trends, early warning, diagnostic, linkages). Next, the essential and important characteristics of ecosystem health indicators for the selected monitoring purposes need to be identified using the information in Table 5.1 (designated as * and 3, respectively, in Table 5.1; IJC 1991). Subsequently, each of the candidate ecosystem health indicators should be scored relative to the essential and important characteristics that were identified (e.g., 0 to 2 for each characteristic, depending on the degree to which they reflect the essential and important characteristics). Finally, a total evaluation score can be calculated (i.e., by summing the score for each characteristic) and used to rank the utility of each candidate ecosystem health indicator relative to the intended use of the monitoring data. A final suite of ecosystem health indicators can then be selected based on the results of this ranking process, with consideration given to the extent to which the highest ranking indicators compliment each other.

5.3 Selection of Ecosystem Health Indicators

Several factors need to be considered in the selection of ecosystem health indicators for assessing sediment quality conditions. First, the indicators that are selected must be related to the ecosystem goals and ecosystem health objectives established for the body of water under investigation (Environment Canada 1996). Second, a suite of indicators should be selected to reduce the potential for errors in decisions that are made based on the results of sediment quality monitoring programs (Environment Canada 1996). Third, the selection of ecosystem health indicators should be guided by selection criteria that reflect the stated purpose of the monitoring program (as described in Section 5.2).

Relative to sediment contamination, COPCs can be classified into two general categories based on their potential effects on ecological receptors, including toxic substances and bioaccumulative substances. For toxic substances that partition into sediments, evaluation of direct effects on sediment-dwelling organisms is likely to represent the primary focus of sediment quality investigations. For bioaccumulative substances, sediment quality assessments are likely to focus on evaluating effects on aquatic-dependent wildlife (i.e., fish, amphibians, reptiles, birds, and mammals) and on human health. In this way, such investigations can provide the information needed to evaluate attainment of the sediment management objectives for the site and the ecosystem health objectives that have been recommended for soft-substrate habitats in freshwater ecosystems (see Section 4.5 of Volume I).

There is a wide range of indicators that can be used to evaluate sediment quality conditions. In the past, physical and chemical indicators have been primarily used to provide a means of assessing environmental quality conditions. More recently, significant effort has also been directed at the development of biological indicators of ecosystem integrity (which are often termed biocriteria; OEPA 1988). These biological indicators may apply to one or more levels of organization and encompass a large number of metrics ranging from biochemical variables to community parameters. Ideally, environmental monitoring programs would include each of the physical, chemical, and biological variables that could, potentially, be affected by anthropogenic activities. However, limitations on human and financial resources preclude this possibility. For this reason, identifying the most relevant ecosystem health indicators for assessing sediment quality conditions is necessary.

The scoring system developed by the IJC (1991) provides a basis for evaluating candidate indicators relative to the intended purpose of the resultant monitoring data (Table 5.1). Application of the IJC (1991) criteria is dependent on identifying the most desirable characteristics of the ecosystem health indicators and subsequently evaluating the candidate indicators relative to these characteristics. Based on the information presented in Table 5.1, it is essential that indicators for any monitoring purpose be sensitive, measurable, cost-effective, supported by historical data, non-destructive, of appropriate scale, and non-redundant (i.e., these are the essential characteristics of ecosystem health indicators). For sediment quality evaluations that are focused on status and trends assessment, indicators that are biologically relevant, socially relevant, interpretable, and provide continuity of measurements over time are likely to be the most relevant (i.e., these are the important characteristics of ecosystem health indicators for this monitoring application). Application of the IJC (1991) evaluation criteria facilitates the identification of ecosystem health indicators that are the most relevant for assessing sediment quality conditions. MacDonald and Ingersoll (2000) evaluated a variety of candidate ecosystem health indicators and concluded that the following were particularly relevant for assessing sediment quality conditions in freshwater ecosystems:

Receptors of Interest	Indicator of Sediment Quality Conditions
Sediment-dwelling organisms	Chemistry of whole sediments Chemistry of pore water Toxicity of sediments to invertebrates Structure of benthic invertebrate communities
Wildlife resources	Toxicity of sediments to fish Health of fish Status of fish communities Chemistry of whole sediments Chemistry of fish and invertebrate tissues

Human health	Chemistry of whole sediments Chemistry of fish and invertebrate tissues Presence of fish and wildlife consumption advisories

Again, the selection of ecosystem health indicators must be guided by the sediment quality issues and concerns that are identified at the site under investigation. Where sediments are primarily contaminated by toxic substances, focusing sediment quality assessments on the receptors that are most likely to be directly affected by contaminated sediments is reasonable (i.e., sediment-dwelling organisms and fish). At sites contaminated by bioaccumulative substances, sediment quality assessments need to have a broader focus, potentially including sediment-dwelling organisms, wildlife resources, and human health. Importantly, the weight of the decision (i.e., size of the site, potential clean-up costs) should be a central consideration when developing a suite of indicators for assessing contaminated sediments (see Chapter 7 of Volume III).

5.4 Establishment of Metrics and Targets for Ecosystem Health Indicators

By themselves, ecosystem health indicators do not provide a complete basis for designing sediment quality monitoring programs. There is also a need to identify and prioritize metrics for each of the ecosystem health indicators that are selected for assessing contaminated sediments (Table 5.2; also see Chapters 2 to 6 of Volume III for recommended metrics for each indicator of sediment quality conditions). Metrics may be defined as any measurable characteristic of an ecosystem health indicator (e.g., the dry weight concentration of mercury in sediments might be identified as an important metric relative to sediment chemistry). As such, the metrics define which variables are to be measured as part of the sediment quality monitoring program.

The selection of appropriate metrics for assessing sediment quality conditions involves several steps. The first step in this process involves the identification of candidate metrics for each indicator (Table 5.2). Subsequently, the candidate metrics for each priority indicator need to be evaluated in terms of the utility of the information that they are likely to generate. This evaluation needs to reflect the sediment management objectives to ensure that the most appropriate metrics are selected for each ecosystem health indicator. For example, the concentrations of metals in sediment are likely to provide an appropriate metric for sediment chemistry in the vicinity of a lead-zinc smelter. However, measurement of the levels of organochlorine pesticides in sediment might be less appropriate at such a site. Therefore, the metric evaluation process provides a basis for focusing limited sediment quality assessment resources on priority sediment quality issues and concerns.

Numerical targets are also required for each metric to support interpretation of the data generated on each ecosystem health indicator. Such targets define the desirable or acceptable range of values for each metric. For example, a numerical sediment quality guideline (e.g., TEC) for total PAHs (tPAH) defines the range of tPAH concentrations that pose a low risk to sediment-dwelling organisms (e.g., 0 to 1.6 mg/kg DW; MacDonald *et al.* 2000). Such targets may vary depending on the management goals that are established at a particular site. For example, a target that would trigger further investigations at a site could be set at a relatively low level (e.g., TEC; MacDonald *et al.* 2000), while a target that would trigger sediment remediation could be set at a higher level [e.g., probable effect concentration (PEC) MacDonald *et al.* 2000]. In addition, targets for areas that are subjected to periodic or frequent physical disturbances may differ from those that are established for areas that are only infrequently disturbed (Crane *et al.* 2000). For this reason, multiple targets may be set for many of the metrics (see Chapter 7 of Volume III).

Chapter 6. Summary

Information from many sources indicates that sediments throughout North America 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), and PCDDs and PCDFs (IJC 1988; USEPA 1997a; 2000a; 2001). Contaminated sediments pose a major risk to the beneficial uses of freshwater ecosystems. For example, imposition of fish consumption advisories has adversely affected commercial, sport, and food fisheries in many areas with contaminated sediments. In addition, degradation of the benthic community and other factors associated with sediment contamination have contributed to the impairment of fish and wildlife populations. Furthermore, fish in areas with contaminated sediments have been observed to have higher levels of tumors and other abnormalities than fish from reference areas. Contaminated sediments have also threatened the viability of many commercial ports through the imposition of restrictions on dredging of navigational channels and disposal of dredged materials (IJC 1997).

This report describes an ecosystem-based framework for assessing and managing contaminated sediments (Chapter 2 of Volume I) which consists of five basic elements, including:

- Collation of the existing ecosystem knowledge base, and identification and assessment of the issues (Chapter 3 of Volume I);
- Development and articulation of ecosystem health goals and objectives (Chapter 4 of Volume I);
- Selection of ecosystem health indicators to gauge progress toward ecosystem health goals and objectives (Chapter 5 of Volume I and Chapters 2 to 6 of Volume III);
- Design and implementation of directed research and monitoring programs (Volumes II and III); and,

- Make informed decisions on the assessment, conservation, protection, and restoration of natural resources (Chapter 7 of Volume III).

The first three steps in the ecosystem-based framework, which are described in Volume I, provide a systematic basis for planning assessments of sediment quality conditions. As such, the framework provides a means of ensuring that assessment activities (i.e., research and monitoring) are focused on the priority issues and concerns at the site under investigation and will provide the information needed to make informed decisions regarding the management of contaminated sediments. More information on the advantages, limitations, and application of the various tools for assessing sediment quality conditions (e.g., sediment chemistry data and sediment toxicity data) is provided in Volume III of this report series. Guidance on the collection of sediment quality data is provided in Volume II, while information on the interpretation of such data is presented in Volume III. When used together with other appropriate guidance documents (e.g., USEPA 1994; 2000b; ASTM 2001a; 2001b; 2001c; 2001d), this guidance manual provides a basis for designing and implementing scientifically-defensible assessments of sediment quality conditions in freshwater ecosystems.

Chapter 7. References

Allen, T.F.H., B.L. Bandurski, and A.W. King. 1991. The ecosystem approach: theory and ecosystem integrity. Report to the Great Lakes Science Advisory Board. International Joint Commission. United States and Canada.

ASTM (American Society for Testing and Materials). 2001a. Standard test methods for measuring the toxicity of sediment-associated contaminants with freshwater invertebrates. E1706-00. ASTM 2001 Annual Book of Standards Volume 11.05. West Conshohocken, Pennsylvania.

ASTM (American Society for Testing and Materials). 2001b. Standard guide for designing biological tests with sediments. E1525-94a. *In:* ASTM 2001 Annual Book of Standards Volume 11.05. West Conshohocken, Pennsylvania.

ASTM (American Society for Testing and Materials). 2001c. Standard guide for collection, storage, characterization, and manipulation of sediments for toxicological testing. E1391-94. *In:* ASTM 2001 Annual Book of Standards Volume 11.05. West Conshohocken, Pennsylvania.

ASTM (American Society for Testing and Materials). 2001d. Standard guide for determination of the bioaccumulation of sediment-associated contaminants by benthic invertebrates. E1688-00a. *In:* ASTM 2001 Annual Book of Standards Volume 11.05. West Conshohocken, Pennsylvania.

BCE (British Columbia Environment). 1997. *Waste Management Act*: Contaminated Sites Regulation. B.C. Reg. 375/96. Schedule 2. Victoria, British Columbia.

Bertram, P.E. and T.B. Reynoldson. 1992. Developing ecosystem objectives for the Great Lakes: Policy, progress and public participation. Journal of Aquatic Ecosystem Health 1:89-95.

CCME (Canadian Council of Ministers of the Environment). 1996. A framework for developing ecosystem health goals, objectives, and indicators: Tools for ecosystem-based management. Prepared by the Water Quality Guidelines Task Group of the Canadian Council of Ministers of the Environment. Winnipeg, Manitoba. 24 pp.

Christie, W.J., M. Becker, J.W. Cowden and J.R. Vallentyne. 1986. Managing the Great Lakes Basin as a Home. Journal of Great Lakes Research 12(1):2-17.

Crane, J.L. 1996. Carcinogenic human health risks associated with consuming contaminated fish from five Great Lakes Areas of Concern. Journal of Great Lakes Research 22:653-668.

Crane, J.L., D.D. MacDonald, C.G. Ingersoll, D.E. Smorong, R.A. Lindskoog, C.G. Severn, T.A. Berger, L.J. Field. 2000. Development of a framework for evaluating numerical sediment quality targets and sediment contamination in the St. Louis Area of Concern. EPA 905-R-00-008. Great Lakes National Program Office. Chicago, Illinois.

Curry, M.S., M.T. Huguenin, A.J. Martin, and T.R. Lookingbill. 1997. Contamination extent report and preliminary injury evaluation for the Calcasieu Estuary. Prepared by Industrial Economics, Incorporated. Prepared for National Oceanic and Atmospheric Administration. Silver Spring, Maryland.

Ecosystem Objectives Work Group. 1992. Ecosystem objectives and their environmental indicators for Lake Ontario. Prepared for the Great Lakes Water Quality Agreement. International Joint Commission. Windsor, Ontario. 26 pp.

Environment Canada, Parks Service. 1992. Toward sustainable ecosystems: A Canadian Parks Service strategy, Western region strategy to enhance ecological integrity. Final report of the Ecosystem Management Task Force. Calgary, Alberta. (As cited in Environment Canada 1996).

Environment Canada. 1993. A proposed national framework for evaluating and reporting ecosystem health: A discussion paper. Prepared by Eco-Health Branch. Ecosystem Science and Evaluation Directorate. Environment Canada. Ottawa, Ontario.

Environment Canada. 1994a. Reviewing CEPA - The issues #3 - The ecosystem approach. Prepared for the CEPA Office. Hull, Quebec. (As cited in Environment Canada 1996).

Environment Canada. 1994b. An ecosystem planning framework. Produced by the Prairie and Northern Region. 26 July 1994. Edmonton, Alberta. (As cited in Environment Canada 1996).

Environment Canada. 1996. The ecosystem approach: Getting beyond the rhetoric. Prepared by the Task Force on Ecosystem Approach and Ecosystem Science at Environment Canada. Prepared for the Environment Canada Long Term Strategic Plan for Ecosystem Initiatives. Ottawa, Ontario.

Environment Canada. 1997. The Salmon River Watershed: An evaluation of the collaboration towards ecosystem objectives and a watershed vision, summary report, February 1997. Fraser River Action Plan, Environment Canada. Ottawa, Ontario.

Evans, F.C. 1956. Ecosystems as the basic unit in ecology. Science 123:1127-1128.

Grant, K. 1997. The Salmon River watershed: An evaluation of the collaboration towards ecosystem objectives and a watershed vision. Summary Report. February 1997. Environment Canada, Fraser River Action Plan. DOE FRAP 1996-16.

Harris, H.J., P.E. Sager, S. Richman, V.A. Harris and C.J. Yarbrough. 1987. Coupling Ecosystem Science with Management: A Great Lakes Perspective from Green Bay, Lake Michigan, USA. Environmental Management 11(5):619-625.

IJC (International Joint Commission). 1988. Procedures for the assessment of contaminated sediment problems in the Great Lakes. Prepared by the Sediment Subcommittee and its Assessment Work Group. Great Lakes Regional Office. Windsor, Ontario. 140 pp.

IJC (International Joint Commission). 1991. A proposed framework for developing indicators of ecosystem health for the Great Lakes region. Council of Great Lakes Research Managers. International Joint Commission. 47 pp.

IJC (International Joint Commission). 1994. Ecosystem charter for the Great Lakes - St. Lawrence Basin. Produced by the Council of Great Lakes Research Managers for the IJC. April 1994 Draft. (As cited in Environment Canada 1996).

IJC (International Joint Commission). 1997. Overcoming obstacles to sediment remediation in the Great Lakes Basin. White Paper by the Sediment Priority Action Committee. Great Lakes Water Quality Board. Windsor, Ontario.

Ingersoll, C.G., T. Dillon, and R.G. Biddinger (Eds.). 1997. Methodological uncertainty in sediment ecological risk assessment. *In*: Ecological Risk Assessments of Contaminated Sediment. SETAC Press. Pensacola, Florida. 389 pp.

Krantzberg, G., M.A. Zarull, and J.H. Hartig. 2001. Sediment management: Ecological and ecotoxicological effects must direct actions. Water Quality Research Journal of Canada 36(3):367-376.

Lackey, R. 1994. The seven pillars of ecosystem management. Draft document modified from a presentation given at the Symposium: Ecosystem health and medicine: Integrating science, policy and management. June 19-23, 1994. Ottawa, Ontario. (As cited in Environment Canada 1996).

Lake Superior Work Group. 1993. Ecosystem principles and objectives for lake Superior. Discussion paper. State of the Lake Superior Basin Reporting Series, Vol. IV. Lake Superior Binational Program.

MacDonald, D.D. 1989. An assessment of ambient water quality conditions in the Slave River basin, NWT. Prepared for Indian and Northern Affairs Canada. Yellowknife, Northwest Territories.

MacDonald, D.D. 1994a. Approach to the assessment of sediment quality in Florida coastal waters. Volume 1: Development and evaluation of sediment quality assessment guidelines. Report prepared for Florida Department of Environmental Protection. Tallahassee, Florida.

MacDonald, D.D. 1994b. Approach to the assessment of sediment quality in Florida coastal waters. Volume 2: Applications of the sediment quality assessment guidelines. Report prepared for Florida Department of Environmental Protection. Tallahassee, Florida.

MacDonald, D.D. 1995. Science advisory group on sediment assessment in Tampa Bay: Summary report. Technical Publication #06-95. Tampa Bay National Estuary Program. St. Petersburg, Florida.

MacDonald, D.D. 1997. Tampa Bay Sediment Quality Workshop: Setting targets and defining management strategies - Final Summary Report. Prepared for the Tampa Bay National Estuary Program. St. Petersburg, Florida.

MacDonald, D.D. 1999. Tampa Bay Sediment Quality Workshop: Establishing impact levels and setting sediment quality targets - Workshop Summary Report. Prepared for the Tampa Bay National Estuary Program. St. Petersburg, Florida.

MacDonald, D.D. 2000. Interests and needs related to the development of freshwater sediment quality guidelines for the State of Florida: Workshop summary report. Prepared for Florida Department of Environmental Protection. Tallahassee, Florida.

MacDonald, D.D. and M. MacFarlane. 1999. Criteria for managing contaminated sediment in British Columbia. Prepared pursuant to Section 26(a) of the Waste Management Act. Prepared for Ministry of Environment, Lands, and Parks. Victoria, British Columbia.

MacDonald, D.D. and C.G. Ingersoll. 2000. An assessment of sediment injury in the Grand Calumet River, Indiana Harbor Canal, Indiana Harbor, and the nearshore areas of Lake Michigan. Volume I. Prepared for U.S. Fish and Wildlife Services. Bloomington Indiana. 238 pp.

MacDonald, D.D., C.G. Ingersoll, and T.A. Berger. 2000. Development and evaluation of consensus-based sediment quality guidelines for freshwater ecosystems. Archives of Environmental Contamination and Toxicology 39:20-31.

MacDonald, D.D., D.E. Smorong, and R.A. Lindskoog. 2001. Development and evaluation of numerical sediment quality criteria for sediment contaminated sites in British Columbia: A retrospective. Prepared for B.C. Ministry of Environment, Lands, and Parks. Victoria, British Columbia. 26 pp.

MESL (MacDonald Environmental Sciences Ltd). 1997. Lower Columbia River from Birchbank to the International Boundary: Water Quality and Quantity Assessment and Objectives Technical Report. Prepared for Environment Canada, Vancouver, British Columbia and the British Columbia Ministry of Environment, Lands and Parks, Victoria, British Columbia.

MacFarlane, M. 1997. Investigation and remediation of sediments. File 26050-01/General. B.C. Environment and Resource Management. Ministry of Environment, Lands, and Parks. Victoria, British Columbia.

Mah, F.T.S., D.D. MacDonald, S.W. Sheehan, T.N. Tuominen, and D. Valiela. 1989. Dioxins and furans in sediments and fish from the vicinity of ten inland pulp mills in British Columbia. Water Quality Branch. Environment Canada. Vancouver, British Columbia. 77 pp.

Marmorek, D.R., T.M. Berry, P. Bunnell, D.P. Bernard, W.A. Kurz, C.L. Murray, K. Paulig, and L. Sully. 1993. Towards an ecosystem approach in British Columbia: Results of a workshop on ecosystem goals and objectives. December 7-9, 1992. Prepared by ESSA Environmental and Social System Analysts Ltd. Vancouver, British Columbia. Prepared for Environment Canada, British Columbia Ministry of Environment, Lands and Parks, and British Columbia Ministry of Forests. Fraser River Action Plan. Vancouver, British Columbia. (As cited in Environment Canada 1996).

McNaughton, S.J., and L.L. Wolf. 1979. General Ecology. 2nd ed. Holt, Rinehart, and Winston. New York.

Odum, H.T. 1983. Systems Ecology: An Introduction. John Wiley and Sons. New York.

OEPA (Ohio Environmental Protection Agency). 1988. Biological criteria for the protection of aquatic life: Volume II: Users manual for biological field assessment of Ohio surface waters. Ecological Assessment Section. Division of Water Quality Planning and Assessment. Columbus, Ohio.

RCFTW (Royal Commission on the Future of the Toronto Waterfront). 1992. Regeneration. Toronto's waterfront and the sustainable city: Final report. Toronto, Ontario.

Reynoldson, T. B., L. Grapentine, M. Zarull, T. Pascoe, L. Richman, C. DeBarros, S. Painter, and J. Anderson. 2000. A support system for decision making using chemical and biological measures. National Water Research Institute. Environment Canada. Burlington, Ontario.

Royal Society of Canada. 1995. Looking ahead: Long-term ecological research and monitoring in Canada. Final report of the long-term ecological research and monitoring panel of the Canadian Global Change Program. Canadian Global Change Program Technical Report No. 95-1. (As cited in Environment Canada 1996).

Ryder, R.A. and C.J. Edwards (Eds.). 1985. A conceptual approach for the application of biological indicators of ecosystem quality in the Great Lakes Basin. Report to the Great Lakes Science Advisory Board. International Joint Commission and The Great Lakes Fishery Commission. Windsor, Ontario.

Standing Committee on Environment and Sustainable Development. 1995. It's about our health! Towards pollution prevention. House of Commons Standing Committee on Environment and Sustainable Development. June 1995. Ottawa, Ontario. (As cited in Environment Canada 1996).

Stoddart, D.R. 1965. Geography and the ecological approach. Geography 50: 242-251.

USEPA (United States Environmental Protection Agency). 1994. Assessment and remediation of contaminated sediments (ARCS) program. Great Lakes National Program Office. EPA 905/B-94/002. Chicago, Illinois.

USEPA (United States Environmental Protection Agency). 1997a. The incidence and severity of sediment contamination in surface waters of the United States: Volume 1: National Sediment Quality Survey. EPA/823/R-97/006. Washington, District of Columbia.

USEPA (United States Environmental Protection Agency). 1997b. Ecological risk assessment guidance for Superfund: Process for designing and conducting ecological risk assessments. Environmental Response Team. Edison, New Jersey.

USEPA (United States Environmental Protection Agency). 1998. Guidelines for ecological risk assessment. Risk Assessment Forum. EPA/630/R-95/002F. Washington, District of Columbia.

USEPA (United States Environmental Protection Agency). 2000a. Draft implementation framework for the use of equilibrium partitioning sediment quality guidelines. Office of Water of Science and Technology. Washington, District of Columbia.

USEPA (United States Environmental Protection Agency). 2000b. Methods for measuring the toxicity and bioaccumulation of sediment-associated contaminants with freshwater invertebrates, second edition. EPA/600/R-99/064. Washington, District of Columbia.

USEPA (United States Environmental Protection Agency). 2001. Fact sheet: Draft report on the incidence and severity of sediment contamination in surface waters of the United States, National Sediment Quality Survey. EPA/823/F-01-031. Office of Water. Washington, District of Columbia.

USEPA and USACE (United States Environmental Protection Agency and United States Army Corps of Engineers). 1998. Evaluation of dredged material proposed for discharge in water of the US. Testing Manual. EPA 823-B-98-004. United States Environmental Protection Agency. Washington, District of Columbia.

Vallentyne, J.R. and A.L. Hamilton. 1987. Managing the human uses and abuses of aquatic resources in the Canadian ecosystem. *In:* M.C. Healey and R.R. Wallace (Eds.). Canadian Aquatic Resources. Canadian Fisheries and Aquatic Sciences Bulletin 215:513-533. (As cited in Vallentyne and Beeton 1988).

Vallentyne, J.R. and A.M. Beeton. 1988. The "ecosystem" approach to managing human uses and abuses of natural resources in the Great Lakes Basin. Environmental Conservation 15(1):58-62.

Wrona, F. 1994. Ecosystem science - Now and in the future. Backgrounder for Science and Technology Review. National Hydrology Research Institute. Saskatoon, Saskatchewan. (As cited in Environment Canada 1996).

Appendices

Appendix 1. Role of Sediments in Aquatic Ecosystems

AI.0 Introduction

The particulate materials that lie below the water in ponds, lakes, stream, 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 food webs (i.e., through the consumption of aquatic organisms).

AI.1 Supporting Primary Productivity

Sediments support the production of food 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, estuaries, and slower-flowing sections of rivers and streams, are comprised largely of sand, silt, and clay. 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, and anthropogenic 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).

AI.2 Providing Essential Habitats

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 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 fish, amphibians, reptiles, 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 alevins (e.g., trout, salmon, and whitefish). 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.

Appendix 2. Bibliography of Relevant Publications

A2.0 Classifications

1. Sediment Chemistry
2. Toxicity Testing
3. Benthic Invertebrate Community Assessment
4. Sediment Quality Triad
5. Bioaccumulation/Tissue Chemistry
6. Bioavailability
7. Sediment Quality Guidelines
8. Toxicity Identification Evaluation
9. Sample Collection and Handling
10. Sediment Quality Assessment
11. Sediment Spiking Studies
12. Fish Health and Community Assessment
13. Environmental Fate
14. Regulations
15. Ecosystem-Based Management
16. Sediment Management
17. Ecological Human Health Risk Assessment
18. Quality Assurance

A2.1 Publications

2 Adams, W.J., R.A. Kimerle, and R.G. Mosher. 1985. An approach for assessing the environmental safety of chemicals sorbed to sediments. *In*: Aquatic Toxicology and Hazard Evaluation: Seventh Symposium. R.D. Cardwell, R. Purdy, and R.C. Bahner, (Eds.). ASTM STP 854. American Society for Testing and Materials. Conshohocken, Pennsylvania. pp. 429-453.

6 Adams, W.J. 1987. Bioavailability of neutral lipophilic organic chemicals contained in sediments. *In*: Fate and Effects of Sediment-bound Chemicals in Aquatic Systems. K.L. Dickson, A.W. Maki, and W.A. Brungs, (Eds.). Proceedings of the Sixth Pellston Workshop. Florissant, Colarodo. August 12-17, 1984. Pergamon Press, New York. pp. 219-244.

10 Ankley, G.T., A. Katko, and J.W. Arthur. 1990. Identification of ammonia as an important sediment-associated toxicant in the lower Fox River and Green Bay, Wisconsin. Environmental Toxicology and Chemistry 9:313-322.

7 Ankley, G.T., G.L. Phipps, E.N. Leonard, D.A. Benoit, V.R. Mattson, P.A. Kosian, A.M. Cotter, J.R. Dierkes, D.J. Hansen, and J.D. Mahony. 1991. Acid-volatile sulfide as a factor mediating cadmium and nickel bioavailability in contaminated sediment. Environmental Toxicology and Chemistry 10:1299-1307.

2 Ankley, G.T., M.K. Schubauer-Berigan, and J.R. Dierkes. 1991. Predicting the toxicity of bulk sediments to aquatic organisms using aqueous test fractions: Pore water versus elutriate. Environmental Toxicology and Chemistry 10:1359:1366.

8 Ankley, G.T. and N. Thomas. 1992. Interstitial water toxicity identification evaluation approach. *In*: Sediment Classification Methods Compendium. EPA-823-R-92-006. United States Environmental Protection Agency. Washington, District of Columbia. pp. 5-1 to 5-14.

5 Ankley, G.T., P.M. Cook, A.R. Carlson, D.J. Call, J.A. Swenson, H.F. Corcoran, and R.A. Hoke. 1992. Bioaccumulation of PCBs from sediments by oligochaetes and fishes: Comparison of laboratory and field studies. Canadian Journal of Fisheries and Aquatic Sciences 49:2080-2085.

2 Ankley, G.T., D.A. Benoit, R.A. Hoke, E.N. Leonard, C.W. West, G.L. Phipps, V.R. Mattson, and L.A. Anderson. 1993. Development and evaluation of test methods for benthic invertebrates and sediments: Effects of flow rate and feeding on water quality and exposure conditions. Archives of Environmental Contamination and Toxicology 25:12-19.

7 Ankley, G.T., V.R. Mattson, E.N. Leonard, C.W.West, and J.L. Bennett. 1993. Predicting the acute toxicity of copper in freshwater sediments: Evaluation of the role of acid volatile sulfide. Environmental Toxicology and Chemistry 12:315-320.

9 Ankley, G.T. and M.K. Schubauer-Berigan. 1994. Comparison of techniques for the isolation of pore water for sediment toxicity testing. Archives of Environmental Contamination and Toxicology 27:507-512.

5 Ankley, G.T., E.N. Leonard, and V.R. Mattson. 1994. Prediction of bioaccumulation of metals from contaminated sediments by the oligochaete *Lumbriculus variegatus*. Water Research 28:1071-1076.

2 Ankley, G.T., D.A. Benoit, J.C. Balough, T.B. Reynoldson, K.E. Day, and R.A. Hoke. 1994. Evaluation of potential confounding factors in sediment toxicity tests with three freshwater benthic invertebrates. Environmental Toxicology and Chemistry 13:637-635.

11 Ankley, G.T., D.J. Call, J.S. Cox, M.D. Kahl, R.A. Hoke, and P.A. Kosian. 1994. Organic carbon partitioning as a basis for predicting the toxicity of chlorpyrifos in sediments. Environmental Toxicology and Chemistry 13(4):621-626.

6 Ankley, G.T., N.A. Thomas, D.M. Di Toro, D.J. Hansen, J.D. Mahony, W.J. Berry, R.C. Swartz, R.A. Hoke, A.W. Garrison, H.E. Allen, and C.S. Zarba. 1994. Assessing potential bioavailability of metals in sediments: A proposed approach. Environmental Management 18(3):331-337.

8 Ankley, G.T. and M.K. Schubauer-Berigan. 1995. Background and overview of current sediment toxicity identification procedures. Journal of Aquatic Ecosystem Health 4:133-149.

2 Ankley, G.T., M.K. Schubauer-Berigan, and P.D. Monson. 1995. Influence of pH and hardness on the toxicity of ammonia to the amphipod *Hyalella azteca*. Canadian Journal of Fisheries and Aquatic Sciences 52(10):2078-2083.

7 Ankley, G.T. 1996. Evaluation of metal acid volatile sulfide relationships in the prediction of metal bioaccumulation by benthic macroinvertebrates. Environmental Toxicology and Chemistry 15(12):2138-2146.

7 Ankley, G.T., D.M. Di Toro, D.J. Hansen, and W.J. Berry. 1996. Assessing the ecological risk of metals in sediments. Editorial. Environmental Toxicology and Chemistry 15(12):2053-2055.

10 Ankley, G.T., K. Liber, D.J. Call, T.P. Markee, T.J. Canfield, and C.G. Ingersoll. 1996. A field investigation of the relationship between zinc and acid volatile sulfide concentrations in freshwater sediments. Journal of Aquatic Ecosystem Health 5:255-264.

2 ASTM (American Society for Testing and Materials). 2000a. Standard test methods for measuring the toxicity of sediment-associated contaminants with freshwater invertebrates: E1706-95b. *In*: Annual Book of ASTM Standards, Vol. 11.05. Conshohocken, Pennsylvania.

9 ASTM (American Society for Testing and Materials). 2000b. Standard guide for collection, storage, characterization, and manipulation of sediments for

toxicological testing: E1391-94. *In*: Annual Book of ASTM Standards*,* Vol. 11.05. Conshohocken, Pennsylvania.

5 ASTM (American Society for Testing and Materials). 2000c. Standard guide for the determination of bioaccumulation of sediment-associated contaminants by benthic invertebrates: E1688-97a. *In*: Annual Book of ASTM Standards*,* Vol. 11.05. Conshohocken, Pennsylvania.

2 ASTM (American Society for Testing and Materials). 2000d. Standard guide for designing biological tests with sediments: E1525-01a. *In*: Annual Book of ASTM Standards, Vol. 11.05. Conshohocken, Pennsylvania.

2 ASTM (American Society for Testing and Materials). 2000e. Standard guide for conducting acute toxicity tests with fishes, macroinvertebraes, and amphipods: E729-96. *In*: Annual Book of ASTM Standards, Vol. 1105. Conshohocken, Pennsylvania.

2 ASTM (American Society for Testing and Materials). 2000f. Standard guide for conducting early life-stage toxicity tests with fishes: E1241-98. *In*: Annual Book of ASTM Standards, Vol. 11.05. Conshohocken, Pennsylvania.

2 ASTM (American Society for Testing and Materials). 2000g. Standard guide for the use of lighting in laboratory testing: E1733-95. *In*: Annual Book of ASTM Standards, Vol. 11.05. Conshohocken, Pennsylvania.

13 ASTM (American Society for Testing and Materials). 2000h. Standard terminology relating to biological effects and environmental fate: E943-97a. *In*: Annual Book of ASTM Standard*,* Vol. 11.05. Conshohocken, Pennsylvania.

5 ASTM (American Society for Testing and Materials). 2000i. Standard practice for conducting bioconcentration tests with fishes and saltwater bivalve mollusks: E1022-94. *In*: Annual Book of ASTM Standards*,* Vol.11.05. Conshohocken, Pennsylvania.

10 Baker, J.E., S.J. Eisenreich, and B.J. Eadie. 1991. Sediment trap fluxes and benthic recycling of organic carbon, polycyclic aromatic hydrocarbons, and polychlorobiphenyl congeners in Lake Superior. Environmental Science and Technology 25(3):500-509.

7 Barrick, R., S. Becker, L. Brown, H. Beller, and R. Pastorok. 1988. Sediment quality values refinement: 1988 update and evaluation of Puget Sound AET. Volume I. PTI Contract C717-01. PTI Environmental Services. Bellevue, Washington.

7 Batts, D. And J. Cubbage. 1995. Summary of guidelines for contaminated freshwater sediments. Publication Number 95-308. Washington State Department of Ecology. Olympia, Washington.

12 Baumann, P.C. 1998. Epizootics of cancer in fish associated with genotoxins in sediment and water. Mutation Research 411:227-233.

12 Baumann, P.C. 1998. Epizootics of cancer in fish associated with genotoxins in sediment and water. Mutation Research 411:227-233.

7 BCMOE (British Columbia Ministry of the Environment). 1995a. Summary of the CSST protocol for the derivation of soil quality matrix numbers for contaminated sites. Draft 2.0. Industrial Wastes and Hazardous Contaminants Branch. Victoria, British Columbia. 24 pp.

13 BCMOE (British Columbia Ministry of the Environment). 1995b. A chemical transport model for the development of chemical criteria in soil protective of groundwater. Industrial Wastes and Hazardous Contaminants Branch. Victoria, British Columbia. 24 pp.

7 Beak Consultants Ltd. 1987. Development of sediment quality objectives: Phase I - Options: Final Report. Prepared for Ontario Ministry of Environment. Mississauga, Ontario.

7 Beak Consultants Ltd. 1988. Development of sediment quality objectives: Phase I - guidelines development. Prepared for Ontario Ministry of Environment. Mississauga, Ontario.

7 Becker, D.S., R.C. Barrick, and L.B. Read. 1989. Evaluation of the AET approach for assessing contamination in sediments in California. PTI Contract C739-01. PTI Environmental Services. Bellevue, Washington.

2 Becker, D.S., C.D. Rose, and G.N. Bigham. 1995. Comparison of the 10-d freshwater sediment toxicity tests using *Hyalella azteca* and *Chironomus tentans*. Environmental Toxicology and Chemistry 14(12):2089-2094.

2 Bennett, J. and J. Cubbage. 1992a. Evaluation of bioassay organisms for freshwater sediment toxicity testing. Prepared for the Freshwater Sediment Criteria Development Project. Washington State Department of Ecology. Olympia, Washington. 34 pp.

2 Bennett, J. and J. Cubbage. 1992b. Review and evaluation of Microtox test for freshwater sediments. Prepared for the Sediment Management Unit. Washington State Department of Ecology. Olympia, Washington. 28 pp.

2 Benoit, D.A., G.A. Phipps, and G.T. Ankley. 1993. A sediment testing intermittent renewal system for the automated renewal of overlying water in toxicity tests with contaminated sediments. Water Research 27:1403-1412.

2 Benoit, D.A., P.K. Sibley, J.L. Jueneman, and G.T. Ankley. 1997. *Chironomus tentans* life-cycle test: Design and evaluation for use in assessing toxicity of contaminated sediments. Environmental Toxicology and Chemistry 16(6):1165-1176.

7 Berry, W.J., D.J. Hansen, J.D. Mahony, D.L. Robson, D.M. DiToro, B.P. Shipley, B. Rogers, J.M. Corbin, and W.S. Boothman. 1996. Predicting the toxicity of metals-spiked laboratory sediments using acid volatile sulfide and interstitial

water normalizations. Environmental Toxicology and Chemistry 15(12):2067-2079.

7 Berry, W.J., M. Cantwell, P. Edwards, J. Serbst, and D.J. Hansen. 1999. Predicting the toxicity of sediments spiked with silver in the laboratory. Environmental Toxicology and Chemistry 18:40-48.

6, 12 Besser, J.M., J.A. Kubitz, C.G. Ingersoll, W.E. Braselton, and J.P. Giesy. 1995. Influences on copper bioaccumulation, growth, and survival of the midge, *Chironomus tentans*, in metal-contaminated sediments. Journal of Aquatic Ecosystem Health 4:157-168.

6 Besser, J.M., C.G. Ingersoll, J.P. Giesy. 1996. Effects of spatial and temporal variation of acid-volatile sulfide on the bioavailability of copper and zinc in freshwater sediments. Environmnetal Toxicology and Chemistry 15(3):286-293.

2 Besser, J.M., C.G. Ingersoll, E. Leonard, and D.R. Mount. 1998. Effect of zeolite on toxicity of ammonia in freshwater sediments: Implications for sediment toxicity identification evaluation procedures. Environmental Toxicology and Chemistry 17:2310-2317.

5 Bligh, E.G. and W.J. Dyer. 1959. A rapid method of total lipid extraction and purification. Canadian Journal of Biochemical Physiology 37:911-917.

5 Boese, B.L., H.Lee, D.T. Specht, R.C. Randall, and M.H. Windsor. 1990. Comparison of aqueous and solid-phase uptake for hexachlorobenzene in the tellinid clam *Macoma nasuta* (Conrad): A mass balance approach. Environmental Toxicology and Chemistry 9:221-231.

1 Boothman, W.S. and A. Helmsetter. 1992. Vertical and seasonal variability of acid volatile sulfides in marine sediments. Research Report. United States Environmental Protection Agency. Narragansett, Rhode Island.

2 Borgmann, U. and M. Munawar. 1989. A new standardized bioassay protocol using the amphipod *Hyalella azteca*. Hydrobiologia 188/189:425-531.

2, 11 Borgmann, U., K.M. Ralph, and W.P. Norwood. 1989. Toxicity test procedures for *Hyalella azteca*, and chronic toxicity of cadmium and pentachlorophenol to *H. azteca*, *Gammarus fasciatus*, and *Daphnia magna*. Archives of Environmental Contamination and Toxicology 18:756-764.

2, 5, 11 Borgmann, U., W.P. Norwood, and K.M. Ralph. 1990. Chronic Toxicity and bioaccumulation of 2,5,2',5'- and 3,4,3',4'- Tetrachlorobiphenyl and Aroclor 1242 in the amphipod *Hyalella azteca.* Archives of Environmental Contamination and Toxicology 19:558-564.

2, 5, 11 Borgmann, U., W.P. Norwood, and I.M. Babirad. 1991. Relationship between chronic toxicity and bioaccumulation of cadmium in *Hyalella azteca*. Canadian Journal of Fisheries and Aquatic Sciences 48:1055-1060.

10 Borgmann, U. and W.P. Norwood. 1993. Spatial and temporal variability in toxicity of Hamilton Harbour sediments: Evaluation of the *Hyalella azteca* 4-week chronic toxicity test. Journal of Great Lakes Research 19(1):72-82.

2 Borgmann, U. 1994. Chronic toxicity of ammonia to the amphipod *Hyalella azteca*: Importance of ammonium ion and water hardness. Environmental Polution 86:329-335.

2 Borgmann, U. 1996. Systematic analysis of aqueous ion requirements of *Hyalella azteca*: A standard artificial medium including the essential bromide ion. Archives of Environmental Contamination and Toxicology 30:356-363.

2 Borgmann, U. and A.I. Borgmann. 1997. The control of ammonia toxicity to *Hyalella azteca* by sodium, potassium, and pH. Environmental Pollution 95:325-331.

2, 5, 11 Borgmann, U. and W.P. Norwood. 1997. Toxicity and accumulation of zinc and copper in *Hyalella azteca* exposed to metal-spiked sediments. Canadian Journal of Fisheries and Aquatic Sciences 54:1046-1054.

2 Borgmann, U. and W.P. Norwood. 1999. Sediment toxicity testing using large water-sediment ratios: An alternative to water renewal. Environmental Pollution 106: 333-339.

6, 2 Borgmann, U., R. Neron, and W.P. Norwood. 2001. Quantification of bioavailable nickel in sediments and toxic thresholds to *Hyalella azteca*. Environmental Pollution 111:189-198.

5 Bridges, T.S., D.W. Moore, P.F.Landrum, J.Neff, and J.Cura. 1996. Summary of a workshop on interpreting bioaccumulation data collected during regulatory evaluations of dredged material. Miscellaneous Paper D-96-1. Waterways Experiment Station. United States Army Corps of Engineers. Vicksbury, Mississippi.

5 Brooke, L.T., G.T. Ankley, D.J. Call, and P.M. Cook. 1996. Gut content weight and clearance rate for three species of freshwater invertebrates. Environmental Toxicology and Chemistry 15(2):223-228.

2 Brouwer, H. and T. Murphy. 1995. Volatile Sulfides and their toxicity in freshwater sediments. Environmental Toxicology and Chemistry 14:203-208.

2, 10 Brumbaugh, W.G., E.L. Brunson, F.J. Dwyer, C.G. Ingersoll, D.P. Monda, and D.F. Woodward. 1994. Toxicity of metal-contaminated sediments form the Upper Clark Fork River, MT, to aquatic invertebrates in laboratory exposures. Environmental Toxicology and Chemistry 13:1985-1997.

2, 5, 10 Brunson, E.L., T.J. Canfield, F.J. Dwyer, N.E. Kemble, and C.G. Ingersoll. Assessing the bioaccumulation with sediments from the Upper Missippi River using field-collected oligochaetes and laboratory-exposed *Lumbriculus variegatus*. Archives of Environmental Contamination and Toxicology 35:191-201.

5 Burkhard, L.P., B.R. Sheedy, D.J. McCauley, and G.M. DeGraeve. Bioaccumulation factors for chlorinated benzenes, chlorinated butadienes and hexachloroethane. Environmental Toxicology and Chemistry 16(8):1677-1686.

5 Burkhard, L.P. 1998. Comparison of two models for predicting bioaccumulation of hydrophobic organic chemicals in a great lakes food web. Environmental Toxicology and Chemistry 17(3):383-393.

2, 11 Burton, G.A., Jr., B.L. Stemmer, K.L. Winks, P.E. Ross, and L.C. Burnett. 1989. A multitrophic level evaluation of sediment toxicity in Waukegan and Indiana Harbors. Environmental Toxicology and Chemistry 8:1057-1066.

2 Burton, G.A., Jr. 1991. Assessment of freshwater sediment toxicity. Environmental Toxicology and Chemistry 10:1585-1627.

9 Burton, G.A., Jr. 1992. Sediment collection and processing factors affecting realism. *In*: Sediment Toxicity Assessment. G.A. Burton, Jr.(Ed.). Lewis Publishers. Boca Raton, Florida. pp. 37-66.

2 Burton, G.A., Jr. M.K. Nelson, and C.G. Ingersoll. 1992. Freshwater benthic toxicity tests. *In*: Sediment Toxicity Assessment. G.A. Burton (Ed.). Lewis Publishers. Chelsea, Michigan. pp. 213-240.

2 Burton, G.A., Jr., T.J. Norberg-King, C.G. Ingersoll, D.A. Benoit, G.T. Ankley, P.V. Winger, J. Kubitz, J.M. Lazorchak, M.E. Smith, E. Greer, F.J. Dwyer, D.J. Call, K.E. Day, P. Kennedy, and M. Stinson. 1996b. Interlaboratory study of precision: *Hyalella azteca* and *Chironomus tentans* freshwater sediment toxicity assay. Environmental Toxicology and Chemistry 15(8):1335-1343.

11 Call, D.J., M.D. Balcer, L.T. Brooke, S.J. Lozano, and D.D. Vaishnav. 1991. Sediment quality evaluation in the lower Fox River and southern Green Bay of Lake Michigan. Cooperative Agreement Final Report. Prepared for United States Environmental Protection Agency. Superior, Wisconsin.

2 Call, D.J., K.Liber, L.T. Brooke, T.D. Dawson, and F.W. Whiteman. 1993. The *Chironomus tentans* survival and growth bioassay: A study of the effect of reduced larval growth upon the following generation and an application of the bioassay in evaluating sediment quality. Final Project Report to the United States Army Corps of Engineers. Waterways Experiment Station. Vicksburg, Mississippi.

2 Call, D.J., L.T. Brooke, G.T. Ankley, D.A. Benoit, and R.A. Hoke. 1994. Appendix G: Biological effects testing procedures. *In:* Great Lakes Dredged Material Testing and Evaluation Manual: July Draft. United States Environmental Protection Agency, Regions II, III, V, Great Lakes National Program Office, and United States Army Corps of Engineers, North Central Division. Chicago, Illinois.

3, 4, 11 Canfield, T.J., N.E. Kemble, W.G. Brumbaugh, F.J. Dwyer, C.G. Ingersoll, and J.F. Fairchild. 1994. Use of benthic invertebrate community structure and the sediment quality triad to evaluate metal-contaminated sediment in upper Clark Fork River, MT. Environmental Toxicology and Chemistry 13:1999-2012.

3, 4, 11 Canfield, T.J., F.J. Dwyer, J.F. Fairchild, P.S. Haverland, C.G. Ingersoll, N.E. Kemble, D.R. Mount, T.W. LaPoint, G.A. Burton, M.C. Swift. 1996. Assessing contamination in Great Lakes sediments using benthic invertebrate communities and the sediment quality triad approach. Journal of Great Lakes Research 22:565-583.

3, 4, 11 Canfield, T.J., E.L. Brunson, F.J.Dwyer, C.G. Ingersoll, and N.E. Kemble. 1998. Assessing upper Mississippi river sediments using benthic invertebrates and the sediment quality triad. Archives of Environmental Contamination and Toxicology 35:202-212.

6, 11 Carlson, A.R., G.L. Phipps, V.R. Mattson, P.A. Kosian, and A.M. Cotter. 1991. The role of acid-volatile sulfide in determining cadmium bioavailability and toxicity in freshwater sediments. Environmental Toxicology and Chemistry 14:1309-1319.

2 Carr, R.S. and D.C. Chapman. 1992. Comparison of solid-phase and pore water approaches for assessing the quality of estuarine sediments. Chemistry and Ecology 7:19-30.

2, 9 Carr, R.S. and D.C. Chapman. 1995. Comparison of methods for conducting marine and estuarine sediment pore water toxicity tests, extraction, storage, and handling techniques. Archives of Environmental Contamination and Toxiocology 28:69-77.

11 Carr, R.S., E.R. Long, H.L. Winsdom, D.C. Chapman, Glen Thurby, G.M. Sloane, and D.A. Wolfe. 1996. Sediment quality assessment studies of Tampa Bay. Environmental Toxicology and Chemistry 15(7):1218-1231.

7 CCME (Canadian Council of Ministers of the Environment). 1994. Guidance manual for developing site-specific soil quality remediation objectives for contaminated sites in Canada: Final Report. Ottawa, Ontario. 88 pp.

7 CCME (Canadian Council of Ministers of the Environment). 1995a. A protocol for the derivation of environmental and human health soil quality guidelines. CCME-EPC-101E. The National Contaminated Sites Remediation Program. Ottawa, Ontario. 167 pp.

7 CCME (Canadian Council of Ministers of the Environment). 1995b. Protocol for the derivation of Canadian sediment quality guidelines for the protection of aquatic life. CCME EPC-98E. Canadian Council of Ministers of the Environment Task Group on water quality guidelines. Ottawa, Ontario.

7 CCME (Canadian Council of Ministers of the Environment). 1996a. Guidance manual for developing site-specific soil quality remediation objectives for contaminated sites in Canada. The National Contaminated Sites Remediation Program. Ottawa, Ontario.

15 CCME (Canadian Council of Ministers of the Environment). 1996b. A framework for developing ecosystem health goals, objectives, and indicators: Tools for ecosystem-based management. Canadian Council of Ministers of the Environment Water Quality Guidelines Task Group. Ottawa, Ontario.

2 Chapman, P.M., M.A. Farrell, and R.O. Brinkhurst. 1982a. Relative tolerances of selected aquatic oligochaetes to combinations of pollutants and environmental factors. Aquatic Toxicology 2:69-78.

2 Chapman, P.M., M.A. Farrell, and R.O. Brinkhurst. 1982b. Relative tolerances of selected aquatic oligochaetes to individual pollutants and environmental factors. Aquatic Toxicology 2:47-67.

4 Chapman, P.M., R.N. Dexter, and E.R. Long. 1987. Synoptic measures of sediment contamination, toxicity, and infaunal community composition (the sediment quality triad) in San Francisco Bay. Marine Ecology Progress Series 37: 75-96.

7 Chapman, P.M. 1989. Current approaches to developing sediment quality criteria. Environmental Toxicology and Chemistry 8:589-599.

2, 7 Chapman, P.M., H.B. Dexter, H.B. Anderson, and E.A. Power. 1991. Evaluation of effects associated with an oil platform using sediment quality criteria. Environmental Toxicology and Chemistry 10:407-424.

4 Chapman, P.M., E.A. Power, and G.A. Burton Jr. 1992. Integrative assessments in aquatic ecosystems. *In*: Sediment Toxicity Assessment. G.A. Burton, Jr. (Ed.). Lewis Publishers. Chelsea, Michigan. pp. 313-340.

4 Chapman, P.M., B. Anderson, S. Carr, V. Engle, R. Green, J. Hameedi, M. Harmon, P. Haverland, J. Hyland, C. Ingersoll, E. Long, J. Rodgers, M. Salazar, P.K. Sibley, P.J. Smith, R.C. Swartz, B. Thompson, and H. Windom. 1997. General guidelines for using the sediment quality triad. Marine Pollution Bulletin 34:368-372.

7 Chapman, P.M., P.J. Allard and G.A. Vigers. 1999. Development of sediment quality values for Hong Kong Special Administrative Region: A possible model for other jurisdictions. Marine Pollution Bulletin 38(3):161-169.

7 Chapman, P.M. and G.S. Mann. 1999. Sediment quality values (SQVs) and ecological risk assessment (ERA). Marine Pollution Bulletin 38(5):339-344.

2 Chappie, D.J. and G.A. Burton, Jr. Optimization of *in situ* bioassays with *Hyalella azteca* and *Chironomus tentans*. Environmental Toxicology and Chemistry 16(3):559-564.

13 Chapra, S.C. 1982. Long-term models of interactions between solids and contaminants in lakes. Ph.D. dissertation. The University of Michigan. Ann Arbor, Michigan. 190 pp.

13 Chin, Y.-P, W.J. Weber, and B.J. Eadie. 1990. Estimating the effects of dispersed organic polymers on the sorption of contaminants by natural solids. 2. Sorption in the presence of humic and other natural macromolecules. Environmental Science and Technology 24(6):837-842.

3 Clements, W.H., D.S. Cherry, and J.H. Van Hassel. 1992. Assessment of the impact of heavy metals on benthic communities at the Clinch River (Virginia): Evaluation of an index of community sensitivity. Canadian Journal of Fisheries and Aquatic Sciences 49:1686-1694.

3 Clifford, H. 1991. Aquatic Invertebrates of Canada. The University of Alberta Press. University of Alberta. Edmonton, Alberta.

11 Collyard, S.A., G.T. Ankley, R.A. Hoke, and T. Goldenstein. 1994. Influence of age on the relative sensitivity of *Hyalella azteca* to diazinon, alkylphenol ethoxylate, copper, cadmium, and zinc. Archives of Environmental Contamination and Toxicology 26:110-113.

16 Connolly, J., J. Rhea, and J. Benaman. 1999. Effective decision-making models for evaluating sediment management options. Quantitative Environmental Analysis, LLC. 26 pp.

3 Cook, S.E.K. 1976. Quest for an index of community structure sensitive to water pollution. Environmental Pollution 11:269-288.

5 Craig, A. L. Hare, and A. Tessier. 1999. Experimental evidence for cadmium uptake via calcium channels in the aquatic insect, *Chironomus staegeri*. Aquatic Toxicology 44:255-262.

17 Crane, J.L. 1996. Carcinogenic human health risks associated with consuming contaminated fish from five great lakes areas of concern. Journal of Great Lakes Research 22(3):653-668.

1 Crecelius, E., B. Lasora, L. Lefkovits, P.F. Landrum, and B. Barrick. 1994. Chapter 5: Chemical Analyses. *In*: Assessment and Remediation of Contaminated Sediments (ARCS) Program: Assessment Guidance Document. EPA 905-B94-002. Great Lakes National Program Office. United States Environmental Protection Agency. Chicago, Illinois. pp. 69-85.

2 Curry, L.L. 1962. A survey of environmental requirements for the midge (Diptera: Tendipedidae). *In*: Biological Problems in Water Pollution, 3rd seminar. C.M. Tarzwell (Ed.). 999-WP-25. United States Public Health Service Publication. pp. 127-141.

16 Cushing, B.S. 1999. State of current contaminated sediment management practices. Applied Environmental Management, Inc. 32 pp.

3 Cushman, R.M. 1984. Chironomid deformities as indicators of pollution from a synthetic, coal-derived oil. Freshwater Biology 14:179-182.

2, 10 Davenport, R. and A. Spacie. 1991. Acute phototoxicity of harbor and tributary sediments from lower Lake Michigan. Journal of Great Lakes Research 17:51-56.

2 Davis, R.B., Bailer, A.J., and J.T. Oris. 1998. Effects of organism allocation on toxicity test results. Environmental Toxicology and Chemistry 17:928-931.

2 Day, K.E., R.S. Kirby, and T.B. Reynoldson. 1995. The effect of manipulations of freshwater sediments on responses of benthic invertebrates in whole-sediment toxicity tests. Environmental Toxicity and Chemistry 14(8):1333-1343.

2, 3 Day, K.E., B.J. Dutka, K.K. Kwan, N. Batista, T.B. Reynoldson, and J.L. Metcalfe-Smith. 1995. Correlations between solid-phase microbial screening assays, whole-sediment toxicity tests with macroinvertebrates and *in situ* benthic community structure. Journal of Great Lakes Research 21:192-206.

2 DeFoe, D.L and G.T. Ankley. 1998. Influence of storage time on toxicity of freshwater sediments to benthic macroinvertebrates. Environmental Pollution 99:123-131.

2 DeWitt, T.H., G.R. Ditsworth, and R.C. Swartz. 1988. Effects of natural sediment features on the phoxocephalid amphipod, *Rhepoxynius abronius*: Implications for sediment toxicity bioassays. Marine Environment Research 25:99-124.

2 DeWitt, T.H., R.C. Swartz, and J.O. Lamberson. 1989. Measuring the acute toxicity of estuarine sediments. Environmental Toxicology and Chemistry 8:1035-1048.

2, 6 DeWitt, T.H., R.C. Swartz, D.J.Hansen, D. McGovern and W.J. Berry. 1996. Interstitial metal and acid sulfide indicate the bioavailability of cadmium during an amphipod life cycle sediment toxicity test. Environmental Toxicology and Chemistry 15:2095-2101.

2, 7 Di Toro, D.M., J. Mahony, D.J. Hansen, K.J. Scott, M.B. Hicks, S.M. Mayr, and M. Redmond. 1990. Toxicity of cadmium in sediments: The role of acid volatile sulfides. Environmental Toxicology and Chemistry 9:1487-1502.

2, 7 Di Toro, D.M., J. Mahony, D.J. Hansen, K.J. Scott, A.R. Carlson, and G.T. Ankley. 1991a. Acid volatile sulfide predicts the acute toxicity of cadmium and nickel in sediments. Environmental Science and Technology 26:96-101.

7 Di Toro, D.M., C.S. Zarba, D.J. Hansen, W.J. Berry, R.C. Swartz, C.E. Cowan, S.P. Pavlou, H.E. Allen, N.A. Thomas, and P.R. Paquin. 1991b. Technical basis for establishing sediment quality criteria for nonionic organic chemicals using equilibrium partitioning. Environmental Toxicology and Chemistry 10:1541-1583.

1, 7 Di Toro, D.M., J. Mahony, D.J. Hansen, and W.J. Berry. 1996. A model of the oxidation of iron and cadmium sulfide in sediments. Environmental Toxicology and Chemistry 15:2168-2186.

3 Dickman, M. I. Brindle, and M. Benson. 1992. Evidence of teratogens in sediments of the Niagara River watershed as reflected by Chironomid (Diptera: Chironomidae) deformities. Journal of Great Lakes Research 18:467-480.

12 Dickson, K.L., Maki, A.W., and W.A. Brungs. 1987. Fate and effects of sediment - bound chemicals in aquatic systems. Pergamon Press. New York, New York.

3 Diggins, T.P.,and K.M. Stewart. 1993. Deformities of aquatic larval midges (Chironomidae: Diptera) in the sediments of the Buffalo River, New York. Journal of Great Lakes Research 19:648-659.

2, 3 Dillon, T.M. and A.B. Gibson. 1990. Review and synthesis of bioassessment methodologies for freshwater contaminated sediments: Final Report. Miscellaneous Paper EL-90-2. United States Army Engineer Waterways Experiment Station. Vicksburg, Mississippi.

2 Ditsworth, G.R., D.W. Schults, and J.K.P. Jones. 1990. Preparation of benthic substrates for sediment toxicity testing. Environmental Toxicology and Chemistry 9:1523-1529.

16 Doody, P. 1999. Advantages and disadvantages of remediation technologies for contaminated sediments. Blasland, Bouck and Lee. 10 pp.

10 Dwyer, F.J., E.L. Brunson, T.J. Canfield, C.G. Ingersoll, and N.E. Kemble. 1997. An assessment of sediments from the Upper Mississippi river. EPA/823/R-97/005. United States Environmental Protection Agency. Washington, District of Columbia.

1,5 Eadie, B.J., P.F. Landrum, and W.R. Faust. 1982. Polycyclic aromatic hydrocarbons in sediments, pore water, and the amphipod *Pontoporeia hoyi* from Lake Michigan. Chemosphere 11:847-858.

1 Eadie, B.J. 1984. Chapter 9: Distribution of polycyclic aromatic hydrocarbons in the Great Lakes. *In*: Toxic Contaminants in the Great Lakes, Volume 14. J.O. Nriagu and M.S. Simmons (Eds.). John Wiley and Sons. New York. pp. 195-211.

1, 13 Eadie, B.J., R.L. Chambers, W.S. Gardner, and G.L. Bell. 1984. Sediment trap studies in Lake Michigan: Resuspension and chemical fluxes in the southern basin. Journal of Great Lakes Research 10(3):307-321.

13 Eadie, B.J. and J.A. Robbins. 1987. The role of particulate matter in the movement of contaminants in the Great Lakes. *In*: Advances in Chemistry Series No. 216: Sources and Fates of Aquatic Pollutants. pp. 319-364.

1, 2, 13 Eadie, B.J., T.F. Nalepa, and P.F. Landrum. 1988. Toxic contaminants and benthic organisms in the Great Lakes: Cycling, fate and effects. *In*: Toxic Contamination in Large Lakes, Volume I. Chronic Effects of Toxic Contaminants in Large Lakes. N.W. Schmidtke (Ed.). Lewis Publishers. Chelsea, Michigan. pp. 161-178.

1 Eadie, B.J., J.A. Robbins, W.R. Faust, and P.F. Landrum. 1991. Chapter 9: Polycyclic aromatic hydrocarbons in sediments and pore waters of the lower Great Lakes: Reconstruction of a regional benzo(a)pyrene source function. *In*: Organic Substances and Sediment in Water: Volume 2, Processes and Analytical. R. Baker (Ed.). Lewis Publishers. Chelsea, Michigan. pp. 171-189.

13 Eisenreich, S.J., P.D. Capel, J.A. Robbins, and R. Bourbonniere. 1989. Accumulation and diagenesis of chlorinated hydrocarbons in lacustrine sediments. Environmental Science and Technology 23(9):1116-1126.

2 Emery, V.L., Jr., D.W. Moore, B.R. Gray, B.M. Duke, A.B. Gibson, R.B. Wright, and J.D. Farrar. 1997. Development of a chronic sublethal sediment bioassay using the estuarine amphipod *Leptocheirus plumulosus* (shoemaker). Environmental Toxicology and Chemistry 16(9):1912-1920.

2 Environment Canada. 1997b. Biological test method: Test for growth and survival in sediment using larvae of freshwater midges (*Chironomus tentans* or *Chironomus riparius*). EPSRN32. Ottawa, Ontario.

2 Environment Canada. 1997a. Biological test method: Test for growth and survival in sediment using the freshwater amphipod *Hyalella azteca*. EPSRN33. Ottawa, Ontario.

2 Ewell, W.S., J.W. Gorsuch, R.O. Kringle, K.A. Robillard, R.C. Spiegel. 1986. Simultaneous evaluation of the acute effects of chemicals on seven aquatic species. Environmental Contamination and Toxicology 5:831-840.

5 Fahnenstiel, G. L., A. E. Krause, M. J. McCormick, H. J. Carrick, and C. L. Schelske. 1998. The structure of the planktonic food-web in the St. Lawrence Great Lakes. Journal of Great Lakes Research 24(3):531-554.

7 Field, L.J., D.D. MacDonald, S.B. Norton, C.G. Severn, and C.G. Ingersoll. 1999. Evaluating sediment chemistry and toxicity data using logistic regression modeling. Environmental Toxicology and Chemistry 18(6):1311-1322.

2 Fisher, S.W., M.J. Lydy, J. Barger, and P.F. Landrum. 1993. Quantitative structure-activity relationships for predicting the toxicity of pesticides in aquatic systems with sediment. Environmental Toxicology and Chemistry 12:1307-1318.

9 Flannagan, J.F. 1970. Efficiencies of various grabs and corers in sampling freshwater benthos. Journal of the Fisheries Research Board of Canada 27:1691-1970.

1, 2, 3, 9 Fox, R., P.F. Landrum, and L. McCrone. 1994. Chapter 1: Introduction. *In*: Assessment and Remediation of Contaminated Sediments (ARCS) Program: Assessment Guidance Document. EPA 905-B94-002. Great Lakes National Program Office. United States Environmental Protection Agency. Chicago, Illinois. pp. 1-9.

1 Gardner, W.S., W.A. Frez, E.A. Chichocki, and C.C. Parrish. 1985. Micromethods for lipids in aquatic invertebrates. Limnology and Oceanography 30:1099-1105.

15 George, J. 1999. Measuring effectiveness of remedial actions against remedial action objectives at contaminated sediment sites. ALCOA, Inc. 9 pp.

2 Giesy, J.P., R.L. Graney, J.L. Newsted, C.J. Rosiu, A. Brenda, R.G. Kreis, Jr., and F.J. Horvath. 1988. Comparison of three sediment bioassay methods using Detroit River sediments. Environmental Toxicology and Chemistry 7:483-498.

2 Giesy, J.P. and R.A. Hoke. 1989. Freshwater sediment toxicity bioassessment: Rationale for species selection and test design. Journal of Great Lakes Research 15(4):539-569.

2 Giesy, J.P. C.J. Rosiu, R.L. Graney, and M.G. Henry. 1990. Benthic invertebrate bioassays with toxic sediment and pore water. Environmental Toxicology and Chemistry 9:233-248.

5 Gobas, F.A.P.C., D.C. Bedard, J.J.H. Ciborowski, and G.D. Haffner. 1989. Bioaccumulation of chlorinated hydrocarbons by the mayfly (*Hexagenia limbata*) in Lake St. Clair. Journal of Great Lakes Research 15:581-588.

7 Gries, T.H. and K.H. Waldow. 1996. 1994 Amphipod and echinoderm larval AETs. *In*: Progress Re-evaluating Puget Sound Apparent Effects Thresholds (AETs). Volume I. Puget Sound Dredged Disposal Analysis (PSDDA) agencies, United States Army Corps of Engineers - Seattle District, United States Environmental Protection Agency - Region 10, and Washington Departments of Ecology and Natural Resources. 82 pp. + appendices.

6 Hamelink, J.L., P.F. Landrum, H.L. Bergmann, and W.H. Benson. 1994. Bioavailability: Physical, chemical and biological interactions. Lewis Publishers. Boca Ration, Florida.

3 Hamilton, A.L. and O.A. Saether. 1971. The occurrence of characteristic deformities in the Chironomid larvae of several Canadian lakes. Can. Int. 103:363-368.

2, 6, 7, 11 Hansen, D.J., J.D. Mahony, W.J. Berry, S.J. Benyi, J.M. Corbin, S.D. Pratt, and M.B. Abel. 1996. Chronic effect of cadmium in sediments on colonization by benthic marine organisms: An evaluation of the role of interstitial cadmium and acid volatile sulfide in biological availability. Environmental Toxicology and Chemistry 15:2126-2137.

2,7 Hansen, D.J., W.J. Berry, J.D. Mahony, W.S. Boothman, D.M. DiToro, D.L. Robson, G.T. Ankley, D.Ma, D. Yan, and C.E. Pesch. 1996. Predicting the toxicity of metal-contaminated field sediments using interstitial concentration of metal and acid volatile sulfide normalizations. Environmental Toxicology and Chemistry 15(12):2080-2094.

3 Hare, L. and J.C.H. Carter. 1976. The distribution of *Chironomus cucini* (salinarius group) larvae (Diptera: Chironomidae) in Parry Sound, Georgian Bay, with

particular reference to structural deformities. Canadian Journal of Zoology 54:2129-2134.

2, 5, 7 Hare, L., R. Carignan, and M.A. Huerta-Diaz. 1994. An experimental study of metal toxicity and accumulation by benthic invertebrates: Implications for the acid volatile sulfide (AVS) model. Limnology and Oceanography. 39:1653-1668.

5 Hare, L. and A. Tessier. 1996. Predicting animal cadmium concentrations in lakes. Nature 380 (April 4, 1996): 430-431.

3 Hare, L. and A. Tessier. 1998. The aquatic insect *Chaoborus* as a biomonitor of trace metals in lakes. Limnology and Oceanography 43(8):1850-1859.

2 Harkey, G.A., P.F. Landrum, and S.J. Klaine. 1994a. Comparison of whole-sediment, elutriate and pore water exposures for use in assessing sediment-associated organic contaminants in bioassays. Environmental Toxicology and Chemistry 13:1315-1329.

2 Harkey, G.A., P.F. Landrum, and S.J. Klaine. 1994b. Preliminary studies on the effect of feeding during whole sediment bioassays using *Chironomus riparius* larvae. Chemosphere 28(3):597-606.

5 Harkey, G.A., S. Kane Driscoll, and P.F. Landrum. 1997. Effect of feeding in 30-day bioaccumulation assays using *Hyalella azteca* in fluoranthene-dosed sediment. Environmental Toxicology and Chemistry 16:762-769.

2, 5 Harrahy, E.A. and W.H. Clements. 1997. Toxicity and bioaccumulation of a mixture of heavy metals in *Chironomus tentans* (Diptera: Chironomidae) in synthetic sediment. Environmental Toxicology and Chemistry 16(2):317-327.

2, 5 Hart, B.A. and B.D. Scaife. 1977. Toxicity and bioaccumulation of cadmium in *Chlorella pyrenoidosa.* Environmental Research 14:401-413.

3 Hilsenhoff, W.L. 1982. Using a biotic index to evaluate water quality in streams. Technical Bulletin No.132. Department of Natural Resources. Madison, Wisconsin.

3 Hilsenhoff, W.L. 1987. An improved biotic index of organic stream pollution. Great Lakes Entomology 20:31-39.

10 Hoke, R.A., J.P. Giesy, G.T. Ankley, J.L. Newsted, and R.J. Adams. 1990. Toxicity of sediments from western Lake Erie and the Maumee River at Toledo, Ohio, 1987: Implications for current dredged material disposal practices. Journal of Great Lakes Research 16:457-470.

2, 7 Hoke, R.A., G.T. Ankley, A.M. Cotter, T. Goldenstein, P.A. Kosian, G.L. Phipps, and F.M. VanderMeiden. 1994. Evaluation of equilibrium partitioning theory for predicting acute toxicity of field-collected sediments contaminated with DDT, DDE and DDD to the amphipod *Hyalella azteca*. Environmental Toxicology and Chemistry 13:157-166.

7 Hoke, R.A., G.T. Ankley and J.F. Peters. 1995. Use of a freshwater sediment quality database in an evaluation of sediment quality criteria based on equilibrium partitioning and screening-level concentrations. Environmental Toxicology and Chemistry14:451-459.

7 Hoke, R.A., P.A. Kosian, G.T. Ankley, A.M. Cotter, F.M. Vandermeiden, G.L. Phipps, and E.J. Durhan. 1995. Studies with *Hyalella azteca* and *Chironomus tentans* in support of the development of a sediment quality criterion for dieldrin. Environmental Toxicology and Chemistry 14:435-443.

7 Hoke, R.A., G.T. Ankley, P.A. Kosian, A.M. Cotter, F.M. VanderMeiden, M. Balcer, G.L. Phipps, C.W. West, and J.S. Cox. 1997. Equilibrium partitioning as the basis for an integrated laboratory and field assessment of the impacts of DDT, DDE and DDD in sediments. Ecotoxicology 6:101-125.

9 Howmiller, R.P. 1971. A comparison of the effectiveness of Eckman and ponar grabs. Transactions of the American Fisheries Society 100:560-564.

3, 10 Howmiller, R.P., A.M. Beeton. 1971. Biological evaluation of environmental quality, Green Bay, Lake Michigan. Journal of Water Pollution Control Federation 43:123-133.

2 Ingersoll, C.G., and M.K. Nelson. 1990. Testing sediment toxicity with *Hyalella azteca* (Amphipoda) and *Chironomus riparius* (Diptera). *In*: Aquatic Toxicology and Risk Assessment, 13th Volume. ASTM STP 1096. W.G. Landis and W.H. van der Schalie (Eds.). Conshohocken, Pennsylvania. pp. 93-109.

2 Ingersoll, C.G., F.J. Dwyer, and T.W. May. 1990. Toxicity of inorganic and organic selenium to *Daphnia magna* (Cladocera) and *Chironomus riparius* (Diptera). Environmental Toxicology and Chemistry 9:1171-1181.

2, 3 Ingersoll, C.G., D.R. Buckler, E.A. Crecelius, and T.W. LaPoint. 1993. Assessment and remediation of contaminated sediment (ARCS) project: Biological assessment of contaminated Great Lakes sediment. Battelle final Report. EPA-905-R93-006. Prepared by the United States Fish and Wildlife Service. Prepared for the Great Lakes National Program Office. United States Environmental Protection Agency. Chicago, Illinois.

2, 5 Ingersoll, C.G., G.T. Ankley, D.A. Benoit, E.L. Brunson, G.A. Burton, F.J. Dwyer, R.A. Hoke, P.F. Landrum, T.J. Norberg-King, and P.V. Winger. 1995. Toxicity and bioaccumulation of sediment-associated contaminants using freshwater invertebrates: A review of methods and applications. Environmental Toxicology and Chemistry14(11):1885-1894.

2, 7 Ingersoll, C.G., P.S. Haverland, E.L. Brunson, T.J. Canfield, F.J. Dwyer, C.E. Henke, and N.E. Kemble. 1996. Calculation and evaluation of sediment effect concentrations for the amphipod *Hyalella azteca* and the midge *Chironomus riparius*. Journal Great Lakes Research 22:602-623.

1, 2, 3, 4, 5 Ingersoll, C.G., T.Dillon, and G.R. Biddinger (Eds.). 1997. Ecological risk assessment of contaminated sediments. SETAC Special Publications Series. SETAC Press. Pensacola, Florida.

2 Ingersoll, C.G., E.L. Brunson, F.J. Dwyer, D.K. Hardesty, and N.E. Kemble. 1998. Use of sublethal endpoints in sediment toxicity tests with the amphipod *Hyalella azteca.* Environmental Toxicology and Chemistry 17(8):1508-1523.

1, 2, 3, 9 International Joint Commission. 1988. Procedures for the assessment of contaminated sediment problems in the Great Lakes. Report to the Great Lakes Water Quality Board. Sediment Subcommittee and its Assessment Work Group. Great Lakes Regional Office. Windsor, Ontario.

7 Jaagumagi, R. 1992a. Development of the Ontario provincial sediment quality guidelines for arsenic, cadmium, chromium, copper, iron, lead, manganese, mercury, nickel, and zinc. Ontario Ministry of Environment. Toronto, Ontario. 46 pp.

7 Jaagumagi, R. 1992b. Development of the Ontario provincial sediment quality guidelines for PCBs and the organochlorine pesticides. Ontario Ministry of Environment. Toronto, Ontario. 82 pp.

7 Jaagumagi, R. 1993. Development of the Ontario provincial sediment quality guidelines for polycyclic aromatic hydrocarbons (PAH). Ontario Ministry of Environment. Toronto, Ontario. 79 pp.

5 Jarvinen, A.W. and G.T. Ankley. 1999. Linkage of effects to tissue residues: Development of a comprehensive database for aquatic organisms exposed to inorganic and organic chemicals. SETAC Press. Pensacola, Florida.

13 Jeremiason, J. D., S. J. Eisenreich, J. E. Baker, and B. J. Eadie. 1998. PCB decline in settling particles and benthic recycling of PCBs and PAHs in Lake Superior. Environmental Science and Technology 32:3249-3256.

2 Johnson, B.T. and E.R. Long. 1998. Rapid toxicology assessment of sediments from estuarine ecosystems: A new tandem *in vitro* testing approach. Environmental Toxicology and Chemistry 17(6):1099-1106.

2, 10 Jones, R.A. and G.F. Lee. 1988. Toxicity of U.S. waterway sediments with particular reference to the New York Harbor area. *In*: Chemical and Biological Characterization of Sludges, Sediments, Dredge Spoils, and Drilling Muds. J.J. Lichtenburg, F.A. Winter, C.I. Weber, and L. Fradkin, (Eds.). STP 976. American Society for Testing and Materials. Philadelphia, Pennsylvania. pp. 403-417.

5 Kaag, N.H., E.M.. Foekema, M.C. Scholten, and N.M. van Straalen. 1997. Comparison of contaminant accumulation in three species of marine invertebrates with different feeding habits. Environmental Toxicology and Chemistry 16(5):837-842.

2, 5, 11 Kane Driscoll, S. and P.F. Landrum. 1997. A comparison of equilibrium partitioning and critical body residue approaches for predicting toxicity of sediment-associated fluoranthene to freshwater amphipods. Environmental Toxicology and Chemistry 16(10):2179-2186.

2, 5, 11 Kane Driscoll, S., G.A. Harkey, and P.F. Landrum. 1997. Accumulation and toxicokinetics of fluoranthene in sediment bioassays with freshwater amphipods. Environmental Toxicology and Chemistry 16(4):742-753.

2, 5, 11 Kane Driscoll, S., P.F. Landrum and E. Tigue. 1997. Accumulation and toxicokinetics of fluoranthene in water-only exposures with freshwater amphipods. Environmental Toxicology and Chemistry 16(4):754-761.

1 Kates, M. 1986. Techniques of Lipidology (Isolation, Analysis, and Identification of Lipids). 2nd revised edition. Elsevier Science Publishing Company. New York. 464 pp.

15 Keenan, R.E., P.D. Anderson, W.R. Alsop, and J.H. Samuelian. 1999. Risk-based management principles for evaluating sediment management options. 23 pp.

2 Kemble, N.E., E.L. Brunson, T.J. Canfield, F.J. Dwyer, and C.G. Ingersoll. 1998. Assessing sediment toxicity from navigational pools of the upper Mississippi River using a 28-d *Hyalella azteca* test. Archives of Environmental Contamination and Toxicology 35:181-190.

2, 11 Kemble, N.E., F.J. Dwyer, C.G. Ingersoll, T.D. Dawson, and T.J. Norberg-King. 1999. Tolerance of freshwater test organisms to formulated sediments for use as control materials in whole-sediment toxicity tests. Environmental Toxicology and Chemistry 18(2):222-230.

3 Kennedy, C.R. 1965. The distribution and habitat of *Limnodrilus claparede* and its adaptive significance. Oikos 16:26-28.

2, 11 Kielty, T.J., D.S White, and P.F. Landrum. 1988a. Short-term lethality and sediment avoidance assays with endrin-contaminated sediment and two oligochaetes from Lake Michigan. Archives of Environmental Contamination and Toxicology 17:95-101.

2, 10 Kreis, R.G. 1988. Integrated study of exposure and biological effects of in-place sediment pollutants in the Detroit River, Michigan: An upper Great Lakes connecting channel. Final Report. Office of Research and Development. United States Environmental Protection Agency. Environmental Research Laboratory - Duluth, Minnesota, and LLRS-Grosse Ile, Michigan. 153 pp.

2, 11 Kubitz, J.A., E.C. Lewek, J.M. Besser, J.B. Drake III, and J.P. Giesy. 1995. Effects of copper-contaminated sediments on *Hyalella azteca*, *Daphnia magna*, and *Ceriodaphnia dubia*: Survival, growth, and enzyme inhibition. Archives of Environmental Contamination and Toxicology 29:97-103.

2 Kubitz, J.A., J.M. Besser, and J.P. Giesy. 1996. A two-step experimental design for a sediment bioassay using growth of amphipod *Hyalella azteca* for the test endpoint. Environmental Toxicology and Chemistry 15(10):1783-1792.

2, 6, 13 Kukkonen, J. and P.F. Landrum. 1994a. Effects of sediment-bound polydimethylsiloxane on the bioavailability and distribution of benzo(a)pyrene in lake sediment to *Lumbriculus variegatus*. Environmental Toxicology and Chemistry 14:523-531.

2, 5, 11 Kukkonen, J. and P.F. Landrum. 1994b. Toxicokinetics and toxicity of sediment bound pyrene in *Lumbriculus variegatus* (Oligochaeta). Environmental Toxicology and Chemistry 13:1457-1468.

2, 6, 11 Kukkonen, J.V.K. and P.F. Landrum. 1998. Effect of particle-xenobiotic contact time on bioavailability of sediment-associated benzo(a)pyrene by benthic amphipod, *Diporeia* spp. Aquatic Toxicology 42:229-242.

2 Lacey, R, M.C. Watzin, and A.W. McIntosh. 1998. Sediment organic matter content as a confounding factor in toxicity tests with *Chironomus tentans*. Environmental Toxicology and Chemistry 18(2):231-236.

6, 7 Lake, J.L., N.I. Rubinstein, H. Lee II, C.A. Lake, J. Heltshe, and S. Pavignano. 1990. Equilibrium partitioning and bioaccumulation of sediment-associated contaminants by infaunal organisms. Environmental Toxicology and Chemistry 9:1095-1106.

11 Lamberson, J.O. and R.C. Swartz. 1992a. Spiked-sediment toxicity test approach. *In*: Sediment Classification Methods Compendium. EPA-823-R-92-006. United States Environmental Protection Agency. Washington, District of Columbia. pp. 4-1 to 4-10.

2, 11 Lamberson, J.O. and R.C. Swartz. 1992b. Use of bioassays in determining the toxicity of sediment to benthic organisms. *In*: Toxic Contaminants and Ecosystem Health: A Great Lakes Focus. M.S. Evans (Ed.). John Wiley and Sons. New York, New York. pp. 257-279.

17 Landis, W.G., A.J. Markiewicz, and V. Wilson. 1997. Recommended guidance and checklist for Tier 1 ecological risk assessment for contaminated sites in the Great Lakes. Prepared for British Columbia. Ministry of Environment, Lands and Parks. Victoria, British Columbia

5, 6 Landrum, P.F. and D. Scavia. 1983. Influence of sediment on anthracene uptake, depuration, and biotransformation by the amphipod, *Hyalella azteca*. Canadian Journal of Fisheries and Aquatic Sciences 40:298-305.

6 Landrum, P.F., S.R. Nihart, B.J. Eadie, and L.R. Herche. 1987. Reduction in bioavailability of organic contaminants to the amphipod *Pontoporeia hoyi* by dissolved organic matter of sediment interstital waters. Environmental Toxicology and Chemistry 6:11-20.

2, 5, 6 Landrum, P.F. 1989. Bioavailability and toxicokinetics of polycyclic aromatic hydrocarbons sorbed to sediments for the amphipod, *Pontoporeia hoyi*. Environmental Science and Technology 23:588-595.

2, 6, 11 Landrum, P.F., W.R. Faust, and B.J. Eadie. 1989. Bioavailability and toxicity of a mixture of sediment associated chlorinated hydrocarbons to the amphipod, *Pontoporeia hoyi*. *In*: Aquatic Toxicology and Hazard Assessment: Twelfth Symposium. U.M. Cowgill and L.R. Williams (Eds.). ASTM STP 1027. Conshohocken, Pennsylvania. pp. 315-329.

6 Landrum, P.F. and J.A. Robbins. 1990. Chapter 8: Bioavailability of sediment-associated contaminants to benthic invertebrates. *In*: Sediments: Chemistry and Toxicity of In-Place Pollutants. R. Baudo, J.P. Giesy, and H. Muntau (Eds.). Lewis Publishers. Ann Arbor, Michigan.

6 Landrum, P.F., B.J. Eadie, and W.R. Faust. 1992. Variation in the bioavailability of polycyclic aromatic hydrocarbons to the amphipod *Diporeia* (spp.) with sediment aging. Environmental Toxicology and Chemistry 11:1197-1208.

6, 11 Landrum, P.F. and W.R. Faust. 1994. The role of sediment composition on the bioavailability of laboratory-dosed sediment-associated organic contaminants to the amphipod, *Diporeia* (spp.). Chemical Speciation and Bioavailability 6:85-92.

2, 6, 11 Landrum, P.F., W.S. Dupuis and J. Kukkonen. 1994. Toxicokinetics and toxicity of sediment-associated pyrene and phenanthrene in *Diporeia* spp.: Examination of equilibrium partitioning theory and residue based effects for assessing hazard. Environmental Toxicology and Chemistry 13:1769-1780.

7 Landrum, P.F. 1995. How should numerical sediment quality criteria be used? Human and Ecological Risk Assessment 1(1):13-17.

5 Landrum, P.F., G.A. Harkey, and J. Kukkonen. 1996. Evaluation of organic contaminant exposure in aquatic organisms: The significance of bioconcentration and bioaccumulation. *In*: Ecotoxicology: A Hierarchial Treatment. M.C. Newman and C. H. Jogoe (Eds.). CRC Press. Lewis Publishers. Boca Raton, Florida. pp. 85-131.

6 Landrum, P.F., D.C. Gossiaux, and J. Kukkonen. 1997. Sediment characteristics influencing the bioavailability of nonpolar organic contaminants to *Diporeia* spp. Chemical Speciation and Bioavailability 9:43-55.

5 Landrum, P.F. 1998. Kinetic models for assessing bioaccumulation. Proceedings of the National Sediment Bioaccumulation Conference. United States Environmental Protection Agency. pp. 47-50.

5 Landrum, P.F. and S.W. Fisher. 1998. Influence of lipids on the bioaccumulation and trophic transfer of organic contaminants in aquatic organisms. *In*: The Ecological Role of Lipids in Freshwater Ecosystems. M.T. Arts and B.C. Wainman (Eds). Springer-Verlang, New York. pp. 203-234.

13 Lang, G.A. and T.D. Fontaine. 1990. Modeling the fate and transport of organic contaminants in Lake St. Clair. Journal of Great Lakes Research 16(2):216-232.

3 Lauritsen, D.D., S.C. Mozley, and D.S. White. 1985. Distribution of oligochaetes in Lake Michigan and comments on their use as indices of pollution. Journal of Great Lakes Research 11:67-76.

5 Lee, H. II, B.L. Boese, J. Pelletier, M. Windsor, D.T. Specht, and R.C. Randall. 1989. Guidance manual: Bedded sediment bioaccumulation tests. 600/X-89/302. United States Environmental Protection Agency.

5 Lee, H. II. 1992. Models, muddles, and mud: Predicting bioaccumulation of sediment-associated pollutants. *In*: Sediment Toxicity Assessment. G.A. Burton Jr. (Ed.). Lewis publishers. pp. 267-293.

3 Lenat, D.R. 1993. A biotic index for the southeastern United States derivation and list of tolerance values, with criteria for assigning water-quality ratings. Journal of the North American Benthological Society 12:279-290.

1 Leonard, E.N., A.M. Cotter, and G.T. Ankley. 1996. Modified diffusion method for analysis of acid volatile sulfides and simultaneously extracted metals in freshwater sediment. Environmental Toxicology and Chemistry 15(9):1479-1481.

2 Liber, K., D.J. Call, T.D. Dawson, F.W. Whiteman, and T.M. Dillon. 1996. Effects of *Chironomus tentans* larval growth retardation on adult emergence and ovipositing success: Implications for interpreting freshwater sediment bioassays. Hydrobiologia 323:155-167.

13 Lick, W. 1980. The transport of contaminants in the Great Lakes. GLERL Open File Report. Great Lakes Environmental Research Laboratory. Ann Arbor, Michigan. 48 pp.

4 Long, E.R. and P.M. Chapman. 1985. A sediment quality triad: Measures of sediment contamination, toxicity and infaunal community composition in Puget Sound. Marine Pollution Bulletin 16:405-415.

2 Long, E.R., M.F. Buchman, S.M. Bay, R.J. Breteler, R.S. Carr, P.M. Chapman, J.E. Hose, A.L. Lissner, J. Scott, and D.A. Wolfe. 1990. Comparative evaluation of five toxicity tests with sediments from San Francisco Bay and Tomales Bay, California. Environmental Toxicology and Chemistry 9:1193-1214.

1, 2 Long, E.R. and L.G. Morgan. 1991. The potential for biological effects of sediment-sorbed contaminants tested in the national status and trends program. NOS OMA 52. National Oceanic and Atmospheric Administration. Technical Memorandum. Seattle, Washington.

7 Long, E.R., D.D. MacDonald, S.L. Smith, and F.D. Calder. 1995. Incidence of adverse biological effects within ranges of chemical concentrations in marine and estuarine sediments. Environmental Management 19(1):81-97.

2, 3 Long, E.R. 1997. The use of biological measures in assessments of toxicants in the coastal zone. Sustainable Development in the Southeastern Coastal Zone. F.J. Vernberg, W.B. Vernberg, T. Siewicki (Eds.). University of South Carolina Press. Columbia, South Carolina pp. 187-219.

4 Long, E.R. and C.J. Wilson. 1997. On the identification of toxic hot spots using measures of the sediment quality triad. Marine Pollution Bulletin 34:373-374.

2 Long, E.R., A. Robertson, D.A. Wolfe, J. Hameedi, and G.M. Sloane. 1997. Estimates of the spatial extent of sediment toxicity in major U.S. estuaries. Environmental Science and Technology 30: 3585-3592.

1, 2 Long, E.R. 1998. Sediment quality assessments: Selected issues and results from the NOAA's National Status and Trends Program. *In*: Ecological Risk Assessment: A Meeting of Policy and Science. A. dePeyster and K. Day (Eds.). SETAC Press. Pensacola, Florida. pp. 111-132.

2, 10 Long, E.R and K.A. Dzinbal. 1998. Toxicity of sediments in Northern Puget Sound: A national perspective. *In*: Puget Sound Research '98 Proceedings, Washington State Convention and Trade Center. Seattle, Washington. March 12 and 13, 1998. Puget Sound Water Quality Action Team. Olympia, Washington. 302-311.

7 Long, E.R. and D.D. MacDonald. 1998. Perspective: Recommended uses of empirically derived, sediment quality guidelines for marine and estuarine ecosystems. Human and Ecological Risk Assessment 4(5):1019-1039.

7 Long, E.R., L.J. Field, and D.D. MacDonald. 1998. Predicting toxicity in marine sediments with numerical sediment quality guidelines. Environmental Toxicology and Chemistry 17(4):714-727.

7 Long, E.R., D.D. MacDonald, J.C. Cubbage, and C.I. Ingersoll. 1998. Predicting the toxicity of sediment-associated trace metals with simultaneously extracted trace metal: Acid volatile sulfide concentrations and dry weight-normalized concentrations: A critical comparison. Environmental Toxicology and Chemistry 17:972-974.

1, 2 Long, E.R. 2000. Degraded sediment quality in U.S. estuaries: A review of magnitude and ecological implications. Ecological Applications 10(2): 338-349.

13 Lou, J., D. J. Schwab, and D. Beletsky. 1999. Suspended sediment transport modeling in Lake Michigan. Canadian Coastal Conference 1999. Victoria, British Columbia, Canada. May 19-22, 1999. pp. 391-405.

2 Long, E.R. 2000. Spatial extent of sediment toxicity in US estuaries and marine bays. Environmental Monitoring 64:391-407.

10 Lorenzato, S.G., A.J. Gunther, and J.M. O'Conner (Eds.). 1991. Summary of a workshop concerning sediment quality assessment and development of sediment

quality objectives. California State Water Resources Control Board, Sacramento, California. 32 pp. + appendices.

9 Lubin, A.N., M.H. Williams, and J.C. Lin. 1995. Statistical techniques applied to sediment sampling (STASS). United States Environmental Protection Agency, Region V. Chicago, Illinois.

7 MacDonald, D.D., S.L. Smith, M.P. Wong, and P. Mudroch. 1992. The development of Canadian marine environmental quality guidelines. Ecosystem Sciences and Evaluation Directorate. Conservation and Protection. Environment Canada. Ottawa, Ontario. 32 pp. + appendices

7 MacDonald, D.D. and A. Sobolewski. 1993. Recommended procedures for developing site-specific environmental quality remediation objectives for contaminated sites in Canada. National Contaminated Sites Remediation Program. Canadian Council of Ministers of the Environment. Ottawa, Ontario. 199 pp.

7 MacDonald, D.D., A. White, B. Charlish, M.L. Haines, and T. Wong. 1993. Compilation of toxicological information on sediment-associated contaminants and the development of freshwater sediment quality guidelines. Prepared for Environment Canada. 24 pp.

7 MacDonald, D.D. 1994. Approach to the assessment of sediment quality in Florida coastal waters. Volume 2 - Application of the sediment quality assessment guidelines. Prepared for Florida Department of Environmental Protection. Tallahassee, Florida.

1, 2, 3, 7 MacDonald, D.D. 1995. Science advisory group workshop on sediment assessment in Tampa Bay: Summary Report. Prepared for the Tampa Bay National Estuary Program. St. Petersburg, Florida.

7 MacDonald, D.D., R.S. Carr, F.D. Calder, E.R. Long, and C.G. Ingersoll. 1996. Development and evaluation of sediment quality guidelines for Florida coastal waters. Ecotoxicology 5:253-278.

7 MacDonald, D.D., C.G. Ingersoll, and T.A. Berger. 2000. Development and evaluation of consensus-based sediment quality guidelines for freshwater ecosystems. Archives of Environmental Contamination and Toxicology 39:20-31

7 MacDonald, D.D., L.M. DiPinto, J. Field, C.G. Ingersoll, E.R. Long, and R.C. Swartz. 2000. Development and evaluation of consensus-based sediment effect concentrations for polychlorinated biphenyls (PCBs). Environmental Toxicology and Chemistry 19(5):1403-1413.

6, 7 Mahony, J.D., D.M. DiToro, R. Koch, W.J. Berry, and D.J. Hansen. 1993. Vertical distribution of AVS and SEM in bedded sediments: Biological implications and the role of metal sulfide oxidation kinetics. Abstracts: 14th Annual Meeting. Society of Environmental Toxicology and Chemistry. Houston, Texas. November 14-18. p. 46.

13 Matisoff, G. and J.A. Robbins. 1987. A model for biological mixing of sediments. Journal of Geological Education 35(3):144-149.

7 Maund, S., I. Barber, J. Dulka, J. Gonzalez-Valero, M. Hamer, F. Heimbach, M. Marshall, P. McCahon, H. Staudenmaier, and D. Wustner. 1997. Development and evaluation of triggers for sediment toxicity testing of pesticides with benthic macroinvertebrates. Environmental Toxicology and Chemistry 16(12):2590-2596.

2, 5, 6 McCarty, L.S. and D. MacKay. 1993. Enhancing ecotoxicological modeling and assessment: Body residues and modes of toxic action. Environmental Science and Technology 27:1719-1728.

17 McCarty, LS and M. Power. 1997. Letter to the Editor: Environmental Risk Assessment within a decision-making framework. Environmental Toxicology and Chemistry 16(2):122-123.

2 McNulty, E.W., F.J. Dwyer, M.R. Ellersieck, E.I. Greer, C.G. Ingersoll and C.F. Rabeni. 1999. Evaluation of ability of reference toxicity tests to identify stress in laboratory populations of the amphipod *Hyalella azteca*. Environmental Toxicology and Chemistry 18(3):544-548.

5 Means, J.C. and A.E. McElroy. 1997. Bioaccumulation of tetrachlorobiphenyl and hexachlorobiphenyl by *Yoldia limatula* and *Nephtys incisa* from bedded sediments: Effects of sediment- and animal- related parameters. Environmental Toxicology and Chemistry 16: 1277-1286.

2 Mearns, A.J., R.C. Swartz, J.M. Cummins, P.A. Dinnel, P.Plesha, and P.M. Chapman. 1986. Inter-laboratory comparison of a sediment toxicity test using the marine amphipod, *Rhepoxynius abronius*. Marine Environment Research 19: 13-37.

3 Merritt, R.W. and K.W. Cummins (Eds.). 1984. An introduction to the aquatic insects of North America. Kendall/Hunt Publishing Co. 722 pp.

1, 13 Meyers, P.A., M.J. Leenheer, B.J. Eadie, and S.J. Maule. 1984. Organic geochemistry of suspended and settling particulate matter in Lake Michigan. Geochimica et Cosmochimica Acta 48:443-452.

2 Milani, D., K.E. Day, D.J. McLeary, and R.S. Kirby. 1996. Recent intra- and interlaboratory studies related to the development and standardization of Environment Canada's biological test methods for measuring sediment toxicity using freshwater amphipods (*Hyalella azteca*) or midge larvae (*Chironomus riparius*). Environment Canada. Burlington, Ontario.

9 Milbrink, G. and T. Wiederholm. 1973. Sampling efficiency of four types of mud bottom samplers. Oikos 24:479-482.

2 Moore, D.W. and T.M. Dillon. 1993. The relationship between growth and reproduction in the marine polychaete *Nereis (Neanthes) arenaceodentata* (Moore): Implications for chronic sublethal sediment bioassays. Journal of Experimental Marine Biology and Ecology 173:231-246.

2 Moore, D.W. and J.D. Farrar. 1996. Effect of growth on reproduction in the freshwater amphipod, *Hyalella azteca*. Hydrobiologia 328:127-134.

2, 9 Moore, D.W., T.M. Dillon and E.W. Gamble. 1996. Long-term storage of sediments: Implications for sediment toxicity testing. Environmental Pollution 89:341-342.

5 Munger, C. and L. Hare. 1997. Relative importance of water and food as cadmium sources to an aquatic insect (*Chaoborus punctipennis*): Implications for predicting Cd bioaccumulation in Nature. Environmental Science and Technology 31: 891-895.

5 Munger, C. and L. Hare. 2000. Influence of ingestion rate and food types on cadmium accumulation by the aquatic insect *Chaoborus*. Canadian Journal of Fisheries and Aquatic Sciences 57:327-332.

1, 3, 13 Nalepa, T.F. and P.F. Landrum. 1988. Benthic invertebrates and contaminant levels in the Great Lakes: Effects, fates, and role in cycling. *In*: Toxic Contaminants and Ecosystem Health; A Great Lakes Focus. M.S. Evans (Ed.). Wiley and Sons, Inc. New York. pp. 77-102.

2 Nebeker, A.V. M.A. Cairns, J.H. Gakstatter, K.W. Malueg, G.S. Schuytema, and D.F. Krawczyk. 1984. Biological methods for determining toxicity of contaminated freshwater sediments to invertebrates. Environmental Toxicology and Chemistry 3:617-630.

2 Nebeker, A.V. and C.E. Miller. 1988. Use of the amphipod crustacean *Hyalella azteca* in freshwater and estuarine sediment toxicity tests. Environmental Toxicology and Chemistry 7:1027-1033.

2 Nebeker, A.V., S.T. Onjukka, and M.A. Cairns. 1988. Chronic effects of contaminated sediment on *Daphnia magna* and *Chironomus tentans*. Bulletin on Environmental Contamination and Toxicology 41:574-581.

2 Nelson, M.K., P.F. Landrum, G.A. Burton, S.J. Klaine, E.A. Crecelius, T.D. Byl, D.C. Gossiaux, V.N. Tsymbal, L. Cleveland, C.G. Ingersoll, and G.Sasson-Brickson. 1993. Toxicity of contaminated sediments in dilution series with control sediments. Chemosphere 27(9):1789-1812.

5 Neumann, P.T.M., U. Borgmann, and W. Norwood. 1999. Effect of gut clearance on metal body concentrations in *Hyalella azteca*. Environmental Toxicology and Chemistry 18(5):976-984.

1 Newman, M.C. 1995. Quantitative methods in aquatic toxicology. *In*: Advances in trace substances research. Lewis Publisher. Boca Raton, Florida. pp. 196-200

7 O'Connor, T.P., K.D. Daskalakis, J.L. Hyland, J.F. Paul, and J.K. Summers. 1998. Comparisons of sediment toxicity with predictions based on chemical guidelines. Environmental Toxicology and Chemistry 17(3):468-471.

3 Ohio Environmental Protection Agency. 1988. Biological criteria for the protection of aquatic life: Volume II. Users manual for biological field assessment of Ohio surface waters. Division of Water Quality Monitoring and Assessment. Columbus, Ohio.

3 Pennak, R.W. 1989. Freshwater invertebrates of the United States: Protozoa to Mollusca. 3rd edition. John Wiley and Sons, Inc. New York, New York. 628 pp.

7 Persaud, D., R. Jaagumagi, and A. Hayton. 1989. Development of provincial sediment quality guidelines. Water Resources Branch. Ontario Ministry of the Environment. Toronto, Ontario. 19 pp.

6 Pesch, C.E., D.J. Hansen, W.S. Boothman, W.J. Berry, and J.D. Mahony. 1995. The role of acid-volatile sulfide and interstitial water metal concentrations in determining bioavailability of cadmium and nickel from contaminated sediments to the marine polychaete *Neanthes arenaceodentata*. Environmental Toxicology and Chemistry 14:129-141.

1, 13 Peterson, G.S., G.T. Ankley, and E.N. Leonard. 1996. Effect of bioturbation of metal-sulfide oxidation in surficial freshwater sediments. Environmental Toxicology and Chemistry 15:2147-2155.

16 Peterson, G., J. Wolfe, and J. DePinto. 1999. Decision tree for sediment management alternatives (printed version). Limno-Tech, Inc; The Sediment Management Work Group. 37 pp.

2, 5 Phipps, G.L., G.T. Ankley, D.A. Benoit, and V.R. Mattson. 1993. Use of the aquatic oligochaete *Lumbriculus variegatus* for assessing the toxicity and bioaccumulation of sediment-associated contaminants. Environmental Toxicology and Chemistry 12:269-274.

2 Phipps, G.L., V.R. Mattson, and G.T. Ankley. 1995. Relative sensitivity of three freshwater benthic macroinvertebrates to ten contaminants. Archives of Environmental Contamination and Toxicology 28:281-286.

1, 9 Plumb, Jr., R.H. 1981. Procedures for handling and chemical analysis of sediment and water samples. Technical committee on criteria for dredged and fill material. USEPA-USACE. EPA-4805572010. Great Lakes Laboratory. United States Environmental Protection Agency. Grosse Ile, Michigan.

1, 2, 7, 16 Porebski, L.M. and J.M. Osburne. 1998. The application of a tiered testing approach to the management of dredged sediments for disposal at sea in Canada. Chemistry and Ecology 14:197-214.

17 Power, M. and L.S. McCarty. 1997. Fallacies in ecological risk assessment practices. Environmental Science and Technology Magazine, May 1, 1998. pp. 370A-375A.

17 Power, M. and L.S. McCarty. 1998. A comparative analysis of environmental risk assessment/risk management frameworks. Environmental Science and Technology Magazine, May 1, 1998. pp. 224A-231A.

1 PTI Environmental Services. 1989a. Edited Draft Report: Data validation guidance manual for selected sediment variables (QA-2). PTI Contract C901-02. Bellevue, Washington. 178 pp.

1, 2 PTI Environmental Services. 1989b. Puget Sound dredged disposal analysis guidance manual: Data quality evaluation for proposed dredged material disposal projects (QA-1). PTI Contract C901-01. Bellevue, Washington. 112 pp.

1 Randall, R.C., H. Lee II, R.J. Ozretich, L.J. Lake, and R.J. Pruell. 1991. Evaluation of selected lipid methods for normalizing pollutant bioaccumulation. Environmental Toxicology and Chemistry 10:1431-1436.

1 Randall, R.C., D.R. Young, H.Lee II, and S.F. Echols. 1998. Lipid methodology and pollutant normalization relationships for neutral nonpolar organic pollutants. Environmental Toxicology and Chemistry 17:788-791.

13 Reible, D.D. and L.J. Thibodeaux. 1999. Using natural processes to define exposure from sediments. 29 pp.

2 Reynoldson, T.B., K.E. Day, C. Clarke, and D.Milani. 1994. Effect of indigenous animals on chronic endpoints in freshwater sediment toxicity tests. Environmental Contamination and Toxicology 13:973-977.

2, 3, 7 Reynoldson, T.B., K.E. Day, R.C. Bailey, and N.H. Norris. 1995. Methods for establishing biologically based sediment guidelines for freshwater quality management using benthic assessment of sediment. Australian Journal of Ecology 20:198-219.

1 Rice, K. C. 1999. Trace-element concentrations in streambed sediment across the conterminous United States. Environmental Science and Technology 33: 2499-2504.

1, 3, 5 Robbins, J.A., T.J. Kielty, D.S. White, and D.N. Edgington. 1989. Relationships among tubificid abundances, sediment composition and accumulation rates in Lake Erie. Canadian Journal of Fisheries and Aquatic Science 46:223-231.

1, 2, 3 Ross, P.E., G.A. Burton, Jr., E.A. Crecelius, J.C. Filkins, J.P. Giesy Jr., C.G. Ingersoll, P.F. Landrum, M.J. Mac, T.J. Murphy, J.E. Rathbun, V.E. Smith, H. Tatem, and R.W. Taylor. 1992. Assessment of sediment contamination at Great Lakes areas of concern: The ARCS program. Journal of Aquatic Ecosystem Health 1:193-200.

2 Ross,P., G.A. Burton, Jr., M. Greene, K. Ho, P. Meier, L. Sweet, A. Auwarter, A. Bispo, K. Doe, K. Erstfeld, S. Goudey, M. Goyvaerts, D. Henderson, M. Jourdain, M. Lenon, P. Pandard, A. Qureshi, C. Rowland, C. Schipper, W. Schreurs, S. Trottier, and G. Van Aggelen. 1999. Interlaboratory precision study of a whole sediment toxicity test with the bioluminescent bacterium *Vibrio fischeri*. *In*: Bioluminescence. John Wiley and Sons, Inc. pp. 339-345.

3, 5 Roy, I. and L. Hare. 1998. Eastward range extension in Canada of the alderfly Sialis Velata (Megaloptera:Sialidae), and the potential of genus as a contaminant monitor. Entomological News 109(4):285-287.

5, 6 Roy, I. and L. Hare. 1999. Relative importance of water and food as cadmium sources to the predatory insect *Sialis velata* (Megaloptera). Canadian Journal of Fisheries and Aquatic Sciences 56:1143-1149.

5 Rubinstein, N.I., J.L. Lake, R.J. Pruell, H. Lee II, B. Taplin, J. Heltshe, R. Bowen, and S. Pavignano. 1987. Predicting bioaccumulation of sediment-associated organic contaminants: Development of a regulatory tool for dredged material evaluation. EPA-600/X-87/368. United States Environmental Protection Agency. Narragansett, Rhode Island. 54 p. + appendices

3 Saether, O.A. 1970. A survey of the bottom fauna in lakes of the Okanagan Valley, British Columbia. Fisheries Research Board of Canada Technical Report 342:1-27.

9 Schaeffer, D.J. and K.G. Janardan. 1978. Theoretical comparison of grab and composite sampling programs. Biometrics Journal 20:215-227.

2 Schlekat, C.E., B.L. McGee, and E. Reinharz. 1991. Testing sediment toxicity in Chesapeake Bay using the amphipod *Leptocheirus plumulosus*: An evaluation. Environmental Toxicology and Chemistry 11:225-236.

2, 3, 10 Schlekat, C.E., B.L. McGee, D.M. Boward, E. Reinharz, D.J. Velinsky, and T.L. Wade. 1994. Tidal river sediments in the Washington, D.C. area. III. Biological effects associated with sediment contamination. Estuaries 17:334-344.

2, 10 Schubauer-Berigan, M.K. and G.T. Ankley. 1991. The contribution of ammonia, metals, and nonpolar organic compounds to the toxicity of sediment interstitial water from an Illinois River tributary. Environmental Toxicology and Chemistry 10:925-939.

2 Schubauer-Berigan, M.K., J.R. Dierkes, P.D. Monson, and G.T. Ankley. 1993. The pH-dependent toxicity of Cd, Cu, Ni, Pb and Zn to *Ceriodaphnia dubia*, *Pimephales promelas*, *Hyalella azteca*, and *Lumbriculus variegatus*. Environmental Toxicology and Chemistry 12:1261-1266.

2 Schubauer-Berigan, M.K., P.D. Monson, C.W. West, and G.T. Ankley. 1995. Influence of pH on the toxicity of ammonia to *Chironomus tentans* and *Lumbriculus variegatus*. Environmental Toxicology and Chemistry 14(4):713-717.

7 Science Advisory Group. 1997. Use of sediment quality guidelines in the assessment and management of contaminated sediments. 1997 Short Course. Society of Environmental Toxicology and Chemistry. San Francisco, California.

2 Scott, K.J. and M.S. Redmond. 1989. The effects of a contaminated dredged material on laboratory populations of the tubicolous amphipod, *Ampelisca abdita*. *In*: Aquatic Toxicology and Hazard Assessment: Twelfth Symposium. UM Cowgill and LR Williams (Eds.). ASTM STP 1027. Philadelphia, Pennsylvania. pp. 289-303.

7 Sediment Criteria Subcommittee. 1989. Review of the apparent effects threshold approach to setting sediment criteria. Report of the Science Advisory Board. United States Environmental Protection Agency. Washington, District of Columbia. 18 pp.

1, 2, 3, 7 Sediment Criteria Subcommittee. 1990. Evaluation of the sediment classification methods compendium. Report of the Science Advisory Board. United States Environmental Protection Agency. Washington, District of Columbia. 18 pp.

16 Sediment Priority Action Committee. 1999. Deciding when to intervene: Data interpretation tools for making management decisions beyond source control. Based on a Workshop to Evaluate Data Interpretation Tools used to Make Sediment Management Decisions. University of Windsor. Windsor, Ontario.

2, 10 Sferra, J.C., P.C. Fuchsman, R.J. Wenning, and T.R. Barber. 1999. A site-specific evaluation of mercury toxicity in sediment. Archives of Environmental Contamination and Toxicology 37:488-495.

2, 7 Sibley, P.K., G.T. Ankley, A.M. Cotter, and E.N. Leonard. 1996. Predicting chronic toxicity of sediments spiked with zinc: An evaluation of the acid volatile sulfide (AVS) model using a life-cycle test with the midge *Chironomus tentans*. Environmental Toxicology and Chemistry 15:2102-2112.

2 Sibley, P.K., P.D. Monson, and G.T. Ankley. 1997. The effect of gut contents on dry weight estimates of *Chironomus tentans* larvae: Implications for interpreting toxicity in freshwater sediment toxicity tests. Environmental Toxicology and Chemistry 16(8):1721-1726.

2 Sibley, P.K., D.A. Benoit, and G.T. Ankley. 1997. The significance of growth in *Chironomus tentans* sediment toxicity tests: Relationship to reproduction and demographic endpoints. Environmental Toxicology and Chemistry 16(2):336-345.

2 Smith, M.E., J.M. Lazorchak, L.E. Herrin, S. Brewer-Swartz, and W.T. Thoeny. A reformulated, reconstituted water for testing the freshwater amphipod, *Hyalella azteca*. Environmental Toxicology and Chemistry 16(6):1229-1233.

7 Smith, S.L., D.D. MacDonald, K.A. Keenleyside, C.G. Ingersoll, and L.J. Field. 1996a. A preliminary evaluation of sediment quality assessment values for freshwater ecosystems. Journal of Great Lakes Research 22(3):624-638.

7 Smith, S.L., D.D. MacDonald, K.A. Keenleyside, and C.L. Gaudet. 1996b. The development and implementation of Canadian sediment quality guidelines. Journal of Aquatic Ecosystem Health.

1 Sonzogni, W.C., and M.S. Simmons. 1981. Notes on Great Lakes trace metal and toxic organic contaminants. GLERL Open File Report. Great Lakes Environmental Research Laboratory. Ann Arbor, Michigan.

16 Sonzogni, W.C., A. Robertson, and A.M. Beeton. 1981. The importance of ecological factors in Great Lakes management. Report 52. Great Lakes Basin Commission. Great Lakes Environmental Planning Study. Ann Arbor, Michigan. 28 pp.

16 Southerland, E., M. Kravitz, and T.Wall. 1992. Management framework for contaminated sediments (the U.S. EPA sediment management strategy). *In*: Sediment Toxicity Assessment. G.A. Burton, Jr. (Ed.). Lewis publishers. Chelsea, Michigan. pp. 341-370.

2 Steevens, J.A. and W.H. Benson. 1998. *Hyalella azteca* 10-day sediment toxicity test: Comparison of growth measurement endpoints. Environmental Toxicology 13:243-248.

2, 6 Suedel, B.C., J. Rodgers Jr., and P.A. Clifford. 1993. Bioavailability of fluoranthene in freshwater sediment toxicity tests. Environmental Toxicology and Chemistry 12:155-165.

2 Suedel, B.C. and J.H. Rodgers, Jr. 1994. Development of formulated reference sediments for freshwater and estuarine sediment toxicity testing. Environmental Toxicology and Chemistry 13:1163-1176.

2, 3 Swartz, R.C., W.A. DeBen, K.A. Sercu, and J.O. Lamberson. 1982. Sediment toxicity and the distribution of amphipods in Commencement Bay, Washington, USA. Marine Pollution Bulletin 13:359-364.

2 Swartz, R.C. 1984. Toxicological methods for determining the effects of contaminated sediment on marine organisms. *In*: Fate and Effects of Sediment-Bound Chemicals in Aquatic Systems. K.L. Dickson, A.W. Maki, W.A. Brungs (Eds.). Pergamon Press. New York, New York. pp. 183-198

2 Swartz, R.C., D.W. Schults, G.R. Ditsworth, and W.A. DeBen. 1984. Toxicity of sewage sludge to *Rhepoxynius abronius*, a marine amphipod. Archives of Environmental Contamination and Toxicology 13:359-364.

2 Swartz, R.C., W.A. DeBen, J.K.P. Jones, J.O. Lamberson, and F.A. Cole. 1985. Phoxocephalid amphipod bioassay for marine sediment toxicity. *In*: Aquatic Toxicology and Hazard Assessment: Seventh Symposium. R.D. Cardwell, R. Purdy, and R.C. Bahner (Eds.). ASTM STP 854. American Society for Testing and Materials. Conshohocken, Pennsylvania. pp. 284-307.

2, 11 Swartz, R.C., P.F. Kemp, D.W. Schultz, and J.O. Lamberson. 1988. Effects of mixtures of sediment contaminants on the marine infaunal amphipod, *Rhepoxynius abronius*. Environmental Toxicology and Chemistry 7:1013-1020.

2 Swartz, R.C. 1989. Marine sediment toxicity tests. *In*: Contaminated Marine Sediments–Assessment and Remediation. National Research Council. Washington, District of Columbia: National Academy Press. pp. 115-129.

1, 2, 3, 10 Swartz, R.C., F.A. Cole, J.O. Lamberson, S.P. Ferraro, D.W. Schults, W.A. DeBen, H.Lee II, and J.R. Ozretich. 1994. Sediment toxicity, contamination, and amphipod abundance at a DDT and dieldrin-contaminated site in San Francisco Bay. Environmental Toxicology and Chemistry 13:949-962.

7 Swartz, R.C., D.W. Schults, R.J. Ozretich, J.O. Lamberson, F.A. Cole, T.H. DeWitt, M.S. Redmond, and S.P. Ferraro. 1995. 3PAH: A model to predict the toxicity of polyaromatic nuclear hydrocarbon mixtures in field-collected sediments. Environmental Toxicology and Chemistry 14(11):1977-1987.

7 Swartz, R.C. 1999. Concensus sediment quality guidelines for PAH mixtures. Environmental Toxicology and Chemistry 18:780-787.

3 Tennessen, K.J. and P.K. Gottfried. 1983. Variation in structure of ligula of Tanypodinae larvae (Diptera: Chironomidae). Entomological News 94:109-116.

3 Thorp, J.H. and A.P. 1991. Ecology and classification of North American freshwater invertebrates. Academic Press Inc. 911 pp.

2 Thursby, G.B., J. Heltshe, and K.J. Scott. 1997. Revised approach to toxicity test acceptability criteria using a statistical performance assessment. Environmental Toxicology and Chemistry 16(6):1322-1329.

2 Tomasovic, M., F.J. Dwyer, I.E. Greer, and C.G. Ingersoll. 1995. Recovery of known-age *Hyalella azteca* (amphipoda) from sediment toxicity tests. Environmental Toxicology and Chemistry 14:1177-1180.

5 Tracey, G.A. and D.J. Hansen 1996. Use of biota-sediment accumulation factors to assess similarity of non-ionic organic chemical exposure to benthically-coupled organisms of differing trophic mode. Archives of Environmental Contamination and Toxicology 30:467-475.

2, 3 USEPA (United States Environmental Protection Agency). 1973. Biological field and laboratory methods for measuring the quality of surface waters and effluents. EPA-670/4-73/001. Cincinnati, Ohio.

1, 18 USEPA (United States Environmental Protection Agency). 1979a. Handbook for analytical quality assurance in water and wastewater laboratories. EPA-600/4-79-019. Cincinnati, Ohio.

1 USEPA (United States Environmental Protection Agency). 1979b. Methods for chemical analysis of water and wastes. EPA-600/4-79-020. Cincinnati, Ohio.

1, 2, 18 USEPA (United States Environmental Protection Agency). 1980a. Physical, chemical, persistence, and ecological effects testing: Good laboratory practice standards (proposed rule). 40 CFR 772. Federal Regulation 45:77353-77365 (November 21, 1980).

2, 18 USEPA (United States Environmental Protection Agency). 1980b. Proposed good laboratory practice guidelines for toxicity testing. Paragraph 163.60-6. Federal Regulation 45:26377-26382 (April 18, 1980).

2 USEPA (United States Environmental Protection Agency). 1985. Methods for measuring the acute toxicity of effluents to freshwater and marine organism. 3rd Edition. EPA-600/4-85/013. Cincinnati, Ohio.

7 USEPA (United States Environmental Protection Agency). 1986a. Occupational Health and safety manual. Office of Administration. Washington, District of Columbia.

7 USEPA (United States Environmental Protection Agency). 1986b. Quality criteria for water. EPA-440/5-86-001. Washington, District of Columbia.

7 USEPA (United States Environmental Protection Agency). 1988. Interim sediment criteria values for nonpolar hydrophobic organic contaminants. EPA, SDC 17. Criteria and Standards Division. Washington, District of Columbia.

7 USEPA (United States Environmental Protection Agency). 1989a. Briefing report to the EPA Science Advisory Board on the equilibrium partitioning approach to generating sediment quality criteria. EPA/440/5-89-002. Washington, District of Columbia.

7 USEPA (United States Environmental Protection Agency). 1989b. Evaluation of the apparent effects threshold (AET) approach for assessing sediment quality. Report of the sediment criteria subcommittee. SAB-EETFC-89-027. Washington, District of Columbia.

5 USEPA (United States Environmental Protection Agency). 1989c. Guidance manual: Bedded sediment bioaccumulation tests. EPA-600/X-89/302. Pacific Ecosystems Branch. Environmental Research Laboratory. Newport, Oregon.

2 USEPA (United States Environmental Protection Agency). 1989d. Short-term methods for estimating the chronic toxicity of effluents and receiving waters to freshwater organisms. EPA-600/4-89/001. Cincinnati, Ohio.

1, 18 USEPA (United States Environmental Protection Agency). 1990a. Analytical procedures and quality assurance plan for determination of PCDD/PCDF in fish. EPA-600/3-90/022. Duluth, Minnesota.

1, 18 USEPA (United States Environmental Protection Agency). 1990b. Analytical procedures and quality assurance plan for determination of xenobiotic chemical contaminants in fish. EPA-600/3-90/023. Duluth, Minnesota.

7 USEPA (United States Environmental Protection Agency). 1990c. Evaluation of the equilibrium partitioning (EqP) approach for assessing sediment quality. Report of the sediment criteria subcommittee of the ecological processes and effects committee. EPA-SAB-EPEC-990-006. Washington, District of Columbia.

7 USEPA (United States Environmental Protection Agency). 1990d. Evaluation of the sediment classification methods compendium. Report of the sediment criteria subcommittee of the ecological processes and effects committee. EPA-SAB-EPEC-90-018. Washington, District of Columbia.

2 USEPA (United States Environmental Protection Agency). 1991a. Methods for measuring the acute toxicity of effluents and receiving waters to freshwater and marine organisms. Fourth Edition. EPA-600/4-90/027F. Cincinnati, Ohio.

8 USEPA (United States Environmental Protection Agency). 1991b. Sediment toxicity identification evaluation: Phase I (Characterization), Phase II (Identification) and Phase III (Confirmation). Modifications of effluent procedures. EPA-600/6-91/007. Duluth, Minnesota.

7 USEPA (United States Environmental Protection Agency). 1992a. An SAB report: Review of sediment criteria development methodology for nonionic organic contaminants. Report of the sediment criteria subcommittee of the ecological processes and effects committee. EPA-SAB-EPEC-93-002. Washington, District of Columbia.

2, 16 USEPA (United States Environmental Protection Agency). 1992b. Proceedings from workshop on tiered testing issues for freshwater and marine sediments. September 16-18. Washington, District of Columbia.

7 USEPA (United States Environmental Protection Agency). 1992c. Sediment classification methods compendium. EPA 823-R-92-006. Office of Water. Washington, District of Columbia. 222 pp.

7 USEPA (United States Environmental Protection Agency). 1993a. Sediment quality criteria for the protection of benthic organisms: Endrin. EPA 822-R-93-016. Office of Water. Washington, District of Columbia.

2 USEPA (United States Environmental Protection Agency). 1993b. Standard operating procedures for culturing *Hyalella azteca* (ERL-D-SOP-CTI-015) and *Lumbriculus variegatus* (ERL-D-SOP-CTI-017). Environmental Research Laboratory. Duluth, Minnesota.

2 USEPA (United States Environmental Protection Agency). 1993c. Test methods for evaluating solid waste, physical/chemical methods (SW-846). Third Edition. Washington, District of Columbia.

18 USEPA (United States Environmental Protection Agency). 1994a. EPA requirements for quality assurance project plans for environmental data operations. Draft interim final. EPA QA/R-5. Office of Research and Development. Washington, District of Columbia.

16 USEPA (United States Environmental Protection Agency). 1994b. EPA's contaminated sediment management strategy. EPA 823-R-94-001. Washington, District of Columbia.

2, 5 USEPA (United States Environmental Protection Agency). 1994c. Methods for measuring the toxicity and bioaccumulation of sediment-associated contaminants with freshwater invertebrates. First Edition. EPA/600/R-94/024. Duluth, Minnesota.

2 USEPA (United States Environmental Protection Agency). 1994d. Methods for measuring the toxicity of sediment-associated contaminants with estuarine and marine amphipods. EPA-600/R-94/025. Narragansett, Rhode Island.

2 USEPA (United States Environmental Protection Agency). 1994e. Short-term methods for estimating the chronic toxicity of effluents and receiving waters to marine and estuarine organisms. Second Edition. EPA-600/4-91/003. Cincinnati, Ohio.

1, 9, 18 USEPA (United States Environmental Protection Agency). 1995. QA/QC guidance for sampling and analysis of sediments, water and tissues for dredged material evaluations-chemical evaluations. EPA 823-B-95-001. Office of water. Washington, District of Columbia.

7 USEPA (United States Environmental Protection Agency). 1996a. Calculation and evaluation of sediment effect concentrations for the amphipod *Hyalella azteca* and the midge *Chironomus riparius*. EPA 905-R96-008. Chicago, IL

8 USEPA (United States Environmental Protection Agency). 1996b. Marine Toxicity Identification Evaluation (TIE). Phase I Guidance Document. EPA/600/R-96/054. R.M. Burgess, K.T. Ho, G.E. Morrison, G. Chapman, D.L. Denton (Eds.). National Health and Environmental Effects Research Laboratory. Narragansett, Rhode Island.

10 USEPA (United States Environmental Protection Agency). 1997a. The incidence and severity of sediment contamination in surface waters of the United States. Volume 1: National sediment quality survey. EPA 823-R-97-006. Office of Science and Technology. Washington, District of Columbia.

16 USEPA (United States Environmental Protection Agency). 1997b. The incidence and severity of sediment contamination in surface waters of the United States.

Volume 2: Data summaries for areas of probable concern. EPA 823-R-97-007. Office of Science and Technology. Washington, District of Columbia.

10 USEPA (United States Environmental Protection Agency). 1997c. The incidence and severity of sediment contamination in surface waters of the United States. Volume 3: National sediment contaminant point source inventory. EPA 823-R-97-008. Office of Science and Technology. Washington, District of Columbia.

16 USEPA (United States Environmental Protection Agency). 1998a. Contaminated sediment management strategy. EPA 823-R-98-001. Office of Water. Washington, District of Columbia.

18 USEPA (United States Environmental Protection Agency). 1998b. EPA guidance for quality assurance project plans. EPA/600/R-98/018. Office of Research and Development. Washington, District of Columbia.

7 USEPA (United States Environmental Protection Agency). 1999a. A short course on collection, analysis, and interpretation of sediment quality data: Applications of sediment quality guidelines and companion tools. State Botanical Garden. Athens, Georgia.

2, 9 USEPA (United States Environmental Protection Agency). 1999b. Methods for collection, storage and manipulation of sediments for chemical and toxicological analyses: May 14, 1999 draft.

5 USEPA (United States Environmental Protection Agency). 2000a. Appendix to bioaccumulation testing and interpretation for the purpose of sediment quality assessment: Status and needs. Chemical-specific summary tables. EPA/823-R-00-002. Office of Water. Office of Solid Waste. Washington, District of Columbia.

5 USEPA (United States Environmental Protection Agency). 2000b. Bioaccumulation testing and interpretation for the purpose of sediment quality assessment: Status and needs. EPA/823-R-00-001. Office of Water. Office of Solid Waste. Washington, District of Columbia.

7 USEPA (United States Environmental Protection Agency). 2000c. Draft implementation framework for the use of equilibrium partitioning sediment guidelines. Office of Science and Technology. Washington, District of Columbia.

7 USEPA (United States Environmental Protection Agency). 2000d. Equilibrium partitioning sediment guidelines (ESGs) for the protection of benthic organisms: Dieldrin. EPA-822-R-00-001. Washington, District of Columbia.

7 USEPA (United States Environmental Protection Agency). 2000e. Equilibrium Partitioning Sediment Guidelines (ESGs) for the Protection of Benthic Organisms: Endrin. EPA-822-R-00-004. Office of Science and Technology and Office of Research and Development. Washington, District of Columbia.

7 USEPA (United States Environmental Protection Agency). 2000f. Equilibrium partitioning sediment guidelines (ESGs) for the protection of benthic organisms: Metals mixtures: (Cadmium, Copper, Lead, Nickel, Silver, and Zinc). EPA-822-R-00-005. Washington, District of Columbia.

7 USEPA (United States Environmental Protection Agency). 2000g. Equilibrium partitioning sediment guidelines (ESGs) for the protection of benthic organisms: Nonionics compendium. EPA-822-R-00-006. Office of Science and Technology and Office of Research and Development. Washington, District of Columbia.

7 USEPA (United States Environmental Protection Agency). 2000h. Equilibrium partitioning sediment guidelines (ESGs) for the protection of benthic organisms: PAH mixtures. Washington, District of Columbia.

2 USEPA (United States Environmental Protection Agency). 2000i. Methods for measuring the toxicity and bioaccumulation of sediment-associated contaminants with freshwater invertebrates. 2nd Edition. EPA-600/R-99/064. Washington, District of Columbia.

7 USEPA (United States Environmental Protection Agency). 2000j. Methods for the derivation of site-specific equilibrium partitioning sediment guidelines (ESGs) for the protection of benthic organisms: Nonionic organics. EPA 822-R-00-002. Washington, District of Columbia.

7 USEPA (United States Environmental Protection Agency). 2000k. Technical basis for the derivation of equilibrium partitioning sediment guidelines (ESGs) for the protection of benthic organisms: Nonionic organics. EPA-822-R-00-001. Washington, District of Columbia.

2, 16 USEPA (United States Environmental Protection Agency) and USACE (United States Army Corps of Engineers). 1998a. Evaluation of dredged material proposed for discharge in water of the US. Testing Manual. EPA 823-B-98-004. United States Environmental Protection Agency. Washington, District of Columbia.

2 USEPA (United States Environmental Protection Agency) and USACE (United States Army Corps of Engineers). 1998b. Method for assessing the chronic toxicity of marine and estuarine sediment-associated contaminants with the amphipod *Leptocheirus plumulosus*: August, 1998 draft. Office of Research and Development. Newport, Oregon.

7 Van Derveer, W.D. and S.P. Canton. 1997. Selenium sediment toxicity thresholds and derivation of water quality criteria for freshwater biota of western streams. Environmental Toxicology and Chemistry 16(6):1260-1268.

2, 8 Van Sprang, P.A. and C.R. Janssen. 1997. Identification and confirmation of ammonia toxicity in contaminated sediments using a modified toxicity identification evaluation approach. Environmental Toxicology and Chemistry 16(12):2501-2507.

5 Vassilaro, D.L., P.W. Stoker, G.M. Booth, and M.L. Lee. 1982. Capillary gas chromatographic determination of polycyclic aromatic compounds in vertebrate tissue. Journal of Analytical Chemistry 54:106-112.

17 Vigerstad, T.J. and L.S. McCarty. 2000. The ecosystem paradigm and environmental risk management. Human and Ecological Risk Assessment 6(3):369-381.

2 Wall, V.D., J. London, J.E. Warren, R. Gossett, M.D. Wenholz, and S.J. Klaine. 1998. Development of a continuous-flow renewal system for sediment toxicity testing. Environmental Toxicology and Chemistry 17(6):1159-1164.

7 Wang, F., P.M. Chapman, and H.E. Allen. 1999. Misapplication of equilibrium partitioning coefficients to derive metals sediment quality values. Marine Pollution Bulletin 38(5):423-425.

5 Warren, L.A., A. Tessier, and L. Hare. 1998. Modelling cadmium accumulation by benthic invertebrates *in situ*: The relative contributions of sediment and overlying water reservoirs to organism cadmium concentrations. Limnology and Oceanography 43(7):1442-1454.

3 Warwick, W.F. 1985. Morphological abnormalities in Chironomidae (Diptera) larvae as measures of toxic stress in freshwater ecosystems: indexing antennal deformities in *Chironomus meigan*. Canadian Journal of Fish and Aquatic Science 42:1881-1941.

3 Warwick, W.F. 1988. Morphological deformities in Chironomidae (Diptera) larvae as biological indicators of toxic stress. *In*: Toxic contaminants and ecosystem health: A Great Lakes focus. M.S. Evans (Ed.). John Wiley and Sons. New York, New York. pp. 281-320.

7 Washington State Department of Ecology. 1995. Sediment management standards. Chapter 173-204 WAC. Olympia, Washington.

2 Wentsel, R., A. McIntosh, and G. Atchison. 1977. Sublethal effects of heavy metal contaminated sediment on midge larvae (*Chironomus tentans*). Hydrobiologia 56:53-156.

1, 3, 10 Wentsel, R., A. McIntosh, and V. Anderson. 1977. Sediment contamination and benthic macroinvertebrate distribution in a metal-impacted lake. Environmental Polution 14:187-193.

2 Wentsel, R., A. McIntosh, and P.C. McCafferty. 1978. Emergence of the midge *Chironomus tentans* when exposed to heavy metal contaminated sediments. Hydrobiologia 57:195-196.

2, 10 West, C.W., V.R. Mattson, E.N. Leonard, G.L. Phipps, and G.T. Ankley. 1993. Comparison of the relative sensitivity of three benthic invertebrates to copper contaminated sediments from the Keweenaw Waterway. Hydrobiologia 262:57-63.

1, 2, 9 West, C.W., G.L. Phipps, R.A. Hoke, T.A. Goldenstein, F.M. VanderMeiden, P.A. Kosian, and G.T. Ankley. 1994. Sediment core versus grab samples: Evaluation of contamination and toxicity at a DDT-contaminated site. Ecotoxicology and Environmental Safety 28:208-220.

2, 5 West, C.W., G.T. Ankley, J.W. Nichols, G.E. Elonen, and D.E. Nessa. 1997. Toxicity and bioaccumulation of 2,3,7,8-Tetrachlorodibenzo-*p*-dioxin in long-term tests with the freshwater benthic invertebrates *Chironomus tentans* and *Lumbriculus variegatus*. Environmental Toxicology and Chemistry 16(6):1287-1294.

2 Whiteman, F.W., G.T. Ankley, M.D. Dahl, D.M. Rau, and M.D. Balcer. 1996. Evaluation of interstitial water as a route of exposure to ammonia in sediment tests with benthic macroinvertebrates. Environmental Toxicology and Chemistry 15(5):794-801.

2 Winger, P.V. and P.J. Lasier. 1994. Sediment toxicity testing: Comparison of methods and evaluation of influencing factors. *In*: Environmental toxicology and risk assessment: Second volume. ASTM STP 1216. J.W. Gorsuch, F.J. Dwyer, C.G. Ingersoll, T.W. La Point (Eds.). American Society for Testing and Materials. Conshohocken, Pennsylvania. pp. 640-662.

2, 10 Wolfe, D.A., E.R. Long, and G.B. Thursby. 1996. Sediment toxicity in the Hudson-Raritan Estuary: Distribution and correlations with chemical contamination. Estuaries 19:901-912.

2 Yu, Q., Y. Chaisuksant, and D.Connell. 1999. A model for non-specific toxicity with aquatic organisms over relatively long periods of exposure time. Chemosphere 38:909-918.

13 Ziegler, C.K. 1999. Sediment stability at contaminated sediment sites. Quantitative Environmental Analysis, LLC. 32 pp.

2 Zumwalt, D.C., F.J. Dwyer, I.E. Greer, and C.G. Ingersoll. 1994. A water-renewal system that accurately delivers small volumes of water to exposure chambers. Environmental Toxicology and Chemistry 13:1311-1314.

Appendix 3. Designated Water Uses of Aquatic Ecosystems

A3.0 Introduction

Freshwater ecosystems are comprised of biotic (producers, consumers, and decomposers) and abiotic (physical and chemical) components, which are linked together by a complicated array of interactions. The nature of these interactions determines how the ecosystem functions, while the type of aquatic organisms that are present dictates the ecosystem's structure. Human activities, such as those that result in releases of toxic and/or bioaccumulative substances, have the potential to adversely affect the biotic components of the ecosystem. In particular, anthropogenic activities that result in elevated levels of sediment-associated contaminants have the potential to adversely affect sediment-dwelling organisms, aquatic-dependent wildlife, or human health. In so doing, such activities can alter the structure and/or the functioning of the ecosystem.

Effective management of sediment quality conditions requires an understanding of the linkages between sediment quality conditions and the designated uses of the aquatic ecosystem. In general there are five designated uses of aquatic ecosystems that have the potential to be adversely affected by sediment contamination, including:

- Aquatic life;
- Aquatic-dependent wildlife;
- Human health;
- Recreation and aesthetics; and,
- Navigation and shipping.

For sites that have been adversely affected by contaminated sediments, restoration of designated water uses that have been impaired by historical contamination and protect those uses that have not been impaired should be identified as high priority goals. For this reason, each of the designated uses of aquatic ecosystems that can be impaired by contaminate sediments are described in the following sections.

A3.1 Aquatic Life

Aquatic life represents an important water use as freshwater ecosystems support a wide variety of fish and aquatic organisms. In addition to their importance in terms of maintaining a healthy ecosystem, many aquatic organisms also support a variety of human uses, including traditional, sport, and commercial fisheries. As many aquatic organisms utilize soft-bottom habitats throughout portions of their life histories, maintenance of acceptable sediment quality conditions is essential for sustaining healthy populations of sediment-dwelling organisms (including infaunal and epibenthic invertebrate species) and associated fish species. Importantly, protection of aquatic life is probably the most sensitive water use relative to the effects of sediment-associated contaminants. Aquatic organisms can be adversely affected by contaminated sediments in several ways, including through direct exposure to contaminated sediments (both invertebrate and fish species), through exposure to degraded water quality as a result of desorption from sediments, and through accumulation of toxic substances in the food web.

A3.2 Aquatic-Dependent Wildlife

While the protection of aquatic organisms is a primary consideration in assessments of aquatic environmental quality, aquatic ecosystems also support a diversity of wildlife species. Aquatic-dependent wildlife species include a wide variety of shorebirds (e.g., avocets, dippers, sandpipers), waterfowl (e.g., scoters, ducks, geese), wading birds, (e.g., cranes, herons), raptors (e.g., eagles, ospreys), mammals (e.g., muskrats, river otters, seals), amphibians (frogs, salamanders), reptiles (e.g., turtles), and fish. Such wildlife species represent integral elements of aquatic food webs and, as such, can be exposed to sediment-associated contaminants through direct exposure to aquatic sediments or through dietary exposure to bioaccumulative contaminants (i.e., through the consumption of contaminated fish and other aquatic organisms). Therefore, protection of wildlife is of greatest concern for those contaminants known to bioaccumulate in aquatic food webs, including mercury, PCBs, certain PAHs, OC pesticides, and PCDDs/PCDFs.

A3.3 Human Health

Protection of human health has typically been a major focus of the water quality criteria and standards. With respect to sediment quality conditions, human health can be adversely affected by direct exposure to contaminated sediments (e.g., swimming or wading) and through the consumption of contaminated fish and waterfowl tissues. Long-term exposure to sediment-associated contaminants can result in both carcinogenic and non-carcinogenic effects in humans (Crane 1996). Numerical sediment quality guidelines (residue-based) and numerical tissue residue guidelines can be used to assess the potential dietary effects of contaminated sediments and tissues on human health.

A3.4 Recreation and Aesthetics

Recreation and aesthetics are emerging water uses, which are likely to become even more important in the future. Recreational water uses include both contact recreation, such as swimming and wading, and non-contact recreation, such as boating and fishing. Recreational activities that involve direct contact with water and sediments can be impaired when sediment-associated contaminant concentrations reach levels that cause skin irritation, respiratory problems, or necessitate beach closures. In contrast, non-contact recreation can be impaired when fish populations are degraded, when fish advisories are issued, when fish have an increased incidence of tumors and other deformities, or when environmental conditions adversely affect the boating experience (i.e., through noxious odors or visual impairments - oil sheens). In addition to the influence of environmental conditions, aesthetic water uses can be impaired through the loss of fish and wildlife habitats or through degradation of wildlife populations (i.e., reduction in opportunities for wildlife viewing).

Protection of human health is the primary consideration for those areas designated for recreational and aesthetic water uses. Therefore, this water use tends to be less sensitive to the effects of sediment-associated contaminants than the other water uses. Nevertheless, aquatic organisms and wildlife species should be afforded at least the level of protection required under federal and state legislation at sites designated for recreational and aesthetic water uses.

A3.5 Navigation and Shipping

Navigation and shipping are important water uses throughout North America. To maintain the water depths necessary to support this water use, periodic dredging is required in many harbors. This water use can be adversely affected when the concentrations of sediment-associated contaminants exceed the levels specified for open water disposal of dredged materials (i.e., in those states that permit open water disposal) or for beneficial use of dredged materials (e.g., beach nourishment). In such cases, the dredged materials must be transported to confined disposal facilities (CDFs) for disposal. The need for confined disposal of dredged material can increase the costs associated with dredging projects, delay the implementation of dredging projects, or preclude dredging altogether (i.e., if sufficient space is not available in the CDFs). In any of these cases, the use of the affected water body for navigation and shipping is likely to be impaired. Numerical sediment quality guidelines, toxicity testing, and bioaccumulation assessments represent important tools for assessing the effects of contaminated sediments relative to navigation and shipping.

Tables

Table 1.1. List of the 42 areas of concern in the Great Lakes basin in which beneficial uses are being adversely affected by contaminated sediments (from IJC 1988).

Lake Superior	*Lake Erie*
Peninsula Harbor	Clinton River
Jackfish Basin	Rouge River
Nipigon Basin	Raisin River
Thunder Basin	Maumee River
St. Louis River and Basin	Black River
Torch Lake	Cuyahoga River
Deer Lake - Carp Creek	Ashtabula River
	Wheatley Harbor
Lake Michigan	
Manistique River	*Lake Ontario*
Menominee River	Buffalo River
Fox River & Green Basin	18 Mile Creek
Sheboygan	Rochester Basin
Milwaukee Harbor	Oswego River
Waukegan Harbor	Bay of Quinte
Grand Calumet River	Port Hope
Kalamazoo River	Toronto Harbor
Muskegon Lake	Hamilton Harbor
White Lake	Niagra River
	St. Lawrence River
Lake Huron	
Saginaw River and Basin	
Collingwood Harbor	
Penatang-Sturgeon Basin	
Spanish River	
St. Marys River	
St. Clair River	
Detroit River	

Table 1.2. A summary of use impairments potentially associated with contaminated sediment and the numbers of Great Lakes

Use impairment	How contaminated sediment may affect use impairment	*Number of Areas of Concern with the impaired use (%)
Restrictions on fish and wildlife consumption	*	36 (86%)
Degradation of fish and wildlife populations	* Contaminant degradation of habitat * Contaminant impacts through direct sediment contact * Food web uptake	30 (71%)
Fish tumors or other deformities	* *	20 (48%)
Bird or animal deformities or reproduction problems	* Contaminant degradation of habitat * Contaminant impacts through direct sediment contact * Food web uptake	14 (33%)
Degradation of benthos	* Contact * Ingestion of toxic contaminants * structure due to oxygen depletion	35 (83%)
Restrictions on dredging activities	* Restrictions on disposal in open water due to contaminants and nutrients and their potential impacts on biota	36 (86%)
Eutrophication or undesirable algae	* Nutrient recycling from temporary sediment sink	21 (50%)
Degradation of aesthetics	* Resuspension of solids and increased turbidity * Odors associated with anoxia	25 (60%)

Table 1.2. A summary of use impairments potentially associated with contaminated sediment and the numbers of Great Lakes

Use impairment	How contaminated sediment may affect use impairment	*Number of Areas of Concern with the impaired use (%)
Added costs to agriculture or industry	* Resuspended solids * Presence of toxic substances and nutrients	7 (17%)
Degradation of phytoplankton or zooplankton populations	* Toxic contaminant release * Resuspension of solids and absorbed contaminants and subsequent ingestion	10 (24%)
Loss of fish and wildlife habitat	* Toxicity to critical life history stages *	34 (81%)

Table 2.1. Selected definitions related to ecosystem management (from Environment Canada 1996).

Source	Definition
Definitions of the ecosystem approach	
IJC (1994)	"…an approach to perceiving, managing and otherwise living in an ecosystem that recognizes the need to preserve the ecosystem's biochemical pathways upon which the welfare of all life depends in the context of multifaceted relationships (biological, social, economic, etc.) that distinguishes that particular ecosystem."
Environment Canada (1994a)	"…means looking at the basic components (air, water, and biota, including humans) and fuctions of the ecosystem not in isolation, but in broad and integrated environmental, social and economic context."
CCME (1996)	"…a geographically comprehensive approach to environmental planning and management which recognizes the interrelated nature of environmental media, and that humans are a key component of ecological systems; it places equal emphasis on concerns related to the environment, the economy, and the community."
Definitions of an ecosystem approach to management	
Environment Canada, Parks Service (1992)	"…requires a broad perspective. It includes knowledge of heritage resources, ecological processes and socio-economic activities…" "…ecosystem-based management must, above all, be sensitive and responsive to the unique status of each ecosystem and its spheres of influence."
IJC (1994)	"…is an active process that emphasizes the maintenance of biological diversity, of natural relationships among species, an dynamic processes that make ecosystems sustainable."
Lackey 1994	"The application of biophysical and social information, options, and constraints to achieve desired social benefits within a defined geographic area and over a specified time period."
Wrona (1994)	"…recognizes there are ecological, social, and economic considerations to be made when assessing and predicting the impacts of human activities on natural systems and practicing the 'ecosystem approach' means that all stakeholders understand the implications of, and are accountable for their actions."
Standing Committee on Environment and Sustainable Development (1995)	"…implies a balanced approach toward managing human activities to ensure that the living and non-living elements that shape ecosystems continue to function and so maintain the integrity of the whole."

Table 2.2. Comparison of four approaches to resolving human-made ecosystem problems (from Environment Canada 1996).

	Approach			
Problem	**Egosystemic**	**Piecemeal**	**Environmental**	**Ecosystemic**
Organic waste	Hold your nose	Discharge downstream	Reduce BOD	Energy recovery
Eutrophication	Mysterious causes	Discharge downstream	Phosphorus removal	Nutrient recycling
Acid rain	Unaware	Not yet a problem	Taller smoke stacks	Recycle sulphur
Toxic chemicals	Unaware	Not yet a problem	Discharge permits	Design with nature
Greenhouse effects	Unaware	Not yet a problem	Sceptical analysis	Carbon recycling
Pests	Run for your life	Broad spectrum insecticides	Selective degradable poisons	Integrated pest management
Attitude to nature	Indifferent	Dominate	Cost/benefit	Respect

Table 3.1. Activities that have a high potential for releasing hazardous substances into the environment (from BCE 1997).

Industry	Associated Activity
Chemical industries and activities	* Adhesives manufacturing or wholesale bulk storage * Chemical manufacturing or wholesale bulk storage * * Fire retardant manufacturing or wholesale bulk storage * Fertilizer manufacturing or wholesale bulk storage * Ink or dye manufacturing or wholesale bulk storage * Leather or hides tanning * wholesale bulk storage * Pharmaceutical products manufacturing * * Textile dying * * Resin or plastic monomer manufacturing, formulation or wholesale bulk storage
Electrical equipment industries and activities	* Battery (lead acid or other) manufacturing or wholesale bulk storage * Communications station using or storing equipment that contains PCBs * Electrical equipment manufacturing refurbishing or wholesale bulk storage * Electrical transmission or distribution substations * Electronic equipment manufacturing *
Metal smelting, processing or finishing industries and activities	* Foundries or scrap metal smelting * Galvanizing * Metal plating or finishing * Metal salvage operations * Nonferrous metal smelting or refining * Welding or machine shops (repair or fabrication)
Mining, milling, or related industries and activities	* Asbestos mining, milling, wholesale bulk storage or shipping * Coal coke manufacture, wholesale bulk storage or shipping * * * * Nonferrous metal mining or milling

Table 3.1. Activities that have a high potential for releasing hazardous substances into the environment (from BCE 1997).

Industry	Associated Activity
Miscellaneous industries, operations or activities	* Appliance, equipment or engine repair, reconditioning, cleaning or salvage * * * Coal gasification (manufactured gas production) * Medical, chemical, radiological or biological laboratories * Rifle or pistol firing ranges * Road salt storage facilities * wholesale bulk storage
Petroleum and natural gas drilling, production, processing, retailing and distribution	* Petroleum or natural gas drilling * Petroleum or natural gas production facilities * Natural gas processing * * Petroleum product dispensing facilities, including service stations and cardlots * Petroleum, natural gas or sulphur pipeline rights of way excluding rights of community * Petroleum or natural gas product or produced water storage in above ground or underground tanks * Petroleum product wholesale bulk storage or distribution * Petroleum refining wholesale bulk storage or shipping * Solvent manufacturing or wholesale bulk storage * Sulphur handling, processing or wholesale bulk storage and distribution
Transportation industries, operations and related activities	* Aircraft maintenance, cleaning or salvage * Automotive, truck, bus, subway or other motor vehicle repair, salvage or wrecking * Bulk commodity storage or shipping (e.g., coal) * Dry docks, ship building or boat repair * Marine equipment salvage * Rail car or locomotive maintenance, cleaning, salvage or related uses, including railyards * Truck, rail or marine bulk freight handling

Table 3.1. Activities that have a high potential for releasing hazardous substances into the environment (from BCE 1997).

Industry	Associated Activity
Waste disposal and recycling operations and activities	* Antifreeze bulk storage or recycling
	* Barrel, drum or tank reconditioning or salvage
	* Battery (lead acid or other) recycling
	* Biomedical waste disposal
	* (nonfarm applications only)
	* Construction demolition material landfilling
	* Contaminated soil storage, treatment or disposal
	* Dredged waste disposal
	* Dry-cleaning waste disposal
	* Electrical equipment recycling
	* Industrial waste lagoons or impoundments
	* Industrial waste storage, recycling or landfilling
	* Industrial woodwaste (log yard waste, hogfuel) disposal
	* Mine tailings waste disposal
	*
	* Organic or petroleum material landspreading (landfarming)
	* Sandblasting waste disposal
	* Septic tank pumpage storage or disposal
	* Sewage lagoons or impoundments
	* Special (hazardous) waste storage, treatment or disposal
	* Sludge drying or composting
	* Street or yard snow removal dumping
	* Waste oil reprocessing, recycling or bulk storage
	* Wire reclaiming operations
Wood, pulp and paper products and related industries and activities	* Particle board manufacturing
	* Pulp mill operations
	* Pulp and paper manufacturing
	* Treated wood storage at the site of treatment
	* Veneer or plywood manufacturing
	* Wafer board manufacturing
	* Wood treatment (antisapstain or preservation)
	*
Agricultural activities	* Insecticide, herbicide, fungicide application
	* Other pesticide application

Table 4.1. A selection of definitions of an ecosystem (from Environment Canada 1996)

Source	Definition
Environment Canada, Parks Service (1992)	"…a community of organisms and their non-living environment. Fundamental to the system is the flow of energy via food chains and the cycling of nutrients."
Marmorek *et al.* (1993)	"…subdivisions of the global ecosphere, vertical chunks which include air, soil, or sediments, and organisms (including humans). Ecosystems occur at various scales, from the global ecosphere to continents and oceans, to ecoregions, to forest, farms and ponds."
Environment Canada (1994b)	"…an assemblage of biological communities (including people) in a shared environment. Air, land, water and
Royal Society of Canada (1995)	"…a community of organisms including humans, interacting with one another, plus the environment in which they live and with which they interact. Ecosystems are often embedded within other ecosystems of larger scale."

Ta

Ecosystem Goals	Ecosystem Objectives
* The Lake Ontario ecosystem should be maintained and as necessary restored or enhanced to support self-reproducing diverse biological communities	* The waters of Lake Ontario shall support diverse, healthy, reproducing and self-sustaining communities in dynamic equilibrium with an emphasis on native species.
* The presence of contaminants shall not limit the use of fish, wildlife and waters of the Lake Ontario basin by humans and shall not cause adverse health effects in plants and animals.	* The perpetuation of a healthy, diverse and self-sustaining wildlife community that utilizes the lake for habitat and/or food shall be ensured by attaining and sustaining the waters, coastal wetlands and upland habitats of the Lake Ontario basin in sufficient quality and quantity.
* We as a society shall recognize our capacity to cause great changes in the ecosystem and we shall conduct our activities with responsible stewardship for the Lake Ontario basin.	* The waters, plants and animals of Lake Ontario shall be free from contaminants and organisms resulting from human activities at levels that affect human health or aesthetic factors such as tainting, odor and turbidity.
	* Lake Ontario offshore and nearshore zones and surrounding tributary, wetland and upland habitats shall be of sufficient quality and quantity to support ecosystem objectives for health, productivity and distribution of plants and animals in and adjacent to Lake Ontario.
	* Human activities and decisions shall embrace environmental ethics and a commitment to responsible stewardship.

Table 4.3. Ecosystem objectives for Lake Superior (as developed by the Superior Work Group; CCME 1996).

Objective Category	Objective Narrative
General	Human activity in the Lake Superior basin should be consistent with "A Vision for Lake Superior"…Future development of the basin should protect and restore the 14 uses identified in Annex 2 of the Great Lakes Water Quality Agreement.
Aquatic Communities	Lake Superior should sustain diverse, healthy, reproducing and self-regulating aquatic communities closely representative of historical conditions.
Terrestrial Wildlife Objective	The Lake Superior ecosystem should support a diverse, healthy, reproducing and self-regulating wildlife community
Habitat Objective	Extensive natural environments such as forests, wetlands, lakes and watercourses are necessary to sustain healthy native animal and plant populations in the Lake Superior ecosystem and have inherent spiritual, aesthetic and educational value. Land and wa
Human Health Objective	The health of humans in the Lake Superior ecosystem should not be at risk from contaminants of human origin. The appearance, taste and odour of water and food supplied by the Lake Superior ecosystem should not be degraded by human activity.
Developing Sustainability	Human use of the Lake Superior ecosystem should be consistent with the highest ethical and scientific standards for sustainable use. Land, water and air use in the Lake Superior ecosystem should not degrade it nor any adjacent ecosystems. Use of the basin's natural resources should not impair the natural capability of the basin ecosystem to sustain its natural identity and ecological functions, nor should it deny current and future generations the benefits of a healthy, natural Lake Superior ecosystem. Technologies and development plans that preserve natural ecosystems and their biodiversity should be encouraged.

Table 5.1. Desirable characteristics of indicators for different purposes (from IJC 1991).

Characteristic of Indicator	Purpose of Indicator				
	Assessment	Trends	Early Warning	Diagnostic	Linkages
Biologically relevant	3	3	2	2	2
Socially Relevant	3	3	2	2	2
Sensitive	*	*	*	*	*
Broadly applicable	2	2	2	1	1
Diagnostic	1	1	1	3	1
Measurable	*	*	*	*	*
Interpretable	3	3	2	1	1
Cost-effective	*	*	*	*	*
Integrative	2	2	1	1	2
Historical data	*	*	*	*	*
Anticipatory	1	1	3	1	2
Nondestructive	*	*	*	*	*
Continuity	2	3	1	1	1
Appropriate scale	*	*	*	*	*
Lack of redundance	*	*	*	*	*
Timeliness	2	2	3	3	2

Table entries are on a scale of importance from one to three, where one indicates lower importance and three indicates an essential attribute. Characteristics that are universally desirable and do not differ between purposes are marked with an asterisk (*).

Table 5.2. Recommended metrics for various indicators of sediment quality conditions for freshwater environments.

Ecosystem Health Indicators	Candidate Metrics	Relative Priority
Sediment Quality Tetrad	* Tetrad evaluation	High
Sediment Chemistry	* Concentration of COPCs	High
	* Mean PEC quotient	High
	* Total organic carbon	High
	* SEM minus AVS	Moderate
	* Pore water chemistry	Moderate
Sediment Toxicity	* 10-day *Hyalella azteca* survival and growth	Moderate
	* 10-day *Chironomus tentans* survival and growth	Moderate
	* 28-day *Hyalella azteca* survival and growth	High
	* Life-cycle Chironomid test	High
	* *In situ* toxicity tests	Low
	* Microtox®/Mutatox®	Low
Benthic Invertebrate Community Structure	* Total abundance	Moderate
	* Abundance of key taxa/groups	High
	* Diversity	High
	* Evenness	Moderate
	* Presence/absence of indicator species	Moderate
	* Biomass	Low
	* Macroinvertebrate index of biotic integrity	High
Physical Characteristics	* Particle size	High
	* Sedimentation rate	Moderate
	* % Depositional area	Moderate
Water Chemistry	* Concentrations of COPCs in pore water	Moderate
	* Concentrations of COPCs in overlying water	Low
	* Dissolved oxygen in overlying water	Moderate
	* Dissolved oxygen in pore water	Moderate
	* Ammonia in pore water	High
	* Hydrogen sulfide in pore water	High
	* Biological oxygen in demand in pore water	Low

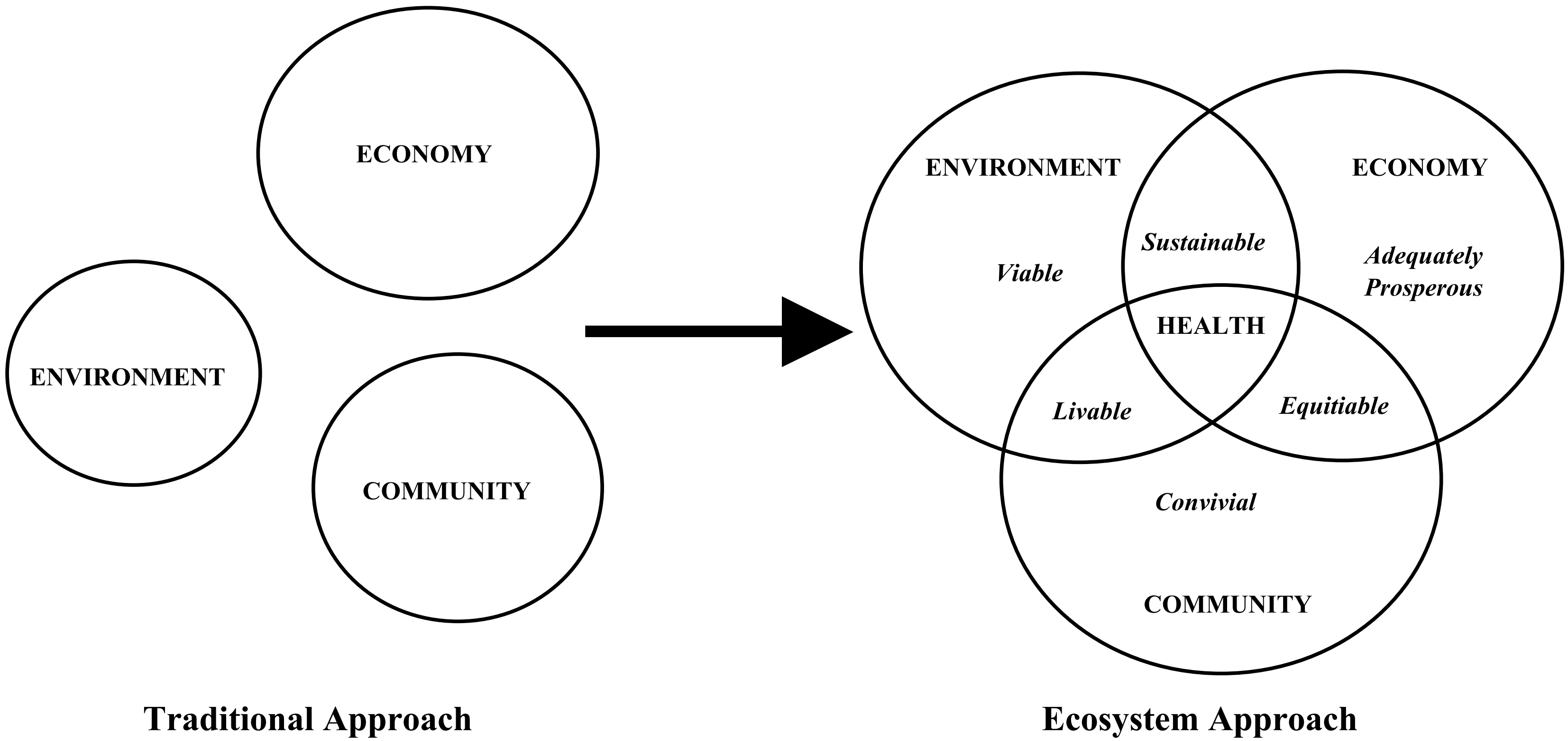
Table 5.2. Recommended metrics for various indicators of sediment quality conditions for freshwater environments.

Ecosystem Health Indicators	Candidate Metrics	Relative Priority
Tissue Chemistry (including bioaccumulation studies)	* Concentrations of COPCs in macroinvertebrate, fish, and wildlife tissues	High
	* 28-day *Lumbriculus variegatus* bioaccumulation	High
	* Number of fish and wildlife advisories	High
	* Hazard quotients	High
Pore water toxicity	* 48-hour *Daphnia magna* survival	Low
	* 7-day *Ceriodaphnia dubia* survival and growth	Moderate
	* 7-day fathead minnow (larval) survival and growth	Low
	* Microtox®	Low
Biomarkers in Fish	* Number of preneoplastic and neoplastic lesions in fish livers	High
	* Presence of external tumors	High
	* P450 activity	Low
	* Internal parasite loads in fish	Low
	* External parasite loads in fish	Low
Water Column and Elutriate Toxicity	* 96-hour *Selenastrum capricorntum* cell yield and cell density	Low
	* 48-hour *Daphnia magna* survival	Low
	* 7-day *Ceriodaphnia dubia* survival and growth	Low
	* 7-day fathead minnow (larval) survival and growth	Low
	* 96-hour rainbow trout (juvenile) or fathead minnow (juvenile) survival	Low

PEC - probable effect concentration; SEM - simultaneously extractable metals; AVS - acid volatile sulfides.

Figures

Figure 2.1. The shift from traditional to ecosystem-based decision making (from CCME 1996).



Relationships within ecosystems can best be visualized as three interlocking circles: environment, economy, and community. Traditionally most decision making separates these three components, with little understanding (or even heed), for example, of the effects of economic decisions on community needs or the environment. The challenge now is two-fold: to understand the links between these components and to redress the balance among them. The ecosystem approach requires an equal and integrated consideration of these elements.

Figure 2.2. A framework for ecosystem-based management (from CCME 1996)

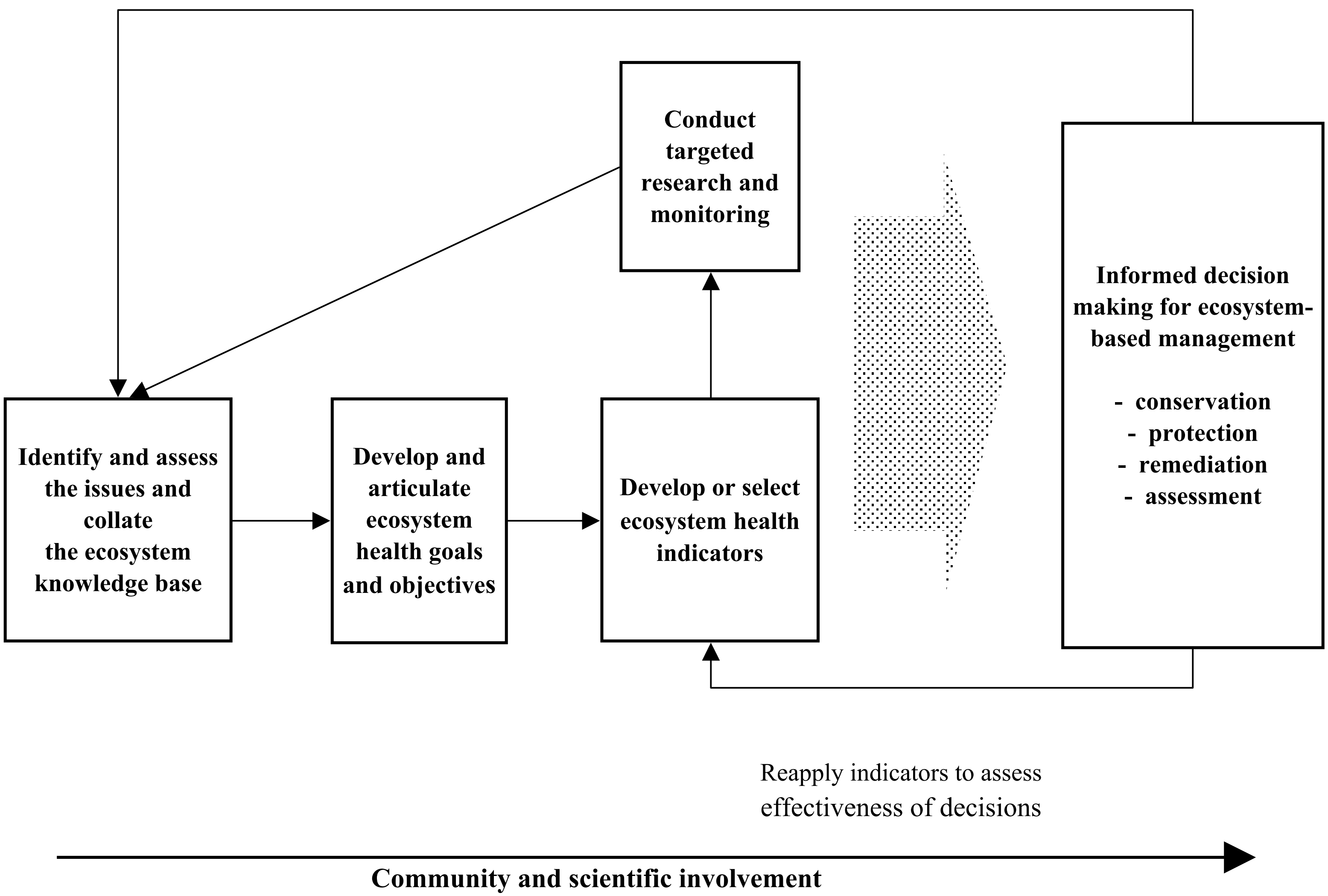


Figure 2.3. Relationship between ecosystem goals, objectives, indicators, metrics, and targets.

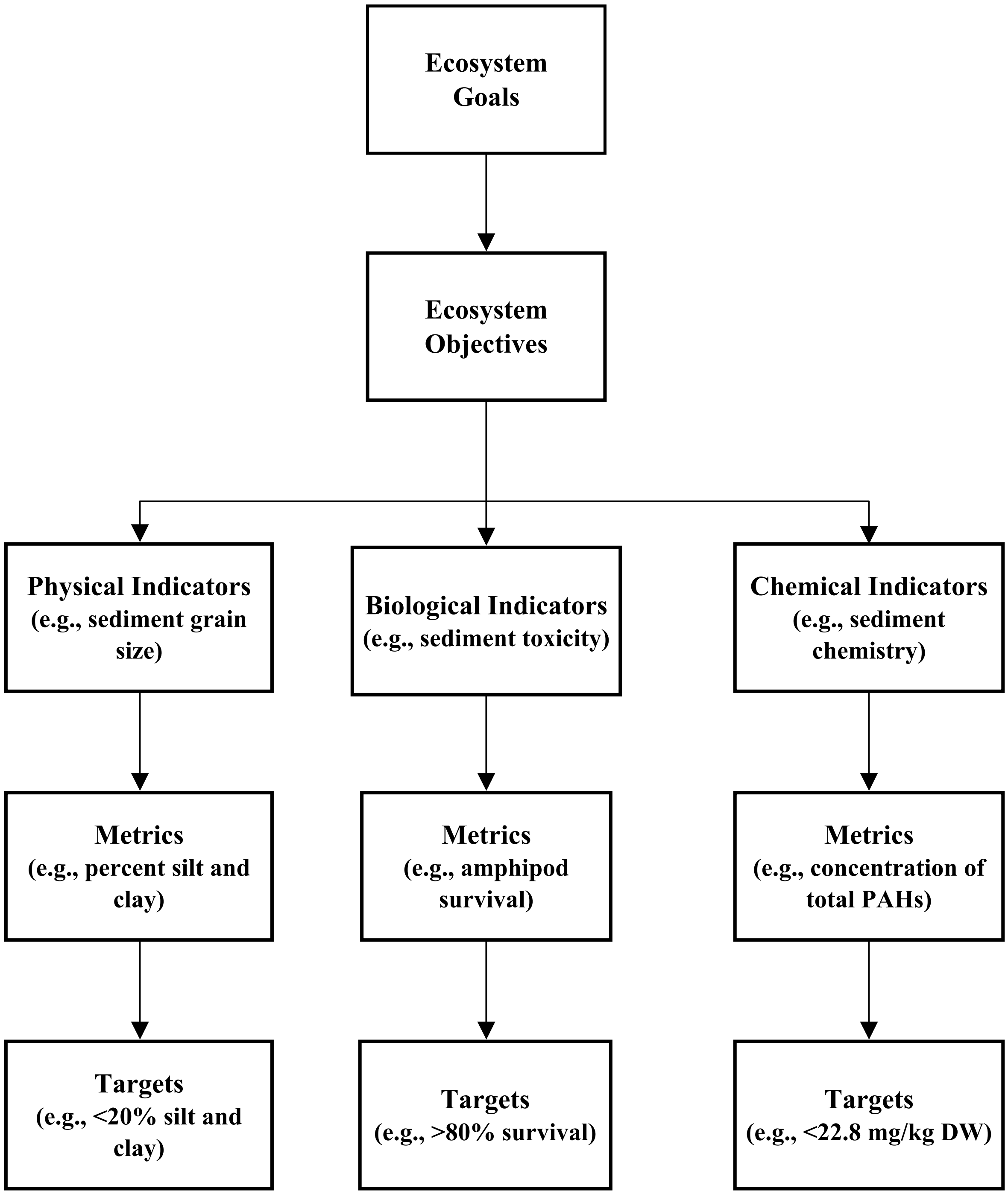


Figure 5.1. An overview of the implementation process for the ecosystem approach to environmental management.