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Port Hueneme, California 93043-4370

User's Guide
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IMPLEMENTATION GUIDE FOR ASSESSING AND MANAGING CONTAMINATED SEDIMENT OF NAVY FACILITIES

Prepared by:
SPAWAR Systems Center (SSC) San Diego

Contributing Author:
Battelle

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EXECUTIVE SUMMARY

This document presents guidelines for conducting sediment site assessments and remedial alternative evaluations within the Navy's Environmental Restoration program. It is intended for use by Remedial Project Managers (RPMs) and their technical support staff as stepwise guidance that will apply to most Navy sediment investigations. Sediment investigations often are more complex than terrestrial investigations for a variety of reasons, including a lack of promulgated sediment quality criteria, incomplete knowledge and understanding of aquatic food webs, and lack of published risk-based threshold data (e.g., toxicity reference values) for many chemicals of potential concern (COPCs). Additionally, sediments commonly require specialized methods for sampling, analysis, and remediation. This guide identifies and discusses sediment-specific issues related to site characterization, risk assessment, and remedial alternative evaluation, and then directs the reader to related Web sites and resources for more detailed technical information. It is intended to help the RPM avoid unfocused or unnecessary studies and to coordinate and integrate data collection activities across all aspects of the sediment investigation. This guide complements Chief of Naval Operations (CNO) *Policy on Sediment Site Investigation and Response Action* (February 2002) as well as other applicable policies and guidance on risk assessment and the use of background chemical levels. Critical sediment issues discussed in this guide include the following:

- Addressing multiple contaminant sources (Navy and non-Navy);
- Development of a detailed and accurate Conceptual Site Model (CSM);
- Collection of important geochemical and physical information for characterizing the source, fate, and transport of chemicals in sediment and supporting the evaluation of remedial alternatives;
- Selection and use of appropriate tests for ecological risk assessments (ERAs) (e.g., bioavailability evaluations, aquatic toxicity tests);
- Use of background and reference site data in risk assessments;
- Use of a weight-of-evidence (WOE) approach and other decision-making tools;
- Development of site-specific risk-based cleanup goals; and
- Evaluating remedial options for sediment and the risk and liabilities associated with each.

This guide is organized into four sections along with a glossary and references. Hyperlinks that connect the reader to related Web sites and documents are found throughout the document.

Section 1 – Introduction presents the purpose and organization of the document, discusses some of the primary differences in conducting aquatic versus terrestrial studies, and provides overviews of applicable Navy policy and guidance as well as pertinent laws and regulations.

Section 2 – Sediment Site Characterization presents an overview of the site characterization process relative to sediment investigations, including planning considerations, developing a CSM, source identification, defining the nature and extent of contamination, and characterizing

contaminant fate and transport. This section also identifies important physical and chemical data that should be collected as part of a sediment investigation, with an emphasis on coordinating data collection for all aspects of the investigation (site characterization, risk assessment, and evaluation of remedial alternatives). This section also provides an overview of sample design and sample collection methods and equipment.

Section 3 – Ecological and Human Health Risk Assessment for Sediment Studies follows the stepwise guidance for conducting ecological and human health risk assessments at sediment sites within the Navy's tiered framework. Issues specific to sediment sites are identified and discussed for each tier.

Section 4 – Sediment Remedial Alternative Evaluations addresses Feasibility Study (FS) planning considerations and determination of site-specific risk-based cleanup levels. Remedial options, including monitored natural recovery, in situ capping, and removal, are described along with monitoring considerations and sediment management issues.

Section 5 – Glossary provides a description of common terminology used in this guide and in sediment investigations in general.

Section 6 – References, Resources, and Applicable Web Sites provides references by section along with Web site addresses for information discussed in the guide.

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ABBREVIATIONS AND ACRONYMS

AEM	Applied Environmental Management, Inc.
AET	apparent effects threshold
ARAR	applicable or relevant and appropriate requirement
ARCS	Assessment and Remediation of Contaminated Sediment
ASTM	American Society for Testing and Materials
AVS	acid volatile sulfide
BAF	bioaccumulation factor
BERA	Baseline Ecological Risk Assessment
BHHRA	Baseline Human Health Risk Assessment
BRAC	Base Realignment and Closure (Act)
BSAF	biota sediment accumulation factors
CAA	Clean Air Act
CAD	contained aquatic disposal
CDF	confined disposal facilities
CERCLA	Comprehensive Environmental Response, Compensation, and Liability Act
CERCLIS	Comprehensive Environmental Response, Compensation, and Liability Information System
CFR	Code of Federal Regulations
CNO	Chief of Naval Operations
COPC	chemical of potential concern
CSF	cancer slope factor
CSM	conceptual site model
CWA	Clean Water Act
DGPS	differential global positioning system
DOT	United States Department of Transportation
DQO	data quality objective
EC50	concentration causing an effect on 50% of test organisms
EFA	Engineering Field Activity
EFD	Engineering Field Division
Eh	redox potential
ERA	ecological risk assessment
ERDC	(USACE) Engineer Research and Development Center
ER-L	effects range-low
ER-M	effects range-median
ESG	equilibrium partitioning sediment guideline
FR	Federal Register
FS	Feasibility Study
FSP	Field Sampling Plan
FW	fresh water
GSI	groundwater-surface water interaction
GW	groundwater

HPS	Hunters Point Shipyard
HHRA	human health risk assessment
HMTA	Hazardous Materials Transportation Act
HQ	hazard quotient
HWIR	Hazardous Waste Identification Rule
IR	Installation Restoration
LBC	level-bottom capping
LC50	concentration lethal to 50% of test organisms
LDR	land disposal restriction
MCSS	Major Contaminated Sediment Sites
MPRSA	Marine Protection, Research, and Sanctuaries Act
NAS	Naval Air Station
NAVFAC	Naval Facilities Engineering Command
NCP	National Oil and Hazardous Substances Pollution Contingency Plan
NFESC	Naval Facilities Engineering Service Center
NHPA	National Historical Preservation Act (of 1966)
NOAA	National Oceanographic and Atmospheric Administration
NPDES	National Pollutant Discharge Elimination System
NRC	National Research Council
NTR	National Toxic Rule
OU	Operable Unit
PA	Preliminary Assessment
PA/SI	Preliminary Assessment/Site Inspection
PAH	polycyclic aromatic hydrocarbon
PCB	polychlorinated biphenyl
PCS	Permit Compliance System
PEC	probable effect concentration
PEL	probable effect level
PRG	preliminary remediation goal
QA/QC	quality assurance/quality control
RAGS	Risk Assessment Guidance for Superfund
RAO	remedial action objective
RAW	Risk Assessment Workgroup
RBC	risk-based concentration
RBS	risk-based screening
RCRA	Resource Conservation and Recovery Act
RfC	reference concentration
RfD	reference dose
RI	Remedial Investigation
RI/FS	Remedial Investigation/Feasibility Study
RPM	Remedial Project Manager
RTDF	Remediation Technologies Development Forum

SAP	Sampling and Analysis Plan
SEM	simultaneously extracted metals
SFBRWQCB	San Francisco Bay Regional Water Quality Control Board
SFEI	San Francisco Estuary Institute
SI	Site Inspection
SMDP	scientific management decision point
SQG	sediment quality guideline
SQG-Q	sediment quality guideline quotient
SRA	Screening Risk Assessment
SSRBS	site-specific risk-based screening
STMS	sediment transport management system(s)
SW	surface water
SWRCB	State Water Resources Control Board
TBF	theoretical bioaccumulation factor
TCLP	Toxicity Characteristic Leaching Procedure
TEC	threshold effect concentration
TEL	threshold effect level
TIE	toxicity identification evaluation
TMDL	total maximum daily load
TOC	total organic carbon
TRV	toxicity reference value
UCL	upper confidence limit
USACE	United States Army Corps of Engineers
USC	United States Code
U.S. EPA	United States Environmental Protection Agency
USGS	United States Geological Survey
WCSD	Watershed Contaminated Source Document
WOE	weight of evidence
WP	Work Plan
WQC	water quality criteria
WSDE	Washington State Department of Ecology
XRF	x-ray fluorescence

1.0 INTRODUCTION

This document presents guidelines for conducting sediment site assessments and remedial evaluations within the Navy's Environmental Restoration program, including Installation Restoration (IR) and Base Realignment and Closure (BRAC). The document focuses on sediment-specific issues associated with the Remedial Investigation and Feasibility Study (RI/FS) process under the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) of 1980. It is intended for use by Remedial Project Managers (RPMs) and their technical support staff as stepwise guidance that will apply to most Navy sediment investigations.

This document is not intended to be a comprehensive method manual. Instead, it identifies and discusses sediment-specific issues related to site characterization, risk assessment, and remedial alternatives evaluation, and then directs the reader to related Web sites and resources for more detailed technical information. This guidance is intended to help the RPM avoid unfocused or unnecessary studies, and to coordinate and integrate data collection activities across all aspects of the sediment investigation. Critical sediment issues discussed in this guide include the following:

- Addressing multiple contaminant sources (Navy and non-Navy);
- Development of a detailed and accurate Conceptual Site Model (CSM);
- Collection of important geochemical and physical information for characterizing the source, fate, and transport of chemicals in sediment;
- Selection and use of appropriate tests for ecological risk assessments (ERAs) (e.g., bioavailability evaluations, aquatic toxicity tests);
- Use of background and reference site data in risk assessments;
- Use of a weight-of-evidence (WOE) approach and other decision-making tools;
- Developing site-specific risk-based cleanup goals; and
- Evaluating remedial options for sediment, and the risk and liabilities associated with each option.

The primary differences between aquatic (i.e., sediment) and terrestrial RI/FS studies are discussed in Section 1.1. The organization of this document is described in Section 1.2, and overviews of Navy policy and framework for sediment investigations and of applicable regulations, laws, and guidelines are provided in Sections 1.3 and 1.4, respectively.

1.1 AQUATIC VERSUS TERRESTRIAL STUDIES

The fundamental elements of conducting aquatic and terrestrial RI/FS investigations are the same. However, sediment investigations are often more complex for a variety of reasons, such as the fact that sediment quality criteria are not fully promulgated, aquatic food webs often are complex or poorly understood, and risk-based threshold data (e.g., toxicity reference values) are not available for many chemicals of potential concern (COPCs). Additionally, sediments may require specialized

methods for sampling, analysis, and remediation. Some of the technical, regulatory, and management challenges associated with contaminated sediments are discussed in detail in a 1997 National Research Council (NRC) report on contaminated sediments in ports and waterways (NRC, 1997). Table 1-1 summarizes the primary differences in the source, type, and transport of COPCs in aquatic versus terrestrial sites; the table also summarizes primary differences between ERAs and human health risk assessments (HHRAs) conducted at aquatic and terrestrial sites. Figure 1-1 illustrates the complexity of the aquatic environment at a contaminated sediment site.

Table 1-1. Comparison of Terrestrial and Aquatic Site Investigations

Focus of Investigation	Terrestrial Site	Aquatic Site
COPC Source and Transport	Point and nonpoint sources, generally lower degree of transport away from source area (i.e., concentration gradient away from source area commonly observed)	Commonly multiple point and nonpoint sources contributing to a water body; COPCs may be redistributed by waves and currents and transported away from source area
COPC Type	Various	Primarily persistent, hydrophobic compounds that are nonvolatile, relatively insoluble, and resistant to biodegradation
Ecological Risk Assessment	Site boundaries usually well-defined; significant human disturbance common; large literature database available regarding food web interactions, exposure parameters, and toxicological effects	Often difficult to define site boundaries, especially in offshore areas; human disturbance typically limited; complex food webs that may be difficult to define; literature on exposure parameters and toxicological effects is limited
Human Health Risk Assessment	Multiple, direct, and indirect exposure pathways typically considered (i.e., ingestion, dermal contact, inhalation)	Evaluations often limited to indirect pathways such as ingestion of fish and shellfish

In general, COPCs are released to terrestrial and aquatic environments from point (i.e., spills or discharges) and nonpoint (e.g., combustion emissions, pesticide application) sources. In terrestrial environments, COPCs may be introduced directly or indirectly to soils, whereas sources to sediments are almost always introduced indirectly through the water column. As a result of the influence of the overlying water, chemicals that are volatile or highly soluble in water rarely accumulate to high concentrations in sediment. COPCs that are highly biodegradable or photosensitive (i.e., transformed or degraded by sunlight) also do not tend to persist in aquatic environments. Instead, sediment COPCs generally are those that partition readily into sediments, such as nonionic polar organic compounds and metals. Consequently, sediments with the greatest partitioning capacity, such as those with high clay and organic carbon content, are often the most contaminated. Additionally, sediment-associated COPCs may be redistributed and transported away from the source area by waves and currents and mixed with contaminants from other sources in the water body, thereby complicating source identification (Apitz et al., 2002) (http://meso.spawar.navy.mil/Docs/MESO-02-TM-01.pdf). General discussions of contaminant fate and transport in sediments can be found in Burton (1992) and Allen (1995).

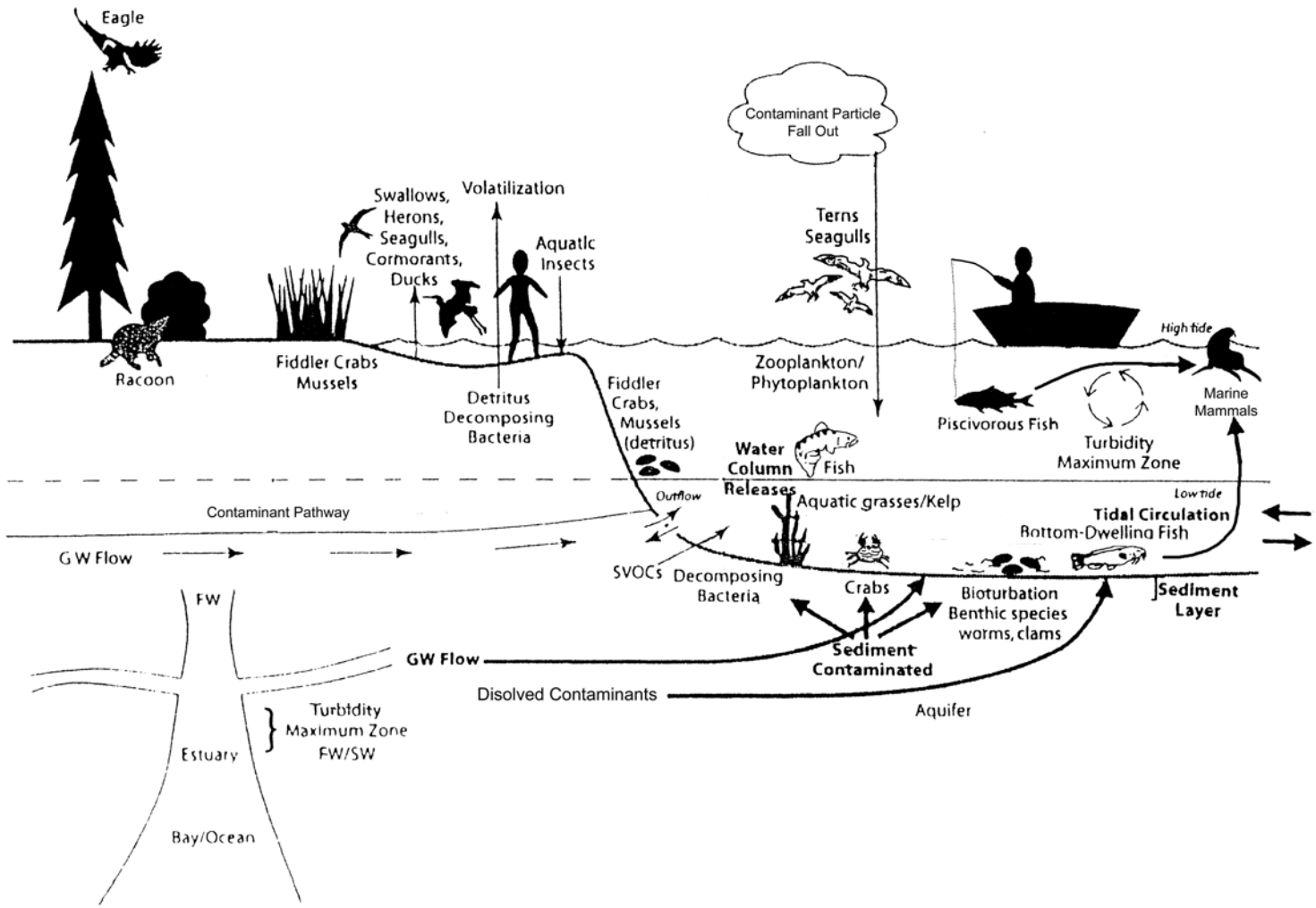


Figure 1-1. Generic Conceptual Site Model Showing Possible Contaminant Exposure Pathways and Receptors in an Aquatic Environment (modified from U.S. EPA diagram)

The overall process for evaluating human health and ecological risk at sediment sites is the same as that followed for terrestrial sites (U.S. Environmental Protection Agency [U.S. EPA], 1989 and 1998). However, there are differences in the process that need to be considered at sediment sites. For example, when evaluating potential ecological risks onshore at a Navy facility, the available habitat typically is clearly delineated by the presence of industrial or residential development. In contrast, it is very difficult to clearly define site boundaries in a submerged offshore area, particularly given the potential transport and redistribution of site contaminants as the result of wave action and currents. It is also important to note that terrestrial ecosystems have been more thoroughly studied than aquatic environments due to issues of accessibility. For human health evaluations, the primary difference is in the identification of exposure pathways: access to submerged sediments is limited; therefore, exposure to humans to offshore sediments is largely associated with indirect pathways such as consumption of contaminated fish and shellfish. Recreational scenarios also may be evaluated as appropriate (e.g. beach use, recreational sports).

1.2 DOCUMENT ORGANIZATION

This document is organized into four sections along with a glossary and references. Hyper-links that connect the reader to related Web sites and documents are found throughout the document. The main document body is organized as follows:

Section 1 – Introduction presents the purpose and organization of the document, identifies the primary differences in conducting aquatic versus terrestrial studies, and provides overviews of the Navy's approach to evaluating risk and remedial alternatives at sediment sites and of pertinent laws and regulations.

Section 2 – Sediment Site Characterization presents an overview of the site characterization process relative to sediment investigations, including planning considerations, developing a CSM, source identification, defining the nature and extent of contamination, and characterizing contaminant fate and transport. This section also identifies important physical and chemical data that should be collected as part of a sediment investigation, and provides an overview of sample design and sample collection methods and equipment.

Section 3 – Ecological and Human Health Risk Assessment for Sediment Studies follows the stepwise guidance for conducting ecological and human health risk assessments at sediment sites within the Navy's tiered framework. Issues specific to sediment sites are identified and discussed for each tier.

Section 4 – Sediment Remedial Alternative Evaluations addresses FS planning considerations and determination of site-specific risk-based cleanup levels. Remedial options, including monitored natural recovery, in situ capping, and removal, are described along with monitoring considerations and sediment management issues.

Section 5 – Glossary provides a description of common terminology used in this guide and in sediment investigations in general.

Section 6 – References, Resources, and Applicable Web Sites provides references by section along with Web site addresses for information discussed in the guide.

1.3 OVERVIEW OF NAVY POLICY AND GUIDANCE

Highlight 1-1 lists the Navy policies and guidance that apply to sediment site investigations. Specific aspects of the policies and guidance are discussed in Sections 2.0 through 4.0. Links to relevant guidance from the U.S. EPA also are provided. The Navy IR Sediments Framework as presented in the *Policy on Sediment Site Investigation and Response Action* (Chief of Naval Operations [CNO], 2002) is shown in Figure 1-2. Some of the CNO Policy's guiding principles for all sediment investigations are as follows:

- All sediment investigations and response actions must be directly linked to Navy-related CERCLA or Resource Conservation and Recovery Act (RCRA) releases.

Highlight 1-1. Navy and U.S. EPA RI/FS Policies and Guidance

Navy Policy on Sediment Site Investigation and Response Action (CNO, 2002)
- http://enviro.nfesc.navy.mil/erb/erb_a/regs_and_policy/don_policy_sediment.pdf

Navy Policy for Conducting Ecological Risk Assessments (CNO, 1999)
- http://enviro.nfesc.navy.mil/erb/erb_a/regs_and_policy/cno-era-policy.pdf

Navy Guidance for Ecological Risk Assessment
- http://web.ead.anl.gov/ecorisk/

Navy Policy for Conducting Human Health Risk Assessments (CNO, 2001)
- http://enviro.nfesc.navy.mil/erb/erb_a/regs_and_policy/HRApolicy.pdf

Navy Guidance for Human Health Risk Assessment
- http://www-nehc.med.navy.mil/hhra/

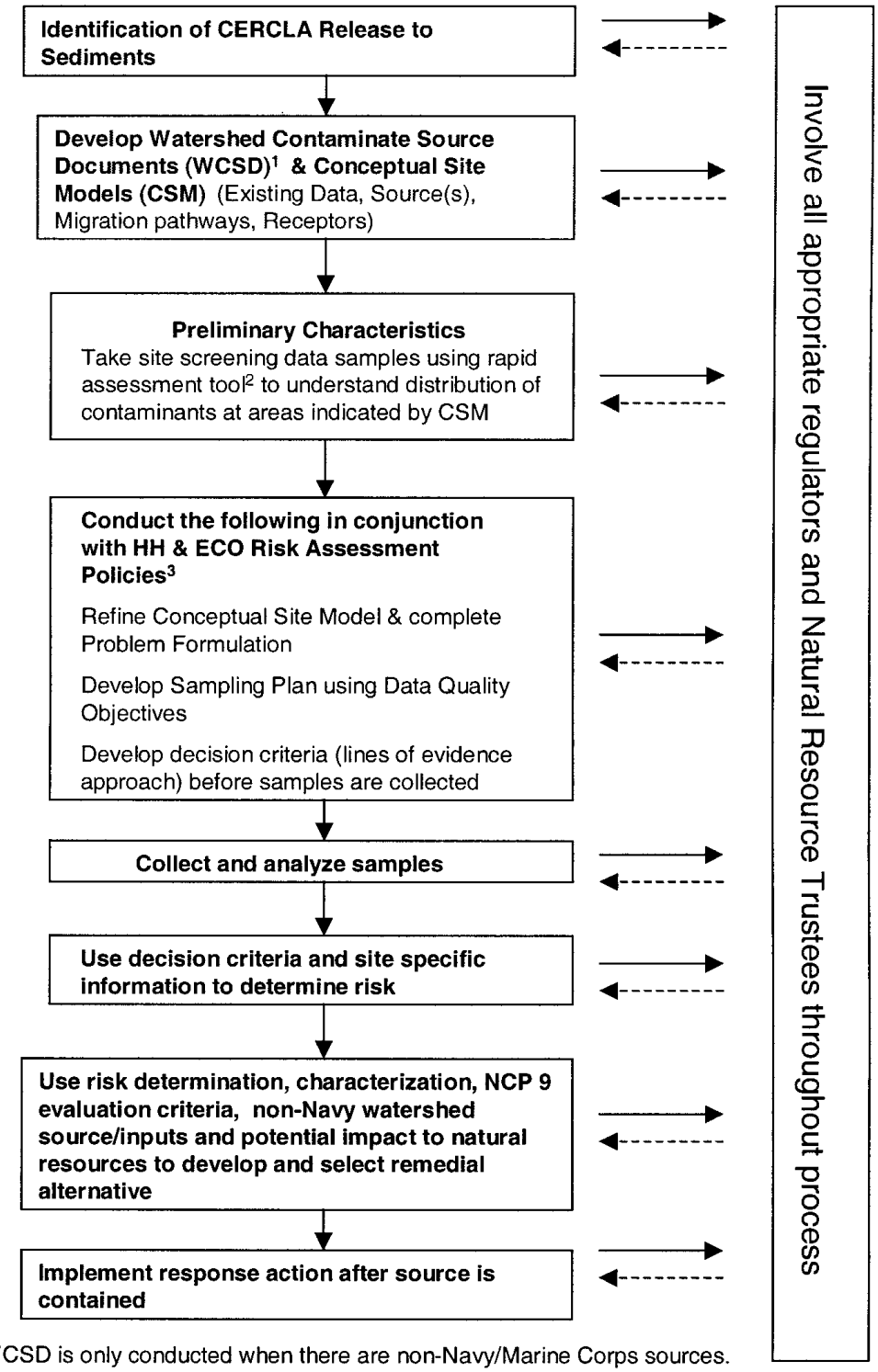
Navy Interim Final Policy on the Use of Background Chemical Levels (CNO, 2000)
- http://enviro.nfesc.navy.mil/erb/erb_a/regs_and_policy/don-background-pol.pdf

U.S. EPA General Superfund Web Site
- http://www.epa.gov/oerrpage/superfund/index.htm
- http://www.epa.gov/oerrpage/superfund/whatissf/sfproces/
  (Index of Superfund document chapters)

U.S. EPA Guidance for Human Health and Ecological Risk Assessments (U.S. EPA, 1989 and 1998)
- http://www.epa.gov/superfund/programs/risk/tooltrad.htm#gp

U.S. EPA Guidance for Conducting the RI/FS under CERCLA (U.S. EPA, 1988)
- http://www.epa.gov/oerrpage/superfund/whatissf/sfproces/rifs.htm

Principles for Managing Contaminated Sediment Risks at Hazardous Waste Sites (EPA OSWER Directive 9285.6-08, February 12, 2002)
- http://www.epa.gov/superfund/resources/principles/9285.6-08.pdf



Notes:

1. WCSD is only conducted when there are non-Navy/Marine Corps sources.
2. A percentage of rapid assessment samples may need lab confirmation.
3. CNO Human Health Risk Assessment & Ecological Risk Assessment Policies.

Figure 1-2. Navy IR Sediments Framework

- If non-Navy sources of contamination are identified at a site, then this information must be documented as early as possible in the RI/FS process and communicated to the appropriate regulatory agencies.

- All sediment investigations and response actions must be scientifically defensible, technically feasible, risk-based, and cost-effective.

- If the reasonably anticipated future land use of property adjacent to the contaminated sediment site is known, then the future land use should be considered in the CERCLA process.

- Stakeholders should be involved early and often in the RI/FS process.

- Risk management decisions can and should be made throughout the RI/FS process.

- Remedial action should not be taken at a sediment site until the primary sources of contamination are controlled or contained, and cleanup levels should not be lower than ambient (i.e., background) chemical concentrations.

Navy sediment investigations will follow the ERA and HHRA tiered approach in accordance with Navy policy and U.S. EPA guidance as identified in Highlight 1-1. Screening and baseline risk assessments (Tiers 1 and 2) are performed as part of the RI. If remedial action is needed at the site based on the findings of the risk assessments, then an FS is performed. The evaluation of remedial alternatives (Tier 3) is performed as part of the FS.

1.4 OVERVIEW OF RELEVANT REGULATIONS, LAWS, AND GUIDELINES

This guide primarily addresses sediment sites managed under CERCLA; however, sediments are subject to a multitude of additional state, national, and international regulatory criteria. It is necessary for the RPM to understand the laws and/or regulations as well as potential applicable or relevant and appropriate requirements (ARARs) that may apply to contaminated sediments at a particular site. According to the NRC study of contaminated sediments in ports and waterways (NRC, 1997), "The mechanisms of the regulatory process in a given situation depend on where the sediments are located; where they will be placed; the nature and extent of the contamination; and whether the purpose of removing or manipulating the sediment is navigation dredging, environmental cleanup, site development or waste management." As a result, different regulators or stakeholders may focus on different COPCs, cleanup criteria, or goals that drive their actions in the sediment management process. The RPM should consult legal counsel if questions or regulatory conflicts are encountered during the CERCLA process.

Potential ARARs are discussed in more depth in Section 4.1.4; however, it is important to note that no national sediment quality criteria currently are promulgated as ARARs (although national ambient water quality criteria are potential chemical-specific ARARs for sediment sites). Therefore, risk evaluations and sediment cleanup goals must be developed on a site-specific and/or regional basis. For an overview of environmental laws and regulations, see the U.S. EPA Web site at http://www.epa.gov/epahome/laws.htm. Additional legislative requirements are discussed under the National Response Center Web site at http://www.nrc.uscg.mil/nrclegal.html. If the sediment site

has a dredging component, then other sources of information are the United States Army Corps of Engineers (USACE) guidelines for dredged material evaluation (http://www.wes.army.mil/el/dots/dots.html):

- Evaluation of Dredged Material Proposed for Ocean Disposal – Testing Manual (i.e., the "Green Book") (U.S. EPA/USACE, 1991; http://www.epa.gov/OWOW/oceans/gbook/).

- Evaluation of Dredged Material Proposed for Discharge in Waters of the U.S. – Testing Manual (i.e., the Inland Testing Manual) (U.S. EPA/USACE, 1998; http://www.epa.gov/waterscience/itm/).

2.0 SEDIMENT SITE CHARACTERIZATION

This section addresses the site characterization phase of a sediment RI/FS, including planning the project, developing the CSM, source identification, defining the nature and extent of contamination, and characterizing contaminant fate and transport. The section also identifies important physical and chemical data that should be collected as part of a sediment investigation, and provides an overview of sample design and sample collection methods and equipment.

2.1 PLANNING AND EXECUTING THE SEDIMENT STUDY

In the initial stages of the sediment RI/FS, the RPM should build the project team, gather existing data, and develop a preliminary CSM. These activities are discussed further below.

2.1.1 Building the Project Team

In order to ensure a scientifically sound and technically defensible study, the RPM should organize a project team with specialized expertise in sediment investigations and issues. The size and complexity of the sediment site will dictate the size and breadth of expertise required of the team (Burton, 1992; Chapter 14). Specific experts may include but are not limited to those listed in Highlight 2-1. Personnel with the appropriate expertise who have prior knowledge of the site can be valuable assets, as can those with specific knowledge of existing data, including data quality.

Highlight 2-1. List of Experts Needed for Sediment RI/FS

- Chemist (sediment/water/tissue; to include expertise in sample collection, preservation, transportation, and laboratory analysis)
- Geologist and/or hydrogeologist; preferably with hydrodynamic/fate and transport modeling expertise
- Geomorphologist
- Geochemist
- Toxicologist (aquatic and terrestrial)
- Ecologist
- Marine/fisheries/benthic biologist
- Aquatic ecological and human health risk assessment experts
- Statistician
- Feasibility study and sediment remedy selection expert
- Engineer

2.1.2 Gathering Existing Data

In the initial stages of the RI/FS, existing data should be gathered and a site visit should be conducted if it has not already been completed. For aquatic sites, the following information should be compiled in addition to the data previously collected for the preliminary assessment/site inspection (PA/SI) phase of the RI/FS:

- Charts and bathymetric surveys of the site water body should be obtained from other Navy sources, the National Oceanographic and Atmospheric Administration (NOAA), the U.S. Coast Guard, the U.S. Geological Survey (USGS), or various state agencies.

- Data for tides, waves, currents, and winds also should be obtained from these sources to support the assessment of contaminant fate and transport (see Section 2.4).

- Information on the adjacent onshore area (e.g., topography, hydrogeology, and environmental condition).

- Data from benthic community surveys, creel samples, or other biological tests.

- Most U.S. bays and harbors have ongoing environmental monitoring programs administered by local agencies that can provide useful information, including data regarding ambient conditions and biological communities.

- Other potential sources of information include published studies, spill reports from the Coast Guard, dredging assessments, National Pollutant Discharge Elimination System (NPDES) permits, and the like.

- Regional or other publicly available data also should be reviewed to identify any potential non-Navy sources of contamination in the vicinity of the site.

In addition to gathering existing data, a site visit is recommended. The objective of the site visit is to understand the physical site setting, identify preliminary COPC sources, and gather relevant background information. Highlight 2-2 lists the information that the RPM should take particular note of during the site visit. If possible, the site should be inspected from a boat to allow examination of the shoreline from the water. If the site is tidally influenced, then the RPM should consider inspecting the site at both high and low tides. If possible, adjacent properties also should be examined to identify other potential sources of contamination to the water body. Non-IR site-related potential sources of contamination also should be identified, such as permitted stormwater discharge pipes.

2.1.3 Developing a Preliminary Conceptual Site Model

Existing information for the sediment site should be used to develop a preliminary CSM. The CSM identifies known or suspected contaminant sources, release and transport mechanisms, contaminated media, exposure routes, and receptors. A CSM may be constructed in several ways, depending upon the amount of information available. The most commonly used method is to construct a simple CSM that identifies broad classes of ecological or human receptors that may be at risk from exposure to sediment contamination. Figure 2-1 is an example of a preliminary CSM for a

Highlight 2-2. Information to be Collected During a Sediment Site Visit

- Site layout, topography, and configuration of water body; particularly notation of features that drain into the water body
- Nature of shoreline (e.g., presence of riprap or debris, slope, type and quantity of vegetation)
- Potential onshore sources of contamination to the water body
- Ecological habitats and potential receptors
- Apparent use of the site for fishing or shellfish harvesting
- Boating activity
- Current and anticipated future use of the water body
- Potential offsite sources of contamination to the water body
- Anecdotal information regarding recreational or commercial fishing from local fisherman.

Navy sediment site that has been contaminated by the release of chemicals from a stormwater outfall and a landfill located in the adjacent nearshore area. This simplistic model is expanded and refined as additional site-specific information is collected, with refined CSMs developed for the ERA and HHRA (see Sections 3.1 and 3.2, respectively). The development of a CSM for a sediment site is discussed further in Chapter 3 of *Critical Issues for Contaminated Sediment Management* (Apitz et al., 2002). Guidance on the development of CSMs is provided on the Navy's ecological and human health risk assessment web pages (http://web.ead.anl.gov/ecorisk/process/html/ch2/ and http://www-nehc.med.navy.mil/hhra/guidancedocuments/process/pdf/plan_scope.pdf).

The sediment site characterization effort focuses on the initial stages of CSM development: source identification, contaminant fate and transport, and extent of contaminated media. These topics are discussed further in Sections 2.2, 2.4, and 2.5, respectively. The refinement of exposure pathways and receptors as part of the ERA and HHRA are addressed in Section 3.0.

2.2 SOURCE IDENTIFICATION

Historical site activities and potential sources of contamination are initially identified during the PA/SI. Table 2-1 identifies the COPCs that typically are encountered in sediments at Navy sites and the sources of these chemicals. The most common mechanisms that release these COPCs to the aquatic environment include discharges from outfalls, spills or discharges from ships, surface water runoff, groundwater discharge, and erosion and transport of contaminated surface soils from onshore areas.

Sediments at Navy installations located near urban and industrial areas may be affected by contamination from multiple sources, both Navy and non-Navy. Because of the complex and dynamic hydrogeologic setting of many of these sites, it can be difficult to distinguish contributions from

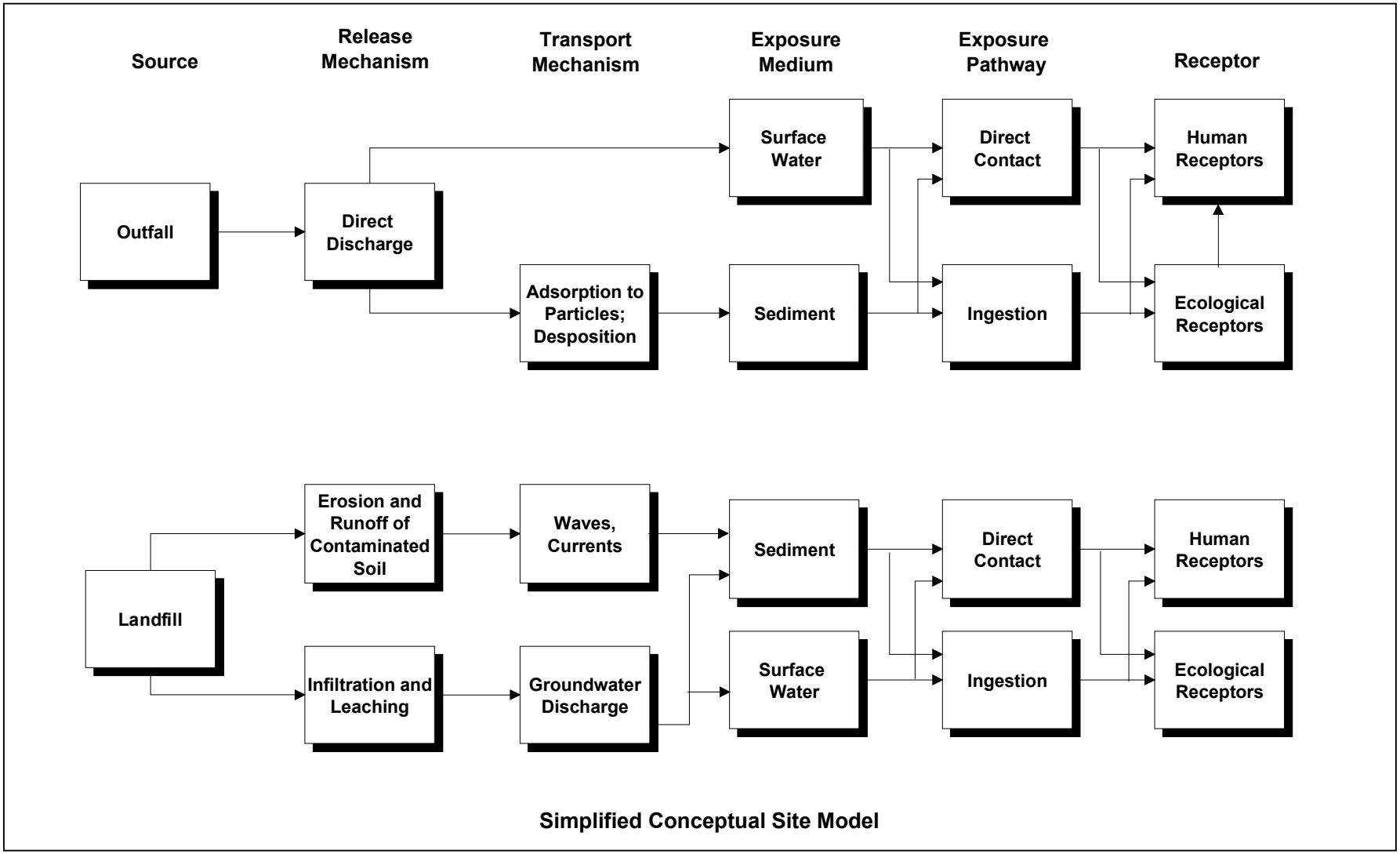


Figure 2-1. Simplified Conceptual Site Model for a Sediment Site

Table 2-1. Common Navy Sediment COPC Classes and Potential Sources

COPC Class	Potential Sources
Heavy and Trace Metals	Ship maintenance and building; aerial fallout; sewage effluent; fungicides (As, Cr, Hg); old paint (Cu, Pb, Zn); marine antifoulants (Cu, Pb, Sn); ballast in submersibles (Hg); former gasoline additives (Pb); naval aviation (Cr, Cd, Pb)
Chlorinated Pesticides	Historical pest control; agricultural runoff, skeet
Polycyclic Aromatic Hydrocarbons (PAHs)	Fuel operations and spills; creosote pier pilings; coal tar; asphalt; fossil-fuel combustion particulates from aerial fallout and road runoff
Polychlorinated Biphenyls (PCBs)	Electrical capacitors and transformers, adhesives, hydraulic oils and paints
Organotins	Marine antifoulant used in vessel paints

various sources. In accordance with the CNO *Policy on Sediment Site Investigation and Response Action* (CNO, 2002; see Highlight 1-1), the RPM must prepare a Watershed Contaminated Source Document (WCSD) if the sediment site is potentially affected by contamination from non-Navy sources. The WCSD is discussed further in Section 2.3. Several methods can be used to identify Navy-related releases and support source identification, including analysis of the spatial distribution of COPCs (see Section 2.5), and specialized chemical analysis to identify chemical "fingerprints" that are unique to a specific source (see Section 2.6.1.2). Data quality objectives (DQOs) for source identification should be developed as part of the RI data collection effort.

2.3 WATERSHED CONTAMINANT SOURCE DOCUMENT

The purpose of the WCSD is to document the existence of both the Navy and other parties whose activities may have had or could continue to have an impact on sediments. The WCSD should generally be no more than 2 to 10 pages in length, but may be longer depending upon the scope and complexity of the water body. The WCSD should include a graphical representation of a watershed CSM. The WCSD should be prepared at the earliest point in the RI/FS process where sufficient data are available to support the CSM and associated interpretations and conclusions. If it is determined that a significant amount of site contamination is due to non-Navy sources, then the appropriate regulators should be informed using the WCSD, and the RPM should consult with counsel to determine the appropriate course of action. Naval Facilities Engineering Command (NAVFAC) Headquarters also should be notified.

The development of a WCSD is important for numerous reasons when multiple sources can contribute to the contamination observed at a sediment site:

- A WCSD can give a broad perspective of the potential origins, fate and transport, and overall influences of contaminants on a watershed and how they relate to the sediment site being investigated within that watershed to all the stakeholders.

- When conducting a Feasibility Study (FS) evaluation, a WCSD can aid in the evaluation of alternatives and the understanding of the potential for recontamination (from non-IR related Navy and/or non-Navy sources) under each alternative.

- A WCSD can assist in the development of realistic and achievable Remedial Action Objectives (RAOs) if remedial action is deemed necessary.

- When developing a long-term monitoring plan following a remedial action, a WCSD should be used in formulating DQOs for designing the plan.

- A WCSD can assist in efforts for prioritizing source control measures.

There are seven basic steps for initially determining the need and subsequently developing the WSCD. These steps provide a logical and general sequence for RPMs to follow in identifying the need, and if necessary, then developing a WSCD. These seven steps are shown in Highlight 2-3.

When conducting literature searches in the development of a WCSD, information can be gathered from a variety of sources, including information collected or gathered by states (e.g., state environmental or health departments), other federal agencies (e.g., U.S. EPA, NOAA, USFWS, USACE, etc.), or by the Navy itself. For example, the U.S. EPA has databases which allow for searches to focus on the hazardous waste sites or facilities holding water discharge permits near a Navy facility and a subject sediment site. The Comprehensive Environmental Response, Compensation, and Liability Information System (CERCLIS) database, located at http://www.epa.gov/superfund/sites/ siteinfo.htm, contains general information on hazardous waste sites across the nation and U.S. territories including location, status, contaminants, and actions taken. The Permit Compliance System (PCS) database in Envirofacts, located at http://www.epa.gov/enviro/html/pcs/ pcs_query_java.html, allows for searches to be conducted for facilities holding NPDES permits. Many states also have similar databases or information on their Internet sites that could further help with gathering relevant information for building a WCSD.

More information on the purpose, development procedure, effort required, and specifics on the content that should be contained within a WCSD will be forthcoming in a fact sheet being developed by CNO. RPMs also can obtain additional information on WCSDs by contacting their Engineering Field Division/Engineering Field Activity (EFD/EFA) Risk Assessment Workgroup (RAW) member or by contacting a member of the RAW sediment subgroup.

2.4 CONTAMINANT FATE AND TRANSPORT

Various fate and transport mechanisms will influence the movement, partitioning, and/or degradation of COPCs in the aquatic environment (Allen, 1995; Burton, 1992; U.S. EPA, 2002). This section presents an overview of the most important fate and transport processes at sediment sites and provides guidance on data that should be collected to characterize these mechanisms.

Major processes affecting the fate of contaminants in sediment are shown in Figure 2-2 (adapted from Allen, 1995) and are described below. Many persistent COPCs, particularly hydrophobic organic compounds, tend to adsorb to clay- and silt-sized sediment particles as well as to organic material. Therefore, the dominant transport mechanism for these contaminants is the movement of sediment particles. Chemical and biological transformation processes also will influence the fate and transport of sediment contaminants.

Step 1 Determine the need for WCSD

- Conduct Internal Discussion
  - Identify water body type (industrial vs. non-industrial) that sediment site is located in and if the Navy is the only source of potential contamination to this site.
  - Determine whether other non-Navy sources could potentially contribute or have historically contributed to potential contamination at the site.
  - Identify if any potential contributions from non-Navy sources could contribute to overall risks and any potential issues regarding long-term remedial strategies for the site.
  - If after internal discussions are conducted, RPMs and management decide that other non-Navy sources could play a potential role in the assessment and/or management of a sediment site, then proceed to Step 2.

Step 2 Conduct literature search

- Conduct a literature search to gather supporting information:
  - Conduct online search.
  - Review databases.
  - Review public records.
  - Review periodic journal records.
- After conducting literature search if it still remains evident that other non-Navy sources could still play a potential role in the assessment and/or management of a sediment site then proceed to Step 3.

Step 3 Preliminary Watershed Conceptual Map

- Develop spatial map
  - Plot findings from literature search on map.
  - Identify all potential sources (i.e., Navy and non-Navy) on map.
  - Identify potential non-Navy sources in a general format (e.g., industrial outfall, former wood treating facility, stormwater discharge outfall, etc.) and **not** in a specific format (e.g., ABC corporation industrial outfall, City of XYZ stormwater outfall, etc.).
  - After developing map, proceed to Step 4.

Step 4 Conduct watershed visit

- Conduct watershed visit to verify accuracy of spatial map (e.g., locations of outfalls, non-Navy cleanup sites, etc.)
- Confirm or refute information that can be verified visually based on literature search
- Document findings of visit and proceed to Step 5

Step 5 Research record to fill data gaps

- Utilizing information from the watershed visit, update the understanding and potential role of all possible sources
- Conduct additional review of literature if determined necessary
- Proceed to Step 6

Highlight 2-3. Seven Steps to Developing a Watershed Contaminated Source Document (WCSD) (Continued)

Step 6 Develop Watershed Conceptual Site Model (pictorial)

- Utilizing an updated map originally developed in Step 3, the RPM should develop a pictorial watershed CSM which should include:
  - Watershed sources (all potential sources [Navy/non-Navy])
    - As noted in Step 3, the identification of potential non-Navy sources must be in a general format and not in a specific format
    - Watershed sources can be color-coded by type of source (e.g., Navy sources, stormwater outfalls, NPDES-permitted outfalls, cleanup sites, industrial facilities)
  - General hydrodynamic conditions of the water body (e.g., general flow direction, tidal movement, etc.).
  - Navigational channels, if applicable.
  - General transport mechanisms, indicating how contamination may enter a water body.
- The development of the watershed CSM could be completed in conjunction with or prior to Step 7, depending on the preference of the RPM

Step 7 Write Watershed Contaminated Source Document

- A general outline that can be used by RPMs in development of a WCSD is as follows:
  - Introduction
    - Overview of why a WCSD is beginning completed (as required by CNO policy)
    - Which IR site(s) are included in discussion
    - Purpose
    - Scope of what the document covers
  - General setting
    - Operations of the installations
    - Extent of area covered by the facility (spatially)
  - Overview of literature search sources
    - **Sources list (e.g., Navy, Public Record, regulatory data, etc.)**
  - Results
    - Summarize findings of the literature search
    - Include Watershed Conceptual Site Model
  - Conclusions and recommendations
    - Conclusions regarding results
      - For example, is there a high, medium, or low potential for non-Navy sources to contribute to overall contamination?
      - What specific sources (both Navy and non-Navy) are likely to contribute primarily to observed sediment contamination?
    - Recommendations
      - For example, how should results be taken into account when considering investigation, remediation, or long-term monitoring strategies of a sediment site?
  - References

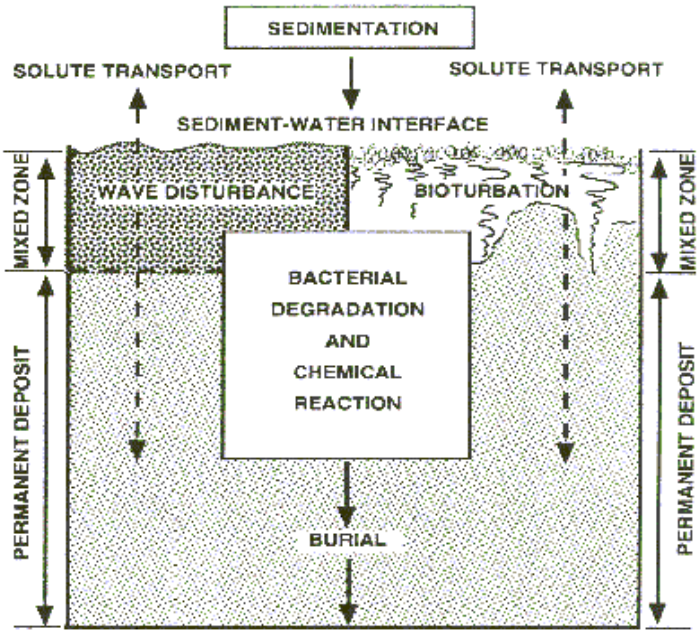


Figure 2-2. Schematic Showing Major Processes Affecting the Fate and Transport of Contaminants in Sediments (from Allen, 1995)

The sediment bed in relatively quiescent areas where contaminants tend to accumulate generally consists of a less consolidated surface layer (i.e., a mixed zone) that is biologically active and more readily eroded and resuspended by waves, currents, propeller wash, and other disturbances. If surface sediments are eroded and resuspended in the water column, they can be transported by wind or tidal currents and redeposited in areas where current speeds are reduced.

Deeper subsurface sediments tend to be more consolidated and isolated from aquatic biota unless exposed by dredging, construction, or an extreme erosional event (e.g., a flood or severe storm). In a net depositional environment, surface sediments will eventually be buried to a depth below the mixed zone by accumulating particles. The accumulating sediment will be relatively cleaner if the sources of contamination to the water body have been controlled or eliminated.

The primary chemical parameter that influences the mobility of many contaminants, particularly metals, is redox potential (Eh). In anoxic (i.e., oxygen depleted) sediment layers with a low Eh, most of the metals are bound to sulfide, carbonate, or organic matter (Allen, 1995). As Eh increases, the sulfides and carbonates may dissolve, releasing the metals in soluble forms. In oxic (i.e., oxygen rich) layers of sediment, most of the metals are complexed to iron and manganese oxide coatings on clay particles. As Eh decreases, the iron and manganese oxides dissolve, releasing metals into solution. Thus, fluxes of metals from sediments into the overlying water column are greatest during changes in redox potential.

During the site characterization phase of a sediment investigation, the RPM should consult with a sediment transport expert and geochemist in order to identify the probable dominant fate and transport processes at a particular site. Some of the questions that should be addressed are provided in Highlight 2-4. Many of these questions can be answered in a qualitative or semiquantitative manner using available site data for sediment grain-size distribution, total organic carbon (TOC) content, sediment COPC concentrations, and acid volatile sulfide/simultaneously extracted metal (AVS/SEM) concentrations (Allen et al., 1993) in conjunction with the existing data described in Section 2.1.2. This initial fate and transport information can be incorporated into the preliminary CSM.

As the sediment investigation progresses and more information becomes available, a more comprehensive and quantitative evaluation of fate and transport may be desired (particularly if monitored natural recovery appears to be a likely remedial alternative for consideration in the FS). In this case the RPM should consider using more sophisticated tools such as site-specific measurements of

Highlight 2-4. Characterizing Contaminant Fate and Transport at a Sediment Site

- What is the distribution of sediment grain size (i.e., sediment type) at the site, and what are the associated depositional environments?
- Under what conditions are the surface sediments likely to be eroded and resuspended (i.e., how stable is the sediment bed)?
- If sediments are resuspended, where are they being transported?
- Is natural burial occurring through sediment accumulation, and if so, at what rate?
- How thick is the mixed surface layer of sediment?
- What types of extreme events might occur at this site, and what are the potential effects?
- Are surface sediments oxic (oxygen rich) or anoxic (oxygen depleted), and how does the redox potential change with depth?
- What is the TOC content and ratio of AVS to SEM?
- What is the flux of COPCs from the sediment bed into the overlying water column?
- What chemical and biological processes might be degrading or transforming COPCs, and are these processes significant?

sediment transport and sediment accumulation rates; use of hydrodynamic and sediment transport models to predict sediment transport patterns, including extreme event analysis; and evaluation of contaminant desorption and/or degradation rates and processes. A detailed technical discussion regarding the evaluation of sediment stability can be found in the proceedings of a January 2002 U.S. EPA-sponsored Sediment Stability Workshop at http://www.hsrc.org/hsrc/html/ssw/sedstab/notes.pdf. Additional information on tools and techniques that can be used for this type of data collection effort is included in Section 2.6.2.

2.5 DEFINING THE NATURE AND EXTENT OF CONTAMINATION

Defining the nature and extent of contamination can be more difficult for a sediment site than for a terrestrial site because of the greater potential for contributions from multiple point and non-point sources and the potentially broad dispersal of contaminated sediments by hydrodynamic processes. However, in many cases, a concentration gradient away from the original source of contamination is observed even if the sediments have been reworked by hydrodynamic processes (Apitz et al., 2002). In relatively quiescent environments (i.e., areas with weak tidal circulation and little wave activity), localized areas with high chemical concentrations (i.e., hotspots) may persist for a long period of time. In areas affected by nonpoint sources of contamination and/or a greater degree of sediment transport, contamination may be more widespread but at lower levels. Although the bulk of the data needed to establish the nature and extent of contamination should be collected during the RI, additional data can be collected after preliminary remediation goals (PRGs) have been developed

(i.e., as part of the FS) to provide more accurate estimates of sediment volumes for evaluation of remedial alternatives.

The sample design used to establish the horizontal and vertical extent of contamination will depend upon the CSM and site-specific DQOs. An overview of sample design is provided in Section 2.7. In general, the extent of sediments with COPC concentrations exceeding either an established level of concern or regional ambient (i.e., background) levels must be defined. The *Navy Interim Final Policy on the Use of Background Chemical Levels* (CNO, 2000; see Highlight 1-1) specifies that background chemical levels should be established as early as the PA/SI phase and used to identify chemicals that are in the environment due to releases from the site. The document *Navy Guidance for Environmental Background Analysis, Volume II: Sediments* (currently under development) provides details on methodologies for establishing background conditions at sediment sites. Surface sediment chemistry data (i.e., representing the biologically active zone) are needed to support the ERA and HHRA as well as the site characterization. Subsurface sediment chemistry data are needed to establish the historical input of contaminants, evaluate the degree of natural recovery (if any), and support the evaluation of remedial alternatives (i.e., depth of dredging that would be required to reach a clean layer).

It can be difficult to predict the maximum depth at which to collect sediment core samples in order to encounter a "clean" layer. Any information on regional and local sediment stratigraphy should be examined to identify older, more consolidated sediment layers that are unlikely to be affected by contamination. Information on sedimentation rates (if available) can be used to predict the depth at which sediments that predate site activities are likely to be found. In the absence of any relevant information, sediment cores should be collected to greatest feasible depth; deeper samples can be frozen and archived for future analysis if the vertical extent of contamination cannot be established from the shallower samples.

Because of the potential widespread distribution of contaminants in the aquatic environment, it may not be feasible or cost-effective to collect numerous sediment samples for full laboratory analysis to define the nature and extent of contamination. Rapid sediment characterization tools such as immunoassay and x-ray fluorescence (XRF) analysis can be used to map the distribution of contamination and refine the preliminary CSM in a relatively fast and inexpensive manner. The Navy IR Sediments Framework (see Figure 1-2) specifies the use of rapid assessment tools in the initial phases of the investigation to understand the distribution of contaminants at the site. A detailed description of rapid sediment characterization tools is provided in Appendix A. Fixed laboratory analysis of a subset of sediment samples can provide confirmatory data and allow development of a correlation between screening and lab measurements. Collection of blind duplicates for screening and laboratory analysis also can provide useful information and increase confidence in the results. The sediment screening results then can be used to focus the sample design for the baseline ERA and HHRA.

2.6 SITE CHARACTERIZATION PARAMETERS

This section provides an overview of the key chemical and physico-chemical parameters that characterize a sediment site and identifies methods that can be used to measure these parameters. Data that can be collected to support the evaluation of remedial alternatives also are described. Site-specific biological data also are required for most sediment investigations to evaluate ecological and human health risk; the most common types of biological data are described in Section 3.1.2.3. Data collection efforts for the site characterization, risk assessments, and evaluation of remedial alterna-

tives should be coordinated as much as possible to optimize the efficient use of resources and avoid unnecessary schedule delays.

2.6.1 Chemical Characterization

This section addresses the measurement of organic and inorganic COPCs in sediment and tissue samples as well as the use of geochemical relationships and specialized chemical analyses to both identify site-related contamination and fingerprint potential contaminant sources. The list of COPCs for evaluation in the RI should be determined on a case-by-case basis depending on historical site activities and potential sources. However, at least some sediment samples should be analyzed for a full suite of chemicals (i.e., the COPC classes identified in Table 2-1) to provide sufficient data for the screening-level risk assessment and rule out the presence of other COPCs early in the process (see Sections 3.1.1 and 3.2.1).

2.6.1.1 Sediment Chemistry Analyses

Analysis of COPCs in sediment often requires specialized chemistry methods because standard U.S. EPA SW-846 methods were designed for solid wastes and usually are not appropriate for analysis of sediment (unless methods are modified). In addition, the quantitation limits and laboratory detection limits achieved by standard methods commonly exceed risk-based ecological benchmark values for sediments. Detection limits and their importance in the risk assessment process are discussed in "Laboratory Detection Limits and Reporting Issues Related to Risk Assessment" (Corl et al., 2002; http://www-nehc.med.navy.mil/hhra/guidancedocuments/issue/pdf/FDI.pdf). This paper provides general information on detection limits and describes steps that can be taken to improve a laboratory's ability to achieve the detection limits needed to meet site-specific DQOs.

Modifications to standard methods have been developed to remove analytical interferences due to salt and organic matter, achieve ultra-low detection limits, and expand the list of target analytes so that the sediment chemistry data are suitable both for site characterization and risk assessment. References for specialized sediment chemistry methods are provided in Table 2-2. Methods for analysis of organic and inorganic analytes in sediment and tissue samples were developed for the NOAA National Status and Trends Program (NOAA, 1993 and 1998). Selection of appropriate analytical techniques for sediment samples from freshwater, estuarine, and saline environments and corresponding method references also are discussed in the *Inland Testing Manual*, which provides guidelines for dredged material evaluations (U.S. EPA/USACE, 1998; see Section 1.4).

Certain classes of compounds can be analyzed either as individual compounds or as functional groups. For example, PCBs may be quantified either as Aroclors or as individual PCB congeners. Aroclors represent commercial mixtures containing a specified percentage of individual PCB congeners. Total PCB concentrations may be derived either by summing the concentrations of the individual Aroclors or by summing the most commonly analyzed congeners and multiplying by a factor of approximately two (NOAA, 1997). Because Aroclor mixtures may change over time due to weathering, evaluation of the individual congener data using techniques similar to those used to fingerprint petroleum products (Stout et al., 1998) may provide more useful information with regard to potential sources. However, congener data are not directly comparable to historical Aroclor data. Therefore, the decision on how best to evaluate PCBs should be made on a site-by-site basis. An issue paper addressing the selection of appropriate methods for PCB analysis is currently in preparation. Similar considerations should be given to the evaluation of total versus individual PAHs.

Table 2-2. Selected Site Characterization Parameters and Methods

Parameter	Importance	Suggested Method
Chemical Characterization		
Heavy and trace metals	Potential COPC	Total acid digestion methods referenced in NOAA Volume III – Technical Memorandum #71: http://ccmaserver.nos.noaa.gov/Pdfpubs/1_cmbad_93-20/techmemo71vol1.pdf With EPA 6010, 6020 & 7000 series found at http://www.epa.gov/epaoswer/hazwaste/test/main.htm EPA 7470A recommended for Hg; EPA 6020 recommended for trace metals other than Hg Rapid sediment characterization methods – see Appendix A
Chlorinated pesticides	Potential COPC	EPA 8082 modified following NOAA Technical Memorandum #130: http://ccmaserver.nos.noaa.gov/Pdfpubs/techmemo130.pdf
PAHs	Potential COPC	EPA 8270 modified for SIM w/extended analyte list to include alkylated homologues w/alumina and gel permeation chromatography cleanup U.S. EPA 40 Code of Federal Regulations (CFR)-J Part 300, Subpart L, Appendix C, Par. 4.6.3-4.6.5 Rapid sediment characterization methods – see Appendix A
PCBs	Potential COPC	EPA 8082 modified for congener analysis following NOAA Status & Trends Methods - Technical Memorandum 130 in http://ccmaserver.nos.noaa.gov/PDFReports.html EPA 1668A for PCB congeners Rapid sediment characterization methods – see Appendix A
Organotins	Potential COPC	NOAA Status & Trends Methods - Technical Memorandum 130 in http://ccmaserver.nos.noaa.gov/PDFReports.html

Table 2-2. Selected Site Characterization Parameters and Methods (page 2 of 3)

Parameter	Importance	Suggested Method
Physico-Chemical Characterization		
Sediment grain size	Finer-grained sediments tend to adsorb contaminants; grain size can be used to characterize depositional environment and sediment dynamics; grain size affects benthic community structure	Inland Testing Manual, Chapter 9 (U.S. EPA/USACE, 1998) http://www.epa.gov/ost/itm/ITM/ch9.htm - physical Analytical method (NOAA Technical Memo. 130): http://ccmaserver.nos.noaa.gov/PDFReports.html ASTM D 422
Total organic carbon (TOC)	TOC tends to sorb contaminants and reduce their bioavailability	Inland Testing Manual, Chapter 9 (U.S. EPA/USACE, 1998) http://www.epa.gov/ost/itm/ITM/ch9.htm - physical Analytical method (NOAA Technical Memo. 130): http://ccmaserver.nos.noaa.gov/PDFReports.html
Acid volatile sulfide (AVS)/simultaneously extracted metals (SEM)	Evaluation of metal bioavailability	Di Toro et al., 1990 Simpson, 2001
Redox potential (Eh)	Influences species and bioavailability of metals	Table G-1, Appendix G of U.S. EPA (2001) Plumb, 1981
pH	Influences species and bioavailability of metals	Commercially available pH meter (Plumb, 1981)
Salinity of porewater (marine/estuarine sediments)	Can cause matrix interferences in some chemical analyses; affects benthic community structure; important in selection of bioassay test species; affects metal speciation, sediment pH, and partitioning	Various methods; see Appendix G of U.S. EPA (2001) http://www.epa.gov/waterscience/cs/collectionmanual.pdf
Alkalinity of porewater (freshwater sediments)	Influences species and bioavailabilty of metals	ASTM (2000)
Ammonia in porewater	Naturally occurring toxicant in organically-enriched sediments	Inland Testing Manual, Chapter 11 (U.S. EPA/USACE, 1998) http://www.epa.gov/ost/itm/ITM/ch11.htm

Table 2-2. Selected Site Characterization Parameters and Methods (page 3 of 3)

Parameter	Importance	Suggested Method
Site Characterization; Contaminant Fate and Transport		
Visual description of sediment cores	Depositional environment and sediment dynamics be inferred and subsurface sediment characteristics can be documented	ASTM D 4288
Radioisotope profiling (e.g. ^{210}Pb and ^{137}Cs isotopes)	For areas that meet criteria (i.e., undisturbed areas of sediment accumulation), provides estimates of sediment accumulation rate and degree of vertical mixing	USGS, 1998 (http://fl.water.usgs.gov/PDF_files/fs73_98_holmes.pdf)
Hydrodynamic and sediment transport measurements	Evaluate sediment stability and fate and transport of sediment-bound contaminants	No standard methods available; study design should be developed based on site-specific characteristics. See discussion in U.S. EPA Sediment Stability Workshop Notes (http://www.hsrc.org/hsrc/html/ssw/sedstab/notes.pdf)
Contaminant flux	Evaluate relative importance of diffusion, advection, erosion, degradation, and sedimentation processes	No standard methods available; study design should be developed based on site-specific characteristics. See Chadwick and Apitz (2001) for description of Pathway Ranking for In Place Sediment Management (PRISM).
FS-Related Characterization		
Hazardous waste characterization	Evaluate sediment disposal options	Testing requirements vary depending on location of site
Dewatering characteristics	Optimal method for dewatering can be identified	No standard methods available; study design should be developed based on site-specific characteristics; discussion of various dewatering technologies provided in U.S. EPA (1994)
Bearing capacity	Evaluate ability of sediment to support cap	ASTM D 1883
Plasticity	Evaluate sediment handling characteristics	ASTM D 4318
Density	Evaluate ability of sediment to support cap	Standard Proctor Test; ASTM D 698 Method A

Sediment results typically are reported on a dry-weight basis with percent moisture and TOC data included as ancillary information. Tissue data also should be reported on a dry-weight basis with percent lipid and percent moisture data included as ancillary information so that data can be converted to a wet-weight or lipid-normalized basis for use in risk assessments. Reporting units should always be clearly identified on data tables (i.e., whether results are reported on dry-weight or wet-weight basis). Analyses of estuarine and marine sediment, water and tissue samples should always be performed by laboratories with demonstrated experience in successfully performing the required analyses.

2.6.1.2 Chemical Fingerprinting

A number of established geochemical relationships can be used to identify sediment contaminant inputs and sources (e.g., Bertine and Goldberg, 1977; Ackerman, 1983; Trefry et al., 1985; Klamer et al., 1990; Schropp et al., 1990; Daskalakis and O'Connor, 1995). An overview of these studies is provided in Appendix B). Additional information on forensic methods for identification of metal contamination can be found at the NOAA Web site (http://research.nwfsc.noaa.gov/pubs/tm/tm16/resultb.htm). For example, metal/aluminum ratios can be used to identify contamination that exceeds ambient levels and which therefore might be site-related. Naturally occurring background metals typically are part of the aluminosilicate (i.e., clay) mineral structure, and a regression of background metals versus aluminum concentrations will produce an approximately straight line. This regression relationship can be generated on a regional basis using ambient or reference site sediment chemistry data. If metals concentrations in site samples are greater than those predicted by the regression, then those metals may be due to an additional (and possibly site-related anthropogenic) source. Additional information on this methodology can be found in the *Navy Guidance for Environmental Background Analysis, Volume II: Sediment* (currently under development).

Other chemical fingerprinting methods can be used to identify sources of petroleum and chlorinated hydrocarbon contaminants (e.g., PAHs or PCBs). The successful use of data for any particular class of compounds to "fingerprint" a sample depends on the following:

- Ability to differentiate chemicals from different geological and anthropogenic sources;
- Relative state of weathering (or aging) of organic contaminants;
- Presence of specific product additives and refinery process signatures for interpretation of petroleum-related contamination; and,
- Availability of data about reference source materials for comparison with site data.

Detailed descriptions of organic contaminant source identification methods can be found in various publications (Page et al., 1995; Douglas et al., 1994 and 1996; Steinhauer and Boehm, 1992). Use of these and other source identification methods usually requires data for extended or modified target analyte lists. For example, in addition to the 16 priority-pollutant PAH compounds, data for alkylated homologues (e.g., C1-C4 naphthalenes, C1-C4 phenanthrenes/anthracenes), and biomarkers (e.g., triterpanes, steranes) are required for source identification of PAHs. Source identification of PCBs may require detailed PCB congener analysis if the Aroclor pattern is not specific to one source.

A summary of the most pertinent points regarding the chemical characterization of a sediment site is provided in Highlight 2-5.

Highlight 2-5. Chemical Characterization Summary

- Use published analytical methods, modified as appropriate, for sediment and aquatic matrices that achieve detection limits suitable for risk assessment; and identify target analytes suitable for source identification
- Use a laboratory that is experienced in the use of appropriate sample cleanup methods to reduce potential interference from organic matter and salt (in marine environments)
- Report sediment results on a dry-weight basis with percent moisture and TOC content as ancillary data
- Report tissue results on a dry-weight basis with percent moisture and percent lipid as ancillary data
- Use techniques such as geochemical normalization (e.g., aluminum/metal ratios) and chemical fingerprinting to better understand chemical distributions and potential sources

2.6.2 Physico-Chemical Characterization

Sediment investigations usually involve bulk chemical analysis of sediment samples for site-related COPCs in conjunction with biological evaluations. Other physical and chemical data also are needed to support the evaluation of COPC bioavailability. Bioavailability is influenced by a variety of factors associated with organism characteristics (e.g. size and feeding behavior) and sediment characteristics (e.g. TOC content and redox potential). Detailed discussions of bioavailability can be found in Power and Chapman (1992) and the Navy's bioavailability guide (Battelle and Exponent, 2001; http://web.ead.anl.gov/ecorisk/methtool/dsp_bioavail.cfm).

The following physical and chemical parameters also should be measured as appropriate to evaluate the form and behavior of site COPCs and support the interpretation of biological test data:

- Sediment grain-size distribution;
- Sediment TOC content;
- AVS/SEM;
- Porewater pH;
- Porewater salinity (marine/estuarine sites) or alkalinity (freshwater sites); and,
- Porewater ammonia and sulfide concentration.

Descriptions of these parameters, the relevance of each, and associated testing methods are described in Appendix G of *Methods for Collection, Storage and Manipulation of Sediments for Chemical and Toxicological Analyses: Technical Manual* (U.S. EPA, 2001; http://www.epa.gov/waterscience/cs/collectionmanual.pdf) and summarized in Table 2-2. The physico-chemical parameters to be characterized will depend upon the CSM and DQOs for the RI sample collection effort.

Grain-size distribution and TOC data are extremely important in a sediment site investigation because they influence COPC distribution, affect contaminant bioavailability, influence benthic community structure, and introduce factors that may confound toxicity test results. Grain-size analysis defines the frequency distribution of the size ranges of particles that make up site sediment (Plumb, 1981). Contaminants tend to adsorb to finer-grained sediment particles (Power and Chapman, 1992; U.S. EPA, 2001). Sediment grain-size data also are extremely important for the evaluation of sediment dynamics, with coarser-grained material typically associated with high-energy environments (e.g., beaches and channels) and finer-grained material found in quiescent basins and depositional environments. The four major size fractions (gravel, sand, silt, and clay) are the broadest categories that are useful in reporting the size distribution of particles in sediment samples, although a larger number of size classifications is preferred for the evaluation of sediment dynamics. TOC content is a measure of the total amount of oxidizable organic material in a sediment sample. TOC is important because many contaminants are strongly bound to dissolved, colloidal, and particulate organic matter.

AVS/SEM can be measured to determine the fraction of metals that are bound to sulfides (Di Toro et al., 1990; NOAA, 1995; http://www.nwn.noaa.gov/sites/hazmat/cpr/sediment/avs.pdf). Although universally accepted guidance on the interpretation of AVS measurements is not yet available, these measurements can provide information on the potential bioavailability of metals. The most important points regarding physico-chemical characterization are summarized in Highlight 2-6.

Highlight 2-6. Physico-Chemical Characterization Summary

- Measure sediment grain size and TOC content to evaluate potential COPC distribution and bioavailability, identify depositional environments, infer site hydrodynamics, and support interpretation of bioassay test results and benthic community analysis
- Measure AVS/SEM to evaluate potential bioavailability of sediment metals
- Measure ammonia and sulfide in porewater and/or overlying water to address potential confounding factors in toxicity tests

2.6.3 Collection of FS-Related Data

During the site characterization phase of an RI/FS, the RPM should consider the adequacy of the existing site data to support the FS and identify any further data needs. Generally, a cost savings to the project can be achieved by collecting FS-related data as part of the RI, thereby reducing the mobilization requirements and streamlining the FS process. Some examples of FS-related data that can be collected during the RI phase of a study are as follows:

- Grain-size distribution and moisture content data to predict behavior of material (these data typically collected as part of the site characterization).

- Hazardous waste characterization (e.g., Toxicity Characteristic Leaching Procedure [TCLP] analysis) to support evaluation of treatment and disposal options;

- Dewatering characteristics to identify most appropriate pretreatment methods;
- Engineering properties (e.g., strength, compressibility) to evaluate capping and reuse options; and,
- Sediment dynamics data to support evaluation of in situ management options, including geologic description of sediment cores.

The RPM should have a reasonably high degree of confidence about the need for remediation in a particular area prior to conducting FS-related data collection or treatability studies. The relevance of the parameters identified above and applicable testing methods are summarized in Table 2-2. These data will allow the development of more realistic remedial alternatives and more accurate cost estimates in the FS.

2.7 OVERVIEW OF STUDY DESIGN AND SAMPLE COLLECTION METHODS

This section provides an overview of study design and sediment sample collection methods and equipment. The sampling plan for a sediment investigation should address the data needs for all aspects of the RI/FS (site characterization, risk assessment, and the evaluation of remedial alternatives) to the greatest degree possible in order to minimize mobilization costs and facilitate development of a focused, well-coordinated study. The U.S. EPA document *Methods for Collection, Storage and Manipulation of Sediments for Chemical and Toxicological Analyses: Technical Manual* (U.S. EPA, 2001; http://www.epa.gov/waterscience/cs/collectionmanual.pdf) provides detailed guidelines for development of DQOs, appropriate sample design (e.g., random or targeted), measurement quality objectives, and all aspects of the field investigation (e.g., vessel positioning; sediment sample collection, preservation, transport, and processing; collection of porewater samples; quality assurance/quality control). Additional information on sediment study sample design can be found in "An Introduction to Environmental Sampling Planning" (Kurtz, 2000; http://meso.spawar.navy.mil/Docs/MESO-00-A003-6.pdf).

Collection of aquatic samples generally is divided into five tasks: mobilization, navigation, sediment sampling, sample processing and demobilization. References for field methods and quality control are provided in Table 2-3. Field activities for sediment investigations almost always require a vessel, are often logistically complex, and may require other specialized equipment. Most vessel studies require a differential global positioning system (DGPS) (usually accurate to ±2 m) to position and navigate the survey vessel, and identify station locations. Surface sediment samples are usually collected with a grab sampler, such as a Van Veen, a box-corer, or a Ponar grab (see Figure 2-3). The grab sampler should be constructed of stainless steel and may be coated with Halar® or Teflon™ to reduce potential cross-contamination in the field. Because the quantity of sediment required for tests usually exceeds the volume of the sampler, multiple grabs should be taken at each station unless a modified (e.g., dual Van Veen) grab is used. Surface grabs should be designed to sample the sediment depth interval of interest, and care should be taken to prevent the loss of fine surface sediments. Usually, the biologically active zone is targeted, which is generally the top 10-15 cm of the sediment surface (ERDC, 2001).

Table 2-3. Information on Aquatic Sample Collection, Field Quality Control, and Equipment

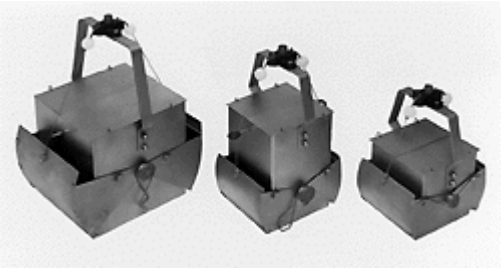
Agency or Organization	Reference and Web Site	Applicable Environment	Topics Covered
U.S. EPA	Methods for Collection, Storage and Manipulation of Sediments for Chemical and Toxicological Analysis: Technical Manual. October 2001. http://www.epa.gov/waterscience/cs/collectionmanual.pdf	Any water body	Sediment monitoring and assessment plans; sediment sample collection; field sample processing, transport, and storage; sediment manipulations; collection of porewater samples; quality assurance/quality control
State of Washington – Dept. of Ecology	Recommended Protocols for Measuring Selected Environmental Variables in Puget Sound. January 1996. http://www.wa.gov/puget_sound/Publications/protocols/protocol.html	Marine reference (applicable to any water body)	Sediment and water sampling; fish and benthic invertebrate collection; vessel positioning; field quality control
State of Wisconsin – Dept. of Natural Resources	Field Procedures Manual, Sediment Sampling Guidelines, Version IV. September 1998. http://www.dnr.state.wi.us/org/water/wm/wqs/sediment/sampling/table.htm	Freshwater	Sediment sampling, equipment, safety and field quality control
Government of British Columbia, Resources Inventory Committee	Lake and Stream Bottom Sampling Manual, Document # 7680000550. 1997 http://www.for.gov.bc.ca/ric/pubs/aquatic/lake-stream/index.htm - a	Rivers and stream bottom sampling	Sediment sampling, equipment, and quality control
San Francisco Estuary Institute (SFEI)	Field Sampling Manual for the Regional Monitoring Program for Trace Substances, Version 1. January 1999. http://www.sfei.org/rmp/documentation/fom/fom_1.html	Estuarine and marine reference (applicable to any water body)	Sediment, porewater, water column, benthic invertebrate sampling; equipment type and use; quality control; remote sensing; vessel safety

To minimize the cost of multiple field efforts, concurrent subsurface sediment data should be collected for defining the vertical extent of contamination (see Section 2.5). Subsurface sediment cores should be collected using stainless steel core tubes with inert liners (e.g., butyrate). Photographs and descriptions of sampling equipment are shown in Figure 2-3 (surface samplers) and Figure 2-4 (coring devices).

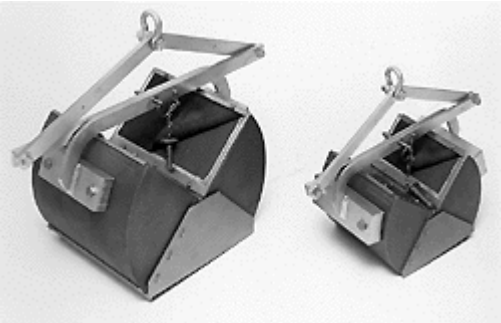
2.8 SUMMARY

Sediment site characterization, including development of the CSM, assessment of contaminant fate and transport, definition of the nature and extent of contamination, and collection of relevant physical and chemical data, is conducted during the initial phases of the RI/FS and continues in conjunction with the ecological and human health risk assessments. Data collection for all aspects of

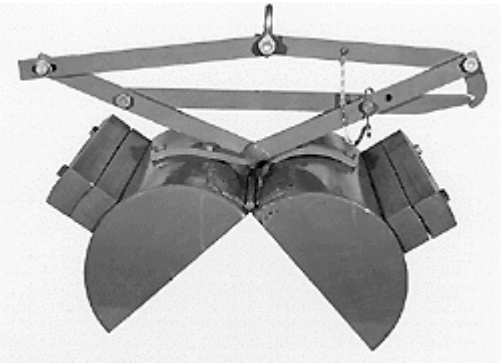
the RI/FS should be coordinated to the greatest degree possible to maximize the efficient use of resources and ensure a focused, well-defined investigation.



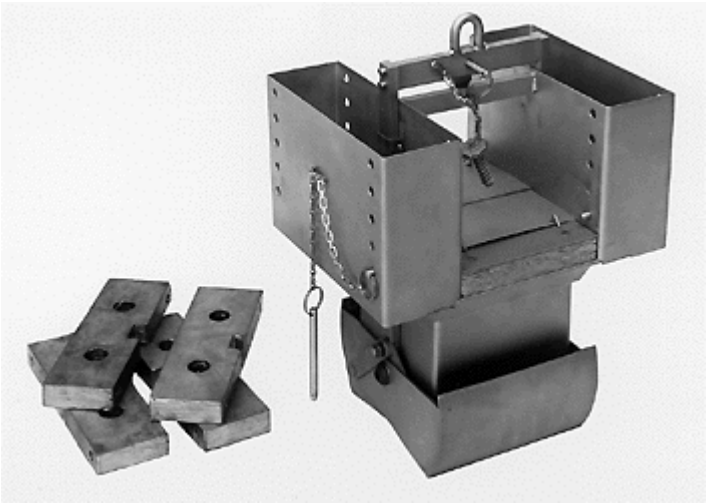
Ekman Grab: Designed to sample in soft, finely divided littoral bottoms free from vegetation and intermixes of sand, stones, and other coarse debris. Best in finely divided muck, mud, ooze, submerged marl, or fine, peaty materials. Lightweight samplers designed for use from smaller boats (standard size: 200 cm by 200 cm wide, 150 cm deep).



Ponar Grab: Designed to sample firm or hard clay bottoms free from stones and other coarse debris. The standard Ponar grab is heavy and should be used from a winch. Smaller versions are light enough for sampling by hand. Removable top screens allow sub-sampling from the closed scoops. Top screens also have rubber flaps to prevent sample washout during retrieval. Similar in design to rigid arm Van Veen grab.



Peterson Grab: Widely used in fresh water sampling hard bottoms, such as sand, pebbles, clay, or clay com-pounds. The Peterson grab scoops are hinged at the top, like a clamshell. Subsampling cannot be performed from closed grab.

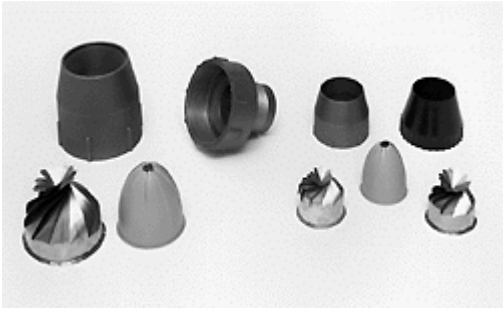


Small Box Corer: Designed to take large sample in bottoms from soft ooze to hard clay free from stones and other coarse debris (photo above of WILDCO® sampler). Winch is required for operation. Removable top screens allow subsampling when scoops are closed. Removable top screens have rubber flaps to prevent sample washout during retrieval. Grab volumes vary with size of device; the most common size is 5 L.

Figure 2-3. Examples of Sediment Surface Grab Samplers

Dual 0.1 m^2 Van Veen Grab: Designed to two side-by-side 0.1 m^2 surface samples, allowing collection of co-located chemistry & biology samples or additional sample for toxicity tests. Samples from soft to hard bottom free from stones and other coarse debris (left photo shows grab before deployment; right photo shows two sediment samples). Winch is required for operation. Removable top screens have rubber flaps to prevent sample washout during retrieval.

Figure 2-3. Examples of Sediment Surface Grab Samplers (continued)



Small Gravity Corer: Sand and silt substrates can be sampled to up to 1.5 m with small gravity corer devices. Corers can be deployed from davits or A-frames and require winches for retrieval. Fins often are used to stabilize descent. Penetration depths depend on substrate and core tube size. Core tube diameters vary from 2 cm to 6 cm, are generally metallic (stainless steel), and can accommodate inert liners (e.g., butyrate, polycarbonate, Teflon™). Corers require check valves, cutting heads and "core catchers" to maintain core during retrieval.

Large Gravity Corer: Sand and silt substrates can be sampled to up to 3 m with large gravity corer devices. Corers must be deployed from large davits or A-frames and require winches for retrieval. Fins may be used to stabilize descent. Penetration depths depend on substrate and core tube size. Core tube diameters can exceed 10 cm, are generally metallic (iron or stainless steel), and can accommodate inert liners (e.g., butyrate, polycarbonate, Teflon™). Corers require check valves, cutting heads and "core catchers" to maintain core during retrieval.

Figure 2-4. Examples of Sediment Coring Devices

Vibracore: Vibracoring is a technique for collecting core samples in unconsolidated sediments by driving a tube with a vibrating device, generally referred to as "vibrohead." The energy imparted by the vibrohead to the coretube assists its vertical penetration by displacing the sediment particles and overcoming the two main forces opposed to its progress, namely frontal resistance and wall friction. This technique is naturally the most efficient in water-saturated sediments by raising the pore-pressure along the wall of the coretube and generating a thin layer of liquefaction. Core lengths retrieved can exceed 10 m with diameters of 6 cm. Core tubes are generally metallic (iron or stainless steel) and can accommodate inert liners (e.g., butyrate, polycarbonate, Teflon™). Corers require check valves, cutting heads and "core catchers" to maintain core during retrieval.

Figure 2-4. Examples of Sediment Coring Devices (continued)

3.0 ECOLOGICAL AND HUMAN HEALTH RISK ASSESSMENT FOR SEDIMENT SITES

The risk assessment process at Navy sediment sites is conducted in accordance with the Navy and U.S. EPA guidance identified in Highlight 1-1. The Navy and U.S. EPA guidance should be reviewed and generally understood by the RPM before a risk assessment is initiated at any site. In addition, regular communication and involvement with the applicable regulatory agencies will facilitate the process of evaluating risks. This is true with all risk assessments; however, it is especially important at sediment sites due to the multitude of additional state, national, and international regulatory criteria applicable to sediments, and the lack of promulgated sediment quality criteria (see Section 1.4).

Briefly, the Navy uses a three-tiered approach, similar to the U.S. EPA's risk assessment guidance for ecological and human health evaluations (U.S. EPA, 1989 and 1998c; see Highlight 1-1 for Navy Guidance). The U.S. EPA guidance should be carefully reviewed for identification of critical scientific management decision points (SMDPs) throughout the process. The first tier consists of a very conservative, screening-level risk assessment intended to eliminate chemicals and areas that do not pose an unacceptable risk. This step focuses the investigation on those chemicals and areas that may pose an unacceptable risk.

Although the overall approach used to evaluate risk at sediment sites is consistent with the Navy and U.S. EPA guidance, technical issues specific to the evaluation of sediments (e.g., physical and chemical properties of sediment) should be considered when performing a risk assessment for aquatic sites. Many of these issues are discussed in Section 2.0. The purpose of this section is to summarize these issues and provide guidance for incorporating them within the context of the Navy's tiered framework. Section 3.1 focuses on the ERA, and Section 3.2 addresses issues specific to the HHRA.

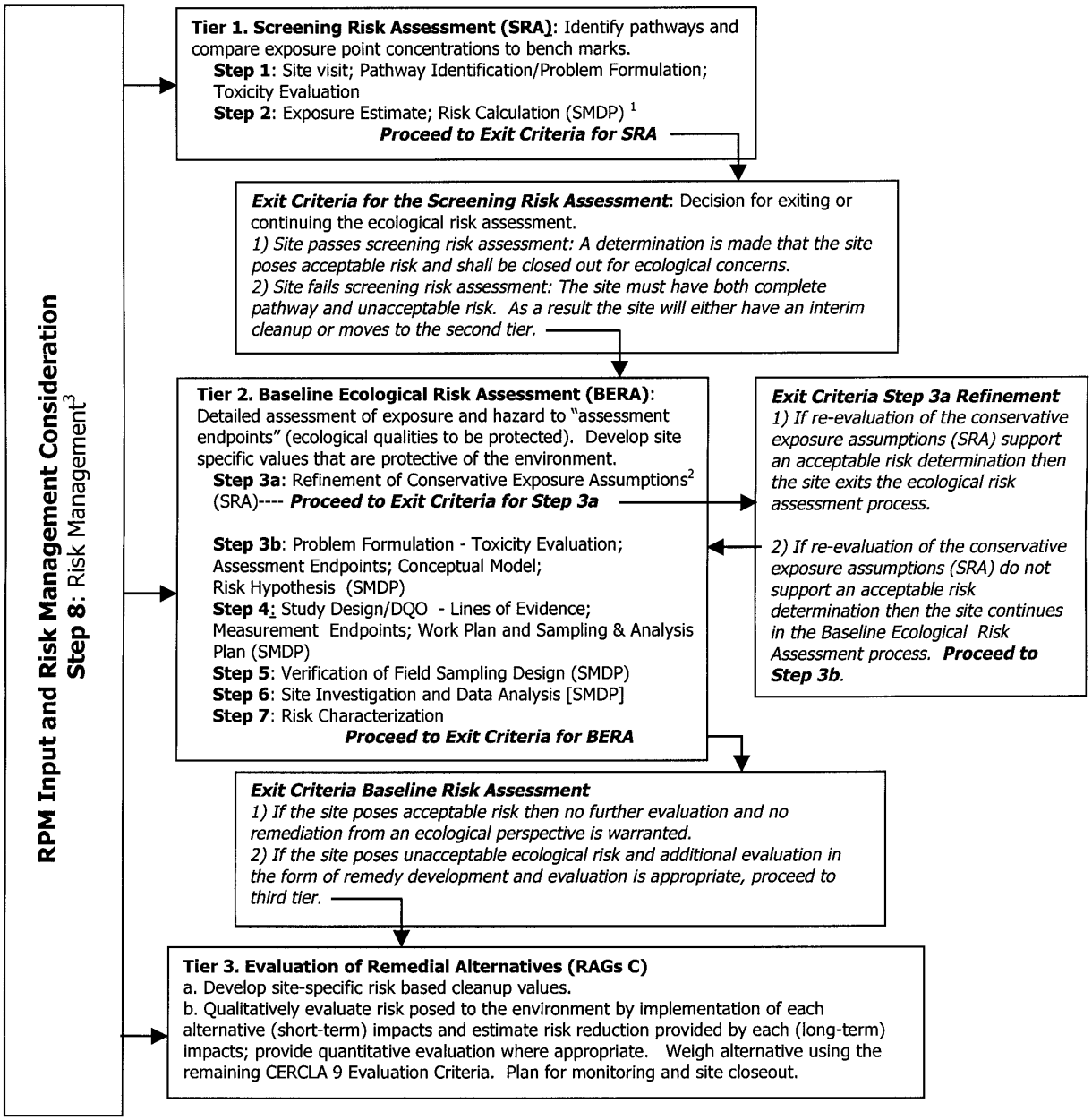
As the HHRA or ERA process is initiated, it is important that the RPM evaluate the project team and confirm that the appropriate expertise is represented. Section 2.1.1 discusses the project team required for sediment site assessments. In addition, regular discussions with relevant regulatory agencies throughout each stage of the investigation are critical to facilitate the process.

3.1 ECOLOGICAL RISK ASSESSMENT

The Navy's ERA approach consists of three tiers (Figure 3-1):

- Tier 1: Screening Risk Assessment (SRA)
- Tier 2: Baseline Ecological Risk Assessment (BERA)
- Tier 3: Evaluation of Remedial Alternatives.

Tier 1 focuses on the development of the fundamental framework of the assessment (i.e., the preliminary problem formulation and conceptual site model) and includes preparing a conservative, screening-level evaluation of potential risks. Tier 2 focuses on the refinement of the assessment to more closely reflect actual site conditions. Tier 3 focuses on the evaluation of remedial alternatives (see Section 4.0). Appendix C presents an example ERA for a hypothetical site.



Notes: 1) See EPA's 8 Step ERA Process for requirements for each Scientific Management Decision Point (SMDP).
2) Refinement includes but is not limited to background, bioavailability, detection frequency, etc.
3) Risk Management is incorporated throughout the tiered approach.

Figure 3-1. Navy Ecological Risk Assessment Tiered Approach

3.1.1 Tier 1: Ecological Screening Risk Assessment

The Navy's Tier 1 SRA consists of Steps 1 and 2 of the eight-step U.S. EPA Superfund ERA process (see Figure 3-1). The purpose of the SRA is to screen out chemicals and areas that do not pose an unacceptable risk as defined for the site through discussion with the regulatory agencies and stakeholders. It is based on the existing data and information gathered during the Preliminary

Assessment/Site Inspection (PA/SI) and initial stages of the RI/FS, as described in Section 2.1.2, and should not require additional or new data collection. If limited additional data are required, rapid screening methods may be considered (see Appendix A) although it is important to note that data from these methods may not meet data quality objectives for an ERA, and should be used for initial screening purposes only. Because the SRA is intended as a screen, conservative assumptions regarding site conditions, chemical bioavailability, and exposure parameters are used for this portion of the evaluation. For example, when evaluating potential affects to the benthic community, toxicity data associated with a species known to be very sensitive to the COPC might be evaluated, or minimum sediment quality guidelines might be considered. Other screening-level assumptions include the use of a maximum chemical concentration to represent the site, the assumption of 100 percent bioavailability of all chemicals present, or the assumption of a site use factor of 1. Through the use of these conservative assumptions that are more likely to overestimate rather than underestimate potential risks, the RPM can have high confidence that a chemical will be eliminated from consideration as a COPC only if it does not pose an unacceptable risk.

3.1.1.1 Sediment Site Characterization

The first step of the SRA involves evaluating the data and site-specific information collected as part of the site characterization (Section 2.0). For sediment investigations, information regarding the physical and environmental conditions at the site should be evaluated to identify relevant aquatic habitats and possible site uses by terrestrial ecological receptors. For example, the composition and diversity of the aquatic community may be highly influenced by a variety of site-specific features including:

- Type of water body (e.g., freshwater or marine, river, estuary, bay);
- Presence of tides, waves, or currents;
- Potential groundwater-surface water interactions (GSI);
- Bathymetry and sediment substrate;
- Presence or absence of exposed sediments;
- Shoreline features (e.g., bulkheads, emergent vegetation, beaches, terrestrial habitats, etc.);
- Potential presence of endangered species; and,
- Extent and nature of surrounding land use (e.g., residential, undeveloped, industrial).

All of these physical features can influence the use of the site by ecological communities and may help to identify complete exposure pathways. In addition, information collected on the nature and extent of contamination should be reviewed to identify the areas of concern and chemicals to be evaluated. Ecological evaluations typically focus on surface sediments (i.e., the biologically active zone, usually defined as approximately the top 10 cm) because benthic communities are not significantly exposed to sediments at depth (USACE, 2001). However, if dredging activities are planned, sediments at depth also should be considered to evaluate potential future risks from sediments that will be exposed.

3.1.1.2 Problem Formulation

The SRA includes the development of a preliminary problem formulation which identifies: (1) sediment COPCs from site knowledge and existing data; (2) ecological receptors potentially at risk; and (3) complete exposure pathways. Based on the results of the preliminary problem formulation, the preliminary CSM developed during the site characterization (Figure 2-1) is updated to reflect the complete exposure pathways and receptors of concern.

3.1.1.2.1 COPC Identification

The identification of preliminary sediment COPCs should be conducted during the site characterization process and presented to the appropriate regulators as soon as possible. Reaching agreement on the key COPCs early in the process will facilitate later discussions. Preliminary COPCs should be identified early in the process as being from Navy sources, non-Navy sources, or a combination (i.e., "mixed"), and then refined as more information becomes available. Common Navy sediment COPCs and potential sources are shown in Table 2-1. An expanded list of multiple-source sediment contaminants also is provided in the U.S. EPA/USACE (1998) *Inland Testing Manual* at http://www.epa.gov/waterscience/itm/ITM/.

For the purpose of the SRA, COPCs should be identified by comparing maximum surface sediment contaminants to appropriately conservative sediment quality benchmark values (see Table 3-1). Due in part to the complexities associated with predicting the toxicity of sediments, no national sediment quality criteria currently are promulgated for use in an ERA. However, sediment quality benchmark values have been developed in an attempt to define concentrations in sediment that are unlikely to result in adverse affects to aquatic organisms. Table 3-1 presents a summary of some of the most commonly used sediment quality benchmarks http://web.ead.anl.gov/ecorisk/methtool/dsp_bench.cfm. The majority of the benchmarks listed in Table 3-1 were developed for individual chemicals. However, U.S. EPA also has recently begun to develop sediment guidelines for chemical mixtures to more accurately reflect actual conditions (see Highlight 3-1).

Each of these benchmark values was derived using a different methodology for linking concentrations to observed effects. Some benchmarks are based on community-level analyses, or on combinations of lethal and sublethal effects such as the apparent effects threshold values (AET) or effects range–low (ER-L) and effects range–median (ER-M) values (Long et al., 1995). Some benchmarks focus specifically on freshwater or marine organisms. In addition, although some values are based on bulk sediment chemistry results, others are normalized to organic carbon or other chemical or physical parameters. The different methods result in widely varying predictions of "safe" sediment levels; therefore, it is important to evaluate the applicability of both the assumptions used and recommended applications of any benchmark values prior to applying them at a specific site. Many regulatory agencies recommend the use of a particular approach, so consultation with the appropriate regulators prior to selecting the benchmarks for use at the site is important. A case study demonstrating one method of selecting sediment screening values for the Philadelphia Naval Complex can be found on the NAVFAC ERA Web site at http://web.ead.anl.gov/ecorisk/case/.

Chemicals without relevant sediment quality benchmarks values or sufficient data to develop applicable background levels also should be retained as COPCs. In addition, most sediment quality benchmarks do not address the potential for bioaccumulation. Bioaccumulation represents the first step in the movement of sediment-associated contaminants into the food web (Lee, 1992). Therefore,

Table 3-1. Examples of Benchmark Values Used in Tier 1 Screening Process

Benchmark	Basis	Source	Website
Sediment			
ER-L/ER-M	Significant toxicity to benthic infauna	Long et al., 1995	http://www.nwn.noaa.gov/sites/hazmat/cpr/sediment/SQGs.html
TEC/PEC	Consensus based guidelines	MacDonald et al., 2000a	NA
TEL/PEL	Significant toxicity to benthic infauna	Florida State Department of Environmental Protection, 1994	http://www.dep.state.fl.us/water/monitoring/docs/seds/vol1/volume1.pdf
PAH ESGs	Significant toxicity to benthic infauna from PAH mixtures	U.S. EPA, 2000e	NA
Apparent Effects Threshold (AET)	Significant toxicity to benthic infauna	Washington Department of Ecology, 1995	http://www.ecy.wa.gov/programs/tcp/smu/sed_chem.htm
SQG-Q	Significant toxicity to benthic infauna from chemical mixtures	Long et al., 1998; MacDonald et al., 2000b	NA
Superfund EcoTox (ET)	Predicted toxicity to benthic infauna based on equilibrium partitioning	U.S. EPA, 1999	http://www.epa.gov/superfund/resources/ecotox
Tissue			
Effects-based tissue residues for selected biological receptors	Tissue residues associated with specified effects	USACE/U.S. EPA, 2001 ERED Database McCarty and Mackay, 1993	www.wes.army.mil/el/ered/index.html

ER-L = Effects Range-Low
ER-M = Effects Range-Median
NA = Not Applicable
PAH ESGs = PAH Equilibrium Partitioning Sediment Guidelines
PEC = Probable Effect Concentration
PEL = Probable Effect Level
SQA = Sediment Quality Guideline
TEC = Threshold Effect Concentration
TEL = Toxic Effect Level
TRV = Toxicity Reference Value
USACE = Army Corps of Engineers

additional consideration should be given to the potential for bioaccumulation, especially for site COPCs that are not necessarily present in sediments at levels that are toxic to aquatic species but that have the propensity to bioaccumulate in higher trophic levels, potentially posing a hazard to piscivorous species through food web exposures. U.S. EPA has identified a general list of bioaccumulative compounds of potential concern, which are discussed in more detail in Chapter 4 of *Bioaccumulation Testing and Interpretation for the Purpose of Sediment Quality Assessment* (U.S. EPA, 2000a; http://www.epa.gov/waterscience/cs/biotesting/bioaccum.pdf). These compounds should be retained as COPCs until sufficient information is available to demonstrate that they are not bioavailable at the site.

Highlight 3-1. Sediment Benchmark Values for Chemical Mixtures

In general, most sediment benchmarks evaluate effects associated with individual chemicals. In reality, most sediments contain a mixture of contaminants; therefore, this approach does not consider potential synergestic effects. To address this issue, U.S. EPA currently is investigating methodologies for deriving benchmark values for chemical mixtures. However, in the interim, recent research has suggested that sediment toxicity may be predicted through the use of a sediment effects ratio described as a Sediment Quality Guideline Quotient (i.e., SQG-Q) (MacDonald et al., 2000b; Ingersoll et al., 2000; Long et al., 1998). The SQG-Q is derived by a three-step process developed by Long et al. (1998). In the first step, the concentration of each chemical in a given sample is divided by its respective sediment quality criteria. The resulting ratio is defined as a SQG quotient or SQG-Q. The SQG-Qs for each chemical are then summed and divided by the number of individual chemicals evaluated to derive a mean SQG-Q for each sample. Preliminary data indicate that the mean SQG-Q may facilitate comparisons between areas and sampling stations, particularly in situations where differing numbers of chemicals have been evaluated. For example, based on a sample size of 175, MacDonald et al. (2000b) found that the incidence of toxicity in freshwater sediments could be predicted in up to 94.4 percent of sediments considered through use of the mean SQG-Q. This approach is relatively new and has not yet been subjected to rigorous field testing; therefore, its application should be discussed with the appropriate regulators.

3.1.1.2.2 Identification of Ecological Receptors

Based on an evaluation of the available habitats identified during the site characterization, relevant ecological receptors of concern are selected for investigation. It is impossible to evaluate all species that might be exposed to COPCs at a site; therefore, a few representative species are identified. Typically, the species selected are chosen to represent the key or primary feeding guilds at the site, or species of special concern (e.g., endangered species). For marine facilities, possible exposures to marine mammals (e.g., sea otters, seals etc.) and pelagic species should be considered. For the purpose of the SRA, the selection of receptors focuses primarily on identifying the key trophic levels that will be evaluated, rather than on selecting the specific species exposed. Figure 1-1 provides a generic aquatic food web, depicting the wide variety of potential receptor classes that may be exposed. A summary of types of receptors usually evaluated is provided below.

Benthic Invertebrates

The benthic invertebrate community includes a wide array of organisms living in close association with the sediments. Some of these organisms burrow into sediments, whereas others live at the sediment water interface or in intertidal areas (Levinton, 1982). Due to their relatively direct exposure to surface sediments, and their position at the base of most aquatic food webs, benthic invertebrates are a key indicator species when evaluating the potential effects of sediment-associated contaminants (Diaz, 1992; La Point and Fairchild, 1992; Ankley, 1997).

Fish Community

La Point and Fairchild (1992) recommend fish for assessment because of their societal value and familiarity as well as their role as integrators of toxicity at lower trophic levels. However, limitations are associated with using these receptors to evaluate site-specific sediment quality due to their relative mobility. The fish community is represented by a diverse assortment of species, some of which live in close association with the sediments (i.e., demersal species) and others which reside primarily in the water column (i.e., pelagic species) (Levinton, 1982). In addition, some species are herbivorous, consuming primarily plant material and detritus, whereas other species are predatory, consuming invertebrates and even smaller fish. All fish are exposed to COPCs to some degree through direct uptake from sediment and the water column, as well as through dietary intakes (Mac and Schmitt, 1992). As a result, COPC exposure and uptake is highly influenced by the life history, foraging range, and feeding regimen of the species evaluated.

Birds and Mammals (Terrestrial and Marine)

Wildlife species may be exposed to contaminated sediments in a variety of ways including through incidental ingestion of sediment and surface water and by trophic transfer through the consumption of prey items (e.g., fish, invertebrates) (U.S. EPA, 1993a). The relative importance of each potential exposure pathway is dependent on the chemical and physical properties of the COPC present in the sediment which control uptake into aquatic organisms (Fordham and Reagan, 1991). For example, piscivorous (i.e., fish-eating) wildlife (e.g., mink, seals, herons) are exposed to persistent, hydrophobic organics (e.g., PCBs) primarily through the consumption of prey (i.e., fish), with incidental ingestion of sediment and surface water playing a smaller role.

3.1.1.2.3 Identification of Complete Exposure Pathways

A complete exposure pathway is one in which the COPC(s) can be expected to travel from the source to a receptor that can be affected. It may include direct exposure through ingestion or dermal contact with sediment, or indirect exposure through trophic transfer. For the purpose of the Tier 1 SRA, potential pathways generally are assumed to be complete provided that the identified COPC can be associated with Navy activities, the site characterization indicates that relevant ecological receptors are likely to be present, and the mechanisms for exposure exist. This assumption is refined throughout the investigation as more information becomes available. However, if a particular exposure pathway can be demonstrated to be incomplete, it should be eliminated from the assessment and the supporting rationale should be documented. For example, risks to benthic-feeding birds should not be evaluated if it can be demonstrated that the appropriate habitat conditions (e.g., presence of mudflats or shallow intertidal areas) for foraging do not exist at the site.

3.1.1.2.4 Conceptual Site Model

As previously discussed, the preliminary CSM developed during the initial site characterization should be updated based on the information collected during the preliminary Problem Formulation to create an ecological CSM (Figure 3-2). This ecological CSM should reflect the complete exposure pathways identified as well as the ecological receptor classes to be evaluated. A distinction also is made between minor and major exposure pathways. For example, as indicated in this figure, sediment associated chemicals may partition between sediment and surface water, creating a dynamic process that is always in flux. Depending on the physical and chemical conditions at the site, as well as their feeding regimen and other behaviors, ecological organisms can be exposed to COPC associated with either of these media; however, concentrations of many sediment-associated COPC are low

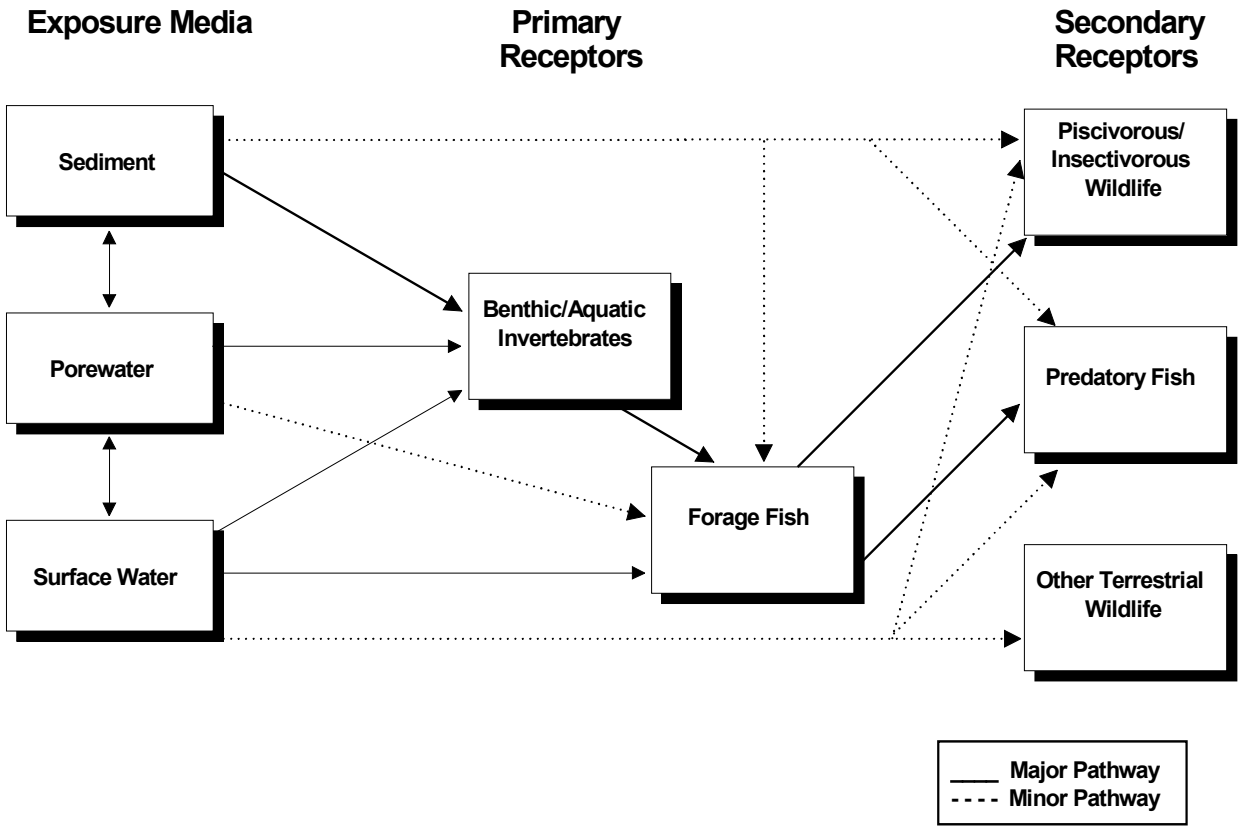


Figure 3-2. Simplified Ecological Conceptual Site Model for Sediment

in surface water (see Section 1.1). As a result, direct exposure to sediment-associated contaminants via surface water is likely to be a minor pathway, accounting for a smaller portion of the overall exposure. This assumption should be adjusted if the site characterization indicates the likelihood of elevated concentrations of COPCs in surface water, based on either actual measurements or physico-chemical conditions.

This preliminary ecological CSM represents the basic framework on which the remainder of the evaluation will be based; therefore, discussions with the appropriate regulators are critical at this point in the assessment.

3.1.1.3 Preliminary Exposure Estimate and Risk Calculations

The second step of the SRA includes a screening-level exposure estimate and an initial screening risk calculation, equivalent to Step 2 of the U.S. EPA eight-step process (http://www.epa.gov/ncea/ecorsk.htm). In this initial phase of the investigation, site-specific information often is limited to bulk sediment chemistry data. Therefore, for the purpose of the SRA, exposure estimates for aquatic organisms usually are evaluated based on conservative estimates of COPC concentrations (i.e., maximum) in surface sediment. In addition, if bioaccumulative chemicals are present, concentrations of COPCs in tissues of exposed organisms also may be evaluated using site-specific tissue data. If such data are not available, tissue concentrations may be estimated using a variety of bioaccumulation models (Highlight 3-2). To evaluate exposures to upper trophic level receptors (i.e.,

Highlight 3-2. Bioaccumulation Models

A variety of bioaccumulation models exist for the purpose of predicting tissue concentrations in aquatic organisms in the absence of measured data from field collections or laboratory bioassays (Lee, 1992). The simplest of these are the bioaccumulation factor (BAF), defined as the ratio between the COPC concentration in the organism and sediment, and the equilibrium partitioning bioaccumulation model, also referred to as the biota/sediment accumulation factor (BSAF). The BSAF is the ratio of the lipid normalized tissue concentration of COPC and the organic carbon normalized sediment concentration. Multiplying these factors by the chemical concentration in sediment (using dry weight for the BAF and TOC normalized for the BSAF) results in an estimated tissue concentration. U.S. EPA (2000a) includes BSAF information on 11 metals, 1 chlorinated phenol, 10 PAHs, 13 chlorinated pesticides, selected dioxins, furans, and both Aroclor and congener forms of PCBs. In addition, a fairly comprehensive list of BSAF and Theoretical Bioaccumulation Factors (TBF) values for several trophic levels of fish can be found at http://www.epa.gov/waterscience/cs/vol1/appdx_c.pdf. Accumulation factors appropriate for screening studies also are available for selected aquatic species at http://www.epa.gov/ecotox/. For full details on the derivation and application of bioaccumulation factors, consult the full document *The Incidence and Severity of Sediment Contamination in Surface Waters of the United States* (EPA/823/R-97/006; http://www.epa.gov/OST/cs/congress.html). A comprehensive database of BSAFs is maintained by USACE at http://www.wes.army.mil/el/bsaf/bsaf.html.

Due to their simplicity, BAFs and BSAFs provide a quick and easy means of estimating tissue concentrations that may be associated with exposures to contaminated sediment. However, prior to applying BAFs or BSAFs, the limitations of these approaches should be considered. The accuracy of BAFs is limited by variations in sediment type and species evaluated. Similarly, BSAFs rely on the assumption that the system evaluated is at steady state and may over or underestimate actual accumulation if those conditions are not met. For some evaluations, the uncertainty associated with these approaches may be too great. Under those circumstances, kinetic process and bioenergetic-based models will provide a more accurate estimation of uptake (Lee, 1992). For a more detailed discussion of the various types of models available, the strengths and limitations associated with each one, and recommendations for selecting a model suitable to your site, see Lee (1992).

wildlife), simplified dose calculations may be performed, using conservative assumptions regarding contaminant bioavailability (e.g., 100 percent bioavailability) and uptake (e.g., assumption of upper bound sediment ingestion rates, or a site use factor of 1).

Preliminary risk estimates for aquatic organisms in Tier 1 typically are limited to comparisons of sediment and tissue concentrations to available sediment and tissue benchmark values (see Table 3-1). Hazard quotients (HQs) for these species may be derived by dividing the sediment or tissue concentration of each COPC associated with the site by its respective benchmark value. Similar to sediment benchmark values, tissue residues associated with adverse effects (e.g., the lethal residue associated with 50% mortality in a population exposed for 96 hours) can be used to predict

the tissue concentration at which adverse effects will be observed in a particular aquatic species (USACE/U.S. EPA, 2001; see Table 3-1). Landrum and Meador (2002) discuss the limitations associated with the use of tissue residues.

It is important to note that many of these sediment and tissue benchmark values are "inferred" from various effects databases. In addition, the ecological relevance of the effect recorded may vary substantially from enzyme induction to acute mortality. For example, ER-L and ER-M values are statistically derived based on a database of chemical concentrations measured in sediment samples associated with some degree of toxicity (ranging from behavioral effects to mortality) to benthic infauna; however, there is no established causal relationship between any single contaminant and the measured effect. As a result, benchmark values should be used for screening purposes only; they are not regulatory criteria, site-specific cleanup standards, or remediation goals.

To estimate Tier 1 risks to wildlife species, screening-level dose estimates may be calculated using conservative exposure assumptions to evaluate all pathways considered complete. In the absence of site-specific tissue data, bioaccumulation models can be used to predict tissue concentrations in aquatic organisms (e.g., fish, shellfish, and benthic invertebrates) exposed at the site. For example, biota sediment accumulation factors (BSAFs) were used at the Philadelphia Naval Complex for the Screening-Level Risk Assessment for Reserve Basin Sediment (http://web.ead.anl.gov/ecorisk/case/study3.cfm). Hazard quotients for this pathway are estimated by comparing these dose estimates to toxicity reference values (TRVs) derived for selected wildlife receptors.

Based on the results of the screening risk calculation, a decision is made for exiting or continuing the ERA. If ecological risks based on the conservative screen are acceptable (i.e., typically defined as HQs less than 1), then the site is determined to pose an acceptable risk and is closed out for ecological concerns. If HQs exceed 1, then the site either proceeds to an interim cleanup, or proceeds to the second tier. A decision also may be made to move forward to Tier 2 for only a limited section of the site, or for a reduced number of COPCs.

3.1.2 Tier 2: Baseline Ecological Risk Assessment

Tier 2 represents the BERA, which is the most extensive activity within the ERA process in terms of data collection and analysis, cost, and effort. It is much more site-specific and technically rigorous than Tier 1. The BERA consists of Steps 3 through 7 of the eight-step U.S. EPA Superfund ERA process (see Figure 3-1).

Step 3: Refinement of Conservative Exposure Assumptions (Step 3a) and Revised Problem Formulation (Step 3b)

Step 4: Study Design/DQO

Step 5: Verification of Field Sampling Design

Step 6: Site Investigation and Data Analysis

Step 7: Risk Characterization.

As the first component of the BERA, the COPCs that were retained from Tier 1 are re-evaluated based on a refinement of the conservative exposure assumptions (i.e., Step 3a). The purpose of Step 3a is to identify and eliminate from further consideration those COPCs that were retained only

because of the use of very conservative exposure scenarios. If the re-evaluation conducted in Step 3a supports an acceptable risk determination, then the site exits the ERA process; otherwise it proceeds to Step 3b. Sediment-specific issues associated with each of these steps are described below.

3.1.2.1 Step 3a: Refinement of Conservative Exposure Assumptions

In Step 3a, a variety of methods are used to refine the assumptions used in the SRA, depending on the information available. For example, in the SRA, conservative values may be used for exposure parameters such as exposure point concentration (e.g., maximum), area use factors (e.g., site use factor of 1), life stage (e.g., the most sensitive stage), body weight, food ingestion rates, dietary composition, and bioavailability (e.g., assuming 100 percent bioavailability or use of conservative BAFs or BSAFs to estimate uptake). For Step 3a, these conservative estimates are replaced with more realistic, site-specific values, as supported by existing data. Relevant questions to ask before calculating less conservative risk estimates concerning source, stressor, and exposure characteristics are found in U.S. EPA (1998b). Risks are recalculated using these refined exposure parameters, and COPCs with HQs below 1 are eliminated from further consideration. A summary of some of the key refinements for sediment sites is provided below.

Bioavailability

Bioavailability refers to the degree to which a contaminant in sediment is available for uptake by a receptor. As discussed in Section 2.6.2, a number of chemical and physical characteristics of sediment may affect the bioavailability of COPCs, primarily through adsorption or complexation of contaminants into the sediment matrix. These characteristics are not always reflected in application of screening-level sediment benchmark values. For example, many sediment benchmarks are based on bulk sediment chemistry concentrations and, therefore, do not account for effects of TOC. In addition, most sediment benchmarks are based on total metals concentration. There is evidence to suggest that the bioavailability of several metals (e.g., arsenic) may be correlated to the species of metal present in sediment (Neff, 1997). In addition, the presence of AVS may also affect the bioavailability of some metals (Ankley, 1996; Ankley et al., 1996).

For the purpose of Step 3a, existing data should be reviewed to evaluate potential chemical and physical conditions that potentially affect the bioavailability of COPCs. It may be necessary to collect limited additional data (e.g., TOC, grain size, AVS/SEM); however, the evaluation should rely on existing information to the extent possible. The Navy has prepared guidance on the incorporation of bioavailability adjustments for metals into ecological risk assessments (Battelle and Exponent, 2000; http://web.ead.anl.gov/ecorisk/issue/pdf/bioavailNavy.pdf).

Comparison to Background

According to the Navy's *Policy on the Use of Background Chemical Levels* (CNO, 2000; see Highlight 1-1), BERAs should not be conducted on chemicals that are present at levels less than background chemical levels (i.e., anthropogenic or naturally occurring levels). According to this policy, background is defined as follows:

- Naturally occurring chemical levels (nonanthropogenic): ambient concentration of chemicals present in the environment that has not been influenced by human activities (e.g., arsenic).

- Anthropogenic chemical levels (not naturally occurring): concentrations of chemicals that are present in the environment due to human-made, nonsite sources (e.g., application of pesticides, herbicides, lead from automobile exhaust).

For the purpose of the BERA, the preliminary COPC list generated during the Tier 1 SRA is refined to reflect only those chemicals that exceed applicable thresholds and background. The Navy's *Policy on the Use of Background Chemical Levels* (CNO, 2000; see Highlight 1-1) provides guidance on how to bring background issues into the process at Step 3a. This policy emphasizes the need to differentiate background contamination from site releases in the Navy IR programs. It is acknowledged that this approach differs slightly from that recommended by U.S. EPA (U.S. EPA, 2002); however, although chemicals that are present at concentrations below background but above applicable benchmark values should not be included as COPC, they should be discussed in the risk characterization and uncertainty section. Additional guidance on the use of background levels to refine COPC lists is provided in U.S. EPA (2001b; http://www.epa.gov/superfund/programs/risk/ecoup/slera0601.pdf).

A variety of methods may be used to develop estimations of background. For example, background may be based on concentrations of chemicals present at a remote reference site or those representative of ambient levels in a specified region (Giesy and Hoke, 1990). Consultation with the relevant regulatory agencies regarding the appropriate estimation of background is recommended early in the process. One method of determining background is though evaluation of a "reference" area. The selection of a reference area is an important step in the evaluation and should be conducted in conjunction with the agencies. Factors to consider include: (1) similar physical characteristics (e.g., grain size, TOC) to site sediments; (2) similar habitat conditions (e.g., subtidal vs. intertidal or estuarine vs. freshwater); (3) representative of regional ambient conditions (i.e., not influenced by point sources of contamination).

Navy guidance (*Navy Guidance for Environmental Background Analysis, Volume I: Soils,* NFESC User's Guide UG-2049-ENV, April 2002) is available to determine background exceedances through the use of statistical comparisons of complete distributions of data rather than relying on earlier practices of point comparisons to statistically derived upper confidence limits (UCLs). Although this guidance was prepared specifically for soil sites, it is applicable to sediment sites with some modifications. An effort currently is underway to complete *Navy Guidance for Environmental Background Analysis, Volume II: Sediment*. This document also provides guidance on the use of geochemical methods to compare to background and to identify sources (see Section 2.6.1.2). These methods can be used to eliminate COPCs that either are shown to occur naturally at the site (e.g., elevated nickel in San Francisco Bay sediments) or are decisively linked to non-Navy sources. Additionally, because many sediment sites are impacted by both Navy and non-Navy contaminants, these methods can be used to perform source allocation of certain COPCs (e.g., PAH, PCBs, metals). A discussion on the application of some of the more common geochemical methods is provided in Appendix B.

Evaluation of Detection Frequency and Analytical Methods

Because many SRA investigations rely on the use of historical sediment data that were generated using outdated methods designed for matrices other than sediments, it is advisable to carefully evaluate the COPC list carried forward in order to ensure that COPCs are not retained solely because of data quality issues. These methods may have grossly over- or underestimated sediment chemical concentrations because: (1) they did not account for matrix interferences from organic material or

salt; (2) detection limits were too high; and/or (3) samples were inappropriately collected or handled. Existing screening data should be reviewed to ensure that contaminant concentrations are accurate and representative of current site conditions. Rapid sediment characterization methods (see Appendix A) or collection of a limited number of samples using appropriate methods should be considered if there is reason to believe that existing data overestimate or underestimate site sediment contaminant concentrations.

3.1.2.2 Step 3b: Problem Formulation

If the re-evaluation and refinement of the conservative assumptions conducted in Step 3a does not support an acceptable risk determination, the investigation continues with Step 3b of the BERA, Problem Formulation. As discussed in the Navy ERA Policy, Steps 3b through 5 represent the most important components of the Tier 2 process (i.e., planning, study design, and verification) because they focus the scope and magnitude of the BERA. Specifically, these steps identify the endpoints to be evaluated, the laboratory methods to be employed, the statistical methods to be used, and the methods used for estimating and characterizing the ecological risks. The intent of these steps is to insure that the assessment focuses on the primary ecological concerns at the site, and that only the data necessary to make a risk management decision are collected. Numerous SMDPs are involved in these steps as indicated in Figure 3-1, and the appropriate U.S. EPA and Navy ERA guidance should be consulted for direction at each of these points.

For the purpose of Step 3b, the preliminary problem formulation derived in the SRA is expanded and refined to focus only on those COPCs that were retained following the Tier 1 assessment and the Step 3a refinement. Another site visit may be conducted to gather additional information regarding available habitats, the sources of COPCs, and fate and transport mechanisms at the site for the purpose of confirming the existence of complete exposure pathways. For example, in Tier 1 it might be assumed that a complete exposure pathway existed for piscivorous birds to be exposed to bioaccumulative COPCs in forage fish associated with the site. However, if all bioaccumulative COPCs are eliminated from the evaluation based on the Step 3a refinement, this exposure pathway also may be eliminated from the refined Problem Formulation. Similarly, additional evaluation of data may indicate that certain COPCs are not available, or that existing habitats are not sufficient to support the ecological receptors of concern.

3.1.2.2.1 Selection of Assessment Endpoints

As part of the refined Problem Formulation, assessment endpoints are identified for the BERA. U.S. EPA (1992) identifies assessment endpoints as "an explicit expression of the environmental value that is to be protected." As discussed in the Navy policy, the assessment endpoints represent the target of the BERA, and set the basis for the development of specific ecological studies and data collection activities. It is not possible to evaluate all individual components of the ecosystem at a site. Instead, assessment endpoints should focus on particular ecosystem components or organisms that are potentially sensitive to contaminants and that are ecologically relevant. For example, the benthic invertebrate community often is selected as an assessment endpoint for sediment evaluations because these organisms are a primary food source for a wide variety of aquatic and terrestrial species and are a key link in most aquatic food webs. In addition, well-established laboratory methods are available for evaluating their toxic response to contaminated sediments. In addition to benthic invertebrates, both aquatic (e.g., predatory fish) and terrestrial (e.g., piscivorous species) upper trophic level species commonly are evaluated. Example assessment endpoints are summarized in Table 3-2.

Table 3-2. Common Sediment Assessment and Measurement Endpoints and Exposure Pathways

Assessment Endpoint	Primary Exposure Pathways	Example Measurement Endpoints
Survival, growth, and reproduction of the benthic invertebrate community	Ingestion, dermal absorption	Comparison to sediment benchmarks/ toxicity/bioaccumulation bioassays; community structure
Survival, growth, and reproduction of the pelagic community	Ingestion, dermal absorption, desorption to water column and subsequent respiration, inges-tion of contaminated prey	Comparison to sediment/surface water/tissue benchmarks/toxicity/ bioaccumulation bioassays; community structure
Health of the relevant wildlife community	Ingestion of contaminated prey; ingestion of contaminated surface water and sediment	Dose modeling

3.1.2.2.2 Development of Risk Questions and Hypotheses

Based on the information evaluated for the refined problem formulation, the risk assessment team will develop risk questions that integrate the information collected into questions about the relationship among assessment endpoints and their responses when exposed to site contaminants. Specific risk questions should be developed for each assessment endpoint and COPC and will serve as the basis for later activities in Tier 2 (see Highlight 3-3).

Highlight 3-3. Examples of Risk Questions Commonly Used in Sediment ERAs

Relative Risk:

- Do COPC concentrations in bulk sediment samples from the site exceed COPC concentrations in bulk sediment samples from the reference area?
- Does mortality measured in laboratory toxicity tests for sediments from the site exceed mortality in laboratory toxicity tests for sediments from the reference area?
- Do COPC concentrations in tissue of organisms exposed to site-specific sediments exceed COPC concentrations in tissues of organisms exposed to sediments from the reference area?
- Is the diversity and abundance of the resident benthic community at the site impaired relative to the reference area community?
- Do dose estimates predicted for the upper trophic level species at the site exceed those predicted for reference areas?

3.1.2.2.3 Refinement of the Conceptual Site Model

In the Tier 1 SRA, a preliminary CSM is prepared (Figure 3-1) to focus the understanding of the site on the basis of available data. Based on the results of Step 3b, a revised CSM is developed that incorporates additional detail and focus. Appendix D provides an example planning table that can be used to assist in developing the refined CSM. An example of a refined CSM is provided in Figure 3-3.

3.1.2.3 Step 4: Study Design and the DQO Process

Step 4 of the Navy ERA process involves the identification and design of scientifically defensible, site-specific investigations necessary to address the risk hypotheses and questions developed. The development of a scientifically defensible design is accomplished through the application of the DQO process (U.S. EPA, 2000b). Each study design will be unique, and will be based on the assessment endpoints, COPCs, and risk hypotheses identified. The primary objective of Step 4 is to produce a draft Work Plan (WP) and a draft Sampling and Analysis Plan (SAP). It is important that these investigations be designed to identify cause-and-effect relationships between COPCs and assessment endpoints, and to support the risk characterization and risk management decisions (including development of PRGs).

3.1.2.3.1 Selecting Measurement Endpoints

One of the first steps in the study design is the selection of measurement endpoints. Measurement endpoints provide a specific, quantifiable means of measuring a specific assessment

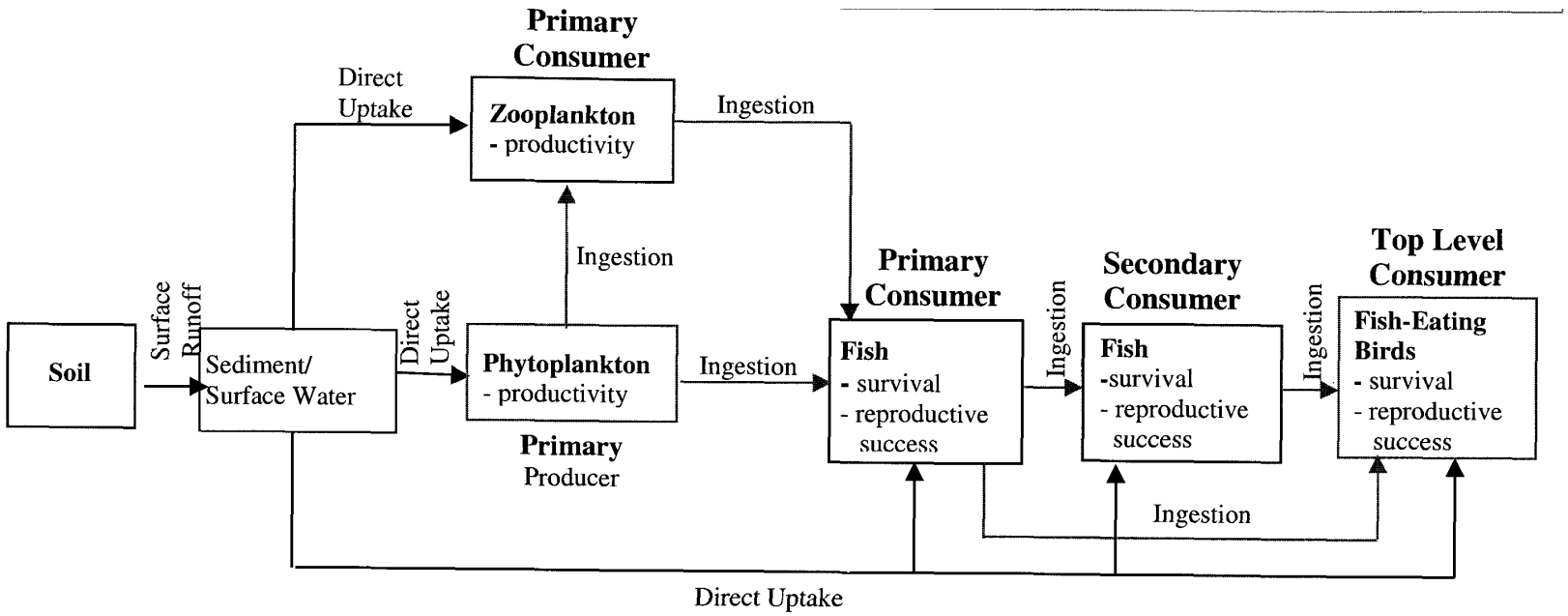
endpoint as defined (U.S. EPA, 1992; 1998a) and can include measures of exposure or effect. For example, an assessment endpoint may be defined as "the survival and reproductive success of benthic invertebrates exposed to contaminated sediments at the site." Suitable measurement endpoints would include percent survival associated with an acute or chronic toxicity test, number of young per female exposed, growth of individuals exposed, or the diversity and species abundance observed in the invertebrate community.

In selecting measurement endpoints, it is important to ensure that there is a direct relationship between the assessment and measurement endpoint, that they address the risk hypotheses and questions, and that there is a connection to the COPC and the routes of exposure. Example measurement endpoints are presented in Table 3-2. The suitability of potential measurement endpoints for addressing the identified assessment endpoints should be discussed with the appropriate regulatory agencies prior to the final selection.

In addition to these specific measurement endpoints, other ancillary data are sometimes evaluated more qualitatively in sediment risk assessments (Table 3-3). These data, although not used to quantitatively support the risk estimate, can be used to evaluate uncertainties or support assumptions.

3.1.2.3.2 Study Design and DQOs

Once the measurement endpoints are selected, the study design is completed. Prior to collection of additional data, DQOs should be developed in accordance with the guidelines provided in the U.S. EPA's seven-step DQO process (U.S. EPA, 2000b). DQOs should include an identification of the study questions (Step 2), a list of the measurements required (Step 3), a discussion of the study boundaries (Step 4), and a description of the decision rules or data evaluation (Step 5). For each



This model identifies the contaminant sources, the fate and transport mechanisms, exposure pathways to ecological receptors (phytoplankton, zooplankton, fish and birds), and the assessment endpoints (productivity of plankton, survival and reproductive success of fish and birds). Note that this model does not identify specific contaminants of concern for each assessment endpoint.

Figure 3-3. Example of a Tier 2 BERA Conceptual Site Model

Table 3-3. Examples of Ancillary Data Interpretation Tools

Use Impairment	Related Measurement Endpoint	Data Interpretation Tools
Restrictions on fish and wildlife consumption	Bioaccumulation in resident fish	Equilibrium partitioning, comparison to guidelines (Table 3-1) provides a summary of example decision rules that can be used in a typical sediment study.
Degradation of fish and wildlife populations	Benthic community structure, bioaccumulation	Food web model, weight of evidence
Fish tumors or other deformities	Bioaccumulation in resident fish	Reference frequencies
Bird or animal deformities or reproduction problems	Bioaccumulation, community structure	Food web model, comparison to reference conditions, weight of evidence
Degradation of benthos	Community structure, toxicity (bioassays)	Comparison to reference conditions, use of impairment indices
Loss of fish and wildlife habitat	Chemistry, bioaccumulation, toxicity, benthos, stability	Comparison to reference conditions, weight of evidence

measurement endpoint evaluated, the corresponding decision rules should be presented. Finally, the DQOs should include a qualitative discussion of decision error types, and the specific consequences that must be considered in the study design (Step 6). Figure 3-4 presents an example of DQOs developed for a sediment assessment. The selection of the measurement endpoints for the BERA and development of the corresponding decision rules are among the most important aspects of the risk assessment process because they ultimately define the exit strategy for the site and should be discussed with the appropriate regulators.

Risk assessments often rely on comparisons of site results to reference area results to provide a measure of relative or incremental risk. Therefore, a key consideration in the development of the study design is the identification and selection of an appropriate reference area. The relevant regulatory agencies should be consulted throughout the process of selecting an appropriate reference area, as it can significantly affect subsequent risk management decisions. To ensure meaningful comparisons of sediment chemistry and bioassay results, it is important that physical and chemical factors at the reference area affecting site chemistry and bioavailability (e.g., grain size, TOC, AVS) are similar to the conditions at the site. In addition, habitat conditions should be as similar as possible to ensure that receptors identified as appropriate for site conditions also might be exposed to reference areas. If site conditions are heterogeneous, it may be necessary to select more than one reference area for evaluation, to ensure that all possible variations are addressed. In addition, some regulatory agencies have established regional reference values, reflecting ambient sediment or tissue concentrations based on monitoring data collected from throughout a specified area over a given period of time (Metcalf and Eddy, 1995).

Upon completion of the DQOs, a detailed Field Sampling Plan (FSP) should be prepared. Depending on the lines of evidence identified, data collection may include sediment samples, tissue samples, or laboratory bioassays (i.e., toxicity or bioaccumulation). Collection of physical and chemical data is discussed in Section 2.6, and an overview of study design and sample collection methods is provided in Section 2.7. A summary of biological data types that are often used during this portion of the risk assessment is provided in the following three subsections.

LABORATORY BIOACCUMULATION (*Macoma nasuta*) MEASUREMENT ENDPOINT
STEP 1: State the Problem Evidence of possible sources of contamination to sediment habitats offshore of the site
STEP 2: Identify the Decision 1. Are COPC concentrations in *M. nasuta* tissue elevated above reference concentrations? 2. At locations where COPC concentrations in *M. nasuta* tissue exceed reference, is potential risk to upper trophic level receptors unacceptable (as determined through a food chain model)?
STEP 3: Identify Inputs to the Decision 1. Acceptable survival of *M. nasuta* in control sediment 2. Sufficient *M. nasuta* tissue mass for acceptable detection of COPCs 3. COPC concentrations in *M. nasuta* tissues in animals exposed for 28 days to site and reference site sediments 4. Background COPC concentrations in unexposed animals 5. Percent lipid and percent moisture of tissue samples 6. COPC concentrations, grain-size distribution, and TOC in site and reference site sediment samples 7. Overlying water quality conditions during testing period: salinity, dissolved oxygen, pH, and temperature. 8. Food-chain model parameters
STEP 4: Define the Study Boundaries Questions 1, 2, and 3 will be based on the results of exposure of *M. nasuta* to the sediment from sampling stations within designated areas. Samples will not be collected in shoreline or intertidal areas covered with riprap or disposal debris. Results for each station will support a decision about the specific, designated area. Bioaccumulation tests will be run for 28 days to allow data comparability with previous studies and other data sets. Five replicates of each reference site sediment and one replicate of each Site station sediment sample will be tested. Question 1 also requires data from reference sites. Reference sites will have similar grain-size and TOC characteristics as Site sediments and will not be affected by known point sources of contamination. Reference sites will be sampled in the same way as Site stations, with surface sediment represented by the top 5 cm.
STEP 5: Develop a Decision Rule *Macoma* tissue concentrations associated with exposure to site sediments will be statistically compared to tissue concentrations associated with reference areas. In addition, HQs will be calculated for COPCs to evaluate the potential risk to upper trophic level receptors. 1. If no more than one COPC exceeds reference and the HQ calculated is ≤1, then the area will be determined to pose no unacceptable risk. 2. If ≥2 COPCs exceed reference, and the HQ calculated is ≥1 but ≤10, the area will be determined to pose a moderate risk. 3. If ≥2 COPCs exceed reference and the HQ calculated is >10 the area will be determined to pose a high risk.
STEP 6: Evaluate Decision Errors In general, if bioaccumulation and risk from consumption of contaminated prey is overestimated (false positive), a potential consequence is unnecessary remedial work that itself could be biologically detrimental. If bioaccumulation and food-chain risks are underestimated (false negative), a possible consequence is to fail to conclude that remedial action is required and biological systems could continue to be detrimentally impacted. Field-collected invertebrates and nondepurated *Macoma* tissues will be analyzed to help reduce uncertainty in estimates of food-chain risk.
STEP 7: Optimize the Design for Obtaining Data Sampling design is presented in the SAP.

Figure 3-4. Example DQOs for Bioaccumulation Evaluation

3.1.2.3.3 Toxicity Bioassays

Laboratory bioassays are the primary means of assessing sediment toxicity because most of the methods are standardized, well documented, and validated. The objective of a toxicity bioassay is to determine the potential impact of site media (e.g., bulk sediment, porewater) on resident or representative site organisms. Toxicity tests provide a direct measure of the toxicity of the bioavailable fraction of COPC (Lamberson et al., 1992).

Typically, toxicity bioassays involve the exposure of a known number of individuals of the selected test species to sediments, both from the site and from a designated reference area, for a specified period of time (e.g., 10 days for acute amphipod tests). A variety of endpoints are evaluated depending on the test design, including percent survival, growth (measured as length and weight), enzyme induction, or observed behavioral changes. Depending on the test design, these endpoints also may be evaluated at predetermined intervals throughout the duration of the test. The results associated with the site and reference sediments are compared statistically. For example, if the percent survival associated with site sediments is statistically lower than that associated with the reference area, it is concluded that site sediments may be toxic to the test species under those conditions. However, different results may be obtained for a particular site evaluated depending on the COPC present. For example, some chemicals may be acutely toxic to a particular species, while another species may only show effects after chronic exposures to the same concentration. Therefore, at some sites, it may be beneficial to consider performing more than one toxicity bioassay, with multiple species. Common test methods, species, and test advantages and disadvantages are summarized in Table 3-4 for estuarine/marine bioassays and in Table 3-5 for freshwater bioassays. Guidance on selecting and performing toxicity tests and interpreting the results can be found in the following documents:

- *Methods for Measuring the Toxicity and Bioaccumulation of Sediment-Associated Contaminants with Freshwater Invertebrates*. Second Edition. (U.S. EPA, 2000c; EPA/600/R-99/064. Office of Research and Development and Office of Water, Washington, DC.

- The *Inland Testing Manual* (U.S. EPA/USACE, 1998, Chapter 11; http://www.epa.gov/waterscience/itm/ITM/).

- *The Evaluation of Dredged Material Proposed for Ocean Disposal* (i.e., the "Green Book"; U.S. EPA/USACE 1991; http://www.epa.gov/OWOW/oceans/gbook/).

- http://www.epa.gov/waterscience/cs/pubs.htm.

Standard bioassay protocols are also published by the American Society for Testing and Materials (ASTM), which at this time are available as hard copy publications, or online for subscribers (see http://www.astm.org/).

The results of toxicity bioassays may be used alone or in conjunction with sediment chemistry and benthic community data to form the sediment quality triad (Chapman, 1986; Chapman et al., 1997). This method is based on the assumption that biological responses (e.g., toxicity observed or reduction in species diversity) are associated with the mixture of COPC in sediments (Chapman, 1986). In this approach, the data from each of these three types of studies are evaluated independently as separate lines of evidence and then combined to derive an overall conclusion about the site. In areas where the individual lines of evidence support the same conclusion, greater confidence in the decision is reached, whereas areas with conflicting information may require further evaluation regarding uncertainties in the data (Chapman, 1986; Chapman et al., 1997).

The organisms used in a toxicity test should represent appropriately sensitive infaunal or epibenthic organisms found in the vicinity of the site. The most common method for assessing acute effects from exposure to marine and estuarine bulk sediment is a 10-day amphipod toxicity test (e.g.,

Table 3-4. Estuarine and Marine Aquatic Bioassays for Use in Sediment Investigations

Test Species, Test Duration, and Medium	Endpoints	Advantages	Disadvantages	Other Remarks	Protocol Reference
Amphipod *Ampelisca abdita* 10 Days Sediment	Survival	Highly reliable test; laboratory exposure analogous to field conditions; very useful in defining gradients of sediment toxicity; readily available and widely distributed species; test salinities from 10 to 35 ppt; tolerant of fine sediments; high regulatory relevance; mortality endpoint has high ecological relevance; moderately cost-effective	Tube dweller, not in direct contact with sediment; sensitive to coarse-grained sediments; species is field-collected	Less sensitive than *E. estuarius* and *R abronius;* LC50 value for un-ionized ammonia is 0.83 mg/L (Kohn et al., 1994)	Test Method 100.4 (EPA, 1994b) ASTM E1367-99 (EPA, 1998)
Amphipod *Eohaustorius estuarius* 10 Days Sediment	Survival, Reburial	Highly reliable test; laboratory exposure analogous to field conditions; very useful in defining gradients of sediment toxicity; readily available species; test salinities from 2 to 28 ppt; tolerant of fine sediments; directly exposed to sediments; high regulatory relevance; mortality endpoint has high ecological relevance; moderately cost-effective	Less sensitive than *R. abronius; p*otential sediment interferences*;* not as well distributed as *L. plummulosus* or *A. abdita; s*pecies is field collected	Remove potential predators from sediment before testing; less sensitive to sulfide than *R. abronius* (LC50 = 104 μM total sulfides/L [Knezovich et al., 1995]); *E. estuarius* mortality is as sensitive as *R. abronius* mortality; *R. abronius* non-reburial is more sensitive than *E. estuarius* nonreburial*; E. estuarius* mortality more sensitive than *N. areanaceo-dentata* biomass, which is more sensitive than *N. areanaceo-dentata* mortality; mortality endpoint more sensitive than reburial; LC50 value for total ammonia is 125.5 mg/L and un-ionized ammonia is 2.49 mg/L (Kohn et al., 1994)	Test Method 100.4 (EPA, 1994b) ASTM E1367-99 (EPA, 1998)

Table 3-4. Estuarine and Marine Aquatic Bioassays for Use in Sediment Investigations (page 2 of 5)

Test Species, Test Duration, and Medium	Endpoints	Advantages	Disadvantages	Other Remarks	Protocol Reference
Amphipod *Leptocheirus plumulosus* 10 Days Sediment	Survival, Growth, Reproduction	Species is cultured; salinity range of 1.5 to 32 ppt (pore water salinities of less than 1 to 35 ppt [Niewolny et al., 1997]); tolerates full range of grain sizes (except sandy sediments with less than 5% silt/clay [Niewolny et al., 1997]); tolerant of fine sediments; highly reliable test; high ecological relevance; laboratory exposure analogous to field conditions; widely distributed and cultured	Tube dweller – not in direct contact with sediment		Test Method EPA 600/R-01/020 (2001)
Amphipod *Leptocheirus plumulosus* 10 Days Sediment	Survival, Reburial	As above.	Tube dweller – not in direct contact with sediment		Test Method 100.4 (EPA 1994b) ASTM E1367-99
Amphipod *Rhepoxynius abronius* 10 Days Sediment	Survival, Reburial	Highly reliable test; most sensitive of amphipods usually tested; laboratory exposure analogous to field conditions; very useful in defining gradients of contamination; readily available species; test salinities from 25 to 32 ppt; directly exposed to sediment; high regulatory relevance; mortality endpoint has high ecological relevance; moderately cost-effective	Sensitive to high total organic content; sensitive to fine grained sediments; not as well distributed as *Leptocheirus plummulosus* and *Ampelisca abdita*; species is field-collected	*R. abronius* mortality as sensitive as *E.estuarius* mortality; *R. abronius* nonreburial is more sensitive than *E. estuarius* nonreburial; LC50 value for unionized ammonia is 1.59 mg/L (Kohn et al., 1994); more sensitive to sulfides than *E. estuarius (*LC50 for total sulfides is 50 µM total sulfides/L [Knezovich et al., 1995]); 10-day survival protocol using *R. abronius* was a more sensitive indicator of toxicity than 20-day test with *N. arenaceodentata* based on statistical power of the test and not greater sensitivity of the organisms or endpoints (Anderson et al., 1998)	Test Method 100.4 (EPA 1994b) ASTM E1367-99 EPA 1998

Table 3-4. Estuarine and Marine Aquatic Bioassays for Use in Sediment Investigations (page 3 of 5)

Test Species, Test Duration, and Medium	Endpoints	Advantages	Disadvantages	Other Remarks	Protocol Reference
Diatom *Thalassiosira pseudomona* *Skeletonema costatum* *Dunaliella tertiolecta* *Phaeodactylum tricornutum* 4 Days Water	Growth, Biomass, Cell Counts	Represents aquatic primary producers; Can be used with filtered porewater	Primarily a water test; not relevant to sediment	Not recommended unless there is clear evidence that Navy activities are currently impacting the water body.	ASTM E 1218-97a
Mollusc *Macoma balthica* 28 Days Sediment	Bioaccumulation	Species is wild-harvested	Ecological relevance; available year-round, surface deposit-feeder; tolerates salinity down to 10 ppt		ASTM 1668-00 (EPA, 1998)
Mollusc *Macoma nasuta* 28 Days Sediment	Bioaccumulation	Species is wild-harvested	Ecological relevance; available year-round, common test species; tolerates salinity down to 10 ppt		ASTM 1668-00 (EPA, 1998)
Mollusc *Yoldia imatula* 28 Days Sediment	Bioaccumulation	Species is wild-harvested	Ecological relevance; available year-round, subsurface deposit-feeder	Seawater must be >25 ppt	ASTM 1668-00 (EPA, 1998)
Mollusc Blue mussel *Mytilus edulis* 2 Days Water column	Development	Species is cultured; high dose responsiveness	Moderate ecological relevance; does not spawn year-round	Less sensitive than *Strongylo-centrotus purpuratus* to sulfides (complete inhibition at 8-µM total sulfide/L [Knezovich et al., 1995])	Test Method 1005.0 (Chapman, 1995)
Polychaete *Capetella* sp. 20-28 Days Sediment	Bioaccumulation	Species can be cultured	Low sensitivity; mortality has moderate dose responsiveness		ASTM 1668-00

Table 3-4. Estuarine and Marine Aquatic Bioassays for Use in Sediment Investigations (page 4 of 5)

Test Species, Test Duration, and Medium	Endpoints	Advantages	Disadvantages	Other Remarks	Protocol Reference
Polychaete *Nereis (Neanthes) areneceo-dentata* 20 Days Sediment	Growth Survival	Species is cultured; species can be tested at salinities less than 20 ppt; growth test is cost-effective; low cost; mortality has high dose response; mortality has high ecological relevance	Low to medium sensitivity; mortality has moderate dose responsiveness; growth has moderate ecological relevance	Test animal age, duration of exposure, food ration, and choice of endpoint affects the magnitude of the toxic response (Bridges and Farrar, 1997; Bridges et al., 1997); *N. arena-ceodentata* biomass is more sensitive than *N. arenaceo-dentata* mortality	(EPA, 1990) ASTM 1611-99
Polychaete *Nereis virens* 28 Days Sediment	Bioacumulation	Species is cultured, or wild harvest, can tolerate salinities as low as 10 ppt	Cannot be tested with other test species (predator).	Surface deposit-feeder and omnivore. Good provider of biomass.	Test Method 1005.0; (Chapman et al., 1995); ASTM 1688-00
Possum mysid *Americamysis bahia* 7 Days Water column	Fecundity Survival Growth	Species is cultured	Very sensitive to changes in ionic balance in test solution	Laboratory success with the fecundity endpoint is rare (WSDE, 1997)	Test Method 1007.0 (EPA, 1994c)
Purple sea urchin *Strongylo-centrotus purpuratus* 72 Hours Water column	Development Survival	Highly sensitive; early-life stage toxicity test; can be performed using filtered porewater	Species is field-collected; not recommended for sediments with a pore-water salinity less than 10 ppt; does not spawn year-round; does not directly live in sediments; moderate ecological relevance	Highly susceptible to unionized ammonia toxicity when testing sediment pore water (EC50 for un-ionized ammonia was 0.057 mg/L [Greenstein et al., 1996]); total inhibition from sulfides at 20-µM total sulfide/L [Knezovich et al., 1995])	Test Method 1008.0 (Chapman, 1995)
Sand dollar *Dendraster excentricus* 72 Hours Water column	Development Survival	Highly sensitive; early-life stage toxicity test; gravid adults can be obtained year-round (U.S. EPA 1993b); can be performed using filtered porewater	Species is field collected; medium dose responsive-ness; moderately cost-effective; moderate ecological relevance	Can be induced to spawn but with reduced gamete viability; proposed echinoderm effect threshold for unionized ammonia is 0.04 mg/L (U.S. EPA, 1993b)	Test Method 1008.0 (Chapman, 1995)

Table 3-4. Estuarine and Marine Aquatic Bioassays for Use in Sediment Investigations (page 5 of 5)

Test Species, Test Duration, and Medium	Endpoints	Advantages	Disadvantages	Other Remarks	Protocol Reference
Topsmelt *Atherinops affinis* 12 Days Sediment-water interface	Percent hatched	Most appropriate for testing early life stage fishes; can tolerate salinities from 2 to 60 ppt; can tolerate wide range in temperature with a preference of 19 to 23°C; reproductive season from early March to July or August depending upon latitude		Suggested test instead of using sediment pore water where fish are receptors of concern; numerically abundant in California estuaries	(Protocol based on Anderson, 1996)
Inland silverside *Menidia beryllina* 7 Days Water column	Survival	Species is cultured; occurs along both coasts of the United States; can tolerate freshwater to salinities of 35 ppt; can tolerate temperatures from 9.8 to 30°C; sexually mature from March or April through July or August			Test Method 1006.0 (EPA, 1994c)

ASTM = American Society for Testing and Materials.
EC50 = Concentration that causes an effect in 50% of the test organisms.
LC50 = Concentration that is lethal to 50% of the test organisms.
WSDE = Washington State Department of Ecology.

Table 3-5. Freshwater Bioassays for Use in Sediment Investigations

Test Species	Test Duration and Medium	Endpoints	Advantages	Disadvantages	Other Remarks	Protocol Reference
Algae, *Selenastrum capricornutum, Scenedesmus subspicatus, Chlorella vulgarius*	4 Days; water	Growth, Biomass, Cell Counts	Represents aquatic primary producers	Primarily a water test. Can be used with filtered pore water extracts		ASTM E 1218-97a
African Clawed Frog (FETAX) *Xenopus laevis*	96 Hours; sediment	Development Teratogenesis	Time and cost-effective; technical ease in conducting test; versatile for testing various media; sensitive to low levels of developmental toxicants; extensive literature available; most predictive when compared to lettuce germination, earthworm survival, *Daphnia* survival, and fathead minnow survival (Fort et al. 1995)		Can be used to test complex industrial mixtures; has been used to test surface water and aqueous extracts of soil; reference toxicant is 6-aminonicotinamide	ASTM E1439-98
Amphipod *Diporeia* sp.	10 Days; sediment	Bioaccumulation	Species can be cultured; pollution tolerant; important component in freshwater food chain	Small size requires massive numbers of individuals for chemical analysis	Subsurface deposit-feeder	ASTM 1688-00 EPA 1998
Amphipod *Hyalella azteca*	10 Days; sediment	Survival, Growth	Species is cultured; most highly sensitive of the freshwater test organisms; tolerates wide range of sediment grain sizes	Alkalinity commonly encountered in sediment porewater is toxic (Lasier et al., 1997; Duh and Myers, 1997)	Tolerates salinities up to 15 ppt	Test Method 100.1 (EPA 1994a) ASTM E-1706-95b
Amphipod *Hyalella azteca*	28 Days; sediment	Survival, Growth, Sexual Maturation	Species is cultured; most highly sensitive of the freshwater test organisms; tolerates wide range of sediment grain sizes	Alkalinity commonly encountered in sediment porewater is toxic (Lasier et al., 1997; Duh and Myers, 1997)	Can be used to evaluate the bioavailability of sediment associated contaminants; tolerates salinities up to 15 ppt	EPA/600/R-94/024, ASTM E-1706-95b

Table 3-5. Freshwater Bioassays for Use in Sediment Investigations (page 2 of 3)

Test Species	Test Duration and Medium	Endpoints	Advantages	Disadvantages	Other Remarks	Protocol Reference
Daphnid *Ceriodaphnia dubia*	8 Days or until 60% of survivors have three broods; water	Survival, Reproduction	Species is cultured; important link in many food chains; species is as sensitive as fathead minnow; wide hardness tolerance; found throughout the United States	Test was originally developed to support water testing. Sediment elutriates containing massive amounts of fine material can mechanically induce mortality and /or create difficulty observing the very small offspring.	Applicable to testing effluents, leachates, liquid phases of sediments with minimal quantities of "permanently" suspended material, and porewater	Test Method 1002.0 (EPA 1994c)
Fathead Minnow *Pimephales promelas,*	7 Days; water column	Survival, Growth	Species is cultured; occurs throughout the United States; eggs and early larvae commercially available; large effects data base	Not typically used in sediment suspended particulate testing	Applicable to testing effluents, leachates, and liquid phases of sediments with minimal quantities of "permanently" suspended material, and porewater	EPA/600/4-91/002
Mayfly - Burrowing, *Hexagenia* sp.	Life Stage Dependent; sediment	Survival, Growth, Bioaccumulation	Species is cultured; sensitive freshwater test organism; tolerates wide range of sediment grain sizes	Can mature into flying form if test duration extended	Important food chain item for freshwater fish	ASTM 1688-00
Midge Larvae, *Chironomus tentans*	10 Days; sediment	Survival, Growth	Species is cultured; sensitive freshwater test organism; tolerates wide range of sediment grain sizes	Can mature into flying form if test duration extended	Important food chain item for freshwater fish	ASTM 1706-95b
Midge Larvae, *Chironomus tentans*	14 Days; sediment	Bioaccumulation	Species is cultured; sensitive freshwater test organism; tolerates wide range of sediment grain sizes	Can mature into flying form if test duration extended, requires many individuals to provide sufficient biomass	Important food chain item for freshwater fish	ASTM 1688-00 EPA 1998

Table 3-5. Freshwater Bioassays for Use in Sediment Investigations (page 3 of 3)

Test Species	Test Duration and Medium	Endpoints	Advantages	Disadvantages	Other Remarks	Protocol Reference
Oligochaete *Lumbriculus variegatus*	28 Days; sediment	Bioaccumulation	Species is easy to culture, know chemical exposure history, tolerant to wide range of sediment types, low acute sensitivity to wide range of chemicals, toler-ates long exposures without feeding	Individuals are small and often difficult to remove from sediment and detritus matrix		ASTM E1688-00, EPA/600/R-94/024

ASTM = American Society for Testing and Materials.
EC50 = Concentration that causes an effect in 50% of the test organisms.
LC50 = Concentration that is lethal to 50% of the test organisms.
WSDE = Washington State Department of Ecology.

Rhepoxynius abronius, Eohaustorius estuarius, Leptocheirus plumulosus). *R. abronius* is a burrowing, deposit feeding amphipod that is commonly used in sediment contamination studies because it is sensitive to a wide range of toxicants. Freshwater bioassays are commonly conducted using *Hyalella azteca* (an amphipod) and *Chironomus tentans* (an insect larvae). When selecting test organisms, it is important to remember that individual species may have different sensitivities to specific COPC and test conditions. As a result, it may be useful to use more than one species. Selection of appropriate test species and methods for assessment of ecological risk are further discussed in *Confounding Factors in Sediment Toxicology* (Lapota et al., 2000).

Toxicity tests may also be conducted to evaluate exposure to porewater or suspended sediments using water column organisms as the test species. However, there are limitations with water column or porewater tests to evaluate sediment quality, as discussed by Chapman et al. (2002). The San Francisco Bay Regional Water Quality Control Board is developing guidance for assessing exposure to the sediment-water interface using intact, field-collected sediment cores and water column organisms (State Water Resources Control Board [SWRCB]; http://www.swrcb.ca.gov/).

The objective of a toxicity bioassay is to determine potential toxicity from exposure to site COPCs in various media; however, results can be difficult to interpret because uncontrolled confounding factors may be present. The most common types of confounding factors in aquatic bioassays are as follows:

- Elevated levels of ammonia or sulfide;
- Low dissolved oxygen concentration;
- Increased test organism sensitivity due to improper acclimation or inappropriate holding time;
- Artifacts due to manipulation of sediments or pore water;
- Unsuitable grain size for the test organism; and,
- Inappropriate porewater salinity.

A description of confounding factors and methods that can be used to minimize their effects is presented in the Issue Paper *Confounding Factors in Sediment Toxicology* (Lapota et al., 2000). The RPM should identify and use a laboratory with demonstrated experience in successfully controlling confounding factors and producing successful bioassay test results. Support for a quality assurance/quality control (QA/QC) evaluation of a toxicity testing laboratory is available through the Naval Facilities Engineering Service Center (NFESC) laboratory evaluation program. At a minimum, toxicity test data packages should include the information listed in Highlight 3-4, and test data should be reviewed as part of the data quality assessment. A summary of the key points regarding toxicity bioassays is provided in Highlight 3-5.

Highlight 3-4. Data Package Contents for Laboratory Bioassays

- Laboratory physical environment
- Feeding and food lot analysis
- Instrument calibration and maintenance
- Sample chain of custody
- Sample preparation for testing
- Test animal collection
- Quality control records (laboratory performance data, offspring sensitivity assessments, results of reference tests, and control charts)
- Dilution water preparation and lot analysis
- Test initiation
- Test animal randomization records
- Daily test conditions and observations
- Determination of percent survival and statistical deriviation of LC_{50}

Highlight 3-5. Bioassay Summary

- Test organisms should represent sensitive infaunal or epibenthic species found at the site; consider using multiple species
- Different tests are used to assess exposure to various site media (e.g., bulk sediment, porewater, water column); consider using more than one kind
- Different tests are used to assess acute versus chronic exposures; consider using both
- Test methods should identify and control factors that potentially confound bioassay results (e.g. ammonia and sulfide levels, grain size effects, low dissolved oxygen concentrations)

3.1.2.3.4 Bioaccumulation Bioassays

The bioavailibility of sediment-associated COPCs can be characterized using either laboratory or field bioaccumulation studies. These studies are important because they address COPCs that may not be acutely toxic to test organisms, but that potentially bioaccumulate in the food web where they may harm receptors of concern, including humans. Bioaccumulation data may be used to evalu

ate toxicity to aquatic organisms through comparison to effect-based tissue residues or in food web models. Bioaccumulation can be modeled from measured sediment concentrations, however, field or laboratory data are generally considered to provide a more accurate estimation (Lee, 1992). Detailed information regarding bioaccumulation evaluations can be found in the following publications:

- *Methods for Measuring the Toxicity and Bioaccumulation of Sediment-Associated Contaminants with Freshwater Invertebrates*. Second Edition. (U.S. EPA, 2000c; EPA/600/R-99/064. Office of Research and Development and Office of Water, Washington, DC.

- *Bioaccumulation Testing and Interpretation for the Purpose of Sediment Quality Assessment* (U.S. EPA, 2000a; http://www.epa.gov/waterscience/cs/biotesting/bioaccum.pdf);

- Washington State Department of Ecology Web site (http://www.ecy.wa.gov/programs/tcp/smu/sediment.html), including a paper regarding bioaccumulation methods for fish and shellfish (http://www.ecy.wa.gov/programs/tcp/smu/bioaccum.doc).

A variety of test species and methods for estuarine/marine and freshwater bioaccumulation tests are summarized in Table 3-4 and Table 3-5, respectively. The most common types of sediment bioaccumulation studies are 28-day flowthrough laboratory tests using worms or clams (e.g., U.S. EPA/USACE, 1991). The marine bivalve clam *Macoma nasuta*, which is a selective deposit and filter feeder, is commonly used on the east and west coasts of the United States. The polychaetes *Nereis diversicolor* and *Neanthes (Nereis) virens* also are standard species for marine bioaccumulation tests. The oligochaete *Lumbriculus variegates* is a common freshwater species. The selection of the specific type of test and the test species to be used should be based on a variety of site-specific factors as summarized by Lamberson et al. (1992) and Burton et al. (1992).

Bioaccumulation also can be evaluated by measuring chemical concentrations in tissues from resident organisms or animals deployed using in situ studies. Successful in situ bioaccumulation studies using caged bivalves and topsmelt were used to assess ecological risk at Site 9, Naval Air Station (NAS) North Island, San Diego, CA. However, caged fish studies may be conservatively biased unless the test species has an extremely limited range in the natural environment. Other disadvantages of caged fish studies include potential loss of cages due to vandalism or weather-related events and potential problems with retrieval of equipment or loss of organisms. Additional discussion of in situ bioaccumulation studies can be found in Chapter 10 of *Critical Issues for Contaminated Sediment Management* (Apitz et al., 2002).

Bioaccumulation also can be estimated through the collection and analysis of organisms living at the site. The advantage of this method is that it provides a snapshot of potential bioavailability and uptake under actual site conditions and avoids the potential introduction of laboratory artifacts (Lee, 1992). However, it is often difficult to link these data to site-specific chemical concentrations, particularly with more mobile species such as lobsters, crabs, or fish that may be exposed at multiple locations (Lee, 1992). In addition, at some locations it may be difficult to obtain sufficient tissue mass for the desired chemical analyses.

The most important points regarding data collection to evaluate bioaccumulation are summarized in Highlight 3-6.

Highlight 3-6. Bioaccumulation Summary

- Well-established, standard laboratory bioaccumulation tests designed for dredged material evaluations can be used although study design should be modified as appropriate for sediment risk assessments
- In situ studies using animals deployed in cages may produce cost savings and more relevant data than standard laboratory tests
- COPCs measured in bioaccumulation studies should be limited to those that are known to bioaccumulate

3.1.2.3.5 Benthic Community Characterization

Another method that can be used to evaluate ecosystem health is the assessment of the resident benthic community attributes. This evaluation most often involves comparison of benthic community attributes at the site versus a suitable reference area. Common attributes used to assess benthic community health include species diversity, abundance, biomass, and key indicator species abundance. Benthic community characterization studies should be designed, conducted, and evaluated by an experienced benthic biologist because of numerous potential problems in selection of appropriate reference sites and community attributes, as well as interpretation of results.

Benthic community attributes are influenced by a number of factors in addition to site COPCs, including food availability, water quality (e.g., salinity, light, temperature, dissolved oxygen, depth), sediment grain-size distribution and TOC content, seasonal cycles and predation. Therefore, community metrics should be used in sediment investigations only when it is possible to distinguish COPC-related impacts to the community from other confounding factors. Additionally, decision criteria should be determined in advance in order to clarify how the results will be used to assess risk.

Benthic community collection and analysis methods can be found in the following documents:

- *Coastal 2000 - Northeast Component: Field Operations Manual* (Strobel, 2001; http://www.epa.gov/emap/nca/html/docs/c2kfm.html); and,
- *Recommended Protocols for Sampling and Analyzing Subtidal Benthic Macroinvertebrate Assemblages in Puget Sound* (U.S. EPA, 1987b; (http://www.wa.gov/puget_sound/Publications/protocols/protocol_pdfs/benthos.pdf).

The most important aspects of benthic community analysis are summarized in Highlight 3-7. Data pertaining to the benthic community structure are often combined with the results of analytical chemistry evaluations and toxicity bioassays in an approach referred to as the sediment quality triad (Chapman, 1986; Chapman et al., 1997) as discussed in Section 3.1.2.3.3.

3.1.2.4 Step 5: Verification of Field Sampling Design

Sediment site assessments often require relatively complex field and analytical programs. Step 5 of the BERA provides for verification of field efforts, especially those that may fail DQOs

established in Step 4 of the BERA. In other words, the feasibility and suitability of the proposed study design is first confirmed under Step 5 to minimize cost, time, and effort associated with data collection, as well as to avoid generation of unusable data. The most common program elements that should be verified or addressed are:

- Site conditions and sampling gear – e.g., can the samples be collected?
- Confounding factors – e.g., will bioassays fail because of noncontaminant effects

Highlight 3-7. Benthic Community Summary

- Select appropriate reference area that matches the physical characteristics of the site
- Consult with an experienced benthic biologist to develop a technically sound study design
- Consider factors other than COPCs that may impact community parameters (e.g., site physical and physico-chemical characteristics, seasonal variations)
- Use standardized collection and taxonomic methods to ensure comparability with historical or local data

(grain size, ammonia, sulfides)?

- Will nonstandard tests meet DQOs – e.g., will in situ bioassays work?
- Does the sample design meet power assumptions – e.g., are a sufficient number of samples being collected?
- Will the contract laboratories meet DQOs – e.g., will matrix interferences compromise chemistry results?
- Is the reference site appropriate—e.g., will physical or chemical differences between the site and reference affect results?

Methods used to verify these elements will vary. For relatively small sampling programs, verification may be limited to a thorough technical review of the Field Sampling and Analytical Work Plan. For larger programs, it may be appropriate to conduct additional site visits or preliminary sampling using rapid sediment characterization methods to ensure that the sampling plan adequately addresses the nature and extent of contamination, or in the case of biological samples, that sufficient numbers of organisms are present.

3.1.2.5 Step 6: Implementation of Field Sampling Design

The process of executing the BERA Field Sampling Design (Step 6) at sediment sites parallels that of the process at terrestrial sites. Execution of this step, including work products, SMDPs, exit strategies, and risk communication, are detailed in Navy and U.S. EPA guidance (see High

light 1-1). Sediment site case studies representing example work products for this step can be found at http://web.ead.anl.gov/ecorisk/case/.

3.1.2.6 Step 7: Risk Characterization

The risk characterization provides an integration of all data and results into one or more conclusions about the risks to the assessment endpoints. It includes three components: (1) a risk estimate; (2) a determination of ecological significance and risk acceptability; and (3) an uncertainty analysis. The uncertainty assessment should include a qualitative discussion of all COPCs that could not be evaluated quantitatively due to lack of benchmark or toxicity values. In general, this process is the same at sediment sites as at terrestrial sites and should follow the guidance provided for ecological risk assessments (U.S. EPA, 1992; 1998c). For most sediment sites, the risk characterization will involve interpreting and integrating the results associated with multiple assessment and measurement endpoints, a potentially complex process. Examples of methods for doing this include the sediment quality triad approach (Chapman, 1992; Long and Chapman, 1985) as well as WOE or lines of evidence approaches (e.g., Menzie et al., 1996). See Appendix E (San Diego, CA, North Island – Site 1 RI Report) for examples of WOE approaches used in sediment BERAs. For upper trophic level species, dose estimates typically are derived and compared to TRVs. A variety of sources exist that either provide estimated TRVs for selected species and chemicals (DON, 1998; Sample et al., 1996) or guidance for developing them (Sample et al., 1996; http://chppm-www.apgea.army.mil/erawg/tox/). As part of the risk characterization, the data collected in Step 6 should be thoroughly reviewed to ensure that it meets the DQO requirements outlined in Step 4 and is of sufficient quality for the investigation.

3.1.2.7 Step 8: Remedial Action Alternatives

The evaluation of remedial action alternatives at sediment sites is discussed in Section 4.0. Based on the results of the risk characterization, a risk management decision is made regarding whether remedial action is required at the site. All risk management decisions should be discussed and agreed to with the appropriate regulators prior to proceeding with the evaluation of remedial alternatives. A site is determined to pose no unacceptable risk if HQs for all pathways evaluated are less than 1. However, depending on site conditions and discussions with the regulators, a determination of no unacceptable risk also may be made if it is demonstrated that the risks are comparable to background or ambient levels, if the population or community at risk is very limited, or if anticipated future uses indicate that exposures will be reduced or eliminated.

3.2 Human Health Risk Assessment

Similar to the ERA approach, the Navy's HHRA approach consists of three tiers (CNO, 2001; see Highlight 1-1):

- Tier 1: Screening Risk Assessment (SRA)
- Tier 2: Baseline HHRA (BHHRA)
- Tier 3: Evaluation of Remedial Alternatives.

The tiered framework is shown in Figure 3-5. Tier 1 focuses on a review of existing data, the development of a preliminary conceptual site model, and a comparison to conservative, risk-based benchmarks. Tier 2 provides a more detailed assessment of actual exposures, and includes the devel

opment of site-specific risk estimates. Tier 3 focuses on the risk-based evaluation of remedial alternatives (see Section 4.0).

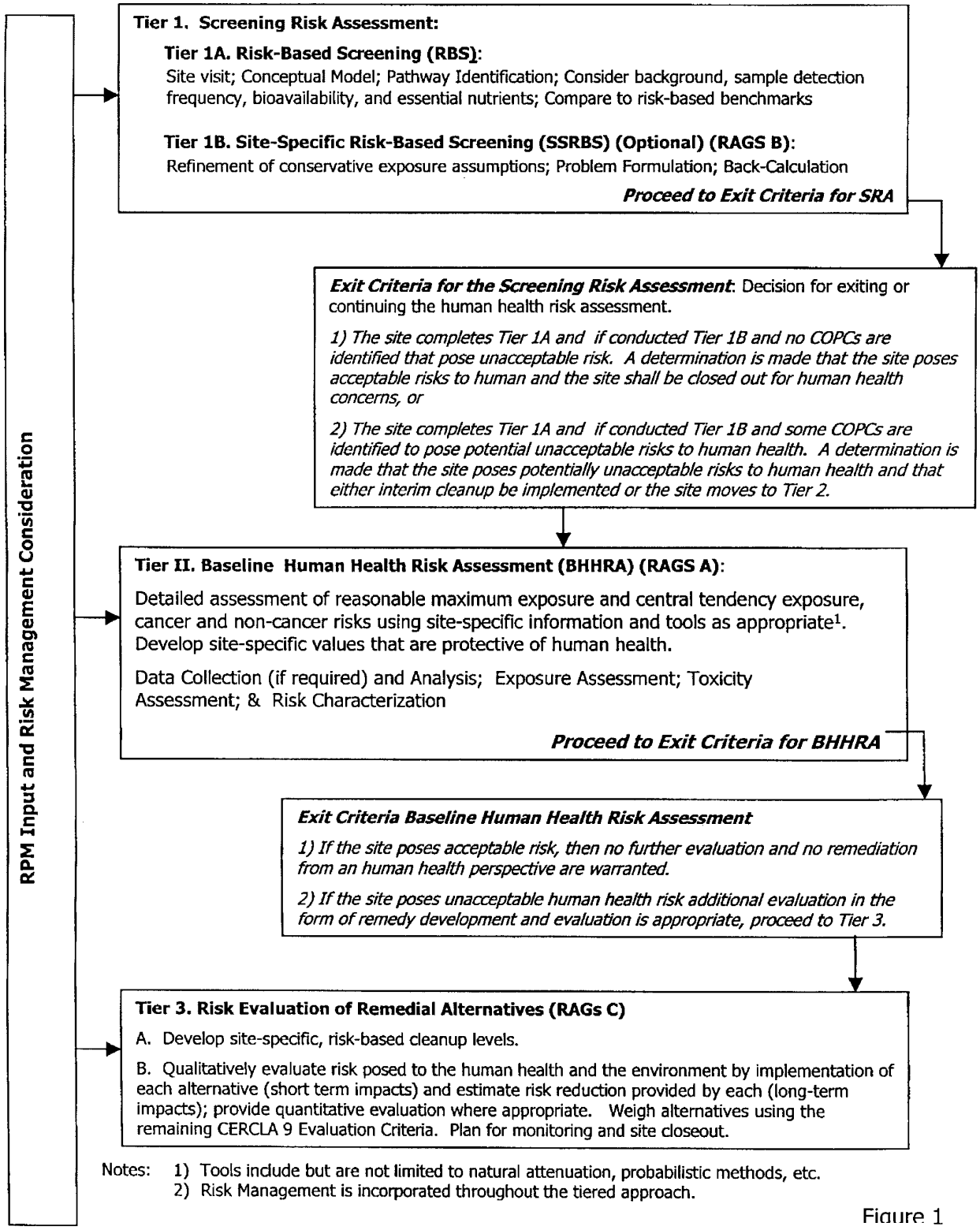


Figure 3-5. Navy Human Health Risk Assessment Tiered Approach

3.2.1 Tier 1: Human Health Screening Risk Assessment

Tier 1 of the Navy's HHRA policy is a risk-based screening step, intended to cost-effectively determine whether a site poses a risk using conservative, default exposure assumptions. The Tier 1 Human Health SRA has two possible components: a risk-based screening evaluation (Tier 1a), and a refinement (Tier 1b) similar to Step 3a of the Navy's ERA process.

Similar to the ERA (Section 3.1.1), the Human Health SRA focuses on existing data gathered and reviewed during the site characterization (Section 2.0). Prior to initiating the human health evaluation, the existing site information should be reviewed to ensure that there is sufficient data to support the risk assessment. See U.S. EPA (1989) for guidance on data evaluation methods. For human health sediment investigations, the key data at this stage are the nature and extent of contamination for the purpose of identifying possible COPCs, and the physical and topographical features at the site that would influence access to sediments and possible site uses under current and future conditions. Access by humans to submerged sediments is usually limited; therefore, it is very important in the site characterization state to identify possible site characteristics or uses that could result in sediment exposures. The following types of information should be considered:

- Type of waterbody (i.e., freshwater or marine, river, estuary, bay);
- Shoreline features and possible access points (e.g., beaches, docks, seawalls);
- Surrounding land use (e.g., industrial, undeveloped, residential) and reasonably foreseeable future land and resource use;
- Bathymetry and sediment substrate;
- Presence or absence of exposed sediments or seeps;
- Presence or absence of suitable habitat for shellfish beds;
- Potential for fishing/shellfishing activities, including by subsistence fishers; and

Based on this information, a CSM is developed as described in the following subsection.

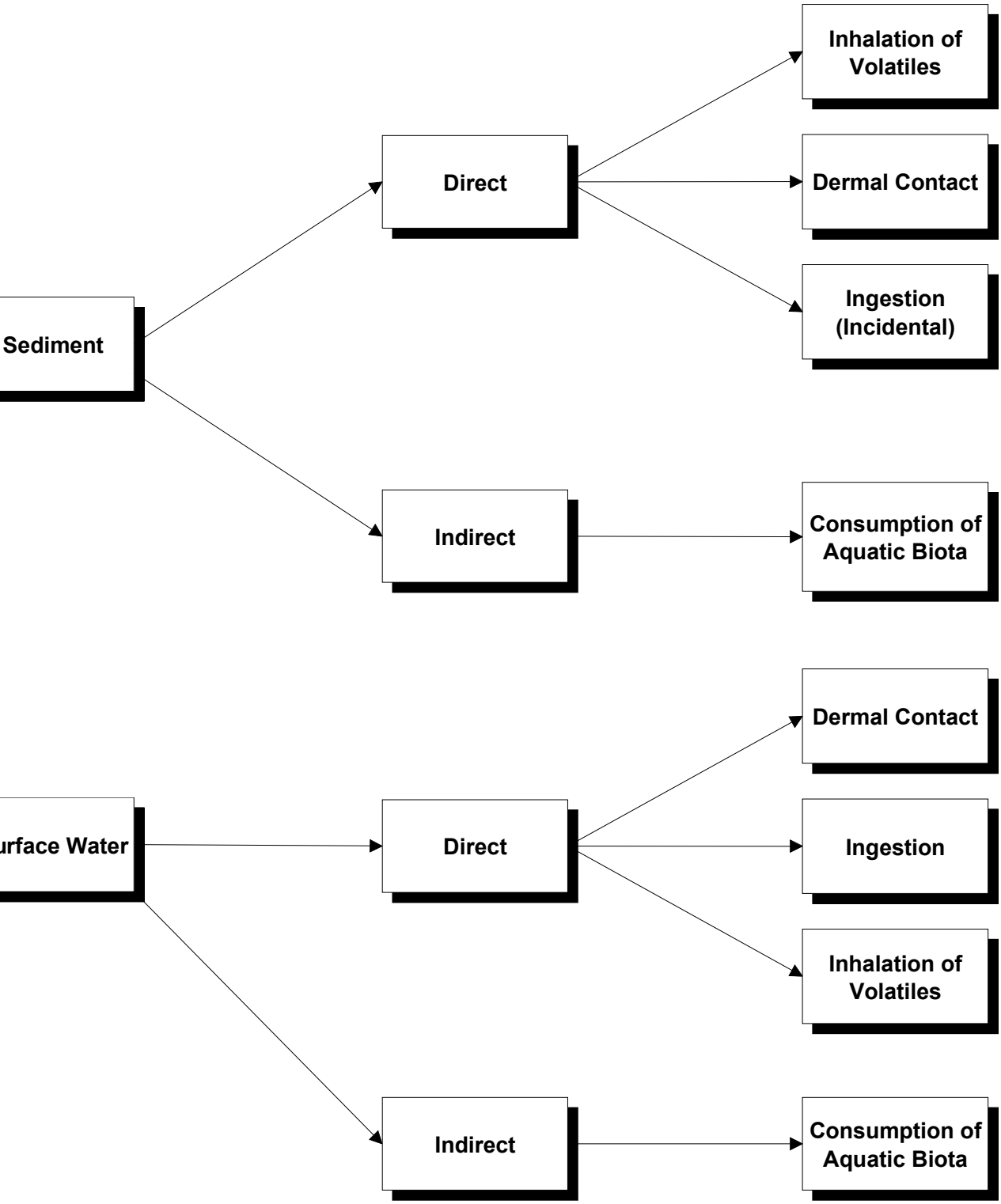
3.2.1.1 Conceptual Site Model

The development of the CSM is a key step in the HHRA process as it identifies the likely COPC source areas, exposure pathways (i.e., direct exposure to sediment, or consumption of biota), and potential human receptors (i.e., expressed as exposure scenarios such as residential user and industrial user). The identification of the COPC source areas, fate and transport mechanisms, and contaminated media are described in Section 2.0. This subsection focuses on identifying complete exposure pathways and potential human receptors. A simplified human health CSM typical of sediment sites is presented in Figure 3-6.

As discussed in Section 3.1.1.2.3, a complete exposure pathway is one in which the COPC(s) can be expected to travel from the source to an identified receptor that can be affected. When select

ing specific exposure pathways, both direct and indirect exposures to sediments should be considered. In general, because sediments are usually submerged, direct exposures to humans (e.g.,

Figure 3-6. Simplified Human Health Conceptual Site Model for Sediments



incidental ingestion, dermal contact) are relatively limited unless there are areas appropriate for recreational activities (e.g., swimming, wading, clam digging), occupational exposures (e.g., mainte

nance of storm drains, underwater pipes, dredging, exposure to seeps) or potential subsistence exposures. These types of activities typically are associated with shallow intertidal areas or exposed mudflats; however, potential exposures also should be considered in areas where docks may be used for either swimming or boating due to the potential for chemicals to partition into the water column. As discussed for ecological receptors, exposures to sediment-associated contaminants via surface water are likely to be very minimal, particularly with persistent, hydrophobic chemicals, which tend to remain bound to sediment. Residential exposure pathways (e.g., gardening, day care) are not relevant to the evaluation of sediment exposures. However, possible exposure to floodplain soils should be considered as part of any on-shore evaluation.

The type of water body at the site will have a significant influence on the likely exposure scenarios and pathways. For example, recreational activities associated with a harbor or bay will differ from those associated with a marshy estuary or shallow stream. The surrounding land use also should be considered. For example, the potential for recreational exposures within a highly industrialized and developed area is different than for a relatively pristine environment, although these conditions may not deter subsistence fishing. Similarly, the presence of residential neighborhoods or day cares also should be considered when selecting pathways for evaluation as well as the exposure parameters used. In addition, possible future uses of the site, as defined by community input, site documentation and proposed site use plans, and surrounding land use should be considered.

3.2.1.2 Evaluation of Data Quality and Comparison to Background

As discussed in the Navy HHRA policy, the available analytical data should be evaluated to ensure that the DQOs for the site have been achieved. The key DQOs for the risk-based screening are as follows:

- Data Quality—The data should be collected in manner that provides a basis for remedial decision-making.

- Site Characterization—Sufficient data are necessary to adequately characterize the site spatially and at likely exposure points. To evaluate human exposures at sediment sites, it also is necessary to ensure that sufficient samples are collected in areas where exposures are likely to occur. For example, sediment concentrations associated with submerged, offshore areas should not be used to evaluate direct exposures to humans (i.e., dermal contact, incidental ingestion) although they could be used to estimate potential indirect exposures via consumption of biota (i.e., through the use of bioaccumulation modeling to estimate tissue concentrations in organisms consumed by humans).

- Analytical Detection Limits—It is important that analytical detection and quantitation limits are below the risk-based concentrations that will be used to identify potential risks.

Once the data have been determined to be of sufficient quality, sediment concentrations should be compared to available background concentrations per the Navy's *Policy on the Use of Background Chemical Levels* (CNO, 2000; see Highlight 1-1). The definition of background is provided in Section 3.1.2.1. HHRAs should not be conducted on chemicals that are present at levels less than background chemical levels (i.e., anthropogenic or naturally occurring levels).

The Navy's background policy (CNO, 2000; see Highlight 1-1) provides guidance on how to bring background issues into the process. This policy emphasizes the need to differentiate background contamination from site releases in the Navy IR programs. Background levels typically are based on data collected during the site investigation regarding ambient conditions. However, consultation with the relevant regulatory agencies regarding the appropriate estimation of background is recommended early in the process.

All chemicals determined to be present below background levels should be eliminated from this evaluation, and those that exceed will be retained as COPCs. However, any potential risks associated with the eliminated chemicals will be discussed in the risk characterization section. The purpose of this process is to focus the investigation on those COPCs that are related to site activities such that incremental risks associated with Navy activities are quantified.

3.2.1.3 Tier 1a: Risk-Based Screening

For the purpose of the Tier 1a evaluation, COPCs (i.e., chemicals for which maximum detected concentrations from the site which exceed background concentrations) are compared to conservative, risk-based concentrations (RBCs). RBCs are defined as chemical concentrations in the affected media (i.e., sediment) that are considered protective of human health. They are determined using standard risk equations rearranged to solve for the media concentration rather than risk. For Tier 1a, conservative, default exposure parameters and risk levels (i.e., 1×10^{-6} cancer risk and an hazard quotient of 1) are used to estimate the RBC. Similar to the background comparison in the ERA, this step is likely to be associated with high false-positive errors.

COPCs for which the maximum detected concentration is below the associated RBC are eliminated from the evaluation; if all COPCs are below the RBCs, the site may be determined to pose no unacceptable risk and the investigation concluded prior to Tier 2. However, those COPCs that exceed RBCs are retained for further evaluation in Tier 1b or Tier 2, as appropriate. Alternatively, if exceptionally high, localized concentrations of chemicals are observed, the best management strategy may be to perform a hot spot removal, lowering the overall site risk.

When selecting an RBC for use in Tier 1a, it is important to ensure that the exposure assumptions used to develop the screening value match the exposure scenario at the site. For example, RBCs based on industrial scenario assumptions should not be used to evaluate residential exposure scenarios if values derived using more appropriate exposure assumptions are available. However, most available RBCs have been developed using either industrial or residential exposure assumptions, rather than the recreational exposures that are most applicable to sediment sites. Therefore, use of these values may represent a very conservative evaluation of sediment exposures. In addition, very few RBCs have been established specifically for sediments. In place of sediment-specific values, guidelines developed for soil are frequently applied. Primary direct exposure pathways for sediments and soils are similar (i.e., dermal contact, incidental ingestion). However, a certain amount of uncertainty is associated with applying soil values to evaluate contaminated sediments due to the physical and chemical differences between soils and sediments and the potential affect they may have on the bioavailability of chemicals, particularly with respect to dermal contact. In addition, soil guidelines may not be protective of exposure associated with bioaccumulation and consumption of biota. As discussed for the ecological SRA, potentially bioaccumulative chemicals should not be completely eliminated from the evaluation based solely on comparison to screening values, although it may be possible to eliminate pathways such as direct contact or incidental ingestion. These and other related concerns should be discussed with the appropriate regulatory agencies prior to using an RBC.

Soil RBCs may be considered as a screening tool in Tier 1. Examples can be obtained from the following sources:

- U.S. EPA Region 3 Risk-Based Concentration Table (U.S. EPA, 1993a; http://www.epa.gov/reg3hwmd/risk/index.htm)
- U.S. EPA Region 6 Human Health Medium-Specific Screening Levels (U.S. EPA, 2000d; http://www.epa.gov/earth1r6/6pd/rcra_c/pd-n/screen.htm)
- Supplemental Guidance for Developing Soil Screening Levels for Superfund Sites (Peer Review Draft; U.S. EPA, 2001c; http://www.epa.gov/superfund/resources/soil/index.htm)
- U.S. EPA Region 9 Preliminary Remediation Goals (U.S. EPA, 2001a; http://www.epa.gov/region09/waste/sfund/prg/index.htm)

If these established RBC values are not appropriate for the specific situation, or if site data exceeds the RBC, then site-specific and sediment-specific RBCs may be calculated in Tier 1b.

3.2.1.4 Tier 1b: Refinement of Risk-Based Screening

The Tier 1b risk-based evaluation has the same general objective as Tier 1a except that more realistic RBCs are calculated in place of conservative, default RBCs, by using site-specific exposure assumptions to evaluate the COPCs retained following Tier 1a. Guidance on developing site-specific RBCs is provided in the following sources:

- U.S. EPA Region 3 Risk-Based Concentration Table (U.S. EPA, 1993; http://www.epa.gov/reg3hwmd/risk/index.htm)
- U.S. EPA Region 6 Human Health Medium-Specific Screening Levels (U.S. EPA, 2000d; http://www.epa.gov/earth1r6/6pd/rcra_c/pd-n/screen.htm)
- Supplemental Guidance for Developing Soil Screening Levels for Superfund Sites (Peer Review Draft; U.S. EPA, 2001c; http://www.epa.gov/superfund/resources/soil/index.htm)
- U.S. EPA Region 9 Preliminary Remediation Goals (U.S. EPA, 2001a; http://www.epa.gov/region09/waste/sfund/prg/index.htm)
- U.S. EPA Risk Assessment Guidance for Superfund. Volume I, Human Health Evaluation Manual, Part B: Development of Risk-Based Preliminary Remediation Goals (U.S. EPA, 1991; http://www.epa.gov/superfund/programs/risk/ragsb/index.htm)
- Navy guidance for conducting human health risk assessments (http://www-nehc.med.navy.mil/HHRA/index.htm).

One source of information on the ranges of values available for various exposure parameters is the *Exposure Factors Handbook* (U.S. EPA, 1998b). This document provides detailed information on general exposure parameters regarding dermal contact and incidental ingestion. Regional or local

data also may be considered, especially for parameters that may vary widely depending on socio-economic factors or regional customs, such as fish consumption rates.

3.2.2 Tier 2: Baseline Human Health Risk Assessment

The Tier 2 BHHRA is intended to be a more rigorous evaluation than the Tier 1 site assessment. Rather than relying on conservative assumptions and comparison to RBCs, Tier 2 incorporates as much site-specific information as possible to calculate risk estimates.

3.2.2.1 Refinement of Conceptual Site Model and Exposure Assumptions

To ensure that Tier 2 reflects an evaluation of realistic exposures at the site, assumptions used to identify relevant exposure scenarios and develop exposure parameters should be carefully reviewed in light of known activities at the site, and adjusted if necessary. For example, if a recreational user is identified as the primary receptor of concern but additional investigation reveals that access to existing beach, dock, and waterfront areas at the site is severely restricted, the CSM and associated exposure parameters should be modified accordingly. Also, additional data collection may be beneficial to fully characterize the nature and extent of contamination.

Initial data collection frequently focuses on identifying sources or hot spots; however, for the purpose of the Tier 2 assessment, it is important to ensure that actual areas of potential exposure as well as all media of concern are accurately represented (U.S. EPA, 1989). Some of the bioassays discussed in Section 3.1.2.3.3 also may provide useful information for the HHRA, specifically the bioaccumulation tests for determining the bioavailability and update of site COPCs. In addition, collection of site-specific fish and shellfish tissue may be useful to reduce uncertainty if it is determined to be a dominant exposure pathway. As discussed in Highlight 3-8, the evaluation of fish should be carefully considered and discussed with the regulatory agencies, particularly if other sources of site COPC exist in the vicinity of the site or the fish species in question are highly mobile. It is very difficult to link measured tissue concentrations with site-specific sediments in species that may be exposed to a variety of different areas, making this data difficult to interpret. Under these conditions, it may be useful to compare concentrations of COPC in fish collected from the vicinity of the site with concentrations measured in fish from other locations representing ambient conditions. In addition, at sites where exposures associated with consumption of fish or other aquatic biota are driving the risk evaluation, it may be worthwhile to consider conducting surveys to derive a site-specific fish consumption rate. Individual fish consumption rates have been shown to vary dramatically by region, as well as by ethnic and socioeconomic group (U.S. EPA, 1998d). As a result, it is critical to ensure that the fish consumption rate selected accurately reflects the exposed populations. As summarized by U.S. EPA (1998d), a wide variety of possible survey methods are available (see Highlight 3-9) many of which can be applied to determine site-specific parameters to describe other activities as well. In addition, the *Exposure Factors Handbook* (U.S. EPA, 1998b) provides a discussion of the range of possible values that may be considered for each exposure parameter.

Generally, most risk assessments employ a deterministic or point estimate approach, relying on a single assumption to select each of the parameter values required in the assessment (e.g., fish consumption rate, exposure duration). Although most risk assessments include a combination of central tendency and high-end values to provide a range of risk estimates, such an approach does not capture the wide array of possible exposure situations due to its dependence on specific assumptions regarding each exposure parameter. In a majority of the cases, the recommended

Highlight 3-8. Factors to Consider When Collecting or Evaluating Fish Tissue Residues

Analytical Methods and Detection Limits

Prior to the analysis of contaminated fish tissue, detection limits for the selected analytical methods should be reviewed to ensure they provide levels that are, at a minimum, adequate for subsequent risk evaluations.

Fish Tissue Data Collection and Reporting

When evaluating and reporting residues of COPCs in fish tissues, it is important to note various factors, such as whether the sample originated from whole fish (i.e. whole tissue) or fillet-only samples and how the data were reported with regard to lipid content (U.S. EPA, 1987a). These kinds of issues inevitably introduce variability into monitoring data that must be addressed in order to provide realistic assessment of exposure point concentrations and exposure doses, and should be taken into account when determining a COPC concentration in fish tissue that is representative of consumption for a particular area. For example, using fillet-only data may under estimate risks to populations that consume the whole fish, whereas using whole body data may over estimate risks to those who consume only the fillet.

Fish Preparation and Cooking Methods

Fish tissue residue levels may also be affected by pre-consumption activities such as preparation and cooking. Preparation that removes skin and fat from filets may reduce the levels of fat-soluble (i.e., lipophilic) compounds such as PCBs. In addition, heat from various cooking methods may cause a change in the concentration of some compounds via physical processes like volatilization, chemical transformations, and mobilization and loss in lipid and water byproducts. Consideration of these factors is useful in an uncertainty analysis of individual risks.

Home Ranges

Species with large ranges may contact COPCs in other contaminated areas that are not associated with the current investigation. The larger the area under investigation, the greater the probability that a given species may contact a site-specific COPC. When conducting site-specific risk assessments, it is important to evaluate the uncertainties regarding whether concentrations for specific COPCs reported in fish tissues are representative of COPCs that may actually be consumed from an area.

exposure factors are protective of 95% of the population. As a result, a high degree of conservatism can be associated with the results when these factors are used concurrently. An alternative to the deterministic model is the application of a probabilistic model such as a Monte Carlo analysis. Probabilistic assessments

Highlight 3-9. Fish Consumption Survey Options

If consumption of sport fish or shellfish species is identified as a potential pathway of concern at a site, one option for addressing potential risks is to evaluate the actual use of the site by recreational or subsistence anglers. Information obtained from such surveys can be used to refine exposure parameters such as fraction ingested and ingestion rate.

The primary types of surveys typically conducted are on-site interviews and telephone surveys. Each of these can be conducted with local angler populations to better understand the typical exposures and consumption patterns for an area. The following types of information can be collected from site-specific angler surveys: demographic characteristics; fishing patterns; species targeted; number of fish caught; fish consumption patterns; the extent to which resident fish were used as food; the method of preparation of the fish to be consumed; and weights and lengths of fish caught by species.

A more detailed description of the methods to be used for conducting fish consumption surveys can be found in the U.S. EPA document *Guidance for Conducting Fish and Wildlife Consumption Surveys* (U.S. EPA, 1998d).

rely on a distribution of data for selected input parameters rather than a single point estimate. U.S. EPA has established protocols for the application of probabilistic analyses (U.S. EPA, 1997; 2001d; http://www.epa.gov/ncea/mcpolicy.htm). However, although probabilistic assessments potentially are useful for characterizing the uncertainty associated with exposures at more complex sites, they require a much larger effort than deterministic models and are often not warranted. In addition, many local, regional, and state regulatory agencies have specific requirements regarding the application of probabilistic methods, and should be consulted prior to initiating a probabilistic assessment. In practice, only a few local agencies have policies for accepting Monte Carlo risk assessment as part of a Tier 2 evaluation.

3.2.2.2 Toxicity Assessment

The toxicity assessment determines the relationship between the magnitude of exposure to a chemical and the nature and magnitude of adverse health effects that may result from such exposure. In human health risk assessment, contaminants are classified into two broad categories: noncarcinogens and carcinogens. Toxicity studies with laboratory animals or epidemiological studies of human populations provide the data used to develop toxicity criteria. Carcinogens are agents that induce cancer and numerical estimates of cancer potency are represented by cancer slope factors (CSFs). Noncarcinogenic effects are evaluated using reference doses (RfDs) and reference concentrations (RfCs) that are thresholds at which toxic effects are not exhibited. CSFs and RfDs can be found at U.S. EPA's Integrated Risk Information System Web site (http://www.epa.gov/IRIS/subst/index.html); individual regions also should be contacted for regional- or state-recommended factors. However, depending on the lead agency, federally approved toxicity values may be preferred at federal/Superfund sites over these other values. Additional guidance for selecting human toxicity factors is provided by USACE (http://www.usace.army.mil/inet/usace-docs/eng-pamphlets/ep200-1-15) and ATSDR (http://www.atsdr.cdc.gov/toxpro2.html).

Chemicals may be present at some sites for which an RfDs and/or CSF are not available. Although these chemicals cannot be evaluated quantitatively in the absence of RfDs and/or CSFs, they should be retained for a more qualitative evaluation. The appropriate regulators should be consulted regarding how to address these chemicals, and a summary of all chemicals of concern that could not be included in the quantitative evaluation should be provided in the uncertainty analysis.

3.2.2.3 Risk Characterization

The outcome of the Tier 2 BHHRA is individual and cumulative cancer and noncancer risk estimates for current and potential future use scenarios. The exit criteria for the Tier 2 BHHRA are defined as follows:

1. All individual and cumulative cancer and noncancer risks are determined to be within acceptable ranges for all COPCs, therefore, no further action or remediation for human health considerations are warranted; or

2. Individual or cumulative cancer or noncancer risks are found to be above acceptable ranges for one or more COPCs; therefore, development and evaluation of preliminary remediation goals and remedial alternatives is appropriate and the investigation proceeds to Tier 3, Evaluation of Remedial Alternatives (see Section 4.0 of this document).

For noncarcinogenic effects, hazard quotients are summed and compared to an acceptable hazard index of 1. U.S. EPA uses the risk range of 1×10^{-6} to 1×10^{-4} as a "target range" when managing risks at Superfund sites, although U.S. EPA has expressed a preference for achieving the goal of 1×10^{-6} for cleanups (http://www.epa.gov/superfund/programs/risk/baseline.pdf). However, site-specific or remedy-specific factors, including but not limited to exposure factors, uncertainty factors, and technical factors, may be taken into consideration on a site-by-site basis (NCP Preamble 8717, FR55 No. 26, March 8, 1990). Therefore, the appropriate regulatory agencies should be consulted regarding the acceptable risk range for a particular site and other risk management issues.

4.0 SEDIMENT REMEDIAL ALTERNATIVE EVALUATIONS

This section provides guidance for conducting an FS for a Navy sediment site. According to Navy policy, Tier 3 of the ecological and human health risk assessments is conducted during the FS (CNO, 1999 and 2001; see Highlight 1-1). Tier 3 is the evaluation of remedial alternatives with respect to the following:

- The effectiveness of reducing risk to acceptable levels;
- Ecological impacts related to remedy implementation; and
- Residual risks.

Sediment-specific issues associated with the Tier 3 evaluation are discussed in this section. As with terrestrial sites, Tier 3 and the FS for sediment sites focuses on the nine evaluation criteria for the selection of a remedy outlined in the National Oil and Hazardous Substances Pollution Contingency Plan (NCP) (U.S. EPA, 1988; http://www.epa.gov/oerrpage/superfund/whatissf/sfproces/rifs/analys.htm).

Highlight 4-1 summarizes some of the challenges associated with the selection and implementation of a remedy for a sediment site. Comparatively few treatment technologies have been applied at sediment sites to date, although contaminated sediment remediation is a rapidly evolving field. This guide does not provide a comprehensive discussion of remedial alternatives for sediments; rather, it presents and discusses the major technical and management issues and provides references for supporting detailed technical information. This section addresses planning considerations, determination of the volume of sediment requiring cleanup, remedial alternative selection, monitoring considerations, and management of sediments in areas requiring maintenance dredging.

Highlight 4-1. Challenges Associated with Sediment Remediation

- There are no presumptive remedies for contaminated sediments
- It can be difficult to develop meaningful and realistic cleanup goals and verify that they have been achieved
- Overlying water poses logistical challenges to active remediation (e.g., difficulties in isolating target area, lack of visibility, interference by currents and waves, difficulties controlling contaminant release during cleanup)
- Little long-term data currently are available on the effectiveness of remedies

4.1 PLANNING CONSIDERATIONS

Prior to initiating the FS, the RPM should consider several issues that will influence the overall approach to the management of a sediment site. These issues include the status of source identification and source control, the potential for implementation of a regional management strategy or remedy, potential reuse issues, and identification of potential ARARs, and are discussed in the following subsections.

4.1.1 Status and Implications of Source Control

Identification and control of the contaminant input sources to sediments are critical (see Section 2.2 for further discussion of source identification). Contaminant sources must be identified and ideally should be eliminated or controlled prior to remediation in order to ensure that a sediment site will not be recontaminated. If environmental investigations are ongoing in adjacent upland areas, then onshore activities should be monitored to ensure that the current status of source identification and control is known. However, complete source control for sediment sites may be impractical because of the wide variety of potential point and nonpoint sources to the water body. If any of the sources cannot be eliminated or controlled, then the contaminant load from the source should be estimated to evaluate whether the site is likely to be recontaminated above established cleanup levels before any action is taken.

4.1.2 Potential Advantages of a Regional Approach

If sediment cleanup is likely to be required at multiple Navy installations in close proximity on the same water body or its tributaries, a regional remedy should be considered, or, at a minimum, the FS evaluations for individual installations should be coordinated. If a proposed regional or watershed approach includes non-Navy parties, then CNO approval must be obtained prior to Navy participation as specified in the *Policy on Sediment Site Investigation and Response Action* (CNO, 2002; see Highlight 1-1). A regional remedy or coordinated FS evaluation has several potential advantages over a series of independent, site-specific actions (see Highlight 4-2). Some of the key issues and factors that will influence the feasibility of a regional approach are summarized below in Highlight 4-2 and also should be taken into consideration.

Highlight 4-2. Should a Regional Approach to Sediment Management Be Adopted?

Potential Advantages

- Local impacts may be minimized and more easily managed (e.g., one dewatering and pretreatment facility could be constructed and operated in the most optimal location)
- Contractor mobilization costs should be reduced
- Coordinated resolution of issues associated with sediment management at all installations within a region will more effectively utilize Navy and stakeholder resources
- Data sharing, especially background and reference site data

Potential Disadvantages

- Potential permitting and legal issues associated with consolidation or disposal of sediments from multiple installations at one site would need to be identified and resolved. The need to obtain permits would significantly reduce the viability of any remedy under CERLCA
- Reconciliation of disparate schedules for completing assessment and remediation activities at various installations

The successful implementation of a regional remedy for contaminated sediments from multiple Navy installations will rely in part on consensus among all stakeholders (the Navy, regulators, other trustees, and the public) that the regional remedy is preferable to a series of independent actions. However, the local community near a proposed disposal site on a Navy base may oppose acceptance of contaminated sediments from other facilities. A process for public involvement in the development of a regional remedy should be developed to identify critical issues, facilitate consensus, and formulate alternatives that will be successful. Ideally, installations within a region should have coincident project schedules so that the FS evaluation can be conducted concurrently.

4.1.3 Consideration of Anticipated Future Land Use

In many instances, the anticipated future use of a sediment site will influence the selection of the final remedy. A proposed remedy may not be acceptable to the installation, state, or community if it is clearly incompatible with the future use of the site. For example, in situ capping or natural recovery is not likely to be accepted for a site where future dredging or construction is anticipated. Identification of possible future site uses should take place during the FS scoping process in consultation with regulatory agencies and other stakeholders.

4.1.4 Identification of Potential ARARs

Potential ARARs should be discussed with federal and state regulatory agencies and documented in the FS report for the site. Generally, the identification of potential chemical-specific and location-specific ARARs begins during the RI data collection effort and the potential action-specific ARARs are identified during the development of the remedial alternatives. Currently there are no federal chemical-specific ARARs for sediments, although some states (e.g., Washington) have promulgated sediment management standards.

The Total Maximum Daily Load (TMDL) program may present a potential issue for contaminated sediment sites and its potential applicability should be investigated while planning the FS. Under Section 303(d) of the Clean Water Act, states are required to identify impaired water bodies that do not meet applicable water quality criteria and develop TMDLs for these water bodies. The TMDL is the maximum amount of a pollutant that a water body can receive and still meet water quality standards, and allocates pollutant loadings among point and nonpoint pollutant sources (http://www.epa.gov/owow/tmdl/intro.html).

A list of potential federal ARARs for sediment sites is provided in Table 4-1. A comprehensive list of ARARs is beyond the scope of this document; however, additional information should be available from legal counsel. Additional legislative requirements are discussed under the National Response Center Web site at http://www.nrc.uscg.mil/nrclegal.htm, including the NCP (at http://www.epa.gov/oilspill/ncpover.htm), Hazardous Materials Transportation Act (HMTA), United States Department of Transportation (DOT) Regulations, and Executive Orders relating to the regulation of environmental activities. Other sources of information if the sediment site has a dredging component are the USACE "Green Book" (U.S. EPA/USACE, 1991) and *Inland Testing Manual* (U.S. EPA/USACE, 1998) (see Section 1.4).

Table 4-1. Potential Federal ARARs for Sediment Sites

Regulatory Requirement	Purpose/Requirement	Applicability to Remedial Action	Citation
Potential Chemical-Specific ARARs			
National Recommended Water Quality Criteria (WQC)	CWA Section 304 requires the U.S. EPA to publish water quality criteria. WQC have been developed by U.S. EPA's Office of Water and are published in the guidance document *Water Quality Standards Handbook* and subsequent revisions.	Remedial action objectives and remedial actions should be consistent with WQC.	33 USC §1314 National Recommended Water Quality Criteria and *Water Quality Standards Handbook* (U.S. EPA, 1994)
National Toxic Rule (NTR)	NTR established water quality standards for states that had failed to adopt their own standards.	If applicable, remedial action objectives and remedial actions should be consistent with standards in the NTR.	57 FR 60848 60 FR 22229
Potential Location-Specific ARARs			
Endangered Species Act	Requires that any proposed work avoid, minimize, or compensate for impacts to endangered or threatened species and critical habitats.	Listed endangered and threatened species, as well as candidate species for listing, may exist at or in the vicinity of offshore sediment.	16 USC §1531 et seq.; 50 CFR Part 216 and Part 402
Marine Mammal Protection Act	Requires that activities avoid, minimize, or compensate for impacts to marine mammals and their habitats	Marine mammals may exist at or in the vicinity of offshore sediments.	16 USC §1361 et seq.
Federal Fish and Wildlife Conservation Act	Requires that activities avoid, minimize, or compensate for impacts to fish and wildlife and their habitats	Fish and wildlife may exist at or in the vicinity of offshore sediments.	16 USC §662 et seq.
Coastal Zone Management Act	Requires that activities conducted within a coastal zone be consistent with an approved state management program.	Offshore sediments being investigated are within the coastal zone.	16 USC §1451 et seq.
National Historical Preservation Act of 1966 (NHPA) and Archaeological Resources Protection Act of 1979	Provides for the recovery and preservation of historical and archaeological significant arti-facts. Implementing regulations for NHPA (36 CFR Part 65) establish the National Register of Historic Places and provide for preservation of historic properties and minimization of damage to historic landmarks.	This regulation may be applicable if scientific, prehistoric, or historic artifacts are found at a site during implementation of the selected remedial alternative. Docks, piers, or other structures may meet the eligibility require-ments of the National Register of Historic Places.	NHPA: 16 USC §470; 36 CFR Part 65. Archaeological Resources Protection Act
Potential Action-Specific ARARs			
Resource Conservation and Recovery Act (RCRA)	Hazardous Waste Determination: Provides criteria for determining whether a solid or liquid waste is a RCRA or non-RCRA hazardous waste.	Applicable for determining whether dredged sediment and water from remedial actions must be managed as a hazardous waste (unless dredged material is excluded from testing pursuant to HWIR).	42 U.S.C. 6901 et seq.; HWIR 40 CFR 261.4(g)
	Generator Requirements: Provide general requirements for generators of hazardous wastes.	Generator requirements will be applicable for dredged sediment and water resulting from remedial actions that are considered a hazardous waste.	40 CFR, Part 262, Subparts A through E

Table 4-1. Potential Federal ARARs for Sediment Sites

Regulatory Requirement	Purpose/Requirement	Applicability to Remedial Action	Citation
Resource Conservation and Recovery Act (RCRA) (continued)	Requirements for Corrective Action Management Units and Temporary Units: Provide requirements for on-site treatment and temporary storage of hazardous waste in temporary units and corrective action management units.	Potentially hazardous sediment and water resulting from remedial action may be temporarily stored or treated on site. Remedial activities proposed for offshore sediment may include onshore pretreatment facilities.	40 CFR, Parts 264.552 and 264.553
	Land Disposal Restrictions: Require that the hazardous waste generator determine whether waste is restricted from land disposal.	Land disposal restrictions will need to be complied with in disposing of any dredged sediment or other waste generated from remedial activities that meets the definition of hazardous waste. Wastes may be treated to meet LDR standards prior to disposal.	40 CFR, Part 268.7
Clean Water Act (CWA), Sections 404 and 404(b)(1)	Prohibits unauthorized discharge of dredged or fill material into U.S. waters; promulgates guidelines to evaluate discharge of fill or dredged material into U.S. waters; may require mitigation for impacts, decided on a case-by-case basis.	Substantive requirements are applicable to placement of dredged sediment or other capping material in wetlands or navigable waters.	33 USC 1341, 1344 et seq.; 40 CFR 320.4; 40 CFR Part 230
Marine Protection, Research, and Sanctuaries Act (MPRSA), Sections 102, 103, and 104	Provides criteria for reviewing and evaluating permits for disposal of material in ocean waters. Section 103 authorizes USACE to issue permit subject to concurrence with the U.S. EPA.	Substantive requirements are applicable to dredging and placement of dredged sediment in ocean waters.	MPRSA Section 102,103, and 104
Rivers and Harbors Act, Section 10	Prohibits unauthorized obstruction or alteration of any navigable water of the U.S. and may require mitigation for impacts decided on a case-by-case basis.	Substantive requirements are applicable to dredging and placement of dredged sediment or other capping material in navigable waters.	33 USC 403; 33 CFR Part 322; 33 CFR Part 323; 40 CFR Part 230

CAA = Clean Air Act.
CFR = Code of Federal Regulations.
CWA = Clean Water Act.
FR = Federal Register.
HWIR = Hazardous Waste Identification Rule.
LDR = Land Disposal Restriction.
USC = United States Code.
WQC = Water Quality Criteria.

4.2 DETERMINING EXTENT AND VOLUME OF SEDIMENT TO BE REMEDIATED

Remedial action objectives (RAOs), PRGs, and site-specific cleanup levels are developed in the initial stages of the FS. If the ecological and human health risk assessments conclude that sediment contamination poses an unacceptable risk, then RAOs must be developed that specify the relevant contaminants, exposure pathway(s) and receptor(s) to be protected. The RAOs are the basis for the PRGs, which represent a range of COPC concentrations corresponding to various levels of risk. Examples of RAOs for sediment sites are presented in Highlight 4-3. Depending on the results of the ecological and human health risk assessments, different RAOs and cleanup levels may be required for different areas of the site.

Highlight 4-3. Examples of RAOs for Sediment Sites

- Protection of humans from the consumption of shellfish containing PCBs
- Protection of benthic invertebrates from the direct exposure to lead and cadmium in sediment

4.2.1 Contaminant- and Site-Specific Remediation Goals and Cleanup Levels

As noted in Section 4.1.4, there are no chemical-specific ARARs for sediments at most sites. The *Policy on Sediment Site Investigation and Response Action* (CNO, 2002; see Highlight 1-1) includes the following guidelines for development of cleanup levels for sediments sites:

- Risk-based sediment cleanup levels should be developed using site-specific information;
- The cleanup levels must be risk-based and achievable;
- Ecological screening values (i.e., published benchmark values) must not be used as cleanup levels; and
- Cleanup levels must not be lower than ambient (i.e., background) levels.

Cleanup should be not be conducted to levels that are less than ambient levels because sediments from elsewhere in the water body can be transported to and deposited at the site through natural processes. This would result in a cleanup that effects little or no ecological improvement (http://enviro.nfesc.navy.mil/erb/erb_a/regs_and_policy/don-background-pol.pdf).

PRGs should be clearly tied to the RAOs. Some approaches that can be used by risk assessors to develop remediation goals for sediment are summarized in Highlight 4-4. Ideally, site-specific data will show a correlation between chemical concentrations in sediment and adverse biological effects (e.g., toxicity or bioaccumulation). If this type of relationship can be established, then chemical concentrations that are protective of a given receptor for a given exposure route can be derived. The risk assessors should derive a range of remediation goals associated with various levels of risk for the risk manager to consider. The risk managers then can determine how to best balance risk reduction with technical feasibility, cost-effectiveness, and other considerations in the FS.

Highlight 4-4. Selected Approaches Used to Develop Remediation Goals for Sediment

- Development of a site-specific relationship between chemical concentration and adverse biological effects and identification of concentrations associated with various effects levels (apparent effects thresholds [AETs])
- Utilization of a food chain model to predict sediment concentration that will protect upper trophic level receptors (including humans) from consumption of contaminated prey
- Calculation of sediment concentration that will result in attainment of ambient water quality criteria in the overlying water column (equilibrium partitioning approach)
- Integration of results for multiple lines of evidence into a single indicator value to delineate areas that pose an unacceptable risk and require remediation

Development of remediation goals for individual chemicals may be difficult if the sediments contain a mixture of chemicals that appear to contribute to observed biological effects. In this case, several approaches should be considered: (1) identification of the chemicals that are likely to be the primary risk drivers; (2) selection of an indicator chemical to represent each class of contaminants; or (3) use of a weight-of-evidence approach to identify areas for remediation on a station-by-station basis. The compound or class of compounds responsible for causing toxicity can be investigated through a toxicity identification evaluation (TIE) (U.S. EPA, 1991), in which a sample is physically or chemically divided into various fractions and the toxicity of each fraction is determined. References for further guidance on the development of site-specific, risk-based remediation goals for sediment can be found in Highlight 4-5.

Remediation goals should not necessarily be used directly as site-specific cleanup levels. Each site has a unique and complex set of physical, chemical, biological, political, economic, and regulatory factors that must be taken into consideration by risk managers. Additionally, remediation of all sediments with chemical concentrations exceeding the goals may not be feasible because of financial or technological limitations. Therefore, the development of site-specific cleanup levels should focus on optimal risk reduction using remediation goals as a starting point, and take into consideration site-specific modifying factors that include but are not limited to:

- Pattern of contaminant distribution (i.e., presence of localized hot spots versus large volumes of sediment with relatively uniform contaminant loads);
- Contaminant fate and transport (i.e., potential for natural recovery or sediment resuspension in areas of concern);
- ARARs and other to-be-considered criteria;
- Regional ambient levels of chemicals; and,
- Community or agency concerns.

The Major Contaminated Sediment Sites (MCSS) Database developed by Applied Environmental Management, Inc. and Blasland, Bouck & Lee, Inc. for the General Electric Company (http://www.hudsonvoice.com/mcss/) contains information on sediment cleanup goals and the basis for the goals for more than 60 remediation projects in the United States. An evaluation of the larger projects in the MCSS database found that in many cases either a mass removal approach was adopted or the cleanup target was not clearly tied to the protection of a given endpoint (Cushing, 1999b). In the FS, every effort should be made to develop cleanup levels that are clearly based on and tied to the site-specific risk information.

Highlight 4-5. Further Guidance for Development of Remediation Goals for Sediment

- Example Approach for the Development of Site-Specific Preliminary Remediation Goals for Protection of Ecological and Human Health at Navy Aquatic Sites (http://newweb.ead.anl.gov/ecorisk/issue/pdf/PRGGuideFinal2-14-01.pdf)
- Guidelines for Assessment and Remediation of Contaminated Sediments in San Diego Bay at NASSCO and Southwest Marine Shipyards (California Regional Water Quality Control Board, San Diego Region, June 1, 2001; http://www.swrcb.ca.gov/rwqcb9/programs/shipyards/SWM%2013267%20Letter%20-%20Assessment%20and%20Remediation.pdf)

4.2.2 Consideration of Contamination at Depth

Ecological and human health risk assessments of sediment sites typically focus on biologically available surface sediments. Therefore, the RPM must ensure that the three-dimensional distribution of chemicals also is delineated as part of the site characterization (see Section 2.5). Subsurface chemical concentrations must be measured and the vertical extent of contamination defined in order to accurately complete the FS. If subsurface chemical concentrations are higher than surface concentrations, then the likelihood of erosion and exposure of deeper sediments must be considered in an evaluation of potential in situ remedies. If dredging is under consideration, then the volume of sediment with chemical concentrations above site-specific cleanup levels must be determined to allow calculation of more accurate cost estimates.

4.3 REMEDIAL ALTERNATIVE SELECTION

Currently, a relatively limited number of effective technology options are available for remediating sediment. A common response action for sediments is removal (dredging) followed by disposal. Dredged sediments generally require processing such as dewatering, physical separation, and limited treatment prior to disposal or reuse. Another common response action is in situ isolation of the sediments from the environment, typically by covering the sediment with a sand or gravel cap. Monitored natural recovery involves the processes wherein contaminated sediments are buried (isolated), degraded, transformed, and/or immobilized under natural conditions such that over time the chemical concentrations in the sediment and overlying water are reduced to acceptable levels.

The strengths, weaknesses and other issues associated with the following remedial alternatives for sediment are discussed in this section:

- Monitored natural recovery;
- In situ capping;
- Dredging;
- Disposal options; and,
- Beneficial reuse options.

A summary table is provided in Section 4.3.9 that summarizes the applicability, strengths, weaknesses, and cost and schedule implications for various sediment remediation options. Also, the Sediments Research Web (http://www.sediments.org/) provides additional information and resources regarding the management and remediation of contaminated sediments. U.S. EPA is in the process of preparing a guidance document for contaminated sediment remediation; a draft of the document is expected to be issued in 2003.

4.3.1 Monitored Natural Recovery

Natural recovery involves leaving contaminated sediments in place and allowing natural processes to contain, destroy, or otherwise reduce the bioavailability of the contaminants (NRC, 1997) (http://books.nap.edu/catalog/5292.html). Natural recovery reduces environmental risk through two primary mechanisms: burial of contaminated sediments by cleaner sediments; and sequestration or transformation of contaminants through biological, chemical, or physical processes to less toxic or bioavailable forms. Burial results in natural capping, which inhibits diffusion of contaminants from sediments to the water column, reduces or prevents resuspension of contaminated sediments, and

protects the benthic community from exposure to the contaminants. Natural recovery differs from a No Action alternative because it entails the inherent assumption or conclusion of some level of unacceptable risk and requires ongoing monitoring to verify that risk reduction is occurring. Additionally, institutional controls may be required to protect human health (e.g., through fish consumption advisories) and prevent sediment disturbance during recovery. Monitored natural recovery is most applicable under the following circumstances:

- The human health or ecological threat is not immediate or substantial.
- Contaminant sources are controlled or eliminated.
- The risk from sediment contaminants can be reduced or eliminated in a reasonable length of time.
- The impact of a remedial action is likely to cause greater environmental harm than leaving the contaminated sediments in place.
- The area of concern includes a large volume of sediment with relatively low contaminant concentrations.
- The area of concern is in a depositional environment with a low potential for sediment resuspension.
- The area is not anticipated to be subject to dredging, construction, or other activities that might disrupt the sediment bed.
- Few other technically feasible or affordable options are available.

The primary strengths and weaknesses of monitored natural recovery are summarized in Highlight 4-6.

In many cases, natural recovery relies primarily on sediment burial. Contaminant concentrations in sediments can be reduced or degraded through dilution, dispersion, volatilization, biodegradation, and other processes (U.S. EPA, 1998); however, these processes can be extremely slow in sediments, requiring decades or centuries for contaminant removal. Sediment burial occurs in net depositional environments where the sediment accumulation rate exceeds the erosion rate. However, the progressive burial of contaminated sediment by new, cleaner sediment does not necessarily prevent the dispersion of contaminants because physical and biological processes can mix surface and subsurface sediments, thereby exposing buried sediments at the surface.

Highlight 4-6. Strengths and Weaknesses of Monitored Natural Recovery

Strengths:

- Eliminates environmental damage caused by dredging
- Potentially feasible option for large volumes of sediment with low contaminant concentrations and relatively low risk
- Low cost relative to other remedial options

Weaknesses:

- It is only appropriate if natural recovery mechanisms can be demonstrated
- Natural recovery processes may be very slow and in many cases contaminants are not likely to be removed or destroyed
- Contaminated sediments have the long-term potential to be remobilized by natural or human activity
- Requires long-term monitoring
- Long-term liability remains

Therefore, candidate sites for natural recovery should undergo a detailed site characterization as described in Sections 2.0 to establish sediment accumulation rate, degree of vertical mixing of surface and subsurface sediments, and likelihood and frequency of sediment resuspension and transport away from the site (see Table 2-2). For example, radioisotope profiles (^{210}Pb and ^{137}Cs) of sediment cores can be used to estimate sediment accumulation rate and degree of vertical mixing (Figure 4-1). Contaminant degradation via chemical and biological contaminant transport pathways also should be evaluated. The behavior of the sediment bed when subjected to extreme weather conditions (e.g., severe storms) also should be evaluated.

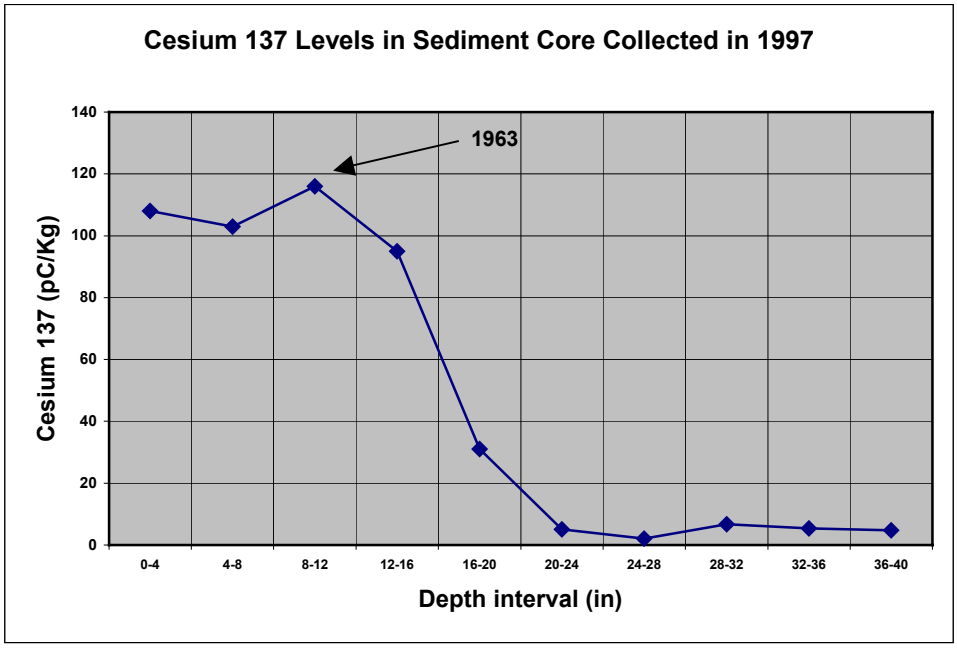


Figure 4-1. ^{137}Cs Activity in Sediment Core Indicates a Sediment Accumulation Rate of 0.3 inch/yr and a Moderate Degree of Vertical Mixing, as Shown by Broad ^{137}Cs Peak

A two-step approach can be used to evaluate the potential for monitored natural recovery at a site. For example, at Hunters Point Shipyard (HPS) in San Francisco, CA, the potential for sediment resuspension initially was evaluated using existing grain size data for surface sediments and readily available wave and current data for South San Francisco Bay (Battelle and Woods Hole Group, 2000). Following the initial evaluation, site-specific data were collected to characterize sediment resuspension and transport patterns around HPS with greater certainty. Time-series measurements of waves, currents, suspended sediment concentrations, temperature, and salinity were collected at three stations for one full tidal cycle using sediment transport measurement systems (STMS). Each STMS included one current meter and turbidity, temperature, conductivity (salinity) and pressure (water depth) sensors. The STMS data were used to estimate the magnitude and direction of suspended sediment flux at each of the stations. Regional sediment transport patterns and areas of net sediment accumulation and erosion were predicted using a regional hydrodynamic and sediment transport model (Woods Hole Group and Battelle, 2002). The regional model also was used to investigate expected sediment resuspension and transport during extreme storm and runoff events. Detailed geologic description of sediment cores, radioisotope profiles and information on benthic fauna also were used to support the characterization of sediment dynamics at HPS.

The paper *Sediment Stability at Contaminated Sediment Sites* (Ziegler, 1999) contains good background information on sediment transport processes and describes a similar two-step approach for estimating scour depth and likelihood of re-exposure and erosion of contaminated subsurface sediments. The first tier involves a relatively simple analysis of sediment stability at a site and can be used as a screening tool. The second tier is a more rigorous evaluation using a sediment transport model and site-specific data to evaluate the potential impacts of rare storms. Case studies of the effects of rare storms on two sites (i.e., a 100-year flood and a hurricane) indicated that only relatively minor erosion of cohesive sediments was likely to occur.

Natural recovery may take years or decades to achieve risk-based goals, depending upon the sediment accumulation rate and degree of vertical mixing. For example, in highly mixed sediments in Richardson Bay near the mouth of the San Francisco Bay estuary, it was estimated that more than 75 years would be required to bury 90% of deposited contamination below the mixing zone (Fuller et al., 1999). Because long-term monitoring is required to monitor contaminant concentrations in sediment and verify the predicted burial rate, monitoring costs are likely to be significantly higher for a natural recovery remedy than they would be for other management strategies.

Monitored natural recovery of sediments has been applied to remediate PCB contamination in Operable Unit (OU) 2 of the Sangamo-Weston/Twelve-Mile Creek/Lake Hartwell Superfund site, GA (U.S. EPA, 1994b) and lead contamination in OU 3 of the Interstate Lead Company Superfund site, AL (U.S. EPA, 1996). Sediment management practices implemented at each site include restrictions on fishing and other recreation activities, public education, routine monitoring, and five-year reviews to protect human health during recovery. Routine monitoring of sediment and biota provides information about the progress of recovery, including sediment accumulation rates and recovery rates for benthic organisms and fish. In Commencement Bay, WA, natural recovery is a candidate remedial technology at those sites that are "marginally" contaminated, which is defined as sites where the remedial action objectives can be met within a 10-year time period with no other intervention than monitoring (Hylebos Cleanup Committee, 1999).

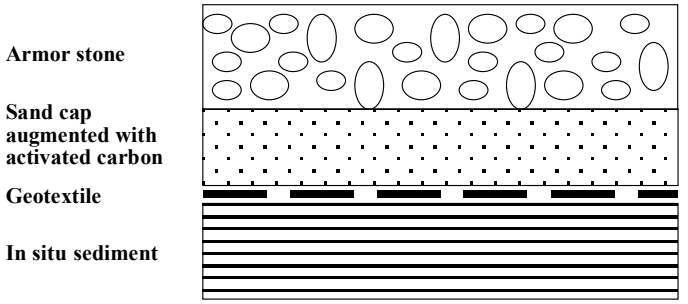
4.3.2 In Situ Capping

In situ capping is the controlled, accurate placement of a clean, isolating material over contaminated sediments without relocating or causing a major disruption to the original bed (NRC, 1997). This remedial option has similar applicability, advantages, and disadvantages as monitored natural recovery except that the capping material will more immediately isolate the contaminated sediments from the aquatic environment. A cap may serve one or more purpose (Palermo et al., 1998; http://www.wes.army.mil/el/dots/doer/pdf/trdoer1.pdf):

- Physical isolation of sediments to prevent exposure of aquatic organisms to sediment-bound contaminants;
- Stabilization of sediments to prevent impacts caused by resuspension, transport, and redeposition elsewhere; and,
- Chemical isolation to prevent contaminant flux to the overlying water column via diffusion.

The intended purpose of an in situ cap and site-specific characteristics (e.g., hydrologic setting, benthic community composition) will drive its design, construction, and monitoring requirements. Caps typically are composed of granular material such as sand, silt, or natural sediments. In general, finer-grained material with some organic carbon (i.e., naturally occurring clean sediment) will provide a greater degree of chemical isolation than sand because of its greater sorption capacity (Palermo et al., 1998). However, sandy materials are stable at steeper slopes, easier to place, less likely to resuspend, and less likely to be subject to burrowing by benthic organisms. Geotextile membranes, armor stone, or a combination of materials (i.e., multilayer cap) also may be used (Figure 4-2).

In situ capping is most effective in relatively sheltered areas that are not exposed to erosive forces such as currents, waves, and navigation propeller wash, or to upwelling from groundwater. An in situ cap can be armored with stone or other material to prevent erosion in higher energy environments. The scour caused by navigation (commercial and recreational vessels) would necessitate very large armor stone, making in situ capping difficult in or near most active navigation channels (Environmental Laboratory, 1987).



Modified from Palermo et al., 1998

Figure 4-2. Example of a Layered Sediment Cap

The feasibility of an in situ cap depends primarily on appropriate site conditions. A comprehensive site characterization must be completed that considers waterway configuration and uses, hydrodynamic and geotechnical conditions, and physical, biological and chemical characteristics of the contaminated sediments (Palermo et al., 1998). Both current and possible future conditions must be considered. If in situ capping appears to be feasible, then specific engineering and design studies would be needed to determine optimum cap thickness and composition. Some of the data needed to support development of a capping remedy are presented in Highlight 4-7.

Highlight 4-7. Data Needed to Support In Situ Capping

Sediment Characteristics:

- Level of contamination
- Grain size distribution
- Shear strength
- Resistance to erosion
- Consolidation
- Plasticity
- Density

Site Characteristics:

- Constraints posed by the cap on waterway traffic
- Water depth
- Typical currents
- Wave climate
- Navigation traffic
- Flood flows
- Aquatic resources
- Groundwater flow patterns

(from Georgia Tech Research Corporation, 2001; http://www.hsrc.org/capping/assessment.html)

Monitoring must be carried out before, during, and after construction of the cap to ensure that the cap was correctly constructed and is effective in isolating the contaminants. The integrity of the cap also must be verified. Guidance on designing and implementing a monitoring program for a capping project can be found in the USACE Waterways Experiment Station Technical Note DRP-5-07 (June 1992; http://www.hsrc.org/capping/monitor-note.html).

Additional detailed information on in situ capping can be found in the following resources:

- The Navy has an in situ capping technology Web page that can be found at http://enviro.nfesc.navy.mil/erb/restoration/technologies/remed/contain_remove/cr-04.asp. This resource provides information about the applicability of in situ capping, its limitations, and schedule and cost considerations.

- The U.S. EPA-sponsored Web site http://www.hsrc.org/capping/ provides a concise overview of sediment capping technology, including recommended practices and situations where it may be used most effectively. It also includes technical resources for those who are familiar with the technology. It provides technical briefs on site selection considerations, design requirements, equipment and placement techniques, and monitoring considerations. It also provides links to current research on capping.

- U.S. EPA's Assessment and Remediation of Contaminated Sediment (ARCS) Program *Guidance for In Situ Subaqueous Capping of Contaminated Sediments* (Palermo et al., 1998; http://www.epa.gov/glnpo/sediment/iscmain/) contains detailed information about site evaluation, cap design, equipment and placement techniques, monitoring, and management.

In situ capping has been employed at various sites around Puget Sound, WA, including the Eagle Harbor Superfund site where a 3 to 6 ft layer of sand was placed over 54 acres of creosote-contaminated sediments in 40 to 60 ft of water (Sumeri, 1995). Another example is a 3-ft layer of sand that was used to cap 5.7 acres of sediment at Convair Lagoon in North San Diego Bay (Applied Environmental Management, Inc. [AEM], 2000). The cap is bounded by the shoreline and a rock berm on the seaward side.

4.3.3 Dredging Considerations

This section reviews the specific technical and management issues that must be addressed if dredging is likely to be chosen as a remedy. Dredging is relatively easy to implement from a technical and administrative standpoint, although controls may be required to minimize the impact of resuspended particulate matter. Dredging activities should be coordinated with the agencies that regulate navigational dredging (i.e., the regional district of USACE and local port authorities). Although dredging activities associated with on-site CERCLA response actions do not require a permit, all substantive requirements of permits would need to be met (permits are required for offsite activities [e.g., offsite disposal of dredged sediment]). Most dredged sediment requires pretreatment or handling after excavation, including dewatering and primary separation of debris. Dredging must be closely coordinated with subsequent treatment or disposal activities.

4.3.3.1 Selection of an Appropriate Dredging Technique

A number of methods are available for dredging, but most of the experience and equipment have been developed for the improvement and maintenance of navigation facilities (NRC, 1997). The objective of navigational dredging is to remove the greatest volume of sediment as efficiently as possible. By contrast, environmental dredging is a more precise operation in which the objective is to remove contaminated sediment without spreading the contamination to the surrounding environment (Figure 4-3). Discussions of various dredging techniques and their applicability can be found in U.S. EPA (1994a) and Zappi and Hayes (1991). Innovations in dredging technology for contaminated sediments are summarized in the USACE Engineer Research and Development Center (ERDC) Technical Note DOER-T1 (http://www.wes.army.mil/el/dots/doer/pdf/doert1.pdf) and discussed more comprehensively in *Innovations in Dredging Technology: Equipment, Operations and Management* (ERDC, 2000a; http://www.wes.army.mil/el/dots/doer/pdf/trdoer5.pdf).

Figure 4-3. Enclosed Clamshell Bucket Prevents Escape of Sediment During Environmental Dredging

4.3.3.2 Environmental Windows

Almost every region in the nation is affected by environmental windows, which are specified time periods during which dredging is permitted to minimize the impact on sensitive biological resources. A series of ERDC technical notes (ERDC, 2000b) that address various aspects of environmental windows and effects of dredging on fish and shellfish populations, including the technical aspects of monitoring, can be found at http://www.wes.army.mil/el/dots/doer/technote.html. In some cases, an extended or alternative dredging window may be requested if data can be provided to demonstrate that the impact on aquatic biota will be minimal (see Highlight 4-8).

Highlight 4-8. Data Collected to Evaluate Potential Dredging Impacts and Feasibility of Extended Environmental Window, McAllister Point Landfill, Newport, RI

- Densities of ichthyoplankton
- Adult fish surveys
- Water quality information
  - Light penetration
  - Salinity
  - Temperature
- Dissolved oxygen

(Source: Normandeau Associates, Inc., 2000.)

4.3.3.3 Water Column Releases of Contaminants and Use of Silt Curtains

Sediment lost to the water column during remedial dredging is a concern, particularly with mechanical dredging. Contaminants typically are associated with the fine-grained suspended sediment particles, and contamination can be spread by desorption of the contaminants from the particles into the water column, or drifting of suspended sediment beyond the area of remediation.

A variety of containment systems have been used in remedial dredging projects including geotextile and geomembrane silt curtains (see Figure 4-4), floating booms and, in one instance, a steel sheet pile (Cushing, 1999a). Silt curtains have been used with mixed success. Silt curtains were reported to be effective at a number of sites, including the Marathon Battery site in New York (AEM, 2000). However, at other sites the silt curtains obstructed ship traffic, and were easily damaged in strong currents (greater than 1.5 ft per second). At the United Heckathorn site in Richmond, CA, silt curtain management problems, including damage from tugboats and extreme tides, resulted in a loss of 23 days over the life of the project (Chemical Waste Management, 1997).

Coagulants that aid in the settling of suspended particulates also have been used in conjunction with silt curtains. After dredging during the Waukegan Harbor project in Illinois, the harbor water was sprayed with Nalcolyte, a coagulant used for potable water supplies. The coagulant settled the suspended particulates and the silt curtains were removed within 48 hours after application (Canonie Environmental, 1996).

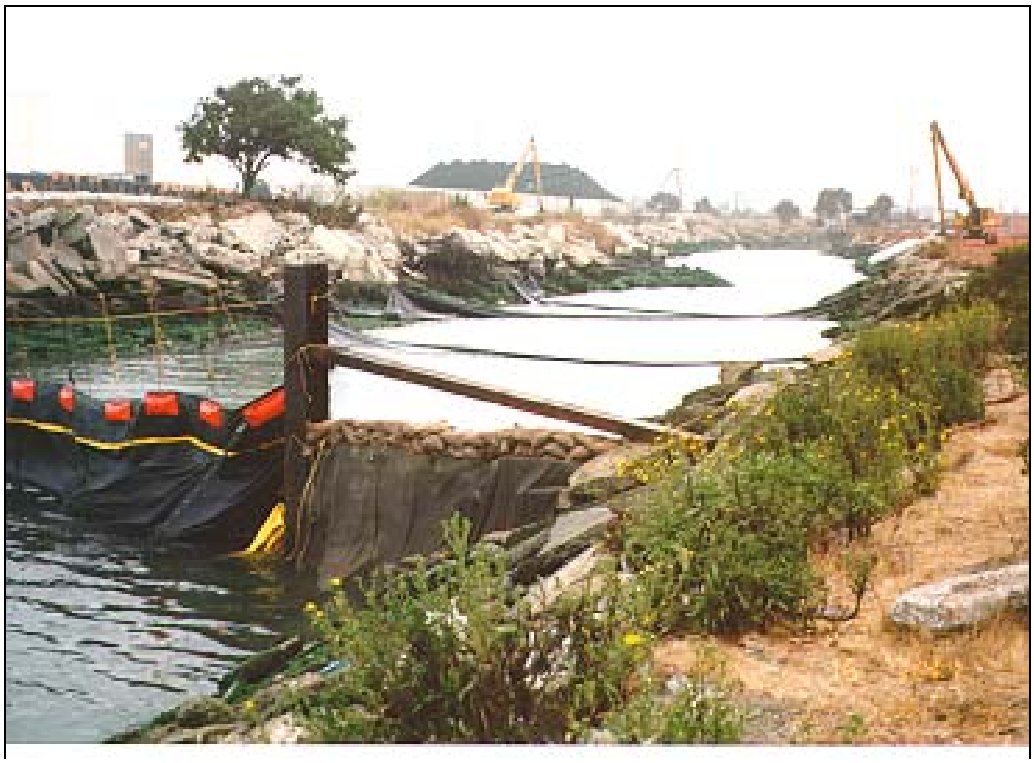


Figure 4-4. Use of a Silt Curtain to Isolate an Area Undergoing Remedial Dredging

Another alternative is dry excavation, which involves the dewatering of the site using coffer dams or otherwise rerouting water temporarily. Dry excavation can provide more accurate contaminant removal with less potential for sediment suspension, but generally at a higher cost than mechanical or hydraulic dredging.

4.3.3.4 Habitat Destruction

Dredging activities have potentially destructive effects on benthos and benthic habitat. Particle size distribution may be altered after surface sediment removal, leading to consequences for the benthos that remain after the dredging or subsequent colonists (Tagatz et al., 1982). Fine sediments from underlying anoxic layers can become resuspended after the dredging event and alter the chemical environment of the habitat (Reimann and Hoffmann, 1991). Freshly exposed anoxic sediments will oxygenate, resulting in the mobilization of several metals that may pose a risk to aquatic organisms. Additionally, dredged areas may be left with a reduced benthic community due to removal of individual organisms with the sediment (Quigley and Hall, 1999).

A literature review of the ecological effects of dredging noted that initial effects can range from negligible to severe and impacts from short to long term, depending on the scale of the project (Morton, 1977). Another study demonstrated that recovery from small scale (<1 m^2) disturbance events can be rapid (within hours) as a result of the immigration of adult individuals from adjacent areas, whereas communities disturbed at the scale of 1 km^2 depend more on the settlement of planktonic larvae for recovery than on the immigration of adults and juveniles (Hall et al., 1994). In the latter case, initial recolonization will vary according to seasonal availability of larval recruits. Recolonization rates are greatest in spring and summer when the densities of ambient species are highest, and lower in the autumn and winter as population densities decreases (Zajac and Whitlatch, 1982). Some of the site-specific data that can be collected to predict the expected habitat loss due to remedial dredging and expected time and modes for recolonization are shown in Highlight 4-9.

Highlight 4-9. Data Needed to Support Evaluation of Habitat Destruction from Remedial Dredging and Time for Recolonization

- Grain size distribution in pre- and post-remediation sediment bed
- Predicted chemical changes in post-remediation environment
- Expected change in light penetration based on change in depth of bed
- Preremediation surveys of aquatic vegetation, invertebrates, and fish
- Analysis of food webs and community structure

A study of benthic invertebrates in a shallow navigation channel in the Columbia River before and after dredging (McCabe et al., 1998) demonstrated the importance of including reference areas in the environmental assessments of dredging projects. Without the data from the reference area, it would not have been possible to make accurate conclusions regarding the impact of the dredging project on the benthos in the channel. Samples collected in the reference area provided a means of assessing natural variation in the standing crops and community structure of benthic invertebrates in a specific reach of the lower Columbia River.

4.3.3.5 Dewatering Requirements

Pretreatment (debris removal, dewatering and possibly stabilization) most likely will be necessary if dredged sediment is destined for upland disposal or beneficial reuse. Some of the highest costs and greatest technical challenges for sediment remediation are associated with pretreatment (Figure 4-5). The type of handling and pretreatment is dependent on the chemical and physical nature of sediment, as well as its final destination. Primary (physical) separation and dewatering are the initial handling requirements. Most sediment requires some dewatering before additional treatment or transportation. Water content can range from approximately 50% by weight with mechanical dredging to more than 80% with hydraulic dredging. Similarly, physical separation of the sediment also may be required before additional handling or treatment. Not only can physical separation be used to concentrate the more contaminated sediment, but it also can help separate debris and large sized sediment particles that could hinder further treatment. Typically, contamination is associated with the silt- and clay-sized particles. If sediments contain a large percentage of sand, separating out the sand can lead to significant savings by reducing the volume that requires treatment. A multitude of process options are available as summarized in U.S. EPA (1994a).

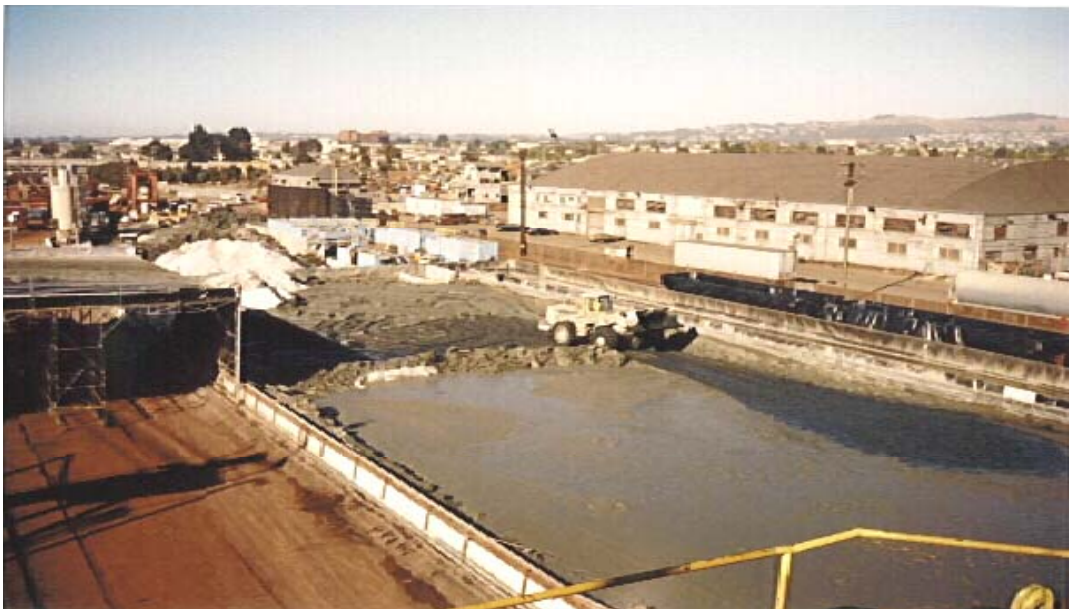


Figure 4-5. Dewatering and Pretreatment Facility for Dredged Sediment

Dredging production rates will vary with dredging method, but the limits on production rate are driven more often by other factors in the process, such as the loading rate of the dewatering facility. Sediments with a lower solids-to-water ratio will require more pretreatment, dewatering, and handling. Because pretreatment areas typically require large land areas to set up, this requirement will affect the applicability of certain dredging methods at a particular site.

Sediment dewatering should reduce the volume of material requiring further handling and disposition, increase the ease of sediment handling and transportation, and reduce the amount of stabilizing agents to be added, if required for final disposition. Dewatering technologies can be broadly divided into two categories: passive and active technologies. A good discussion of dewatering

technologies can be found in U.S. EPA (1994a). Some commonly used dewatering technologies are shown in Highlight 4-10.

Highlight 4-10. Commonly Used Dewatering Technologies

- Spreading and natural evaporation; drying agents (e.g., lime) may be added to promote drying
- Placement in geotextile bags
- Plate and frame compression
- Centrifugation (cyclone separation)

4.3.3.6 Residual Surface Sediment

Although some precision dredging techniques are available, it is inevitable that some residual sediment will remain after remediation is complete, because of the technological limitations of dredging technologies and the redeposition of sediment that was suspended during dredging. In particular, obstructions such as piles, piers, and other shoreline structures; the presence of large debris; and a convoluted shoreline may interfere with dredging and increase the amount of residual surface sediment (see Figure 4-6). The potential for residual surface sediment and associated degree of risk should be considered in the FS, particularly with respect to achieving remedial goals via dredging and verification requirements.

Figure 4-6. Residual Sediment Around Pilings Can Reduce the Effectiveness of Dredging

4.3.3.7 Cost

The cost for environmental dredging is substantially higher than navigational dredging because of the greater precision of cut required, the slower production rates to minimize resuspension, multiple passes needed to achieve cleanup goals, use of contaminant barriers, and restrictions posed by other remedial components such as pretreatment and handling (NRC, 1997). Poor three-dimensional characterization of the extent of contamination can result in the need for multiple passes or over-dredging, which can increase disposal volumes and costs. The major cost elements for dredging are as follows:

- Mobilization/demobilization;
- Dredge method;
- Sediment containment barriers; and,
- Monitoring.

Additional cost considerations include dredged material handling, pretreatment, and treatment or disposal. Additional handling and/or treatment costs after excavation can add more than \$100/yd^3 depending upon the approach.

In general, larger sediment excavation volumes lead to lower cost per unit volume. Conversely, small dredging projects will involve a high cost per unit volume. Overall costs for recent remedial dredging projects range from \$44 to \$1,842 per yd^3 (Cushing, 1999b). The high overall cost is due to two primary factors: low production rates relative to navigational dredging, and disposal costs. As noted above, inadequate site characterization can result in higher-than-necessary volumes.

4.3.4 Sediment Disposal Options

Generally, contaminated sediments are unsuitable for unconfined open water disposal and require containment or treatment after dredging. Containment is the most common approach for management of dredged sediments and has been widely applied. More recently, development of beneficial reuse options for dredged material has become a priority for the USACE and port authorities. Although the emphasis has been on reuse of clean material dredged for navigational purposes, some of the reuse options may be feasible for contaminated material (see Section 4.3.6).

Containment technologies for dredged sediment include contained aquatic disposal (CAD), including level-bottom capping (LBC); confined disposal facilities (CDF); and upland disposal in landfills. Figure 4-7 is a conceptual drawing of various containment options. The use of geotextile bags is another option for disposal of small volumes of sediment. Each containment technology is summarized below. The applicability, advantages and disadvantages and cost and schedule considerations for various disposal technologies are summarized in Section 4.3.9.

4.3.4.1 Contained Aquatic Disposal

CAD involves the dredging of contaminated sediments from areas to be remediated, transport to the underwater disposal site, controlled placement on the seafloor, and capping. CAD is similar to in situ capping, except that a cap is placed over dredged sediments rather than on the original seafloor. Dredged sediments can be placed in a natural or excavated depression or contained within

berms, then covered with clean sediment or other capping material. The cap prevents physical contact

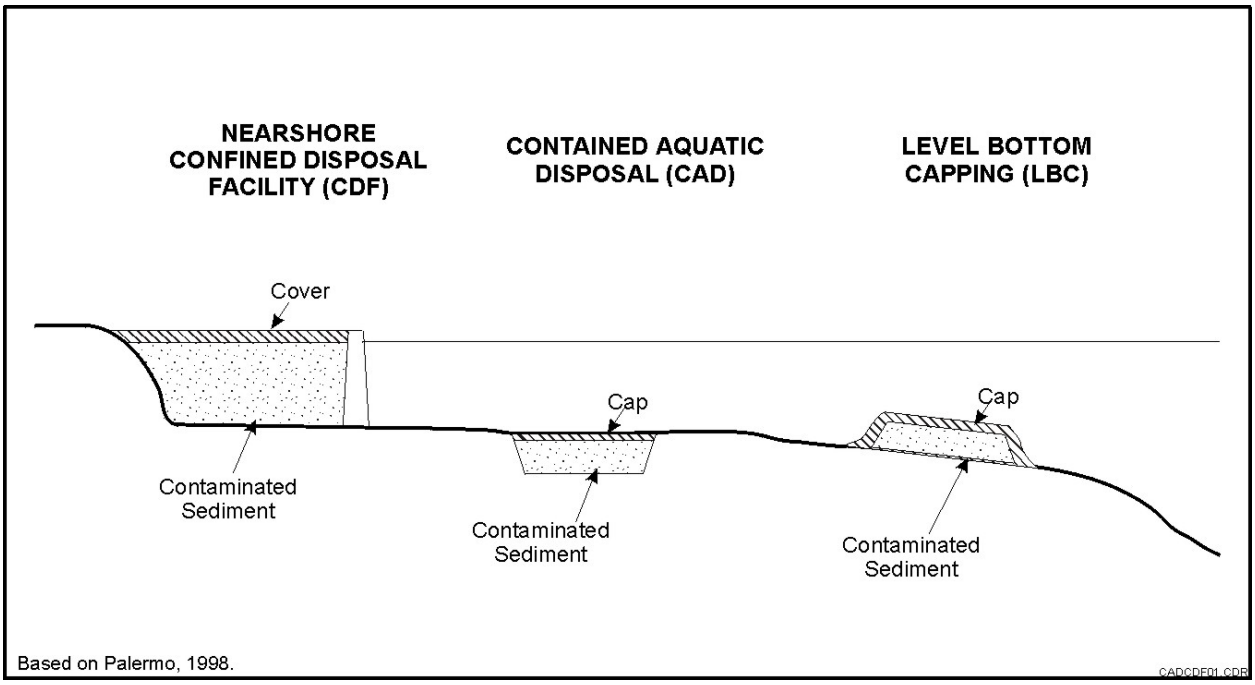


Figure 4-7. Conceptual Drawing of Various Containment Options for Dredged Sediment

between the sediments and the benthic community, prevents sediment resuspension and dispersion, and may inhibit contaminant flux to the water column. As with all capping alternatives, the site must be monitored for cap integrity over a long period of time. Technical considerations associated with a

CAD include location of a suitable site, selection of appropriate placement methods for sediments and cap, long-term integrity of the cap, and habitat restoration potential, if applicable.

The first CAD project completed in the United States involved the placement of sediments containing metals and PCBs in a depression in the lower Duwamish River in Seattle, WA and construction of a clean sand cap (USACE et al., 1999). Large CAD pits (up to 1.5 million yd^3) have been excavated in New Jersey and Massachusetts for disposal of contaminated sediments from navigational dredging projects (Knoesel et al., 1998; Murray et al., 1998). However, CAD has not been widely applied exclusively for disposal of contaminated sediments.

Design, feasibility and implementation of a CAD are discussed in various technical documents, including *Guidance for Subaqueous Dredged Material Capping* (http://www.wes.army.mil/el/dots/doer/pdf/trdoer1.pdf). Current information on the recent construction of CADs in Boston Harbor can be found at http://www.nae.usace.army.mil/projects/ma/BHNIP/cover.pdf.

4.3.4.2 Confined Disposal Facilities

Confined disposal involves the placement of dredged material in a nearshore area behind a dike, berm, or other containment structure. Most CDFs use the natural shoreline as part of the containment structure, with a dike or berm constructed in the water to complete the enclosure (USACE et al., 1999) (Figure 4-7). Dredged sediments are placed in the CDF, dewatered, and consolidated. Effluent from dewatered sediments must be monitored and treated if necessary before discharge. The filled CDF then can be capped with clean material and either vegetated or paved and made available for a variety of end uses. The Navy's technology Web page for CDFs, which can be found at http://enviro.nfesc.navy.mil/erb/restoration/technologies/remed/contain_remove/cr-02.asp, provides more information on this topic.

Potential contaminant releases from the CDF can be controlled using appropriate design, materials, and operational procedures. Seepage of leachate through the CDF walls is most effectively prevented by use of clay or bentonite-cement slurries as sealers (U.S. EPA, 1993). A CDF requires long-term monitoring and maintenance to ensure its integrity and verify its effectiveness in isolating contaminants.

The USACE uses CDFs to contain about 30% of the sediments produced by navigational dredging programs (U.S. EPA, 1993). A large CDF (greater than 2 million yd^3) was constructed in the Milwaukee Waterway in Commencement Bay, WA, to contain contaminated sediments and clean navigational dredged material (Verduin et al., 1994). A berm was constructed across the mouth of the waterway, and sediments were either offloaded from a barge or placed directly by pipeline from the dredged area. Effluent control was provided by an overflow weir and discharge line. After dewatering, settling, and consolidation, the CDF was capped with paving and converted to a container terminal.

In addition, existing piers or other port structures can be used to provide partial containment for a CDF. In Elliot Bay, the Port of Seattle constructed two berms between solid fill piers to form a CDF (Converse Consultants et al., 1992). At the Outboard Marine site in Lake Michigan, a double sheetpile cut off wall was constructed across an existing slip (AEM, 2000; http://www.hudsonvoice.com/mcss/). A clay slurry wall also was constructed to form a watertight barrier. The CDF was used to contain 50,000 yd^3 of hydraulically dredged sediments, which took 2.5 years to dewater and consolidate prior to placement of the final cap.

4.3.4.3 On-Site Upland Disposal

On-site upland disposal refers to the placement of dredged sediment in a containment facility on or beneath surface lands that are typically near the remediation site. Depending on the level of contamination in the sediments, the sediments may be placed directly on the land surface after dewatering, or they may be placed in a fully designed and engineered RCRA facility. For example, at Point Potrero in Richmond, CA, dredged sediments contaminated with metals and PCBs were placed on an adjacent upland area and capped with asphalt when dewatering was complete (San Francisco Bay Regional Water Quality Control Board [SFBRWQCB], 1999). For on-site upland disposal, sediments are dredged and transported to a pretreatment area where they are dewatered and, depending on the nature of contamination present, stabilized to reduce contaminant mobility and increase load-bearing capability. The treated sediments then are transported to either an engineered cell or a land parcel, where they are compacted, graded, and fixed in place by a vegetative cover.

From Ellicott International, 2001
(http://www.dredge.com/casestudies/tp_geot.htm)

Figure 4-8. Geotextile Tube Filled with Dredged Sediment

4.3.4.4 Commercial Landfill Disposal

Commercial landfill disposal of dredged sediment is generally expensive because of the associated transportation and disposal costs. However, it can be a good option for disposal of small volumes of highly contaminated sediment, especially if remediation must be completed in a short time frame. Although not usually cost-effective, commercial landfills have been used for the disposal of relatively large volumes of sediment that were transported a great distance from the site. For example, approximately 100,000 cubic yards of dewatered sediment from the United Heckathorn Site in California were transported by rail to landfills in Arizona and Utah for disposal (Chemical Waste Management, 1997). An appropriate off-site landfill should be identified based on the ability to meet the landfill's waste discharge requirements, confirmation of sufficient landfill capacity and evaluation of disposal costs.

4.3.4.5 Geotextile Bags

Geotextile bags are large sacks that can be filled with dredged sediment (Figure 4-8). They are usually constructed of a nonwoven, felt inner liner surrounded by a coarser, nonwoven outer bag. The fabric retains the sediment while allowing water to seep through so that the sediment will dewater under its own weight. The sediment-filled bags are easier to handle and transport than loose sediments in addition to providing some confinement of the sediment. In addition to dredged material, geotextile bags have been used to contain sewage sludge, animal waste, fly ash, potash lagoons, drilling mud and cuttings, and mine tailings.

Because most contaminants are sorbed to sediment particles and do not seep through the fabric of the bag, underwater placement of filled geotextile bags might be environmentally safe and

Highlight 4-11. Factors that Reduce the Viability of Sediment Treatment Options

- Sediments typically are contaminated with more than one class of contaminant
- Sediments are relatively inaccessible beneath surface water
- Compared with terrestrial soils, contaminated sediments are characterized by relatively large volumes with relatively low contaminant concentrations
- Fine-grained sediments with a high organic content tend to adsorb and bind chemicals, thereby inhibiting many treatment options
- Sediments typically are difficult to handle and process because of the high moisture content and predominance of fine-grained material
- The chemistry associated with treatment technologies is complex, requiring extensive treatability studies
- Residual waste streams such as cleaned solids, concentrated residuals, and off-gas require management
- Cleanup criteria are generally orders of magnitude lower for sediments than for soils, pushing the limits of even the most standard technologies
- Successful delivery of amendments for in situ approaches is problematic: the addition and successful delivery of amendments to sediment in situ may adversely affect water quality

would eliminate the need for a land-based disposal site (NRC, 1997). However, the leachate would need to be recovered and tested to verify that chemical concentrations are acceptable. Although filled geotextile bags have been placed in the aquatic environment for wetlands creation and reef construction, case studies of their use for underwater disposal of contaminated sediments were not found.

4.3.5 Sediment Treatment Options

Contaminated sediment can be treated using physical, chemical, biological or thermal technologies, either in-place or after dredging and pretreatment. However, treatment of contaminated sediments has been applied at very few sites and is still very expensive. Treatment to destroy or immobilize contaminants in sediment either in situ or ex situ is complicated by the factors identified in Highlight 4-11.

Relatively few cost-effective technologies effectively treat contaminants in sediment, and the treatment technologies that currently exist have not been widely applied. However, sediment treatment is an active field of research and several promising technologies are under development.

A good summary of selected treatment technologies for sediment is provided in *Innovative Technologies For Decontamination and Treatment of Dredged Material* (WES, 2000b; (http://www.wes.army.mil/el/dots/doer/pdf/doert2.pdf). This paper provides information on some of the more promising treatment technologies for sediments, including a variety of thermal processes and containment or partial removal processes. The table of existing and emerging remedial technologies

Highlight 4-12. Potential Beneficial Uses for Dredged Sediment

- Habitat restoration/enhancement (wetland, upland, island, and aquatic sites, including use by waterfowl and other birds)
- Beach nourishment
- Aquaculture
- Parks and recreation (commercial and noncommercial)
- Agriculture, forestry, and horticulture
- Strip mine reclamation and landfill cover for solid waste management
- Shoreline stabilization and erosion control (including fills, artificial reefs, and submerged berms)
- Construction and industrial use (including port development, airports, urban, and residential)
- Material transfer (including fill, dikes, levees, parking lots, and roads)
- Multiple purpose

(From U.S. EPA and USACE, 1992.)

presented in Section 4.3.9 includes information on a variety of treatment technologies including phytoremediation, solidification and stabilization, biological treatment, direct injection, use of gas permeable membranes, sediment washing, and thermal technologies.

In situ treatment of sediment is an identified focus area of the Remediation Technologies Development Forum (RTDF) (www.rtdf.org/public/sediment/default.htm). A number of in situ remediation technologies are under consideration by the RTDF's Sediment Remediation Subgroup, including natural attenuation, phytoremediation, introduction of chemical additives to enhance the natural processes, and electrokinetics. The subgroup is most interested in passive technologies that will remediate contaminants without significantly increasing the stress on the ecology.

4.3.6 Beneficial Reuse

Beneficial reuse refers to the use of dredged material as a resource in construction or environmental restoration projects. Interest has developed over the last 25 years in improving dredge management practices including beneficial reuse of dredged material (National Dredging Team, 1998; USACE, 1987b). U.S. EPA and USACE define ten broad categories of beneficial uses based on the functional use of the dredged material or site (see Highlight 4-12). Although the emphasis has been on the reuse of clean material dredged for navigational purposes, some of the reuse options may be feasible for contaminated material.

The feasibility of beneficial reuse as a remediation option depends upon the level of contamination in sediment and the proposed reuse. Sediment with low to moderate levels of contamination might be suitable for some applications such as foundation (noncover) material for habitat restoration projects. Additionally, some limited treatment such as the addition of cement kiln dust or fly ash could improve the engineering characteristics of lightly contaminated material and render is useable as landfill cover or construction fill. RPMs should investigate local or regional opportunities for beneficial reuse, and consult with regional dredging authorities regarding potential reuse opportunities that may have been developed for material that is classified as not suitable for open water disposal.

4.3.7 In Situ vs. Removal Responses

As noted in Section 4.3.3, most sediment cleanups to date have involved dredging. Dredging is generally considered to be a permanent remedy for a site because it eliminates long-term liability for the remediated site and places no limitations on its future use. However, dredging may not be the most appropriate solution for some sites because of disproportionate costs and unacceptable environmental impacts. In particular, dredging might not be suitable for sites that have a large area affected by low or moderate contamination (both laterally and vertically) or are located in nearshore or wetland areas that provide valuable habitat. In these cases, in situ management may be a more cost-effective and viable option.

In some cases, sites that have undergone remedial dredging have actually experienced negative ecological impacts. Contaminants can be incompletely removed and/or made more bioavailable by the exposure of more highly concentrated, less-weathered contaminants that were previously buried (Thibideaux et al, 1999). Additionally, the change from an anoxic to an oxic environment may remobilize some contaminants. However, dredging may be the only viable option in some circumstances. Site characteristics that indicate whether an in situ response or dredging may be more appropriate are summarized in Highlight 4-13.

Highlight 4-13. In Situ vs. Removal Remedies

Site characteristics that support an in situ response:

- Large area or volume of sediment affected by relatively low levels of contamination
- Contaminated sediment located in an area with sensitive/valuable habitat
- Contaminated sediment located in a quiescent area with low resuspension and erosion potential

Site characteristics that support a dredging response:

- Limitations cannot be placed on the future use of the site
- Institutional controls (e.g., fishing advisories) are not feasible
- Human health or ecological risk is immediate or substantial and capping is not feasible
- Contaminated sediments are located in a dynamic environment with high resuspension and erosion potential
- Insurmountable public or regulatory resistance to an in situ remedy

4.3.8 Risks Inherent in Each Remedial Alternative

The short- and long-term risks associated with any remedial alternative are identified and assessed as part of the nine criteria evaluation set forth in the NCP (U.S. EPA, 1988; http://www.epa.gov/oerrpage/superfund/whatissf/sfproces/rifs/analys.htm). The long-term effectiveness and permanence criterion evaluates the potential magnitude of the residual risk and the adequacy and reliability of the controls implemented to manage the risk. The short-term effectiveness criterion addresses: (1) protection of the community and workers during remedial actions, (2) environmental impacts during remedy implementation, and (3) time until RAOs are achieved. The long- and short-term risks associated with some of the major remedial technologies for sediments and associated management strategies are summarized in Tables 4-2 through 4-5. These tables do not address community or worker safety during implementation of a remedy because it is assumed that these risks can be easily identified and addressed in health and safety plans.

In addition to long- and short-term risks associated with a given remedial strategy, the RPM must consider the risk and cost associated with assuming long-term liability for the site. Any remedial action that results in on-site containment of contaminated sediment (e.g., natural recovery, in situ

Table 4-2. Risks and Management Strategies Associated With Dredging

Long-Term Risks	Management Strategies
Residual sediment not removed by dredging	Use precision dredging techniques, minimize sediment resuspension during dredging, remove obstructions such as pilings and debris before dredging, conduct post-remediation monitoring
Permanent destruction of habitat and biological resources	Consider restoration
Recontamination by uncontrolled sources	Complete source identification and control before remediation
Short-Term Risks	**Management Strategies**
Benthic habitat destruction	Evaluate expected recolonization time and promote recovery if necessary (e.g., provide suitable substrate)
Sediment resuspension/dispersal during dredging and release of contaminants to water column	Use of environmental dredging techniques, silt curtains or other barriers, and coagulants; adherence to environmental windows

Table 4-3. Risks and Management Strategies Associated With In Situ Capping and CAD

Long-Term Risks	Management Strategies
CAD cap disrupted by natural or human activity	Ensure that proper site selection and design criteria are met, implement institutional controls as needed, long-term monitoring and maintenance of CAD site
Upward diffusion of contaminants through cap	Ensure that proper design criteria are met, long-term monitoring and maintenance of CAD site
Short-Term Risks	**Management Strategies**

Loss of contaminated sediment during placement operations	Use of precision placement techniques and silt curtains or other barriers
Disruption and displacement of contaminated sediments by cap material	Ensure sufficient consolidation of contaminated sediments before placement of capping material, use proper placement techniques for cap

Table 4-4. Risks and Management Strategies Associated With CDFs

Long-Term Risks	Management Strategies
Escape of sediment or leachate from containment structure	Ensure that design criteria are met, long-term monitoring and maintenance of CDF
Short-Term Risks	**Management Strategies**
Environmental impact at disposal site from construction of CDF	Use construction techniques and materials that minimize impact
Loss of contaminated sediment during transport and placement in CDF	Use equipment and techniques that ensure containment of sediment
Environmental impact of effluent from dewatering	Proper control and treatment of effluent before discharge to receiving waters
Remobilization of some contaminants if moved from anoxic to oxic environment	Ensure proper containment of sediment and effluent and treat as necessary

Table 4-5. Risks and Management Strategies Associated With Upland Disposal

Long-Term Risks	Management Strategies
Escape of sediment or leachate from containment structure	Ensure that design criteria are met, long-term monitoring and maintenance of landfill site
Short-Term Risks	**Management Strategies**
Escape of sediment during transport, dewatering and placement	Use equipment and techniques that ensure containment of sediment
Escape of contaminants in effluent from dewatering sediment	Proper control and treatment of effluent prior to discharge

capping or dredging followed by on-site disposal in a CAD, CDF, or landfill) will in most cases result in long-term monitoring responsibilities and liability issues.

4.3.9 Table of Existing and Innovative Remedial Technologies

The management of sediments is best handled through the integration of risk management and remediation. This will often entail a systems engineering analysis or decision analysis approach to optimize the results and obtain the overall goal of protection of human health and the environment. Table 4-6 presents a summary of existing and emerging remedial technologies for sediments. These technologies can be used alone or in combination. Typically, more than one technology or approach must be applied to achieve the goals for a site. For example, precision dredging of hot spots may be coupled with in situ capping or monitored natural recovery. If sediments are dredged, a number of alternatives are available for handling and treating the sediment. Table 4-6 summarizes the applicability, strengths, weaknesses, and associated costs for each technology.

4.4 MONITORING CONSIDERATIONS

Monitoring must be conducted before, during, and after a remedial action at a sediment site. Baseline monitoring helps define existing conditions and provides the data for meaningful comparisons once the remedy is complete. Often, the relevant data will have been previously collected as part of the human health and ecological risk assessments and will be sufficient to establish baseline conditions. If baseline conditions are to be used as a basis for direct comparison, it may be necessary to collect data over a period of years to obtain adequate representation of seasonal variability.

Short-term monitoring is required to monitor environmental impacts during remedy implementation and ensure that target cleanup levels have been achieved. Short-term monitoring parameters could include suspended sediment and dissolved oxygen levels in the water column during dredging or capping. Post-remediation sediment sampling also may be required to verify that all sediment above cleanup levels has been removed or contained.

After the remedy has been implemented, a long-term monitoring program must be carried out according to a systematic schedule to verify the effectiveness of the remedy. The U.S. EPA, in partnership with the Navy, is preparing a long-term monitoring guidance document that will provide a framework for developing scientifically defensible monitoring plans with clear exit criteria. The monitoring plan should be developed in conjunction with the remedial action plan. The most critical element in the plan is the link between the performance of the remedy and the RAOs. Long-term

Table 4-6. Summary of Existing and Innovative Remedial Technologies for Sediment

Technology Type	Description/ Applicability	Chemicals Used in Process	Major Advantages	Major Disadvantages	Relative Cost*	Cost and Schedule Considerations	References/ Resources
In Situ Actions							
Monitored natural recovery	The degradation or isolation of contaminants primarily through burial that occurs from natural sedimentation (deposition)	None	Reasonable alternative if dredging is not desirable or feasible. Can be cost-effective, preserves habitat, nonintrusive implementation.	Not appropriate for all site settings. Extensive characterization required to validate approach. Site should be in an area of deposition and not subject to major erosional events (i.e., storm erosion, prop scour)	4 (Characterization and monitoring costs highly variable)	Extensive upfront characterization required to support decision. Long-term monitoring required. Characterization and monitoring costs can be significant.	Huggett and Bender, 1980; Hahnenberg, 1995. National Research Council, 1997 www.smwg.org/
In situ capping	Placement of cover material over sediments to physically isolate sediments	None	Eliminates need to remove contaminated material; minimizes contaminant release to the environment that could occur with dredging; relatively easy to implement.	Cap with incompatible bottom material can alter benthic community. Long-term maintenance typically required. Potentially can limit future site uses. Politically not appropriate for all site settings.	3	Costs, equipment, and procedures are available from other sites.	National Research Council, 1997; Palermo et al. 1998 www.epa.gov/glnpo/sediment/iscmain/
Confined Disposal Facility (CDF)	Placing dredged sediments within near-shore disposal facility	Typically none; could augment with bioamendments or stabilizers	Low cost compared to ex situ treatment or off-site disposal. Involves conventional equipment. Site can be used for beneficial purposes following closure with proper safeguards.	Can alter benthic community through dredging. Does not destroy or detoxify contaminants unless combined with treatment. Near-shore land may be difficult to find if wetlands or critical ecological niches would be lost.	2	Conventional engineering approaches used. Costs equipment and procedures are available from other sites.	USACE, 1987a; National Research Council, 1997; www.wes.army.mil/el/dots/doer U.S. EPA, 1994a; http://www.epa.gov/glnpo/sediment/iscmain/index.html
Contained Aquatic Disposal (CAD)	Moving sediments to a natural subaqueous topographic low or constructed depression and capping.	Typically none; could augment with bioamendments or stabilizers	Eliminates need for ex situ handling. Segregates contaminants into one location. Minimizes institutional controls at site such as limits on prop wash, navigational depths, etc. and adds flexibility in use of site.	Can alter benthic community through dredging and relocating. Long-term maintenance typically required for cap. Potential loss of contaminants to water column during movement requires controls. Politically not appropriate for all site settings.	2	Costs, equipment, and procedures are available from other sites.	Price and Lee, 1999 www.wes.army.mil/el/dots/doer (DOER-C11, 18 DOER-N5) Garbaciak and Miller, 1995 National Research Council, 1997 http://www.epa.gov/glnpo/sediment/iscmain/index.html

Table 4-6. Summary of Existing and Innovative Remedial Technologies for Sediment (page 2 of 6)

Technology Type	Description/ Applicability	Chemicals Used in Process	Major Advantages	Major Disadvantages	Relative Cost*	Cost and Schedule Considerations	References/ Resources
Phyto-remediation	Removal of contaminants from sediment through plant uptake. Can be applied to submerged sediments, but is considered more useful for upland application after sediment removal.	Plant amendments	Uses natural processes to promote cleanup. Potential cost savings over other sediment handling options. If used in situ may provide alternative to removing sediment by dredging.	Relatively immature technique. Requires extensive screening to determine if applicable. Considered most useful in upland applications which in turn require dredging. Plants must be maintained and for some contaminants (e.g., metals) must be harvested periodically for disposal.	Limited costing data.	Relatively immature; limited data available. Requires significant characterization and testing to determine suitability.	Price and Lee, 1999 www.wes.army.mil/el/dots/doer Cunningham and Lee, 1995
Hydraulic modifications	Physical alteration of bottom or water body to control movement of contaminated sediments and promote deposition of clean sediments	None	Controls contaminated sediment migration, promotes natural attenuation through deposition. Bottom alterations not as drastic as dredging. Sediment can be contained and physically separated.	Relatively new technique; has been applied to fluvial systems, not yet to marine. Modification of ecological habitat, may limit use of site by construction of barriers.	Limited costing data.	Applied to three locations (Moss American, Tennessee River, Mississippi River) set precedent on cost and schedule.	www.smwg.org/
Solidification/ stabilization	Agents injected directly into sediments to solidify or stabilize	Cement, fly ash	Immobilizes contaminants in place. Stabilizes sediments preventing erosion. Eliminates need to remove contaminated material.	Limited long-term testing data on sediments. Limits future site uses.	2	Relatively immature; limited data available; few studies documented.	National Research Council, 1997
In Situ Treatment							
Biological treatment	Fostering microbial biodegradation by providing amendments.	Oxygen, electron receptors, nitrogen	Treats sediments in place through reduction of toxicity. Uses natural processes to promote cleanup.	Subaqueous environments are difficult to manipulate. There are unresolved microbial, geochemical and hydrological issues because technology in the marine environment is relatively immature.	Limited costing data	Relatively immature, few studies documented for marine sediments, freshwater sediment are limited to pilot scale.	National Research Council, 1997; Abramowicz et al. 1992; Bragg et al. 1994. Harkness et al., 1993
Direct injection	Inject reactants for abiotic treatment. Tines can be driven into sediment for the injection of reactants	Ozone, hydrogen sulfide, potassium permanganate	Detoxifies or immobilizes contaminants in place.	Relatively immature technique, sediments typically have multiple contaminants making it difficult to address all contaminants. Subaqueous environments are difficult to manipulate.	2	Relatively immature, few studies documented for marine sediments. Increases uncertainty in cost and schedule.	National Research Council, 1997 Vendor: http://www.oceta.on.ca/profiles/limnofix/list.html

Table 4-6. Summary of Existing and Innovative Remedial Technologies for Sediment (page 3 of 6)

Technology Type	Description/ Applicability	Chemicals Used in Process	Major Advantages	Major Disadvantages	Relative Cost*	Cost and Schedule Considerations	References/ Resources
Gas-permeable membranes	Reactants delivered to sediments via gas permeable membrane (tubing)	Ozone, oxygen, hydrogen, hydrogen sulfide	Detoxifies or immobilizes contaminants in place. Provides long-term sustained delivery of reactants with minimal energy input. Potential for significant cost savings.	Has not been demonstrated on sediments.	Limited costing data	Undeveloped technology increases uncertainty in cost and schedule	Gilmore and Oostrom, 1999
Ex Situ Actions							
Mechanical dredging	Direct application of mechanical force to remove sediment	Not applicable	Little residual risk at site. No limitations on future use. Established industry supporting dredging. Entrains less water than hydraulic dredging.	Destroys benthic community. Potential water column impacts from resuspended sediment. Sediment must be handled, after dredging. Can remove more sediment than required (lack of precision).	2 (Includes removal and transportation; additional handling or treatment not included)	Costs, equipment, and procedures are available from other sites.	National Research Council, 1997 http://www.smwg.org/ Vendor: http://www.on.ec.gc.ca/glimr/metadata/contam-sediment-removal/eta-005.html
Hydraulic dredging	Removal of sediment slurry by suction	Not applicable	Little residual risk at site. No limitations on future use. Established industry supporting dredging. Can be used for more precision removal; limiting sediment. Less suspended sediment released to water column.	Destroys benthic community. Sediment must be handled after dredging. Water content of dredged sediment is increased over mechanical. Sediment most be predominantly fine-grained to be handled by hydraulic dredge.	2 (Includes removal and transportation; additional handling or treatment not included)	Costs, equipment, and procedures are available from other sites.	National Research Council, 1997 http://www.smwg.org/ Vendor: http://www.on.ec.gc.ca/glimr/metadata/contam-sediment-removal/eta-004.html
Ex Situ Treatment (Requires Dredging)							
Primary separation	Removal of large debris from sediment	Not applicable	Increases ease of handling for dewatering, treatment and/or disposal.	Can be technically challenging and time-consuming. Debris requires disposal.	2	Costs, equipment, and procedures are available from other sites.	National Research Council, 1997
Dewatering	Removal of free water from saturated sediments	Chemicals typically not used; however some methods use adsorbents.	Reduces volume of sediment requiring disposition. Increases ease of handling. Decreases disposal and/or treatment costs.	Passive/gravity dewatering requires significant time and space to be effective. Mechanical dewatering can be technically challenging and more expensive. Excessive fines in sediment can decrease effectiveness.	2	Dewatering takes time but decreases overall costs. Costs equipment and procedures are available from other sites.	National Research Council, 1997
Sediment washing	Removal of contaminants from sediment using a wash solution	Can include detergents or solvents	Contaminants are removed from sediments increasing the potential uses of the sediment and minimizing disposal costs.	Ineffective with fine-grained sediment. Wash solution difficult to formulate for contaminant mixtures. Contaminant removal is incomplete.	2	Costs, equipment, and procedures are available from other sites.	National Research Council, 1997; USACE, 1994a

Table 4-6. Summary of Existing and Innovative Remedial Technologies for Sediment (page 4 of 6)

Technology Type	Description/ Applicability	Chemicals Used in Process	Major Advantages	Major Disadvantages	Relative Cost*	Cost and Schedule Considerations	References/ Resources
Physical separation	Various methods to physically separate the sediment for more efficient treatment and/or disposal ▪ Screens and classifiers ▪ Hydrocyclones ▪ Gravity separation ▪ Froth flotation ▪ Magnetic separation	Typically none; some processes may use foaming agents	Can be used to reduce volume of sediment requiring treatment or disposal. Results in lower handling costs.	Does not destroy contaminants but concentrates them into smaller volumes. Not suitable for all sediments; typically requires a significant coarse fraction (≥25% sand-size).	1	Costs, equipment, and procedures are available from other sites.	National Research Council, 1997
Solidification/ stabilization	Reduction of contaminant mobility by addition of a binding agent	Cements, plasticizers	Can use standard slurry mixing equipment. History of use for sludge. Relatively inexpensive.	Long-term effectiveness has not been demonstrated. May result in a significant increase in volume. May not be appropriate for contaminant mixtures. Moisture content must be relatively low	2	Costs, equipment, and procedures are available from other sites.	National Research Council, 1997
Chemical separation and thermal desorption	Using heat and chemicals for mobilizing contaminants into a fluid or gas phase for collection and deposition.	Acid or base solutions for leaching. Solvents.	Removes contaminants from sediments for easier disposal.	Has limited application to sediments.	1	Costs, equipment, and procedures are available from other sites.	National Research Council, 1997; USACE, 1993, 1994b
Phyto-remediation	Removal of contaminants from sediment through plant uptake.	Plant amendments	Potentially less expensive than other methods.	Relatively immature technique. Requires extensive screening to determine if applicable. Plants must be maintained and for some contaminants (e.g., metals) be periodically harvested for disposal.	Limited costing data	Relatively immature; limited data available; requires significant characterization and testing to determine suitability.	Price and Lee, 1999 http://www.wes.army.mil/el/dots/doer/pdf/doerc2.pdf Cunningham and Lee, 1995
Biological treatment	Degradation of contaminants by microorganisms. Land farming most common technique	Bioamendments	Degrades organic pollutants, public acceptability, relatively low cost.	Handling of material is substantial. Method is time consuming, and adequate space is required. Not suitable for some contaminants such as metals. Does not remove 100% of contaminants	1	Costs, equipment, and procedures are available from other sites.	National Research Council, 1997; Thoma, 1994

Table 4-6. Summary of Existing and Innovative Remedial Technologies for Sediment (page 5 of 6)

Technology Type	Description/ Applicability	Chemicals Used in Process	Major Advantages	Major Disadvantages	Relative Cost*	Cost and Schedule Considerations	References/ Resources
Incineration	Thermal decomposition at high temperatures	None	Destroys a large proportion of organic contaminants. Mature, commercially available technology. Has been used to treat a wide variety of hazardous wastes and sediment.	Dewatering needed to reduce energy consumption. Heavy metals remain in a bottom ash or fly ash. Off-gas requires treatment. Potentially expensive. Volatile metals (Hg, As, Se, Pb) may be emitted to the atmosphere in gaseous forms.	0	Costs, equipment, and procedures are available from other sites.	National Research Council, 1997
Thermal desorption	Heating and agitating sediment to volatilize water and organic contaminants	None	Has been applied to sediments.	High temperatures required to remove persistent organic contaminants (e.g., PCBs). High clay, humic material, or moisture content increases costs.	0	Costs, equipment, and procedures are available from other sites.	National Research Council, 1997
Disposal							
On-site upland disposal	Placement of dredged material in an upland containment structure adjacent to dredged site	None	Contaminants effectively contained. Lower transportation costs relative to off-site disposal.	Dewatering and pretreatment generally is required. Long-term integrity of disposal site must be maintained. Potential for long-term liability.	2-3 Depending on waste classification	Permitting facility is on critical path. Costs, equipment, and procedures are available from other sites.	National Research Council, 1997
Off-site upland disposal	Disposal of dredged material at permitted landfill	None	Readily available. Well-established approach to sediment management.	Dewatering and pretreatment generally is required. Relatively high cost. Transport required.	2-3 Depending on waste classification	Effective transportation is important. Straightforward costing and scheduling.	National Research Council, 1997
Open water disposal	Placement of dredged material at designated aquatic disposal site	None	Well-established dredged material management program. Availability of disposal site.	Contaminated sediments are not likely to be suitable for open water disposal.		Requires open water disposal area.	National Research Council, 1997
Beneficial Reuse							
Wetland creation	Use of sediment for wetland habitat restoration or enhancement	None	Precedent exists for wetland creation. Anticipated available capacity in wetland creation projects. Greater chance of public acceptance.	Some sediments may not meet acceptance criteria for wetland creation.		Work with other agencies contributes to uncertainty in scope and budget.	http://sfbay.wr.usgs.gov/access/saltponds/index.html Price and Lee, 1999 http://www.wes.army.mil/el/dots/doer/pdf/doerc2.pdf

Table 4-6. Summary of Existing and Innovative Remedial Technologies for Sediment (page 6 of 6)

Technology Type	Description/ Applicability	Chemicals Used in Process	Major Advantages	Major Disadvantages	Relative Cost*	Cost and Schedule Considerations	References/ Resources
Levee/dike construction	Use of dredged sediment for construction or repair of levees	None	Precedent exists for levee construction. Greater chance of public acceptance.	Some sediments may not meet suitability requirements or will require pretreatment.		Work with other agencies contributes to uncertainty in scope and budget.	Price and Lee, 1999 http://www.wes.army.mil/el/dots/doer/pdf/doerc2.pdf Krause and McDonnell, 2000 http://www.glc.org/dredging/benuse/Reusepaper_1.PDF
Landfill cover	Use of dredged sediment as daily cover at a permitted landfill	None	Precedent exists for use as landfill cover and landfill cover is in demand. Greater chance of public acceptance.	Some sediments may not meet suitability requirements or will require pretreatment.		Must identify a user of the material and negotiate costs.	
Construction	Use of dredged sediment as construction fill	None	Precedent exists for use as construction fill. Greater chance of public acceptance.			Must identify a user of the material and negotiate costs.	
Thermal conversion to building products	Thermal conversion to lightweight aggregate, portland cement, or glass aggregate products	None	Destroys a large proportion of organic contaminants. Allows beneficial reuse of treated sediment. Enhances immobilization of residual inorganic wastes. Greater chance of public acceptance.	Pilot testing required. Limited availability of local vendors to treat/convert sediments to ceramic products.		Must identify a user of the material and negotiate costs.	

Cost was based primarily on the National Research Council (1997).

*Cost
0 $1,000/yd^3
1 $100/yd^3
2 $10/yd^3
3 $1/yd^3
4 <$1/yd^3

monitoring helps facilitate the attainment of RAOs by (1) assessing the level of risk reduction as a result of remediation; (2) providing information that can be used to enhance the performance of the remedy and facilitate midcourse corrections if necessary; and (3) providing information that can be used to reduce the level of uncertainty in future decision-making on similar projects. A long-term operations and maintenance plan also may be required for containment remedies (e.g., in situ capping or disposal in a CDF).

In order to develop the monitoring plan, performance criteria must be established. Performance criteria are standards by which to evaluate measurable or otherwise observable aspects of the restored system and thereby indicate the progress of the system toward meeting the project goals (Thom and Wellman, 1997). Performance criteria should be as closely linked to the RAOs as possible; the closer the tie, the better the ability to judge progress. From the performance criteria, monitoring parameters (i.e., measurement endpoints) can be chosen. Monitoring parameters are the aspects of the system's structure and function that can be measured. These measurement endpoints define the acceptable or optimal range of values for the chosen parameters. Ideally, the parameters are easy to measure and provide direct feedback on performance of a system toward meeting the RAOs. Examples of monitoring parameters for sediment sites are shown in Highlight 4-14. Generally, a combination of physical, chemical and biological monitoring parameters are needed to fully evaluate the degree of residual risk at the site.

Highlight 4-14. Examples of Physical Monitoring Parameters for Sediment Sites

- Surface sediment grain size distribution (habitat characteristics, sediment behavior)
- Bathymetry (configuration of dredged sediment bed or in situ cap)
- Sediment accumulation rate (monitored natural recovery rate)
- Chemical
- Sediment chemistry (attainment of site-specific final cleanup levels)
- Surface water chemistry (attainment of water quality criteria)
- Biological
- Benthic community analysis (recovery and health of benthic community)
- Toxicity tests (laboratory assessment of sediment toxicity)
- Tissue residues (bioaccumulation, food-chain risks)

The timing, frequency, and duration of long-term monitoring are dependent on the project's complexities and uncertainties. The monitoring program should extend through the period of most rapid change and into the period of stabilization in order to provide reasonable assurances that the remedy either has met its performance criteria and RAOs, or that it will not likely meet the criteria, in which case midcourse corrections will be necessary. For remedial actions under CERCLA, a

five-year review is required to determine whether the remediation has succeeded in protecting human health and the environment.

The results of the monitoring program provide information to project managers about the potential need for further action at the site. If monitoring results indicate that the project is progressing as expected, no action may need to be taken; however, if the project is not progressing as expected, potential modifications must be discussed. It is important to note that a divergence from the project's original goals is not necessarily undesirable. It is very possible that new goals that are better aligned with the natural tendencies of the system can be developed in such a way that the project is guided towards a new, but equally beneficial endpoint (Thom and Wellman, 1997).

4.5 MANAGEMENT OF SEDIMENTS IN AREAS REQUIRING MAINTENANCE DREDGING

If contaminated sediments are in a region being evaluated for maintenance or construction dredging, then the sediment should be evaluated according to the guidelines in the USACE/U.S. EPA "Green Book" for marine and estuarine sediments (U.S. EPA and USACE, 1991; http://www.epa.gov/OWOW/oceans/gbook/) or the *Inland Testing Manual* for freshwater sediments (U.S. EPA and USACE, 1998; http://www.epa.gov/OST/itm/index.html). If the sediment fails the dredged material testing guidelines, then open water disposal will not be permitted and other disposal options should be considered.

5.0 GLOSSARY

Acute toxicity = the ability of a substance to cause severe biological harm or death soon after a single exposure or dose. Also, any poisonous effect resulting from a single short-term exposure to a toxic substance.

Ambient concentration = the concentration of a chemical in a medium resulting from the addition of an incremental concentration to a background concentration.

Background concentration = the concentration of a substance in an environmental media (air, water, or soil) that occurs naturally or is not the result of human activities.

Bioaccumulation = process by which substances increase in concentration in living organisms because the substances are very slowly metabolized and/or excreted.

Bioassay = a test to determine the relative strength of a substance by comparing its effect on a test organism with that of a standard preparation.

Bioavailability = the degree of ability to be absorbed and ready to interact in organism metabolism.

Bioconcentration = the accumulation of a chemical in tissues of a fish or other organism to levels greater than the surrounding medium.

Bioturbation = the biological activities that occur at or near the sediment surface that cause the sediment to become mixed.

Chronic toxicity = the capacity of a substance to cause long-term poisonous health effects in humans, animals, fish, and other organisms.

Coagulation = clumping of particles in wastewater to settle out impurities, often induced by chemicals such as lime, alum, and iron salts.

Contaminant = any physical, chemical, biological, or radiological substance or matter that has an adverse effect on air, water, or soil.

Ecological risk assessment = the application of a formal framework, analytical process, or model to estimate the effects of human actions(s) on a natural resource and to interpret the significance of those effects in light of the uncertainties identified in each component of the assessment process. Such analysis includes initial hazard identification, exposure and dose-response assessments, and risk characterization.

Ecotoxicity = the study of toxic effects on nonhuman organisms, populations, and communities.

Effects Range-Low (ER-L) = the contaminant concentration representing the 10th percentile of data associated with biological effects.

Effects Range- Median (ER-M) = the contaminant concentration representing the median of the data associated with biological effects.

Estuary = region of interaction between rivers and near-shore ocean waters, where tidal action and river flow mix fresh and salt water. Such areas include bays, mouths of rivers, salt marshes, and lagoons. These brackish water ecosystems shelter and feed marine life, birds, and wildlife.

Exposure = the amount of radiation or pollutant present in a given environment that represents a potential health threat to living organisms.

Exposure pathway = the path from sources of pollutants via, soil, water, or food to humans and other species or settings.

Food chain = a sequence of organisms, each of which uses the next, lower member of the sequence as a food source.

Food web = the feeding relationships by which energy and nutrients are transferred from one species to another.

Higher trophic levels = the upper feeding level in a food chain or food web, consisting of consumers such as herbivores and carnivores.

Hydrogeology = the geology of groundwater, with particular emphasis on the chemistry and movement of water.

Hydrology = the science dealing with the properties, distribution, and circulation of water.

In situ = in its original place; unexcavated; remaining at the site or in the subsurface.

Infauna = benthic fauna living in the substrate of a body of water.

LC_{50} concentration = Median level concentration, a standard measure of toxicity. It tells how much of a substance is needed to kill half of a group of experimental organisms in a given time.

Lowest Observed Adverse Effect Level (LOAEL) = the lowest level of a stressor that causes statistically and biologically significant differences in test samples as compared to other samples subjected to no stressor.

No Observed Adverse Effects Level (NOAEL) = an exposure level at which there are no statistically or biologically significant increases in the frequency or severity of adverse effects between the exposed population and its appropriate control; some effects may be produced at this level, but they are not considered as adverse, or as precursors to adverse effects.

Organism = any form of animal or plant life.

Piscivorous = habitually feeding on fish.

Planktivorous = habitually feeding on plankton.

Redox = oxidation-reduction; a chemical reaction between two substances in which one substance is oxidized and the other reduced.

Reference site = a relatively unpolluted site used for comparison to polluted sites in environmental monitoring studies, often incorrectly referred to as a control site.

Remediation = cleanup or other methods used to remove or contain a toxic spill or hazardous materials from a Superfund site.

Risk assessment = qualitative or quantitative evaluation of the risk posed to human health and/or the environment by the actual or potential presence and/or use of specific pollutants.

Risk characterization = the last phase of the risk assessment process that estimates the potential for adverse health or ecological effects to occur from exposure to a stressor and evaluates the uncertainty involved.

Risk management = the process of evaluating and selecting alternative regulatory and nonregulatory responses to risk. The selection process necessarily requires the consideration of legal, economic, and behavioral factors.

Stressors = physical, chemical, or biological entities that can induce adverse effects on ecosystems or human health.

Toxicity = the degree to which a substance or mixture of substances can harm humans or animals. Acute toxicity involves harmful effects in an organism through a single or short-term exposure. Chronic toxicity is the ability of a substance or mixture of substances to cause harmful effects over an extended period, usually upon repeated or continuous exposure, and sometimes lasting for the entire life of the exposed organism. Subchronic toxicity is the ability of the substance to cause effects for more than one year but less than the lifetime of the exposed organism.

Watershed = the land area that drains into a stream; the watershed for a major river may encompass a number of smaller watersheds that ultimately combine at a common point.

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Section 1.0: Introduction

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Section 4.0: Sediment Remedial Alternative Evaluations

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http://www.epa.gov/epahome/ for laws, regulations, and programs

http://www.cwo.com/~herd1/ for California HERD info and eco checklist

http://web.ead.anl.gov/ecorisk/ for NAVFAC Ecological Risk Assessment Guidance

http://www.clu-in.org/ for EPA's Technology Innovation Office

http://regscreen.nfesc.navy.mil/htm/search.htm for regulatory searches

http://www.smwg.org/ Sediment Management Working group Advocates risk-based cleanups; information on Natural Attenuation.

http://www.hudsonvoice.com/mcss/ Major Contaminated Sediments Sites Database. A joint effort of the General Electric Co., Applied Environmental Management, Inc., and Blasland, Bouck & Lee, Inc. Extensive data base that includes cleanup standards and project costs.

http://www.sediments.org/ Sediment Research Web. Project summaries, technical reports and information on sediments.

http://www.ecy.wa.gov/programs/tcp/smu/sediment.html Washington State's Department of Ecology internet site on sediments.

http://sfbay.wr.usgs.gov/access/saltponds/index.html U.S. Geological Survey site; Wetlands creation in the San Francisco Estuary

http://www.oehha.org/ecotox/documents/caleco1.html for the new CalEPA OEHHA Ecotox info

http://chppm-www.apgea.army.mil/erawg/ for the Tri-Service Ecological Risk Assessment Working Group

http://www.acs-envchem.duq.edu/ Division of Environmental Chemistry Home Page, American Chemical Society

http://www.acs-envchem.duq.edu/ Resources for chemical information

http://www.epa.gov/OST/cs/stratefs.html for Contaminated Sediment Management Strategy fact sheet

http://www.epa.gov/OST/cs/stratndx.html for Contaminated Sediment Management Strategy document

http://www.epa.gov/superfund/programs/risk/humhlth.htm

http://www.epa.gov/ordntrnt/ORD/WebPubs/carcinogen/

http://www.epa.gov/ordntrnt/ORD/WebPubs/repro/

http://www.epa.gov/ncea/nurotox.htm.