A Guidance Manual to Support the Assessment of Contaminated Sediments in Freshwater, Estuarine, and Marine Ecosystems in British Columbia

Volume II – Design and Implementation of Sediment Quality Investigations in Freshwater Ecosystems

Submitted to:

Mike Macfarlane
British Columbia Ministry of Environment, Lands, and Parks
Industrial Wastes and Hazardous Contaminants Branch
2975 Jutland Road
Victoria, British Columbia
V8V 1X4

Submitted – June 2003 – by:

MacDonald Environmental Sciences Ltd.
#24 - 4800 Island Highway North
Nanaimo, British Columbia V9T 1W6

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Donald D. MacDonald[1] and Christopher G. Ingersoll[2]

[1]MacDonald Environmental Sciences Ltd.
#24 - 4800 Island Highway North
Nanaimo, British Columbia V9T 1W6

[2]United States Geological Survey
4200 New Haven Road
Columbia, Missouri 65201

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Executive Summary

Traditionally, concerns relative to the management of aquatic resources in freshwater, estuarine, and marine ecosystems have focussed 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 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 in aquatic ecosystems 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 Canada and the United States. 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 often have higher levels of tumours 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. Such use impairments have been observed at numerous sites in British Columbia, particularly in the Fraser River basin, Columbia River basin, and nearshore areas in the vicinity of industrial developments.

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, estuarine, and marine ecosystems. 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 four-volume series and was developed for the British Columbia Ministry of Water, Land and Air Protection, based on guidance prepared for the United States Environmental Protection Agency and the 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 recommended procedures for designing and implementing sediment quality investigations in freshwater ecosystems (Volume II);
- Describing the recommended procedures for interpreting the results of sediment quality investigations (Volume III); and,

- Providing supplemental guidance on the design and implementation of detailed site investigations in marine and estuarine ecosystems (Volume IV).

The first volume of the guidance manual, ***An Ecosystem-Based Framework for Assessing and Managing Contaminated Sediments***, 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 in Freshwater Ecosystems***, describes the recommended procedures for designing and implementing sediment quality assessment programs. More specifically an overview of the recommended framework for assessing and managing sediment quality conditions 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 and on the evaluation of sediment quality data is provided in the Appendix 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 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 focussed sediment quality assessment programs.

The final volume of the series, ***Supplemental Guidance on the Design and Implementation of Detailed Site Investigations in Marine and Estuarine Ecosystems***, is intended to complement the guidance that is provided in the other three volumes by supporting the design and implementation of assessments of sediment quality conditions in marine and estuarine ecosystems. Accordingly, the document describes the objectives of a detailed investigation for marine and estuarine sites (Chapter 2). In addition, guidance is provided on the collection of physical, chemical, and biological data and information to support such a detailed site investigation (Chapter 3). Furthermore, guidance is provided on the interpretation of the data collected in the detailed site investigation (Chapter 4). Together, this guidance is intended to provide readers with some of the information needed to design and implement detailed investigations of marine and estuarine sites with contaminated sediments.

List of Acronyms

%	percent
µg	microgram
µg/kg	micrograms per kilogram
µg/L	micrograms per litre
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_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
NRDAR	natural resource damage assessment and restoration
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
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
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 toxic or bioaccumulative substances that occur at concentrations that are sufficient to cause or substantially contribute to adverse effects on microbial, benthic invertebrate, plant, fish, avian or mammalian communities.

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 and restoration – 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 or 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.

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Chapter 1. Introduction

In response to concerns raised regarding contaminated sediments, a number of programs have been established or expanded to support the assessment and management of contaminated sediments in the United States and Canada. The information generated under these programs provides important guidance for designing and implementing investigations at sites with contaminated sediments (see USEPA 1994; MacDonald 1994a; 1994b; Reynoldson *et al.* 2000; Ingersoll *et al.* 1997; USEPA and USACE 1998a; ASTM 2001a; USEPA 2000a; 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 four-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 and USACE 1998a; USEPA 2000a; 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 in freshwater ecosystems (Volume II);
- Describing the recommended procedures for interpreting the results of sediment quality investigations (Volume III); and,
- Providing supplemental guidance on the design and implementation of detailed site investigations in marine and estuarine ecosystems (Volume IV).

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 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 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 in Freshwater Ecosystems***, describes the recommended procedures for designing and implementing sediment quality assessment programs. More specifically, 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 Appendix to Volume II.

The third volume in the series, ***Interpretation of the Results of Sediment Quality Investigations***, describes the four types of indicators 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 indicators 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 indicators 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 focussed sediment quality assessment programs.

The final volume of the series, ***Supplemental Guidance on the Design and Implementation of Detailed Site Investigations in Marine and Estuarine Ecosystems***, is intended to complement the guidance that is provided in the other three volumes by supporting the design and implementation of assessments of sediment quality conditions in marine and estuarine ecosystems. Accordingly, the document describes the objectives of a detailed investigation for marine and estuarine sites (Chapter 2). In addition, guidance is provided on the collection of physical, chemical, and biological data and information to support such a detailed site investigation (Chapter 3). Furthermore, guidance is provided on the interpretation of the data collected in the detailed site investigation (Chapter 4). Together, this guidance is intended to provide readers with some of the information needed to design and implement detailed investigations of marine and estuarine sites with contaminated sediments.

Chapter 2. Recommended Framework for Assessing and Managing Sediment Quality Conditions

2.0 Introduction

Guidance on the design and implementation of sediment quality investigations is available from a number of sources (e.g., WDOE 1995; USEPA 1994; 1998a; 1999b; 2000a; USEPA and USACE 1998a; ASTM 2001a). Based on a review of the guidance generated to date, the following framework was developed to assist in the design and implementation of efficient and effective sediment quality assessments. This framework identifies the steps that should be followed in conducting site-specific sediment quality assessment programs and comprises the following elements (Figure 1):

- Identifying sediment quality issues and concerns;
- Evaluating existing sediment quality data;
- Designing and implementing preliminary and detailed site assessments;
- Developing and implementing remedial action plans; and,
- Conducting confirmatory monitoring and assessment.

The recommended framework is intended to provide general guidance to support the sediment quality assessment (Figure 2) and remediation (Figure 3) processes in the province. More detailed guidance on preliminary and detailed site investigations is provided in Chapter 3 (Figures 4 and 5) and Chapter 4 (Figure 6) of Volume II, respectively. Importantly, this guidance is not intended to supplant any program-specific guidance that has been developed previously (e.g., USEPA 1997).

2.1 Identify Sediment Quality Issues and Concerns

The first phase of a site-specific sediment quality assessment involves the evaluation of sediment issues and concerns at the area (or site) under investigation (see Chapter 3 of Volume I for additional information). As a first step in this process, the pertinent historical information on the area under consideration is collected and reviewed. More specifically, information is required on the types of industries and businesses that operate or have operated in the area, on the location of wastewater treatment plants, on land use patterns in upland areas, on stormwater drainage systems, on residential developments, and on other historic, ongoing, and potential activities within the area. These data provide a basis for identifying potential contaminant sources in the area. Information on the chemical composition of wastewater effluent discharges, types of substances likely to be associated with non-point sources, and physical/chemical properties [e.g., octanol-water partition coefficients (K_{ow}), organic carbon partition coefficients (K_{oc}), solubility] of those substances provides a basis for developing an initial list of chemical of potential concern (COPCs; i.e., the substances that could be posing risks or hazards to ecological receptors or human health) at the site. By evaluating the probable environmental fate of these COPCs, it is possible to establish a list of COPCs and areas of interest with respect to sediment contamination at the site (Figure 4).

In addition to information on contaminant sources, information should be collected that helps define the ecosystem health goals and objectives (if these have not already been defined; Chapter 4 of Volume I). In many jurisdictions, protection and restoration of the designated uses of the aquatic ecosystem represents a primary ecosystem health goal for areas of concern. As such, ecosystem goals in freshwater systems may be based on protection of the ecosystem as a whole, maintenance of viable populations of sportfish species, protection of human health (e.g., swimmable and fishable), or a variety of other considerations (e.g., regional stormwater management, industrial development). In turn, information on existing uses of the site provides a basis for making decisions regarding the nature and extent of the investigations that should be conducted at the site. Mudroch and McKnight (1991), Baudo and Muntau (1990) and MacDonald (1989) provide detailed descriptions of the types of background information (e.g., location and nature of industrial facilities, location and characteristics of point source effluent discharges, location of stormwater discharges, land and water uses in the vicinity of the site, and location of sediment depositional zones) that

should be obtained and guidance on how these data may be used to help define sediment quality issues and concerns.

The existing data on the various indicators selected for assessing sediment quality conditions should also be collected and collated at this stage of the process. Such data may include information on sediment chemistry, tissue chemistry, sediment toxicity, benthic invertebrate and fish community structure, fish health, and the presence of fish consumption advisories (see Volume III for more information on each of these indicators). State, tribal, federal, and provincial agencies represent primary sources of such data; however, industrial interests, local governments, and environmental groups should not be overlooked.

2.2 Evaluating Existing Sediment Chemistry Information

Acquisition and evaluation of existing sediment quality data is a critical component of the sediment quality assessment process. Because such data may have been collected under a variety of programs and for a number of reasons, it is essential that these data be fully evaluated to determine their applicability in the sediment quality assessment process. This evaluation should cover the overall quality of the data set (i.e., relative to project data quality objectives; DQOs) and the degree to which the data are thought to represent current conditions at the site under consideration.

Concerns regarding data quality may be resolved by evaluating the quality assurance/quality control (QA/QC) measures that were implemented during collection, transport, and analysis of sediment samples (Appendix 1 of Volume II). A number of conventions have been established to provide guidance on the field aspects of sediment sampling programs (USEPA and USACE 1998a; ASTM 2001c; USEPA 2001); this guidance can be used to evaluate the sample collection, handling, and transport procedures used in previous investigations. A diversity of standardized analytical procedures have been developed to quantify concentrations of COPCs in sediments (e.g., USEPA and USACE 1991; APHA *et al.* 1998; see Chapter 2 of Volume III). However, explicit adherence to standard methods does not necessarily assure that project DQOs will be met. For this reason, evaluating the performance of analytical laboratories using the quality assurance data generated during the

investigation is essential. More specifically, analytical results may be evaluated based on the reported accuracy and precision of the technique (i.e., the results of analyses performed on certified reference materials, and on split and spiked sediment samples; USEPA 1994). Analytical detection limits are also relevant to the assessment of potential biological effects at the site. The suitability of the detection limits may be assessed by comparing them with the threshold effect concentration (TEC)-type SQGs for that substance (MacDonald *et al.* 2000). Criteria for evaluating the applicability of candidate data sets for use in sediment quality assessments are presented in Appendix 4 of Volume III.

Assessment of sediment quality conditions requires information that adequately represents the contemporary environmental conditions at the site under consideration. Therefore, the age of the data is a central question with respect to determining the applicability of the data. Natural degradative processes in sediments can lead to reductions in the concentrations of certain organic COPCs over time (Mosello and Calderoni 1990). Major events (such as storms) can result in the transport of sediments between sites, while industrial developments and/or regulatory activities can alter the sources and composition of COPCs released into the environment over time. Thus, it is important that assessments of sediment quality be undertaken with the most recent data available. In many cases, new data will need to be collected to support such assessments if the existing data is of questionable relevance (i.e., > 10 years old).

In addition to temporal variability, the sediment quality is known to vary significantly on a spatial basis (Long *et al.* 1991; 1996). Therefore, any single sample is likely to represent only a small proportion of the geographic area in which it was collected. For this reason, data from a number of stations should be available to provide a representative picture of sediment quality conditions at the site, with the actual number of stations required dependent on the size of the area under consideration, the concentrations of sediment-associated COPCs, and the variability of COPC concentrations (see Appendix 1 of Volume II for more information for assessing the extent to which data sets represent sediment quality conditions at a site).

Another important factor to consider in evaluating the applicability of existing sediment quality data is the list of variables that were analysed. It is important that the list of analytes reflects the existing and historical contaminant sources from land and water use activities in

the area (Table 1). In harbors, for example, variables such as pentachlorophenol (which is often used as a preservative for pilings), tributyltin (which is often used in antifouling paints for ships), and copper (which is often used in antifouling paints for pleasure craft) should be measured. Similarly, elevated concentrations of polycyclic aromatic hydrocarbons (PAHs) and lead are frequently observed in sediments in the vicinity of urban stormwater discharges. In agricultural areas, persistent pesticides and nutrients should be considered in sediment quality assessments. At minimum, data on the levels of metals, PAHs, and polychlorinated biphenyl (PCBs) are needed to assess sediment contamination at most sites. It is also important to determine if the available biological effects data (e.g., acute toxicity tests) are relevant for determining if the management objectives established for the site have been compromised by contaminated sediments (i.e., the results of chronic toxicity tests and/or benthic invertebrate community assessments are usually needed to determine if sediment-dwelling organisms are likely to be or have been adversely affected by sediment contamination).

Development of a project database is an important element of the overall sediment quality assessment process. Designing and populating the project database early in the process (i.e., during the collation of existing information) is beneficial to support the evaluation of current conditions and the identification of any additional investigations that may be needed at the site. In general, a relational database format is the most flexible for conducting subsequent analyses of the historic data (Field *et al.* 1999; 2002; Crane *et al.* 2000). Importantly, the format of the database should support linkage to various analytical tools, such as NOAA's Query Manager and Marplot applications and ESRI's Spatial Analyst and ArcView applications (MacDonald and Ingersoll 2000).

If the results of the data evaluation process indicate that sufficient quantities of acceptable quality data are available, then initiating the data interpretation process is possible. However, if the sediment chemistry or other historical effects data are considered to be of unacceptable quality or are not considered to adequately represent the site, additional data may be required to complete the sediment quality assessment. Such data gaps may be addressed by conducting additional sampling to acquire the data needed to support a preliminary site investigation (Section 2.3 and Chapter 3 of Volume II) and/or a detailed site investigation (Section 2.4 and Chapter 4 of Volume II).

2.3 Conducting a Preliminary Site Investigation (PSI)

The term PSI is used to describe a screening level-type investigation (e.g.,screening-level ecological risk assessment; SERA; Figures 4 and 5). Preliminary site investigations are typically phased and should be conducted at any site suspected of having contaminated sediments. The PSI is intended to provide information for assessing the probability that adverse effects can be attributed to elevated concentrations of contaminants in sediments at the site. A PSI may be conducted using historical data (if deemed adequate) or by collecting additional data to fill any identified data gaps. In the PSI, evaluations of sediment quality conditions typically rely on sediment chemistry data alone (although other types of data can be used if available).

The first stage of the PSI (Phase I) involves the use of historical records, interviews with local individuals, reconnaissance trips, and related activities to ascertain if sediments are likely to be contaminated, to identify which locations are most likely to be affected, and to determine which substances are likely to occur in sediments at the site (Figure 4). If sufficient information is available and the results indicate that sediment contamination is unlikely, then no further investigations are required at the site. However, further investigation is required if insufficient information is available to evaluate the potential for sediment contamination and/or if the available information indicates that the site is likely to contain contaminated sediments (see Chapter 3 of Volume II).

The second stage of the PSI (Phase II) is undertaken to provide information on the general location of contaminated sediments at the site and determine the degree of any contamination that exists (Figure 5). The Phase II PSI generally includes three main activities, including design and implementation of a sampling and analysis plan (SAP; which may utilize random and/or biassed sampling designs; Chapter 5 of Volume II), chemical analysis of the samples to determine the concentrations of COPCs, and comparison of the ambient concentrations of COPCs to selected targets for sediment quality assessment. Numerical, effects-based SQGs (such as those reported by MacDonald *et al.* 2000; USEPA 2000a) are particularly useful in this application because they provide a basis for estimating the probability of observing sediment toxicity in samples with various chemical characteristics. In addition bioaccumulation-based SQGs can be used to evaluate potential effects of bioaccumulation of sediment-associated COPCs on aquatic-dependent wildlife or human health (e.g.,

NYSDEC 1999; Section 4.1.4). These activities need to be directed through the development of a SAP, which includes a quality assurance project plan (QAPP; see WDOE 1995 for more information on the development of a SAP; guidance on the development of a QAPP is provided in USEPA 1991a; 1991b; 1991c; 1991d; 2000b; also see Section 3.2.1 and 4.1.6 of Volume II). No further investigations are required if the results of the PSI indicate that it is unlikely that COPCs at the site are adversely affecting sediment-dwelling organisms, wildlife, or human health (i.e., through comparison to appropriate sediment quality criteria or equivalent tools). However, a more detailed site investigation should be conducted if the results of the PSI indicate that sediments may be contaminated by toxic and/or bioaccumulative substances at levels that are likely to adversely affect sediment-dwelling organisms, wildlife, or human health.

In addition to the specific goals identified above, the preliminary site assessment must consider the specific nature of the site under investigation and the potential effects of physical or geophysical factors on contaminant transport or exposure routes. For example, factors such as storm water discharges, over-bank seeps, and sediment transport can influence the accumulation of COPCs in surficial sediments. In addition, scour, dredging, groundwater upwelling, and other processes can affect the quality of deeper sediments or transport COPCs to the surface. Therefore, sampling programs need to be designed to acquire broad information on the site, including the data needed to apportion liability among proponents.

2.4 Conducting a Detailed Site Investigation (DSI)

A DSI should be conducted when the results of the PSI indicate that a site contains or is likely to contain concentrations of contaminants in sediments that are adversely affecting sediment-dwelling organisms, wildlife, or human health. In this context, the term DSI is used to describe various types of detailed investigations that are conducted under specific programs [e.g., baseline ecological risk assessment (BERA) or human health risk assessment (HHRA); USEPA 1997]. The DSI is intended to provide detailed information on the site, including:

- The identity of the substances that are causing or substantially contributing to adverse effects on ecological receptors or human health (i.e., contaminants of concern; COCs);
- The magnitude and areal extent of sediment contamination at the site; and,
- The potential for and/or actual effects of contaminated sediments on ecological receptors and/or human health.

By fulfilling these objectives, the DSI provides the information needed for assessing the risks to ecological receptors and/or human health posed by contaminated sediments and for developing a remedial action plan (RAP) for the site, if required (Figure 6). In many ways, the DSI is an extension of the Stage II PSI. Therefore, combining these two types of investigations under certain circumstances may be cost-effective (i.e., following the completion of a Stage I PSI, which primarily involved compilation and evaluation of existing sediment quality data and related information).

A number of important and potentially costly decisions are dependent on the results of the DSI. For this reason, it is essential that the DSI be based on a detailed study design, as articulated in the SAP and the associated QAPP. More specifically, the study should be designed to confirm or refute the presence of COPCs, to determine the spatial extent of chemical contamination (both in surficial and in deeper sediments), to identify chemical gradients (which can be used to identify possible sources of contamination), and to identify the location of sediment hot spots. While whole-sediment chemistry, sediment toxicity, and benthic invertebrate community structure are a primary focus of this investigation, the DSI should also provide data for assessing the nature, severity, and extent of contamination in surface water, pore water, and biological tissues (including sediment-dwelling organisms, fish, and wildlife, as appropriate) and for assessing the status of fish communities inhabiting the area. Such information on the levels of COPCs can then be evaluated relative to the SQGs, water quality criteria (WQC), or tissue residue guidelines (TRGs; Volume III). In this way, it is possible to identify the COCs at the site.

While the results of chemical analysis of environmental samples provide important information for assessing the risks that contaminated sediments pose to human health and environmental receptors, other types of data should also be collected during the DSI to

confirm the results of such assessments and to provide multiple lines of evidence for assessing risks to ecological receptors. Specifically, data from toxicity (including whole-sediment and pore-water tests), benthic invertebrate community, and fish community assessments can provide important information for evaluating the effects of contaminated sediments on aquatic organisms. In addition, bioaccumulation assessments can be used to assess the potential effects of COPCs that tend to bioaccumulate in the food web and, in so doing, pose risks to aquatic-dependent wildlife and/or human health. In designing the DSI, it is important to remember that the weight of evidence required needs to be proportional to the weight of the decisions that are likely to be made at the site (D. Mount. United States Environmental Protection Agency. Duluth, Minnesota. Personal communication). More detailed guidance on the design and implementation of DSIs is presented in Chapter 4 of Volume II, while supplemental guidance for sampling design is provided in Chapter 5 of Volume II.

2.5 Remedial Action Planning

The results of the DSI provide the information needed to assess the risks to aquatic organisms, aquatic-dependent wildlife, and human health associated with exposure to sediment-associated COPCs. At sites where such risks are not deemed to be significant, further action is likely to be limited to periodic monitoring to assess trends in environmental contamination. At other sites, remedial action may be needed to reduce risks to acceptable levels. Accordingly, a feasibility study is typically conducted following completion of the DSI to analyse the benefits (i.e., risk reduction), costs, and risks associated with various remedial options (Suter *et al.* 2000).

The feasibility study is intended to include a range of options that could be used to achieve the sediment management objectives at the site. Under the CERCLA Program in the United States, various remedial alternatives are evaluated using a total of nine criteria, thereby providing a basis for clearly articulating the relative advantages and disadvantages of each proposed alternative. The criteria are (Suter *et al.* 2000):

Threshold Factors - must be met by all alternatives:

1. Overall protection of human health and the environment; and,
2. Compliance with ARARs (applicable or relevant and appropriate requirements).

Primary Balancing Factors - used to compare alternatives with each other:

3. Long-term effectiveness and permanence;
4. Reduction in toxicity, mobility and volume through treatment;
5. Short-term effectiveness;
6. Implementability; and,
7. Cost.

Modifying Considerations - evaluated as a result of public comment:

8. State (support agency) acceptance; and,
9. Community acceptance.

Although comparable criteria have not been established for use in British Columbia, the CERCLA Program approach has been applied successfully at a number of sites. Therefore, it is recommended that feasability studies conducted in British Columbia employ the nine criteria that were established by USEPA. In this way, the results of the feasibility study are likely to provide the information needed to develop an effective RAP for the site.

Development of an RAP is a critical component of the contaminated site remediation process (Figure 7). The RAP should contain the results of any investigations conducted on the site, evaluations of various remediation options (including the results of public consultations), an evaluation of the potential impacts of the preferred remediation option, and a description of the monitoring and evaluation procedures that will be employed to assess the efficacy of the remedial measures. The reader is directed to Zarull *et al.* (2001), Krantzberg *et al.* (2000), Santiago and Pelletier (2001), Dewees and Schaefer (2001), and USEPA (2000b) for more information on remedial action planning for sites with contaminated sediments.

2.6 Confirmatory Monitoring and Assessment

Sediment quality assessments are typically conducted to determine if sediment contamination poses unacceptable risks to aquatic organisms, aquatic-dependent wildlife and/or human health. When the results of such assessments demonstrate that such unacceptable risks exist, remedial actions may be taken to reduce risks to acceptable levels (i.e., to facilitate achievement of ecosystem goals and objectives). Because it is difficult to precisely predict the outcome of remedial measures on an *a priori* basis, it is important to conduct confirmatory sampling and analysis to determine if the remedial measures implemented have achieved the goals identified in the RAP. The procedures for conducting follow-up monitoring and evaluation are the same as those that would be applied during a DSI.

Chapter 3. Conducting a Preliminary Site Investigation

3.0 Introduction

A PSI should be conducted at all sites that are suspected of containing contaminated sediments (see Section 2.3 of Volume II). A PSI is typically conducted in two distinct phases. The first phase of the investigation (i.e., Stage I PSI) is intended to provide the information needed to more fully assess the potential for sediment contamination at the site and is conducted using existing information (Figure 4; e.g., preliminary site characterization and scoping assessment; Suter *et al.* 2000). The second phase of the investigation (i.e., Stage II PSI) is intended to provide information on nature, areal extent, and severity of sediment contamination at the site (Figure 5; e.g., SERA; Suter *et al.* 2000). The sediment chemistry data compiled during this process provide essential information for determining if contaminated sediments pose unacceptable risks to human health and/or to the environment. The recommended procedures for conducting Stage I and Stage II PSIs for sites with contaminated sediments are described in the following sections of this chapter.

3.1 Stage I Investigation

The first phase of a site-specific sediment quality assessment involves the collection and review of historical information on the site under consideration. Specifically, information is required on the current and historic activities and uses, accidents and spills of chemical substances, and practices and management relating to potential contamination at the site. It is also important to obtain information on land use patterns and on the location of effluent and stormwater discharges in the vicinity of the site to evaluate the potential for contamination from off-site sources. Existing water quality, effluent quality, and sediment quality data should also be obtained at this stage of the PSI. This type of information can be acquired by conducting reconnaissance visits to the site and by conducting interviews with key individuals, such as current and former owners, occupants, neighbours, managers, and employees of the facility. Government agency staff represents an important source of

information on land use practices, designated water uses, contaminant sources, and ambient environmental conditions in the area.

The data collected during Stage I of the PSI should provide a basis for determining the nature and location of potential sources of contaminants to aquatic ecosystems. Information on the chemical composition of wastewater effluent discharges, on the chemicals used in the area, on the nature of spills and accidents, and on types of substances likely to be associated with non-point sources should be used to develop a preliminary list of COPCs at the site. The available information on the physical/chemical properties of the COPCs should then be used to identify the substances that are likely to partition into sediments (i.e., those with K_{ow}s of >3.5). These substances, then, form the basis of the refined list of COPCs with respect to sediment quality (Figure 4; see Chapter 3 of Volume I for more information on the identification of sediment quality issues and concerns).

During the Stage I PSI, information should be collected that helps to define the environmental management goals for the site. In many watersheds, for example, ecosystem goals and objectives have been established to guide resource management and restoration activities and to facilitate cooperation among the various participants. More specific goals and objectives for managing fine-grained sediments are established based on the legislative mandates of the responsible agencies. Information on the designated uses of sediment in the area is also needed to establish narrative management goals for the site (see Volume I of this guidance manual for more information on the establishment of ecosystem goals and objectives).

Evaluation of existing sediment chemistry data is a critical component of the site-specific sediment quality assessment process. Because sediment chemistry data are generated under various federal, tribal, state, and provincial programs for a variety of purposes, such data must be fully evaluated to determine their applicability to the sediment quality assessment that is being conducted. Some of the factors that should be considered in this evaluation include, sampling procedures, sample handling, transport, and holding procedures, analytical methods and detection limits, toxicity testing methods, age of the data, geographic distribution of the sampling stations, and the analytes measured (i.e., relative to the refined list of COPCs generated). More information on the evaluation of candidate data sets for use in sediment quality assessments is provided in Appendix 4 of Volume III.

Together, the information collected in the first phase of the PSI should provide a basis for determining if sediment contamination is likely to represent an unacceptable risk to the environment or to human health. Sediment contamination should be suspected if toxic or bioaccumulative substances have been or are likely to have been released into the aquatic ecosystems at or near the site, or if ambient monitoring data indicate that sediment contamination has occurred at or near the site (i.e., based on exceedances of SQGs). If the minimum data requirements have been met and evaluation of these data indicates that sediment contamination is unlikely, then the need for further action at the site is generally obviated. If the minimum data requirements have not been met, then the outstanding data gaps should be identified and preparations for proceeding to the next stage of the process should be made. Depending on the nature and extent of contamination and on the complexity of the site, investigators may choose to conduct a Stage II PSI or move directly to the DSI.

3.2 Stage II Investigation

A Stage II PSI is conducted if the results of the Stage I investigation indicate that the sediments at the site are likely to be contaminated with toxic or bioaccumulative substances. The second stage of the PSI is intended to provide information on the nature, location, and magnitude of sediment contamination at the site. The existing sediment chemistry data, which were assembled in Stage I, may be used in this investigation if they provide suitable areal coverage, include the substances on the refined list of COPCs, and are of sufficient quality. However, additional sediment sampling is required when existing data are of insufficient quality or quantity to support an assessment of sediment quality at a site. The Stage II PSI consists of two main elements, including the data collection phase and the data interpretation phase of the investigation.

3.2.1 Data Collection

A Stage II PSI should be conducted when the results of the Stage I PSI indicate that sediments are likely to be contaminated by toxic and/or bioaccumulative substances, but insufficient data are available to fully evaluate the nature, areal extent, and severity of sediment contamination. Therefore, the first step in the Stage II PSI involves designing a sampling program that will provide the information needed to fill the data gaps identified during the Phase I PSI. Some of the key steps involved in developing a Phase II PSI SAP include:

- Map and describe the area to be sampled;
- Map location and extent of sediment depositional zones at the site;
- Map and describe the proposed sampling sites (including latitude and longitude; both primary and alternate sampling sites should be identified at this stage of the process, with criteria specified for when alternate sites should be sampled);
- Describe the sediment sampling, handling, and storage procedures that will be used;
- List the chemical analytes that will be measured in sediment samples and associated data quality objectives; and,
- Describe the quality assurance procedures that will be used in the field and the laboratory to assure that the resultant data meet project DQOs (i.e., which should be included as an appendix to the SAP).

The first step in the development of a contaminated site sampling plan is to define the boundaries of the sediment sampling zone (SSZ). This step in the process is important because it defines the area that will be sampled to assess the areal extent of contamination and to identify sediment hot spots. For the purposes of conducting a Stage II investigation, it is recommended that the SSZ encompass the area that could, potentially, be contaminated due to releases of COPCs into receiving waters. The SSZ should extend from a point located well upstream of the discharge point or source area to a point located downstream of the first identified depositional area. It is important to note, however, that the SSZ does not, in any

way, indicate the limit of responsibility or liability for contaminated sediments. Instead, it provides an operational definition of the area that is most likely to be contaminated by activities at the site and, hence, the area to be targeted by the Stage II PSI. Because additional sampling is required if significant contamination is detected near the boundary of the SSZ, it is usually most efficient to initially define the SSZ broadly (i.e., to avoid the need to remobilise a sampling team to collect additional data).

Development of a sampling grid is a critical element of the Stage II PSI sampling plan (i.e., identification of the location of sampling sites). As the sampling program needs to provide information on the spatial distribution of chemical contaminants at the site, it is important that the sampling design consider the results of the Stage I investigation. Two general sampling designs can be utilized at this stage of the site investigation, including stratified random sampling and biassed sampling (Chapter 5 of Volume II). Stratified random sampling is recommended when the sediment contamination is suspected but little information is available on the specific location of potential contaminant sources. By comparison, a biassed sampling design is recommended when the location of probable contaminant sources and downstream depositional areas are known, largely because identifying sediment hot spots is more likely using this approach (i.e., areas with elevated contaminant concentrations). Because characterizing the areal extent of contamination and identifying the location of hot spots is essential, investigators may collect samples from a relatively large number of sites and use analyses of indicator variables [e.g., total organic carbon (TOC), total petroleum hydrocarbons] to identify the samples that will be analysed for the full suite of COPCs. In this way, it is possible to maximize the areal coverage of the site using screening chemistry and, in so doing, optimize the use of resources for chemical analyses. Importantly, the sampling program should be designed to determine the concentrations of COPCs in both surficial and deeper sediments.

The sampling and analysis plan should include descriptions of the methods that will be used to collect, handle, and store sediment samples that are collected for chemical analysis. Importantly, the collection, handling, and storage of sediment samples should follow established protocols, such as those developed by the ASTM (2001c) and USEPA (2001). To achieve this objective, everyone involved in the sampling program should receive training on these methods before initiating the sampling program. Additional guidance on sediment sampling is provided by Mudroch and McKnight (1991).

The procedures that will be used to identify and quantify the chemical substances in the sediment samples should also be described in the SAP. As a first step, a list of substances for chemical analysis should be compiled from the list of COPCs that was prepared in Stage I. This list should also include the variables that provide ancillary information for interpreting the resultant sediment chemistry data (e.g., TOC, AVS, NH_3, H_2S, Al, Li). Although the preferred analytical method for each analyte can also be specified in the SAP, establishing performance-based criteria for evaluating the analytical results may be preferable in many circumstances. Such criteria, which are articulated in the data quality objectives (DQOs) established for the investigation, provide analytical laboratories with a clear understanding of the project analytical requirements and, hence, a basis for selecting and/or refining methods that will assure that the project DQOs are met.

The procedures that will be applied to assure the overall integrity of the sampling program and the quality of the resultant data should be described in a QAPP (USEPA 1991a; 1991b; 1991c; 1991d; 2000c). The QAPP, which is typically included as an appendix to the SAP, should apply to both the field and laboratory components of the program. Some of the important elements that need to be contained in a QAPP include:

- Project organization and responsibilities;
- Personnel training and instruction;
- Data quality objectives, including the methods that will be used for assessing precision, accuracy, completeness, representativeness, and comparability of the data generated;
- Sampling procedures, including sampling equipment, decontamination of equipment, collection of field duplicates, generation of field blanks, positional data collection, sample containers, sample identification and labelling, sample preservation and holding times, field documentation, and field data sheets;
- Sample custody and transportation, including field custody procedures, chain-of-custody documentation, sample packaging and transport, and laboratory log-in procedures and documentation;
- Analytical methods, including target detection limits, accuracy, and precision for each analyte (i.e., DQOs);

- Data management, validation, analysis, and reporting procedures; and,
- Quality assurance report preparation.

Implementation of a focussed, well-designed monitoring program will ensure that the resultant sediment chemistry data will support a defensible sediment quality assessment. More information on the design of sediment quality sampling programs is provided in Chapter 5 of Volume II, while the elements of sampling and analysis plans are described in Appendix 1 of Volume II.

3.2.2 Data Interpretation

Interpretation of the data collected in the Stage II PSI should be conducted in three steps. As a first step, the quality assurance information collected during the sampling program should be reviewed in light of the acceptance criteria established in the QAPP (see Appendix 1 of Volume II for more details). This initial evaluation provides a basis for assessing the validity of the resultant data and determining if additional sampling is required. Any data gaps that are identified should be documented and used to support the design of the DSI, if required.

In the second step of the data analysis, the sediment chemistry data are compared to the numerical effects-based SQGs or bioaccumulation-based SQGs that have been established to protect and/or restore the sediment uses at the site. The results of this analysis provide a basis for identifying the contaminants that are present in sediments at concentrations that may be sufficient to impair one or more beneficial uses of the aquatic ecosystem. Application of mean SQG-quotients provides a basis for estimating the probability that individual sediment samples would be toxic to sediment-dwelling organisms (MacDonald *et al.* 2000; USEPA 2000d; Ingersoll *et al.* 2001). In addition, the results of the Stage II PSI provide the data needed to ascertain the locations of sediment hot spots and to assess the relative hazards posed by each COPC (i.e., by considering the degree to which ambient concentrations exceed the effects-based or bioaccumulation-based SQGs).

While exceedances of the SQGs provide strong evidence of chemical contamination, it should be recognized that all or a portion of the exceedances may be associated with elevated background concentrations. For this reason, the third step of the data analysis should involve comparison of the data from the site to regional background concentrations and/or contemporary background concentrations of each COPC. The substances that exceed both the SQGs and background levels should be considered to be the contaminants of concern (COCs) at the site. Some of the methods for determining background concentrations of metals and organic contaminants are described in Appendix 2 of Volume III of this guidance manual. Further information on the interpretation of sediment chemistry data is also provided in Volume III.

Chapter 4. Conducting a Detailed Site Investigation

4.0 Introduction

A detailed site investigation (DSI) is required if the results of the preliminary site investigation (PSI; which is conducted using sediment chemistry data) indicate that sediments are sufficiently contaminated to impair the beneficial uses of the aquatic ecosystem (i.e., pose unacceptable risks to sediment-dwelling organisms, and aquatic-dependent wildlife, or human health). The information collected and compiled during the PSI should be used to design the DSI. As the PSI was conducted to evaluate the nature, magnitude, and extent of sediment contamination at the site, the results of the investigation should provide the information needed to identify which substances occur in sediments at potentially harmful levels (e.g., in excess of the SQGs), describe the range of concentrations of priority substances, and identify the locations that contain elevated levels of sediment-associated COPCs. Importantly, the PSI should also provide essential background information on the site, such as the location of contaminant discharges and spills. As such, the PSI provides critical information for designing a well-focussed DSI.

The DSI is designed to provide the information needed to assess risks to sediment-dwelling organisms, wildlife, and human health associated with exposure to contaminated sediments. In addition, the DSI should provide the necessary and sufficient information to support the evaluation of remedial alternatives and the development of a RAP. Because the results of the DSI will be used directly to support sediment management decisions, the scope of this investigation will necessarily be broader than that of a PSI. More specifically, the DSI should be designed to answer four main questions, including:

- Does the presence of COPCs in whole sediments and/or pore water pose an unacceptable risk to the receptors under consideration (i.e., sediment-dwelling organisms, aquatic-dependent wildlife, or human health)?
- What is the nature, severity, and areal extent of the risk to each receptor under consideration?

- Which COPCs are causing or substantially contributing to the risk to the receptor under consideration (i.e., the COCs)?
- What are the concentrations of COPCs, by media type, that are associated with negligible risk to the receptor under consideration?

The DSI consists of two elements, including the data collection phase and the data interpretation stage. The following sections of this chapter provide an overview of the recommended procedures for conducting a DSI. More specific guidance on ecological and human health risk assessments relative to contaminated sediments are described in other documents (e.g., Ingersoll *et al.* 1997; Landis *et al.* 1997; USEPA 1998b; Wenning and Ingersoll 2002). More detailed guidance on the design of sampling programs and the development of sampling and analysis plans is provided in Chapter 5 and Appendix 1 of Volume II, respectively.

4.1 Collection of Sediment Quality Data

The development of a DSI SAP and associated QAPP represent essential steps in the overall data collection process. Some of the key steps involved in developing a SAP for the DSI include (see Chapter 5 of Volume II for more information):

- Map and describe the area to be sampled (i.e., sediment sampling zone; SSZ);
- Determine the data requirements for ecological and human health risk assessments;
- Map and describe the proposed sampling sites (including latitude and longitude; both primary and alternate sampling sites should be identified at this stage of the process, with criteria specified for when alternate sites should be sampled);
- Describe the sediment sampling, handling, and storage procedures that will be used for obtaining sediment samples for chemical analysis;

- List the chemical analytes that will be measured in sediment samples and associated data quality objectives;
- Describe the sediment sampling, handling, and storage procedures that will be used for obtaining sediment samples for toxicity and bioaccumulation testing;
- Describe the toxicity tests that will be conducted on the sediment samples, including the associated description of the selected metrics (e.g., survival and growth);
- Describe the procedures that will be used to assess bioaccumulation;
- Describe the procedures that will be used for sampling the benthic invertebrate community, including associated descriptions of the selected metrics (e.g., benthic index); and,
- Describe the quality assurance procedures that will be used in the field and the laboratory to assure that the resultant data meet project DQOs (i.e., which should be included as an appendix to the sampling plan).

Definition of the SSZ is the first step in the development of a sampling plan for the DSI. As the DSI is designed to provide further information on the areal extent of sediment contamination, including the extent to which COPCs have been transported to adjoining properties, the SSZ may be larger than that identified in the PSI. For example, if significant contamination was found near the boundaries of the SSZ for the PSI, then the SSZ for the DSI should be expanded substantially to support characterization of the areal extent of contamination. While near-term sampling costs are likely to be it less if the SSZ for the DSI is relatively small, additional sampling may be required if the results of the DSI indicate that contaminated sediments occur at or near the boundaries of the SSZ. Therefore, it may be more cost-effective to err on the side of inclusiveness when defining the SSZ for the DSI (i.e., making it larger than what seems absolutely necessary). As was the case for the PSI, the size of the SSZ does not, in any way, indicate the limit of responsibility or liability for contaminated sediments. Instead it provides an operational definition of the area that is most likely to be contaminated by activities at the site.

The second step in the design of a DSI sampling plan is to develop a sampling grid (i.e., identify the location of sampling sites). As the DSI needs to provide information on the specific areas, depths, and magnitude of contamination at the site and in nearby areas, it is important to review the results of the PSI to identify potential hot spots with respect to sediment contamination. In general, a biassed sampling design is preferred for the DSI because it can be used to focus sampling effort on the areas that are most likely to be contaminated (i.e., by conducting targeted sampling to delineate the location and extent of hot spot areas). Within the original SSZ (i.e., the area sampled during the PSI), intensive sampling should be conducted in the vicinity of sediment hot spots to confirm the results of the PSI, to determine the areal extent of contamination at each hot spot, and to identify gradients in contaminant concentrations. Outside the original SSZ, biassed sampling should be used to target potential hot spots (i.e., near the contaminated areas within the original SSZ) and random sampling should be used to investigate the potential for contamination in other areas.

Importantly, the DSI sampling program should be designed to determine the concentrations of COPCs in both surficial and deeper sediments. The sampling plan should identify the location of each site that will be sampled, with decision criteria also provided in the event that sampling certain sites is not feasible. As the mobilization/demobilization costs associated with sediment sampling can be substantial, it may be prudent to collect and archive samples from additional locations during the DSI. This makes it possible to, for example, analyse samples collected 10 m from a hot spot if the samples collected 5 m from that hot spot show significant contamination. In this way, the costs associated with chemical analyses can be minimized. However, attention needs to be paid to acceptable holding times to ensure that only high quality data are generated (ASTM 2001a; 2001c).

The sampling plan should include descriptions of the methods that will be used to collect, handle, and store sediment samples. These instructions are particularly important in the DSI because sediment samples are likely to be collected for several purposes, including chemical analysis, toxicity testing, bioaccumulation assessment, and/or benthic invertebrate community analyses. As one of the objectives of the DSI is to confirm that the contaminated sediments are actually toxic to sediment-dwelling organisms, it is critical that sediments be collected in a manner that facilitates the generation of matching sediment chemistry and biological effects data (i.e., by preparing splits of homogenized sediment samples). The

collection, handling, and storage of sediment samples needs to follow established protocols, (ASTM 2001a; 2001b; 2001d; USEPA 2000a; 2001). To achieve this objective, everyone involved in the sampling program should receive specialized training on these methods before starting the sampling program.

In addition to the foregoing considerations, development of the DSI sampling program should consider additional factors that apply to each of the key indicators of sediment quality conditions, including sediment chemistry data, sediment toxicity data, benthic invertebrate community assessments, and bioaccumulation assessments (Krantzberg *et al.* 2000). Some additional considerations that should be taken into account in designing the DSI sampling program are discussed in the following sections. Additional guidance on each of these indicators is provided in Volume III.

4.1.1 Sediment Chemistry

The procedures that will be used to identify and quantify the chemical substances in the sediment samples should be described in the sampling and analysis plan (see Chapter 2 of Volume III and Chapter 3 of Volume IV for more information). As a first step, a list of substances for chemical analysis should be compiled using the results of the PSI and other considerations (e.g., substances used to calculate mean SQG-quotients). This list should also include the variables that provide ancillary information for interpreting the resultant sediment chemistry data (e.g., TOC, AVS, Al, Li). The preferred analytical method for each analyte can also be specified in the sampling plan; however, it may be more prudent to let the analytical laboratory select the methods based on the DQOs for the project. Clearly articulating the data quality requirements (i.e., accuracy, precision, and detection limits) to the laboratory personnel at the outset of the project is likely to minimize the potential for problems later. The threshold effect concentrations developed by MacDonald *et al.* (2000) provide a reasonable basis for establishing target detection limits for COPCs.

The procedures that will be used to assess the biological effects associated with contaminated sediments should also be included in the sampling plan. Biological assessment is an essential tool for evaluating sediment quality conditions at contaminated sites because it

provides important information for interpreting sediment chemistry data. The five types of biological assessments that are commonly conducted at sites with contaminated sediments include toxicity testing, benthic invertebrate community assessments, bioaccumulation testing, fish health, and fish community structure. More detailed information on each of these indicators is presented in Volume III of this guidance manual.

4.1.2 Toxicity Testing

The selection of appropriate toxicity tests is an important element of the overall biological assessment process (Chapter 3 of Volume III and Chapter 3 of Volume IV). Provision of guidance in this area is particularly important because various regulatory programs (e.g., dredged material analysis programs) have developed conventions that may not be directly applicable for DSIs at sites with contaminated sediments. Because sediment-dwelling organisms are exposed to contaminated sediments for extended periods, at least one chronic toxicity test on a sensitive sediment-dwelling organism, in which sub-lethal endpoints are measured, should be included in the DSI. Although several such tests are available, the 28-day whole-sediment toxicity test with the amphipod, *Hyalella azteca*, is likely to be relevant in many situations. Survival and growth are the endpoints measured in this toxicity test (USEPA 2000a; ASTM 2001a).

Acute toxicity tests can also be used to assess the toxicity of contaminated sediments to sediment-dwelling organisms. However, the results of such tests must be interpreted with caution due to the potential for obtaining false negative results (i.e., erroneous concluding that contaminated sediments are unlikely to adversely affect sediment-dwelling organisms). Amphipods (*Hyalella azteca*) and midges (*Chironomus riparius* and *Chironomus tentans*) are the invertebrate species most commonly used in acute toxicity tests (ASTM 2001a; USEPA 2000a). Pore-water toxicity assessments can also be used to provide further information on the toxicity of contaminated sediments. There is no standardized test for assessing the effects of pore water in freshwater sediments; however, bacteria, amphipods, daphnids, and other species have been used successfully to assess toxicity in this medium (ASTM 2001b).

4.1.3 Benthic Invertebrate Community Assessments

A wide variety of techniques have been used to evaluate the effects of contaminated sediments on benthic invertebrate communities (see Rosenberg and Resh 1993; Ingersoll *et al.* 1997). These techniques can be classified into four general categories based on the level of organization considered (Chapter 4 of Volume III and Chapter 3 of Volume IV). The assessments are reliant on measurements of endpoints that are relevant to the following organizational scales:

- Individual (e.g., morphological changes, biomarkers);
- Population (e.g., abundance of keystone species; population age/size structure);
- Community structure (e.g., benthic index, multivariate analyses); and,
- Community function (e.g., energy transfer, functional groups).

All of the various measurement endpoints are evaluated based on departure from an expected or predicted condition (such as observations made at appropriate reference sites). Uncertainty in the application of these techniques stems from incomplete knowledge of the system (i.e., what represents normal conditions); systematic error in the method being used; and, the sampling scale selected (Ingersoll *et al.* 1997). Of the organization scales evaluated, the measurement endpoints which provide information on the status of invertebrate populations and community structure were considered to be the most reliable (Reynoldson *et al.* 1995; Ingersoll *et al.* 1997).

4.1.4 Bioaccumulation Assessments

Bioaccumulation assessments are used to evaluate the extent to which sediment-associated COPCs accumulate in the tissues of sediment-dwelling organisms (see Chapter 5 of Volume III and Chapter 3 of Volume IV for additional information on bioaccumulation assessments; ASTM 2001d). In laboratory bioaccumulation tests, individuals of a single species are

exposed to field-collected sediments under controlled conditions. After an established period of exposure (usually 28 days), the tissues of the test species are analysed to determine the concentrations of COPCs. Bioaccumulation is considered to have occurred if the final concentrations of the COPCs in tissues exceed the concentrations that were measured in tissue at the beginning of the test or in the tissues of organisms exposed to control sediments. In field investigations, sediment-dwelling organisms may be collected at the site under consideration and their tissues analysed for the COPCs. Alternatively, organisms can be transplanted to the site from an uncontaminated location and the tissues analysed for COPCs after a predetermined exposure period (e.g., caged mussels; ASTM 2001e). Modelling procedures can also be used to estimate the concentrations of contaminants that could accumulate in the tissues of aquatic organisms as a result of exposure to contaminated sediments.

An expert panel evaluated the uncertainty associated with all four of the procedures established for conducting bioaccumulation assessments (Ingersoll *et al.* 1997). The results of this evaluation indicate that bioaccumulation is a highly variable endpoint that primarily provides information on exposure to contaminants. It is particularly useful for determining the bioavailability of sediment-associated contaminants. Of the four approaches evaluated, laboratory assessments were considered to be the most reliable and are recommended for assessing bioaccumulation potential at contaminated sites. The preferred test species for freshwater bioaccumulation assessments is the oligochaete (*Lumbriculus variegatus)*; however, many other species may be used in this application (see ASTM 2001d). It should be noted that such data do not necessarily provide a direct means of estimating tissue residues in the field. For this reason, it is also recommended that the tissues of resident species also be collected and analysed to provide a basis for assessing hazards to human health and aquatic-dependent wildlife species (i.e., by comparing measured tissue concentrations to tissue residue guidelines). However, this may not be possible at sites where appropriate receptor species are absent or present in low numbers only (i.e., due to COPC-related effects or substrate alteration).

4.1.5 Other Tools for Assessing Sediment Quality Conditions

While sediment chemistry, sediment toxicity, benthic invertebrate community structure, and bioaccumulation data represent the primary tools for assessing sediment quality conditions in freshwater ecosystems, there are a number of other tools that can be used to support the sediment quality assessment process. For example, in certain circumstances it may be necessary to identify the substances that are causing or substantially contributing to the effects observed in the investigation (i.e., COCs). In these cases, spiked sediment toxicity tests and/or toxicity identification evaluation (TIE) procedures can be used to help identify the putative causal agents. In addition, numerical SQGs can be used to assist in the identification of the substances that are causing or substantially contributing to sediment toxicity (Wenning and Ingersoll 2002). Furthermore, various data analytical approaches, such as multiple regression analysis and principal components analysis, can be applied to identify the substances that are most directly linked to the toxic effects observed in field collected samples. Some of these tools and their applications are described in Chapter 7 of Volume III and Chapter 3 of Volume IV.

4.1.6 Quality Assurance Project Plan

The sampling and analysis plan for the DSI should include a QAPP that applies to both the field and laboratory components of the program. Some of the important elements that need to be contained in a QAPP for a DSI include:

- Project organization and responsibility;
- Personnel training and instruction;
- Quality assurance objectives and methods for assessing precision, accuracy, completeness, representativeness, and comparability of the data generated;
- Sampling procedures, including sampling equipment, decontamination of equipment, collection of field duplicates, generation of field blanks, collection

of positional data, sample containers, sample identification and labelling, sample preservation and holding times, field documentation, and field data sheets;

- Sample handling and preparation procedures for each media type and purpose (i.e., chemistry, toxicity testing, etc.);
- Sample custody and transportation, including field custody procedures, chain-of-custody documentation, sample packaging and transport, and laboratory log-in procedures and documentation;
- Analytical methods, including target data quality objectives;
- Toxicity testing procedures, including descriptions of negative controls, positive controls, and reference samples, and associated criteria for data acceptance;
- Bioaccumulation testing procedures and associated criteria for data acceptance;
- Benthic invertebrates identification and counting procedures and associated criteria for data acceptance;
- Data management, validation, analysis, and reporting procedures; and,
- Quality assurance report preparation.

Implementation of a well-designed sampling program is likely to provide the data needed to conduct a comprehensive assessment of sediment quality conditions at the site. More information on the design of sediment quality sampling programs is provided in Chapter 5 of Volume II, while the elements of sampling and analysis plans are described in Appendix 1 of Volume II.

4.2 Data Interpretation

Interpretation of the data collected in the DSI is more involved than the interpretation of Stage II PSI data. As was the case for the PSI, the review and evaluation of the quality assurance information (i.e., in light of the acceptance criteria that were established in the QAPP) represents the first stage of the data interpretation process. This initial evaluation

provides a basis for assessing the validity of the resultant data and determining if additional sampling is required.

In the second step of the data analysis process, the data collected in the DSI are compiled and used to assess exposures to contaminated sediments, the effects of contaminated sediments on ecological receptors and human health, and the risks posed by contaminated sediments to beneficial uses of the aquatic ecosystem. The objectives of the exposure assessment are to identify the receptors at risk, describe the relevant exposure pathways, and determine intensity and areal extent of the exposure to COPCs. Sediment chemistry data and/or pore-water chemistry data may be used, in conjunction with applicable benchmarks (e.g., SQGs, water quality criteria, background levels) to identify the areas, depths, and degree of contamination at the site and in nearby areas. If significant contamination (i.e., > SQGs) is observed at or nearby the boundaries of the SSZ (either in surficial sediments or at depth), then additional sampling may be required to fully characterize the spatial extent of contamination.

The primary objective of the effects assessment is to describe the nature and severity of effects that are being caused by contaminated sediments. Sediment chemistry data can also be used in the effects assessment to estimate the probability that specific types of effects would be associated with exposure to contaminated sediments (i.e., using the dose-response relationships established for individual COPCs or groups of COPCs; e.g., Swartz 1999; MacDonald *et al.* 2000; USEPA 2000d; Wenning and Ingersoll 2002). Additionally, the results of the toxicity tests can be used to determine if sediments with elevated concentrations of COPCs (i.e., relative to the SQGs) are toxic to aquatic organisms. Contaminants may be present in relatively unavailable forms or other factors may be mitigating toxicity at the sites that have elevated chemical concentrations but are not toxic to sediment-dwelling organisms. The results of benthic invertebrate community assessment can also be used to evaluate the effects of contaminated sediments on sediment-dwelling organisms. Agreement among the three measures of adverse biological effects (i.e., the SQGs, toxicity tests, and benthic assessments) provides strong evidence for identifying the specific areas and sediment depths that are contaminated to levels that are adversely affecting or have the potential to adversely affect sediment-dwelling organisms (Chapter 7 of Volume III).

The data collected in the DSI can also be used to assess the hazards associated with exposure to bioaccumulative substances at the site. In this assessment, the results of laboratory bioaccumulation tests provide a basis for identifying which substances are bioavailable and have the potential to bioaccumulate in the food web. The results of chemical analyses of biological tissues collected at the site can then be used to confirm the results of the laboratory bioaccumulation tests. To evaluate the potential effects associated with exposure to bioaccumulative substances, the tissue residue data can be compared to the tissue residue guidelines that have been established for the protection of wildlife and human health. In this way, the chemicals and the locations that pose the greatest hazards to human health and wildlife can be identified. Integration of the results of the exposure and effects assessments provides a basis for estimating risks to ecological receptors associated with exposure to contaminated sediments. A matrix of data interpretation tools relating to various ecological impairments associated with sediment contamination is provided in Table 2 (Krantzberg *et al.* 2000).

The results of the investigations that are conducted during this phase of the project should be compiled and collated into a comprehensive DSI report. This report should include the objectives of the investigation, provide a summary of the background information on the site, a description of the study approach, a summary of the existing information on sediment quality conditions at the site, a description of the methods that were used to generate the new data, a summary of the results of the investigations, and a discussion of the interpretation of the resultant data. All of the data collected during the investigation should be compiled in appendices that facilitate access to and/or re-analysis of the information. The reader is directed to Volume III of this guidance manual for more information on the interpretation of data on individual and multiple indicators of sediment quality conditions generated during the DSI.

Chapter 5. Developing Sampling and Analysis Plans for Assessing Sediment Quality Conditions

5.0 Introduction

A primary goal of most sediment quality assessment programs is to determine if the presence of toxic chemicals in sediment is adversely affecting sediment-dwelling organisms. When sediments contain bioaccumulative substances, a primary goal of assessment programs is to determine if these contaminants are accumulating in the tissues of aquatic organisms to such an extent that they pose a hazard to sediment-dwelling organisms, aquatic-dependent wildlife, or human health. More specifically, sediment assessments can be used to:

- Determine the relationship between toxic effects and bioavailability;
- Investigate interactions among chemicals;
- Compare the sensitivities of different organisms;
- Determine spatial and temporal distribution of contamination;
- Evaluate hazards of dredged material;
- Measure toxicity as part of product licensing or safety testing;
- Rank areas for clean up; and,
- Evaluate the effectiveness of remediation or management practices.

Considering the diversity of reasons for conducting sediment quality assessments and the variety of programs under which such assessments can be implemented, it is not feasible to provide guidance on the design of sediment quality assessments that applies uniformly to every application. Therefore, this chapter is intended to compliment the general guidance that was provided on preliminary and detailed site investigations (i.e., PSIs - Chapter 3; DSIs

- Chapter 4 of Volume II) by identifying the essential elements of SAPs for assessing contaminated sediments, including:

- Background information on the site;
- Objectives of the sediment assessment program;
- Field sampling methods;
- Sample handling procedures;
- Technical oversight and auditing;
- Quality assurance and quality control procedures;
- Data validation and quality control;
- Data evaluation and validation
- Data analysis, record keeping, and reporting;
- Health and safety; and,
- Responsibilities of the project team members.

Each of these elements of SAPs are briefly described in the following sections of this chapter (see Table 3 for a sediment sampling and analysis plan outline and checklist). More detailed information on several key issues related to the design of sampling programs for assessing contaminated sediments in provided in Appendix 1 of Volume II.

5.1 Background Information

Development of a sampling and analysis plan that explicitly addresses the objectives of the sediment quality assessment program requires background information on the site under investigation. The types of background information that should be collected to inform the design of the sediment quality assessment program include (WDOE 1995):

- Site history;
- Regulatory framework;
- Results of previous investigations (including data on physical, chemical, and biological conditions);
- Location and characteristics of historic and current contaminant sources in the vicinity of the site, including stormwater discharges, wastewater discharges, hazardous waste storage/disposal, and, hazardous material spills;
- Location of depositional areas; and,
- Designated water uses.

Collectively, this information provides a basis for identifying the sediment quality issues and concerns at the site, including the COPCs and areas of interest (Chapter 3 of Volume I). This information also supports the design of a sampling program that characterizes the nature, extent, and severity of sediment contamination.

Review of available historical data is important both in the selection of sampling stations and in subsequent data interpretation. Local experts should be consulted to obtain information on site conditions and on the origin, nature, and degree of contamination. Other potential sources of information include government agency records, municipal archives, harbor commission records, news media reports, past geochemical analyses, hydrographic surveys, and bathymetric maps. Potential sources of contamination should be identified and their locations noted on a map or chart of the proposed study area. An inspection of the site is recommended when developing a study plan to assess the completeness and validity of the collected historical data and to identify any significant changes that might have occurred at the site since the historical data were collected. Conducting some reconnaissance sampling to refine the sampling design is also useful (i.e., which may be focussed on particle size distribution, TOC, total petroleum hydrocarbons, sentinel substances, or some other suitable indicators of chemical contamination). Reconnaissance sampling is particularly helpful in defining appropriate station locations for targeted sampling or to identify appropriate strata for stratified sampling or subareas for multistage sampling.

5.2 Objectives of the Sediment Investigation

The objectives of sediment quality assessments can vary markedly depending on the regulatory program under which they are conducted. In turn, the objectives of the assessment play a central role in dictating the design of the investigation. For example, certain investigations may be explicitly designed to assess trends in environmental quality conditions, while others are designed to evaluate the status of sediment quality conditions. Such differences in objectives need to be reflected in the sampling design that is described in the SAP.

Assessments of trends in environmental quality conditions typically focus on evaluating either spatial trends or temporal trends. In assessments of spatial trends, sampling programs may be designed to facilitate the collection and analysis of sediment samples from a large number of stations within the study area. In contrast, assessments of temporal trends typically involve repeated collection of sediment samples from a number of stations at pre-determined time intervals. Both types of investigations typically focus on chemical analysis of the selected media types (e.g., whole sediments, pore water); however, other indicators of sediment quality conditions can be used in trend assessments.

The designs of sampling programs to assess the status of sediment quality conditions tend to differ markedly from those that are focussed on trend assessment. Such sampling programs are typically undertaken to evaluate the effects of contaminated sediments on the attributes of key groups of receptors (e.g., sediment-dwelling organisms, aquatic-dependent wildlife, and/or human health, which are often referred to as assessment endpoints). The measurement endpoints (i.e., indicators of sediment quality conditions that are actually measured) that are ultimately included in the sampling program are based on the selected assessment endpoints and the exposure pathways that are most relevant for the receptor groups under consideration. As such, the sampling program designs are more likely to include sediment toxicity, benthic invertebrate community, and bioaccumulation assessments, as well as sediment and pore-water chemistry. In addition, it is necessary to include control and reference sediments in these types of investigations to facilitate interpretation of the resultant data (Appendix 1 of Volume II). Controls are used to evaluate the acceptability of the test, whereas testing of reference sediments provides a site-specific

basis for evaluating toxicity of the test sediments. Comparisons of test sediments to multiple reference or control sediments representative of the physical characteristics of the test sediment (i.e., grain size, organic carbon) may be useful in these evaluations.

In some cases, sediment quality assessments are conducted to determine if sediments are suitable for open water disposal. In these cases, tiered assessment techniques may be applied to obtain the requisite data to support sediment management decisions. Such tiered assessment frameworks may rely primarily on sediment chemistry data in the earlier tiers of the assessment, while biological testing is used more extensively in later tiers (USEPA and USACE 1998b).

Sediment quality assessments can also include an evaluation of the toxicity of an individual contaminant or mixtures of contaminants on selected receptors. In these cases, known quantities of the substance or substances under investigation are spiked into whole sediments. Toxicity tests are then conducted to evaluate the effects of each exposure concentration on the selected receptor (e.g., amphipods, chironomids) and test endpoint (e.g., survival, growth). Evaluation of the resultant data provides a basis for determining the lethal concentrations (e.g., LC_{50}) or effective concentrations (e.g., EC_{50}) of the substance or substances in sediments. Such investigations require a negative control sediment, a positive control, a solvent control, and/or several concentrations of sediment spiked with a chemical (ASTM 2001a; USEPA 2000a).

If the purpose of the study is to conduct a reconnaissance field survey to identify the portions of the study area that require further investigation, the experimental design might include only one sample from each station to allow for sampling a larger area. The lack of replication at a station usually precludes statistical comparisons such as analysis of variance (ANOVA), but these surveys can be used to identify stations for further study or may be evaluated using regression techniques (ASTM 2001a; USEPA 2000a).

More information on the selection of sediment quality indicators, metrics, and targets for assessing contaminated sediments, based on the objectives of the sampling program, is provided in Chapter 5 of Volume I and in Chapters 2 through 5 in Volume III.

5.3 Field Sampling Methods

The purpose of the sampling program is to collect undisturbed sediment samples from one or more stations within the assessment area. Such samples are typically collected to support physical-chemical analyses, toxicity testing, benthic invertebrate community assessments and/or bioaccumulation assessments. To assure that field personnel are adequately prepared to collect the required sample volumes from each sampling station, it is essential that the methods that will be used to collect sediment samples in the field be fully described in the project SAP. The selection of such methods for collecting sediment samples will be influenced by a variety of factors, including:

- Sampling design;
- Type of sampling platforms available;
- Location of and access to the sampling stations;
- Physical characteristics of the sediments;
- Number of sites to be sampled;
- Water depth;
- Number and experience of personnel; and,
- Budget.

In general, the sediment samplers that are used in most freshwater sediment assessments can be classified into two major categories, grab samplers and corers (USEPA 2001; ASTM 2001c). Some of the commonly utilized grab samples include Birge-Ekman grab samplers (standard and petite), Ponar grab samplers (standard and petite), Van Veen grab samplers (standard and large), and Shipek grab sampler. Hand corers, single-gravity corers, multiple-gravity corers, box corers piston corers, and vibratory corers represent the primary classes of sediment corers that are currently available. Specific methods are also available for obtaining pore-water samples. The advantages and disadvantages of various sediment samplers are described in Table 4 (WDOE 1995). The minimum sample volumes to support physical-chemical analyses and toxicity testing are presented in Table 5.

To enhance comparability of the resultant data, the same method should be used to collect samples from all of the sampling station within the assessment area, whenever practicable. However, the need to collect both surficial and deeper sediments may preclude this possibility in certain circumstances. The reader is directed to Mudroch and McKnight (1991), Mudroch and Azcue (1995), USEPA (2001), and ASTM (2001c) for more information on the collection of sediment samples.

5.4 Sample Handling Procedures

The sediment samples that are collected in the field are likely to be subjected to a physical, chemical, and/or biological testing to support the overall sediment assessment program. The methods that are applied for handling, preserving, transporting, and storing the samples are dependent on the objectives of the study and the type of testing to which each sample will be subjected. In cases where data on multiple indicators of sediment quality conditions are to be generated, the importance of synoptically-collected sediment samples cannot be over stated (i.e., collecting sufficient volumes of sediment at each station to facilitate the preparation of a subsample for toxicity testing and subsamples for chemical analysis from a single, homogenized sediment sample). Appropriate methods for handling, transporting, and storing sediment samples for chemical analysis and toxicity testing are presented in ASTM (2001c) and USEPA (2001). The recommended storage temperatures and maximum holding times for physical-chemical analyses and sediment toxicity testing are presented in Table 6. Recommended chain-of custody procedures and methods for delivering sediment samples to analytical laboratories are summarized in WDOE (1995).

5.5 Technical Oversight and Auditing

In many cases, the field component of the sediment quality assessment is conducted by contractors who have ready access to sampling vessels and equipment. While these contractors may have a good deal of experience in the collection of environmental media, there may be unique aspects of the sediment quality assessment that require special attention

in the field (e.g., collection of matching samples for chemical analysis, toxicity testing, and benthic community structure). For this reason, it is recommended that one or more individuals be assigned the task of providing technical oversight and auditing of all aspects of the field program. This individual would be responsible for reviewing the SAP (and associated QAPP), overseeing the training of the field crew, confirming sample locations prior to sampling, observing sample collection procedures, documenting any inconsistencies and errors that are observed, assuring that corrective actions are taken, and documenting sample handling and transport procedures.

5.6 Quality Assurance Project Plan

A QAPP, which outlines specific steps that will be used to perform the study, should be prepared in advance of collecting samples and appended to the SAP. The scope of the QAPP is dependant on the specific objectives of the study. Some of the preliminary issues that need to be considered prior to preparing this plan include:

- Defining the potential problem that needs to be addressed;
- Determining resources that are available for the project;
- Reviewing the existing information and identifying the specific objectives for the study; and,
- Determining the data that are likely to be needed to fulfill the project objectives.

Detailed guidance on the development of QAPPs is available from a number of sources. First, USEPA has developed a quality system to assure the quality of data that are collected, generated, and used under its programs. As part of this program, USEPA has developed a number of training courses on QA/QC activities, including both generic and specialized training (see www.epa.gov/quality/trcourse.html for more information). In addition, USEPA has published a number of guidance documents to support the development of QAPPs for sediment quality and related assessments (see USEPA 1991a; 1991b; 1991c; 1991d; 1993; 1994; 1998a; 1999a for further information). Furthermore, similar guidance documents have

been established to support certain state government programs (e.g., WDOE 1995). The quality control procedures that have been identified by WDOE (1995) for organic analyses, metal analyses, conventional analyses, and freshwater sediment toxicity testing are presented in Tables 7, 8, 9, and 10, respectively. ASTM (2001a; 2001b; 2001c) and USEPA (2000a) provide more recent guidance on test conditions for conducting whole-sediment toxicity tests.

5.7 Data Evaluation and Validation

Data evaluation and validation represents an essential component of the overall sediment assessment process. The results of this step of the process determine which data can be reliably used in the assessment. The project data quality objectives, which are included in the QAPP, provide functional guidance for evaluating data quality (USEPA 1998a). Procedures for validating the data generated during the assessment should be determined on an *a priori* basis and included in the SAP. In general, there are five factors that are considered in the evaluation of physical, chemical, and biological data, including:

- Precision
- Accuracy;
- Representativeness;
- Completeness; and,
- Comparability.

Precision, accuracy, representativeness, completeness, and comparability (PARCC) parameters are indicators of data quality. PARCC goals are established for the site characterization to aid in assessing data quality. More information on each of the five indicators of data quality is provided in Appendix 1 of Volume II.

5.8 Data Analysis, Record Keeping, and Reporting

Data analysis, record keeping, and reporting represent essential elements of a sediment quality assessment. For this reason, the procedures that are to be used to support the assessment should be described in the SAP. The recommended procedures for interpreting individual and multiple lines of evidence are presented in Chapter 7 of Volume III. Additional information on data analysis, record keeping, and reporting is provided in WDOE (1995).

5.9 Health and Safety Plan

It is recommended that a comprehensive health and safety plan be included in the project SAP. The health and safety plan should cover all aspects of worker safety during the collection, handling, transport, and analysis of sediment samples (USEPA 2001; ASTM 2001c). The health and safety plan should include a list of the tasks to be performed, a listing of key personnel and responsibilities, a description of the chemical and physical hazards associated with the site, and an analysis of the health and safety risks associated with each task. In addition, the plan should include an air monitoring plan, a description of the personal protective equipment that will be used for each task (including contingencies), procedures for decontaminating personnel and equipment, procedures for disposing of contaminated media and equipment, a description of safe work practices, and standard operating procedures. Finally, a contingency plan, personnel training requirements, a medical surveillance program, and record-keeping procedures should be included in the health and safety plan. The members of the sampling team should be reminded about key health and safety issues related to sampling and sample preparation prior to initiating activities on each day of the sampling program.

5.10 Project Schedule

A project schedule represents an important component of the SAP. The project schedule should clearly specify when each element of the sediment quality assessment will be completed. Some of the activities that should be included in the project schedule include field mobilization, field sampling (including time for sampling sub-areas and sequencing for sampling each station), field demobilization, shipment of samples to laboratories, initiation and completion of physical, chemical, and biological analyses, initiation and completion of data validation, completion of data reports, and completion of interpretive reports. Because laboratories may not be available on demand, it is important to consider holding times for chemical and biological samples when developing sampling schedules for the field program. In addition to supporting the technical aspects of the program, a detailed project schedule is likely to support the administrative components of the process (i.e., funding, contracting, etc.).

5.11 Project Team and Responsibilities

The SAP should include a brief description of the responsibilities of each member of the project team. In general, the project team will include a project manager, a number of scientists that are responsible to various field and laboratory components of the project, and a number of field and laboratory technicians. In addition, a QA/QC coordinator, database coordinator, data analysts, and other specialists are likely to play important roles during the planning and implementation of the investigation.

Chapter 6. References

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Tables

Table 1. Examples of chemicals that should be measured on a site-specific basis (adapted from WDOE 1995).

Chemical Contaminant	Reason for Suspected Presence in Sediments
Ammonia	* Associated with fish processing plants and aquaculture
Other potentially toxic metals (e.g., antimony, beryllium, nickel)	* Associated with mining wastes and metal plating operations
Organotin complexes (especially tributyltin)	* Used historically in antifouling paint and, therefore, potentially associated with shipyards and marinas
Pesticides, herbicides	* Associated with agriculture or with agricultural chemical companies
Polycyclic aromatic hydrocarbons	* Associated incomplete combustion of organic matter and are constituents of petroleum, coal, and their derivatives
Petroleum compounds (e.g., benzene, toluene, ethylbenzene, xylene, PAHs)	* Associated with refineries, fuel storage facilities, marinas, gas stations, non-point source inputs
Polychlorinated dibenzo-*p*-dioxins and polychlorinated dibenzofurans (PCDDs/PCDFs)	* Associated with the presence of polychlorinated biphenyls and pentachlorophenol and with pulp and paper mills using chlorination
Polychlorinated biphenyls (PCBs)	* Associated with a variety of industrial activities, especially those involving capacitors and transformers
Guaiacols and resin acids	* Associated with pulp and paper mills and other wood products operations
Volatile organic compounds (e.g., trichloroethene, tetrachloroethene)	* Used as solvents and in chemical manufacturing operations
Radioactive substances	* Associated with nuclear power plants, nuclear processing plants, medical wastes, and military installations

Note: the substances identified in this table should be measured when there is reason to suspect that they could be present in sediments. Measurement of these substances is in addition to the standard suite of analytes that should be measured at all sites with contaminated sediments, including PCBs, PAHs, and priority heavy metals (arsenic, cadmium, chromium, copper, lead, mercury, nickel, and zinc).

Table 2. A matrix of data interpretation tools for assessing ecological impairments associated with contaminated sediments (from Krantzberg *et al.* 2000).

Use Impairment	Assessment Element	Data Interpretation Tools	Sample References
Restriction on fish and wildlife consumption	Bioaccumulation	Equilibrium partitioning, comparison to guidelines	USEPA 1989; Beltran and Richardson 1992
Degradation of fish and wildlife populations	Community structure, bioaccumulation	Food web model, weight of evidence	USEPA 1989; Beltran and Richardson 1992
Fish tumors or other deformities	Bioaccumulation, chemistry	Reference frequencies	Baumann 1992
Bird or animals deformitites or reproduction problems	Bioaccumulation, community structure	Food web model, comparison to reference conditions, weight of evidence	Jaagumagi and Persaud 1996
Degradation of benthos	Community structure, toxicity (bioassays)	Comparison to reference conditions	Jaagmagi and Persaud 1996; Reynoldson *et al.* 1997
Restrictions on dredging activities (no open water disposal)	Chemistry, toxicity (bioassays), stability*	Comparison to guidelines and/or reference conditions	Persaud *et al.* 1993; USEPA 1998c
Eutrophic or undesirable algae	Chemistry, stability	Modeling	PDEP 1998
Degradation of aesthetics	Chemistry, stability	Comparison to reference conditions	Heidtke and Tauriainen 1996
Added costs to agriculture or industry (to prevent or avoid contaminated water)	Chemistry, stability	Comparison to reference conditions	OMOE and MDNR 1991

Table 2. A matrix of data interpretation tools for assessing ecological impairments associated with contaminated sediments (from Krantzberg *et al.* 2000).

Use Impairment	Assessment Element	Data Interpretation Tools	Sample References
Dregraded phytoplankton and zooplankton populations	Bioaccumulation, chemistry, stability	Comparison to reference conditions, target nutrient loads	Bierman *et al.* 1984
Loss of fish and wildlife habitat	Chemistry, bioaccumulation, toxicity, benthos, stability	Comparison to reference conditions, weight of evidence	Minns *et al.* 1996

*Physical sediment characteristics, quiescent versus energetic site characteristics, etc.

Table 3. Sediment sampling and analysis plan outline and checklist (from WDOE 1995).

Introduction and Background Information

* Site history
* Regulatory framework (e.g., NPDES, MTCA, SMS, CERCLA)
* Summary of previous investigations, if any, of the site
* Location and characteristics of any current and/or historical wastewater or storm water discharge(s) at the site
* Location and characteristics of any current and/or historical wastewater or storm water discharge(s) in the local area
* Information on on-site waste disposal practices or chemical spills in the local area, if any
* Site location map showing the surrounding area
* Site map showing site features

Objectives and Design of the Sediment Investigation

* Objectives of the sediment investigation
* Overall design of the sediment investigation, including related investigations, if any
* Chemical analytes (including description of their relevance to the objectives and the regulatory framework)
* Biological tests (including description of their relevance to the objectives and the regulatory framework)
* Sampling station locations
  - Rationale for station locations
  - Site map(s) showing sampling stations and other pertinent features (e.g., bathymetry and current regime; outfall(s)/diffuser(s); authorized mixing zone(s), if any; sites of waste disposal, spills, or other activities that may have affected the sediments, such as sandblasting, boat repair, etc.;
  - Proposed reference stations
  - Table showing the water depth at each proposed station
  - Proposed depth(s) below the sediment surface where sediments will be collected

Field Sampling Methods

* Station positioning methods
* Sampling equipment
* Decontamination procedures
* Sample compositing strategy and methods
* Sample containers and labels
* Field documentation procedures
* Procedures for disposal of contaminated sediments

Sample Handling Procedures

* Sample storage requirements (e.g., conditions, maximum holding times) for each type of sample
* Chain-of-custody procedures
* Delivery of samples to analytical laboratories

Table 3. Sediment sampling and analysis plan outline and checklist (from WDOE 1995).

Laboratory Analytical Methods

* Chemical analyses and target detection limits
* Biological analyses
* Corrective actions

Quality Assurance and Quality Control Requirements

* QA/QC for chemical analyses
* QA/QC for biological analysis
* Data quality assurance review procedures

Data Analysis, Record Keeping, and Reporting Requirements

* Analysis of sediment chemistry data
* Analysis of biological test data
* Data interpretation
* Record keeping procedures
* Reporting procedures

Health and Safety Plan (required for cleanup investigations)

* Description of tasks
* Key personnel and responsibilities
* Chemical and physical hazards
* Safety and health risk analysis for each task
* Air monitoring plan
* Personal protective equipment
* Work zones
* Decontamination procedures
* Disposal procedures for contaminated media and equipment
* Safe work procedures
* Standard operating procedures
* Contingency plan
* Personnel training requirements
* Medical surveillance program
* Record keeping procedures

Schedule

* Table or figure showing key project milestones

Project Team and Responsibilities

* Description of sediment sampling program personnel
* Table identifying the project team members and their responsibilities

References

* List of references

Table 4. Advantages and disadvantages of various sediment samplers (from WDOE 1995).

Sampler	Sediment Depth Sampled	Advantages	Disadvantages
Surface Sediment Samplers			
van Veen or Young grab	0-3 cm	Useful in deep water and on most substrates. Young grab coated with inert polymer. Large sediment volume obtained. May be subsampled through lid.	Loss of fine surface sediments and sediment integrity may occur during sampling. Incomplete jaw closure possible. Young grab is expensive. Both may require a winch.
Ponar grab	0-10 cm	Commonly used. Large volume of sediment obtained. Adequate on most substrates. Weight allows use in deep waters. Good sediment penetration.	Loss of fine surface sediments and sediment integrity may occur during sampling. Incomplete jaw closure occurs occasionally. Heavy and requires a winch.
Petite Ponar grab	0-10 cm	Similar in design to the Ponar grab, but smaller and more easily handled from a small boat. Can be deployed by hand without a winch in shallow water.	Small volume. Loss of fine surface sediments and sediment integrity may occur during sampling. Incomplete jaw closure occurs occasionally. May require winch in deeper water.
Ekman or box dredge	0-10 cm	Relatively large volume of sediment may be obtained. May be subsampled through lid. Lid design reduces loss of surficial sediments as compared to many dredges. Usable in moderately compacted sediments of varying grain sizes.	Loss of fine surface sediments may occur during sampling. Incomplete jaw closure occurs in coarse-grain sediments or with large debris. Sediment integrity disrupted.
Petersen grab	0-30 cm	Large sediment volume obtained from most substrates in deep waters.	Loss of fine surface sediments and sediment integrity. Incomplete jaw closure may occur. May require winch.
Orange-peel grab	0-30 cm	Large sediment volume obtained from most substrates. Efficient closure.	Loss of fine surface sediments and sediment integrity. Requires winch.

Table 4. Advantages and disadvantages of various sediment samplers (from WDOE 1995).

Sampler	Sediment Depth Sampled	Advantages	Disadvantages
Shipek grab	0-10 cm	Adequate on most substrates.	Small volume. Loss of fine surface sediments and sediment integrity; sample may be compressed during sampling.
Sediment Corers			
Vibrocorer	to >200 cm	Samples deep sediment for historical analyses. Samples consolidated sediments.	Expensive and requires winch and A-frame. Outer core integrity slightly disrupted.
Impact corer	to >200 cm	Samples deep sediment for historical analyses. Samples consolidated sediments.	Large impact corers may be expensive and require specialized sampling vessel. Outer core integrity slightly disrupted.
Box corer	0-30 cm	Maintains sediment layering of large volume of sediment. Fine surface sediments retained relatively well. Quantitative sampling allowed. Excellent control of depth of penetration.	Size and weight require power winch; difficult to handle and transport. Some box corers may not be suitable for sampling very coarse sediments.
Hand and gravity corers	0-30 cm	Maintain sediment layering of the inner core. Fine surface sediments retained by hand corer. Replicate samples efficiently obtained. Removable liners. Inert liners may be used. Quantitative sampling allowed.	Small sample volume. Gravity corer may result in loss of fine surficial sediments. Liner removal required for repetitive sampling. Not suitable in coarse-grain or consolidated sediments.
Piston corer	to 20 m	Samples deep sediment for historical analyses. Samples consolidated sediments.	Expensive and requires winch and A-frame. Outer core integrity slightly disrupted.

Table 5. Minimum sediment samples sizes and acceptable containers for physical/chemical analyses and sediment toxicity tests (from WDOE 1995).

Sample Type	Minimum Sample Size[a]	Container Type[b]
Physical/Chemical Analyses		
Grain size	100–150 g	P,G
Total solids	50 g	P,G
Total volatile solids	50 g	P,G[c]
Total organic carbon	25 g	P,G
Ammonia	25 g	P,G
Total sulfides	50 g	P,G[c]
Oil and grease	100 g	G
Metals (except mercury)	50 g	P,G
Mercury	1 g	P,G
Volatile organic compounds	50 g	G,T[c]
Semivolatile organic compounds	50–100 g	G
Pesticides and PCBs	50–100 g	G,T
Toxicity Tests		
Amphipod (*Hyalella azteca*)	0.1 L per replicate (0.8 L per station)	G
Mayfly (*Hexagenia limbata*)	0.2 L per replicate (1.0 L per station)	G
Midge (*Chironomus tentans*)	0.1 L per replicate (0.8 L per station)	G
Frog embryo *(Xenopus laevis)*	45 g (dry weight) per station	G
Microtox® solid phase or deionized water	200 g (wet weight) per station	G

[a]Recommended field sample sizes (wet weight basis) for one laboratory analysis. If additional laboratory analyses are required (e.g., laboratory replicates, allowance for having to repeat an analysis), the field sample size should be increased accordingly. For some chemical analyses, smaller sample sizes may be used if comparable sensitivity can be obtained by adjusting instrumentation, extract volume, or other factors of the analysis.

[b]P - linear polyethylene; G - borosilicate glass; T - polytetrafluorethylene (PTFE, Teflon®)-lined cap.

[c]No headspace or air pockets should remain. If such samples are frozen in glass containers, breakage of the container is likely to occur.

Table 6. Storage temperatures and maximum holding times for physical/chemical analyses and sediment toxicity tests (from WDOE 1995).

Sample Type	Storage Temperature	Maximum Holding Time
Grain Size	Cool, 4°C	6 months
Total solids	Cool, 4°C Freeze, -18°C	14 days 6 months
Total volatile solids	Cool, 4°C Freeze, -18°C	14 days 6 months
Total organic carbon	Cool, 4°C Freeze, -18°C	14 days 6 months
Ammonia	Cool, 4°C	7 days
Total sulfides	Cool, 4°C (1 N zinc acetate)	7 days
Oil and grease	Cool, 4°C (HCl) Freeze, -18°C (HCl)	28 days 6 months
Metals (except mercury)	Cool, 4°C Freeze, -18°C	6 months 2 years
Mercury	Freeze, -18°C	28 days
Semivolatile organic compounds; pesticides and PCBs; PCDDs/PCDFs	Cool, 4°C Freeze, -18°C	10 days 1 year
after extraction	Cool, 4°C	40 days
Volatile organic compounds	Cool, 4°C Freeze, -18°C	14 days 14 days
Sediment toxicity tests	Cool, 4°C Cool, 4°C, nitrogen atmosphere	2 weeks[a] 8 weeks[a]

HCl - hydrochloric acid; PCB - polychlorinated biphenyl; PCDD - polychlorinated dibenzo-*p*-dioxin; PCDF - polychlorinated dibenzofuran.

[a] The PSEP (1995) protocols recommend a maximum holding time of 2 weeks, but recognize that it may be necessary under certain circumstances to extend the holding time to accommodate a tiered testing strategy in which chemical analyses are conducted prior to toxicity testing. The PSDDA program, for example, allows sediments to be stored in the dark in a nitrogen atmosphere at 4°C for up to 8 weeks.

Table 7. Quality control procedures for organic analyses (from WDOE 1995).

Quality Control Procedure	Frequency	Control Limit	Corrective Action
Instrument Quality Assurance/Quality Control			
Initial Calibration	As recommended by PSEP (1989a) and specified in analytical protocol	≤30 %RSD for SVOCs and VOCs; ≤20 %RSD for PCBs. Relative response factors ≥0.05 for SVOCs and VOCs	Laboratory to recalibrate and reanalyze affected samples
Continuing Calibration	After every 10–12 samples (6 samples for PCBs) or every 12 hours (6 hours for PCBs), whichever is more frequent, and after the last sample of each work shift	≤25 %D for SVOCs and VOCs; ≤ 15 %D for PCBs. Relative response factors ≥ 0.05 for SVOCs and VOCs	Laboratory to recalibrate and reanalyze affected samples
Method Quality Assurance/Quality Control			
Holding Times	Not applicable	1 year (samples stored frozen [-18°C]) or 14 days (samples stored at 4°C) for SVOCs and PCBs; analyze extract within 40 days; 14 days (samples stored at 4°C) for VOCs	Qualify data or collect fresh samples
Method Blank	With every extraction batch; every 12-hour shift for VOCs	Analyte concentration >PQL (the LOD constitutes the warning limit)	Laboratory to eliminate or greatly reduce contamination; reanalyze affected samples
Surrogate Compounds	Added to every sample as specified in analytical protocol	EPA CLP control limits	Laboratory to follow EPA CLP protocols (reanalyzes or reextraction may be required)
Matrix Spike Sample and Matrix Spike Duplicate	With every sample batch or every 20 samples, whichever is more frequent	Recovery of 50–150 percent; precision of ≤50 RPD	Follow EPA CLP protocols

Table 7. Quality control procedures for organic analyses (from WDOE 1995).

Quality Control Procedure	Frequency	Control Limit	Corrective Action
Method Quality Assurance/Quality Control (cont.)			
Laboratory Control Sample	With every sample batch or every 20 samples, whichever is more frequent	Recovery of 50–150 percent	Laboratory to correct problem and reanalyze affected samples
Internal Standards	Added to every sample as specified in analytical protocol	Area response of 50–200 percent of calibration standard; retention time within 30 seconds of calibration standard	Laboratory to correct problem and reanalyze affected samples
Detection Limits	Not applicable	Target detection limits should be established at one-half of the TEC values (MacDonald *et al.* 2000)	Laboratory must initiate corrective actions (which may include additional cleanup steps as well as other measures, see) and contact the QA/QC coordinator and/or project manager immediately
Field Quality Assurance/Quality Control			
Field Replicates	At project manager's discretion	Not applicable	Not applicable
Blind Certified Reference Material	Overall frequency of 5 percent of field samples	Within 95 percent confidence interval of true value	At project manager's discretion: discuss results with laboratory; qualify sample results

CLP - Contract Laboratory Program; EPA - U.S. Environmental Protection Agency; LOD - limit of detection; PCB - polychlorinated biphenyl; PQL - protection quantification limit; RPD - relative percent difference; RSD - relative standard deviation; SVOC - semivolatile organic compound; VOC - volatile organic compound; QA/QC - quality assurance/quality control.

Table 8. Quality control procedures for metal analyses (from WDOE 1995).

Quality Control Procedure	Frequency	Control Limit	Corrective Action
Instrument Quality Assurance/Quality Control			
Initial Calibration	Daily	Correlation coefficient > 0.995	Laboratory to recalibrate the instrument and reanalyze any affected samples
Initial Calibration Verification	Immediately after initial calibration	90–110 percent recovery (80–120 percent for mercury)	Laboratory to resolve discrepancy prior to sample analysis
Continuing Calibration Verification	After every 10 samples or every 2 hours, whichever is more frequent, and after the last sample	90–110 percent recovery (80–120 percent for mercury)	Laboratory to recalibrate and reanalyze affected samples
Initial and Continuing Calibration Blanks	Immediately after initial calibration, then 10 percent of samples or every 2 hours, whichever is more frequent, and after the last sample	Analyte concentration ≤CRDL	Laboratory to recalibrate and reanalyze affected samples
ICP Interelement Interference Check Sample	At the beginning and end of each analytical sequence or twice per 8 hour shift, whichever is more frequent	80–120 percent of the true value	Laboratory to correct problem, recalibrate, and reanalyze affected samples
Method Quality Assurance/Quality Control			
Holding Times	Not applicable	6 months if samples are held at 4°C; 2 years if samples are frozen (-18°C); 28 days for mercury regardless of whether samples are held at 4°C or frozen	Qualify data or collect fresh samples

Table 8. Quality control procedures for metal analyses (from WDOE 1995).

Quality Control Procedure	Frequency	Control Limit	Corrective Action
Method Quality Assurance/Quality Control (cont.)			
Method Blanks	With every sample batch or every 20 samples, whichever is more frequent	Analyte concentration ≤CRDL	Laboratory to redigest and reanalyze samples with analyte concentrations ≤10 times the highest method blank
Laboratory Control Sample	With every sample batch or every 20 samples, whichever is more frequent	EPA control limits (varies with laboratory control sample)	Laboratory to correct problem and redigest and reanalyze affected samples
Matrix Quality Assurance/Quality Control			
Matrix Spike Sample	With every sample batch or every 20 samples, whichever is more frequent	75–125 percent recovery	Laboratory may be able to correct or minimize problem; or qualify and accept data
Duplicate Sample Analysis	With every sample batch or every 20 samples, whichever is more frequent	±35 RPD (2 times CRDL for sample duplicate results >5 times CRDL)	Laboratory may be able to correct or minimize problem; or qualify and accept data as reported
Method of Standard Additions (for GFAA)	As required when analytical spike recovery fails quality control limits (EPA current CLP statement of work)	Correlation coefficient ≥0.995	Qualify and accept data as reported
Detection Limits	Not applicable	Target detection limits should be established at one-half of the TEC values (MacDonald *et al.* 2000)	Laboratory must initiate corrective actions and contact the QA/QC coordinator and/or the project manager immediately

Table 8. Quality control procedures for metal analyses (from WDOE 1995).

Quality Control Procedure	Frequency	Control Limit	Corrective Action
Matrix Quality Assurance/Quality Control (cont.)			
Field Replicates	At project manager's discretion	±35 RPD (2 times CRDL for sample duplicate results >5 times CRDL)	Examine laboratory replicate results to rule out analytical imprecision; examine and modify sample homogenization procedures in the field
Cross-Contamination Blanks	At project manager's discretion	Analyte concentration ≤CRDL	Examine method blank results to rule out laboratory contamination; modify sample collection and equipment decontamination procedures
Blind Certified Reference Material	Overall frequency of 5 percent of field samples	80–120 percent recovery	Project Manager decision: discuss results with laboratory; qualify sample results

CLP - Contract Laboratory Program (EPA); CRLD - contract required detection limit; EPA - U.S. Environmental Protection Agency; GFAA - graphite furnace atomic absorption; ICP - inductively coupled plasma-atomic emission spectrometry; RPD - relative percent difference; QA/QC - quality assurance/quality control.

Instrument and method QA/QC monitor the performance of the instrument and sample preparation procedures, and are the responsibility of the analytical laboratory. When an instrument or method control limit is exceeded, the laboratory is responsible for correcting the problem and reanalyzing the samples. Instrument and method QA/QC results reported in the final data package should always meet control limits (with a very small number of exceptions that apply to difficult analytes as specified by EPA for the CLP). If instrument and method QA/QC procedures meet control limits, laboratory procedures are deemed to be adequate. Matrix and field QA/QC procedures monitor matrix effects and field procedures and variability. Although poor analytical procedures may also result in poor spike recovery or duplicate results, the laboratory is not held responsible for meeting control limits for these QA/QC samples. Except in the possible case of unreasonably large exceedances, any reanalyses will be performed at the request and expense of the project manager.

Table 9. Quality control procedures for conventional analyses (from WDOE 1995).

Analyte	Suggested Control Limit						
	Initial Calibration	**Continuing Calibration**	**Calibration Blanks**	**Laboratory Control Samples**	**Matrix Spikes**	**Laboratory Triplicates**	**Method Blank**
Ammonia	Correlation coefficient ≥0.995	90–110 percent recovery	Analyte concentration ≤CRDL	80–120 percent recovery	75–125 percent recovery	35 percent RSD	Analyte concentration ≤CRDL
Grain size	Not applicable	Not applicable	Not applicable	Not applicable	Not applicable	35 percent RSD	Analyte concentration ≤CRDL
Total organic carbon	Correlation coefficient ≥0.995	90–110 percent recovery	Analyte concentration ≤CRDL	80–120 percent recovery	75–125 percent recovery	35 percent RSD	Analyte concentration ≤CRDL
Total sulfides	Correlation coefficient ≥0.990	85–115 percent recovery	Not applicable	65–135 percent recovery	65–135 percent recovery	35 percent RSD	Analyte concentration ≤CRDL
Total solids	Not applicable	Not applicable	Not applicable	Not applicable	Not applicable	35 percent RSD	Analyte concentration ≤CRDL

CRLD - contract-required detection limit; EPA - U.S. Environmental Protection Agency; PSEP - Puget Sound Estuary Program; QA / QC - quality assurance and quality control; RSD - relative standard deviation.

EPA and PSEP control limits are not available for conventional analytes. The control limits provided above are suggested limits only. They are based on EPA control limits for metals analyses (Table 8), and an attempt has been made to take into consideration the expected analytical accuracy using PSEP methodology. Corrective action to be taken when control limits are exceeded is left to the Project Manager's discretion. The corrective action indicated for metals in Table 8 may be applied to conventional analytes.

When applicable, the QA/QC procedures indicated in this table should be completed at the same frequency as for metals analyses (Table 8).

Table 10. Examples of recommended test conditions for conducting freshwater sediment toxicity tests (from WDOE 1995).

Toxicity Test *Test Species*	Frequency of Water Quality		Control Limits		Control Samples			Performance Standards
	Temp, DO	Hardness, Alkalinity, Conductivity, pH, Ammonia	Temp (°C)	DO (% saturation)	Negative Control	Positive Control	Reference Sediment	
Amphipod *Hyalella azteca*	Daily	Beginning/end	23±1[a]	40–100	Clean sediment	Reference toxicant in freshwater	Yes	Mean mortality in control sediment <20%
Mayfly *Hexagenia limbata*	Daily	Beginning/end	20±2	Not applicable[b]	Clean sediment	Reference toxicant in freshwater	Yes	Mean mortality in control sediment <20%
Midge *Chironomus tentans*	Daily	Beginning/end	23±1[a]	40–100	Clean sediment	Reference toxicant in freshwater	Yes	Mean mortality in control sediment <30%
Frog embryo (FETAX) *Xenopus laevis*	DO at beginning/end	Beginning/end	24±2	Not applicable	FETAX solution	Reference toxicant in FETAX solution	Yes	Mean mortality in negative control <10%, or mean malformation occurrence in negative control <7%
Microtox® (solid phase) *Vibrio fisheri*[c]	Not applicable	Not applicable	15	Not applicable	Clean sediment	Reference toxicant	Yes	Determined by ecology on case-by-case basis.
Microtox® (deionized water elutriate) *Vibrio fisheri*[c]	Not applicable	Not applicable	15	Not applicable	Clean sediment	Reference toxicant	Yes	Determined by ecology on case-by-case basis.

DO - dissolved oxygen; Temp = temperature.

[a] The temperature of the water bath or the exposure chamber should be continuously monitored. The daily mean temperature must be within ±1°C of the desired temperature. The instantaneous temperature must always be within ±3°C of the desired temperature.

[b] Continuous aeration is required by the protocol, so the dissolved oxygen concentration should not be cause for concern.

[c] Formerly known as *Photobacterium phosphoreum*.

Note: more recent guidance on conducting freshwater toxicity tests is provided in USEPA (2000a) and ASTM (2001a; 2001b).

Figures

Figure 1. Overview of the process for designing and implementing sediment quality investigations.

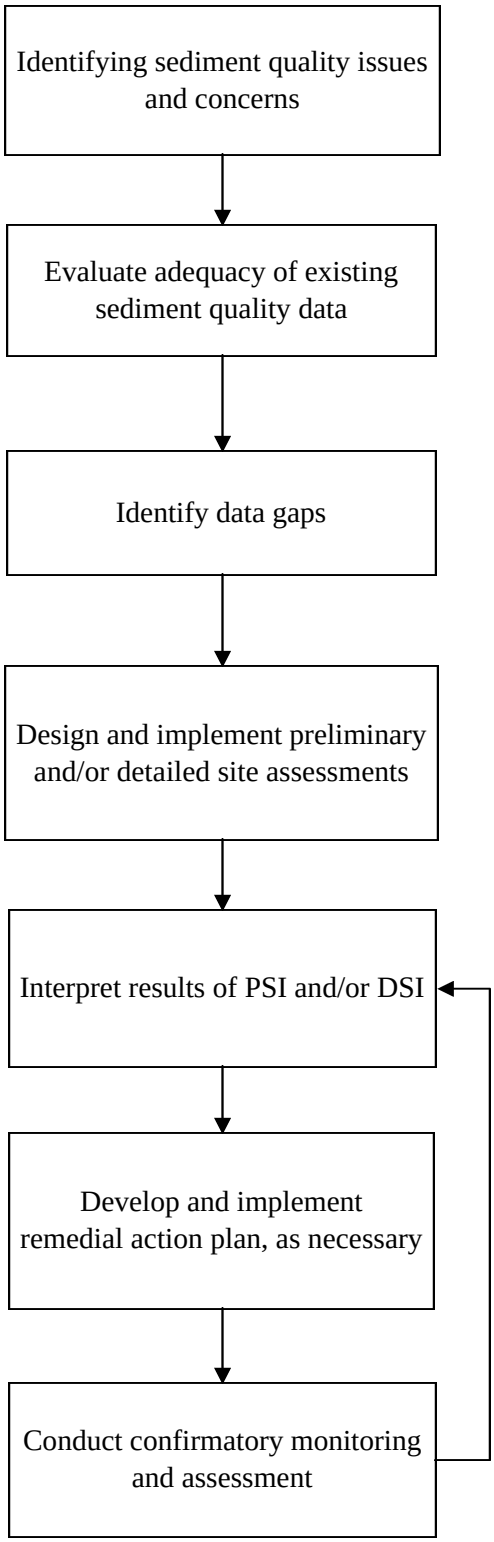


Figure 2. Overview of the recommended process for managing sites with contaminated sediments.

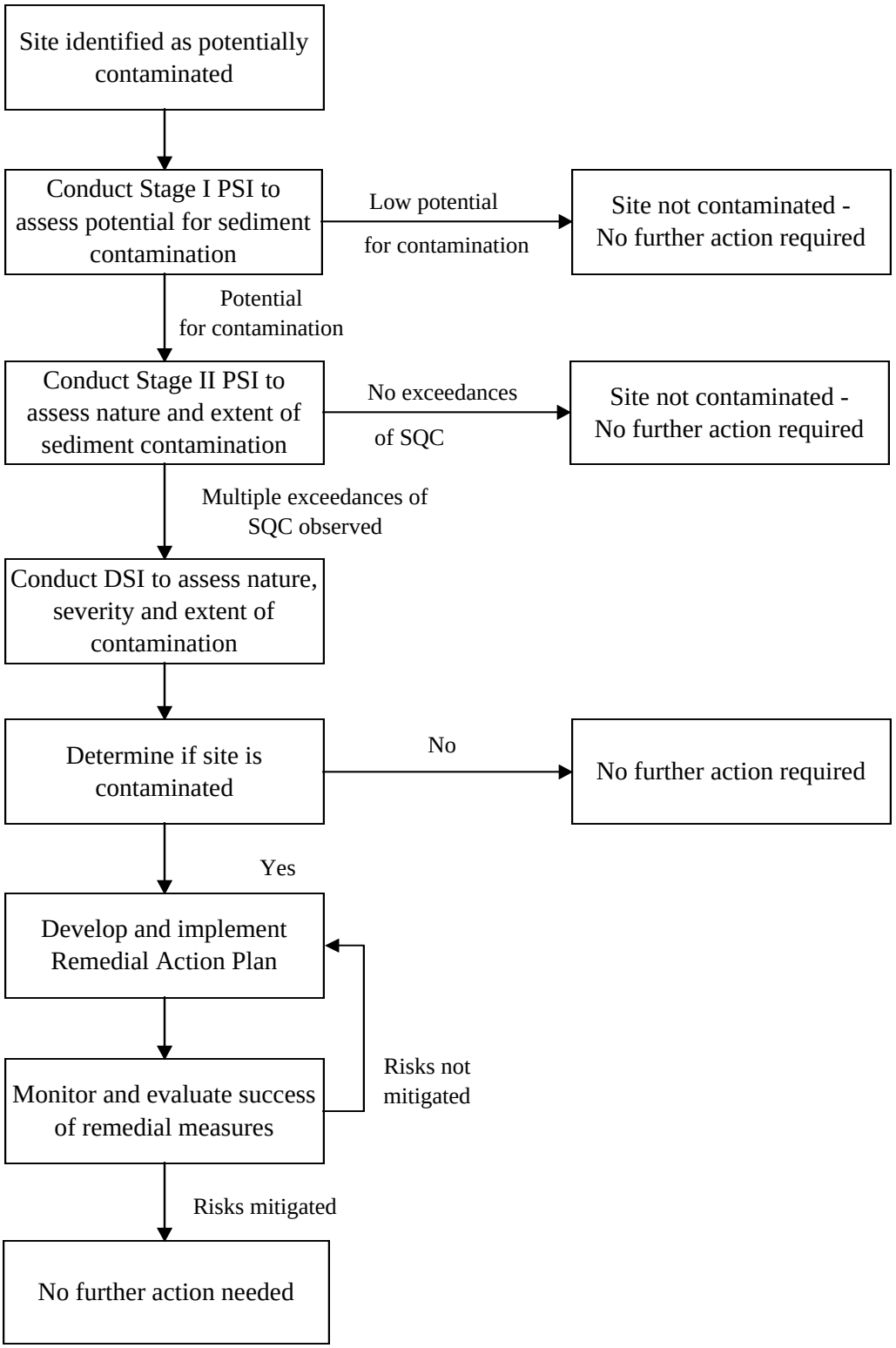


Figure 3. Overview of the sediment assessment and remediation process in British Columbia.

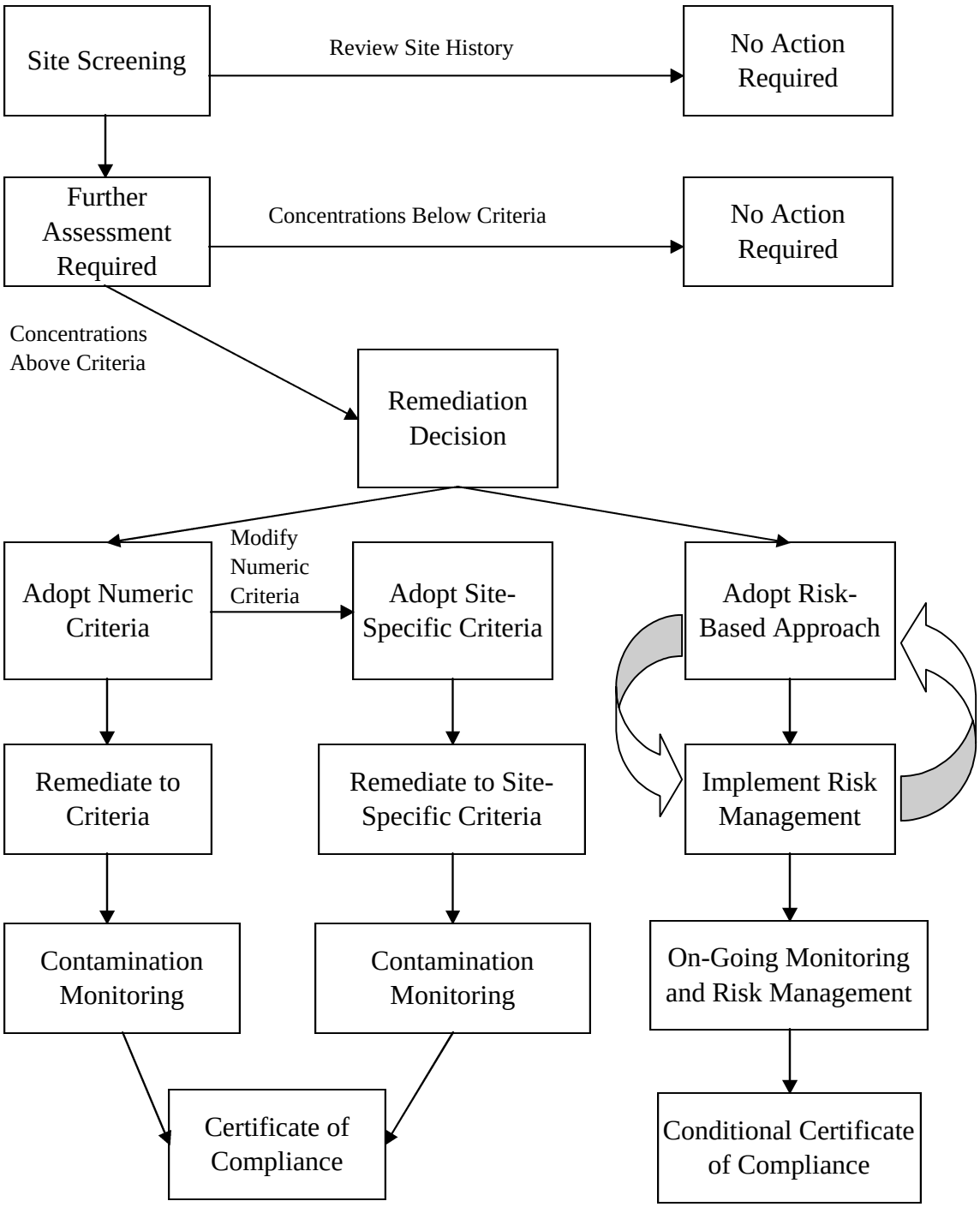


Figure 4. An overview of Stage I of the preliminary site investigation (PSI).

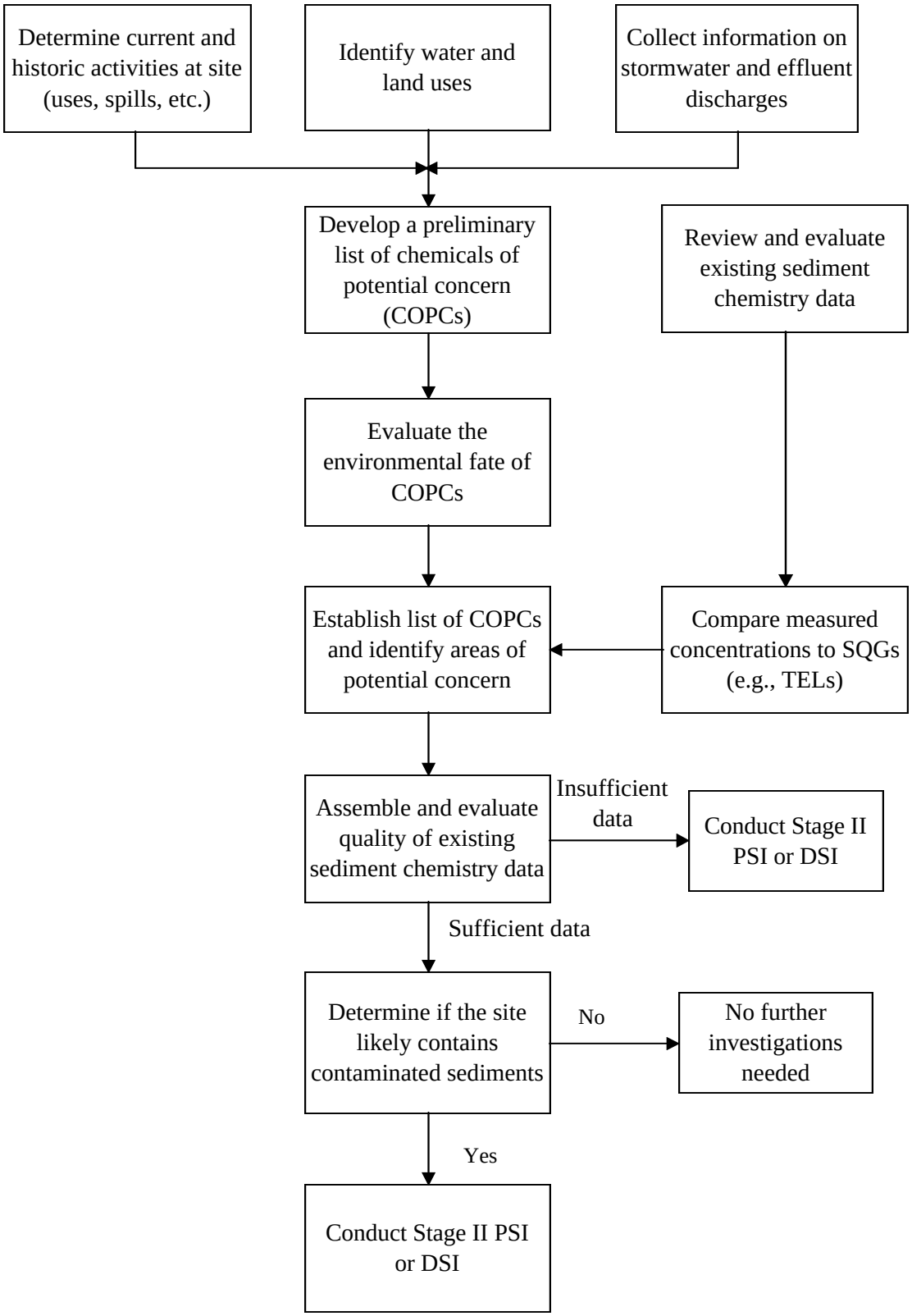


Figure 5. An overview of Stage II of the preliminary site investigation (PSI). A Stage II PSI is conducted if the results of the first stage of the PSI indicates that sediments are likely to be contaminated with toxic or bioaccumulative substances.

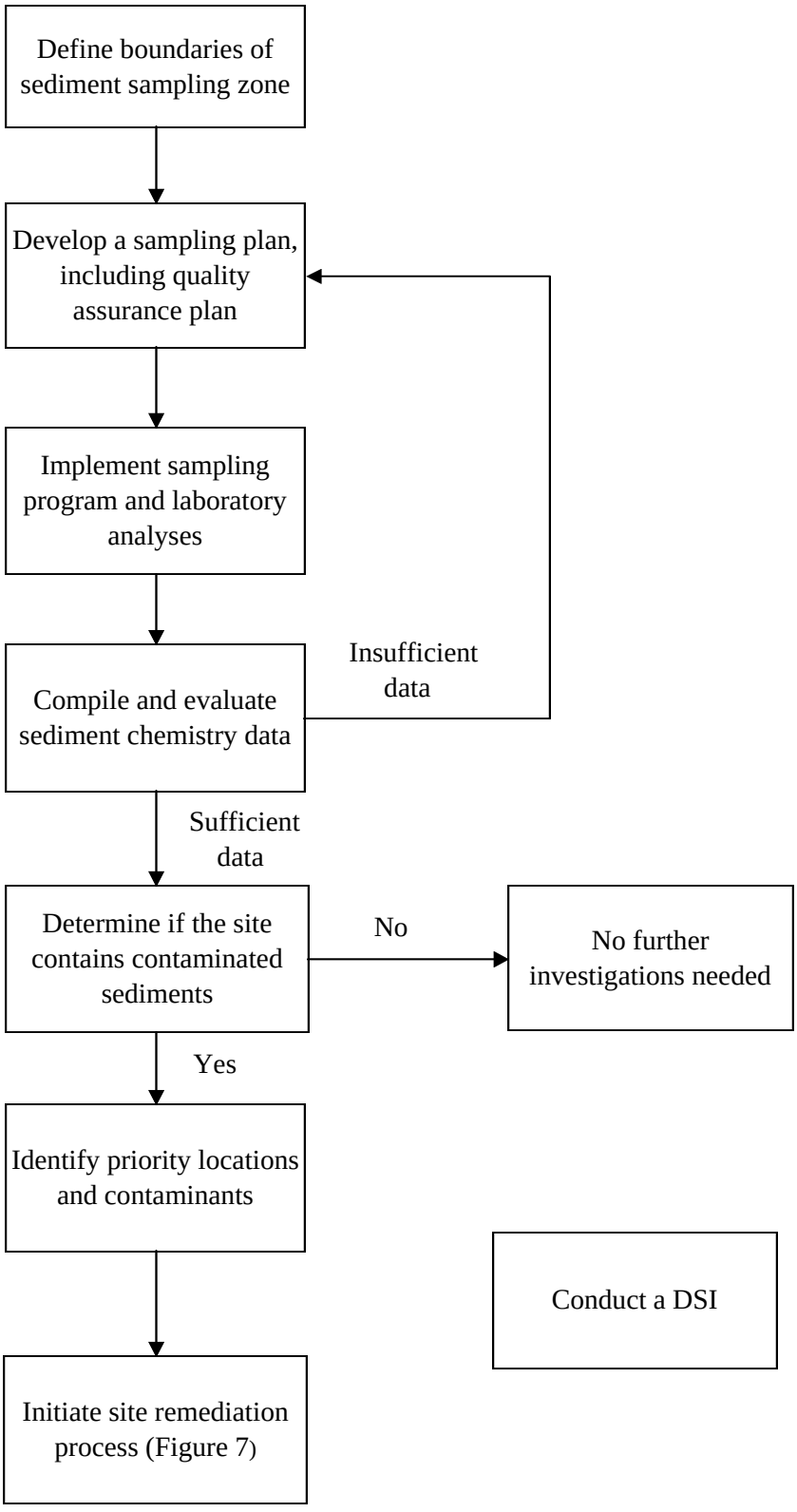


Figure 6. An overview of the detailed site investigation (DSI).

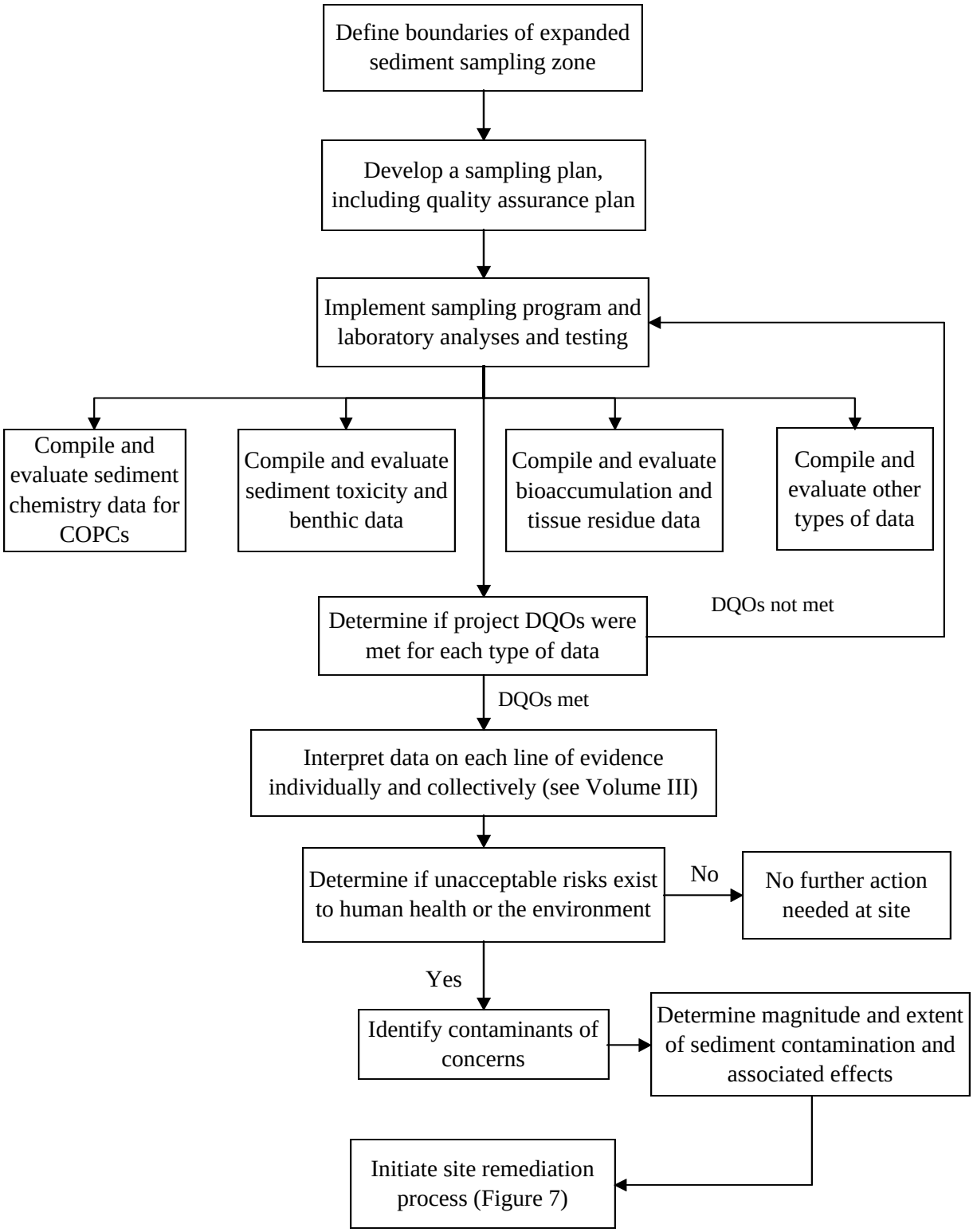
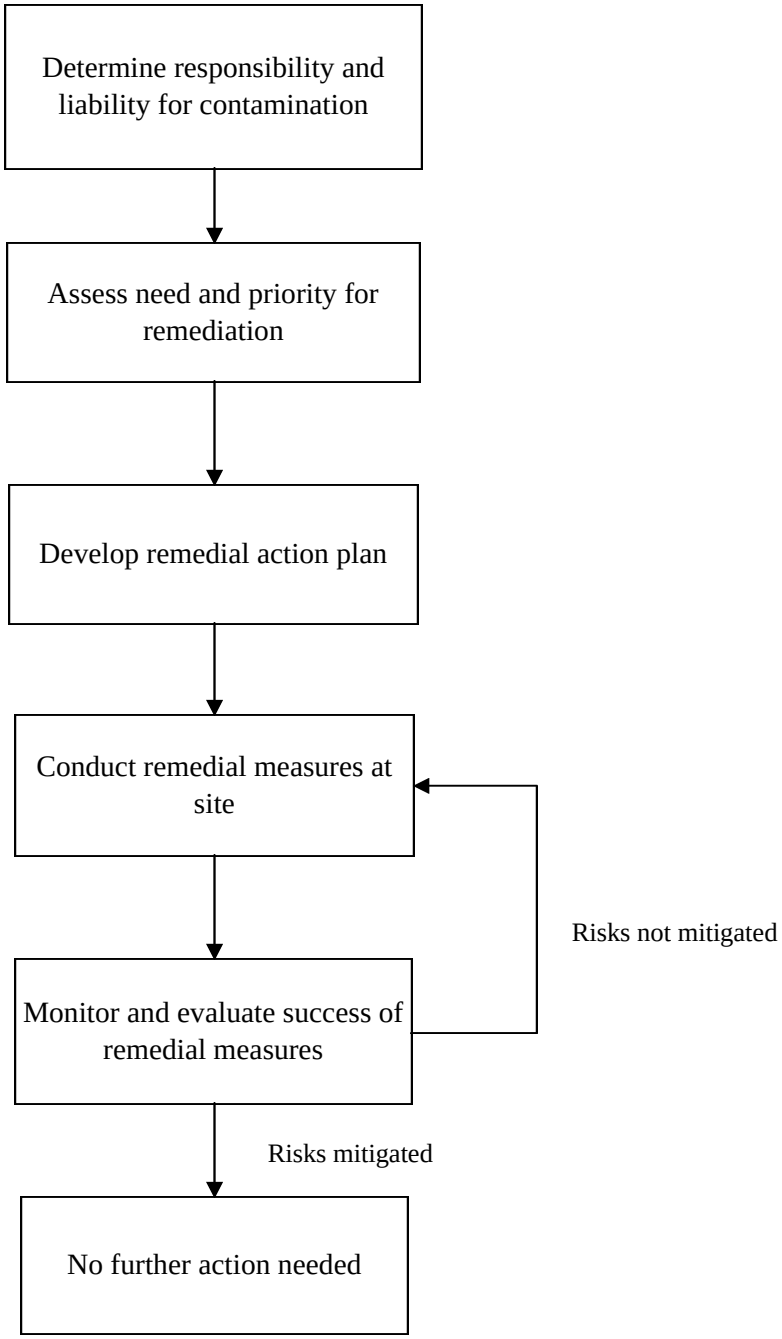


Figure 7. An overview of the contaminated site remediation process.



Appendices

Appendix 1 Additional Considerations for Designing Sediment Quality Sampling Programs

A1.0 Introduction

To be effective, a sediment quality sampling program must be designed to fulfill the specific objectives that have been established for the assessment. Nevertheless, general guidance on the design and implementation of preliminary and detailed site investigations was provided in Chapter 3 and Chapter 4 of Volume II, respectively, of this guidance manual. Furthermore, the key elements of sampling and analysis plans for assessing contaminated sediments were identified in Chapter 5 of Volume II. The supplemental guidance that is offered in this appendix is intended to provide additional information on the design of sediment quality sampling programs, including the selection of control and reference sediments. This information was obtained primarily from USEPA (2001), ASTM (2001c), and CDM (2000).

A1.1 Selection of Sampling Stations

The study area (or site) refers to the body of water that contains the sampling station(s) to be evaluated, as well as adjacent areas (land or water) that might influence the conditions of the sampling station. The size and characteristics of the study area will influence the sampling design and station positioning methods. The boundaries of the study area need to be defined using a hydrographic chart or topographic map.

The selection of an appropriate sampling design is one of the most critical steps designing the study. The design will be a product of the general study objectives. Station location and sampling methods will necessarily follow from the study design. Ultimately, a study design should control extraneous sources error to the extent possible so that data are directly applicable for addressing the project objectives.

Most projects do not have the resources to fully characterize the spatial or temporal variability of sediment quality conditions. To address the constraints imposed by resource limitations, sampling can be restricted to an index period when biological measures are expected to show the greatest response to pollution stress and within-season variability is the lowest (Holland 1985; Barbour *et al.* 1999). This type of sampling can be also be advantageous for characterizing benthic invertebrate and fish community structure in the field. In addition, this approach is useful if sediment contamination is related to high flow events (USEPA 2001). Alternatively, investigations can focus on measurement endpoints that exhibit less seasonal variability (e.g., sediment toxicity).

There are a number of options for selecting sampling stations; however, most of these options fall into two major categories of design, including random sampling and targeted (or biassed) sampling. USEPA (2001) presents a thorough discussion of sampling design issues and detailed information on the various sampling designs, including the following recommendations regarding sampling design:

- Historical data and the locations of sediment deposition zones should be considered when selecting sampling stations;
- A systematic random sampling strategy may be most appropriate if the objective of the program is to identify areas of toxic or contaminated sediments on a quantitative spatial or temporal basis;
- A targeted station location design may be most appropriate if the objective of the program is to evaluate the extent of sediment contamination originating from a specific source or tributary;
- Stratified sampling should be used where historical, sediment-mapping data are available and there are well-defined zones of different sediment types or adjacent land uses; and,
- A probability-based random sampling design may be most appropriate for watershed or regional assessment programs.

In systematic random sampling, the first sampling location is chosen randomly and all subsequent stations are placed at regular intervals (e.g., 50 meters apart) throughout the study

area. Depending on the types of analyses desired, such sampling can become expensive unless the study area is relatively small or the density of stations is relatively low. Systematic sampling can be effective for detecting previously unknown "hot spots" in the study area.

Targeted sampling of sediments is appropriate for situations in which any of the following apply: (1) relatively small-scale features or conditions are under investigation; (2) small numbers of samples (e.g., fewer than 20 observations) will be evaluated; (3) there is reliable historical and physical knowledge about the feature or condition under investigation; (4) the objective of the investigation is to screen an area(s) for contamination at levels of concern; or, (5) schedule or budget limitations preclude the possibility of implementing a statistical design (USEPA 2001).

Targeted sampling designs can often be quickly implemented at a relatively low cost. As such, this type of sampling can meet schedule constraints that cannot be met by implementing a more rigorous statistical design. In many situations, targeted sampling offers an additional important benefit of providing an appropriate level-of-effort for meeting objectives of the study within a limited budget. Targeted sampling does not allow the level of uncertainty in the field sampling to be accurately quantified. In addition, targeted sampling limits the inferences that can be made to the units actually analysed and the extrapolation from those units to the overall population from which the units were collected.

Stratified random sampling consists of dividing the target population into non-overlapping parts or subregions (e.g., watersheds), which are termed strata, to obtain a better estimate of the mean or total for the entire population. The information required to delineate the strata and estimate sampling frequency needs to be known before sampling. This information is typically obtained from historic data or by conducting a reconnaissance survey. Sampling locations are randomly selected from within each of the strata. In stratified designs, the selection probabilities may differ among strata.

A related design is multistage random sampling, in which large subareas within the study area are first selected (usually on the basis of professional knowledge or previously collected information). Stations are then randomly located within each subarea to yield average or

pooled estimates of the variables of interest. This type of sampling is especially useful for statistically comparing variables among specific parts of a study area.

Use of random sampling designs may miss relationships among variables, especially if there is a relationship between an explanatory and a response variable. As an example, estimation of COPC concentrations nearby an outfall requires data from a number of sampling stations, including those located directly adjacent to the outfall and those that are located further from the outfall. A simple random sample of stations may not capture the entire range, because the high end of the gradient would likely be under-represented in the design.

Probability-based sampling designs avoid bias in the results of sampling by randomly assigning and selecting sampling locations. A probability-based design requires that all sampling units have a known probability of being selected. Stations can be selected on the basis of a random scheme or in a systematic way (e.g., sample every 10 meters along a randomly chosen transect). In simple random sampling, all sampling units have an equal probability of selection. This design is appropriate for estimating means and totals of environmental variables if the population is homogeneous. To apply simple random sampling, it is necessary to identify all potential sampling times or locations, then randomly select individual times and/or locations for sampling.

A1.2 Sample Size, Number of Samples, and Replicate Samples

Before starting a sampling program, the type and number of analyses and tests needs to be determined and the required volume of sediment per sample needs to be established (ASTM 2001a; USEPA 2001; Table 5). When determining the required sample volumes, it is useful to know the general characteristics of the sediments being sampled. For example, if pore-water analyses are to be conducted, the percent water of the sediment will influence the amount of water extracted. It is recommended that additional sediment (i.e., beyond the volume that is calculated to meet the needs of the various chemical analyses and toxicity tests) be collected at each station during the sampling program and stored in an appropriate way in the laboratory. In this way, it will be possible to retest samples that yield anomalous results or to provide sediment to other laboratories if samples are lost or broken during

transport. The testing laboratories should be consulted to confirm the amount of sediment required for each toxicity test or chemical analysis.

The number of samples collected is usually determined by the size of the sampling station, type and distribution of COPCs being measured, heterogeneity of the sediment, concentrations of COPCs in the sediments, sample volume requirements, and desired level of statistical resolution. Accordingly, sample requirements needs to be determined on a case-by-case basis. The number of samples to be collected will ultimately be an outcome of the questions asked. For example, if one is interested in characterizing effects of a point source or a gradient (e.g., effects of certain tributaries or land uses on a lake or estuary), then many samples in a relatively small area may need to be collected and analysed. If, however, one is interested in identifying "hot spots" or locations that are highly contaminated within a watershed or large water body, relatively few samples at targeted locations may be appropriate. The number of samples to be collected usually results from a compromise between the ideal and the practical. The major practical constraints are the logistics of sample collection and the costs of analyses.

The objective of collecting replicate samples at each sampling station is to allow for quantitative statistical comparison within and among different stations. Separate subsamples from the same grab or core sample might be used to measure the variation within a sample but not necessarily within the station. The collection of separate samples within a sampling station can impart valuable information on the spatial distribution of contaminants at the station and on the heterogeneity of the sediments within the station. However, the collection of replicate samples at each station will dramatically increase the analytical chemical costs needed for the assessment. Approaches that can be used to determine the number of replicates required to achieve a minimum detectable difference at a specific confidence level and power are outlined in USEPA (2001). Traditionally, acceptable coefficients of variation vary from 10 to 35%, the power from 80 to 95%, the confidence level from 80 to 99%, and the minimum detectable relative difference from 5 to 40%.

Replicate samples collected from a sampling station can be kept separate and treated as true replicate samples, or they can be combined to generate a composite sample. A composite sample from a sampling station is treated as a single sample. Compositing of sediment samples within a habitat location might be desirable if resources prevent detailed spatial

characterization, if a large area is being sampled, or if split sampling is being conducted (e.g., comparisons of toxicity, bioaccumulation, and sediment chemistry; ASTM 2001a).

A1.3 Control and Reference Sediments

Sediment toxicity and bioaccumulation tests must include a control sediment (sometimes called a negative control) to support an assessment of test validity (i.e., acceptability). A control sediment is a sediment that is essentially free of contaminants and is used routinely to assess the acceptability of a test and is not necessarily collected near the site of concern (ASTM 2001a; USEPA 2000a). For example, control sediments for toxicity tests can be obtained from the locations that the test organisms were collected. Any COPCs in control sediment are thought to originate from the global spread of pollutants and do not reflect any substantial inputs from local or non-point sources. Comparing test sediments to control sediments provides a means of measuring the toxicity of a test sediment beyond that associated with background contamination and organism health. A control sediment provides a measure of test acceptability, evidence of test organism health, and a basis for interpreting data obtained from the test sediments. A reference sediment is collected near an area of concern and is used to assess sediment conditions exclusive of material(s) of interest. Testing a reference sediment provides a site-specific basis for evaluating toxicity.

In general, the performance of test organisms in the negative control is used to judge the acceptability of a test, and either the negative control or reference sediment may be used to evaluate performance in the experimental treatments, depending on the purpose of the study. Any study in which organisms in the negative control do not meet performance criteria must be considered questionable because it suggests that adverse factors affected the response of test organisms (i.e., other than the variables of interest, sediment contamination; ASTM 2001a; USEPA 2000a). The key to avoiding this situation is to use only control sediments that have a demonstrated record of performance for the test procedure that will be employed. This includes testing of new collections from sediment sources that have previously provided suitable control sediment. It is recommended by USEPA (2000a) and ASTM (2001a) that a laboratory demonstrate acceptable control responses of organisms in a minimum of five separate tests with the control sediment and proposed test conditions.

Because of the uncertainties introduced by poor performance in the negative control, such studies should be repeated to ensure that accurate results are generated. However, the scope of sampling associated with some studies may make it difficult or impossible to repeat a study (unless extra sediment was collected during the sampling program). Some researchers have reported cases where performance in the negative control is poor, but performance criteria are met in a reference sediment included in the study design. In these cases, it might be reasonable to infer that other samples that show good performance are probably not toxic; however, any samples showing poor performance should not be judged to have shown toxicity, since it is unknown whether the adverse factors that caused poor control performance might have also caused poor performance in the test treatments.

A1.4 Evaluation of Data Quality

Evaluation of the quality of the data that are collected in sediment sampling and analysis programs represents an essential element of the overall sediment quality assessment process. In general, there are five primary indicators of the quality of physical, chemical, and biological data, including:

- Precision;
- Accuracy;
- Representativeness;
- Completeness; and,
- Comparability.

The following descriptions of these data quality indicators was obtained from CDM (2000).

Precision - The precision of a measurement is an expression of mutual agreement among individual measurements of the same property taken under prescribed similar conditions. Precision is quantitative and most often expressed in terms of relative percent difference (RPD). The precision of laboratory analyses is usually assessed by comparing duplicate

analytical results, where applicable. The RPD is calculated for each pair of applicable duplicate analyses using the following equation:

$$\text{Relative Percent Difference} = [(S - D) \div (S + D) \div 2)] \times 100$$

where:

S = First sample value (original value); and,

D = Second sample value (duplicate value).

Precision of reported results is a function of inherent field-related variability and/or laboratory analytical variability, depending on the type of QC samples that are submitted. Data may be evaluated for precision using the following types of samples (in order of priority): field duplicates, laboratory duplicates, laboratory control sample/laboratory control sample duplicates (LCS/LCSDs), or matrix spike/matrix spike duplicates (MS/MSDs).

The acceptable RPD limits for duplicate measurements are listed in USEPA Contract Laboratory Program, National Functional Guidelines for Inorganic Data Review (USEPA 1994b) and USEPA Contract Laboratory Program National Functional Guidelines for Organic Data Review (USEPA 1999b).

Accuracy - Accuracy is the degree of agreement of a measurement with an accepted reference or true value and is a measure of the bias in a system. Accuracy is quantitative and usually expressed as the percent recovery (%R) of a sample result. Percent R is calculated as follows:

$$\text{Percent Recovery} = [SSR - (SR \div SA)] \times 100$$

where:

SSR = Spiked Sample Result;

SR = Sample Result; and,

SA = Spike Added.

Ideally, the reported concentration should equal the actual concentration present in the sample. Data may be evaluated for accuracy using (in order of priority) certified reference materials, LCS/LCSDs, MS/MSDs, and/or surrogates. The acceptable %R limits are presented in USEPA National Functional Guidelines for Inorganic Data Review (USEPA

1994b) and USEPA National Functional Guidelines for Organic Data Review (USEPA 1999b). It should be noted that no procedures are currently available to evaluate the accuracy of toxicity tests.

Representativeness - Representativeness expresses the degree to which sample data accurately and precisely represent the characteristic being measured, parameter variations at a sampling point, and/or an environmental condition. Representativeness is a qualitative and quantitative parameter that is most concerned with the proper sampling design and the absence of cross-contamination of samples. Acceptable representativeness is achieved through:

- Careful, informed selection of sampling sites;
- Selection of testing parameters and methods that adequately define and characterize the extent of possible contamination and meet the required parameter reporting limits;
- Proper gathering and handling of samples to avoid interferences and prevent contamination and loss; and,
- Collection of a sufficient number of samples to allow characterization.

Representativeness is assessed qualitatively by reviewing the sampling and analytical procedures and quantitatively by reviewing the results of analyses of blank samples. If an analyte is detected in a method, preparation, or rinsate blank, any associated positive result less than five times the detection limit (10 times for common laboratory COPCs) may be considered a false positive. Holding times are also evaluated to determine if analytical results are representative of sample concentrations.

Completeness - Completeness is a measure of the amount of usable data obtained from a measurement system compared to the amount that was expected to be obtained under correct normal conditions. Usability is determined by evaluating the PARCC parameters excluding completeness. Those data that are validated, evaluated and are not considered estimated, or are qualified as estimated or non-detect are all considered to be usable. Rejected data are not considered usable. Completeness is calculated using the following equation:

$$\text{Percent Completeness} = (DO \div DP) \times 100$$

where:

DO = Data Obtained and usable; and,

DP = Data Planned to be obtained.

A completeness goal of 90 percent is often applied to sediment quality assessments.

Comparability - Comparability is a qualitative parameter. Consistency in the acquisition, handling, and analysis of samples is necessary for comparing results. Application of standard methods and appropriate quality control procedures are the primary means of assuring comparability of results with other analyses performed in a similar manner.