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affected fish and wildlife populations. Furthermore, fish in many of these areas often 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 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 and was developed for the United States Environmental Protection Agency, British Columbia Ministry of Water, Land and Air Protection, and Florida Department of Environmental Protection, 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 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 of Relevant Publications (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 is presented in this document (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 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

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
ESB	equilibrium partitioning-derived sediment benchmarks
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
mIBI	macroinvertebrate index of biotic integrity
-min	- minutes
mm	millimeter
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€	

€no guideline available

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
PRGs	preliminary remedial goals
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	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 sediment sampling zone

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.

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.

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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 39the2GuTidance65M005 Tanual w1er3e8 pr0652 0 Td (Sedimxt for2126 Tc 2.1848 0 Td (for)Tj -0.0039 Tc 1.3478 0 Tc

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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 criteria 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).

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 2.

1.2 Purpose of the Report

In response to 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 Water, Land and Air Protection 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 and was developed for the United States Environmental Protection Agency, British Columbia Ministry of Water, Land and Air Protection, and Florida Department of Environmental Protection, 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. 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 of Relevant Publications (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 (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 sediments 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 to Volume II.

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: whole-sediment and pore-water chemistry data (Chapter 2); whole-sediment and pore-water 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 (Allen *et al.* 1991; Environment Canada 1996; IJC 1997; MacDonald 1997; Crane *et al.* 2000). 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

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 morn 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; MacDonald *et al.* 2002a; 2002b).

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):

- 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 goals management paulTc 1.82 0 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 a 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 (FTc 0 Tw [illegible] 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 (i.e., within an adaptive management context; by systematically evaluating the efficacy of management decisions and using that information to refine management strategies in the future). 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 as a whole. 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 5 (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 substances, 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

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 chemical substances to aquatic ecosystems. In turn, information on potential 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

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 5).

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}

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 may be 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

- 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.

- Humans 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 can be defined in terms of various spatial and temporal scales. The choice of scale depends on the problem to be addressed and/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 in assessment and management processes.

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 animals, 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

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4.4 Convening Multi-Stakeholder Workshops

Multi-stakeholder workshops and community meetings can provide participants with an opportunity to describe the desired future state of the ecosystem (i.e., the long-term vision for the future). 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.

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 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.

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 sed

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objectives

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 future 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 and on interpretation of data generated from these indicators 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 status 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 the amphipod, *Hyalella azteca*, in 28-day toxicity tests), while a target defines the desirable range of a specific metric (e.g., not statistically different from the control response; Volume III). 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 3 and 4.

The identification of candidate ecosystem health indicators represents an important step in the ecosystem-based management process. Candidate ecosystem health indicators

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 soeTindiv0 u naspecieicators; determination of their status should be supported by procedures for which it is c>drBw (ch it is)

- 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 9 (designated as * and 3, respectively; 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 should 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

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 (e.g., species richness). 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 9). 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 9, 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) and MacDonald *et al.* (2002a; 2002b) evaluated a variety of candidate ecosystem health indicators and concluded that the following were particularly relevant for assessing sediment quality conditions in freshwater ecosystems.

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 varietof2045.96 TTc 2.21 0 T05 es

- 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 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. Guidance on the collection of sediment quality data [illegible]

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Tables

Table 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 2. A summary of use impairments potentially associated with contaminated sediment and the numbers of Great Lakes areas of concern with such use impairments (from IJC 1997).

Use impairment	How contaminated sediment may affect use impairment	*Number of Areas of Concern with the impaired use (%)
Restrictions on fish and wildlife consumption	* Contaminant uptake via contact with sediment or through the food web	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	* Contaminant transfer via contact with sediment or through the food web * Possible metabolism to carcinogenic or more carcinogenic compounds	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 * Nutrient enrichment leading to a shift in species composition and 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%)

Table 2. A summary of use impairments potentially associated with contaminated sediment and the numbers of Great Lakes areas of concern with such use impairments (from IJC 1997).

Use impairment	How contaminated sediment may affect use impairment	*Number of Areas of Concern with the impaired use (%)
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%)
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 * Degradation of spawning and nursery grounds due to siltation	34 (81%)

Table 3. 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 4. Comparison of four approaches to resolving human-made ecosystem problems (from Environment Canada 1996).

Problem	Approach			
	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 5. 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 * Explosives or ammunition 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 * Paint, lacquer or varnish manufacturing, formulation, recycling or wholesale bulk storage * Pharmaceutical products manufacturing * Plastic products (foam or expanded plastic products) manufacturing * Textile dying * Pesticide manufacturing, formulation or wholesale bulk storage * 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 * Transformer oil manufacture, processing or wholesale bulk storage
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 * Coal or lignite mining, milling, wholesale bulk storage or shipping * Milling reagent manufacture, wholesale bulk storage or shipping * Nonferrous metal concentrate wholesale bulk storage or shipping * Nonferrous metal mining or milling

Table 5. 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 * Ash deposit from boilers, incinerators, or other thermal facilities * Asphalt tar roofing manufacture, wholesale storage and distribution * Coal gasification (manufactured gas production) * Medical, chemical, radiological or biological laboratories * Rifle or pistol firing ranges * Road salt storage facilities * Measuring instruments (containing mercury) manufacture, repair or 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 coke manufacture, wholesale bulk storage or shipping * Petroleum product dispensing facilities, including service stations and cardlots * Petroleum, natural gas or sulphur pipeline rights of way excluding rights of way for pipelines used to distribute natural gas to consumers in a 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 6. 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 the living organisms among them interact to form an ecosystem."
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."

Table 7. Ecosystem goals and objectives for Lake Ontario (as developed by the Ecosystem Objectives Work Group; CCME 1996).

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 8. 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	T*33previn perior WsC napmeal l thsca>>BfeapmeehC /P <18.5551 SuperiDegran pefeapmeeh onsistent rehab

Table 9. Desirable characteristics of indicators for different purposes (from IJC 1991).

Characteristic of Indicator	Purpose of Indicator	
	Assessment	Trends

Table 10. Recommended metrics for various indicators of sediment quality conditions for freshwater environments.

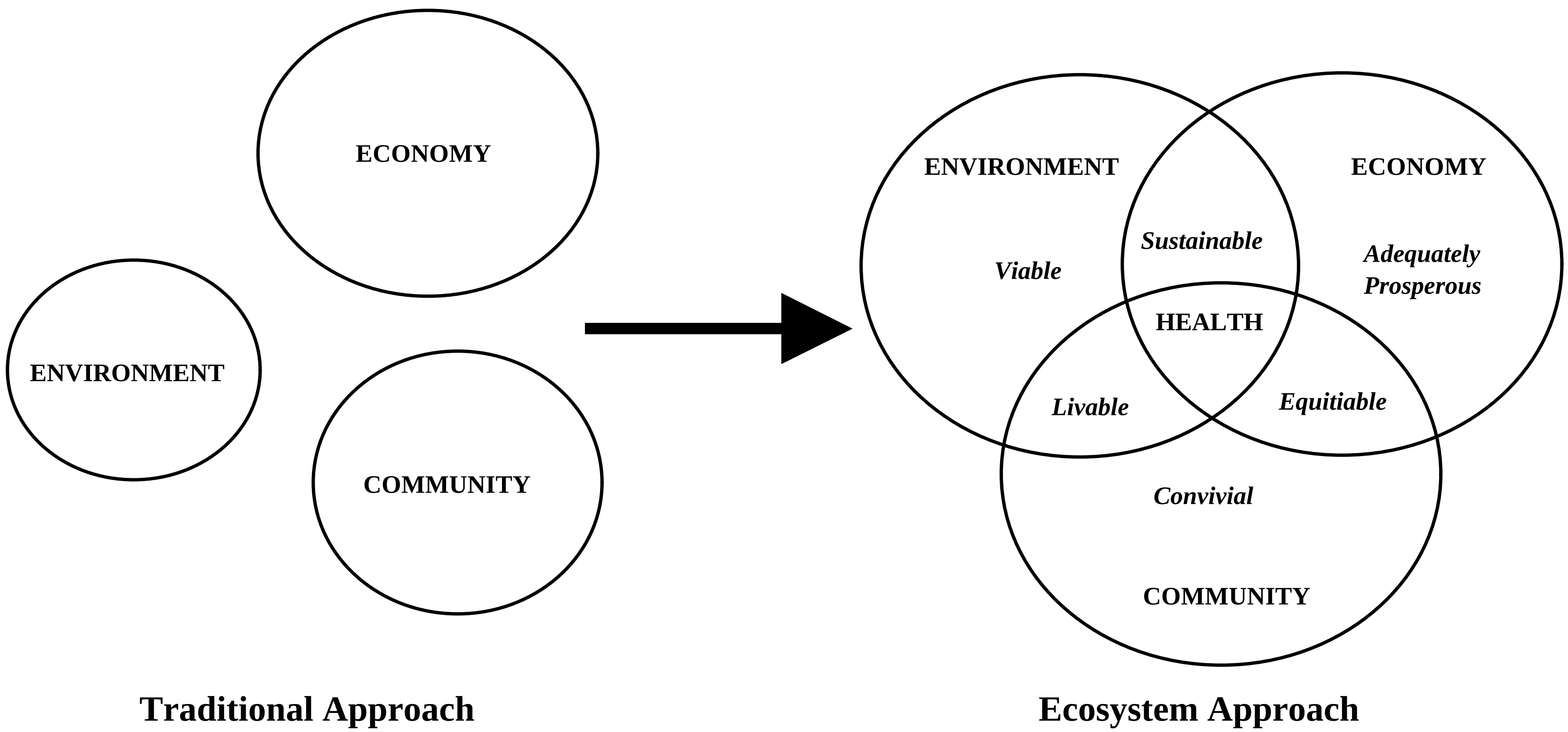
Table 10. Recommended metrics for various indicators of sediment quality conditions for freshwater environments.

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

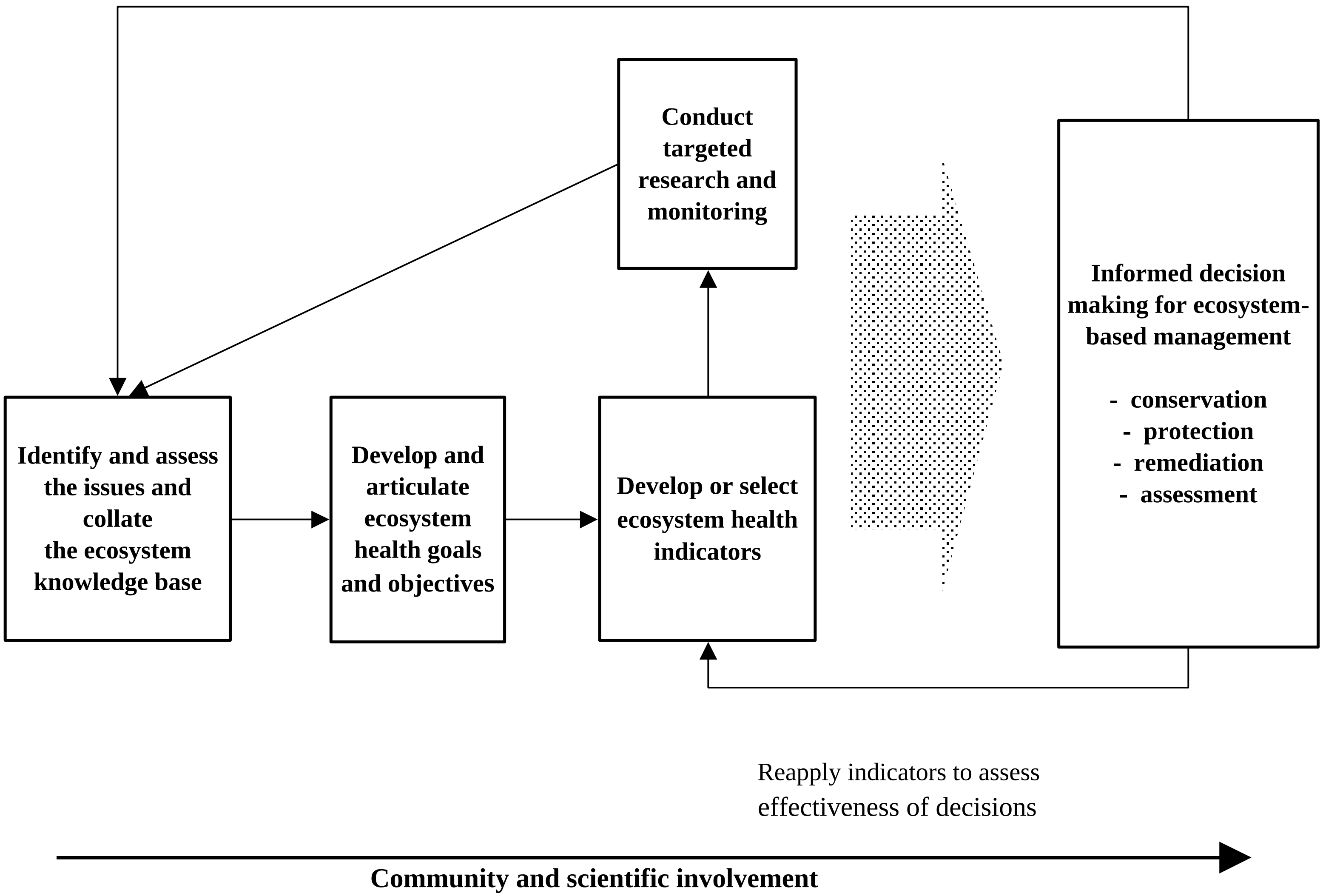
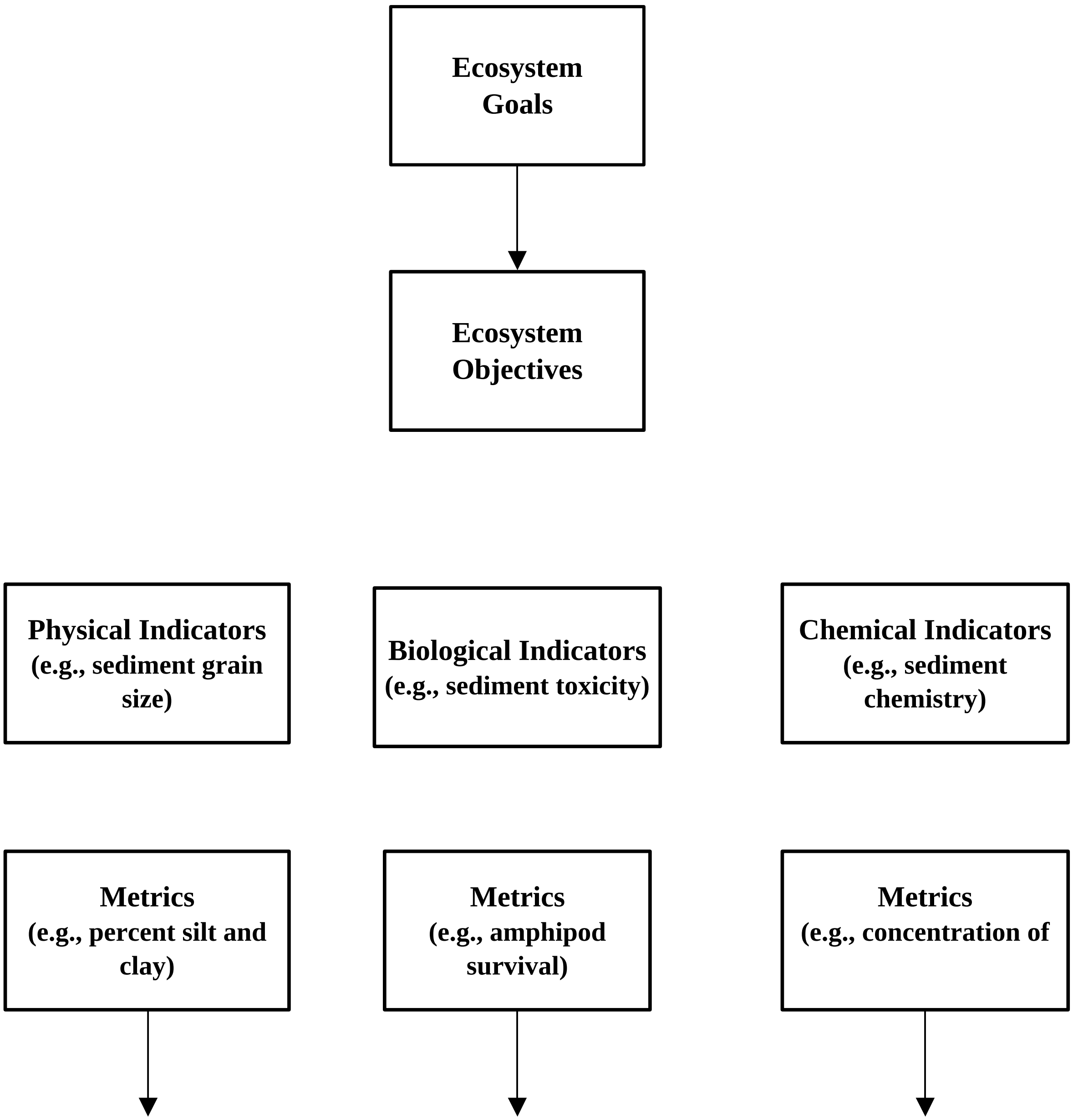


Figure 3. Relationship between ecosystem goals, objectives, indicators, metrics, and targets.



Appendices

Appendix 1. Role of Sediments in Aquatic Ecosystems

A1.0 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).

A1.1 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).

A1.2 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 primh.1.05 al(E0Tj -0.00 s10 Td (cycl. Td (r7tos))Tj 5.74 0 Tdor)Tj -0.0

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 Introduction

This appendix provides a bibliography of publications that are relevant to the assessment of contaminated sediments in freshwater ecosystems. The references are sorted in alphabetic order by first author. To assist readers in accessing key documents, each reference was classified according to the primary topic or topics that it addresses, as follows:

Classification Number	Topic
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 Listing of Publications

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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

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).