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and Emergency Response

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Contaminated Sediment Remediation Guidance for Hazardous Waste Sites

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DISCLAIMER

EPA is issuing this draft document to ask for public comment. When finalized, this document will provide technical and policy guidance to the U.S. Environmental Protection Agency (EPA) and state staff on making risk management decisions for contaminated sediment sites. It also will provide guidance to the public and to the regulated community on how EPA intends to exercise its discretion in implementing its regulations at contaminated sediment sites. It is important to understand, however, that this document does not substitute for statutes EPA administers nor their implementing regulations, nor is it a regulation itself. Thus, even when finalized this document will not impose legally-binding requirements on EPA, states, or the regulated community, and may not apply to a particular situation based upon the specific circumstances. Rather, the draft document suggests approaches that may be used at particular sites as appropriate, given site-specific circumstances. EPA expects to change this draft document based on public comment. Even after the document is finalized, however, EPA will welcome public comments on the document at any time and will consider those comments in any future revisions to the document which EPA may make without public notice.

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National Oceanic and Atmospheric Administration (NOAA)
U.S. Army Corps of Engineers (USACE)
U.S. Fish and Wildlife Service (USFWS)

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Oregon Department of Environmental Quality
Massachusetts Department of Environmental Quality
Wisconsin Department of Natural Resources

The following individuals led subgroups to draft various sections of the guidance or otherwise contributed substantially to the overall character of the guidance:

Allison Hiltner (EPA Region 10)
Doug Johnson (EPA Region 4)
Fran Kremer (EPA ORD)
Judith McCulley (EPA Region 8)
Richard Nagle (EPA Region 5)
Michael Palermo (USACE)

The following individuals drafted sections of the guidance or assisted in various substantial ways in preparation of the document and EPA also sincerely appreciates their assistance:

David Allen (USFWS)
Daniel Averett (USACE)
Ed Barth (EPA ORD)
Gary Baumgarten (EPA Region 6)
Stacey Bennett (EPA Region 6)
Barbara Bergen (EPA ORD)
Ned Black (EPA Region 9)
Richard Brenner (EPA ORD)
Daniel Chellaraj (EPA OERR)
Scott Cieniawski (EPA GLNPO)
Sherri Clark (EPA OERR)
Barbara Davis (OERR Oil)
Kevin E. Donovan (EPA OSW)
David Drake (EPA Region 7)
Bonnie Eleder (EPA Region 5)
Steve Ells (EPA OERR)
Jane Marshall Farris (EPA OST)
Joan Fisk (EPA OERR)
Tom Fredette (USACE)
Gayle Garman (NOAA)
Joanna Gibson (EPA OERR)
Ron Gouguet (NOAA)
Patricia Gowland (EPA OERR)
Jim Hahnenberg (EPA Region 5)

Earl Hayter (EPA ORD)
Richard Healy (EPA OST)
Glynis Hill (EPA OWOW)
Robert Hitzig (EPA OERR)
Michael Horne (USFWS)
Michael Hurd (EPA OERR)
Sheila Igoe (EPA OGC)
Sharon Jaffess (EPA Region 2)
Brenda Jones (EPA Region 5)
Karen Keeley (EPA Region 10)
Anne Kelly (EPA Region 2)
Michael Kravitz (EPA ORD)
Tim Kubiak (USFWS)
Carlos Lago (EPA OSW)
Amy Legare (EPA OSRE)
Sharon Lin (EPA OWOW)
John Lindsay (NOAA)
Terry Lyons (EPA ORD)
Kelly Madalinski (EPA TIO)
John Malek (EPA Region 10)
Steve Mangion (EPA Region 1)
Dale Matey (EPA OERR)
Bruce Means (EPA OERR)
Amy Merten (NOAA)
David Mueller (USGS)
Jan A. Miller (USACE)
William Nelson (EPA ORD)
Walter Nied (EPA Region 5)
Mary Kay O'Mara (USACE)
Charles Openchowski (EPA OGC)
David Petrovski (EPA Region 5)
Cornell Rosiu (EPA Region 1)
Fred Schauffler (EPA Region 9)
Ken Seeley (USFWS)
Betsy Shaw (EPA OERR)
Robert Shippen (EPA OST)
Craig Smith (EPA Region 7)
Mark Sprenger (EPA OERR)
Laurel Staley (EPA ORD)
Pam Tames (EPA Region 2)
Dennis Timberlake (EPA ORD)
Yolaanda Walker (EPA OSRE)
Larry Zaragoza (EPA OERR)
Craig Zeller (EPA Region 4)

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Ernie Watkins, Chair, Contaminated Sediment Remediation Guidance Workgroup

Leah Evison, Project Manager, Office of Emergency and Remedial Response Sediment Team

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ACRONYMS

ADCP:	Acoustic Doppler Current Profiler
ADDAMS:	Automated Dredging and Disposal Alternatives Management System
AOC:	Administrative Order on Consent
ARAR:	Applicable or Relevant and Appropriate Requirement
ARCS:	Assessment and Remediation of Contaminated Sediments
ASTM:	American Society for Testing and Materials
AVS:	Acid Volatile Sulfide
AWQC:	Ambient Water Quality Criteria
BSAF:	Biota Sediment Accumulation Factors
BEAST:	Benthic Assessment of Sediment
CAD:	Contained Aquatic Disposal
CAG:	Community Advisory Group
CASRGW:	Contaminated Aquatic Sediment Remedial Guidance Workgroup
CD:	Consent Decree
CDF:	Confined Disposal Facility
CERCLA:	Comprehensive Environmental Response, Compensation, and Liability Act (1980)
COC:	Contaminants of Concern
CRC:	Coastal Resource Coordinator
CSM:	Conceptual Site Model
CSTTP:	Contaminated Treatment Technology Program
CWA:	Clean Water Act
DDD:	Dichloro-Diphenyl-Dichloroethane
DDE:	Dichloro-Diphenyl-Dichloroethylene
DDT:	Dichloro-Diphenyl-Trichloroethane
DGPS:	Differential Global Positioning System
DNAPL:	Dense Non-Aqueous Phase Liquids
DOD:	Department of Defense
DOE:	Department of Energy
DOI:	Department of the Interior
DQO:	Data Quality Objective
EPA:	Environmental Protection Agency
ESD:	Explanation of Significant Difference
ESGs:	Equilibrium-partitioning Sediment Guidelines
ET:	Ecotox Threshold
FIELDS:	Fully Integrated Environmental Location Decision Support
FFRRO:	Federal Facilities Restoration and Reuse Office
FMP:	Fishery Management Plan
FS:	Feasibility Study
GIS:	Geographic Information System
GPS:	Global Positioning System
GLNPO:	Great Lakes National Program Office
HASP:	Health and Safety Plan
HSRC:	Hazardous Substance Research Center
HWIR:	Hazardous Waste Identification Rule

IC:	Institutional Control
LTFATE:	Long-Term Fate Model
MNA:	Monitored Natural Attenuation
MNP:	Monitored Natural Processes
MNR:	Monitored Natural Recovery
NAPL:	Non-Aqueous Phase Liquids
NCP:	National Oil and Hazardous Substance Pollution Contingency Plan
NMFS:	National Marine Fisheries Service
NOAA:	National Oceanic and Atmospheric Agency
NPDES:	National Pollutant Discharge Elimination System
NPL:	National Priorities List
NRC:	National Research Council
O&M:	Operation and Maintenance
OERR:	Office of Emergency and Remedial Response
OGC:	Office of the General Counsel
OMB:	Office of Management and Budget
ORD:	Office of Research and Development
OSWER:	Office of Solid Waste and Emergency Response
OU:	Operable Unit
OW:	Office of Water
PAH:	Polynuclear Aromatic Hydrocarbon
PA/SI:	Preliminary Assessment/Site Inspection
PBTs:	Persistent Bioaccumulative Toxics
PCB:	Polychlorinated Biphenyl
PCLT:	Pancake Column Leach Test
PIANC:	Permanent International Association of Navigational Congresses
PRGs:	Preliminary Remediation Goals
PRP:	Potentially Responsible Party
QA/QC:	Quality Assurance/Quality Control
QAPP:	Quality Assurance Project Plan
RAOs:	Remedial Action Objectives
RCRA:	Resource Conservation and Recovery Act
REACH IT:	Remediation and Characterization Innovative Technologies
RGs:	Remediation Goals
RI:	Remedial Investigation
ROD:	Record of Decision
RPM:	Remedial Project Manager
RREL:	Risk Reduction Engineering Laboratory
SAB:	Science Advisory Board
SEM:	Simultaneously Extracted Metals
SITE:	Superfund Innovative Technology Evaluation
SPC:	Sediment Profile Camera
SQuiRTs:	Screening Quick Reference Tables
SSFATE:	Suspended Sediment Fate Model
STFATE:	Short-Term Fate Model
TAG:	Technical Assistance Grants

TBC:	To-Be-Considered Advisories, Criteria, or Guidance
TCLP:	Toxicity Characteristic Leachate Procedure
TMDL:	Total Maximum Daily Load
TMV:	Toxicity, Mobility, and Volume
TOC:	Total Organic Carbon
TOSC:	Technical Outreach Services for Communities
TSCA:	Toxic Substances Control Act
TSS:	Total Suspended Solids
UAO:	Unilateral Administrative Order
USACE:	United States Army Corps of Engineers
USCG:	United States Coast Guard
USDA:	United States Department of Agriculture
USFWS:	United States Fish and Wildlife Service
USGS:	United States Geological Survey
WES:	USACE Waterways Experimental Station
WQLS:	Water Quality Limited Segment
WRDA:	Water Resources Development Act

Executive Summary

In 2001, the U.S. Environmental Protection Agency (EPA) released for comment a draft report, *The Incidence and Severity of Sediment Contamination in Surface Waters of the United States*, identifying locations in all regions of the country where sediment contamination could be associated with probable or possible adverse effects to aquatic life and/or human health (U.S. EPA 2001a). In addition, contaminated sediment has significantly impaired the navigational and recreational uses of rivers and harbors in the U.S. (NRC 1997 and 2001). As of 2001, EPA had decided to take an action under the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) to clean up sediment at approximately 140 sites (U.S. EPA 2001a) and additional sites under the Resource Conservation and Recovery Act (RCRA). The remedies for 66 sites are large enough that they are being tracked at the national level. Many other sites are being cleaned up under state authorities, other federal authorities, or as voluntary actions.

This document provides technical and policy guidance for project managers and management teams making risk management decisions for contaminated sediment sites. It is primarily intended for project managers considering actions under CERCLA, although technical aspects of the guidance are also intended to assist project managers addressing sediment contamination under RCRA. However, many aspects of this guidance will be useful to other governmental organizations and potentially responsible parties (PRPs) that may be conducting a sediment cleanup. Provided below is a short summary of each of the eight chapters. Sediment cleanup is a complex issue, and as new techniques evolve, EPA will issue new or updated guidance.

Chapter 1, Introduction, describes the general backdrop for sediment remediation and reiterates EPA's previously issued OSWER Directive 9285.6-08, *Principles for Managing Contaminated Sediment Risks at Hazardous Waste Sites* (U.S. EPA 2002a). Other issues addressed here include the role of the natural resource trustees, states, tribes, and the community at sediment sites. Where there are natural resource damages associated with sediment sites, coordination between the remedial and trusteeship roles at the federal, state, and tribal levels is especially important. In addition to their role as natural resource trustees, certain state cleanup agencies and certain Indian tribes or nations have an important role as co-regulators and/or affected parties and as sources of essential information. Communities of people who live and work adjacent to waterbodies containing contaminated sediment should be given understandable information about the safety of their activities, and be provided opportunities for involvement in the EPA's decision-making process for sediment cleanup. Social and cultural practices should also be considered in evaluating the impacts associated with contaminated sediment and sediment cleanup.

Chapter 2, Remedy Investigation Considerations, introduces investigation issues unique to the sediment environment, including those related to characterizing the site, developing

conceptual site models, understanding current and future watershed conditions, controlling sources, and developing cleanup goals. Especially important at sediment sites is an accurate conceptual site model that identifies contaminant sources, transport mechanisms, exposure pathways, and receptors at various levels of the food chain. Project managers should consider the role of a sediment site in the watershed context, including other potential contaminant sources, key issues within the watershed, and current and reasonably anticipated or desired future uses of the waterbody and adjacent land. Essential parts of good site characterization and remedy selection include the identification and control of continuing sources of contamination and an accurate understanding of their contribution to site risk and potential for recontamination. It is also very important that remedial action objectives, remediation goals, and cleanup levels are based on site-specific data and are clearly defined. At most Superfund sites, chemical-specific remediation goals should be developed into final sediment cleanup levels by weighing the National Oil and Hazardous Substances Pollution Contingency Plan (NCP) balancing and modifying criteria and other factors relating to uncertainty, exposure, and technical feasibility.

Chapter 2 also introduces issues relating to sediment bed stability and modeling at sediment sites. An important part of the remedial investigation at many sediment sites is a site-specific assessment of the extent of sediment disturbance in the past, and a prediction about whether there is likely to be significant disturbance in the foreseeable future. An accurate assessment of sediment stability (e.g., erosion and deposition rates) can be one of the most important factors in identifying areas suitable for monitored natural recovery (MNR), in-situ caps or near-water confined disposal facilities. Evaluation of alternatives should include consideration of disruption from human and natural causes, including at a minimum, the 100-year flood and other events with a similar probability of occurrence. Project managers should make use of the variety of empirical field methods available for evaluating sediment stability and, where appropriate, also use numerical models for evaluating events for which there is no field record and for predicting future stability. There is a wide range of empirical models and more robust computer models that can be applied to contaminated sediment sites. Models are useful tools, but they can be very time consuming and expensive to apply at complex sediment sites. Nevertheless, models are helpful in that, when properly applied, they provide a more complete understanding of the future transport and fate of contaminants. When using models, project managers should be aware of the uncertainties and variability of model predictions and, where possible, quantify these using sensitivity analysis or other evaluation methods. Project managers should, where possible, use validated and verified models that are in the public domain and calibrate them to site-specific conditions.

Chapter 3, Feasibility Study Considerations, supplements existing EPA guidance by offering sediment-specific guidance about developing alternatives, applying the NCP remedy selection criteria, identifying applicable or relevant and appropriate requirements (ARARs), estimating cost, and using institutional controls. Major cleanup methods include dredging and excavation, in-situ capping, and MNR. Innovative pilot and lab testing of in-situ treatment in the form of reactive caps or sediment additives are underway and may be useful in the future. Due

to the limited number of cleanup methods available for contaminated sediment, generally project managers should evaluate both in-situ and ex-situ methods at every site where they may be appropriate. At large or complex sites, project managers have found that alternatives that combine a variety of cleanup methods are frequently cost effective. All final remedial actions at CERCLA sites must be protective of human health and the environment, and must comply with ARARs unless a waiver is justified. Developing accurate cost estimates is an essential part of evaluating sediment alternatives. Project managers should evaluate capital costs, operation and maintenance costs (including long-term monitoring), and net present value. Institutional controls are frequently evaluated as part of sediment alternatives to prevent or reduce human exposure to contaminants. Common types of institutional controls at sediment sites include fish consumption advisories, commercial fishing bans, and waterway use restrictions. In some cases, land use restrictions or structure maintenance requirements have also been important elements of an alternative.

Chapter 4, Monitored Natural Recovery, summarizes the natural processes that should be considered when evaluating MNR as a cleanup method, and briefly discusses enhanced natural recovery through thin-layer placement. The chapter defines MNR as a sediment cleanup method that uses known, ongoing, naturally occurring processes to contain, destroy, or otherwise reduce the bioavailability or toxicity of contaminants in sediment. Although "natural recovery" may be ongoing at many sites, the key factors that distinguish use of MNR as a remedy are the presence of unacceptable risk (i.e., the need for action), the ongoing burial or degradation/transformation of contaminants, and the establishment of a cleanup level that is expected to be met in a particular time frame. Although burial by clean sediment is often the dominant process relied upon for natural recovery, multiple physical, biological, and chemical mechanisms frequently act together to reduce risk. MNR should be evaluated based on site-specific data collected over a number of years, including an assessment of seasonal variation. Project managers should evaluate the long-term stability of the sediment bed and the likely ecological and human health impacts of sediment movement. Contingency measures should be included as part of a MNR remedy when there is significant uncertainty that the remedial action objectives will be achieved within the predicted time frame. MNR should generally be used as one component of an overall site remedy, and cautiously as the sole cleanup method.

Chapter 4 also discusses the major advantages and disadvantages of MNR. The major advantages of MNR are its relatively low cost and its non-invasive nature which involves minimal disruption to the existing biological community. In addition, because no construction or infrastructure is needed, it is generally much less disruptive to communities than active cleanup methods. Major disadvantages of MNR are that it generally leaves contaminants in place without engineered containment; it can be slow to reach cleanup levels in comparison to active cleanup methods; its effectiveness may be more uncertain than active cleanup methods; and it frequently relies upon institutional controls, such as fish consumption advisories, which may have limited effectiveness to control human exposure during the recovery period.

Chapter 5, In-Situ Capping, summarizes the major capping technologies and describes the site conditions that are critical to understand in evaluating the feasibility and effectiveness of in-situ capping. In-situ capping refers to placement of a subaqueous covering or cap of clean material over contaminated sediment. A cap reduces risk through three primary functions: 1) physical isolation of the contaminated sediment from the aquatic environment; 2) stabilization of contaminated sediment, preventing resuspension and transport to other sites; and 3) reduction of the movement of dissolved and colloidally transported contaminants. Backfill of clean material designed to mix with dredging or excavation residuals or to fill post-dredging depressions, rather than act as a engineered cap to isolate buried contaminants, is not considered in-situ capping in this guidance.

Chapter 5 also discusses the major advantages and disadvantages of in-situ capping. The major advantage of in-situ capping is that it can quickly reduce exposure to contaminants. Compared to dredging and excavation, less infrastructure is needed (e.g., materials handling, treatment, disposal), and the potential for contaminant resuspension and the risks associated with dispersion of contaminated materials during construction is typically lower. In-situ capping may also be less disruptive to communities than dredging or excavation. The major disadvantage of in-situ capping is that the contaminated sediment is left in place in the aquatic environment where contaminants may be exposed or dispersed if the cap is significantly disturbed or not properly maintained. Another potential disadvantage to in-situ capping may be that in some situations usable habitat may not be provided by the cap materials.

Chapter 6, Dredging and Excavation, summarizes excavation (conducted in the dry) and dredging (conducted under water) technologies; the components involved in transport, treatment, storage, and disposal of dredged or excavated sediment; and describes the importance of evaluating site conditions that are critical to the feasibility and effectiveness of dredging and excavation. A dredging or excavation alternative should include a thorough evaluation of the details concerning all phases of the project, including removal, transport and storage, treatment (pretreatment, treatment of decant and/or dewatering effluents and sediment, if necessary), and disposal (liquids and solids). When conducted, environmental dredging should use equipment and methods of operation which minimize resuspension. In some environments, excavation may lead to lower levels of residual contamination than dredging, although site preparation for excavation can be more lengthy and costly than for a dredging project due to the need for re-routing or draining the waterbody. Dredging projects should make realistic assumptions regarding residual contamination. Where over-dredging is possible, residual contamination is generally lower than where this practice is not possible. When predicting the effects on risk reduction of a dredging or excavation remedy which includes removal of deeply buried contaminants, it is important that project managers recognize that contaminant levels in fish tissue or other biota will only respond to removal of contaminants that are bioavailable.

Chapter 6 also discusses the major advantages and disadvantages of sediment removal by dredging and excavation. One of the principal advantages of removing contaminated sediment

from the aquatic environment is that, if residuals are low, it results in the least uncertainty regarding future environmental exposure to contaminants because they are removed from the aquatic ecosystem and treated and/or disposed in a controlled environment. Sediment removal is currently the only cleanup method that allows for treatment and/or beneficial reuse of previously contaminated material. Sediment removal also allows maximum flexibility regarding future use of a waterbody. The principal disadvantages of sediment removal are that it is usually more complex and costly than in-situ cleanup methods, and that there is frequently significant uncertainty concerning the extent of residual contamination. The need for transport, storage, treatment (where applicable), and disposal facilities may lead to increased social or risk impacts on communities. In particular, disposal capacity may be limited in existing municipal or hazardous waste landfills and it may be difficult to site new local disposal facilities. Another disadvantage includes the potential for contaminant losses during dredging through resuspension, and to a generally lesser extent, through other processes during transport, treatment, or disposal. Finally, short-term disruption of the benthic environment is unavoidable during sediment removal, as it is for a capping remedy.

Chapter 7, Remedy Selection Considerations, discusses applying the NCP expectations (NCP §300.430(a)(1)(iii)) to CERCLA sediment remedies, considering a no-action alternative, choosing among sediment cleanup methods, and considering alternatives that include institutional controls. Generally, selecting a "no-action" remedy may be appropriate when: 1) the site poses no current or potential threat to human health or the environment; 2) CERCLA or RCRA do not provide the authority to take action; or 3) a previous action has eliminated the need for further action. Where a remedy is necessary, the best route to overall risk reduction depends on a large number of site-specific considerations, some of which may be subject to significant uncertainty. Any decision regarding the specific choice of a risk management strategy for contaminated sediment should be based on careful consideration of the advantages and disadvantages of each available option and a comparison among them. Documenting and communicating how and why remedy decisions were made are especially important at complex sediment sites. When considering remedies that include institutional controls, project managers should determine what entities possess the legal authority, capability and willingness to implement, and where applicable, monitor, enforce and report on the status of the control. When evaluating cleanup alternatives, project managers should include realistic assumptions concerning residuals and contaminant releases from in-situ and ex-situ remedies, the potential effects of those residuals and releases, and the length of time over which a risk may persist. In addition to considering the impacts of each alternative on human health and ecological systems, the social and cultural impacts of each alternative on the community and the opportunities for site reuse and redevelopment should be assessed.

At many sites, but especially at large sites, a combination of sediment cleanup methods may be the most appropriate way to manage the risk. The remedy selection process for sediment sites should include a clear understanding of the uncertainties involved, including uncertainties concerning the predicted effectiveness of various alternatives and the time frames for achieving

remedial goals. The uncertainty of factors very important to the remedy decision should be quantified, so far as this is possible. Where it is not possible to quantify uncertainty, sensitivity analysis may be helpful to determine which apparent differences between alternatives are most likely to be significant.

Chapter 8, Remedial Action and Long-Term Monitoring, provides an approach to developing an effective remedial action and long-term monitoring program at contaminated sediment sites. It presents the key elements of a contaminated sediment site monitoring program, introduces some of the monitoring techniques available for physical, chemical, and biological measurements, and summarizes some of the factors to consider when monitoring remedies which include natural recovery, in-situ capping, or dredging/excavation. A monitoring program is important for all types of sediment remedies, both during the remedial action and over the long-term to ensure that sediment risks and exposure pathways at a site have been adequately managed and the remedy remains protective. The development of monitoring plans should follow a systematic planning process that identifies monitoring objectives, decision criteria, endpoints, and data collection and analysis methods. Remedial action monitoring includes both construction/operational monitoring and monitoring intended to measure whether cleanup levels and remedial action objectives have been met. After completion of the remedial action, long-term monitoring is important to assess potential re-contamination, to evaluate continued containment of buried or capped contaminants, and to monitor dredging residuals and on-site disposal facilities. Additional monitoring data will help not only to answer site-specific questions but will also contribute to better understanding of technology performance at the national level.

1.0 INTRODUCTION

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1.0 INTRODUCTION

1.1 PURPOSE AND CONTENT

This document provides technical and policy guidance for project managers and management teams making risk management decisions for contaminated sediment sites. It is primarily intended for project managers considering remedial response actions or non-time-critical removal actions under the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA), or more commonly known as "Superfund," although technical aspects of the guidance are also intended to assist project managers addressing sediment contamination under the Resource Conservation and Recovery Act (RCRA). Many aspects of this guidance will also be useful to other governmental organizations and potentially responsible parties (PRPs) that are conducting a sediment cleanup under environmental statutes, such as the Clean Water Act (CWA) or the Water Resource Development Act (WRDA).

Contaminated sediment is addressed in this guidance in a wide variety of aquatic environments, including rivers, streams, wetlands, ponds, lakes, reservoirs, harbors, estuaries, bays, intertidal zones, and coastal ocean areas. Sediment in wastewater lagoons, detention/sedimentation ponds, on-site tanks, on-site storage/containment facilities, or roadside ditches is not addressed. Although flood plain soils and upland source materials are important aspects of sediment sites, existing guidance [e.g., the U.S. Environmental Protection Agency's (EPA's) *Soil Screening Guidance* (U.S. EPA 1996a)] makes inclusion of these aspects less critical for new guidance. This guidance addresses both in-situ and ex-situ cleanup methods for sediment, including monitored natural recovery (MNR), in-situ capping, and dredging and excavation.

Following this introductory chapter, the guidance presents sediment-specific considerations during remedial investigations [(RI), see Chapter 2] and feasibility studies [(FS), see Chapter 3); evaluation of the three major cleanup methods for sediment (see Chapter 4, Monitored Natural Recovery, Chapter 5, In-Situ Capping, and Chapter 6, Dredging and Excavation); selection of sediment remedies (see Chapter 7); and sediment site monitoring (see Chapter 8). Although some issues concerning site characterization and risk are discussed early in the guidance, the emphasis of the guidance is on evaluating cleanup methods (i.e., the FS stage of the Superfund process).

1.2 CONTAMINATED SEDIMENT

For the purposes of this guidance, contaminated sediment is soil, sand, or other mineral or organic matter that accumulates on the bottom of a waterbody and contain toxic or hazardous materials that may adversely affect human health or the environment. It may wash from land, be deposited from air, erode from aquatic banks or beds, or form from underwater breakdown or buildup of minerals (U.S. EPA 1998a). Contaminated sediment may be present in wetlands, streams, rivers, lakes, reservoirs, harbors, along ocean margins, or in other waterbodies. In this guidance, "waterbody" generally includes all of these environments.

Examples of primary and secondary sources of contaminants in sediment are included in Highlight 1-1.

Highlight 1-1: Potential Sources of Contaminants in Sediment

- Direct pipeline discharges into a waterbody from industrial facilities, waste water treatment plants, storm water, or combined sewer overflows
- Chemical spills into a waterbody or wetland
- Surface runoff or erosion of flood plain soil from contaminated sources on land, such as spills, waste dumps and chemical storage facilities, and agricultural or urban areas
- Air emissions from power plants, incinerators, pesticide applications, or other sources, that may be transferred to a waterbody or wetland through precipitation, runoff, or direct deposition
- Up welling or seepage of contaminated ground water or non-aqueous phase liquids (NAPL) into a waterbody or wetland

Organic contaminants in sediment typically adsorb to sediment particles and exist in the pore water between sediment particles. Metals also adsorb to sediment and may bind to sulfides in the sediment. The relative proportion of contaminants between sediment and pore water depends on the type of contaminant and the physical and chemical properties of the sediment and water.

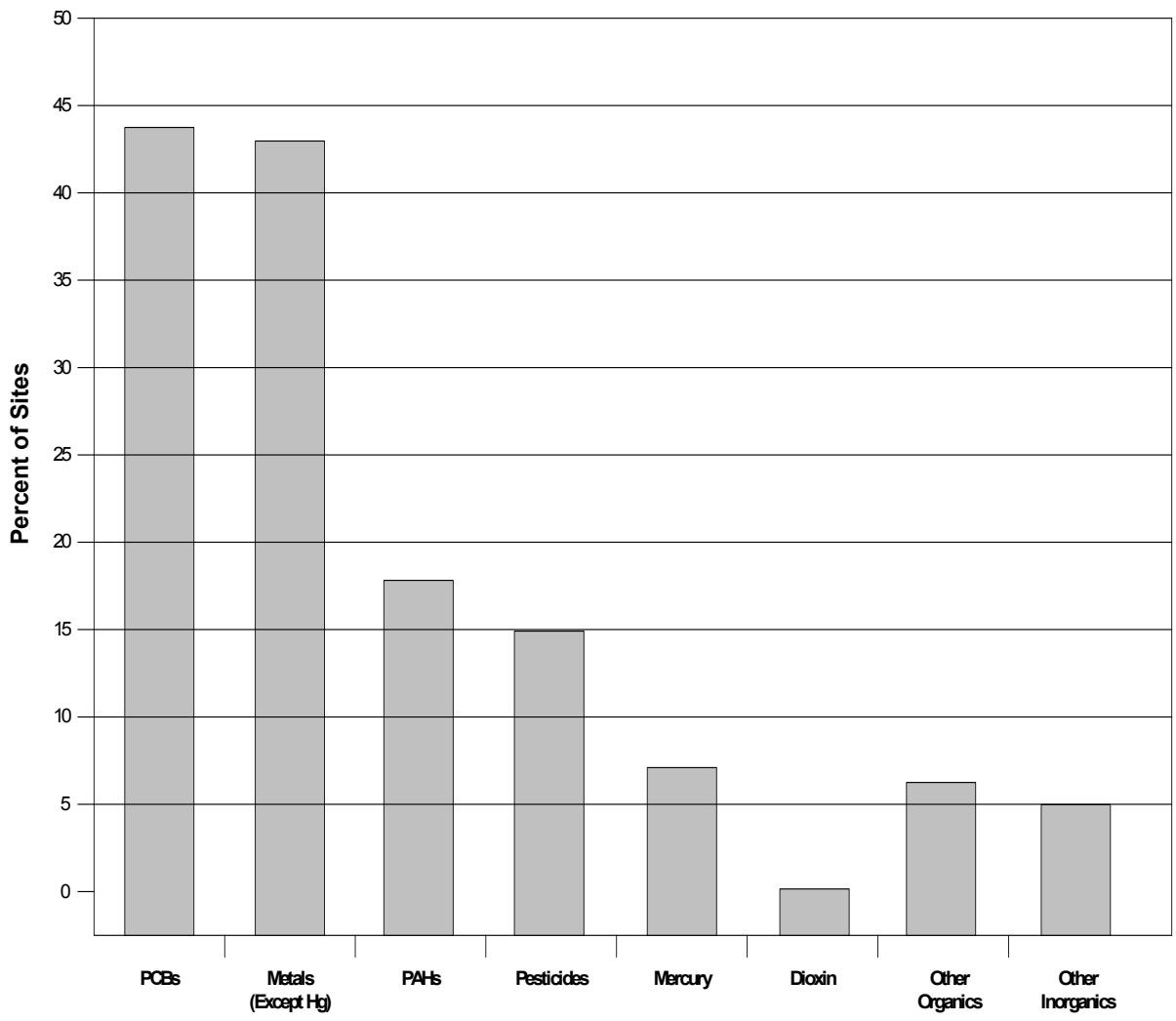
Many contaminants persist for years or decades because the contaminant either does not degrade or degrades very slowly in the aquatic environment. Some bottom-dwelling organisms ingest contaminated sediment, and in shallow water environments, humans may also come into contact with contaminated sediment. Contaminants sorbed to sediment normally develop an equilibrium with the dissolved fraction in the pore water. Also, contaminants may dissolve back into the water column, to be taken up by fish and other aquatic organisms. Some contaminants, such as most metals, are primarily hazardous because of direct toxicity. Others, called persistent bioaccumulative toxics [(PBTs), e.g., polychlorinated biphenyls (PCBs), pesticides, and methyl mercury], are of concern because they may bioaccumulate, or magnify in concentration as they are passed up the food chain. Fish may become highly contaminated and endanger humans and wildlife that eat fish. Women of childbearing age, young children, people that derive much of their dietary protein from fish and shellfish, and people with impaired immune systems may be especially at risk.

In 2001, the EPA released for comment a draft report, *The Incidence and Severity of Sediment Contamination in Surface Waters of the United States* (U.S. EPA 2001a). This report identifies locations where sediment contamination could be associated with probable or possible adverse effects to aquatic life and/or human health; these locations are in all regions of the country (U.S. EPA 2001a). The EPA is working on completing this document and expects to release in final form in 2003. States have issued more than 2,618 advisories limiting consumption of fish and wildlife, in large part due to sediment contamination (U.S. EPA 2002b). In addition, contaminated sediment has significantly impaired the navigational and recreational uses of rivers and harbors in the U.S. Navigational dredging is not currently being performed in many harbors and waterways because of the concern for impacts of dredging on water quality, liability to those doing the dredging, and disposal options for the contaminated dredged material [(National Research Council) NRC 1997 and 2001].

As of 2001, the Superfund program decided to take an action to clean up sediment at approximately 140 sites (U.S. EPA 2001a). The remedies for 66 sites are large enough that they are being

tracked at the national level. These sites include a wide variety of contaminants, as presented in Highlight 1-2.

Highlight 1-2: Major Contaminants at Superfund Sediment Sites (Remedy Selected through 2001)



Many aspects of the cleanup process may be more complex at sediment sites versus sites with soil or ground water contamination alone. Some potential complicating factors are listed in Highlight 1-3. For these and other reasons as presented in this guidance a team of experts is frequently needed to advise the project manager.

Highlight 1-3: Why Are Sediment Sites a Unique Challenge?

- Sediment sites may have a large number of sources, some of which can be difficult to control
- The sediment environment is usually dynamic, and understanding the effect of natural and man-made events on sediment stability and contaminant transport can be difficult
- Cleanup work in an aquatic environment is frequently difficult from an engineering perspective and more costly than other media
- Contamination is often diffuse and the sites large and diverse (e.g., mixed use, numerous property owners)
- Many sediment sites contain ecologically valuable resources or legislatively protected environments
- For large sites, a number of communities with differing views and opinions may be affected
- There may be significant natural resource damages at interest in sediment sites

1.3 RISK MANAGEMENT PRINCIPLES AND METHODS

OSWER Directive 9285.6-08, *Principles for Managing Contaminated Sediment Risks at Hazardous Waste Sites* (U.S. EPA 2002a), presents eleven risk management principles that will help project managers make scientifically sound and nationally consistent risk management decisions at contaminated sediment sites. Project managers should carefully consider these principles when planning and conducting site investigations, involving the affected parties, and selecting and implementing a response. While the directive applies to sediment sites addressed under CERCLA or RCRA, its implementation at particular sites should be tailored to the size and complexity of the site, to the magnitude of site risks, and to the type of action contemplated. The principles should be applied within the framework of the EPA's existing statutory and regulatory requirements, such as the National Oil and Hazardous Substances Pollution Contingency Plan's (NCP's) nine criteria in NCP §300.430(c). The eleven principles are listed in Highlight 1-4 and are incorporated throughout this guidance (see Appendix A for a complete version of the directive).

1.3.1 Cleanup Methods

Highlight 1-5 lists the major cleanup methods available for managing risks from contaminated sediment. Frequently, a final sediment remedy combines more than one type of method. In addition to these methods, many sediment remedies include the use of institutional controls, such as waterway or land use restrictions, and fish consumption advisories to limit exposures to contaminants. Institutional controls are discussed further in Chapter 3, Feasibility Study Considerations.

Highlight 1-4: Risk Management Principles for Contaminated Sediment Sites

- Control sources early
- Involve the community early and often
- Coordinate with states, local governments, tribes, and natural resource trustees
- Develop and refine a conceptual site model that considers sediment stability
- Use an iterative approach in a risk-based framework
- Carefully evaluate the assumptions and uncertainties associated with site characterization data and site models
- Select site-specific, project-specific, and sediment-specific risk management approaches that will achieve risk-based goals
- Ensure that sediment cleanup levels are clearly tied to risk management goals
- Maximize the effectiveness of institutional controls and recognize their limitations
- Design remedies to minimize short-term risks while achieving long-term protection
- Monitor during and after sediment remediation to assess and document remedy effectiveness

Source: U.S. EPA 2002a

Highlight 1-5: Potential Cleanup Methods for Contaminated Sediment

In-situ Methods	Ex-situ Methods
In-Situ Capping: • Single-layer granular caps • Multi-layer granular caps • Combination granular/geotextile caps	Dredging: • Hydraulic • Mechanical • Combination • Treatment and/or disposal of dredged material
Monitored Natural Recovery: • Physical processes • Chemical processes • Biological processes	Excavation: • Water diversion/dewatering • Treatment and/or disposal of excavated material
In-situ Treatment (currently experimental only): • Reactive caps • Additives/enhanced biodegradation	

1.3.2 Urban Revitalization and Reuse

Revitalization of urban areas and returning land and waterbodies to productive use have become increasingly important to the Superfund program in recent years. Sediment sites may present opportunities to incorporate these concepts into remedy selection, remedial design, and into other phases of the risk management process. At sediment sites in urban areas, project managers should look for opportunities to help meet the goals of local governments and other entities to revitalize use of waterfront property, harbors, and other waterbodies. This may involve identifying potential partners such as land owners, elected officials, local land and water planning and development agencies, and reviewing local land use plans. It may lead to opportunities to tailor remedies to conform with the wishes of local stakeholders, land owners, and land use planners. For example, it may be possible to locate disposal structures or rail lines in areas that maximize future reuse. Beneficial reuse of dredged material also may present an opportunity for urban revitalization.

1.4 DECISION-MAKING PROCESS

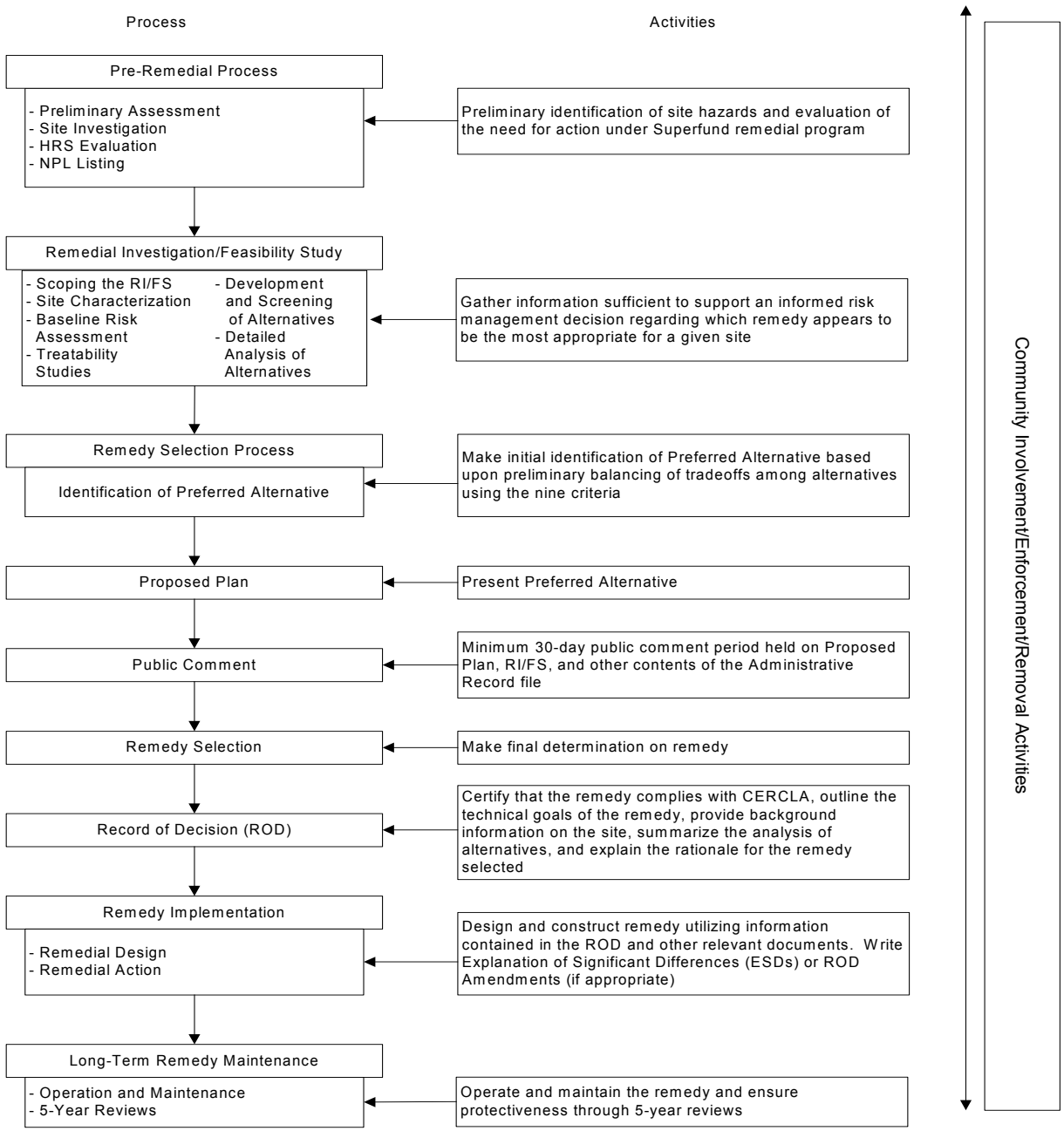
The Superfund remedial response process is shown in Highlight 1-6, taken from *A Guide to Preparing Superfund Proposed Plans, Records of Decision, and Other Remedy Selection Decision Documents*, also referred to as the "ROD Guidance" (U.S. EPA 1999a). See the ROD Guidance for detailed descriptions of each stage of the process. This process is the decision-making framework that project managers should use for remedial actions under CERCLA. The RCRA remedial process is laid out in the May 1, 1996 Advanced Notice of Proposed Rulemaking [(ANPR), 61 FR 19447].

In the report *A Risk-Management Strategy for PCB-Contaminated Sediments* (NRC 2001), the NRC recommended the use of the iterative decision-making approach shown in Highlight 1-7. This approach fits within the context of EPA's existing remedial process (Highlight 1-6) and serves to remind project managers of the usefulness of iteration and the importance of public involvement throughout the decision-making process. However, as the NRC (2001) noted: "The use of the NRC approach should not be used to delay a decision at a site if sufficient information is available to make an informed decision. Particularly in situations where there are immediate risks to human health or the ecosystem, waiting until more information is gathered may result in more harm than making a preliminary decision in the absence of a complete set of information."

1.5 TRUSTEE, STATE, AND TRIBAL INVOLVEMENT

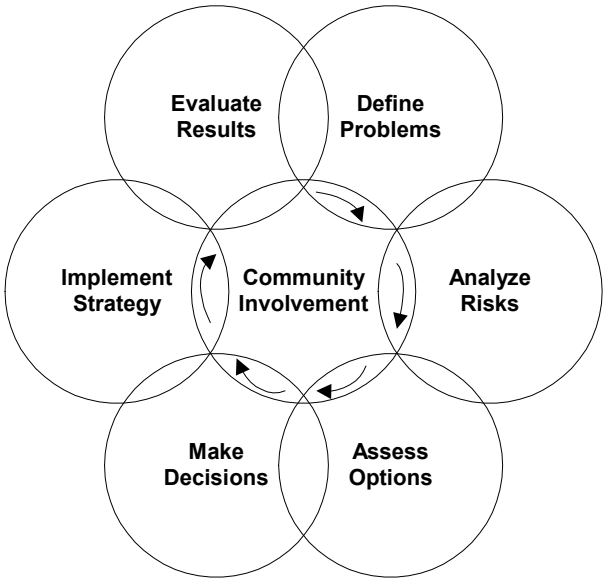
Where there are natural resource damages associated with sediment sites, coordination between the remedial and trusteeship roles at the federal, tribal, and state levels is especially important. Several different federal, state, or tribal natural resource trustees may have an interest in decisions concerning contaminated sediment sites and should be involved throughout the investigation and remedy selection process. The EPA is required to promptly notify natural resource trustees whenever a release of hazardous materials, contaminants, or pollutants may injure natural resources (CERCLA §104 (b)(2)). Trustees may include federal natural resource trustee agencies, such as the U.S. Department of the Interior (DOI), the National Oceanic and Atmospheric Administration (NOAA), U.S. Department of Agriculture (USDA) Forest Service, U.S. Department of Defense (DoD), or U.S. Department of Energy (DOE). State agencies and federally-recognized tribes may also be natural resource trustees. Where NOAA is the natural resource trustee, project managers should contact the Coastal Resource

Highlight 1-6: Superfund Remedial Response Process



Source: U.S. EPA 1999a

Highlight 1-7: National Research Council - Recommended Framework for Risk Management



Source: Adapted from NRC 2001

Coordinators (CRCs) who are assigned to each EPA Region (except Regions 7 and 8, where there are no NOAA trust resources). These CRCs are also designated natural resource trustee representatives for marine resources, including migratory fish.

Interests and data needs of the trustees and the EPA may be similar. Project managers should consult trustees early in the RI/FS process regarding potential contaminant migration pathways, ecological receptors, and characteristics of the waterbody and watershed. Sharing information early with federal, tribal, and state trustees (rather than bringing them in later in the process) often leads to better protection of human health and the environment and reduces the time needed to negotiate liability settlements. Information on coordinating with trustees is found in *EPA's ECO Update: The Role of Natural Resource Trustees in the Superfund Process* (U.S. EPA 1992a), in OSWER Directive 9200.4-22A, *CERCLA Coordination with Natural Resource Trustees* (U.S. EPA 1997a), and in OSWER Directive 9285.7-28P, *Ecological Risk Assessment and Risk Management Principles for Superfund Sites* (U.S. EPA 1999b).

In addition to their role as natural resource trustees, state cleanup agencies and affected Indian tribes or nations have an important role as co-regulators and/or affected parties and as sources of essential information. States can be the lead agency at some sediment sites, or lead the cleanup of source areas or particular Operable Units within a site. States and tribes are frequently an indispensable source of historic and current information about waterbody uses, fish consumption patterns, ecological habitat, other sources of contamination within a watershed, and other information useful in characterizing the site and selecting an appropriate remedy. Additional information on coordinating with states and tribes can be

found in OSWER Directive 9375.3-03P, *The Plan to Enhance the Role of States and Tribes in the Superfund Program* (U.S. EPA 1998b), and OSWER Directive 9375.3-06P, *Enhancing State and Tribal Role Directive* (U.S. EPA 2001b), both available at http://www.epa.gov/superfund/states/strole/index.htm.

1.6 COMMUNITY INVOLVEMENT

People who live, work, and play adjacent to waterbodies that contain contaminated sediment should receive accurate information about the safety of their activities, and be provided opportunities for involvement in the EPA's decision-making process for sediment cleanup. Both communication and outreach pose unique community involvement challenges at sediment sites. Sediment sites that span large areas may present barriers to communicating effectively with the different communities along the waterbody. Community members may have a wide variety of needs and wishes for current and future uses of the waterbody. Highlights 1-8 and 1-9 list some of the common community concerns about contaminated sediment and sediment cleanup methods. These lists are compiled from information provided by Superfund project managers and by the NRC (2001). Project managers should be aware of these potential concerns and others specific to their sites.

Highlight 1-8: Common Community Concerns about Impacts/Effects of Contaminated Sediment

- Human health impacts from eating fish/shellfish, wading, and swimming
- Ecological impacts on wildlife and aquatic species
- Loss of recreational, and subsistence fishing opportunities
- Loss of recreational swimming and boating opportunities
- Loss of traditional cultural practices by tribes and others
- Economic effects of loss of fisheries
- Economic effects on development, reduction in property values, or property transferability
- Economic effects on tourism
- Concern whether all contamination sources have been identified
- Increased costs of drinking water treatment, other effects on drinking water, and other water uses
- Loss or increased cost of commercial navigation

Highlight 1-9: Common Community Concerns about Adverse Impacts of Sediment Cleanup

Concerns about Monitored Natural Recovery	Concerns about In-Situ Capping	Concerns about Dredging and Excavation
• Long time-frame for recovery	• Increased truck or rail traffic	• Increased truck or rail traffic
• Spreading of contamination due to flooding/other disturbance	• Loss of resource/ harvesting rights	• Noise, emissions, and lights at treatment and disposal facilities
• Extended loss of resources and uses	• Navigational limitations	• Siting of new disposal facilities
• Perception of "do nothing" remedy, doubts about effectiveness	• Increased flooding	• Loss of capacity at existing disposal facilities
• Environmental justice and other community concerns with leaving waste in place	• Disturbance of aquatic habitat	• Loss of privacy during construction
• Property value/transferability concerns with leaving waste in place	• Cap material source issues	• Infrastructure needs on adjacent land
	• Loss of ship anchoring access	• Recreation and tourism impacts
	• Access to buried utilities	• Access to private property
	• Cap erosion or disruption	• Property values near dredging, treatment and disposal facilities
	• Contaminant migration through cap	• Disturbance of aquatic habitat
	• Loss of privacy during construction	• Environmental justice and other community concerns with disruption
	• Recreation and tourism impacts	• Resuspension/spreading contamination
	• Environmental justice and other community concerns with disruption and leaving waste in place	
	• Property value/transferability concerns with leaving waste in place	

Existing community involvement and sediment guidance from the EPA and elsewhere offer some guidelines for involving the community in meeting these and other concerns, as identified in Highlight 1-10.

Highlight 1-10: Community Involvement Guidance and Advice

EPA Office of Solid Waste and Emergency Response on Community Involvement:

- *Early and Meaningful Community Involvement* (U.S. EPA 2001c)
- *Superfund Community Involvement Handbook and Toolkit* (U.S. EPA 2001d)
- *Community Advisory Group Toolkit for EPA Staff* (U.S. EPA 1997b)
- *The Model Plan for Public Participation*, National Environmental Justice Advisory Council (U.S. EPA 1996b)

RCRA Community Involvement Guidance:

- *RCRA Public Participation Manual* (http://www.epa.gov/epaoswer/hazwaste/permit/pubpart/manual.htm)
- *RCRA Expanded Public Participation Rule* (60 FR 63417-34)
- *RCRA Corrective Action Workshop Communication Tools* (http://www.epa.gov/epaoswer/hazwaste/ca/resource/guidance/pubinvol/comtools.htm)

Office of Water on Communication of Fish Consumption Risks and Surveys:

- *Guidance for Conducting Fish and Wildlife Consumption Surveys* (U.S. EPA 1998c)
- *National Conference on Risk Communication and National Forum on Contaminants in Fish* (Chicago 2001 conference proceedings available at http://www.epa.gov/ost/fish)

National Research Council:

- *A Risk-Management Strategy for PCB-Contaminated Sediments, Chapter 4, Community Involvement* (NRC 2001)

Considering existing EPA guidance, and advice from the NRC and others, the three points below highlight some of the most critical aspects of community involvement at sediment sites.

1: Involve the Community Early and Often

One of EPA's eleven principles for managing risk of contaminated sediment is to involve the community early and often. The mission of the Superfund and RCRA community involvement programs is to advocate and strengthen early and meaningful community participation during Superfund cleanups. Planning for community involvement at contaminated sediment sites should begin as early as the site discovery and site assessment phase and continue throughout the entire Superfund process. As noted by the NRC (2001): "Community involvement will be more effective and more satisfactory to the community if the community is able to participate in or directly contribute to the decision-making process. Passive feedback about decisions already made by others is not what is referred to as community or stakeholder involvement." Early community involvement enables EPA to learn what community members think are important exposure pathways and to assess societal and cultural impacts of the contamination and of potential response options. Available materials about community involvement in the risk assessment process include *A Community Guide to Superfund Risk Assessment – What's it All about and How Can You Help?* (U.S. EPA 1999c). This guide and other Superfund community

involvement materials are available at http://www.epa.gov/superfund/resources and guidance for RCRA corrective action programs at http://www.epa.gov/epaoswer/hazwaste/ca/guidance.htm. Although the regulators have the responsibility to make the final cleanup decision at CERCLA and RCRA sites, early and frequent community involvement helps the regulators understand differing views and allows the regulators to factor these views into their decision.

2: Build an Effective Working Relationship with the Community

Building partnerships with key community groups and interested parties is critical to implementing a successful community involvement program. Involving communities by fostering and maintaining relationships can lead to better site decisions and faster cleanups. Writing specifically about PCB-contaminated sites, but with application to all sediment sites, the NRC (2001) report recommended that: "Community involvement at PCB-contaminated sediment sites should include representatives of all those who are potentially at risk due to contamination, although special attention should be given to those most at risk."

Participants at EPA's 2001 *Forum on Managing Contaminated Sediments at Hazardous Waste Sites* (U.S. EPA 2001e) offered the following ideas, among others, for building effective working relationships with communities at sediment sites. Project managers should consider the following advice as they formulate their plans for community involvement:

- Create realistic expectations up front for both public involvement and sediment cleanup;
- Where possible, do not ask for extra meetings, instead, ask for time at existing community meetings;
- Use store-front on-site offices for public information when possible;
- Be aware of tribal cultural and historic sites, not all are registered or are on tribal land;
- Minimize jargon when speaking and writing for the public;
- Use independent facilitators for public meetings when needed;
- Include broad representation of the community;
- Look for areas where you can act on input from the community; and
- Encourage continuity of membership as much as possible.

A complete list of Forum presentation materials is available at http://www.epa.gov/superfund/new/sedforum.htm.

3: Provide the Community with the Resources They Need to Participate Effectively in the Decision-Making Process

Project managers should ensure that community members have access to the tools and information they need to participate throughout the cleanup process. Educational materials should be accessible, culturally sensitive, relevant, timely, and translated when necessary.

Contaminated sediment sites often involve difficult technical issues. It is especially important to give community members opportunities to gain the technical knowledge necessary to become informed participants. Project managers should provide technical information to communities in formats that are accessible and understandable. The EPA has a number of resources available to help make large volumes of complex data more easily understandable. These resources are often valuable communication tools not only with the community, but also within the EPA and between cooperating Agencies. An example includes the Region 5 Fully Integrated Environmental Location Decision Support (FIELDS) process. FIELDS began as an effort to more effectively solve contaminated sediment problems in and around the Great Lakes and is applied in other regions as well. Information about FIELDS is available at http://www.epa.gov/region5fields.

Information about Superfund community services is available at http://www.epa.gov/superfund/action/community/index.htm. This web site provides information on Community Advisory Groups (CAGs), EPA's Technical Assistance Grant (TAG) program, and the Technical Outreach Services for Communities (TOSC) program. The TOSC program uses university educational and technical resources to help community groups understand the technical issues involving hazardous waste sites in their communities. The Superfund statute provides for only one TAG per site. At very large sites with diverse community interests, communities may choose to form a coalition and apply for grant funding as one entity. The coalition would need to function as a nonprofit corporation for the purpose of participating in decision making at the site. Individual organizations may choose to appoint representatives to a steering committee that decides how TAG funds should be allocated, and defines the statement of work for the grant. The coalition group may hire a grant administrator to process reimbursement requests to the EPA and to ensure consistent management of the grant. In some cases, EPA regional office award officials may waive a group's $50,000 limit if site characteristics indicate additional funds are necessary due to the nature or volume of site-related information.

2.0 REMEDIAL INVESTIGATION CONSIDERATIONS

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2.0 REMEDIAL INVESTIGATION CONSIDERATIONS

Generally, the purpose of investigating contaminated sediment, as with other media, is to determine the nature and extent of contamination sufficient to assess risks and to evaluate potential cleanup methods. The remedial investigation (RI) process is described in the U.S. Environmental Protection Agency's (EPA) *Guidance for Conducting Remedial Investigations and Feasibility Studies under CERCLA*, also referred to as the "RI/FS Guidance" (U.S. EPA 1988a). The remedial process in Resource Conservation and Recovery Act (RCRA) corrective action is best described in OSWER Directive 9902.3-2A, *RCRA Corrective Action Plan*, and the May 1, 1996 Advanced Notice of Proposed Rulemaking [(ANPR) 61 FR 19447]. This chapter supplements existing guidance by offering brief sediment-specific guidance about site characterization and other investigation issues unique to sediment. More detailed guidance concerning site characterization is beyond the scope of this document, but may be developed as needed in the future. One important aspect of the investigation process not addressed here is the performance of human health and ecological risk assessments. Project managers should use existing EPA risk guidance (U.S. EPA 1989, U.S. EPA 1997c, U.S. EPA 1999b) and consider additional guidance as it is developed.

2.1 SITE CHARACTERIZATION AND CONCEPTUAL SITE MODELS

The site characterization process for a contaminated sediment site should allow the project manager to accomplish the following goals:

- Identify and quantify the contaminants present in sediment, surface water, and biota;
- Understand the vertical and horizontal distribution of the contaminants within the sediment;
- Identify the sources of historical contamination and quantify any continuing sources;
- Understand the physical, chemical, and biological processes affecting the fate, transport, and bioavailability of sediment contaminants at the site;
- Identify the complete human and ecological exposure pathways for the contaminants;
- Identify current and potential human and ecological risks posed by the contaminants; and
- Provide a baseline of data that can be used to monitor remedy effectiveness.

The types of data the project manager should collect are determined mostly by information needed to conduct the risk assessments, document baseline condition prior to implementation of the remedy, evaluate potential remedies, and to design and implement the selected remedy. Data quality objectives (including the type and number of samples, as well as the desired quality of the data) should be coordinated with other agencies (e.g., trustee agencies, state health departments) that have similar data needs. Highlight 2-1 lists some general types of physical, chemical, and biological data that a project manager should consider collecting when characterizing a sediment site. At these sites, it is important to

Highlight 2-1: Example Site Characterization Data for Sediment Sites

Physical	Chemical	Biological
• Sediment mineralogy and particle size/distribution	• Near-surface contaminant concentrations in sediment	• Sediment toxicity
• In-situ porosity/bulk density	• Contaminant concentration profiles in sediment cores	• Presence/absence of indicator species
• Bearing strength	• Contaminant concentrations in biota	• Benthic species abundance/diversity
• Specific gravity	• Total organic carbon (TOC) in sediment	• Abundance/diversity of emergent and submerged vegetation
• Salinity profile of sediment cores	• Dissolved, suspended, and colloidal contaminant concentrations in water column	• Reproduction rates of fish, birds, other biota
• Geometry/bathymetry of waterbody	• Simultaneously extracted metals (SEM) of sediment	• Pathological condition, such as presence of tumors
• Turbidity	• Acid volatile sulfide (AVS) in sediment	• Other contaminant effects
• Sediment deposition rate	• Oxidation/reduction profile of sediment cores	
• Depth of mixing layer/ degree and depth of bioturbation	• pH profile in sediment cores	
• Geophysical surveys	• Carbon/nitrogen/ phosphorus ratio	
• Annual and event-driven hydrographs and current velocities	• Un-ionized ammonia	
• Tidal regime		
• Freeze/thaw cycle of water body		

understand how characteristics change with seasonal conditions, especially during high and low water flows or with fluctuating water temperatures. The relative importance of these types of data are dependent on the site.

The data needed to determine the nature and extent of contamination and the risks to human health and the environment should be collected during the RI. A site characterization should include sufficient data to document long-term post-remedial data trends in a statistically defensible manner. Additional sampling could be needed during remedial design to establish a baseline for a long-term monitoring program. Any measurement used in a long-term monitoring program such as contaminant concentration in fish tissue not collected during site characterization should be quantified prior to any remedial action so that temporal and spatial changes may be documented accurately. While sediment

sites typically demand more types of data for effective characterization than other types of sites, the data acquisition process should not prevent early action when appropriate.

For sediment sites as for other types of sites, the conceptual site model is an important element needed for evaluating remedies. The initial conceptual site model provides the project manager with a simple understanding of the site based on available data early in the RI, including any historical data, prior to the gathering of new site data. Later, this conceptual model should be modified as additional sources, pathways, and contaminants are identified during site characterization. The state, tribal, and federal natural resource trustee agencies may have information about the ecosystem that is important in developing the conceptual site model and it is recommended that trustees have input at this stage of the site investigation. Information gaps may be discovered in development of the conceptual site model requiring collection of new data.

Typically, the essential elements of the conceptual site model are the sources of the contaminants of concern, contaminant transport pathways, exposure pathways, and receptors at various levels of the food chain. Project managers may find it useful to develop several conceptual site models which highlight different aspects of the site. Highlight 2-2, Highlight 2-3, and Highlight 2-4 present examples which focus on ecological and human health threats.

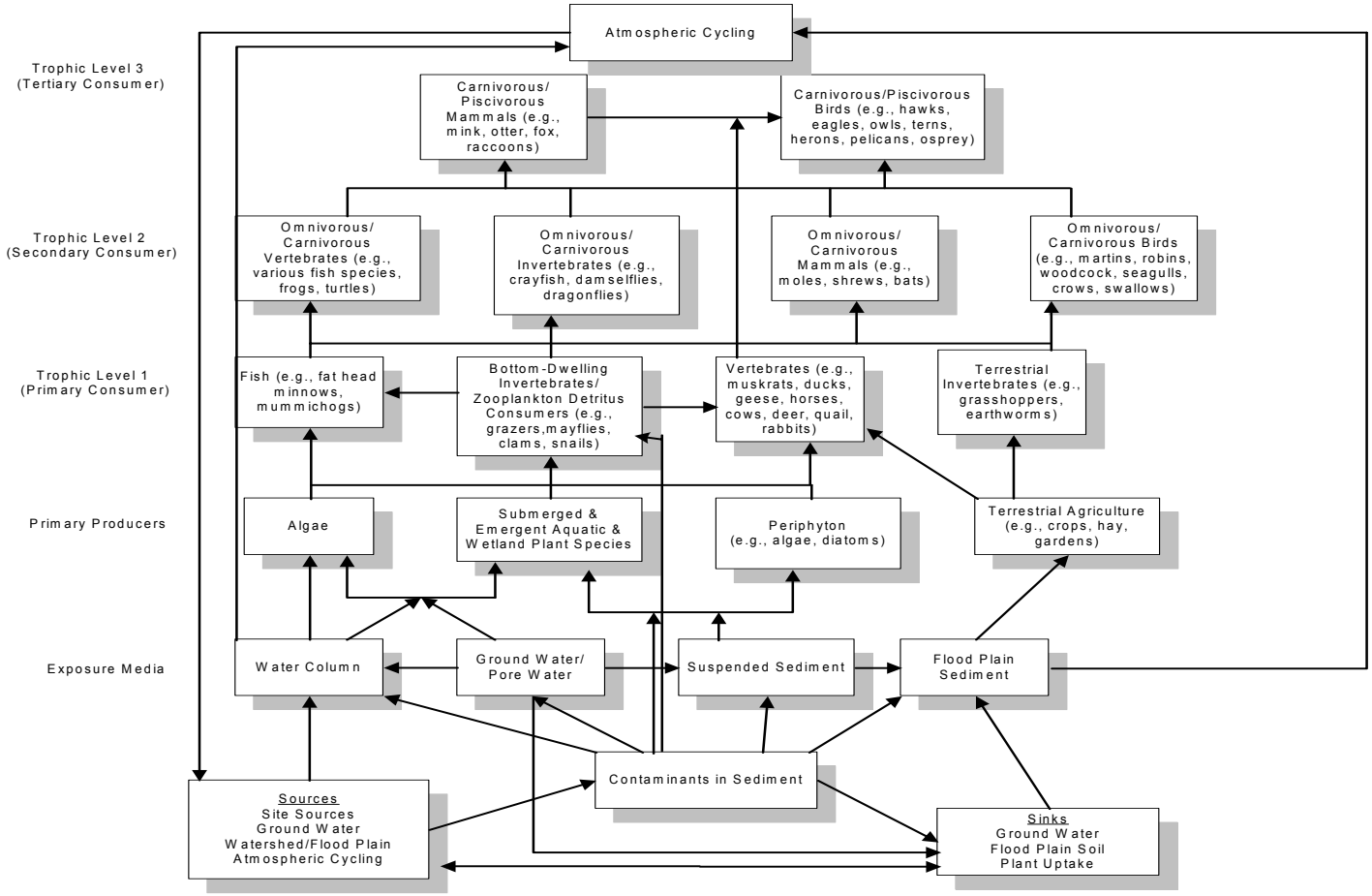
2.2 WATERSHED CONSIDERATIONS

A unique aspect of contaminated sediment sites is their relationship with the overall watershed in which they are located. Project managers should consider the role of the site in the watershed context, including other potential contaminant sources, key issues within the watershed, and current and reasonably anticipated or desired future uses of the waterbody and adjacent land.

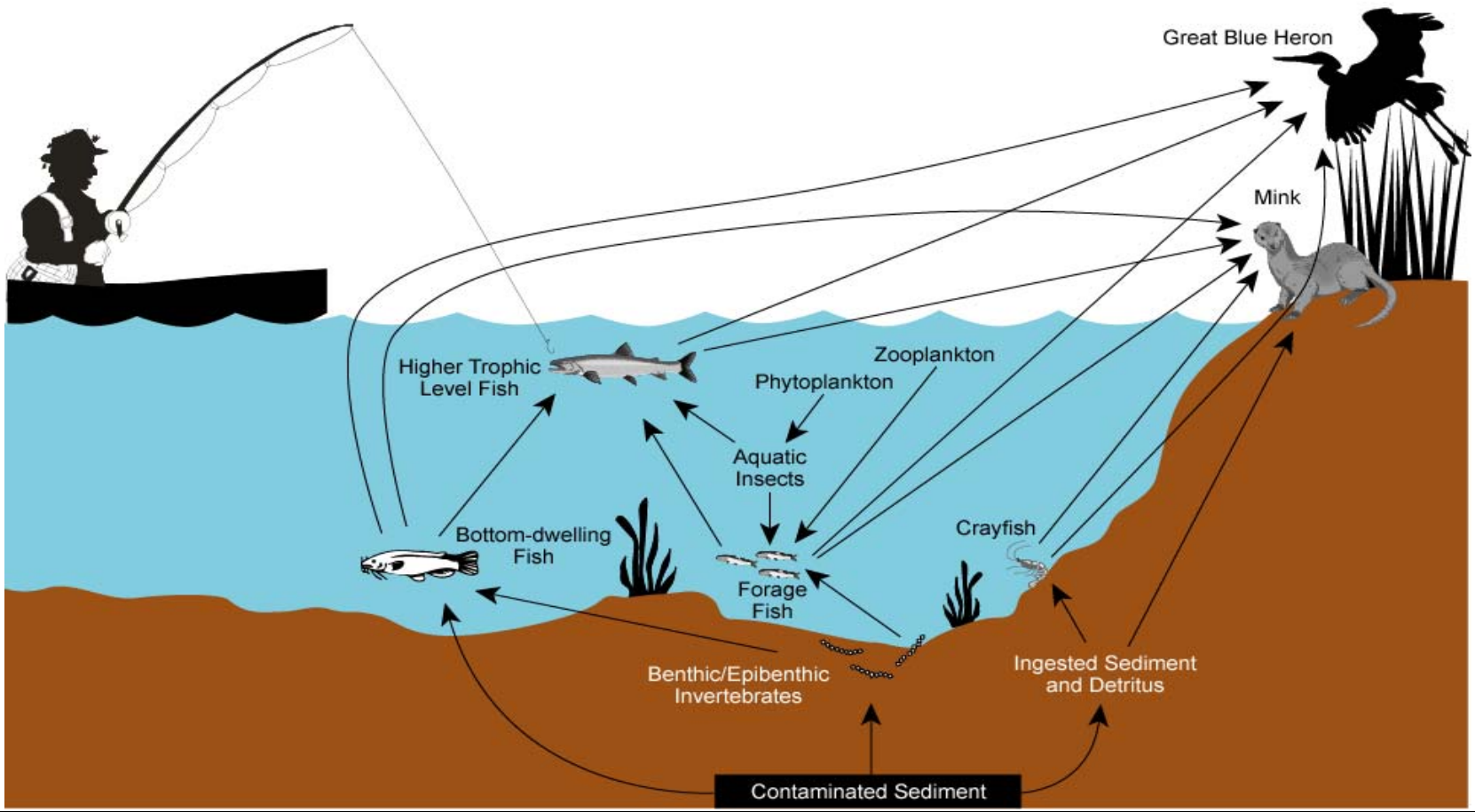
Within the watershed there are a spectrum of issues that the project manager may need to consider. Many contaminated sediment sites provide (or could provide) an important ecological environment for spawning, migration, or food production for fish, shellfish, birds, and other aquatic and land-based animals. One significant watershed issue is the protection of migratory fish. These are fish such as salmon, shad, and herring, that migrate as adults from marine waters up estuaries and rivers to streams and lakes, where they spawn. The juveniles spend varying lengths of time in freshwater, before migrating back to estuarine/marine waters. It is difficult to evaluate the impact of a particular contaminated sediment site on wide-ranging species that may encounter several sources of contamination along their migratory route. This is an important watershed consideration, as these fish populations may not show improvement if any link in their migratory route is missing, blocked, or toxic.

The size, topography, and land use of a watershed, among other factors, may affect characteristics of a waterbody, such as water quality, sedimentation rate, grain size and volume, seasonal changes in water volumes and current velocities, and the potential for ice formation. For example, wetland areas store flood waters and enable ground water recharge, thereby protecting downstream areas from increased flooding, whereas an agricultural or urbanized watershed may have increased erosion and greater flow during storm events. Watershed changes can result from natural events, such as wildfires, or from human activities such as road and dam construction/removal, impoundment releases, and urban/suburban development. When considering watershed characteristics, it is important to consider both current and future watershed conditions.

Highlight 2-2: Conceptual Site Model Focusing on Ecological Threats

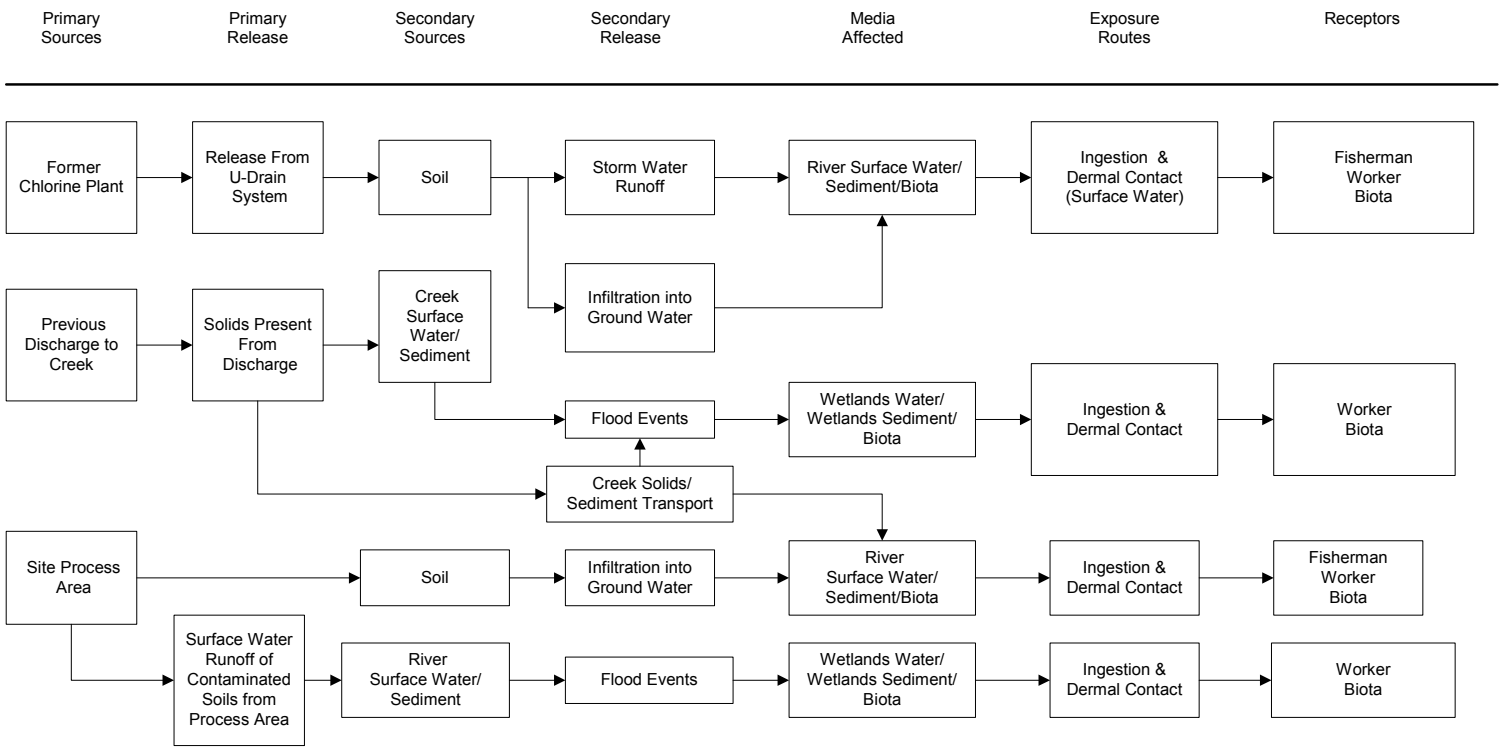


Highlight 2-3: Pictorial-Style Conceptual Site Model Focusing on Human and Ecological Threats



Source: Adapted from EPA Region 5, Sheboygan Harbor and River Site

Highlight 2-4: Conceptual Site Model Focusing on Human Health Threats



Waterbody uses may include commercial navigation, recreation, other commercial or industrial uses, recreational, subsistence or cultural fishing, and other, less easily categorized uses. Most waterbodies used for commercial navigation, such as for shipping channels, turning basins, and port areas, are periodically dredged to conform to the minimum depth for the area prescribed by Congress; such dredging is typically implemented by the U.S. Army Corps of Engineers (USACE). Other commercial or industrial uses of a site may include the presence of commercial fisheries or other resource harvesting, such as gravel pits, drinking water use, and industrial uses of water including cooling, washing, or waste disposal.

Recreational uses encompass a wide variety of activities including recreational fishing/shellfishing leading to ingestion of contaminated biota. These activities may involve direct human contact with contaminated sediment, for example, shallow waterbodies used for swimming, fishing, bird-watching adjacent to wetlands, or hunting. Activities may also include those with a lower probability of direct human contact with contaminated sediment, such as recreational boating.

Societal and cultural practices throughout the watershed should be considered in evaluating the risk associated with the contaminants at the site and during remedy evaluation. Refer to Chapter 1, section 1.6, Community Involvement, and Highlight 1-8 for a list of common community concerns at sediment sites. The National Research Council's (NRC) report, *A Risk-Management Strategy for PCB-Contaminated Sediments* (NRC 2001), emphasizes that societal and cultural impacts should be considered when developing risk-management goals for contaminated sediment sites.

The National Oil and Hazardous Substances Pollution Contingency Plan (NCP) states that both current and future land uses should be evaluated in assessing risks posed by contaminants at a Superfund site, and that Superfund remedies should protect for reasonably anticipated future use. EPA has provided further guidance on how to evaluate future land use in the OSWER Directive 9355.7-04, *Land Use in the CERCLA Remedy Selection Process*, also referred to as the "Land Use Guidance" (U.S. EPA 1995a). This guidance promotes early discussions with local land use planning authorities, local officials, and the public regarding reasonably anticipated future uses of upland properties associated with an NPL site. This coordination should begin during the scoping phase of the RI/FS, and ongoing coordination is required to ensure that any changes in expectations are incorporated into the remedial process.

The Land Use Guidance provides tools to help the project manager plan for future land use in the watershed, including the fate of nearshore areas. However, there are additional factors the project manager should consider in anticipating future use for aquatic sites that are not specifically addressed in the Land Use Guidance. For example, future use of the site by ecological receptors may be a more important consideration for an aquatic Superfund or RCRA site as compared to an upland site. This could suggest the possibility of habitat restoration and subsequent increases in local wildlife populations. A remediated aquatic site, especially where habitat has been restored, attracts more recreational, subsistence, and cultural use, including fishing, swimming, and boating. Where applicable, the project manager should consider tribal treaty rights to collect fish or other aquatic resources. The project manager should also consider designated uses in the state's water quality standards, priorities established as a result of total maximum daily loads (TMDLs), or pollution reduction efforts under various Clean Water Act (CWA) programs in projecting future waterway uses. In ports and harbors, the project manager should consult future use master plans developed by port and harbor authorities for projections of future use. The USACE should also be contacted regarding future dredging of federally maintained channels.

There are likely to be more parties to consult about anticipated future use at aquatic sites than at upland sites. These parties include the community, environmental groups, natural resource trustees, Indian tribes, the local department of health, as well as local government, port and harbor authorities, and land use planning authorities. As with upland sites, consultation should start at the RI/FS scoping phase and continue throughout the life of the project. Different stakeholders often have divergent and conflicting ideas about future use at the site. Local residents and environmental groups may anticipate future habitat restoration and increased recreational and ecological use while local industrial landowners project increased shipping and industrial use. The NCP Preamble (55 FR 8710) states that, in the baseline risk assessment, more than one future use assumption is considered when decision makers wish to understand the implications of unexpected exposures. Especially where there is some uncertainty regarding the anticipated future uses, the project manager should compare the potential risks associated with several use scenarios.

Appropriate future use assumptions during the baseline risk assessment and the feasibility study allow the project manager to focus on the development of practicable and cost-effective remedial alternatives. In addition, coordination with stakeholders on land and waterway uses leads to opportunities to coordinate Superfund or RCRA remediation with local development or habitat restoration projects. For example, at some sites the EPA has worked with port authorities to combine Superfund or RCRA remedial dredging with dredging needed for navigation. Others have combined capping needed for Superfund or RCRA remediation with habitat restoration, allowing potentially responsible parties to settle natural resource damage claims in conjunction with the cleanup.

2.3 PHASED APPROACHES

At some sediment sites, a phased approach to remedy selection or remedy implementation may be the best or only practical option. For example, at sites where contaminant fate and transport processes are not well understood or all potential risks are not yet well characterized, it may be appropriate to control sources or take early or interim actions, followed by a period of monitoring before deciding on a final remedy. Phasing may also be useful where the effectiveness of source control is in doubt. By studying the effectiveness of source control prior to sediment cleanups, the risk of having to revisit re-contaminated areas is lessened. High remedy costs and/or the lack of available services and/or equipment can also lead to a decision to phase the cleanup.

Project managers are also encouraged to use an iterative approach, especially at complex sediment sites in order to provide additional certainty and information to support decisions. In general, this means testing of hypotheses and conclusions and reevaluating site assumptions as new information is gathered. For example, an iterative approach might include gathering and evaluating multiple data sets or pilot testing to determine the effectiveness of various remedial technologies at a site. The extent to which iteration is cost-effective is, of course, a site-specific decision. Using iteration to reduce uncertainty may be extremely cost-effective where it allows use of less costly alternatives; however, uncertainty in some areas is less critical.

2.3.1 Source Control

Identifying and controlling contaminant sources is an important consideration in any Superfund sediment cleanup. Source control is defined as those efforts that are taken to eliminate or reduce, to the extent practicable, the release of contaminants from direct and indirect continuing sources to the

waterbody under investigation. At some sediment sites, the original sources of the contamination have already been controlled, but subsequent sources such as contaminated flood plain soils, storm water discharges, and seeps of non-aqueous phase liquids may continue to introduce contamination to a site. At other sediment sites, some sources may be outside the boundaries of the Superfund or RCRA site and may best be handled under another authority, such as the CWA or state toxics program. These types of sites present an opportunity for partnering with private industry and other governmental entities to control sources on a watershed basis.

The identification of continuing sources and their potential to re-contaminate site sediment are essential parts of site characterization. When there are multiple sources, it is important to prioritize sources to determine the relative significance of continuing sources versus on-site sediment in terms of site risks in order to assess where to focus resources. To assist with that prioritization effort, project managers should consider developing a source control strategy or approach for the site as early as possible in the process of site characterization. The source control strategy should include requirements for documenting and tracking source control plans, source prioritization, completed source control actions, and effectiveness of source control measures. It is also useful to establish administratively defined milestones for source control that can be linked with sediment design and cleanup actions.

Generally, significant continuing sources should be controlled to the greatest extent possible before or concurrent with cleanup of sediment. Once source control is implemented, project managers should evaluate the effectiveness of the source control actions, and should refine and adjust levels of source control, as warranted. In most cases, before any sediment action is taken, project managers should consider the potential for re-contamination and factor that potential into the remedy selection process. If a site includes a source that could result in significant re-contamination, source control measures will likely be necessary as part of that response action. However, where EPA believes that sediment remediation may be a benefit to human health and/or the environment after considering the risks caused by an unaddressed or ongoing source, it may be appropriate for the Agency to select a response action for sediments prior to completing all source control actions.

Source control activities are often broad-ranging in scope. Source control may include application of regulatory mechanisms and remedial technologies to be implemented according to applicable or relevant and appropriate requirements (ARARs), including the application of technology-based and water quality-based National Pollutant Discharge and Elimination System (NPDES) permitting to achieve and maintain sediment cleanup levels. Source control actions may include the following:

- Elimination of the source;
- Development of a TMDL and pollutant load reductions of point and non-point sources;
- Implementation of best management practices (e.g., reducing chemical releases to a storm drain line);
- Treatment of sources (e.g., installing additional waste treatment systems prior to discharge); and
- Isolation or containment of sources (e.g., capping of contaminated soil) with attendant engineering controls.

Where applicable, project managers should consider continuing atmospheric and other background contributions to sites (U.S. EPA 2002c). *EPA's Contaminated Sediment Strategy* (U.S. EPA 1998a) includes some discussion of EPA's strategy for abating and controlling sources of sediment contamination. Source control activities may be implemented by governmental entities using combinations of site inspections, promotion of voluntary actions, technical assistance, onsite cleanup actions, and legal actions.

2.3.2 Early Action

Highlight 2-5 provides examples of early actions taken to control sources and other types of early actions at contaminated sediment sites. Early or interim actions are used frequently to prevent human or ecological exposure to contaminants or to control migration or redistribution of contaminated sediment. However, they do not generally preclude the need for additional cleanup actions at sites. Factors for determining which response components may be suitable for early or interim actions include the time frame needed to attain specific objectives, the relative urgency posed by potential or actual exposure, the degree to which an action may reduce site risks, and compatibility with likely long-term actions (U.S. EPA 1992b).

An early action taken under Superfund removal authority may be appropriate at a sediment site when, for example, it is necessary to respond quickly to a release or a threatened release of a hazardous substance. At contaminated sediment sites, removal authority has been used to implement many of the actions listed in Highlight 2-5. The NCP §300.415 outlines criteria for using removal authority, as further explained in the EPA guidance and directives (U.S. EPA 1993a, U.S. EPA 1996c, U.S. EPA 2000a). Project managers may also consider separating the management of source areas from other, less concentrated areas by establishing separate Operable Units (OUs) for the site.

2.4 CLEANUP GOALS

In order to select the most appropriate remedy for a site, it is imperative that clearly defined remedial action objectives (RAOs) be developed. RAOs are used in evaluating the clean-up options for the site and in providing the basis for developing more specific remediation goals (RGs) including contaminant-specific final sediment clean-up levels. RAOs, RGs, and clean-up levels are dependent on each other and represent three steps along a continuum leading from the scoping to the selection of a remedial action that will be protective and provide the best balance among the NCP nine criteria.

2.4.1 Remedial Action Objectives

RAOs provide a general description of what the cleanup is expected to accomplish, and help focus the development of the remedial alternatives in the feasibility study. RAOs are derived from the conceptual site model (section 2.1), and address the significant exposure pathways. RAOs may vary widely for different parts of the site, whether or not these parts are managed as separate OU's. For example, a sediment site may include a recreational area used by fishermen and children, as well as a wetland that provides critical habitat for fish and wildlife. Though both areas may contain similarly-contaminated sediment, the different receptors and exposure pathways may dictate that the project manager develop different RAOs for each area.

Highlight 2-5: Examples of Early Actions at Contaminated Sediment Sites

Actions to prevent releases of contaminants from sources include the following:

- Excavation or containment of flood plain soils or other source materials in the associated watershed
- Engineering controls (e.g., sheet pilings, slurry walls, grout curtains, and extraction) to prevent highly contaminated ground water or leachate from reaching surface water and sediment
- Engineering controls to prevent contaminated runoff from reaching surface water and sediment

Actions to prevent exposure to contaminants include the following (coordinated with the appropriate agencies):

- Access restrictions
- Fish consumption advisories
- Use restrictions and advisories for waterbodies
- Actions to protect downstream drinking water supplies

Actions to prevent further migration of contaminated sediment include the following:

- Boating controls (e.g., vessel draft or wake restrictions to prevent propeller wash, anchoring restrictions)
- Excavating, dredging, or capping of contaminated sediment hot spots (i.e., localized areas of high contaminant concentration)

The development of RAOs should also include a discussion of their basis and how the RAOs address all the unacceptable risks identified in the risk assessment. Examples of RAOs specific for sediment sites are included in Highlight 2-6. During development of RAOs project managers should evaluate whether the RAO is achievable by remediation of the site or if it requires additional actions outside the control of the project manager. For example, biota recovery which depends on cleanup of sources under other authorities may not be appropriate for site-specific RAOs. However, the project manager may discuss these other actions in the record of decision (ROD) and should consult with other agencies/authorities as appropriate.

2.4.2 Remediation Goals

Generally, preliminary remediation goals (PRGs) protective of human health and the environment are identified early in the remedial investigation process (at scoping meetings) based on readily available information [e.g., from the PA/SI (preliminary assessment/site inspection), NPL (National Priorities List) listing packages, or screening risk assessments]. As more information is generated during the RI, these PRGs are modified to incorporate an improved understanding of site conditions, resource use, human activities, and the nature and extent of contamination. However, the completed RI/FS should identify an appropriate remediation goal (or range of goals) for each contaminant of concern in each medium of significance. These remediation goals should be based on ARARs (if they exist), or on the site-specific baseline risk assessment. Currently, there are no federal ARARs for sediment media, and although some states have promulgated sediment clean-up standards, most RGs and clean-up levels for sediment are risk-based. RGs should represent as a range of acceptable risk levels so that the project manager may consider the NCP criteria when selecting the final cleanup levels. The size and shape of the risk range depends on

Highlight 2-6: Example Remedial Action Objectives for Contaminated Sediment Sites

Human Health:

- Reduce the risks to children and adults from the incidental ingestion of and dermal exposure to contaminated sediment while playing, swimming, or fishing at or near the site to acceptable levels
- Reduce the risks to adults and children from ingestion of contaminated fish taken from the site to acceptable levels

Ecological Risk:

- Reduce the toxicity to benthic aquatic organisms living at the surface water/sediment interface to levels that are acceptable
- Reduce the risks to birds and mammals that feed on fish that have been contaminated due to food chain transport from contaminated sediment to levels that are acceptable

the level of uncertainty associated with the reference dose and the exposure factors used. Remediation goals should be developed which acknowledge the following concepts:

- *Ecological risks:* Sediment remediation goals should be based on the site-specific no adverse effects level and the maximum acceptable adverse effects level; concentrations associated with these levels generally should form the lower and upper bounds, respectively, of the risk range for ecological effects;

- *Human health cancer risks:* Sediment remediation goals should be based on an excess upper bound lifetime cancer risk to an individual (based on a reasonable maximum exposure scenario) of between 10^{-4} and 10^{-6}. While the 10^{-6} risk level generally should be used as a point of departure for analysis of alternatives, other levels within this risk range may be helpful in evaluating different remedial strategies; and

- *Human health risk effects that result from systemic toxicity:* Sediment remediation goals should be based on levels to which human populations, including sensitive subgroups, may be exposed without adverse effect during a lifetime or part of a lifetime, incorporating an adequate margin of safety. This generally means that levels should be determined through back-calculation from the appropriate Hazard Indices identified in the baseline risk assessment.

Baseline risk assessments provide an evaluation of the potential threat to human health and the environment in the absence of any remedial action or institutional controls. Generally, they provide the basis for determining whether remedial action is necessary as well as the framework for determining risk based remediation goals. Detailed guidance on evaluating potential human health and ecological impacts is provided in *Risk Assessment Guidance for Superfund*, also referred to as "RAGS," (U.S. EPA 1989) and *Ecological Risk Assessment Guidance for Superfund: Process for Designing and Conducting Ecological Risk Assessment*, also referred to as "ERAGS" (U.S. EPA 1997c). In addition, OSWER Directive 9285.7-28P, *Ecological Risk Assessment and Risk Management Principles for Superfund Sites*

(U.S. EPA 1999b), provides risk managers with several principles to consider when making ecological risk management decisions.

The selection of assessment endpoints is a critical component of the ecological risk assessment. Once assessment endpoints have been selected, testable hypotheses and measurement endpoints can be developed to evaluate the potential threat to the assessment endpoints. Polychlorinated biphenyls (PCBs), for example, bioaccumulate in food chains and can diminish reproductive success in upper trophic level species (e.g., mink) exposed to contaminants through their diet. Therefore, reduced reproductive success in fish-eating birds and mammals may be an appropriate assessment endpoint. An appropriate measurement endpoint in this case might be contaminant concentrations in fish or in the sediment where the concentrations in these media can be correlated to reproductive effects in the top predator that eats the fish. The sediment concentration range associated with an acceptable level of reproductive success would constitute the remediation goal.

Site-specific data should be collected and used wherever practicable to develop RGs that are protective. For ecological risks, in order to identify appropriate goals, the risk assessor should use data from the same toxicity tests, population or community-level studies, tissue residue concentrations, or bioaccumulation models that were used to determine that there was an unacceptable ecological risk. As discussed in OSWER Directive 9285.7-28P, *Ecological Risk Assessment and Risk Management for Superfund Sites Principles* (U.S. EPA 1999b), the data may be used to establish a concentration and response gradient to define the concentration range that represents an acceptable (i.e., protective) level of risk. At some small sites, however, responsible parties may determine that it is more cost effective and quicker to remove or contain all contaminated sediment rather than to conduct a full baseline risk assessment and generate a concentration and response gradient. There is no standard number that can be used in determining an acceptable level of adverse effects for the receptors to be protected (e.g., the LC_{50} from the sediment toxicity tests, a 25 percent reduction in benthic abundance, a 10 percent reduction in fish reproduction, the value used in dependent on the assessment endpoints selected and the measurement endpoints used). This level should be discussed by the risk assessor and risk manager as early as possible in the risk assessment process and should be coordinated with the trustees.

The EPA equilibrium-partitioning sediment guidelines (ESGs) or benchmarks and other published sediment guidelines [e.g., NOAA (National Oceanic and Atmospheric Agency) Screening Quick Reference Tables (SQuiRTs), available at http://response.restoration.noaa.gov/cpr/sediment/squirt/squirt.html] are useful as screening values at Superfund sediment sites, but are not appropriate as default, site-specific RGs or clean-up levels. The Superfund program has also developed a set of screening values called Ecotox Thresholds (ETs) available at http://www.epa.gov/superfund/resources/ecotox/index.htm. EPA's *ECO Update on EcoTox Thresholds* (U.S. EPA 1996d) describes, in detail, how to use ETs as screening levels.

2.4.3 Cleanup Levels

At most sites, RGs are developed into final, chemical-specific, sediment cleanup levels by weighing the NCP balancing and modifying criteria and other factors relating to uncertainty, exposure, and technical feasibility. The nine NCP criteria (NCP §300.430) for remedy selection are discussed in Chapter 3, section 3.2.

As noted above, final cleanup levels for protection of human health are developed from the RGs by considering exposure factors, uncertainty factors, technical factors, and by weighing the NCP balancing and modifying criteria. Exposure factors that may be relevant to consider include (among others) cumulative impacts of multiple contaminants at the site as well as site-specific exposure information that can replace some generic assumptions. Uncertainty factors that may be relevant to consider include (among others) the reliability of inputs and outputs of the model to estimate risks and establish cleanup levels, reliability of alternatives to achieve those modeled results, and the likelihood of exposure scenarios. Technical factors include (among others) the ability to monitor and control movements of contaminants in the environment, technical limitations of remedial alternatives, and detection and quantification limits of contaminants in environmental media. All of these factors are considered when establishing final cleanup levels that are within the risk range.

The derivation of ecologically-based cleanup levels is a complex and interactive process balancing contaminant fate and transport issues with toxicological considerations and potential habitat impacts of the remediation alternatives. Before selecting a cleanup level, the project manager, in consultation with the ecological risk assessor, should consider at least the following factors (U.S. EPA 1999b):

- The magnitude of the observed or expected effects of site releases and the level of biological organization affected (e.g., individual, local population, or community);
- The likelihood that these effects will occur or continue;
- The ecological relationship of the affected area to the surrounding habitat;
- Whether the affected area is a highly sensitive or ecologically unique environment; and
- The recovery potential of the affected ecological receptors and expected persistence of the chemicals of concern under present site conditions.

Generally, the ROD should include chemical-specific cleanup levels as provided in the NCP §300.430(c)(2)(I)(A). The ROD should also indicate the approach that will be used to measure attainment of the cleanup level. Generally, the cleanup levels are an important piece of the performance standards designed to determine when the RAOs have been met. At some sites, however due to uncertainty in human health and ecological systems and models/data used to derive the cleanup levels or the contribution of other sources, the attainment of cleanup levels may not coincide with the attainment of RAOs. Where cleanup levels have been achieved but RAOs have not been met and are not expected to be met, it may be necessary to issue a ROD Amendment or Explanation of Significant Difference (ESD) to modify the remedy. The equivalent of a ROD Amendment in RCRA corrective action is the RCRA Permit Modification. Consistent with the NCP requirement (NCP §300.430(f)(4)(ii)), Superfund sites should be reviewed no less than every five years after initiation of the selected remedial action. Chapter 8, Remedial Action and Long-Term Monitoring, provides additional guidance on the information to be collected for this review to be effective.

2.5 SEDIMENT STABILITY

An important part of both the remedial investigation at many sediment sites is an assessment of the extent of sediment movement or transport by processes and events in the past and a prediction about whether there is likely to be significant movement in the foreseeable future. This topic has become known as an assessment of sediment stability. Sediment stability is also important to consider during the feasibility study and remedial design. It can be one of the most important factors in identifying areas suitable for monitored natural recovery, in-situ caps, or near-water confined disposal facilities (CDFs). This section focuses on the qualitative analyses of factors that affect a remedy's vulnerability to physical and biological forces and briefly introduces some quantitative tools that may be needed. A detailed guide to quantitative methods is not provided in this guidance as technical expertise in geomorphology, oceanography, hydrodynamic modeling, etc. is often required for applying these methods.

Most sediment sites are subject to some degree of contaminant movement, although the movement may be large or small. Both natural and man-made (anthropogenic) forces may cause sediment movement. Highlight 2-7 lists some examples of events which may disrupt sediment.

Highlight 2-7: Examples of Natural and Anthropogenic Causes of Sediment Movement

Natural causes include:

- Tides in marine waters and estuaries
- Floods
- Seiches (rapid oscillation of lake elevation caused by wind), especially in the Great Lakes
- Hurricanes
- Earthquakes, landslides, dam failures, and tsunami
- Pacific cyclones
- Ice thaw and ice dam-induced scour
- Bioturbation from micro- and macrofauna

Anthropogenic causes include:

- Boat propeller wash and ships' wakes
- Ship grounding and anchor dragging
- Navigational dredging and channel maintenance
- Placer mining, and sand and gravel mining
- Intentional removal or breaching of hydraulic structures such as dams, dikes, weirs, groins, and breakwaters
- In-water construction such as bridge supports

Anthropogenic and natural forces may differ greatly in frequency (e.g., daily tides or frequent ship traffic versus infrequent navigational dredging or storm surges) and intensity (e.g., bioturbation versus storm-generated waves). It is the origin, frequency, and intensity of a given force which must be assessed collectively when determining the potential impacts of the force on sediment stability and/or contaminant mobility.

Project managers should recognize that there may be a difference between sediment stability and contaminant mobility. While these two concepts are interrelated and often discussed simultaneously, contaminant mobility and availability are not exclusively related to the transport and movement of sediment. A stable sediment bed may not necessarily imply low contaminant availability, for example, if upward ground water flow is high and contaminants are mobilized. Conversely, small scale sediment movement may not necessarily imply high contaminant availability, for example if most contaminants are below the surface layer where most movement occurs.

The physical processes governing sediment stability are complex and understood with varying levels of certainty. There are a variety of empirical methods for evaluating sediment stability in the field and a variety of numerical modeling methods for evaluating events for which there is no field record for predicting future stability. Each of the empirical methods and models have limitations, so it is critical to include a variety of methods in evaluating a site and to compare the results of each method. For large or complex sediment sites, project managers should approach an assessment of sediment stability from the following aspects:

- An assessment of empirical site characterization data (see section 2.5.1);
- An assessment of the origins, frequencies and intensities of expected disruptive forces at the site (see sections 2.5.2 and 2.5.3);
- Fate and transport modeling of sediment and contaminants (see section 2.5.6); and
- An assessment of the expected consequences or results of expected sediment movement and transport (see section 2.5.4).

Where multiple lines of evidence point to similar conclusions, project managers may have more confidence in their predictions. Where the lines of evidence do not concur, project managers should bring their technical experts together, determine the source of the discrepancies, and reach a decision.

2.5.1 Empirical Data on Sediment Stability

An assessment of the past impacts of forces on sediment stability begins with the collection of a variety of empirical data (i.e., data derived from field or laboratory observation). The vertical and horizontal sediment distributions present at a site are a result of all of the routine and extreme, natural, or anthropogenic, forces that contribute to the physical, chemical, and biological attributes of a waterbody. Site conditions at the time of evaluation reflect a combination of influences. Project managers should not assume that current conditions represent stable conditions when, in fact, sediments may be actively responding to recent or current forces and/or events. Conversely, project managers should not assume that a site or all areas of a site are unstable or unstable at a scale which significantly impacts contaminant release.

Forces that are important in terms of their larger scale influences on watershed characteristics may be less important to the stability of sediment in smaller, more isolated areas of a waterbody. Both scales of investigation are important. For example, in some situations, the large scale rainstorms associated with hurricanes may greatly impact sediment loading to the waterbody, but have little effect on stability of the sediment bed itself. When considering the potential impacts of disruptive forces on sediment movement, it is important to assess these forces as they relate to the overall watershed and in terms of current and future site characteristics.

Many site characteristics affect sediment stability, but primary among them are the shear stress at the bottom of the waterbody during various conditions, and the properties (e.g., cohesiveness) of the upper sediment layers. In most environment, bottom shear stress is controlled by currents, waves, and bottom roughness (e.g., sand ripples, biologically-formed mounds in fines). In some environments, suspended sediment (often present during floods) or a fluff, floc, or low density mud layer (present in some estuaries and lakes) may decrease the erosion of underlying sediment. This is sometimes known as "dynamic armoring."

Sediment properties that affect erosion in many sediment environments include bulk density, particle size (average and distribution), mineralogy (especially clay mineralogy), the presence of gas, and the organic content (amount and type). Erosion rates typically vary by 2 to 3 orders of magnitude spatially at a site, depending on currents, bathymetry, and other factors. In a fairly uniform cohesive sediment core, erosion rates may drop several orders of magnitude with depth, but in more variable cores this is not the case. Armoring (winnowing of fine material from the sediment surface) can significantly reduce the erosion of mixed and cohesive sediment.

Biological processes by macro- and microorganisms also affect sediment stability in multiple ways, both to increase erosion (e.g., by lowering bulk density) and to decrease erosion (e.g., aquatic vegetation, floc effects, biochemical reactions increases shear strength of sediment). The process of sediment mixing caused by bioturbation is discussed further in section 2.5.3.

Highlight 2-8 lists examples of empirical methods which may be useful to assess sediment stability.

2.5.2 Hydrodynamic Forces

The majority of naturally occurring hydrodynamic forces such as those generated by wind, waves, currents, and tides, occur with great predictability and significantly influence sediment characteristics and movement (Hall 1994). While these routine forces seldom cause changes that are dramatically visible, they may be the events causing highest shear stress and therefore the most important factors in controlling the physical structure of a given waterbody. It is important to note that seasonal, or other changes in water flow may affect where erosion and deposition occur. Depending on the location of the site, (e.g., riverine areas, coastal/marine area, inland waterbodies), different waterbody factors will play important roles in determining sediment movement. To determine the frequency of particular routine forces acting upon sediment, project managers should obtain historical records on water currents and other hydrodynamic forces, especially those from nearby gauging stations. While the intensity of these routine forces may be low, their high frequency may cause them to be the primary control of sediment movement within some waterbodies.

Highlight 2-8: Empirical Methods to Evaluate Sediment Stability

Bathymetry (comparing sediment surface elevations to known datum):

- Single point/local area devices
- Transects/cross-sections (with known vertical and horizontal accuracy)
- Longitudinal river profiles
- Acoustic surveys (with known vertical and horizontal accuracy)
- Comparison to dredging records, air photos, overall geomorphology

Geochronology (age-dating segments of cores):

- Cs^{137}, Pu^{239}, Pu^{240}, lignin, stable Pb (longer-lived species to evaluate burial rate and age progression with depth)
- Pb^{210}, Be^{7}, Th^{234} (shorter-lived species to evaluate depth of mixing zone)
- X-radiography, color density analysis

Contaminant data (from cores, surface sediments, and water column):

- Time-series observations (event scale and long-term seasonal, annual, decade-scale)
- Comparison of core pattern with pollutant loading history
- Comparison of temporal patterns in surface sediment with pollutant loading history (accounting for response time)
- Comparison of concentration patterns during and after high energy events

Geomorphological studies:

- Spacial and temporal variability
- Human modifications

Sediment-contaminant mass balance studies during high energy events:

- Upstream and tributary loadings (grain size distributions and rating curves)
- Tidal cycle sampling (in marine estuaries)
- Sampling during the rising hydrograph (frequently greatest erosion)

In contrast, some waterbodies are significantly affected by extreme forces generated by short time frame and less common events. In many cases, these “extreme” forces originate by the same mechanisms as “routine” forces (e.g., wind) but are significantly stronger than routine conditions and capable of moving large amounts of sediment. Some extreme events, however, have no routine event counterparts (e.g., earthquakes). Meteorological events, such as hurricanes, may move large amounts of sediment in coastal areas due to storm surges and unusually high tides that cause flooding. Flooding may occur from

snow-melt and other unusually heavy precipitation events resulting in the movement of large amounts of sediment. Scour, resulting from the movement of ice and/or natural or man-made debris, may also be an important consequence of a flood event.

While the existence of extreme hydrodynamic forces are generally predicable within particular climatic settings, they are commonly viewed as unforeseeable. What is actually unknown is the precise points in time in which they will occur and whether their frequency may change through time. To obtain a preliminary understanding of extreme event frequency at a site, it is important to examine both the historical records and site characterization data (such as core and bathymetry data).

Floods are frequently classified by their probability of occurrence; for example 50-year, 100-year, 200-year, and probable maximum flood. While the term "100-year flood" suggests a time frame, it is in fact a probability expression that a flood has a one percent probability of occurring (or being exceeded) in any year. Similarly, 200-year flood refer to a flood with a 0.5 percent probability of occurring in any year. However, it is not uncommon for multiple low probability events to happen more frequently than they are expected, especially where the record upon which they were based is not very long or where climate is shifting. Probable maximum flood refers to the most extreme flood that could theoretically occur based on maximum rainfall and maximum runoff in a watershed.

It is important to consider the intensity of extreme hydrodynamic forces as well as their frequency. Intensity is a measure of the strength, power or energy of a force. The intensity of a force will be a significant determinant of its possible impact on the proposed remedy. Tropical storms (including hurricanes) are often classified according to their intensity, that is, the effects at a particular place and time which is a function of both the magnitude of the event and the distance from it. Tropical storms such as hurricanes are commonly classified by intensity using the Saffir-Simpson Scale of Category 1 to Category 5 tropical storms. Other physical forces and events, such as earthquakes, may be classified according to magnitude, that is a measure of the strength of the force or the energy released by it. Earthquakes are most commonly classified in this way (e.g., the Richter scale) although they may also be classified by intensity at a certain surface location (e.g., the Modified Mercalli scale).

For sites in areas which may be affected by extreme events, project managers should assess the record of occurrence near the site and determine the appropriate category or categories for analysis. At a minimum, project managers should evaluate the impacts of a 100-year flood and other events or forces with a similar probability of occurrence (i.e., 0.01 in a year) on sediment stability. A U.S. Geological Survey (USGS) fact sheet explaining the 100-year flood is in Appendix B. At some sites, especially where human and ecological risk is high, it may be appropriate to analyze the effects of events with lower probabilities. Recorded characteristics of physical events, such as current velocities or wave heights, may provide project managers with parameters needed to calculate or model sediment movement. If information from historical records is insufficient or the historical record is too short to be useful, project managers should consider obtaining technical assistance to model a range of potential events to estimate effects on sediment movement and transport. Section 2.6 of this chapter discusses modeling in more detail.

A variety of information resources are available on the Internet, which may assist the project manager in evaluating sediment movement in response to hydrodynamic forces (Highlight 2-9).

Highlight 2-9: Flood Data Information Resources	
Tropical Storms	http://www.nhc.noaa.gov
State Flood Data	http://water.usgs.gov
USGS Historical Notional Water Information System Web Site (NWIS) Data Retrieval for the United States	http://waterdata.usgs.gov/nwis-w/US/
Heavy Precipitation and High Streamflow in the United States	http://www.ncdc.noaa.gov/ol/climate/severeweather/rainfall.html
USGS Real-Time Water Data	http://water.usgs.gov/realtime.html

2.5.3 Bioturbation

The most important natural process causing sediment movement within otherwise stable sediment deposits is bioturbation. Broadly speaking, bioturbation is the movement of sediment by the activities of aquatic organisms. While many discussions of bioturbation are focused on sediment dwelling animals, such as worms and clams, bioturbation may also include the activity of larger organisms such as fish and aquatic mammals. The effects of bioturbation can include the mixing of sediment layers, alteration of chemical forms of contaminants, bioaccumulation and transport of contaminants from the sediment, and/or a reduction in the effectiveness of a remedy based on in-situ capping or monitored natural recovery based on natural sedimentation.

Many bottom-dwelling organisms also physically move sediment particles during activities such as locomotion, feeding, and shelter building. These activities may alter sediment structure, biology, and chemistry, but the extent and magnitude of the alteration depends on site location, sediment type, and the types of organisms and contaminants present. For purposes of a sediment stability analysis, the factor of most concern is the depth to which significant physical mixing of sediment takes place, sometimes known as the "mixing zone." The mixing zone is best determined by examination of sediment cores. However, it is also useful to be aware of the typical burrowing depths of aquatic organisms in environments similar to the site.

Typically, the upper 5 to 15 centimeters of sediment contain the greatest number of organisms and activity, and are therefore of greatest interest when attempting to determine the mixing zone or when evaluating current exposure of biota to contaminants. However, project managers should also consider the activity type, the intensity of the activity, and organism population density, when determining the extent to which bioturbation should be considered in site evaluation. Highlight 2-10 provides examples of organisms that cause bioturbation, their activity type, and the general depth of the activity.

A project manager should be aware of at least the following parameters when assessing the depth of the mixing zone and the potential role bioturbation will play on a given sediment bed:

- Site location (e.g., salinity, water temperatures, depths, seasonal variation);
- Sediment type (e.g., size distribution, organic and carbonate content, bulk density); and

- Organism type (e.g., organisms either present and/or likely to recruit to and recolonize the area).

Highlight 2-10: Example Depths of Bioturbation Activity

Organism	Activity Type	Depth	Reference
Freshwater			
Tubificid worm (oligochaete)	Burrowing/Feeding	2 cm - 3 cm	Pennak 1978
Mayfly (insect)	Burrowing	5 cm - 15 cm	Pennak 1978
Crayfish (crustacean)	Burrowing	5 cm - 3 m	Pennak 1978
Burbot (fish)	Burrowing	0 cm - 30 cm	Boyer et al. 1990
Marine/Estuarine (Atlantic Coast)			
Bristleworm (polychaete)	Burrowing	0 cm -15 cm	Hylleberg 1975
Bamboo worm (polychaete)	Burrowing/Feeding	0 cm - 20 cm	Rhoads 1967
Fiddler crab (crustacean)	Burrowing	0 cm - 30.5 cm	Warner 1977
Clam (bivalve)	Burrowing	0 cm - 3 cm	Risk and Moffat 1977
Marine/Estuarine (Pacific Coast)			
Bristleworm (polychaete)	Burrowing	0 cm - 15 cm	Hylleberg 1975
Fiddler crab (crustacean)	Burrowing	0 cm - 30.5 cm	Warner 1977
Clam (bivalve)	Burrowing	0 cm - 3 cm	Risk and Moffat 1977

This analysis may be done for naturally deposited sediment as well as potential in-situ capping material. Where bioturbation is likely to be a significant process, it is important to evaluate its effects using site-specific data and assistance by technical experts.

2.5.4 Predicting the Consequences of Sediment Movement

Depending on its extent, movement or disturbances of contaminated sediment or in-situ cap material may or may not have significant consequences for risk, cost, or other factors important at a specific site. A number of differing factors may be important in determining whether expected or predicted movements or disturbances are acceptable. Historical records or monitoring data for contaminant concentrations in sediment and water during events such as floods may be valuable in analyzing the increase in risk. Where this information is not available or has significant uncertainty, models may also be very useful. This analysis should include not only increased risk from contaminant releases to the waterbody, but wherever those contaminants are likely to be deposited. Increased cost may include remedy costs such as cap repair or costs related to contaminant dispersal, such as increased disposal cost of downstream navigational dredging. There may also be societal or cultural impacts of

contaminant releases the project manager should consider, such as lost use of resources. These factors are discussed further in Chapter 1, section 1.6, Community Involvement.

Project managers should assess the impacts of contaminant release caused by sediment movement on potential receptors on a site-specific basis. Most of the needed information concerning human and environmental receptors is the same information that is gathered during the baseline risk assessment, and project managers should consult the site risk assessors for assistance. Where natural recovery is being evaluated, project managers should recognize that not only the rate of sediment burial, but also the frequency of sediment movement, determines the rate of recovery for surface sediment and biota. Where in-situ capping is being evaluated, project managers should recognize that some amount of transport may be acceptable and incorporated into plans for remedial design and cap maintenance. Increased risk due to sediment transport during dredging is a related analysis when considering dredging. Comparing the increased risk, cost, or other consequences of sediment disruption due to natural causes or the remedy itself is an important part of the remedy selection process.

When evaluating in-situ remedy alternatives, the significance of potential harm due to re-exposure of contaminated sediments or contaminated sediment redistribution is an important consideration. Factors to be considered include the nature of the contaminants, the nature of the potential receiving environment and biological receptors, and the potential for repair or recovery from the disturbance. These factors can be used to evaluate risks, costs, and/or other effects of different events on existing contaminated sediment or sediment remedies.

2.6 MODELING

This section briefly discusses the role of contaminated sediment transport and fate modeling in evaluating alternative risk management options at sediment sites. It is intended to assist project managers in deciding whether models can be a useful tool at a site, and if so, what type of model (or level of analysis) should be considered. This section does not advocate the use of models at every site, nor does it recommend specific models. Whether to use a model and what model to use are site-specific decisions for which modeling experts should be consulted. Guidance on the recommended process to follow in making these decisions is given below. Technical assistance is available to project managers from EPA's Office of Research and Development (ORD). Project managers should contact the ORD liaison in their region or the Office of Emergency and Remedial Response (OERR) for information about the appropriate laboratory and personnel for assistance. Additional research about contaminated sediment modeling is underway at ORD and project managers should monitor the EPA web site or contact their ORD liaison for more information.

There is a wide range of assessment techniques, empirical models, and more robust computer (i.e., multi-dimensional numerical) models that can be applied to contaminated sediment sites. Numerical models are frequently applied to the most complex sites. These sites typically have a long history of data collection and have documented contaminant concentrations in sediment and biota and often have fish consumption advisories already in place. In addition, cleanup has often been delayed at these sites because of the spatial magnitude of the problem, potential costs associated with remediation, and difficulty of decision-making due to the complexity of the issues.

Models are useful tools, but they can be very time consuming and expensive to apply at complex sediment sites. Most modeling efforts require large quantities of site-specific data and typically a team of

experienced modelers. Nevertheless, models are helpful in that they give, when properly applied, a more complete understanding of the transport and fate of contaminants than can be provided by empirical data (from field or laboratory) alone. Modeling of contaminated sediments, just as with other modeling, should follow a systematic planning process that involves examination of data quality objectives (or other measures), uncertainty, and specific hypothesis. In most cases, models are expected to complement environmental measurements and address gaps that exist in empirical information. Examples of the uses of models include the following:

- Illustrating how contaminant concentrations vary spatially at a site. Empirical information can provide useful benchmarks that can be interpolated or modeled to get a better understanding of the distribution of contaminants;

- Predicting contaminant fate and transport over long periods of time (e.g., multiple years) or during episodic, high-energy events (such as a tropical storm or low-frequency flood event);

- Predicting future contaminant concentrations in sediment, water and biota to evaluate relative differences among the proposed remedial alternatives, ranging from monitored natural recovery to extensive removal; and

- Comparing modeled results to observed measurements to show convergence of information. Both modeling results and empirical data will have a measure of uncertainty, and modeling can help to examine the uncertainties (e.g., through sensitivity analysis) and refine estimates (which may include where to sample next).

The use of models at sediment sites is not limited to the remedy selection phase. Most sites that do use models for evaluation of proposed remedies are those that have previously developed a mass balance or other type of model during the development of the baseline risk assessment to quantify the relationships among contaminant sources and exposure pathways. At these sites, the same model is generally used to predict the response of the system to various cleanup options. Where this is done, it is important to continue to test the model predictions by monitoring during the remedy implementation and post-remedy phases to assess whether cleanup is progressing as predicted.

2.6.1 Sediment Transport Model Characteristics

A sediment transport model is a mathematical or conceptual representation of the movement of sediment and associated contaminants, as governed by physical, chemical and biological factors, in bodies of water. As such, a sediment model is limited by our current understanding of these factors and the ability to quantify (i.e., represent mathematically, their interactions and effects on the transport and fate of sediment). Thus, a sediment model is a relatively simplistic representation of the movement of sediment through natural and engineered waterbodies. It is simplistic due to the following

- Limitations in our understanding of natural systems, as reflected in the current state-of-the-science;

- Empiricism inherent in predicting flow-induced sediment transport, bank erosion, and non-point source loads;

- The relatively coarse spatial and temporal discretization (breaking space and time into blocks) of the waterbody being modeled when using a numerical model; and

- The inability to simulate geomorphological processes such as river meandering, bank erosion, and localized effects due to, for example, fallen trees and beaver dams.

Nevertheless, generally sediment transport models are the following:

- Useful tools when properly applied, although not required at every site;

- Data intensive, and require specialized expertise to apply and interpret; and

- One of several tools that should be used in making a remedial decision, not a stand-alone decision-maker

There are two basic types of sediment transport models, conceptual and mathematical models. In addition there are several different types of mathematical models. General types of models are described in Highlight 2-11 and an example of a conceptual site model is presented in Highlight 2-12.

Highlight 2-11: Types of Sediment Transport Models

Conceptual Model:

Identifies the 1) contaminants of potential concern, 2) sources of the contaminants, 3) physical and biogeochemical processes and interactions that control the transport and fate of sediment and associated contaminants, 4) exposure pathways, and 5) ecological and human receptors.

Mathematical Model:

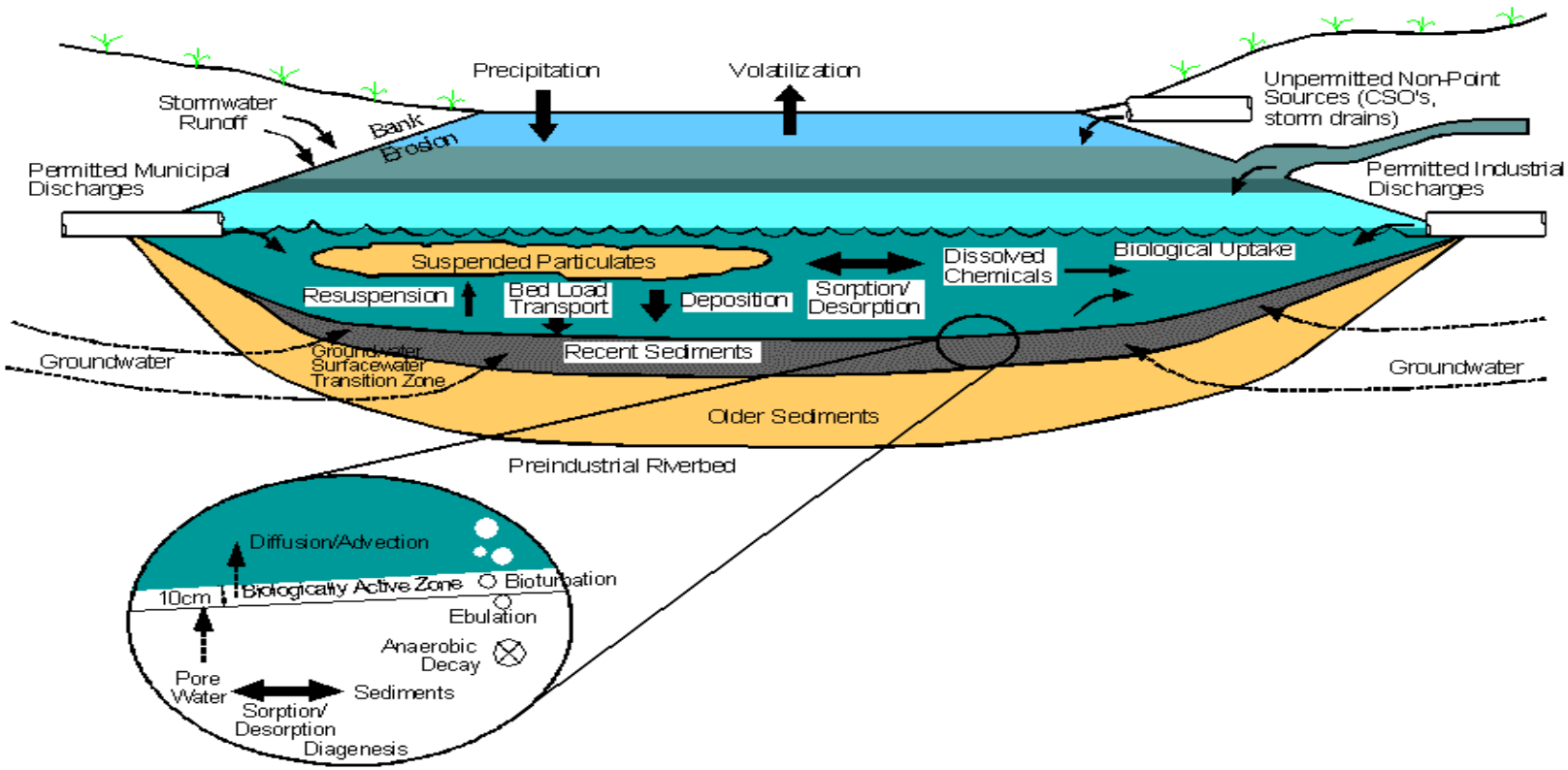
A set of equations that quantitatively represent the processes and interactions identified by the conceptual model that govern the transport and fate of sediment and associated contaminants. Mathematical models include analytical, regression, and numerical models:

- Analytical Model: An analytical model is one or more equations (e.g., simplified - a linearized, one-dimensional form of the advection-diffusion equation) for which a closed-form solution exists. This type of model would not be applicable at most sediment sites due to the complexities associated with the forcing hydrodynamics and spatial and temporal heterogeneities in sediment and contaminant properties/characteristics.

- Regression Model: A regression model is a statistically determined equation that relates a dependent variable to one or more independent variables. A stage-discharge rating curve is an example of a regression model in which stage (e.g., water level) and discharge (e.g., amount of water flow) are the independent and dependent variables, respectively.

- Numerical Model: In a numerical model, an approximate solution of the set of governing differential equations is obtained using a numerical technique. Examples include finite difference and finite element methods. A numerical model is used when the processes being modeled involve nonlinear equations for which closed-form solutions do not exist. Therefore, the solution obtained is an approximate solution.

Highlight 2-12: Conceptual Site Model Focusing on Sediment-Water Interaction



Source: Sediment Management Workgroup (SMWG)

2.6.2 Determining Whether A Mathematical Model is Needed

Mathematical sediment transport models can be time-intensive and expensive to apply, both in terms of costs to collect the data required for the models as well as to perform the modeling study, and their use and interpretation generally require specialized expertise. Because of this, mathematical modeling is not recommended for every sediment site. In some cases, empirical data from historical sources and new monitoring data may be sufficient to support a decision. A mathematical modeling study may not be recommended for very small (i.e., localized) sites, where cleanup may be relatively easy and inexpensive. However, mathematical modeling would generally be recommended for large or complex sites, especially where it is necessary to predict contaminant transport and fate over extended periods of time to evaluate relative differences among possible cleanup methods. Mathematical modeling becomes especially important when the existing empirical data are insufficient to predict future scenarios, as is frequently the case.

Project managers can decide whether a mathematical model is useful at a site by answering the following series of questions:

- Have the questions or hypotheses used to test the model been determined?
- Are historical data and/or simple quantitative techniques available to answer these questions with the desired accuracy?
- Have the spatial extent, heterogeneity and levels of contamination at the site been defined?
- Have the sources of sediment contamination been defined?
- Do sufficient data exist to support the use of a mathematical model, and if not, are time and resources available to collect the required data to achieve the desired level of confidence in model results? and
- Are time and resources available to perform the modeling study?

If the decision is made that some level of modeling is appropriate, the following section should assist project managers in deciding what level of analysis (i.e., what type of model) should be used.

2.6.3 Determining the Appropriate Level of Model

When the decision is made that a mathematical model is needed at a site, project managers generally should use three steps in determining what level of modeling is most appropriate. It is important that all three steps be followed in order.

<u>Step 1: Develop Conceptual Site Model</u>

Development of a Conceptual Site Model (CSM) is the key first step in this process. As described in section 2.1, Site Characterization and Conceptual Site Models, a CSM identifies the processes and interactions that control the transport and fate of sediment and associated contaminants. If

this step is not performed, then the decision of what level of modeling is appropriate will be made with less than the requisite information needed to make a scientifically defensible decision.

The development of a CSM requires examination of all existing site data to assist in determining the significant physical and biogeochemical processes and interactions. Relatively simple quantitative expressions of key transport and fate processes using existing site data, such as presented by Reible and Thibodeaux (1999), may help in identifying those processes that are most significant at the site.

Step 2: Determine Processes that Can and Cannot be Modeled

This step concerns determining if all the processes and interactions that control the transport and/or fate of contaminated sediment, as identified in the CSM, can be simulated with one or more existing sediment transport and fate models. If it is determined that there are existing models capable of simulating at a minimum the most significant (i.e., first-order) processes and interactions, then the project manager should (using the appropriate technical experts) identify the types of models (e.g., analytical, regression, numerical) that have this capability. This will eliminate those types of models that do not have this capability from further consideration.

Mathematical models (in particular numerical models) have been developed that can simulate most of the processes that control the transport and fate of sediment and contaminants in waterbodies, including a wide variety of physical, chemical, and biological processes. Highlight 2-13 depicts the inter-relationship of some major processes and the type of model with which they are associated. Depending on the needs at the site, models or model components ("modules") may link many of these processes into one model. Examples of the processes that can be modeled include the following:

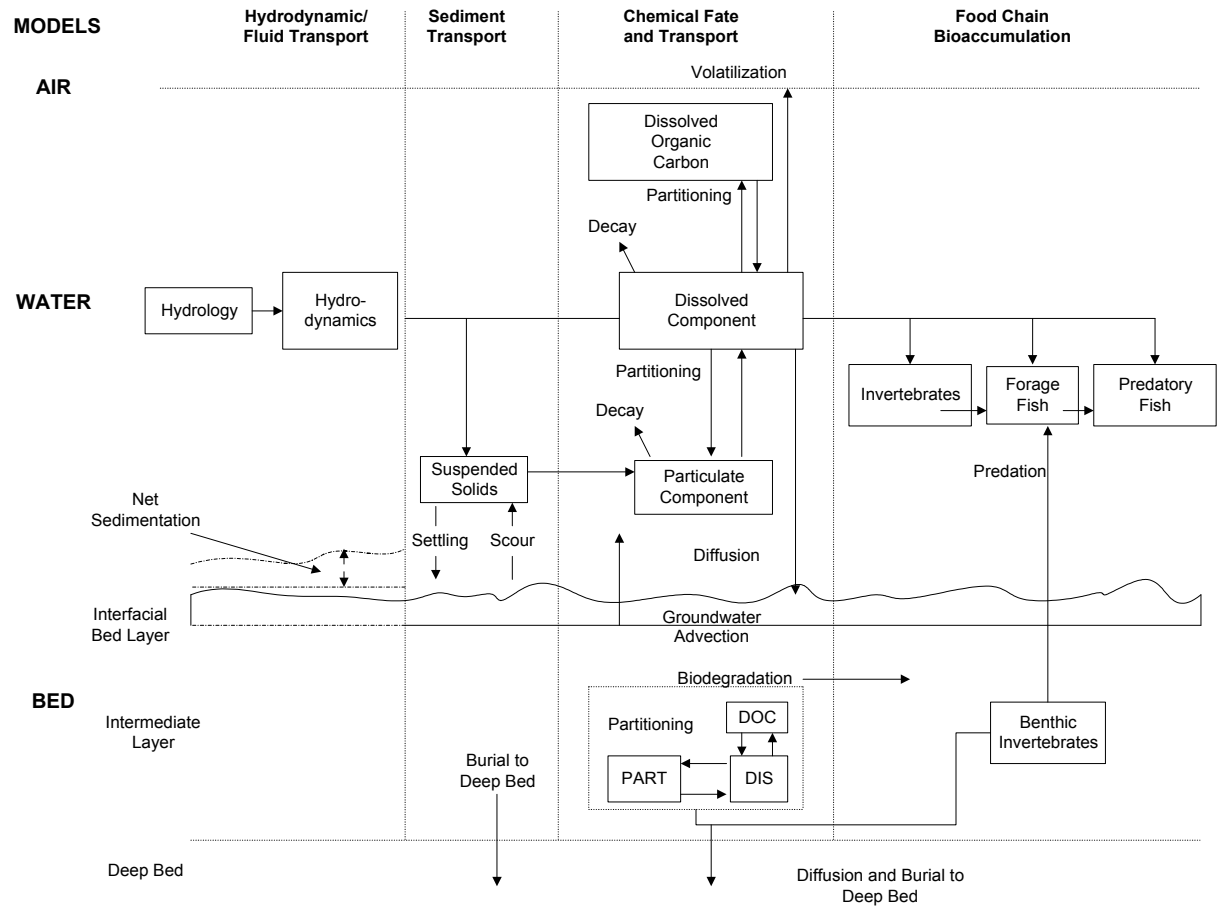
- On land and in the air, physical processes that result in loading of contaminants to water bodies may include point discharges, overland flow, discharge from ground water, and air deposition;

- In the water column, physical processes that may result in movement of dissolved or sediment-sorbed contaminants include transport via the water's ambient flow (advection), diffusion, and settling of sediment particles containing sorbed contaminants;

- In the sediment bed, important physical processes include the movement of pore water and dissolved contaminants, seepage into and out of the sediment bed and banks, and the mixing of dissolved and sediment-sorbed contaminants by bioturbation. In addition, both sorbed and dissolved material may be exchanged between the water column and sediment bed due to sediment deposition and resuspension or erosion; and

- In the water column and in the sediment bed, physiochemical processes influencing the fate and transport of contaminants include two-phase and three-phase chemical partitioning as described below. Biogeochemical reaction processes influencing the fate of contaminants include speciation, volatilization, anaerobic gas formation, hydrolysis, oxidation, photolysis, biodegradation, and biological uptake.

Highlight 2-13: Contaminant-Exposure Modeling Framework



Source: (NRC 2001)

In two-phase partitioning, the total concentration of the contaminant is defined as the sum of the dissolved and particulate fractions, whereas the partition coefficient is defined as a distribution coefficient in terms of the total suspended solids (TSS). The dissolved fraction is specified by the distribution coefficient and the TSS concentration. In three-phase partitioning, a contaminant is partitioned into three forms as a bio-available dissolved phase, a non-available dissolved organic carbon phase, and a particulate organic carbon phase. A three phase model is appropriate for waters in which internally produced organic material is a significant proportion of total solids as compared to solids supplied by watershed runoff, bank and bed erosion.

If it is determined that there are no existing models capable of simulating, at a minimum, the most significant (i.e., first-order) processes and interactions, then project managers may need to rely on other

tools or methods for evaluating proposed cleanup methods or develop and test new models or modules. This latter approach is a research and development level effort and should be avoided if at all possible.

Examples of processes that cannot be dynamically simulated, even using state-of-the-art sediment transport models, are geomorphological processes such as the development of meanders in streams and rivers, and bank cutting/erosion. There are empirical methods for estimating the total quantity of sediment that would be introduced to a waterbody due to the failure of a river/stream bank, but this process cannot be dynamically simulated.

Step 3: Select an Appropriate Model

If one or more models or types of mathematical models exist that are capable of simulating the controlling transport and fate processes and interactions, then project managers should use the process described above to choose the appropriate type of model (i.e., level of analysis). If the decision is made to apply a numerical model at a sediment site, selection of the most appropriate contaminated sediment transport and fate model to use at a specific site is one of the critical steps in a modeling program. During this process, familiarity with existing sediment transport models is essential. Comprehensive technical reviews of available models are currently being conducted by the EPA's National Exposure Research Laboratory.

Where numerical models are used verification, calibration, and validation are critical to attaining useful results. The project manager should be aware that the terms "verification" and "validation" are frequently used interchangeably in modeling literature. These terms, as used in this guidance, are defined as follows:

- *Model verification*: Evaluating the theory, consistency of the computer code with model theory, and evaluation of the computer code for integrity in the calculations. (This is an on-going process, especially for newer models.);

- *Model calibration*: Using site-specific information from a historical period of time to adjust model parameters to more accurately reflect measured site-specific conditions; and

- *Model validation*: Demonstrating that the calibrated model accurately reproduces known conditions over a different period of time or in a different waterbody than that used for calibration.

The extent of verification, calibration, and validation in large part determines the accuracy of a model. If a verified model has not been calibrated or validated to a specific site, then its use may be of little value. Where possible, project managers should use verified and validated models that are in the public domain, calibrated to site-specific conditions. Proprietary models may also be useful, but project managers should be aware that they contain code that has not been shared publically and may not have been verified. The interpretation of modeling results and the reliance placed on those results should heavily consider the extent of model verification, calibration, and validation.

2.6.4 Peer Review

It is EPA policy that a peer review of numerical models is often necessary to ensure that a model provides decision makers with useful and relevant information. Project managers should use EPA's *Guidance for Conducting External Peer Review of Environmental Regulatory Models* (U.S. EPA 1994a) and *Peer Review Handbook* (U.S. EPA 2000b) whenever a numerical model is used to determine whether a peer review is appropriate and, if so, what type of peer review should be used. As a rule of thumb, major scientifically and technically based work products that support Agency decisions normally should be peer reviewed. In addition, when a model is being used outside the niche for which it was developed, is being applied for the first time, or is critical to a decision that is very costly, a peer review may be needed. In addition, project managers should refer to OSWER Directive 9285.6-08, *Principles for Managing Contaminated Sediments at Hazardous Waste Sites*, Principle 6 (Appendix A).

The EPA (1994a) also noted that: "Environmental models (i.e., fate and transport, estimation of contaminant concentrations in soil, ground water, surface water and ambient air, exposure assessment) that may form part of the scientific basis for regulatory decision making at EPA are subject to the peer review policy. However, it cannot be more strongly stressed that peer review should only be considered for judging the scientific credibility of the model including applicability, uncertainty, and utility (including the potential for misuse) of results and not for directly advising the Agency on specific regulatory decisions stemming in part from consideration of model output."

Highlight 2-14 summarizes some important points to remember about modeling at sediment sites.

Highlight 2-14: Points to Remember about Modeling at Sediment Sites

- Consider the range of available historical data that can be used in assessment techniques or models. Determine the level of model to be applied, commensurate with the issues and questions being raised
- Decide early whether to use models. If models are useful, seek assistance from modeling experts early in the site characterization process; for example, when scoping the RI and planning data collection efforts
- Choose models and model components appropriate to the scope of the questions that need to be answered. Simpler questions may be best answered by simpler models or other assessment techniques
- Concentrate site-specific data collection on factors that most influence model outcome. For some parameters, use of conservative "bounding" assumptions can replace site-specific data. For other parameters, site-specific data are important
- Be aware of the uncertainties and variability of model predictions. Where possible, quantify these using sensitivity analysis or other evaluation methods
- Consider the extent of model validation, calibration, and verification when assessing model results. Where possible, use validated and verified models that are in the public domain, calibrated to site-specific conditions
- Compare model predictions to monitoring results during and after remedy implementation to test model assumptions. Such comparisons provide insight as to the performance of individual models and provide a basis for model adjustments that improves model performance
- Where a model is being applied outside the niche for which it was developed, is being applied for the first time, or is being applied to help make decisions that are very costly, critical aspects of the modeling study should be peer-reviewed

3.0 FEASIBILITY STUDY CONSIDERATIONS

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3.0 FEASIBILITY STUDY CONSIDERATIONS

Generally, the purpose of a feasibility study for a contaminated sediment site is to develop and evaluate a number of alternative methods for achieving remedial action objectives. This process lays the groundwork for selecting a remedy for the site that best eliminates, reduces, or controls risks to human health and the environment. The general feasibility study process is described in the U.S. Environmental Protection Agency's (EPA's) *Guidance for Conducting Remedial Investigations and Feasibility Studies under CERCLA*, also referred to as the "RI/FS Guidance" (U.S. EPA 1988a). This chapter is intended to supplement existing guidance by offering sediment-specific guidance about developing alternatives, considering the National Oil and Hazardous Substances Pollution Contingency Plan (NCP) criteria, identifying applicable or relevant and appropriate requirements, estimating cost, and using institutional controls. Chapters 4, 5, and 6 present more detailed guidance on evaluating alternatives based on the three major cleanup methods for sediment: monitored natural recovery (MNR), in-situ capping, and dredging (or excavation) with treatment or disposal.

3.1 DEVELOPING SEDIMENT ALTERNATIVES

The following steps, modified from EPA's RI/FS Guidance by adding details specific to sediment, generally apply to developing alternatives at sediment sites:

- Develop remedial action objectives specifying the contaminants and media of interest, exposure pathways, and cleanup goals that permit a range of alternatives to be developed including each of the three major cleanup methods (removal, capping, and natural recovery);

- Identify estimated volumes or areas of sediment to which the cleanup methods may be applied, taking into account the requirements for protectiveness as identified in the remedial action objectives and the chemical and physical characteristics of the site;

- Identify the time frame(s) in which the alternatives are expected to achieve cleanup goals and remedial action objectives;

- Develop additional detail concerning the equipment, methods, and locations to be evaluated for each of the three major cleanup methods (e.g., number and types of dredges or excavators, transport methods, treatment methods, type of disposal units, general disposal location, general cap materials, cap placement methods, detail concerning the processes being relied upon for natural recovery, need for monitoring and/or institutional controls); and

- Assemble the more detailed methods into a set of alternatives representing a range of removal, capping, and natural recovery options or combination of options, as appropriate.

This process is best done in an iterative fashion, especially at complex sites. For example, investigation into equipment and disposal options for sediment removal may lead to evaluation of a variety of time frames for achieving cleanup goals. The number and type of remedial alternatives that a project manager develops for any site is a site-specific decision. The project manager should take into account the size, characteristics, and complexity of the site. However, due to the limited number of

cleanup methods available for contaminated sediment, generally project managers should evaluate each of the three major cleanup methods: monitored natural recovery, in-situ capping, and removal through dredging or excavation, at every sediment site at which they may be appropriate.

3.1.1 Alternatives which Combine Cleanup Methods

At sites with multiple waterbodies or sections of waterbodies with different characteristics or uses, project managers have found that alternatives that combine a variety of cleanup methods are frequently the most promising. In many cases, institutional controls are also part of many alternatives (see section 3.5, Institutional Controls). The following examples illustrate a few ways cleanup methods have been combined into alternatives for evaluation at sediment sites:

- A variety of combinations of dredging, transport, and disposal methods have been developed as options for a variety of volumes of contaminated sediment "hot spot" areas combined with capping or MNR for the remainder of the site;

- Dredging has been developed as an option for areas that also require navigational dredging or for areas where there is insufficient water depth to maintain navigation with a cap, and capping has been developed for intertidal and under-pier areas where dredging may be infeasible and/or impractical; and

- Thin-layer placement (see Chapter 4, Monitored Natural Recovery) has been combined with MNR where the natural rate of sedimentation is insufficient to bury contaminants in a reasonable time frame

3.1.2 The No-Action Alternative

The NCP §300.430(e)(6) provides that the no-action alternative be developed as one of the alternatives under consideration at every site. The no-action alternative should reflect the site conditions described in the baseline risk assessment and remedial investigation. This alternative may be a no-further-action alternative if some removal or remedial action has already occurred at the site.

No-action or no-further-action alternatives should not include any treatment, engineering controls, or institutional controls but may include monitoring. However, a no-action alternative is different from a MNR alternative where natural processes are relied upon as a risk-reduction method.

If a no-action or no-further action alternative does not meet the NCP's threshold criteria of protection of human health and the environment and meeting applicable or relevant and appropriate requirements, it may be dropped from the detailed analysis of alternatives. However, the record of decision (ROD) should explain why the no-action alternative was dropped from the analysis.

Chapter 7, Remedy Selection Considerations, includes guidance on when it may be appropriate to select a no-action alternative.

3.1.3 In-Situ Treatment Alternatives

In-situ treatment is an experimental cleanup method that involves the biological, chemical, or physical treatment of contaminated sediment in place. Although significant technical limitations exist currently, active research and pilot studies in this field may make it a viable alternative in the future. Project managers are encouraged to watch the development of in-situ treatment methods for contaminated sediment. Potential in-situ treatment methods include the following:

- *Biological Treatment:* Microbial degradation of contaminants by the addition of enhancement materials such as oxygen and nutrients (e.g., nitrogen), or microorganisms into the sediment or a reactive cap;

- *Chemical Treatment:* The destruction of contaminants through oxidation and dechlorination processes by providing chemical reagents, such as permanganate, hydrogen peroxide, or potassium hydroxide, into the sediment or a reactive cap; and

- *Immobilization Treatment:* Solidification or stabilization by adding Portland cement, fly ash, limestone, or other additives to the sediment for encapsulating the contaminants in a solid matrix and/or chemically reducing the contaminants by converting them into a less soluble, less mobile, or less toxic form.

Techniques for in-situ treatment of sediment are in the early stages of development, and few methods are currently commercially available. Experiences gained to date in experimental or small-scale applications of in-situ remedies have indicated that technical limitations to the effectiveness of available in-situ treatments continue to exist. For example, in-situ remedies relying on the addition of required substrates and nutrients, reagents, or catalysts have been developed for some contaminants, such as polychlorinated biphenyls (PCBs), but no effective in-situ delivery system has been developed to deliver the needed reagents to contaminated sediment (NRC 2001). The lack of an effective delivery system has also hindered the application of in-situ stabilization systems (NRC 2001). However, new developments may make this a more promising cleanup method in the future.

Several EPA-funded bench and field studies in this area are underway. These include EPA's Superfund Innovative Technology Evaluation (SITE) program, which encourages the development and routine use of innovative treatment, monitoring, and measurement technologies. The SITE program is in the process of demonstrating in-situ treatment technologies (Highlight 3-1). More information on the SITE program is available at http://www.epa.gov/ORD/SITE/. Also, the Hazardous Substance Research Center (HSRC) - South-SouthWest, centered at Louisiana State University, has received funding for research about in-situ treatment and other innovative capping alternatives for contaminated sediment in the Anacostia River in Washington, D.C. More information on this program is available from the HSRC at http://www.hsrc.org.

3.2 NCP REMEDY SELECTION CRITERIA

The NCP §300.430(e)(9) establishes a framework of nine criteria for evaluation and selection of remedies. These criteria address the requirements and considerations of the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA), and additional technical and policy considerations that have proven to be important for selecting remedial actions. Many of these

Highlight 3-1: SITE Program In-situ Treatment Technology Demonstrations

Site	Technology Type	Contaminant
Jones Island CDF	Phytoremediation	Polynuclear aromatic hydrocarbons (PAHs) and PCBs
Milwaukee Harbor	Phytoremediation	PAHs and PCBs
Whatcom Waterway	Electrochemical Oxidation	Mercury and PAHs
Bellingham Bay, Puget Sound	Electrokinetics	Phenolic Compounds
Pearl Harbor	Bioremediation	PCBs
Anacostia River	Multiple In-situ Caps	PAHs and PCBs

criteria are also of importance to the Resource Conservation and Recovery Act (RCRA). The NCP §300.430(e)(7) describes a method for screening potential alternatives prior to developing detailed alternatives when a large number of alternatives are being considered at a site. Only the alternatives judged as the best or most promising following this screening are retained for further development and for a detailed analysis. The three broad criteria for screening preliminary remedial alternatives are: 1) effectiveness; 2) implementability; and 3) cost. Although a screening level analysis may be necessary in some cases, due to the limited number of cleanup methods available for sediment, project managers generally should not screen out any of the major cleanup methods early in the FS.

More detailed discussions of what is included under each of the nine criteria can be found in the *Guide to Preparing Superfund Proposed Plans, Records of Decision, and other Remedy Selection Decision Documents* (U.S. EPA 1999a) and the RI/FS Guidance. The following provides a summary of the nine criteria (U.S. EPA 1988a):

- *Overall Protection of Human Health and the Environment*: This criterion is used to evaluate how the alternative as a whole achieves and maintains protection of human health and the environment;

- *Compliance with Applicable or Relevant and Appropriate Requirements (ARARs)*: This criterion is used to evaluate whether the alternative complies with chemical-specific, action-specific, and location-specific ARARs or if a waiver is justified. Although not a statutory requirement, this criterion also commonly includes whether the alternative considers other criteria, advisories, and guidance that are to be considered (TBC) at the site;

- *Long-Term Effectiveness and Permanence*: This criterion includes an evaluation of the magnitude of human health and ecological risk from untreated waste or treatment residuals remaining after remedial action has been concluded (known as residual risk), and the adequacy and reliability of controls to manage that residual risk. It also includes an assessment of the potential need to replace technical components of the alternative, such as a cap or a treatment system, and the potential risk posed by that replacement;

- *Reduction of Toxicity, Mobility, and Volume Through Treatment*: This criterion refers to the evaluation of whether treatment processes can be used, the amount of hazardous material treated, including the principal threat that can be addressed, the degree of expected reductions, the degree to which the treatment is irreversible, and the type and quantity of treatment residuals;

- *Short-Term Effectiveness*: This criterion includes an evaluation of the effects of the alternative during the construction and implementation phase until remedial objectives are met. This criterion includes an evaluation of protection of the community and workers during the remedial action, the environmental impacts of implementing the remedial action, and the expected length of time until remedial objectives are achieved;

- *Implementability*: This criterion is used to evaluate the technical feasibility of the alternative, including construction and operation, reliability, monitoring, and the ease of undertaking an additional remedial action if the remedy fails, the administrative feasibility of activities needed to coordinate with other offices and agencies, such as for obtaining permits for off-site actions, rights of way, and institutional controls, and the availability of services and materials necessary to the alternative, such as treatment, storage, and disposal facilities;

- *Cost*: This criterion includes an evaluation of direct and indirect capital costs, including costs of treatment and disposal, annual costs of operation, maintenance, monitoring of the alternative, and the total present worth of these costs, as discussed in section 3.4, Estimating Cost;

- *State (Or Support Agency) Acceptance*: This criterion is used to evaluate the technical and administrative concerns of the state (or the support agency, in the case of state-lead sites) regarding the alternatives, including an assessment of the state or the support agency's position and key concerns regarding the alternative, and comments on ARARs or the proposed use of waivers. Tribal acceptance is also evaluated under this criterion; and

- *Community Acceptance*: This criterion includes an evaluation of the concerns of the public regarding the alternative. It determines which component of the alternatives interested persons in the community support, have reservations about, or oppose.

3.3 APPLICABLE OR RELEVANT AND APPROPRIATE REQUIREMENTS FOR SEDIMENT ALTERNATIVES

Pursuant to CERCLA §121(d)(4), all remedial actions at CERCLA sites must be protective of human health and the environment and must comply with ARARs unless a waiver is justified. Cleanup levels for response actions under CERCLA generally are based on site-specific risk assessments, ARARs, and/or TBCs. ARARs may be waived only under limited circumstances. TBCs are generally non-promulgated advisories or guidance issued by federal, state or tribal governments that are not legally binding and do not have the status of potential ARARs. However, TBCs are considered along with ARARs as part of the site risk assessment and may be useful in developing CERCLA remedies. The project manager should also refer to *CERCLA Compliance with Other Laws Manual* (U.S. EPA 1988b).

Also, the preamble to the final NCP (55 FR 8741) states that, as a matter of policy, it is appropriate to treat Indian tribes as states for the purpose of identifying ARARs. See also NCP §300.515(b) for the conditions a tribal government should meet to be afforded substantially the same treatment as states.

The process of identifying ARARs typically begins in the scoping phase of the RI/FS, continues until the ROD is finalized, and may be reexamined during the five-year review process. ARARs include the following:

- Applicable requirements are those cleanup standards, standards of control, and other substantive environmental protection requirements, criteria, or limitations or facility siting law promulgated under federal, state, or tribal law that specifically address a hazardous substance, pollutant, contaminant, remedial action, location, or other circumstance at a CERCLA site; and

- Relevant and appropriate requirements are those cleanup standards, standards of control, and other substantive environmental protection requirements, criteria, or limitations promulgated under federal, tribal, or state law or facility siting law that, while not applicable to a hazardous substance, pollutant, contaminant, remedial action, location or other circumstance at a CERCLA site, address problems or situations sufficiently similar to those encountered at the CERCLA site that their use is well suited to the particular site.

A requirement is applicable, or relevant and appropriate, but not both. Identification of ARARs should be done on a site-specific basis and usually involves a two-part analysis. First, a determination of whether a given requirement is applicable should be made, and second, if it is not applicable, then a determination should be made as to whether it is relevant and appropriate. Highlight 3-2 lists some examples of potential federal, state, and tribal ARARs for sediment sites and examples of how remedial strategies have been adapted to comply with ARARs.

On-site actions should comply with the substantive portions of ARARs unless the ARAR is waived. Compliance with administrative procedures, such as permits, is not required for on-site response actions. Off-site actions must comply with both substantive and administrative requirements of legally applicable laws and regulations.

For more information about ARARs, the project manager should consult guidance available at http://www.epa.gov/superfund, the *Compendium of CERCLA ARARs Fact Sheets and Directives* (U.S. EPA 1991a), and the *Assessment and Remediation of Contaminated Sediments (ARCS) Program Remediation Guidance Document* (U.S. EPA 1994b).

As part of the ARARs analysis, project managers, in consultation with the site attorney, should consider requirements promulgated under the Clean Water Act (CWA). For example, federal water quality criteria as well as state-promulgated regulations including state water quality standards may be potential ARARs for surface water. Some states may have water quality standards or their own promulgated sediment quality standards that may be potential ARARs for sediment.

Total maximum daily loads (TMDLs) established or approved by the EPA under the Clean Water Act are planning tools designed to reduce contributing sources of pollutants in water quality limited segments (WQLS). TMDLs calculate the greatest amount of loading of a pollutant that a waterbody can

Law or Regulation		
	Potential Federal ARARs	
Clean Water Act §304(a)	EPA publishes national recommended Ambient Water Quality Criteria (AWQC) for the protection of aquatic life and human health. CERCLA §121(d)(2) requires EPA eo consider whether nationally recommended AWGC should be relevant and appropriate requirements at a site. CERCLA §121(d)(2)(B) establishes the guidelines to consider in determining when AWQC may be relevant and appropriate requirements, including consideration of the designated or potential uses of surface water, the purposes for which the criteria were developed and the latest information available.	In developing a remedy for the upland soils portion of a sediment site, EPA determined that a revised AWQC was relevant and appropriate criteria for surface water runoff from the upland soils discharging to the waterway.
Clean Water Act §404 40 CFR 230	Regulates the discharge of dredged or fill materials into waters of the U.S. Discharges of dredged or fill materials are not permitted unless there is no practicable alternative that would have less adverse impact on the aquatic ecosystem. Any proposed discharge must avoid, to the fullest extent practicable, adverse effects, especially on aquatic ecosystems. Unavoidable impacts must be minimized, and impacts which cannot be minimized must be mitigated.	The Wycoff/Eagle Harbor, WA, NPL site included construction of a sheet pile barrier wall to control subsurface NAPL migration. To compensate for the loss of habitat, intertidal habitat was created in another part of the harbor by returning a diked off area to its historic intertidal character.
Rivers and Harbors Act, Section 10 33 CFR 320 to 323	Activities that could impede navigation and commerce are prohibited. Prohibits authorized obstruction or alteration of any navigable waterway.	A site with contaminated sediment has an authorized navigation depth of 30 feet. The evaluation of alternatives needs to consider the need to maintain this minimum depth when evaluating whether capping is or is not a feasible alternative for the entire site.

Law or Regulation	Description	Examples of How Remedial Strategies have been Adapted to Comply with ARARs
Endangered Species Act	Section 7 requires federal agencies to ensure that the actions they authorize, fund or carry out are not likely to jeopardize the continued existence of endangered or threatened species, or adversely modify or destroy their critical habitat. Will be an applicable requirement where a threatened or endangered species or their habitat is or may be present. By policy, EPA consults with the U.S. Fish and Wildlife Service and the National Marine Fisheries Service (NMFS).	Chinook salmon are threatened species that are found at the Commencement Bay NPL site during part of the year. After following EPA's policy of consulting with the NMFS, EPA decides that to avoid harming the species, some in-water remedial work will be done only between August and February when juvenile salmon are not migrating through the area. Other in-water work will be performed between March and July, utilizing special conditions recommended by NMFS to minimize impacts to salmon.
Resource Conservation and Recovery Act (RCRA); 40 CFR 260 to 268	Dredged material may be subject to RCRA regulations if it contained a listed waste, or if it displays a hazardous waste characteristic, for example by the Toxicity Characteristic Leaching Procedure (TCLP). Most states have been authorized to implement the RCRA program in lieu of EPA. RCRA regulations may potentially be ARARs for the storage, treatment, and disposal of the dredged material unless an exemption applies. One such exemption is if CWA 404 applies to the cleanup activity (40 CFR 261).	The material to be dredged contains a listed pesticide formulation waste, and thus RCRA may be an applicable ARAR. However, CWA §404 applies to the selected cleanup action, and the site is located in a state where EPA implements the RCRA program. Thus the cleanup action is exempted from RCRA. This situation is explained in the description of the selected remedy chapter of the ROD.

Law or Regulation	Description	Examples of How Remedial Strategies have been Adapted to Comply with ARARs
Toxic Substances Control Act (TSCA) 40 CFR 761	Regulates the storage, treatment and disposal of material contaminated with PCBs. Contaminated dredged sediment would generally follow the substantive requirements of 40 CFR 761.61, cleanup and disposal requirements for PCB remediation waste. Material meeting the definition of PCB remediation waste (761.3) would be disposed of using the three options under 761.61, which include a self-implementing option (761.61(a)), a performance-based option (761.61(b)), and a risk-based option (761.61(c)). Determination of whether there is a PCB remediation waste (as per 761.3) at the site may require determination of date of spill, PCB concentration of material spilled, or PCB concentration currently at site. If information is not available (e.g., date of spill), 761.61 may still be relevant and appropriate. The definition of PCB remediation waste, under 761.3, may include any concentration of PCBs. As such, 761.61 may be an ARAR for any concentration of PCBs. Selection of cleanup/disposal options under 761.61 for a Superfund site is made at the Regional level, in conjunction with the TSCA program. The risk-based option under 761.61(c) would be expected to be selected most often at Superfund sites.	Example 1. Although the source of PCBs is not known at this site, 761.61 may be relevant and appropriate. The risk-based option under 761.61 is selected. EPA's remedy is to dredge the contaminated sediments and send the dewatered sediments to a landfill, meeting the requirements for disposal of PCB remediation waste. Example 2. A PCB transformer is known to have broken open in the area of PCB-contaminated sediments prior to 1978, resulting in sediments, currently at the site, with PCB concentrations greater than 50 ppm. As this meets the 761.3 definition for PCB remediation waste, 761.61 may be applicable. A risk-based disposal plan is selected and is made part of the ROD.
Potential State and Tribal ARARs		
State Water Quality Standards Regulation	Under the CWA, states are required to designate surface water uses, and to develop water quality standards based on those uses and the AWQC. Often an applicable requirement. Where a tribe has promulgated water quality standards, these may also be an applicable requirement.	A tribe has an EPA approved water quality standard regulation which designated the uses of a river to include rearing of aquatic life and other uses. Design and construction of the selected remedy, including the confined aquatic disposal facility, needs to achieve the tribe's water quality standards based on that use.

Law or Regulation	Description	Examples of How Remedial Strategies have been Adapted to Comply with ARARs
State Hazardous Waste Regulations	Many states have been authorized by EPA to implement the RCRA Subtitle C Hazardous Waste Program in lieu of EPA.	The sediment at a site was contaminated with a listed hazardous waste. The state has been authorized for RCRA, and decided to not adopt the hazardous waste identification rule (HWIR) sediment exemption. Treatment and disposal of the dredged contaminated sediment must meet or waive the state's hazardous waste regulations.
State Solid Waste Regulations	Most states have regulations for the location, design, construction, operation and closure of solid waste management facilities. Potential applicable or relevant and applicable requirement for disposal of non-hazardous waste contaminated sediment.	An alternative includes on-site upland disposal of dredged sediment. The feasibility study looks at the state solid waste regulations and determines that a disposal facility at two of the three possible sites can be designed to meet the ARAR. The third site is eliminated from further analysis.
Total Maximum Daily Load Regulation	Some states have established wasteload allocations in an EPA-approved and promulgated TMDLs. May be an applicable or a relevant and appropriate requirement, where such regulations exist, depending on whether the regulation specifically addresses the discharge. Non-promulgated TMDLs may be a TBC.	An alternative includes residual contamination that provides a small continuing load to the waterbody. EPA consulted with the state TMDL program to determine whether TMDLs are a potential ARAR or TBC and how they interact with an alternative that includes residual contaminants.
National Pollutant Discharge Elimination Permit regulations (NPDES)	Under the CWA, many states have been delegated the authority for the NPDES permit program. These regulations generally regulate discharges, including monitoring requirements and effluent discharge limitations for point sources. Where a remedy has a point discharge that is not regulated, the substantive requirements may be an applicable regulation.	A Superfund remedy includes dewatering of dredged contaminated sediments prior to disposal with discharge of the water to surface water. EPA consulted with the state NPDES permit program to determine water treatment standards prior the discharge.

receive without exceeding CWA water quality standards. TMDLs are established by the states, territories, or authorized tribes and approved by the EPA. Effluent limits in point source NPDES permits should be consistent with the assumptions and requirements in a wasteload allocation in an approved TMDL. The EPA established TMDLs are not promulgated as rules, are not enforceable, and, therefore, are not ARARs. TMDLs established by states, territories or authorized tribes may or may not be promulgated as rules. Therefore, TMDLs established by states, territories, or authorized tribes, should be evaluated on a regulation-specific and site-specific basis. Even if a TMDL is not an ARAR it may aid in setting protective cleanup levels and may appropriately be a TBC guidance. This should also be determined on a site-specific basis. In any case, project managers should work closely with regional EPA Office of Water and state personnel to coordinate matters relating to TMDLs. The project manager should remember that even when a TMDL or wasteload allocation is not enforceable the water quality standards on which they are based may be ARARs. TMDLs can also be useful in helping project managers evaluate the impacts of continuing sources, contaminant transport, and fate and effects. Similarly, Superfund's remedial investigation/feasibility study may provide useful information and analysis to the federal and state water programs charged with developing TMDLs.

Project managers should also be aware of Executive Orders such as those covered by the *Statement of Procedures on Floodplain Management and Wetland Protections*, 50 CFR Part 6, Appendix A. Although not ARARs, the Agency may follow Executive Orders as a matter of policy. The Statement of Procedures cited above sets forth EPA policy and guidance for carrying out Executive Orders 11990 and 11988. Executive Order 11988 concerns flood plain management and the evaluation by federal agencies of the potential effects of actions they may take in a flood plain to avoid, to the extent possible, adverse effects associated with direct and indirect development of a flood plain. Executive Order 11990 concerns protection of wetlands and the avoidance by federal agencies, to the extent possible, of the adverse impacts associated with the destruction or loss of wetlands if a practical alternative exists. OSWER Directive 9280.0-03, *Considering Wetlands at CERCLA Sites* (U.S. EPA 1994c), contains further guidance on addressing this Executive Order.

Examples of ways in which remedial strategies have been adapted in light of these Executive Orders as a matter of policy include the following:

- EPA determined that capping above grade would be an inappropriate alternative for remediating contaminated sediments in a small river, as the increased bottom elevation would increase the risk of flooding. Instead, the final EPA remedy called for dredging contaminated sediments and capping back to the existing grade; and

- When evaluating possible alignments for the access road to the contaminated sediment site, the region selected a route that avoided the wetland and that would minimize the potential for effects on the flood plain. During design of the access road, additional features were incorporated to further minimize any indirect impact on the flood plain.

3.4 ESTIMATING COST

Developing cost estimates is an essential part of evaluating alternatives. Guidance on preparing cost estimates and the general role of cost in remedial alternative selection is discussed in *A Guide to Developing and Documenting Cost Estimates During the Feasibility Study* (U.S. EPA and USACE 2000).

The general elements of a cost estimate include the following:

- Capital costs;
- Operation and maintenance costs (O&M); and
- Net present value.

This cost estimate should not include potential claims for natural resource damages, but may include costs for mitigation of habitat lost or impaired by the remedial action, where appropriate.

3.4.1 Capital Costs

Capital costs are those expenditures that are needed to construct or install an alternative. Capital costs include only those expenditures that are initially incurred to implement a remedial alternative and major capital expenditures in future years. Capital cost elements that may be important at sediment sites include those listed in Highlight 3-3.

Highlight 3-3: Example Categories of Capital Costs for Sediment Cleanup

Categories	Capital Costs
General (may apply to several or all cleanup methods)	• Mobilization/demobilization • Site preparation (e.g., fencing, roads, utilities) • Construction monitoring, sampling, testing, and analysis before, during and immediately following construction (e.g., bathymetric surveys) • Environmental monitoring before, during, and immediately following construction (e.g., water quality monitoring) • Debris and/or structure (e.g., piers, pilings) removal and disposal • Project management and support throughout construction, including preparation of remedial action documentation and construction submittals • Post-construction habitat restoration (e.g., plantings) • Pilot studies • General contingency • Indirect costs • Implementation of institutional controls
Monitored Natural Recovery	• Monitoring and reporting prior to attainment of cleanup levels

Categories	Capital Costs
In-situ Capping	• Cap materials – Material costs – Equipment costs – Cost of mitigation if required under CWA §404 • Transport, storage, and placement of cap materials – Barge/tug lease costs – Stockpiling of cap material
Dredging or Excavation	• Dredging or excavation equipment costs • Engineering controls to protect water quality, such as silt curtains • Site decontamination for support facilities (e.g., truck wash, dewatering area) • Sediment isolation for excavation (e.g., sheetpile, earthen dams) • Construction of dewatering area/temporary storage of dredged material • Transporting sediment to treatment or disposal site – Barge/tug lease costs – Pipeline costs • Land acquisition costs for construction easements or relocating utilities
Pre-Treatment/Treatment	• Land acquisition costs • Construction of pre-treatment/treatment/storage buildings • Treatment of sediment • Treatment and discharge of water from dewatering process • Disposal of treatment residuals
In-Water Contained Aquatic Disposal, and In-Water or Upland Confined Disposal Facilities	• Land acquisition costs • Construction of disposal site – Demolition of existing facilities – Excavation to support berm • Berm construction – Imported materials for berm – Equipment costs • Capping disposal site – Cap materials – Equipment costs • Engineering controls to protect water quality • Cost of mitigation if required under CWA §404

Categories	Capital Costs
Upland Landfill Disposal	• Land acquisition costs • Construction costs • Transportation costs • Tipping fees for regional landfill

3.4.2 Operation and Maintenance Costs

Operation and maintenance costs are those post-construction/installation costs necessary to operate, maintain, or monitor the continued effectiveness of a remedy. These costs may be annual or periodic (e.g., once only, or once every five years). It is important to note that short-term O&M costs (e.g., operation of a sediment dewatering facility) are incurred as part of the Remedial Acton phase of a project, while long-term O&M costs (e.g., long-term monitoring after attainment of cleanup levels, or long-term cap maintenance) are part of the O&M phase of a project (U.S. EPA and USACE 2000). Some examples of O&M costs at sediment sites include the following:

- Operation of sediment or water treatment facilities;
- Maintenance of cap or disposal site;
- Maintenance of engineering site controls;
- Maintenance and monitoring of institutional controls;
- Long-term monitoring, sampling, testing, analysis, and reporting;
- Cost overrun contingency; and
- Project management and support.

3.4.3 Net Present Value

The NCP also provides that an analysis of remedy net present value, or present worth, should be used. A net present value analysis should be used to compare expenditures that occur over different time periods. This standard methodology allows for a cost comparison of different alternatives that have capital and operation, maintenance, and monitoring costs that would be incurred in different time periods on the basis of a single cost figure for each alternative. In general, the period of analysis should be equivalent to the project duration, resulting in a complete life cycle cost estimate for implementing the remedial alternative. Past EPA guidance recommended the general use of a 30-year period of analysis for estimating present value costs (U.S. EPA 1988a). While this may be appropriate in some circumstances, the blanket use of a 30-year period is not recommended. Site-specific justification should be provided for the period of analysis selected, especially when the project duration (i.e., time period required for design,

construction, operation and maintenance, and closeout) exceeds the selected period of analysis (U.S. EPA and USACE 2000).

The discount rate that should be used for this analysis is established by the Office of Management and Budget (OMB). Based on NCP Preamble (55 FR 8722) and the OSWER Directive 9355.3-20, *Revisions to OMB Circular A-94 on Guidelines and Discount Rates for Benefit-Cost Analysis* (U.S. EPA 1993b), a seven percent discount rate should be used in estimating the present worth value for potential alternatives. This figure could be revised in the future, and project managers should use the current figure contained in an update of the OSWER Directive 9355.3-20. These rates may not be the same value that various potentially responsible parties (PRPs) or federal facilities use for similar analyses. For long-term projects (e.g., more than 30-years), it is recommended that the present value analysis also include a "no-discounting" scenario. The project manager should refer to *A Guide to Developing and Documenting Cost Estimates for the Feasibility Study* (U.S. EPA and USACE 2000) for more information.

The basis for a cost estimate may include a variety of sources, including cost curves, generic unit costs, vendor information, standard cost estimating guides, and similar estimates, as modified for the specific site. Because relevant site-specific cost data may not be available, costs estimates used early in the feasibility study frequently rely on historical data and parameters of similar past projects.

Substantial amounts of historical cost data for some components of sediment remediation, for example removal, transport, disposal, and residue management, may be available from other project managers. The project manager should refer to the ARCS program (U.S. EPA 1994b) for a discussion on the general elements of cost estimates for sediment sites. This document provides examples of percentages for general costs and site-specific costs for both in-situ and ex-situ remedies. In addition, many of the local district USACE offices have extensive experience with dredging and in-water construction and may be an additional source of good cost information.

3.5 INSTITUTIONAL CONTROLS

The term "institutional control" (IC) refers to non-engineering measures intended to affect human activities in such a way as to prevent or reduce exposure to hazardous substances by limiting land or resource use. ICs can be used at all stages of the cleanup process to reduce exposure to contamination. Chapter 7, Remedy Selection Considerations, offers guidance on when it may be appropriate to select a remedy that includes institutional controls at sediment sites and considerations regarding their effectiveness and enforceability. For more detailed information on ICs in general, refer to OSWER Directive 9355.0-74FS-P, *Institutional Controls: A Site Manager's Guide to Identifying, Evaluating, and Selecting Institutional Controls at Superfund and RCRA Corrective Action Cleanups* (U.S. EPA 2000c) and Federal Facilities Restoration and Reuse Office (FFRRO) guidance, *Institutional Controls and Transfer of Real Property under CERCLA Section 120 (h)(3)(A), (B), or (C)* (U.S. EPA 2000d).

The following lists four general categories of ICs (U.S. EPA 2000c):

- Governmental controls;
- Proprietary controls;

- Enforcement and permit tools with IC components; and
- Information devices.

Usually, governmental controls (e.g., bans on harvesting fish or shellfish) are implemented and enforced by the state or local government. Proprietary controls, such as easements or covenants, involve legal instruments placed in the chain of title of the site or property. Enforcement tools include provisions of CERCLA Unilateral Administrative Orders (UAOs), Administrative Orders on Consent (AOCs), or Consent Decrees (CD). Information devices provide information or notification to the public, for example, non-enforceable fish consumption advisories.

Examples of three common types of ICs and informational devices at sediment sites include the following:

- Fish consumption advisories and commercial fishing bans;
- Waterway use restrictions; and
- Land use restriction/structure maintenance.

3.5.1 Fish Consumption Advisories and Fishing Bans

Fish consumption advisories are informational devices that are frequently selected as part of sediment site remedies. Commercial fishing bans are government controls which ban commercial fishing for specific species or sizes of fish or shellfish. Usually, state departments of health are the governmental entities that establishes these advisories and bans. Frequently, fish consumption advisories and fishing bans are already in place before a site is listed on the National Priorities List (NPL), but if not, it could be necessary for the state to issue or revise them in conjunction with an early or interim action, or the final remedial action. An advisory usually consists of informing the public that they should not consume fish from an area, or consume no more than a specified number of fish meals over a specific period of time from a particular area. Sensitive sub-populations or subsistence fishers may be subject to more stringent advisories. Advisories can be publicized through signs at popular fishing locations, pamphlets, or other educational outreach materials and programs.

3.5.2 Waterway Use Restrictions

For any alternative where subsurface contamination remains in place (e.g., capping, monitored natural recovery, or an in-water confined disposal site), waterway use restrictions may be necessary in order to ensure the integrity of the alternative. Examples include restricting boat traffic in an area to establish a no-wake zone, or prohibiting anchoring of vessels. In considering boating restrictions, it is important to determine who can enforce the restrictions, and under what authority and how effective such enforcement has been in the past. It may be necessary to evaluate remedial alternatives that involve changing the navigation status of a waterway. For a federally authorized navigation channel, deauthorization of the channel would be required. This can be a lengthy process that requires a formal request to the U.S. Army Corps of Engineers (USACE), an opportunity for users of the waterway to comment, and, ultimately, deauthorization by Congress. The state can have additional regulations to be

followed to change harbor lines or the navigation status of a waterway. Lastly, a restriction on easements for installing utilities, such as fiber optic cables, can be important.

3.5.3 Land Use Restrictions/Structure Maintenance

Where contamination remains in place, it may be necessary for the project manager to work with private parties to implement use restrictions on nearshore areas and adjacent upland properties. For example, construction of boat ramps, retaining walls, or marina development can expose subsurface contamination and compromise the long-term effectiveness of the alternative. Ownership of aquatic lands varies by state and locality. In many cases, nearshore areas can be privately owned out to the end of piers. For private property owners, more traditional ICs, such as proprietary controls or enforcement tools with IC components, can be considered. Potentially, some of these restrictions can be implemented through agencies who permit construction activities in the aquatic environment. Several federal, state, and local laws place restrictions on and may require permits to be obtained for dredging, filling, or other construction activities in the aquatic environment. These include Section 404 of the Clean Water Act, 33 U.S.C. 1344, and Sections 9 and 10 of the Rivers and Harbors Act of 1899, 33 U.S.C. 401 and 403. It may also be possible to implement some ICs through coordination with existing permitting processes. Harbor Master Plans, state-designated port areas, and local authorities may also function to restrict certain uses.

4.0 MONITORED NATURAL RECOVERY

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4.0 MONITORED NATURAL RECOVERY

4.1 INTRODUCTION

Monitored natural recovery (MNR) is a sediment cleanup method that uses ongoing, naturally occurring processes to contain, destroy, or otherwise reduce the bioavailability or toxicity of contaminants in sediment. These processes may include multiple physical, biological, and chemical mechanisms that act together to reduce the risk posed by the contaminants. Depending on the contaminants and the sediment environment, this risk reduction may occur in one or more of the following ways:

- Exposure levels are reduced by a decrease in contaminant concentration levels in the near-surface sediment zone through burial or mixing-in-place with cleaner sediment;
- The contaminant is converted to a less toxic form through destructive processes, such as biodegradation or abiotic transformations; or
- Contaminant mobility and bioavailability are reduced through increased sorption to the sediment matrix.

MNR is a new term for a sediment remedy that currently is being called by a number of different names including monitored natural attenuation (MNA) and monitored natural processes (MNP). As defined in this guidance, MNR is similar in some ways to the MNA remedy previously defined for ground water and soils (U.S. EPA 1999d). Two key differences between MNA and MNR are in the type of processes at work and the extent to which risks during remedy implementation are controllable.

The major components of a MNR remedy generally include the following:

- A detailed understanding of the natural processes that are affecting sediment and contaminants at the site;
- Conceptual and predictive modeling (either using computer modeling or another method) to predict effects of those processes in the future;
- A means to control any significant ongoing contaminant sources;
- A means to control contaminant exposure during the recovery period (to the extent possible); and
- The ability to monitor the natural processes and their effects to see if recovery is occurring.

MNR has been selected as a cleanup method for contaminated sediment at about a dozen Superfund sites so far. It usually (although not always) is combined with dredging or in-situ capping of other areas of a site. In general, project managers should evaluate each of the three major cleanup methods: MNR, capping, and removal through dredging or excavation, at every sediment site at which they may be appropriate. Some consider that all sediment site remedies are using “natural recovery”

because natural processes are ongoing whether or not an active cleanup is underway (e.g., NRC 2001). Although it is true that natural processes will continue to reduce residual risk at many sites, it is important for project managers to distinguish whether they are relying upon MNR to reduce risk to an acceptable level (i.e., using MNR as a remedy), or simply noting the fact that natural processes are ongoing at a site. The key factors that distinguish MNR as a remedy are the presence of unacceptable risk, the ongoing burial or degradation/transformation of the contaminant, and the establishment of a cleanup level that MNR is expected to meet in a particular time frame. Although partial natural recovery has been noted in many areas (e.g., decreases in contaminant levels in fish), there is not yet a body of literature documenting complete recovery. However, monitoring results from some areas are promising (e.g., U.S. EPA 2001f, U.S. EPA 2001g, Swindoll et al. 2000).

Unless biodegredation or transformation is a major process at the site, MNR generally does not meet the CERCLA §121 (b)(1) preference for treatment. When contaminants left in place are above levels that allow for unlimited use and unrestricted exposure, a five year review generally is necessary (U.S. EPA 2001h).

Highlight 4-1 lists some of the general site conditions which may be appropriate for consideration of MNR.

Highlight 4-1: General Site Conditions Appropriate for Monitored Natural Recovery

Generally, MNR may be an effective cleanup method in a variety of environments within a site, especially where:

- Sources are controlled
- Contaminant concentrations in the biologically active zone of the sediment are near risk-based cleanup goals and declining
- Contaminant concentrations in biota are near risk-based goals and declining
- Institutional controls effectively restrict human exposure
- Natural recovery processes have a high degree of certainty to continue at rates which will contain, destroy, or reduce the bioavailability or toxicity of contaminants within an acceptable time frame
- The sediment bed is stable and likely to remain stable

4.2 ADVANTAGES AND DISADVANTAGES

Two advantages of MNR are its relatively low cost and its non-invasive nature. Costs associated with MNR are primarily associated with monitoring, but may also include the cost of implementing institutional controls, public education to increase the effectiveness of those controls, and, where applicable, a possible separate cost of a contingency remedy. MNR involves minimal disruption to the existing biological community, which may be an important advantage for some wetlands or sensitive environments where the harm to the ecological community due to sediment disturbance may outweigh the risk reduction of an active cleanup.

Other advantages of MNR include the fact that no construction or infrastructure is needed, and it is therefore much less disruptive of communities than active cleanup methods such as dredging or in-situ

capping. No property is needed for materials handling, treatment, or disposal facilities, and no contaminated materials are transported through communities.

Two disadvantages of MNR are that it generally leaves contaminants in place and that it can be slow in comparison to active cleanup methods. When recovery is based on natural burial, contaminants may be re-exposed or dispersed if the sediment bed is significantly disturbed by unexpected natural or man-made forces. Although biological and chemical transformation of contaminants can occur, these processes are frequently too slow to provide for remediation in a reasonable time frame for the persistent contaminants of concern at many Superfund sites.

Other disadvantages of MNR include the fact that it may have a higher level of uncertainty associated with it than active cleanup methods and the need to rely upon institutional controls. Major areas of uncertainty frequently include the ability to predict future sedimentation rates in dynamic watersheds. Remedies which include MNR frequently rely upon institutional controls, such as fish consumption advisories, to control human exposure during the recovery period. These controls may have limited effectiveness and have no ability to control ecological exposures.

4.3 NATURAL RECOVERY PROCESSES

The natural processes of interest for MNR include a variety of processes that, under favorable conditions, act without human intervention to reduce the mass, toxicity, mobility, volume, or concentration of contaminants in the sediment bed. These natural processes include the following:

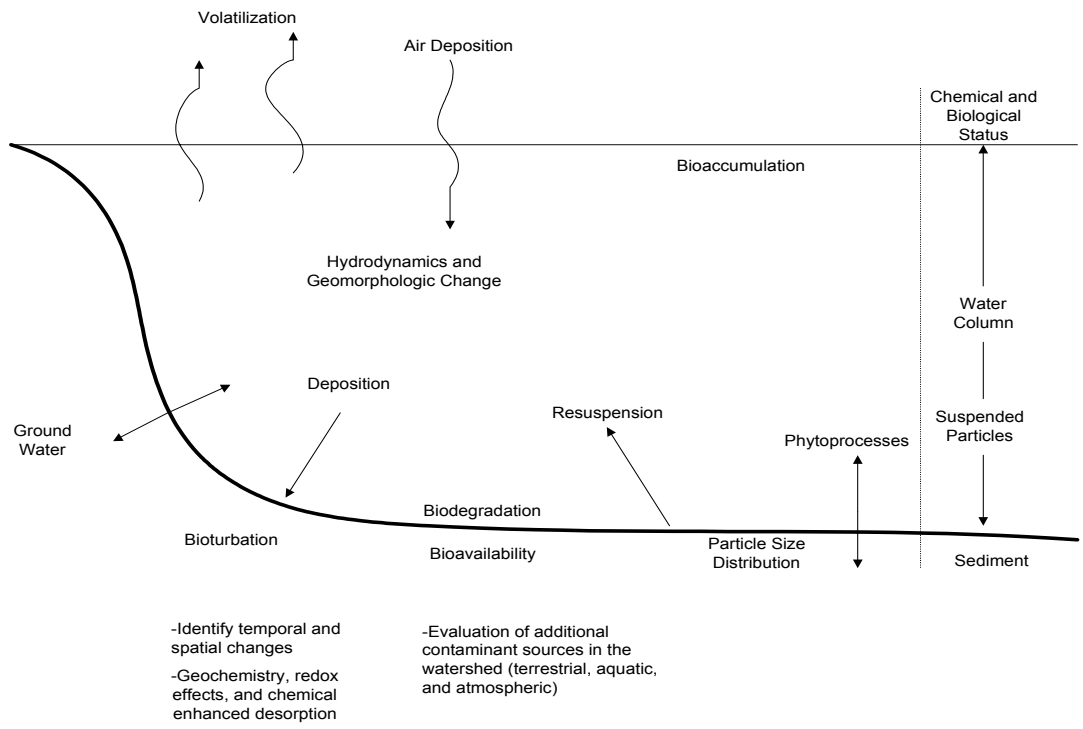
- Physical processes (e.g.,sedimentation, advection, diffusion, dilution, bioturbation, volatilization);
- Biological processes (e.g., biodegradation, biotransformation, phytoremediation, biological stabilization); and
- Chemical processes (e.g., oxidation/reduction, stabilization, sorption).

Highlight 4-2 illustrates some of the natural processes that the project manager should consider during evaluation of MNR. With few exceptions, these processes interact in aquatic systems, sometimes reducing risks and at other times, increasing them. For example, as recognized by the U.S. Environmental Protection Agency's (EPA) Science Advisory Board (SAB) Environmental Engineering Committee, *Monitored Natural Attenuation: USEPA Research Program - An EPA Science Advisory Board Review* (U.S. EPA 2001i), sustained burial processes can impede certain degradation processes, such as aerobic biodegradation. Understanding the interactions between effects and prioritizing the significance of these effects to the MNR remedy should be part of a natural process analysis.

4.3.1 Physical Processes

Physical processes do not change the chemical nature of contaminants. Instead, physical processes may bury, mix, dilute, or move contaminants to another medium. Physical processes of

Highlight 4-2: Example Natural Processes for Consideration of Monitored Natural Recovery



interest for MNR include sedimentation, erosion, re-suspension, diffusion, dilution, bioturbation, advection, and volatilization (including temperature-induced desorption of semi-volatiles). All of these processes may reduce contaminant concentrations in surface sediment. However, of these processes, only sedimentation (i.e., deposition and consolidation) reduces risk by containing contaminants in place. Erosion, dispersion, dilution, bioturbation, advection, and volatilization also may reduce contaminant concentrations in sediment, but at the expense of moving the contaminants to another medium or dispersing them over a wider area (e.g., via ground water or surface water). These processes may reduce or increase the risk posed by the contaminants.

Physical processes in sediment operate at vastly different rates. Some are continuous processes, others seasonal or episodic. In general, processes in which contaminants are transported by bulk movement of particles or pore water (e.g., erosion, bioturbation, advection) occur at faster rates than processes in which contaminants are transported by diffusion or volatilization and, therefore, are generally more important when evaluating MNR. Processes that result in particle movement are particularly important for hydrophobic or other contaminants that are strongly sorbed to sediment particles.

In high-energy environments, sediment transport and deposition are likely to be the dominant factors in contaminant movement and burial, and thus it is likely that the sediment transport process will need to be adequately characterized in such environments. In low-energy environments, sedimentation and bioturbation are likely to dominate contaminant redistribution processes.

Hydraulic transport (i.e., advection and dispersion) of cleaner sediment in the watershed may lead to natural burial of contaminated sediment in a depositional environment. Natural burial may reduce the availability of the contaminants to aquatic plants and animals and, therefore, may reduce bioaccumulation. Particles of all size ranges deposit in quiescent water, forming layers of sediment. These particles with time consolidate, expelling pore water. The process, called bed accretion, results in the burial of the contaminated sediment by clean sediment (i.e., sediment from uncontaminated or remediated portions of the watershed). The overlaying cleaner sediment serves to reduce the flux of contaminants into the surface water by creating a longer pathway that the desorbed contaminants must travel to reach the sediment bed/water column interface.

The protectiveness provided by sedimentation depends upon the stability of the new sediment bed, which is mainly related to the shear stresses to which the deposited materials are subjected. Major events, such as severe storms or flood events, may scour the buried sediment, exposing contaminated sediment and releasing the contaminants into the water column, resulting in the transport of the sorbed contaminants over wide areas. In addition, while bioturbation by burrowing organisms may promote mixing and dilution of contaminated sediment with newly deposited cleaner sediment, for bioaccumulative contaminants it may also result in continued bioaccumulation into the food web until contaminant isolation occurs. Storm events and bioturbation may limit the long-term effectiveness of natural sedimentation, and uncertainties regarding their effects may increase the uncertainty of MNR based on sedimentation. Sediment stability is discussed in more detail in Chapter 2, section 2.5.

There are a variety of methods to assess site-specific sedimentation rates. These methods range from direct measurement of the sedimentation rate in specially constructed traps to indirect inference of sedimentation rates using vertical concentration gradients of known contaminant releases or natural or man-made geochemical tracers that are measured in sediment core samples. Information concerning the use of radioactive tracers is included in Appendix C of this guidance.

Methods to assess other sediment physical processes include empirical approaches such as changes in bathymetry through time, observations of bed forms and sedimentary features in core samples or sediment profile imagery, and aerial distribution of grain size (sediment trend analysis) as discussed in Chapter 2, section 2.5, Sediment Stability. Physical processes may also be assessed through modeling. Sediment transport modeling and other uses for models are discussed in Chapter 2, section 2.6, Modeling. Selection of an appropriate technical assessment approach should be based upon site-specific physical factors and the site conceptual model.

4.3.2 Biological Processes

In biological processes such as biodegradation (or the more general term of biotransformation), a chemical change is facilitated by microorganisms living in the sediment. Biological processes depend on site-specific conditions and are highly variable. One of the important limitations to the usefulness of biodegradation as a risk-reduction mechanism is that the greater the molecular weight of the organic contaminants, the greater partitioning to sorption sites on sediment particles (Mallhot and Peters 1988)

and the lower the contaminant availability to microorganisms. Degradation of high molecular weight organic compounds occurs naturally, but slowly, in soil and sediment with anaerobic and aerobic microorganisms (Brown et al. 1987, Abramowicz and Olsen 1995, Bedard and May 1996, Shuttleworth and Cerniglia 1995, Cerniglia 1992, Seech et al. 1993). Degradation rates vary with depth in sediment partly due to the change from aerobic or anaerobic conditions. This changes occurs at depths of a few millimeters to a few centimeters where sediments have substantial organic content and conditions are quiescent. Longer residence times of contaminants in the sediment (aging) also usually results in increased sequestration (Luthy et al. 1997, Dec and Bollag 1997). These processes reduce the availability of the organic compounds to microorganisms and, therefore, reduce the extent and rates of biodegradation (Luthy et al. 1997, Tabak and Govind 1997).

The class of hydrocarbons known as polynuclear aromatic hydrocarbons (PAHs) biodegrade more quickly through aerobic processes, although the degradation rates usually decrease as the number of aromatic rings increases (Shuttleworth and Cerniglia 1995, Cerniglia 1992, Seech et al. 1993). While biodegradation of PAHs may occur under anaerobic conditions, PAHs usually persist longer in anaerobic sediment compared to aerobic environments (U.S. EPA 1996e, Safe 1980).

The composition of polychlorinated biphenyl (PCB) mixtures that occur in the environment may be quite different from those of the original mixtures released to the environment. This is a result of the combined effects of such processes as differential volatilization, solubility, sorption, anaerobic dechlorination, and metabolism, and results in changes in the composition of the PCB mixture over time and between trophic levels (NRC 2001).

Highly chlorinated congeners of PCBs and other chlorinated contaminants may gradually dechlorinate naturally in anaerobic sediment (Brown et al. 1987, Abramowicz and Olsen 1995, Bedard and May 1996). In general, less chlorinated PCBs and other partially dechlorinated organic species tend to bioaccumulate less than the highly chlorinated congeners or species, but are more soluable and therefore more readily transported in the water column than highly chlorinated PCBs. The less chlorinated PCBs exhibit significantly less potential human carcinogenic and dioxin-like (coplanar structure) toxicity (Abramowicz and Olsen 1995, Safe 1992), but may be transformed in humans into forms with potential for other toxicity (Bolger 1993). Aerobic processes may then biodegrade the less chlorinated PCB congeners and other lightly chlorinated organics (Flanagan and May 1993, Harkness et al. 1993). The sediment concentrations of other chemicals and the total organic content tend to control these processes. However, little evidence exists that lower chlorinated congeners under the anaerobic or anoxic conditions found in most sediment are significantly transformed. Therefore, these partially dechlorinated organics tend to accumulate and persist (U.S. EPA 1996e, Harkness et al. 1993).

Chlorinated pesticides and industrial chlorinated organics may also be transformed or partially degraded in sediment. However, the degradation products may be equally or more toxic and persistent than the original pesticide or chlorinated organic. For example, dichloro-diphenyl-trichloroethane (DDT) may be transformed under anaerobic conditions to dichloro-diphenyl-dichloroethane (DDD) and under aerobic conditions to dichloro-diphenyl-dichloroethylene [(DDE), Johnsen 1976, Rochkind and Blackburn 1986). Although all three DDT constituents may be found in sediment, DDE may be the constituent of the DDT-related compounds most widely detected (U.S. EPA 1992c, Stull et al. 1996) and most resistant to further biotransformation (NRC 1977).

The role of biological processes in MNR is summarized by the NRC (2001): "Of the natural-attenuation processes, biodegradation is generally considered the most desirable because it can result in elimination of risk." While desirable, it is unclear whether biologically mediated dechlorination of pesticides and PCBs would be effective in achieving remedial objectives in a reasonable time frame and may result in the production of more toxic byproducts. Although aerobic biological degradation of PAHs has been demonstrated in the laboratory, the low levels of dissolved oxygen typically found in natural sediment limit the potential for substantial degradation of PAHs in the field.

4.3.3 Chemical Processes

Many environmental variables govern the chemical state of metals in sediment, which in turn affects their mobility, toxicity, and bioavailablity making natural recovery due to chemical processes difficult to predict. Much of the current understanding of the role of chemical processes in controlling risk is focused on the important geochemical changes in bioavailability of metal and organic metal compounds with changes in redox potential. Formation of relatively insoluble metal sulfides under reducing conditions often can effectively control the risk posed by metal contaminants if reducing conditions are maintained. Environmental variables include pore water pH and alkalinity, sediment grain size, oxidation-reduction (redox) conditions, and the amount of sulfides and organic carbon present in the sediments. Furthermore, many chemical processes in sedimentary environments are biologically mediated. For example, if mercury is present in sediments, formation of methylated mercury can increase bioaccumulation risk by increasing the mobility and the bioaccumulation potential of mercury under both anaerobic and aerobic conditions (Bisogni and Lawrence 1973).

4.4 LINES OF EVIDENCE

An evaluation of MNR as a remedy or remedy component should be thoroughly and adequately supported with site-specific characterization and analysis and verified through long-term monitoring and modeling. The SAB review (U.S. EPA 2001i) noted that: "Considerable effort will be required to establish appropriate implementation of MNA at contaminated sediment sites. Although information on contaminant attenuation in soils and ground water can serve as a basis for understanding certain process of attenuation in contaminated sediments, the dynamic and heterogeneous nature of sediment systems introduces complexities not found in soil or ground water." Swindoll et al. (2000) include a chapter on natural remediation of sediment which presents a useful summary discussion.

An evaluation of natural processes at a site should be based on site-specific data collected during different seasons over a year's. Time-series data from a number of years are frequently needed as well. Lines of evidence or types of site-specific information used to construct a plausible case for the use of MNR include the following:

- Documentation that any ongoing sources of contamination have been controlled;
- Time series data for sediment and biota that demonstrate a clear and meaningful trend of decreasing contaminant concentration, mass, or toxicity over time;
- Core data demonstrating a predictable rate of sedimentation or contaminant transformation;

- Historical information concerning frequency and intensity of natural and man-made disruptive events;

- Reliable future predictions (through modeling or other methods) of contaminant levels in surface water, sediment, and biota that demonstrate how human and ecological risks will be reduced to acceptable levels in an acceptable time frame;

- Reliable future predictions concerning natural and man-made disruptive events, their frequency, intensity, and impact on contaminant migration;

- Data from field studies (e.g., core data) that demonstrate the depth of the sediment mixing zone or zone that is currently bioavailable or likely to become so in the future;

- Data from field studies (conducted in or with actual contaminated site media and representative of site-wide exposure) that directly demonstrate the occurrence of a particular attenuating process at the site and its ability to degrade the contaminants of concern or reduce the risk of exposure to the contaminants;

- Development of conceptual and predictive models to assess current and future human and ecological exposures from the contaminated sediment; and

- Knowledge of future plans for use and development of the site and watershed.

The amount of physical, biological, and chemical processes information needed to adequately assess the applicability of MNR is site-specific. Integration of the data quality objective (DQO) process with the risk evaluation process should identify which natural processes are most critical to the evaluation of MNR at a site. Generally, the identification of MNR data needs and preparation of study design can be structured similarly to the DQO process (U.S. EPA 2000e) which is normally integrated within the RI/FS. The DQO process is intended to help site managers plan to collect data of the right type, quality, and quantity to support defensible site decisions. Initial key steps in the DQO processes can help assure that only data critical to the MNR decision are collected. For example these steps could include the following:

- *State the problem:* There is current and future exposure to humans through contaminant concentrations in fish tissue and ecological exposure to a contaminated sediment-based food web;

- *Identify the decision:* Natural physical, biological, and/or chemical processes are sufficient to reduce risk to acceptable levels over a defined time frame; and

- *Identify inputs to the decision:* What are acceptable risk levels of contaminants in the biologically active zone and the deeper zones susceptible to disruption? What is the current accretion rate? What are the biological and chemical degradation rates? How long will these processes require to reduce sediment concentrations to acceptable levels.

EPA guidance on the DQO process describes in detail all of the seven steps and provides examples of how each step can be applied (U.S. EPA 2000e). Data needs for evaluation of MNR can be

logically coordinated via the DQO process with risk assessment and other data needs of the site characterization.

4.5 ENHANCED NATURAL RECOVERY

In some areas, natural recovery appears to be the most appropriate cleanup method, yet, the rate of sedimentation or other natural processes is insufficient to reduce risks within an acceptable time frame. Where this is the case, project managers should consider accelerating the recovery process by the addition of a thin layer of clean sediment or by some other method of augmenting natural recovery.

Thin-layer placement accelerates natural recovery by adding a layer of clean sediment over contaminated sediment. The acceleration can occur through several processes, including increased dilution through bioturbation of clean sediment mixed with underlying contaminants. Thin-layer placement is different than the isolation caps discussed in Chapter 5, In-situ Capping, because it does not provide long-term isolation of contaminants from benthic organisms. While thickness of an isolation cap can range up to several feet, the thickness of a thin layer placement could be as little as a few inches. The grain size and organic carbon content of the clean sediment to be used for thin layer placement should be carefully considered in consultation with aquatic biologists. The clean sediment should be selected based on its ability to provide habitat to support a healthy community of bottom-dwelling organisms and submerged aquatic vegetation.

Clean sediment can be placed in a uniform thin layer over the contaminated area or it can be placed in berms or windrows, allowing natural sediment transport processes to distribute the clean sediment to the desired areas. Placement methods would be similar to those used for a cap. Several numerical models are available to assist in developing a strategy for thin layer placement. The Short-Term Fate (STFATE) model can be used to estimate the depositional pattern using various placement methods and source materials (USACE 1992, USACE and U.S. EPA 1998). The USACE also has a Suspended Sediment Fate model (SSFATE) that is useful. Subsequent movement of windrow-distributed material can be predicted using the Long-Term Fate (LTFATE) model (USACE 1995).

4.6 CONCLUSIONS

The long-term effectiveness of MNR is usually dependent on the following: 1) the likelihood for overlying clean sediment to remain in place; 2) the likelihood for transport of contaminants through overlying clean sediment to the biologically active zone or the water column; and 3) the effectiveness of source control. Assessment of all three is important at most sites. Some potential mechanisms for physical disruption of overlying sediment such as propeller wash, keel drag, navigational dredging, and pipeline construction, may be amenable to human management. Others, such as ice scour or flooding, may only be partly manageable or not manageable. This is discussed further in Chapter 2, section 2.5, Sediment Stability, of this guidance. The importance of contaminant movement through overlying sediment depends on the chemical characteristics of the contaminant, physical characteristics of the sediment, and patterns of ground water flow. This issue is also of concern for in-situ capping and is discussed further in Chapter 5, In-Situ Capping, and the USACE Technical Note, *Subaqueous Capping and Natural Recovery: Understanding the Hydrogeologic Setting at Contaminated Sediment Sites* (USACE 2002).

MNR is likely to be effective most quickly in stable depositional environments where contaminant exposures are mostly due to recent releases from sources other than the sediment. Where external sources were controlled several decades previously and no further source control opportunities have been identified, yet site risks remain unacceptable, it may be questionable whether natural processes alone will reduce risks significantly in the future. For MNR, as for other sediment cleanup methods, effective source control is critical to reaching remedial objectives in a reasonable time frame and to preventing re-contamination.

Similar to EPA's policy for MNA of ground water and soil, MNR for sediment should generally be used as one component of an overall site remedy and cautiously as the sole cleanup method at a contaminated sediment site. MNR should usually be used either in conjunction with source control or active sediment remediation or as a follow-up measure to an active cleanup method. For example, dredging or capping might be selected to address the most contaminated hot spot areas that pose the greatest risk, and MNR could be selected to address more widespread, low-level contamination in remaining areas that contribute to the residual site-wide risk.

When considering the use of MNR as a follow-up measure, project managers should consider the conditions caused by the active cleanup method. As noted by the SAB (U.S. EPA 2001i): "If MNA [or, as used in this guidance, MNR] is to be considered after a remedial action (e.g., the removal of heavily contaminated portions or capping), the effects of the remedial action on the chemistry, biology, and physics of contaminated sediments should be evaluated. The effects include: 1) potential disturbances on reaction conditions and aquatic life when dredging is used, and 2) changes on reaction conditions and mass transfer in the sediment and at the sediment/water interface when capping is used."

MNR should be considered when it would meet remedial objectives within a time frame that is reasonable compared to active cleanup methods. However, the Agency recognizes that MNR usually takes longer to reach cleanup levels in sediment than dredging or in-situ capping and, therefore, usually takes longer to reach all remedial action objectives, such as contaminant reductions in fish. Factors that the project manager should consider in determining whether the time frame for MNR is "reasonable" in comparison to the time frame needed for active cleanup methods include the following:

- The extent of human exposure to contaminants during the recovery period, and if controlled by institutional controls, the effectiveness of those controls;
- The value of ecological resources that may be impacted by contaminant releases during the recovery period;
- The societal, cultural, and economic resources affected during the recovery period;
- The time frame in which affected portions of the site may be needed for future uses which will be available after MNR has achieved cleanup levels; and
- The uncertainty associated with the prediction

Project managers should carefully consider the need for contingency measures, contingency remedies, or interim decisions where there is significant uncertainty about the effectiveness of MNR.

Project managers should carefully consider how risks can be controlled during the recovery period. In most cases, no institutional controls can protect ecological exposure during this period. Although institutional controls exist to protect human exposure, some, such as fish consumption advisories, cannot be expected to be fully effective and may be unenforceable. See Chapter 3, section 3.5, Institutional Controls, and Chapter 7, section 7.4, Considering Institutional Controls, for more information concerning institutional controls at sediment sites. Highlight 4-3 lists some important points to remember from this chapter.

Highlight 4-3: Points to Remember When Considering Monitored Natural Recovery

- Source control generally should be implemented to prevent re-contamination
- MNR frequently includes multiple physical, biological, and chemical mechanisms that act together to affect risk
- Evaluation of MNR should be based on site-specific data collected repeatedly over a number of years, including an assessment of seasonal variation
- Project managers should evaluate the long-term stability of the sediment bed and the likely ecological and human health impacts of disruption
- Multiple lines of evidence are frequently needed to evaluate MNR (e.g., time-series data, core data, modeling)
- Thin layer placement of clean sediment may accelerate natural recovery in some cases
- Institutional controls such as fish consumption advisories are of variable effectiveness and should be relied upon with caution
- Contingency measures should be included as part of an MNR remedy when there is significant uncertainty that the remedial action objectives will be achieved within the predicted time frame
- MNR should generally be used as one component of an overall site remedy, and cautiously as the sole cleanup method

5.0 IN-SITU CAPPING

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5.0 IN-SITU CAPPING

5.1 INTRODUCTION

In-situ capping refers to the placement of a subaqueous covering or cap of clean material over a deposit of contaminated sediment. Caps are generally constructed of granular material, such as clean sediment, sand, or gravel. A more complex cap design can include geotextiles, liners, and multiple layers as well as additions of material to attenuate the flux of contaminants (e.g., organic carbon). Depending on the contaminants and sediment environment, a cap reduces risk through the following primary functions:

- Physical isolation of the contaminated sediment from the aquatic environment;
- Stabilization/erosion protection of contaminated sediment, preventing resuspension and transport to other sites; and
- Chemical isolation/reduction of the movement of dissolved and colloidally transported contaminants.

Caps may be designed with different layers to serve these primary functions or in some cases a single layer may serve multiple functions.

In-situ capping has been selected as a cleanup method for contaminated sediment at about a dozen Superfund sites as of 2001. Most frequently, although not always, this method is combined with sediment removal (i.e., dredging or excavation) or monitored natural recovery of other sediment site areas. In general project managers should evaluate each of the three major cleanup methods: monitored natural recovery, in-situ capping, and removal through dredging or excavation, at every sediment site at which they may be appropriate.

Variations of in-situ capping include installation of a cap after partial removal, through dredging or excavation, of contaminated sediment, and innovative caps which incorporate treatment components. Capping is sometimes considered following partial sediment removal where capping alone is not feasible due to hydraulic or navigation restrictions on the waterway depth, or where it is desirable to leave deeper contaminated sediment in place to preserve bank or shoreline stability following hot spot removals. Backfill of clean material which is designed to mix with dredging residuals rather than act as a engineered cap to isolate buried contaminants is not considered in-situ capping in this guidance. There are a number of pilot studies underway to investigate the types of in-situ caps which incorporate various forms of treatment (see Chapter 3, section 3.1.3, In-Situ Treatment Alternatives).

Much has been written about subaqueous capping of contaminated sediment. The majority of this work has been performed by, or in cooperation with, the U.S. Army Corps of Engineers (USACE). Comprehensive technical guidance on in-situ capping as a cleanup method for contaminated sediment can be found in the U.S. Environmental Protection Agency's (EPA) *Assessment and Remediation of Contaminated Sediment (ARCS) Program Guidance for In-Situ Subaqueous Capping of Contaminated Sediments* (U.S. EPA 1998d) and the *Assessment and Remediation of Contaminated Sediments (ARCS) Program Remediation Guidance Document* (U.S. EPA 1994b). Unless an effective treatment component is incorporated into the cap, in-situ capping generally does not meet CERCLA §121(b)(1) preference for

treatment. When contaminants left in place are above levels that allow for unlimited use and unrestricted exposure, a five-year review generally is necessary (U.S. EPA 2001h).

Highlight 5-1 lists some of the general site conditions which may be appropriate for consideration of in-situ capping.

Highlight 5-1: General Site Conditions Appropriate for In-Situ Capping
• Sources are controlled
• Contaminants are not both, highly toxic and at high concentrations
• Suitable types and quantities of cap materials are available
• Hydrologic conditions (e.g., floods, ice scour) will not compromise the cap or can be accommodated in design
• Water depth is adequate to accommodate cap with anticipated uses (e.g., navigation, flood control)
• Ground water flow gradients are low or contaminants of low mobility
• Weight of the cap can be supported by the underlying sediment without slope failure
• Anticipated infrastructure needs (e.g., piers, pilings, buried cables) are compatible with cap
• Habitat disruption is outweighed by long-term risk reduction

5.2 ADVANTAGES AND DISADVANTAGES

Two advantages of in-situ capping are that it can quickly reduce exposure to contaminants and that, unlike dredging or excavation, less infrastructure in terms of material handling, dewatering, treatment and disposal is needed. A well-designed and well-placed cap should provide a clean substrate for re-colonization by bottom-dwelling organisms. Another advantage is that the potential for contaminant resuspension and the risks associated with dispersion and volatilization of contaminated materials during construction are typically lower for in-situ capping than for dredging operations. Most capping projects use conventional and locally available materials, equipment, and expertise. For this and other reasons, in-situ capping may be implemented more quickly and may be less expensive than cleanup methods involving removal and disposal or treatment.

In-situ capping may be less disruptive of communities than dredging or excavation. Although some local land facilities are usually needed for materials handling, no dewatering, treatment or disposal facilities need to be located and no contaminated materials are transported through communities.

The major disadvantage of in-situ capping is that the contaminated sediment is left in place in the aquatic environment where contaminants may be exposed or dispersed if the cap is significantly disturbed. It is often necessary to rely on institutional controls, which can be limited in terms of effectiveness and reliability, to protect the cap.

Another potential disadvantage to in-situ capping may be that in some situations usable habitat may not be provided by the cap materials. To provide erosion protection, it may be necessary to use cap materials that are different from native bottom materials and thus can alter the biological community. For example, it may be desirable to select capping materials that discourage colonization by native deep-burrowing organisms to limit bioturbation. In either case, if the cap provides relatively poor habitat for the local biological community, potential mitigation requirements or natural resource damages may be incurred.

5.3 COMPONENTS OF CAPPING TECHNOLOGY

The general elements or components of an in-situ capping project include the following:

- Identifying candidate capping materials that are physically and chemically compatible;
- Assessing the bioturbation potential of local benthic organisms, and designing a cap component to physically isolate them from contaminated sediment;
- Evaluating the potential for erosion of the cap due to natural and anthropogenic disruptive forces and designing a cap system that will be stable or have acceptable losses under these conditions;
- Assessing the potential flux of sediment-associated contaminants, and designing a cap component to reduce the flux of dissolved and colloidal contaminants into the water column sufficiently to achieve and maintain remedial action objectives;
- Evaluating geotechnical considerations including consolidation of compressible materials and potential interactions and compatibility among cap components;
- Evaluating construction and placement methods, and identifying performance objectives and monitoring methods for cap placement and long-term assessment;
- Assessing the operational considerations and determining restrictions or additional protective measures (e.g., institutional controls) needed to ensure cap integrity; and
- Assessing the potential for long-term habitat alteration (e.g., changes in depth, substrate, and hydrodynamic regime) and mitigating, if appropriate.

The first six of these topics are discussed briefly below. General monitoring considerations for in-situ capping are discussed in Chapter 8, section 8.4.2. Institutional controls are discussed in Chapter 3, section 3.5, and habitat considerations are addressed in section 5.4.4 of this chapter.

5.3.1 Identification of Capping Materials

Caps are generally composed of clean granular materials, such as sediment, sand, or soil; however, more complex cap designs could be required to meet site-specific remedial action objectives. As discussed below, the project manager should take into consideration the need for effective short- and long-term chemical isolation of contaminants, bioturbation, consolidation, erosion, and other related

processes. For example, if the potential for erosion of the cap is significant, the cap thickness could be increased using a material with larger grain size, or an armor layer could be incorporated into the design. Porous geotextiles do not contribute to contaminant isolation, but serve to reduce the potential for mixing and displacement of the underlying sediment with the cap material. A cap composed of naturally occurring sand is generally preferred over processed sand because the associated fine fraction and organic carbon content found in natural sands are more effective in providing chemical isolation by sequestering contaminants migrating through the cap. In some conditions it may be feasible to consider use of lightly contaminated dredged material as sub-grade cap material, if the site remedy includes both dredging and capping. Also, specialized materials may be considered for caps to enhance the chemical isolation capacity. Examples include engineered clay aggregate materials (e.g., AquaBlok™). Highlight 5-2 illustrates some examples of cap designs.

5.3.2 Physical Isolation Component

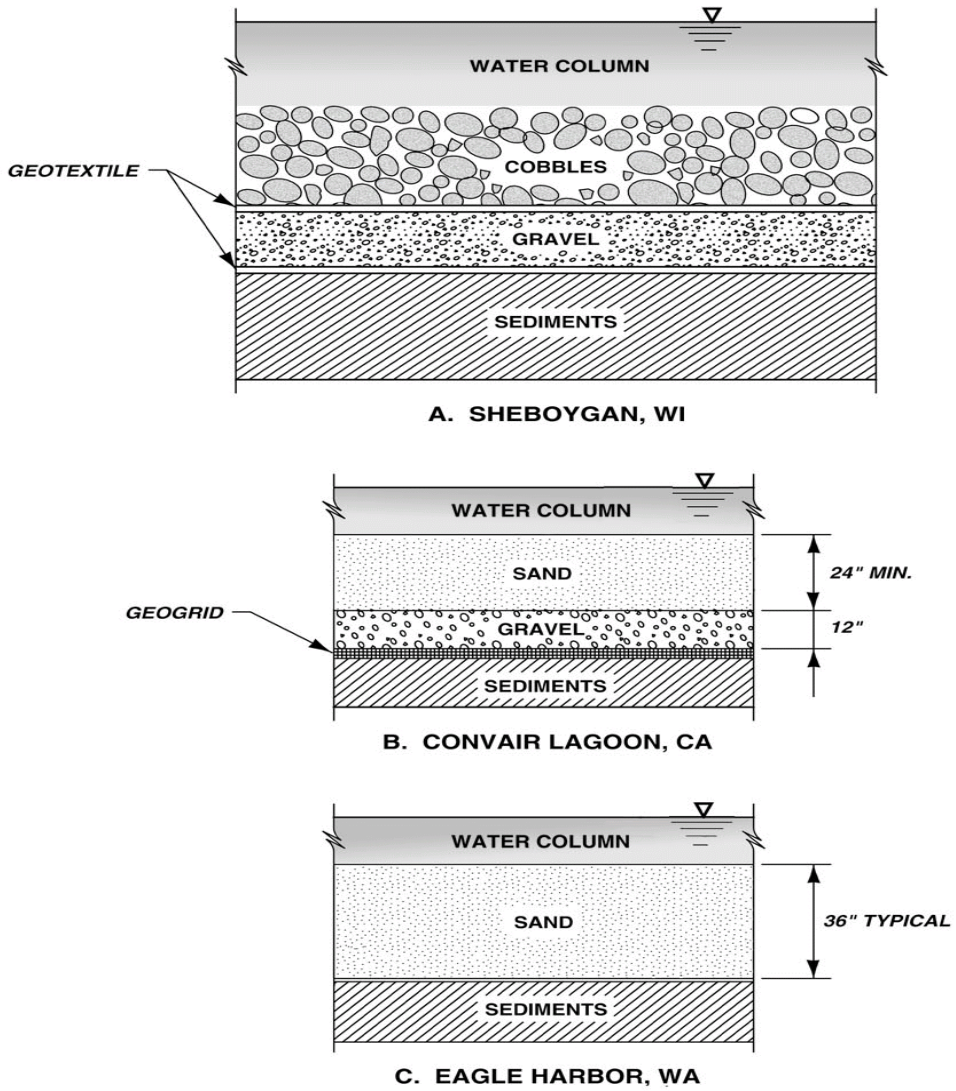
The cap should be designed to isolate sediment contaminants from the aquatic environment. The physical isolation component of the cap includes separate subcomponents for isolation and consolidation.

To provide long-term protection, a cap should be sufficiently thick to effectively separate contaminated sediment from aquatic organisms which dwell or feed on, above, or within the cap. To design a cap component for this function, the bioturbation potential of local bottom-dwelling organisms should be evaluated. In marine environments, the potential for colonization by deep burrowing organisms (e.g., certain species of mud shrimp) could require increases in cap design thickness. Measures to prevent colonization or disturbance of the cap by deep burrowing bottom-dwelling organisms can be considered in cap design, and in developing biological monitoring requirements for the project. Project managers should refer to Chapter 2, section 2.5.3 and consult with aquatic biologists with knowledge of local conditions for evaluation of the bioturbation potential. In some cases, a site-specific biological survey of bioturbators would be appropriate. In addition, the USACE Technical Note, *Subaqueous Cap Design: Selection of Bioturbation Profiles, Depths and Process Rates* (USACE 2001), provides information on designing in situ caps and also provides many useful references on bioturbation. This document is available at http://www.wes.army.mil/el/dots/doer/technote.html.

The project manager should consider consolidation when designing the cap. Fine-grained granular capping materials can undergo consolidation due to self-weight. Even if the cap material is not compressible, most contaminated sediment is highly compressible. Underlying contaminated sediment will almost always undergo consolidation due to the added weight (i.e., overburden) of the capping material or armor stone. The thickness of granular cap material should have an allowance for consolidation so that the minimum required cap thickness is maintained following consolidation.

An evaluation of consolidation is important in interpreting monitoring data to differentiate between changes in cap surface elevation or cap thickness due to consolidation, as opposed to erosion. Also, the degree of consolidation will provide an indication of the volume of pore water that will be expelled through the contaminated layer and capping layer due to consolidation. The consolidation-driven advection of pore water should be considered in the evaluation of contaminant flux. Also,

Highlight 5-2: Example Cap Designs



Source: U.S. EPA 1998d

consolidation may decrease the vertical permeability of the capped sediment. Methods used to define and quantify consolidation characteristics of sediment and capping materials, such as standard laboratory tests and computerized models, are available (U.S. EPA 1998d and Palermo et al. 1998a).

5.3.3 Stabilization/Erosion Protection Component

The cap component for stabilization/erosion protection has a dual function. This component of the cap is intended to stabilize the contaminated sediment being capped, and prevent the sediment from being resuspended and transported off site. The other function of this component is to make the cap itself resistant to erosion as represented in the Sheboygan example in Highlight 5-2.

The potential for erosion generally depends on the magnitude of the applied bed shear stresses due to river, tidal and wave-induced currents, and turbulence generated by ships/vessels (due to propeller action and vessel draft), and sediment properties such as particle size, mineralogy and bed bulk density. These and other aspects of investigating sediment stability are discussed in Chapter 2, section 2.5, Sediment Stability. Conventional methods for analysis of sediment transport are available to evaluate erosion potential of caps, ranging from simple analytical methods to complex numerical models (U.S. EPA 1998d and Palermo et al. 1998a). Uncertainty in the estimate of erosion potential should be evaluated as well.

The design of erosion protection features of an in-situ cap (i.e., armor layers) should be based on the magnitude and probability of occurrence of extreme erosive forces estimated at the capping site. At a minimum, in-situ caps should be designed to withstand forces with a probability of 0.01 per year, for example, the 100-year storm. As is discussed further in Chapter 2, section 2.5, Sediment Stability, in some circumstances, lower probability events should also be considered.

For sediment with high organic content (e.g., wood processing sites) significant gas generation may occur due to anaerobic degradation. Gas generation in sediment beneath the cap could add significant uplift forces on impermeable membrane and geotextiles and threaten the physical stability of the overlying capping materials. The possible influence of this process on cap effectiveness presents an uncertainty that the project manager should consider in the analysis of remedial alternatives.

5.3.4 Chemical Isolation Component

If a cap has a properly designed physical isolation component, contaminant migration associated with the movement of sediment particles should be controlled. However, the vertical movement of contaminants by advection (flow of pore water) through the cap is possible, while movement by molecular diffusion (across a concentration gradient) over long periods is inevitable. If reduction of contaminant flux is necessary to meet remedial action objectives, a more involved analysis to include capping effectiveness testing and modeling should be conducted as a part of cap design.

Both advective and diffusive processes should be considered in cap design. If a ground water/surface water interaction study indicates that advection is not significant at a given location (e.g., migration of ground water upward through the cap would not prevent attaining the remedial action objectives), the cap design may only need to address diffusion and the physical isolation and stabilization of the contaminated sediment. In this case, it may not be necessary to design for dissolved and/or colloidally facilitated transport due to advection (Ryan et al. 1995). In contrast, where ground water flow upward through the cap is expected to be significant, the hydraulic properties of the cap should also be determined and factored into the cap design. These properties should include the hydraulic conductivities of the cap materials, the contaminated sediment, and underlying clean sediment or bedrock. According to a USACE laboratory study, ground water flow velocities exceeding 10^{-5} cm/sec potentially result in

conditions in which equilibrium partitioning processes essential to cap effectiveness could not be maintained (Myers et al. 1991). Such conditions should be carefully considered in the cap design. In areas with high rates of ground water flow discharges through contaminated sediment, in-situ capping may not be an effective remedial approach without additional protective measures. More information on the interactions of ground water can be found in the USACE Technical Note, *Subaqueous Capping and Natural Recovery: Understanding the Hydrogeologic Setting at Contaminated Sediment Sites* (USACE 2002).

Laboratory tests can be used to define sediment- and capping material-specific diffusion and chemical partitioning coefficients. Several numerical models are available to predict long-term movement of contaminants due to advection and diffusion processes into or through caps, including caps with engineered components. The results generated by such models include flux rates and sediment contaminant pore water concentrations as a function of time. These results can be compared to applicable water quality criteria, or interpreted in terms of a mass loss of contaminants as a function of time. Results could be compared to similar calculations for other remediation technologies. The models can evaluate the effectiveness of varying thicknesses of granular cap materials with differing properties [grain size and total organic carbon (TOC)].

5.3.5 Geotechnical Considerations

Usually, contaminated sediment is predominately fine-grained, and often has high water content and low shear strength. These materials are generally compressible. Unless appropriate controls are implemented, contaminated sediment can be easily displaced or resuspended during cap placement. Following placement, cap stability and settlement due to consolidation are two additional geotechnical issues.

As with any geotechnical problem of this nature, the shear strength of the underlying sediment will influence its resistance to localized bearing capacity or sliding failures, which could cause localized mixing of capping and contaminated materials. Cap stability immediately after placement is critical, before any excess pore water pressure due to the weight of the cap has dissipated. Usually, gradual placement of capping materials over a large area will reduce the potential for localized failures. Information on the behavior of soft deposits during and after placement of capping materials is limited, although some field monitoring data have shown successful sand capping of contaminated sediment with low strength. Conventional geotechnical design approaches should, therefore, be applied with caution. These design approaches should be conservative for conditions normally encountered in cap design. For example, a cap should be built up gradually over the entire area to be capped. This will reduce the potential for mixing and overturning of the contaminated sediment. Similarly, caps with flat transition slopes at the edges are not generally subject to a sliding failure normally evaluated by conventional slope stability analysis.

5.3.6 Placement Methods and Performance Monitoring

A variety of equipment types and placement methods have been used for capping projects. The use of granular capping materials (sediment and soil), geosynthetic fabrics, and armored materials are all in-situ cap considerations discussed in this section. Important considerations in selection of placement methods include the need for controlled, accurate placement of capping materials. Slow, uniform application that allows the capping material to accumulate in layers is often necessary to avoid

displacement of or mixing with the underlying contaminated sediment. Uncontrolled placement of the capping material can also result in the resuspension of contaminated material into the water column.

Granular cap material can be handled and placed in a number of ways. Mechanically excavated materials and soils from an upland site or quarry have relatively little free water. These materials can be handled mechanically in a dry state until released into the water over the contaminated site. Mechanical methods (such as clamshells or release from a barge) rely on gravitational settling of cap materials in the water column, and could be limited by depth in their application. Granular cap materials can also be entrained in a water slurry and carried to the contaminated site wet, where they can be discharged by pipe into the water column at the water surface or at depth. These hydraulic methods offer the potential for a more precise placement, although the energy required for slurry transport could require dissipation to prevent resuspension of contaminated sediment. Armor layer materials can be placed from barges or from the shoreline using conventional equipment, such as clamshells. Placement of cap components, such as geotextiles, could require special equipment. Examples of equipment types used for cap placement are shown in Highlight 5-3. The *Guidance for In-Situ Subaqueous Capping of Contaminated Sediments* (U.S. EPA 1998d) contains more detailed information about cap placement techniques.

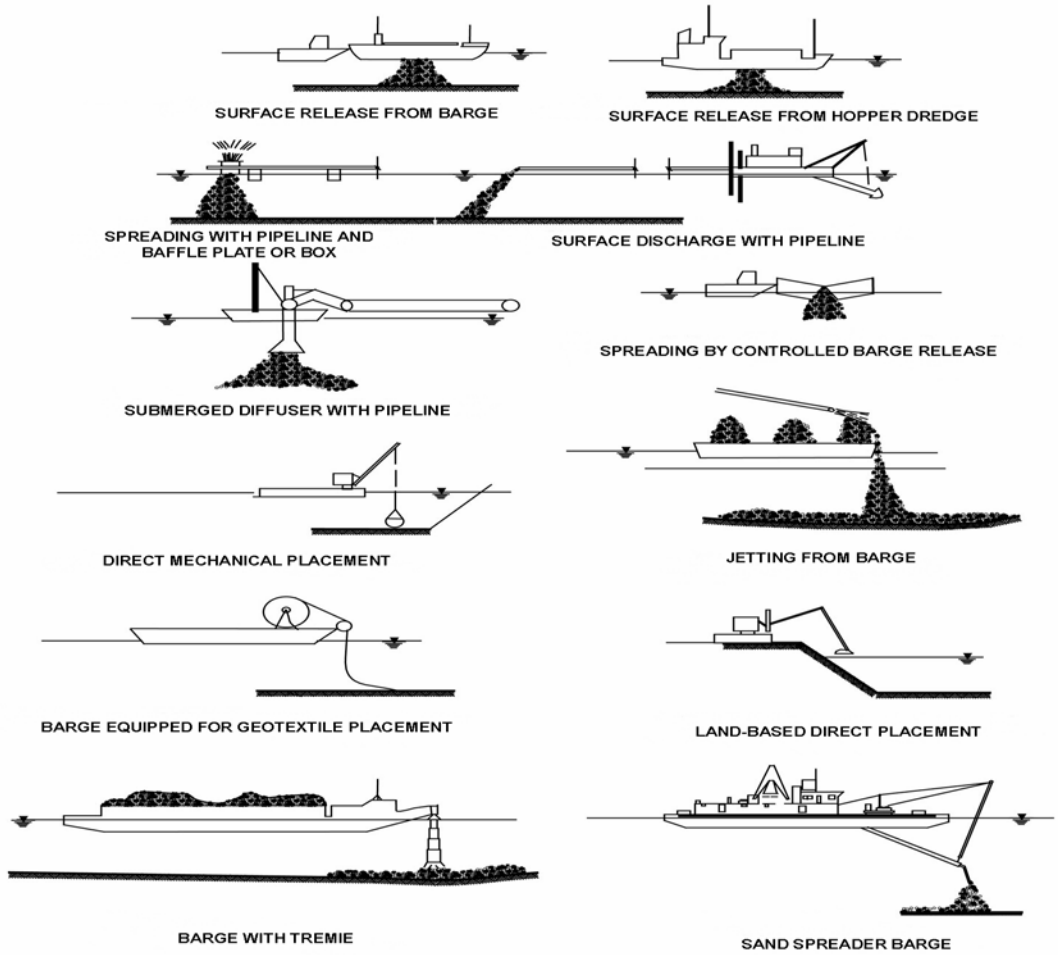
Monitoring of both placement and performance of in-situ caps are important. Cap placement can resuspend some contaminated sediment, leading to contaminant release and increased risks during and following cap placement. Therefore, designs should include plans to mitigate and monitor impacts during and after construction.

Performance objectives for an in-situ cap relate to its ability to provide sufficient physical isolation and stabilization of contaminated sediment. Broader remedial action objectives such as decreases in contaminant concentrations in biota also should evaluated when applicable, and are discussed in Chapter 8, Remedial Action and Long-Term Monitoring. The following processes should be considered when evaluating the performance of a cap, and in developing a cap design and monitoring program:

- Upward contaminant flux rates (mass of contaminant/unit area/unit time);
- Movement of contaminants into pore water of cap;
- Changes in chemical environment (e.g., redox potential) that may change mobility of contaminants;
- Long-term accumulation of contaminants in cap material;
- Contaminant breakthrough as a function of time; and
- Ability of the cap to withstand bioturbation and erosive forces.

For example, contaminant flux and the resulting contaminant concentration in surface sediment, cap pore water, overlying surface water quality or underlying ground water quality can be compared to

Highlight 5-3: Example Capping Equipment and Placement Techniques



Source: U.S. EPA 1998d

site-specific sediment cleanup levels or water quality standards (e.g., federal water quality criteria or state promulgated standards). In addition, the concentration of contaminants accumulating in the cap material as a function of time can be compared to site-specific target cleanup levels during long-term cap performance monitoring. Both analytical and numerical models exist to predict cap performance and have been compared and validated with laboratory tests and field results (e.g., Ruiz et al. 1999).

5.4 EVALUATING SITE CONDITIONS

A good assessment of site-specific conditions is critical to the feasibility and effectiveness of in-situ capping. Site conditions affect all aspects of a capping project, including design, equipment and cap material selection, and monitoring and management programs. Some limitations in site conditions can be accommodated in the cap design. A thorough examination of site conditions should determine if further consideration of capping is appropriate. General aspects of site characterization are discussed in Chapter 2, Remedial Investigation Considerations. Some specific aspects of site characterization important for in-situ capping are introduced briefly below.

5.4.1 Physical Environment

Some considerations concerning the physical environment of an in-situ cap include the waterbody dimensions, depth and slope (bathymetry) of sediment bed, and flow patterns, including tides, currents, and other potential disturbances. Existing infrastructure such as bridges, utility crossings, and other marine structures are discussed in section 5.4.3.

The bathymetry of the site influences the amount of spread during placement and the stability of capping material. Flatter bottom slopes allow material to be placed more accurately, especially if capping material is to be placed hydraulically. Water depth also influences the amount of spread during cap placement. Generally, the longer the descent of the cap material through the water column, the more water is entrained in the plume, resulting in a thinner layer of cap material over a larger area than intended.

The energy of water flows is also an important consideration. Capping projects are easier to design in low energy environments (e.g., protected harbors, slow-flowing rivers, or micro-tidal estuarine systems). In open water, deeper sites are generally less influenced by wind or wave generated currents and less prone to erosion than shallow, near-shore environments. However, armoring techniques or selection of erosion-resistant capping materials can make capping technically feasible in some high energy environments. Currents within the water column affect dispersion during cap placement and can influence the selection of the equipment to be used for cap placement. Bottom currents generate shear stresses which act on the cap surface and may potentially erode the cap. In addition to ambient currents due to normal riverine or tidal flows, the project manager should consider the effects of storm-induced waves and other episodic events (e.g., floods, ice scour).

The presence of an in-situ cap can alter existing hydrodynamic conditions. In harbor areas or estuaries, the decrease in depth or change in bottom geometry can affect the near-bed current patterns, and thus the flow-induced bed shear stresses. In a riverine environment, the placement of a cap generally reduces depth and restricts flow and may alter the sediment carrying capacity of the channel. Modeling studies may be useful to assess these changes in site conditions. In depositional areas, the effect of new sediment deposited on the cap should be considered. Clean sediment accumulating on the cap can increase the isolation effectiveness of the cap over the long term and may also increase consolidation of underlying sediment bed.

5.4.2 Sediment Characteristics

The project manager should determine the physical, chemical, and biological characteristics of the contaminated sediment pursuant to the data quality objective (DQO) process during the remedial investigation. The results of the characterization, in agreement with the remediation goals and objectives, determines the areal extent or boundaries of the area to be capped.

Shear strength of contaminated sediment deposits is of particular importance in determining the feasibility of in-situ capping. Most contaminated sediment is fine-grained, and is usually high in water content and relatively low in shear strength. Although a cap can be constructed on sediment with low shear strengths, the ability of the sediment to support a cap and the need to construct the cap using appropriate methods to avoid displacement of the contaminated sediment should be carefully considered. The presence of other materials within the sediment bed, such as debris, wood chips or high sludge fractions, or other non-mineral-based sediment fractions, can also present special problems when interpreting grain size and other geotechnical properties of the sediment. It could be necessary to remove large debris prior to placing a cap.

The chemical characteristics of the contaminated sediment is an important factor that may affect design or selection of a cap, especially if capping highly mobile or highly toxic sediment. In addition, capping may change the contaminated sediment from an oxidizing to an anoxic condition, which may change the solubility of metal contaminants and the susceptibility of organic contaminants to microbial decomposition. For example, many of the divalent metal cations (e.g., lead, nickel, zinc) become less soluble in anaerobic conditions, while other metal ions (e.g., arsenic, copper) become more soluble. Metals solubility is also greatly affected by pH, and so varies between fresh-water and marine systems. Mercury becomes methylated through the action of anaerobic bacteria and highly chlorinated PCBs may degrade to less chlorinated forms in an anaerobic environment. These issues are also discussed in Chapter 4, sections 4.3.2 and 4.3.3.

When contaminated materials or sludge containing concentrated organic matter are capped, the organic matter may be decomposed by anaerobic microorganisms. The products of this decomposition process may include methane and hydrogen sulfide gases. As these dissolved gases accumulate and transfer into a gaseous phase they could begin to percolate through the capped matrix by convective or diffusive transport. This transport of gases percolating through the cap can facilitate a more rapid contaminant migration (than that due to diffusion) by providing avenues for contaminant release or solubilizing the contaminants of concern and carrying them through the saturated porous media dissolved in the gaseous molecules. These factors should be considered during cap design.

5.4.3 Waterway Uses and Infrastructure

If the site under consideration is adjacent to or within a navigation, recreation or flood control channel, the effect of cap placement on those functions of the channel should be evaluated. Effects of cap placement on habitat function of a waterbody are discussed in the following section. Cap placement may have the beneficial effect of restoring habitat, but it also decreases the water depth and cross-sectional area of the channel. The flow carrying capacity of a channel and the navigable depth could also be reduced. If water depths are reduced in a harbor or river channel, some commercial and recreational vessels may have to be restricted or banned. The acceptable draft of vessels allowed to navigate over a capped area depends on water level fluctuations (seasonal, tidal, and wave) and the potential effects of

vessel groundings on the cap. Due to potential cap erosion caused by propeller wash, engine size restrictions could also be needed. Generally, anchoring should not be allowed at locations on or near a cap. It may be necessary to restrict fishing and swimming to prevent recreational boaters from dragging anchors across a cap. In some situations, dredging prior to cap placement may minimize these adverse impacts of cap construction.

Other activities in and around the waterbody may also impact cap integrity and maintenance needs, and should be evaluated. These include the following:

- Water supply intakes;
- Storm water or effluent discharge outfalls;
- Utilities and utility crossings;
- Construction of bulkheads, piers, docks, and other waterfront structures;
- Navigational dredging adjacent to the cap area; and
- Future development of commercial navigation channels in the vicinity of the cap.

Utilities (e.g., storm drains) and utility crossings (e.g., water, sewer, gas, oil, telephone, cable, and electric) are commonly located in urban waterways. It may be necessary to relocate existing utility crossings under portions of waterbodies if their deterioration or failure might impact cap integrity or if they could not be repaired without disturbing the cap. Future construction or maintenance of utility crossings would have to consider the cap, and it may be necessary to consider limiting those activities through institutional controls if cap repair cannot be assured. The presence of the cap can also place constraints on future waterfront development that could require dredging in the area.

To date, environmental agencies have little experience with the ability to enforce use restrictions necessary to protect the integrity of an in-situ cap (e.g., vessel size limits, bans on anchoring, etc.), although experience is growing. Generally, a local enforcement mechanism is necessary to control specific use restrictions. Project managers should consider mechanisms for compliance assurance, enforcement, and the consequences of non-compliance, on use restrictions when evaluating in-situ capping.

5.4.4 Habitat Alterations

In-situ capping alters the aquatic environment and, therefore, affects aquatic organisms. Habitat considerations are especially important when evaluating materials for the uppermost layers of a cap. Sandy sediment and stone armor layers are often used to cap areas with existing fine-grained sediment. Although the capped areas are already affected by contamination, the new substrate can change the habitat for benthic organisms. At least initially, changes in organic carbon content of the capping material may change the feeding behavior of benthic organisms in the capped area. Generally, the uppermost cap layers become a substrate for re-colonization. Where possible, caps should be designed to provide habitat for these organisms. In some cases it is possible to provide a habitat layer over an erosion protection layer by filling the interstices of armor stones with materials such as crushed gravel. In some

cases, natural sedimentation processes after cap placement can create desirable habitat characteristics. For example, placement of a rock cap in some riverine systems can result in a final cap surface that is similar to that which previously existed because the rock may become embedded with sands/silts through natural sedimentation.

Desirable habitat characteristics for cap surfaces vary by location. Providing a layer of appropriately sized rubble that can serve as hard substrate for attached molluscs (e.g., oysters or mussels) can greatly enhance the ecological value. Material suitable for colonization by foraging organisms, such as bottom-dwelling fish, can also be appropriate. A mix of cobbles and boulders may be desirable for aquatic environments in areas with substantial flow. In addition, the potential for attracting burrowing organisms incompatible with the cap design or ability to withstand additional physical disturbances should be considered. Habitat enhancements should not impair the function of the cap or its ability to survive the shear stresses of storms, floods, propeller wash, or other disturbances. Project managers should consult with local resource managers and natural resource trustee agencies to determine what types of modifications to the cap surface would provide suitable substrate for local organisms.

Project managers should also consult EPA staff working with the Clean Water Act, as well as natural resource trustees, where Section 404 of the Clean Water Act is applicable or relevant and appropriate (see Chapter 3, section 3.3, Applicable or Relevant and Appropriate Requirements for Sediment Alternatives). Where cleanup methods are being considered which damage aquatic habitat, substantive requirements may include minimizing the permanent loss of habitat and mitigating it by creation or restoration of a similar habitat elsewhere. Habitat considerations are also important when evaluating post-capping bottom elevations. Capping often increases bottom elevations, which in itself can alter the pre-existing habitat. For example, a remediated subtidal habitat can become intertidal, or lake habitat can become a wetland (Cowardin et al. 1979).

Highlight 5-4 presents some general points to remember from this chapter.

Highlight 5-4: Points to Remember When Considering In-Situ Capping

- Source control generally should be implemented to prevent re-contamination
- In-situ caps generally reduce risk through three primary functions: physical isolation, stabilization, and reduction of contaminant transport
- Caps may be most suitable where water depth is adequate, slopes are moderate, ground water flow gradients are low or contaminants not mobile, substrates are capable of supporting a cap, and an adequate source of cap material is available
- Evaluation of capping alternatives and design of caps should consider buried infrastructure, such as water and sewer lines, fuel pipelines, and telephone and cable systems
- Substrate and depth alteration from capping should be evaluated for impacts to aquatic biota
- In evaluating a capping project in natural riverine environments, the project manager should consider a fluvial system's inherent dynamics, especially the effects of channel migration and flow variability including extreme events
- Evaluation of capping alternatives should include consideration of cap disruption from human and natural sources, including at a minimum, the 100-year flood and other events with a similar probability of occurrence
- Cap placement methods should be selected to minimize the resuspension of contaminated sediment
- The use of experienced contractors skilled in marine construction techniques is very important to placement of an effective cap
- In-situ caps should be monitored during and after placement to ensure long-term integrity of the cap, recovery of biota, and test for re-contamination

6.0 DREDGING AND EXCAVATION

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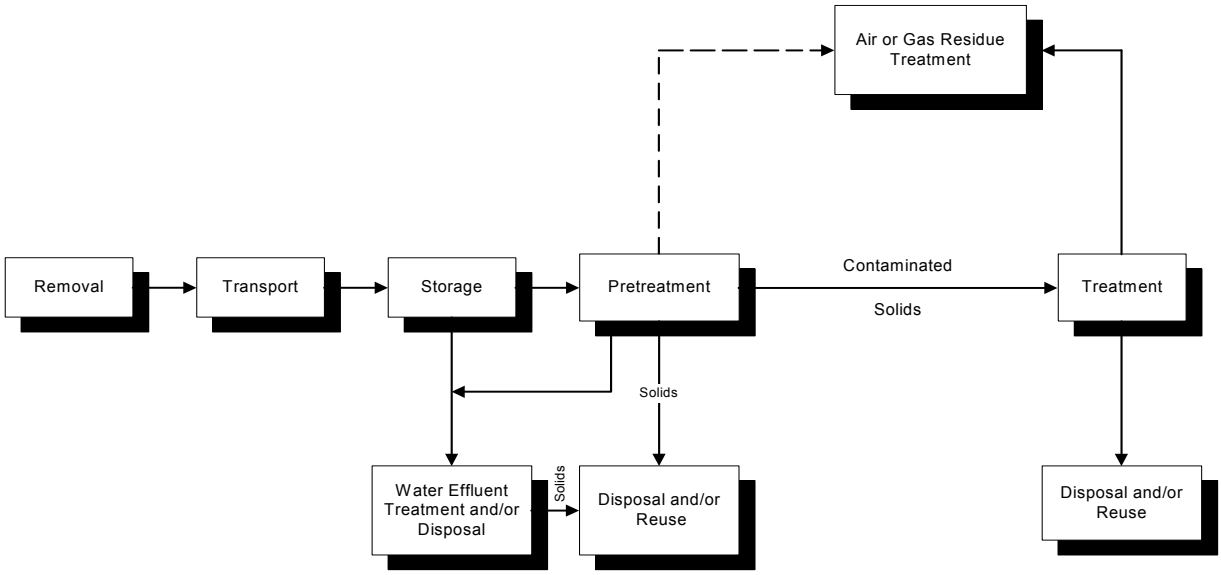
6.0 DREDGING AND EXCAVATION

6.1 INTRODUCTION

Dredging and excavation are means of removing contaminated sediment from a waterbody, either while it is submerged (dredging) or after water has been diverted or drained (excavation). Both methods necessitate transporting the sediment to a location for treatment and/or disposal of the sediment. They also frequently need treatment of water from dewatered sediment prior to discharge. Sediment is dredged on a routine basis at numerous locations for the maintenance of navigation channels. Use of the term environmental dredging has evolved in recent years to characterize dredging performed specifically for the removal of contaminated sediment. The objective of navigational dredging is to remove sediment as efficiently and economically as possible to maintain waterways for recreational, national defense, and commercial purposes. Environmental dredging is intended to remove sediment contaminated above certain action levels while minimizing the spread of contaminants to the surrounding environment (NRC 1997).

The components to be evaluated when considering dredging or excavation as a cleanup method are removal, transport and storage, treatment (pretreatment, treatment of decant and/or dewatering effluents and sediment, if necessary), and disposal (liquids and solids). Highlight 6-1 provides a flow diagram of the steps in a typical dredging or excavation alternative. In its simplest form, a dredging or excavation project may consist of as few as three of the components shown in Highlight 6-1. A complex project may include all of these components.

Highlight 6-1: Example Flow Diagram for Dredging/Excavation



Sediment removal by dredging or excavation is the most frequent cleanup method for sediment used by the Superfund program in the past. Dredging or excavation have been selected as a cleanup method for contaminated sediment at more than 100 Superfund sites as of 2001 (some as an initial removal action). At about 15 to 20 percent of these sites, an in-situ method was also selected for sediment at part of the site. In general, project managers should evaluate each of the three cleanup methods: monitored natural recovery, in-situ capping, and removal through dredging or excavation, at every sediment site at which they may be appropriate.

Project managers should also refer to the U.S. Environmental Protection Agency's *Assessment and Remediation of Contaminated Sediments (ARCS) Program Remediation Guidance Document* (U.S. EPA 1994b) and *Handbook:Remediation of Contaminated Sediments* (U.S. EPA 1991b), and the National Research Council's (NRC's) *Contaminated Sediments in Ports and Waterways: Cleanup Strategies and Technologies* (NRC 1997) for detailed discussions of the processes and technologies available for dredging and excavation. The project manager should evaluate the entire removal process with a coordinated systems approach. Efficient coordination of each component is important for a cost-effective cleanup.

6.2 ADVANTAGES AND DISADVANTAGES

One of the principal advantages of removing contaminated sediment from the aquatic environment is that , where it is done effectively, sediment removal may result in the least uncertainty about long-term effectiveness of the cleanup, particularly regarding future environmental exposure to contaminated sediment. Removal of contaminated sediment can minimize the uncertainty associated with predictions of sediment bed or in-situ cap stability and the potential for exposure and transport of contaminants.

Another principal advantage of removal of contaminated sediment is the flexibility it leaves regarding future use of the waterbody. In-situ cleanup methods such as monitored natural recovery and capping frequently need institutional controls which limit waterbody uses. Sediment removal usually requires fewer institutional controls because larger amounts of contaminants do not remain in place in the aquatic environment.

Another advantage, where dredging residuals are low, concerns the time to achieve remedial action objectives. Active cleanup methods such as sediment removal and capping may reduce risk more quickly by achieving faster reductions in sediment concentrations. Contaminant uptake can be limited or controlled by disposing the dredged or excavated material in an alternate setting, such as an engineered landfill, upland or nearshore confined disposal facility (CDF), or contained aquatic disposal (CAD). Also, sediment removal is the only cleanup method which allows for treatment and/or beneficial reuse of dredged or excavated material. Treatment of contaminated sediment can also reduce the demands on limited landfill disposal capacity.

There are also significant disadvantages to sediment removal. Implementation of dredging or excavation is usually more complex and costly than monitored natural recovery or in-situ capping because of the removal technologies themselves (especially in the case of dredging) and the need for transport, storage, treatment (where applicable), and disposal. Treatment technologies for contaminated sediment offer implementation challenges because of limited full-scale experience and cost. Disposal

capacity may be limited in existing municipal or hazardous waste landfills and it may be difficult to site new local disposal facilities.

Another disadvantage of sediment removal is the residual contamination left following removal, especially when dredging is used. No removal technology can remove every particle of contaminated sediment, and especially where work is conducted under water, there can be significant uncertainties concerning the extent of residuals. Residual contamination is likely to be greater in the presence of cobbles, boulders, or buried debris, in high energy environments, at greater water depths, and where contaminated sediment directly overlies bedrock or a hard bottom. These complicating factors can make the sediment removal process and achievement of remediation goals difficult and costly.

Another disadvantage of dredging includes the increased potential for contaminant losses through resuspension and, generally, to a lesser extent through volatilization. Resuspension of sediment from dredging will result in both dissolved and particle-associated releases to the water column. Resuspended particulate material may be redeposited at the dredging site or, if not controlled, transported to other locations in the waterbody downstream. Some resuspended contaminants may also dissolve into the water column where they are available for uptake by biota. While aqueous resuspension is much less of a concern during excavation, there may be increased concern with releases to air. Losses at the disposal or treatment site may include effluent or runoff discharges to surface water, leachate discharges to ground water, or volatile emission to air. Each component of a sediment removal alternative necessitates additional handling of the material and presents a possibility of contaminant loss.

Finally, short-term disruption of the benthic environment is unavoidable during dredging or excavation and includes at least a temporary destruction of the aquatic community and habitat within the remediation area. If removed sediment is to be disposed of in an in-water disposal site, there may be additional impacts to sensitive ecological environments in or near the in-water disposal site.

Where it is feasible, excavation sometimes has advantages over dredging for the following reasons:

- It is difficult to visually observe the removal operation underwater. Although in some cases diver-assisted hydraulic dredging or video-monitored dredging can be used to guide the removal operation, turbidity, safety and other constraints typically make it necessary for dredging to be performed without visual assistance;

- Water flow in the dredged area during removal may result in greater potential for waterborne releases; and

- Water bottom conditions (e.g., debris) and sediment characteristics (e.g., grain size and specific gravity) typically require greater consideration than for excavation.

However, site preparation for excavation can be more lengthy and costly than for a dredging project due to the need for dewatering or water diversion.

6.3 EXCAVATION TECHNOLOGIES

Excavation of contaminated sediment generally involves isolating the contaminated sediment from the overlying waterbody, pumping or diverting water from the area, and managing any continuing inflow followed by sediment excavation using conventional dryland equipment. However, excavation may be possible without water diversion in some areas such as wetlands during dry seasons or while the sediment and water are frozen. Typically, excavation is performed in shallow waterbodies or near shore areas.

Prior to pumping out the water, the area is isolated using the following:

- Sheet piling;
- Earthen dams;
- Rerouting the waterbody using temporary dams or pipes; or
- Permanent relocation of the waterbody.

Sediment isolation using sheet piling commonly involves driving interlocking metal plates (sheet piles) into the subsurface, and thereby either blocking off designated areas or splitting a stream down the center. Highlight 6-2 shows an example of where this has been used. Sheet piling may not be feasible where bedrock or hard strata are present at or near the surface. If a stream is split down its center, then one side of the stream may be excavated in the dry. When the excavation of the first side of the stream is completed, water may be diverted back to the excavated side and sediment on the other side may be excavated. Temporarily rerouting a waterbody with dams is sometimes done for small streams or ponds (Highlight 6-3). This includes the use of temporary dams to divert the water flow allowing excavation of contaminated sediment. The ability and cost to provide hydraulic isolation of the contaminated area during remediation is a major factor in selecting the appropriate removal technology.

Once isolated, standing water within the excavation area will need to be removed. As surface water flows are eliminated ground water may infiltrate the confined area. The ground water can be collected in sumps or dewatering wells. After collection, the ground water should be characterized, managed, treated (if necessary), and discharged to an appropriate receiving waterbody. Management of water within the confined area is an important logistical and cost factor that can influence the decision of wet versus dry removal techniques.

Isolation and dewatering of the area is normally followed by excavation using conventional earthmoving equipment such as a backhoe or dragline. When the excavation activities are complete, temporary dam(s) or sheet piling(s) are removed and the waterbody is restored to its original hydraulic condition. The stream bank and bed may need to be restabilized or restored upon completion of the remediation project depending on applicable regulations.

Another less common type of excavation project involves permanent relocation of a waterbody (Highlight 6-3). The initial phases of such a project may be similar to excavation projects that temporarily reroute a waterbody. However, in a permanent stream relocation project, a replacement

Highlight 6-2: Excavation Following Isolation Using Sheet Piling

Source: Pine River/Velsicol, EPA Region 5

stream is constructed before the original waterbody is capped and converted into an upland area. Because the original waterbody is covered over, direct exposure to residual contamination is reduced or eliminated.

Excavation may also include excavation of sediment in areas that experience occasional dry conditions, such as intermittent streams and wetlands. These types of projects are logistically similar to upland construction projects and frequently use conventional earthmoving equipment.

6.4 DREDGING TECHNOLOGIES

Dredging projects are conducted underwater. Dredging involves mechanically penetrating, grabbing, raking, cutting, or hydraulically scouring the bottom of a waterway to dislodge the sediment. Once dislodged, the sediment may be removed from a waterway either mechanically(with buckets) or hydraulically (by pumping). Therefore, dredges may be categorized as either mechanical or hydraulic depending on the basic means of moving the dredged material. Some dredges employ pneumatic (compressed air) systems to pump the sediment out of the waterway (U.S. EPA 1994b).

6.4.1 Mechanical Dredging

The fundamental difference between mechanical and hydraulic dredging equipment is the form in which the sediment is removed. Mechanical dredges offer the advantage of removing the sediment at nearly the same solids content and, therefore, volume as the in-situ material. Little additional water is

Highlight 6-3: Permanent or Temporary Rerouting of the Waterbody

A: Permanent River Relocation – Triana/Tennessee River Site

The Triana/Tennessee River Site consists of an 11-mile stretch of two tributaries, the Huntsville Spring Branch and Indian Creek, which both empty into the Tennessee River. Remedial actions involved rerouting of the channel in Huntsville Spring Branch (HSB mile 5.4 to 4.0), the filling and burial in place of the DDTR (dichloro diphenyl trichloroethane and its metabolites) in the old channel, the construction of diversion structures at the upper and lower end of the stream to prevent stream reversion to the former stream channel, and the diversion of storm water runoff to prevent flow across the filled channel. Remedial actions for HSB mile 4.0 to 2.4 consisted of constructing four diversion structures; excavating a new channel between HSB mile 3.4 and 2.4; filling three areas; constructing a diversion ditch around the fill areas; and excavating portions of the sediment from the channel.

These remedial actions effectively isolated in place 93% of the DDTR in the Huntsville Spring Branch-Indian Creek system of the Tennessee River. These remedial actions began on April 1, 1986, and were completed on October 16, 1987. Through March 1, 2001, the remedial actions have been inspected yearly by a federal and state Review Panel. The remedial action has not required any repair of the structures to maintain their integrity, and monitoring has shown that DDTR concentrations in fish and water continue to decline.

B: Temporary Re-Routing of a River – Bryant Mill Pond Project at the Allied Paper, Inc./Portage Creek/Kalamazoo River Site

In EPA Region 5, an EPA-conducted removal and onsite containment action removed polychlorinated biphenyls (PCBs)-contaminated sediments from the Bryant Mill Pond area of Portage Creek. During the removal action, that was conducted from June 1998 - May 1999, Portage Creek was temporarily diverted from its normal streambed so that 150,000 cu yds of the creek bed and floodplain soils could be excavated using conventional excavation equipment. PCB concentrations remaining after the removal action were below 1 ppm.

Source: U.S. EPA Region 5

entrained with the sediment as it is removed. Thus, the volumes of contaminated material and process water to be disposed, managed, and/or treated are minimized. Major types of mechanical dredges that have been used in environmental dredging include clamshell bucket (including specialized enclosed clamshell buckets) and backhoes.

Redesigned environmental clamshell dredges address a number of issues often raised relative to remedial dredging including contaminant removal efficiency, sediment resuspension, and overall cost. A new technology tested at the New Bedford Harbor Superfund site in Massachusetts involved precise positioning of the dredging apparatus to minimize over-dredging, a sealed horizontal profiling clamshell bucket to minimize resuspension, and a water recirculating system that reduces water treatment for the hydraulic dredge material pipeline system. Results indicate that PCB-contaminated sediment removal

efficiency was very high (> 97 percent) and that resuspension due to dredging was almost non-detectable. Highlight 6-4 shows two examples of mechanical dredges including the type used at New Bedford.

Highlight 6-4: Examples of Mechanical Dredges

Note: A = Use of specially designed "environmental" mechanical dredges cam reduce suspension (Source: Cable Arm, Corp.)
B = New Bedford Site; Bean Company prototype low-resuspension mechanical dredge (Source: Barbara Bergen, U.S. EPA)

6.4.2 Hydraulic Dredging

Hydraulic dredges remove and transport sediment in the form of a slurry through the addition of high volumes of water at some point in the removal process (Zappi and Hayes 1991). The total volume of material processed may be greatly increased and the solids content of the slurry may be considerably less than that of the in-situ sediment although solids content varies between dredges (U.S. EPA 1994b). The excess water is usually discharged as effluent at the treatment or disposal site and may need treatment prior to discharge. Hydraulic dredges may be equipped with rotating blades, augers, or high-pressure water jets to loosen the sediment (U.S. EPA 1995b). The ARCS *Remediation Guidance*

Document (U.S. EPA 1994b) contains figures and summaries of dredge capabilities for several commonly available hydraulic dredges. The hydraulic dredges most commonly used in the U.S. are the conventional cutterhead dredge and the horizontal auger.

Certain hydraulic dredges such as the modified dustpan dredge, cleanup dredge, horizontal profiling grab dredge, Eddy pump, and matchbox dredges, have been specifically developed to reduce resuspension during the removal process. Redesigned hydraulic dredges have recently been tested that can move sediment with less water and others that recycle the water used to move the sediment. Highlight 6-5 presents examples of hydraulic dredges.

6.4.3 Dredge Equipment Selection

The selection of appropriate dredging equipment is essential for an effective dredging operation. The following factors should be evaluated:

- *Solids Concentration:* In most cases it is preferable to use a dredging system that is capable of delivering material at high solids concentrations to minimize costs for handling, treating, and disposal of water and sediment. However, in some cases the advantages of slurried sediment that may be transported by pipeline may override these considerations;

- *Production Rate:* A high production rate or large dredge may be necessary to complete large projects within acceptable time frames or necessary to cut through harder sediment. Alternatively, a low production rate may be beneficial to minimize sediment resuspension or because of constraints caused by sediment transport, treatment, or disposal components, or when rocks or debris are present in the sediment;

- *Dredging Accuracy:* Precise control of operational dredging depth is particularly important when dredged sediment is to be handled in expensive treatment and disposal facilities (Averett et al. 1990). The vertical and lateral accuracy of the dredge is important to ensure that contaminated sediment is removed, while minimizing the amount of clean sediment removed;

- *Water Depth:* Dredges are limited to dredging areas with an adequate depth of water to accommodate the draft of the dredging vessel. This factor becomes important when contaminated sediment is located outside of navigable waterways. Some dredging equipment may be operated from land to access sediment in shallow waterways. The maximum depth to which dredges reach may be a limiting factor. Some dredges are limited by the length of the dredging arm or ladder. Hydraulic dredging in very deep water (i.e., greater than 20 meters) may need submerged pumps or remotely operated dredges;

- *Ability to Handle Large or Dangerous Debris:* Sediment, especially in urban areas and cargo loading/unloading areas may contain very large debris (e.g., greater than 0.5 meters in any dimension) which can only be removed mechanically. Mechanical dredges generally remove large debris with the sediment, however they may produce greater

Highlight 6-5: Examples of Hydraulic Dredges

Note: A = Fox River, WI; horizontal auger hydraulic dredge deployment (Source of photo, Jim Hahnenberg U.S. EPA)
B = Manistique, MI; closeup of twin-vortex pump, hydraulic dredge cutterhead (Source of photo, Ernie Watkins U.S. EPA)
C = Closeup of swinging ladder hydraulic dredge cutterhead (Source of photo, Ellicott Corporation)

turbidity in the process. Dredgeheads equipped with cutters may be able to reduce the size of some debris, such as wood. Although debris that is larger than the diameter of the suction pipe or not cut by the cutter cannot be removed by hydraulic dredges, smaller debris may also clog hydraulic pipelines and damage pumps. At some sites the risk and approach for dealing with buried munitions from past military activities should be evaluated;

- *Sediment Resuspension, Release and Residual Concentration:* Sediment resuspension, contaminant release, and residual sediment concentrations are primary concerns at many sites and may override other factors in selecting a dredge. The degree of resuspension is influenced by both the type of dredge and its operation. Specialty dredges have been designed in recent years to minimize resuspension, although dredge operation is extremely important;

- *Site Restrictions:* Channel widths, surface and submerged obstructions, overhead restrictions, such as bridges, and other site access restrictions may limit the type and size

of equipment that can be used. The presence of buried utilities, pipelines, and other infrastructure should also be considered in the evaluation of dredging technologies;

- *Compatibility:* The overall compatibility of dredging equipment with the transport, treatment, and disposal requirements for the project is critical to an efficient and effective dredging remedy. In most cases it is preferable to use a dredging system that is capable of delivering material at high solids concentrations. This tends to minimize the costs of handling, treating, and disposing of sediment. Mechanically dredged sediment does not need intensive dewatering, which is an expensive pre-treatment process. Mechanical dredging keeps the volume of dredged material to a minimum and greatly reduces the costs of water treatment; and

- *Distance to Treatment or Disposal Sites:* The distance from the dredging site to the treatment, disposal, or re-handling site affects the method of transport and, hence, the type of dredge. If there is access for a pipeline slurried sediment can be transported by pipeline several kilometers where there is little elevation gain, and can be transported over longer distances with the use of booster pumps. If pipeline transport is not feasible, sediment can be transported at high solids concentrations (e.g., as produced with mechanical or pneumatic dredges) by scows or barges, provided that the water is deep enough for barge transport and there are no other limitations on navigation.

The operational characteristics of conventional mechanical and hydraulic dredges are shown in Highlight 6-6. Highlight 6-7 displays an assessment of various dredges against the factors listed above and additional factors that may be important in dredge selection at some sites. The information in these highlights is intended as general guidelines to help project managers make an initial assessment of dredge capabilities. There are many site specific circumstances that dictate which equipment will work for any given situation. In addition, because new equipment is being continuously developed, project managers will need to consult with experts who are familiar with the latest technologies in order to make a final selection.

Experience has shown that an environmentally effective dredging operation depends on the use of highly skilled dredge operators familiar with the goals of environmental remediation, in addition to close monitoring and management of the dredging operation. For additional advice regarding dredge equipment selection and use project managers should consult professionals in this field and the additional technical documents listed in Appendix D.

6.4.4 Dredge Positioning

A critical element of sediment remediation is the precision of the dredge cut, both horizontally and vertically. Technological developments in surveying (vessel) and positioning (dredgehead) instruments have improved the dredging process. Vertical control may be particularly important when contamination occurs in a relatively thin or uneven layer. Video cameras may be used to continuously monitor dredging operations. The working depth of the dredgehead may be measured using acoustic instrumentation and by monitoring dredged slurry densities. In addition, surveying software packages may be used to generate pre- and post-dredging bathymetric charts, determine the volume of dredged sediment, locate obstacles, and calculate linear dimensions of surface areas (St. Lawrence Centre 1993).

Highlight 6-6: Operational Characteristics of Various Dredges

Dredge Type[1]	Percent Solids by Weight	Range of Production Rates (cubic m/hr)[2]	Dredging Accuracy[3]		Operational Dredging Depth		Debris Removal (+ indicates capability)
			Vertical (cm)	Horizontal (m)	Minimum (m)[4]	Maximum (m)	
Clamshell or Grab	Near in-situ	20-500	10-60	0.1-0.3	--	50	+
Backhoe	Near in-situ	20-150	5-30	0.05-0.15	--	15	+
Enclosed Bucket	Near in-situ	20-500	5-30	0.1-0.3	--	50	
Bucket/pump	Near in-situ	20-150	5-30	0.05-0.15	--	15	
Cutterhead (6-8 in.)	10-20	20-100	5-30	0.1-0.5	1.2	4	
Cutterhead (10-12 in.)	10-20	60-500	5-30	0.1-0.5	1.4	8	
Cutterhead (14-18 in.)	10-20	200-900	5-30	0.1-0.5	1.5	12	
Horizontal Auger (6-18 in.)	10-30	50-100	5-15	0.15-0.5	0.5	5	
Pneumatic	25-40	50-300	5-30	0.1-0.3	--	45	
Diver Assisted Vacuum	5-10	10	--	0.15	0.5	30	
Plain Suction	5-15	20-4000	5-30	0.1-0.5	2	19	
Dry Excavation	In situ or greater	10-500	10	0.1	0	Stability Limitations	+

[1] This table only includes dredge sizes normally considered for environmental projects. Larger dredge sizes commonly used for navigation dredging are available.
[2] Production rates include both environmental and navigational dredging. Removal of contaminated sediments tend toward the low end of the range.
[3] Where a range is shown for positioning accuracy, the lower value reflects use of state-of-the-art electronic positioning equipment to define dredgehead position employed under favorable conditions, while the upper value reflects use of electronic positioning for the vessel only with visual indicators of dredgehead positioning with respect to the vessel.
[4] Note that the minimum operating depth limitations may be overcome by an excavation sequence from deeper water into the area to be dredged.

Sources: U.S. EPA 1994b, USACE 1983, Bray 1997, Herbich 1992

Highlight 6-7: Selection of Dredges for Contaminated Sediment Removal

Dredging Issue/ Concern/ Constraint	Mechanical Dredges				Hydraulic Dredges					
	Clamshell	Backhoe	Enclosed Bucket	Bucket/ Pump	Cutterhead	Horizontal Auger	Pneumatic	Diver-Assisted Vacuum	Plain Suction	Dry Excavation
Sediment resuspension[1]	-	-	+	+	+	0	+	+	+	+
Volatiles control	-	-	+	+	+	+	+	+	+	-
Low clean-up targets	-	-	-	-	+	+	+	+	+	+
Spillage	-	-	+	+	+	+	+	+	+	+
Transport by pipeline	-	-	-	-	+	+	+	+	+	-
Transport by barge	+	+	+	-	-	-	-	-	-	+
High solids concentration	+	+	+	+	-	-	-	-	-	+
Vertical cut control	-	+	-	-	+	+	-	-	-	+
Lateral cut control	-	+	-	+	-	+	-	-	-	+
Positioning support required	0	0	0	0	+	+	0	0	0	+
Shallow water (<3 ft)	-	-	-	+	+	+	-	+	+	+
Deep water (>20 ft)	+	+	+	0	0	-	+	-	0	-
Current/tides[2]	+	+	+	-	-	-	-	-	-	0
Piers and utilities	+	+	+	-	-	-	-	+	+	+
Debris/boulders/rocks[3]	+	+	-	-	-	-	-	+	-	+
Vegetation removal[4]	+	+	+	+	-	-	-	-	-	+
Production rate	+	+	+	-	+	+	-	-	-	+
Hardpan (native clay/till)	+	+	-	-	+	-	-	-	-	+
Thin lift for removal	-	-	-	-	+	+	+	+	+	+
Availability	+	+	+	+	+	+	+	+	+	+
Portability	-	-	-	+	+	+	-	+	-	0
Positioning control	-	+	+	+	-	+	-	+	-	+

	Mechanical Dredges				Hydraulic Dredges					
Dredging Issue/ Concern/ Constraint	**Clamshell**	**Backhoe**	**Enclosed Bucket**	**Bucket/ Pump**	**Cutterhead**	**Horizontal Auger**	**Pneumatic**	**Diver-Assisted Vacuum**	**Plain Suction**	**Dry Excavation**
Operator health & safety	▬	▬	▬	✚	✚	✚	✚	✚	✚	▬

Note:
✚ indicates a technology which may generally be favorable for addressing this issue or concern
▬ indicates a technology which may not be generally favorable for addressing this issue or concern
0 indicates a technology which may be neutral for addressing this issue or concern

[1] Conventional backhoes are normally used for dry excavation and can cause resuspension when used in wet environments. Special enclosed backhoes can be used if resuspension is a problem.
[2] Most mechanical dredges are able to maintain their position in currents and tides better than hydraulic dredges.
[3] In general mechanical dredges have advantages in removing debris and boulders, although they may have trouble closing because of these obstructions, resulting in leakage of water and sediment. Hydraulic dredges can pass moderate sized rocks and can suction around boulders.
[4] Many hydraulic dredges have problems removing vegetation without becoming clogged.

Digital positioning systems are available that enable dredge operators to follow a complex sediment contour (Van Oostrum 1992).

The horizontal position of the dredge should be continuously monitored during dredging. Satellite- or transmitter-based positioning systems, such as differential global positioning systems (DGPS) should be used to define the dredge position. In some cases, however, the accuracy of these systems is inadequate for precise dredging control. Where the accuracy of site characterization data or the high cost of disposal warrant very precise control, it is possible to use optical (laser) surveying instruments set up at one or more locations on shore. These techniques, in conjunction with on-vessel instruments and spuds (if water depths are less than about 50 feet) and anchoring systems may enable the dredge operator to more accurately target specific sediment deposits. The effectiveness of anchoring systems diminishes as water depth increases.

The positioning technology described above enhances the accuracy of dredging. However, project managers should not develop unrealistic expectations of dredging accuracy. Contaminated sediment may not be removed with surgical accuracy even with the most sophisticated equipment. Equipment may not be the only factor affecting the accuracy of the dredging operation. Site conditions (e.g., weather, currents), sediment conditions (e.g., bathymetry, physical characteristics), and the skill of the dredge operator are all important factors. In addition, the distribution of sediment contaminants may only be defined at a crude level and there could be a substantial margin for error. The level of accuracy required for environmental dredging should reflect the accuracy needed to attain the remedial action objectives.

6.4.5 Control of Dredging Losses and Residuals

In environments with significant water movement due to tides or currents, resuspended sediment may be transported away from a dredging site; therefore, limiting resuspension or increasing containment should be an important consideration. Another potential problem may be the volatilization of contaminants that reach the water's surface, either near the dredge site or in a holding facility (Chiarenzeli et al. 1998).

When evaluating short-term effects of dredging, it is important to compare impacts to baseline conditions including water quality impacts due to any natural sediment disruption that would continue to occur if the contaminated sediment was not dredged. All dredges resuspend some sediment during the dredging processes. Some contaminants in the dissolved form and some contaminants associated with resuspended particles will be released and transported away from the dredging site. Monitoring during dredging is critical to evaluate resuspension and its effects on water quality. Much can be done to limit sediment resuspension from conventional dredges without substantial impact upon the efficiency of the dredging operation. Precautions in operation and/or minor plant modifications can be made with only a small increase in cost, however, other factors such as maneuverability requirements, hydrodynamic conditions, and location of the disposal site may dictate the type of dredge that should be used. The strategy for the project manager should be to minimize the resuspension levels generated by any specific dredge type. If conventional dredges are unacceptable, a special purpose dredge may be required. These dredges generally resuspend less material than conventional dredges, but associated costs may be much greater. As in the case of conventional dredges, the selection of a special purpose dredge will likely be dictated by site specific conditions, economics, and availability (Palermo et al. 1998b). The EPA's Office of Research and Development and others are in the process of evaluating resuspension and its effects,

both in field and modeling studies. The results of this research should help project managers predict and control effects of resuspension during future cleanup actions.

During dredging volatile contaminants trapped in the sediment may be released to the water column and atmosphere in the vicinity of the dredge and/or at the CDF posing a potential risk to workers and the nearby community. This exposure route may be minimized by reducing dredging production rates so that resuspension is minimalized. Covering the surface of the water with a physical barrier or an absorbent compound may minimize volatilization. At the New Bedford Harbor site, a cutterhead dredge was modified by placing a cover over the dredgehead that retained PCB-laden oils, thus reducing the air concentrations during dredging to background levels (Bergen in preparation). In addition, the CDF that the dredged sediment was pumped into was fitted with a plastic cover to effectively reduce air emissions. To further minimize the potential for volatile releases, dredging operations were conducted during cooler weather periods, such as at night.

During excavation, volatilization could be of greater concern as contaminated materials may be exposed to air. Care should be taken in dewatering activities to ensure that temperatures are not elevated (e.g., cautious application of lime or cement for de-watering), and other control measure should be taken as needed (e.g., foam).

The potential for residual contamination left behind by the dredging operation is dependent on a number of factors including the design and operating mode of the dredgehead, the size of the dredge (e.g. cutterhead diameter), operating parameters (e.g. swing speed, advance rate of the dredge, cutter rotation, and depth of burial of the dredgehead), skill of the operator, sediment physical properties, thickness of the layer to be removed, and site hydrodynamics such as currents and waves. Additional passes of the dredge may be required to achieve the desired results. Placement of a thin layer of clean material designed to mix with underlying sediment is another approach to address the problem of residual sediment. Project managers should conduct a site-specific assessment of anticipated sediment resuspension, contaminant release and transport, and its potential ecological impacts prior to dredging. Also, the project manager should make realistic assumptions regarding residual contamination. Where over dredging is not possible, residual contamination is generally higher than where this practice is possible.

6.4.6 Containment Barriers

Transport of resuspended contaminated sediment released during dredging can often be reduced by using physical barriers around the dredging operation. Barriers commonly used to reduce the spread of contaminants during the removal process include oil booms, silt curtains, silt screens, sheet-pile walls, and cofferdams (U.S. EPA 1994b). Under favorable site conditions these barriers help limit the areal extent of particle bound contaminant migration resulting from dredging resuspension and enhance the long-term benefits gained by the removal process. Conversely, because the barriers contain resuspended sediment they typically increase contaminant concentrations inside the barrier where it may need to be managed.

Structural barriers, such as sheet pile walls, have been used for sediment excavation and in some cases (e.g., high current velocities) for dredging projects. The determination of whether these types of barriers are necessary should be made based on a thorough evaluation of the site. This can be accomplished by evaluating the relative risks posed by the anticipated release of contaminants from the dredging operation absent use of such structural barriers, the predicted extent and duration of such

releases, and the potential for trapping and accumulating residual contaminated sediment within the barrier. The project manager should consult the *Risk Assessment and Modeling Overview Document* (U.S. EPA 1993d) and *Estimating Contaminant Losses from Components of Remediation Alternatives for Contaminated Sediment* (U.S. EPA 1996f) for further information about evaluating the need for structural barriers.

Oil booms are appropriate for sediment that may likely release oils or floatables when disturbed. Such booms typically consist of a series of synthetic foam floats encased in fabric and connected with a cable or chains. Oil booms may be supplemented with oil absorbent materials, such as polypropylene mats (U.S. EPA 1994b). However, booms do not aid in retaining the soluble portion of floatables [e.g., polynuclear aromatic hydrocarbons (PAHs) from oils].

Silt curtains and silt screens are flexible barriers that hang down from the water surface. Both systems use a series of floats on the surface and a ballast chain or anchors along the bottom. Although the terms "silt curtain" and "silt screen" may frequently be used interchangeably there are fundamental differences. Silt curtains are made of impervious materials, such as coated nylon, and primarily redirect flow around the dredging area rather than blocking the entire water column. In contrast, silt screens are made from synthetic geotextile fabrics, which allow water to flow through, but retain a large fraction of the suspended solids (Averett et al. 1990). Silt curtains or silt screens may be appropriate when contaminant concentrations are high or site conditions dictate the need for minimal transport of susupended sediment. A typical configuration of silt curtains or screens is shown in Highlight 6-8.

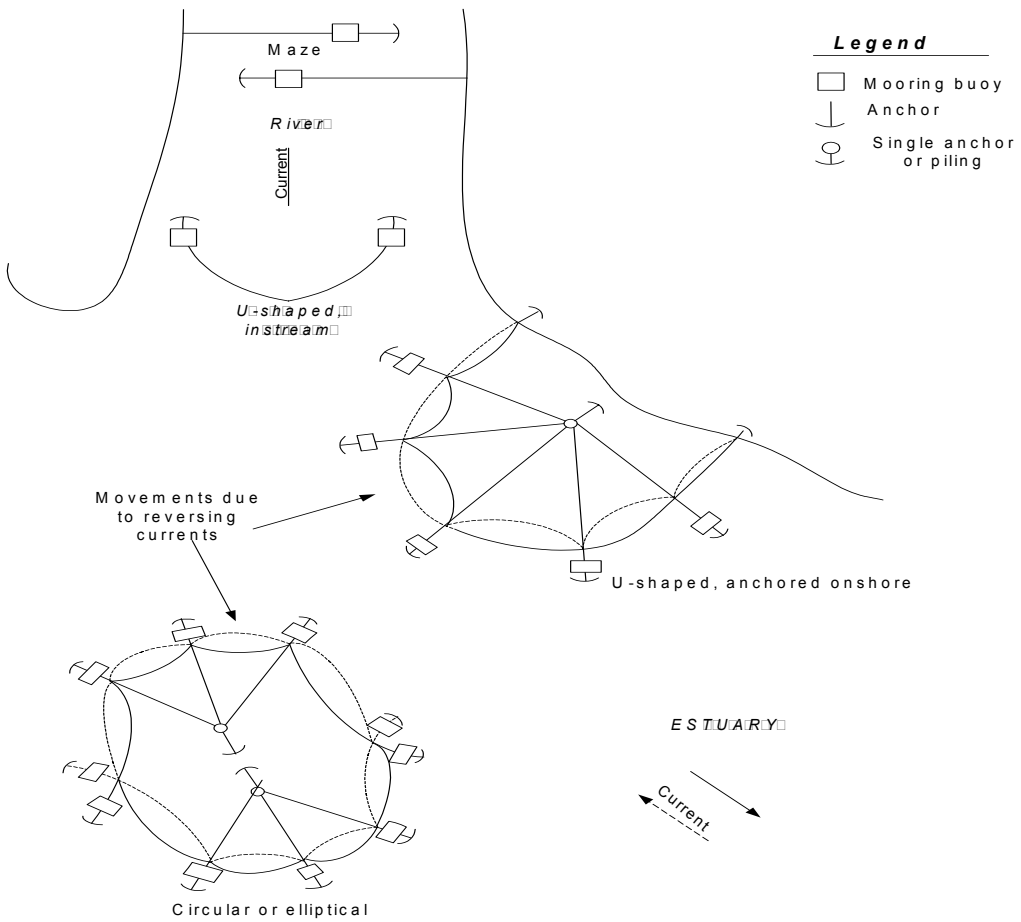
Silt curtains have been used at many locations with varying degrees of success. For example, silt curtains were found to be effective in limiting suspended solids transport during in-water dike construction of the CDF for the New Bedford Harbor pilot project. However, the same silt curtains were ineffective in limiting contaminant migration during dredging operations at the same site primarily as a result of tidal fluctuation and wind (Averett et al. 1990). Problems were experienced during installation of silt curtains at the General Motors site (Massena, New York) due to high current velocities and back eddies. Dye tests conducted after installation revealed significant leakage and the silt curtains were removed. Sheet piling was then installed around the area to be dredged with silt curtains used as supplemental containment for hot spot areas. A silt curtain/silt screen containment system was effectively applied during dredging of the Sheboygan River in 1990 and 1991, where water depths were two meters or less. A silt curtain was found to reduce suspended solids from approximately 400 milligrams per liter (inside) to 5 milligrams per liter (outside) during rock fill and dredging activities in Halifax Harbor, Canada (MacKnight 1992).

The effectiveness of silt curtains and screens at a sediment remediation site is primarily determined by the hydrodynamic conditions at the site. Conditions that may reduce the effectiveness of barriers include the following:

- Strong currents;
- High winds;
- Changing water levels, such as tidal fluctuation;

- Excessive wave height, including ship wakes; and
- Drifting ice and debris.

Highlight 6-8: Typical Configuration of Silt Curtains and Screens



Source: U.S. EPA 1998d

Silt curtains and screens are generally most effective in relatively shallow, undisturbed water. As water depth increases and turbulence caused by currents and waves increases, it becomes difficult to effectively isolate the dredging operation from the ambient water. The St. Lawrence Centre (1993) advises against the use of silt curtains in water deeper than 6.5 meters or in currents greater than 50 centimeters per second.

The effectiveness of containment barriers is also influenced by the quantity and type of suspended solids, the mooring method, and the characteristics of the barrier (JBF Scientific Corp. 1978). To be effective, barriers are deployed around the dredging operation and should remain in place until the

operation is completed at that site. For large projects it may be necessary to relocate the barriers as the dredge moves to new areas. Where possible barriers should not impede navigation traffic. Containment barriers may also be used to protect specific areas, for example valuable habitat, water intakes, or recreational areas, from suspended sediment contamination.

6.5 TRANSPORTATION AND STORAGE

After removal, sediment is transported to a disposal, storage, or re-handling area for further processing or final disposal. Transport links all dredging or excavation components and may involve several different technologies or modes of transport. The first element in the transport process is to move sediment from the removal site to the disposal, storage, or re-handling site. Sediment may then be transported for pretreatment, treatment, and/or ultimate disposal (U.S. EPA 1994b).

Modes of transportation may include one or more of the following waterborne or overland technologies:

- *Pipeline:* Direct placement of material into disposal sites by pipeline is economical only when the disposal and/or treatment site is located near the dredging areas (typically a few kilometers or less unless booster pumps are used). Mechanically dredged material may also be re-slurried from barges and pumped into nearshore disposal sites by pipeline;

- *Barge:* A re-handling facility located on shore is a commonly considered option. With a re-handling facility, dredging can be accomplished with mechanical (bucket) dredges where the sediment is excavated at near in-situ density (water content) and placed in a scow or barge for transport to the re-handling facility;

- *Conveyor:* Conveyors may be used to move material from barges to adjacent re-handling facilities or to move material relatively short distances. Materials should be in a dewatered condition for transport by conveyor;

- *Railcar:* Rail spurs may be constructed to link re-handling/treatment facilities to the rail network. Many licensed landfills have rail links, so long-distance transport by rail is generally an option; and/or

- *Truck/Trailer:* Dredged material can be re-handled directly from the barges to roll-off containers or dump trucks for transport to a CDF by direct dumping or unloading into a chute or conveyor. Truck transport of treated material to landfills may also be considered. The material should be dewatered prior to truck transport over surface streets. In some smaller sites where construction of dewatering beds may be difficult or the cost of disposal is not great, addition of non-toxic absorbent materials such as lime or cement may be feasible.

A wide variety of transportation methods are available for moving sediment and residual wastes with unique physical and chemical attributes. In many cases, contaminated sediment is initially moved using waterborne transportation. Exceptions are the use of land-based or dry excavation methods. Hydraulic dredges produce contaminated dredged-material slurries that can be transported by pipeline to either a disposal or re-handling site. Mechanical removal methods typically produce dense, contaminated

material that is hauled by barge, railcar, truck/trailer, or conveyor systems. The feasibility and costs of transportation are frequently influenced by the scale of the remediation project. Key resources for information on transport methods are listed in Appendix D.

Storage of contaminated sediment may also be necessary to dewater prior to upland disposal or to allow for pretreatment and equalization prior to treatment. For example, a temporary CDF may be designed to store material for periods when dredging or excavation is not possible due to weather or environmental concerns, while the treatment process may continue on a near 24-hour operating schedule. Storage may be temporary (e.g., pumping onto a barge with frequent off-loading) or more permanent (e.g., moving the sediment to a land-based CDF where it may be de-watered and treated).

The project manager should consider potential contaminant losses to the water column and atmosphere during transportation to the treatment or disposal site, and temporary storage, if applicable. The risks of potential exposures during transport, through volatilization, water loss, or accidental spills during movement should also be evaluated.

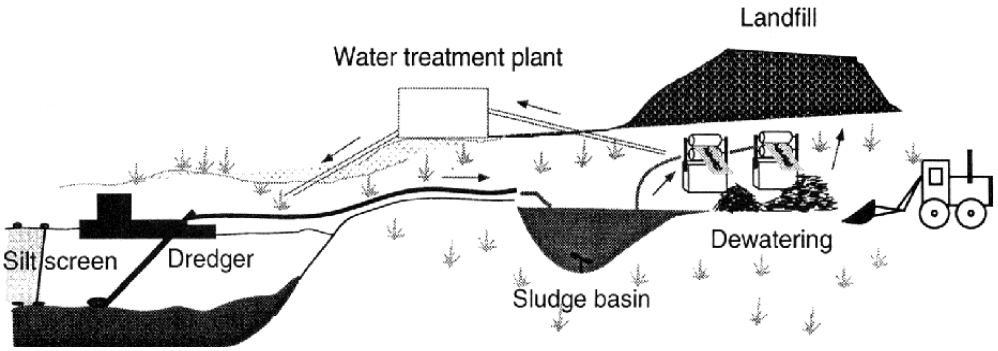
The risks associated with a temporary storage site are similar to those associated with CDFs, as discussed in section 6.7. In particular, in-water temporary CDFs can prove to be attractive nuisances, especially to waterfowl, by providing attractive habitat that encourages use of the CDF by wildlife and present the opportunity for exposure to contaminants. For highly contaminated sites, it may be necessary to provide a temporary cover or sequence dredging to allow for coverage of highly contaminated sediment with cleaner sediment to minimize short-term exposures. This method of control has proven effective for minimizing exposures at upland sanitary landfills. In addition, because some holding areas may not be designed for long-term storage of contaminated sediment, the risk of contaminant transport to ground water should be evaluated and monitored.

6.6 TREATMENT

The treatment of contaminated sediment is not usually a single process, but often involves a combination of processes to address various contaminant problems, including pre-treatment, operational treatment and/or effluent treatment/residual handling.

Some form of pre-treatment and effluent treatment/residual handling are necessary at almost all sediment removal projects. A typical dewatering process is shown in Highlight 6-9. Sediment treatment processes of a wide variety of types have been applied in pilot-scale demonstrations, and some have been applied full-scale. However, the relatively high cost of most treatment alternatives, especially those involving thermal and chemical destruction techniques, can be a major constraint on their use at the present time (NRC 1997). The base of experience for treatment of contaminated sediment is still limited, as discussed in more detail later in this chapter. Each component of a potential treatment train is discussed below.

Highlight 6-9: Example of Dredging Dewatering Process



6.6.1 Pre-Treatment

Pre-treatment modifies the dredged or excavated material in preparation for final treatment or disposal. When pre-treatment is part of a treatment train, distinguishing between the two components may be difficult and is not always necessary. Pre-treatment is generally performed to condition the material to meet the chemical and physical requirements for treatment or disposal; and/or to reduce the volume and/or weight of sediment that requires transport, treatment, or restricted disposal. Pre-treatment processes typically include dewatering and physical or size separation technologies.

Most treatment technologies require that the sediment be relatively homogeneous and that physical characteristics be within a relatively narrow range. Pre-treatment technologies may be used to modify the physical characteristics of the sediment to meet these requirements. Additionally, some pretreatment technologies may divide sediment into separate fractions, such as organic matter, sand, silt, and clay. Often the sand fractions contain lower contaminant levels and may be suitable for unrestricted disposal and/or beneficial use if it meets applicable standards and regulations. Selection factors, costs, pilot-scale demonstrations, and applicability of specific pre-treatment technologies are discussed in detail in EPA (1994b).

6.6.2 Operational Treatment

Depending on the contaminant concentration and composition of the sediment, it may be advisable or necessary to treat the sediment to reduce the toxicity, mobility, or volume of the contaminants before disposal or final placement. In general, treatment processes have the ability to reduce sediment contaminant concentrations, mobility, and/or sediment toxicity by contaminant destruction or detoxification, extraction of contaminants from sediment, reduction of sediment volume or sediment solidification/stabilization.

Treatment technologies for sediment are generally classified as biological, chemical, extraction or washing, immobilization (solidification/stabilization), and thermal (destruction or desorption). In some cases, particle size separation is also considered a treatment technology. Pilot and full-scale treatment processes have been conducted at a variety of sites, although there is limited experience at Superfund

sites. Some of these sites are listed in Highlight 6-10. Additional information concerning treatment technologies for contaminated sediment may be found in U.S. EPA Office of Water's *Selecting Remediation Technologies for Contaminated Sediment* (U.S. EPA 1993e) and other references listed in Appendix D.

Bioremediation

Bioremediation is the process in which microbiological processes are used to degrade or transform contaminants to less toxic or nontoxic forms. Bioremediation technologies harness this process by promoting the enzymatic production and microbial growth necessary to convert the target contaminant to non-toxic end products. Biological treatment has been used for decades to treat domestic and industrial waste waters. In recent years, it has been demonstrated as a technology for destroying some organic compounds in sediment.

Microbial degradation of many persistent contaminants in the environment, such as PCBs and PAHs, may be influenced by the compound's toxicity to microbial organisms; microbial feeding strategies, genetic ability to use the contaminant as a source of carbon and energy and the ability of microbes to propagate under site-specific environmental conditions.

Bioremediation often attempts to alter the environmental conditions in the dredged or excavated material to stimulate the development of an appropriate microbial population. Such changes may include adjusting concentrations of nutrients or compounds, pH, oxygen concentration, temperature, or microbial population. The project manager should refer to EPA (1994b), Myers and Bowman (1999), and Myers and Williford (2000) for a summarization of bioremediation technologies and their application under site-specific conditions.

Chemical Treatment

Chemical treatment refers to processes in which chemical reagents are added to the dredged or excavated material for the purpose of contaminant destruction. Contaminants may be destroyed completely, or may be altered to a less toxic form. Averett et al. (1990) reviewed several general categories of chemical treatment. Of the categories reviewed, the following treatments were considered most promising:

- *Chelation:* Formation of a stable complex between a metal cation and a ligand (chelating agent), binding of the metal cation in this stable complex renders it unavailable for further reaction, efficiency varies with the chelating agent and dosage used (U.S. EPA 1994b);

- *Dechlorination:* Removes chlorine molecules from contaminants (e.g., PCBs and dioxins) through the addition of chemical agents under alkaline conditions and increased temperatures (U.S. EPA 1990b, and U.S. EPA 1990c). The process releases steam and volatile organic vapors and the vapors are further treated using activated carbon. The resulting products are generally less toxic than the original contaminants; and

Highlight 6-10: Sediment Treatment Examples

Country/Location	Project Type	Contaminants	Process Options	Scale	Reference
BIOLOGICAL					
USA/WI Sheboygan River	Remedial (Superfund)	PCBs	Contained land (sheet pile structure)	Pilot	Foster 1991
Canada/ON Hamilton Harbor	Remedial CSTTP	PAHs	Contained land	Pilot	Wardlaw 1993 (personnel communication)
Canada/ON Toronto Harbor	Remedial CSTTP	PAHs	Bioslurry	Pilot	U.S. EPA 1993f
Netherlands Zeeland	Navigation DPTP	PAHs	Land farming	Pilot	Van Dillen and Bruggeman 1992
Milwaukee Harbor	Navigation	PAHs	CDF Management/ Land farming	Pilot	Myers and Bowman 1999
CHEMICAL					
Canada/ON Hamilton Harbor	Remedial CSTTP	PAHs	Reduction (thermal w/hydrogen)	Pilot	ELI Eco Logic 1992
Netherlands Elburg	Navigation DPTP	PAHs	Wet oxidation	Pilot	Van den Eede 1994
EXTRACTION					
USA/IN Gr. Calumet	Remedial ARCS/SITE	PCBs, PAHs	Triethyl amine solvent	Pilot	U.S. EPA 1994d
USA/MA New Bedford	Remedial SITE	PCBs	Supercritical propane	Pilot	U.S. EPA 1990a
NY/NJ Harbor	Navigation	Dioxins, PCBs, PAHs	Organic solvent	Pilot	Stern et al. 1994 Jones et al. 1999
Canada/ON Toronto Harbor	Remedial CSTTP	Metals	Acid extraction Chelation	Pilot	U.S. EPA 1993f
IMMOBILIZATION					
USA/NY Marathon Battery	Remedial Superfund	Metals Cd, Ni	Stabilization	Full	Simmons 1993 (personnel communication)
Belgium Vilvoorde		Metals	Solidification	Full	
USA/NY/NJ Harbor	Navigation	Metals, organics	Stabilization	Full	Stern et al. 1994 Jones et al. 1999
USA/NY Buffalo River	Remedial ARCS	Metals	Solidification (post-thermal desorption)	Pilot	U.S. EPA 1993g

Country/Location	Project Type	Contaminants	Process Options	Scale	Reference
			THERMAL		
USA/LA Bayou Bonfouca	Remedial Superfund	Creosote PAHs	Incineration	Full	Sensebe 1994 (personal communication)
USA/IL Waukegan	Remedial Superfund	PCBs	Thermal desorption	Full	Hutton and Shanks 1992
USA/OH Ashtabula	Remedial ARCS	PCBs	Thermal desorption	Pilot	U.S. EPA 1993g
USA/NY Buffalo River	Remedial ARCS	PAHs	Thermal desorption	Pilot	U.S. EPA 1993f
Netherlands Elburg	Remedial	Metals	Sintering	Pilot	Van den Eede 1994
USA/NY/NJ Harbor	Navigation	Dioxins, Metals, PCBs, PAHs	Vitrification	Pilot	Jones et al. 1999
USA/NY/NJ Harbor	Navigation	Dioxins, Metals, PCBs, PAHs	Rotary Kiln--Blended Cement Production	Pilot	Jones et al. 1999
			PARTICLE SEPARATION		
USA/MI Saginaw River	Remedial ARCS	PCBs Metals	Screens, Hydro cyclones	Pilot	U.S. EPA 1994d
Canada/ON Toronto	Remedial CSTTP	Metals PAHs	Attrition scrubbers Hydro cyclones	Pilot	U.S. EPA 1993f
Germany Hamburg	Navigation	Metals PAHs, PCBs	Screens, Hydro cyclones, Belt filter	Full	Detzner 1993
Canada/ON Welland	Remediation CSTTP	Metals	Screens, Screw class, Centrifuge	Pilot	Acres International 1993
Netherlands Rotterdam	Remediation	Metals PAHs	Hydro cyclones Settling basins	Pilot	Deibel and Zwakhals 1993

- *Oxidation (of organic compounds):* Involves the use of chemical additives to transform and degrade organic contaminants. Oxidation may be commonly used to treat amines, phenols, chlorophenols, cyanides, halogenated aliphatic compounds, mercaptans, and certain pesticides in liquid waste streams (U.S. EPA 1991c). It may also be used on soil and sediment slurries and sludge (U.S. EPA 1994b).

Specific applications, limitations, specifications, and efficiencies of these processes are discussed more fully in the ARCS Program's *Remediation Guidance Document* (1994b).

Extraction/Washing

The primary application of extraction processes is to remove organic, and in some cases, metal contaminants from the sediment particles. Sediment washing is another term used to describe extraction processes, primarily when water may be a component of the solvent. In the extraction process dredged or excavated material is slurried with a chemical solvent and cycled through a separator unit. The separator divides the slurry into the three fractions: 1) particulate solids; 2) water; and 3) concentrated organic contaminants. The concentrated organics are removed from the separator for post-process treatment. Often the cycle is repeated several times before the treated solids are removed from the process. By separating the contaminants from the solids and water matrix, the extraction process can result in volume reductions of 20-fold or more (U.S. EPA 1994b).

Pre-treatment is often necessary before solvent extraction in order to reduce oversized debris present in the dredged or excavated material. The maximum particle size depends on the scale and configuration of the extraction process, size is process specific and depends on size of equipment. Implementability for most of these processes may be difficult because of limited full-scale development for handling sediment and the problems of solvent recovery and potential toxicity of residual solvents.

Immobilization

Immobilization, commonly referred to as solidification/stabilization, alters the physical and/or chemical characteristics of the sediment through the addition of binders, including cements and pozzolans (U.S. EPA 1994b). Immobilization technologies primarily work by changing the engineering properties of the sediment so that contaminants are less prone to leaching. Alteration of the physical character of the sediment to form a solid material, such as a cement matrix, reduces the accessibility of the contaminants to water and entraps the contaminated solids in a stable matrix (Myers and Zappi 1989). The presence of free water in the original dredged or excavated material may be a large contributor to the initial leachate volume at a disposal site. By binding the free water into a hydrated solid, solidification reduces contaminant losses through leaching (U.S. EPA 1994b).

Solidification with cement has been demonstrated for use on a large scale (greater than 1 million cubic yards) for New York/New Jersey Harbor dredged material (Myers and Adrian 2000). The material was used to cap a Brownfields site and a landfill that was subsequently used for a shopping mall. Chemical characteristics of the solidified sediment should be compatible with the environmental requirements of the reuse project (e.g., cement stabilized sediment may have elevated pH).

Another form of immobilization, chemical stabilization, minimizes the solubility of metals primarily through the control of pH and alkalinity. In some cases, chemical stabilization technologies can

decrease the solubility of some metals, but increase the mobility of other metals (Myers and Zappi 1989). Anions, which may be more difficult to bind in insoluble compounds, may be immobilized by entrapment or micro-encapsulation. Chemical stabilization of organic compounds may be possible, but the mechanisms involved are not well understood (Myers and Zappi 1989).

The potential for implementation of immobilization processes is better than other treatment processes because they are not as sensitive to process-control conditions. Stabilization processes have recently been used for contaminated New York Harbor sediment and at the Marathon Battery project. However, bench scale studies are recommended to ensure a successful project. For example, although solidification with lime is a simple process, the ensuing exothermic reaction can drive off volatiles, and/or create steam or dust problems.

Thermal Treatment

Thermal technologies include incineration, pyrolysis, thermal desorption, sintering, and other processes that require heating the sediment to hundreds or thousands of degrees above ambient temperatures. Thermal destruction processes, such as incineration, are effective for destroying organic contaminants, but are also expensive and have significant energy costs. Thermal treatment does not destroy toxic metals. There are chemical processes that destroy organic contaminants, such as reductive dechlorination, but these process are also expensive (and may have significant energy costs).

Thermal desorption processes heat sediment to temperatures of 90°C to 540°C to physically separate volatile and semivolatile organic compounds from sediment. Water, organic compounds, and volatile metals are vaporized by the heating process and subsequently condensed and collected as a liquid, captured on activated carbon, or destroyed in an afterburner. Heating is accomplished using indirectly fired rotary kilns, heated screw conveyors, externally heated distillation chambers, or fluidized beds (U.S. EPA 1991d). The resulting volume of volatilized contaminants should be collected for subsequent treatment.

The Superfund Innovative Technology Evaluation (SITE) program and New York Harbor, and Francingues and Thompson (2000) are evaluating two thermal treatment processes to remove enough contamination from the sediment for beneficial use purposes, such as aggregate. A specific SITE example is the Sediment Melter Technology Pilot-Scale study, which treated 70 tons of PCB-contaminated sediment from the Fox River, produce a glass aggregate material suitable as a foundation material.

Particle Size Separation

Particle size separation involves separation of the fine material from the coarse material by physical screening. A site demonstration of the Bergman USA (U.S. EPA 1994d) process resulted in the successful separation of less than 45 micron fines from washed coarse material and a humic fraction. As noted in the preceding paragraphs, particle size separation may serve as a pretreatment step prior to implementation of a treatment alternative. Many treatment processes require particle sizes of 1 cm or less for optimal operation.

Effluent Treatment/Residue Handling

Treatment of process effluents (liquid/gas/solid) is a major consideration during selection, design, and implementation of dredging or excavation. As shown in Highlight 6-1, dredging or excavation may require management of several types of residual wastes from the pretreatment and operational treatment processes that include liquid and/or air/gas effluents from dewatering or other pretreatment/treatment processes, residual solids and runoff/discharges from active CDFs.

These wastes can be handled through the use of conventional technologies for water, air, and solids treatment and disposal. However, the technical, cost, and regulatory requirements can be important considerations during the evaluation of dredging or excavation as a cleanup method. The project manager should refer to EPA (1994b) for a discussion of the implications and selection criteria for residual management.

Information Resources for Treatment Technologies

The list of potential sediment treatment technologies may continue to change as new technologies are developed and other technologies are improved. EPA has recognized the need for an up-to-date list of treatment alternatives and has developed the following databases:

- *EPA Remediation and Characterization Innovative Technologies (EPA REACH IT):* Provides information on more than 750 service providers that offer almost 1,300 remediation technologies and more than 150 characterization technologies (includes a variety of media, not just sediment). More information is available at http://www.epareachit.org/index3.html; and

- *Risk Reduction Engineering Laboratory (RREL) Treatability Database:* Provides results of published treatability studies that have passed the EPA quality assurance reviews, it is not specific to sediment, and is available from the EPA's Risk Reduction Engineering Laboratory, Cincinnati, Ohio, 45268 and at http://www.epa.gov/ncepihom/Catalog/EPA600C93003A.html.

The NY/NJ Harbor Project is an example of a large-scale demonstration of dredged decontamination technologies. Each of the technologies presented in Highlight 6-11 has demonstrated destruction, removal, or immobilization of organic chemicals and metal contaminants and production of uncontaminated material that could be used in one or more commercial products such as manufactured cement, glass and ceramic tiles, facade bricks, and topsoil (Stern et al. 2000, Mulligan et al. 2001).

Highlight 6-11: NY/NJ Harbor - Treatment Technologies and Beneficial Use

The goal of the NY/NJ Harbor Sediment Decontamination Project is to assemble a complete decontamination system for cost effective transformation of dredged material into an environmentally safe material used in the manufacturing of a variety of beneficial use products.

The following four treatment technologies are being used at the NY/NJ site: 1) sediment washing; 2) thermal treatment; 3) solidification; and 4) vitrification. Each technology has a sponsor from the private sector that will provide the capital needed for facility construction and operation.

Sediment washing (extraction) uses high-pressure water jets and proprietary chemical additives to extract both organic and inorganic contaminants from the sediment. The resulting materials can be used to produce manufactured soil for commercial, and in some cases, residential landscaping applications. The advantages to this treatment are modest capital costs and high throughput. A limitation to this treatment is that to be cost effective, the original sediment has to contain a significant amount of sand.

A thermal treatment being used is a thermo-chemical manufacturing process that, at high temperatures, will destroy organic contaminants. The process will melt a mixture of sediment and modifiers, and the resulting product is a manufactured grade cement comparable to Portland Cement. This is a very effective treatment, but expensive.

A third process is a "treatment train" that includes dewatering, pelletizing, and transport to an existing light-weight aggregate facility. Pelletizing is a type of solidification treatment. After the sediment is dewatered, it is mixed with shale fines and extruded into pellets. The pellets are fed into a rotary kiln, and the organic matter explodes. The resulting material can be used as a structural component in concrete, insulation (pipeline) and for other geotechnical uses.

Finally, the process includes a high temperature vitrification, which uses an electrical current to heat (melt) and vitrify the soil in place. This process can destroy organic contaminants and incorporate metals into a glassy matrix which can be used to produce an architectural tile.

Source: Stern et al. 2000, Mulligan et al. 2001, Stern 2001, NRC 1997

6.7 DISPOSAL

Disposal refers to the placement of dredged or excavated material and process wastes into a temporary or permanent structure, site, or facility. The goal of disposal is to prevent contaminants associated with sediment and/or residual wastes from reentering the environment and impacting human health and the environment. Disposal is a major component of any dredging or excavation alternative. The identification of disposal sites may often be the most controversial component of planning, design, and implementation.

Contaminated sediment is typically managed in upland sanitary landfills, hazardous or chemical waste landfills, CDFs, or CADs. Also, the material may have a beneficial use in an environment other that the aquatic ecosystem from which it was removed (e.g., foundation material beneath a newly constructed Brownfields site), especially if the sediment has undergone treatment.

Highlight 6-12 provides summary descriptions and extent of use for each of these technologies. Additionally, the EPA (1994b) provides a discussion of the available technologies, including an in-depth discussion of costs, design considerations, and selection factors associated with each technology. Averett et al. (1990), EPA (1991b), and Palermo and Averett (2000) provide additional discussion of disposal options and considerations.

Highlight 6-12: Summary of Disposal Technologies

Technology	Description	Use
Sanitary Landfill	Dewatered material disposed of in a properly licensed landfill.	Commonly used for disposal of dredged material and pretreatment/treatment process residuals.
Hazardous/Chemical Waste Landfill	Highly contaminated, dewatered material disposed of in a landfill specially licensed to accept hazardous and chemical wastes.	Commonly used for disposal of dredged material and pretreatment/treatment process residuals.
Confined Disposal Facilities	In-water or upland, diked facility specifically constructed for disposal of dredged material.	Routinely used for disposal of raw dredged material from navigational and remedial projects.
Level-Bottom Capping	Material placed on a flat bottom of a waterbody and covered with a layer of clean sediment.	Used for disposal of contaminated sediment from navigational dredging within Clean Water Act (CWA) 404 jurisdiction.
Contained Aquatic Disposal	Material placed into an excavated or natural depression or underwater diked area and covered with clean material or cap.	Used for disposal of contaminated sediment from navigational and environmental dredging within CWA 404 jurisdiction.
Beneficial Use	Lightly contaminated, raw or treated material used for construction, beach nourishment, or other beneficial uses.	Used infrequently in environmental dredging projects; may be appropriate for treated sediment.

6.7.1 Sanitary/Hazardous Waste Landfills

Existing commercial and municipal sanitary and hazardous waste landfills are one of the most widely used options for disposal of dredged or excavated material and pre-treatment/treatment residuals associated with environmental dredging and excavation. Landfills may also be constructed specifically for use in disposing of sediment from environmental dredging. Landfills can be categorized by the types of wastes they accept and the laws regulating their operation. Most solid waste landfills accept all types of waste (including hazardous substances) that are not regulated as Resource Conservation and Recovery Act (RCRA) hazardous waste or Toxic Substances Control Act (TSCA) toxic materials. Additionally, a limited number of RCRA-hazardous and TSCA-toxic landfills may be available for disposal of hazardous and toxic materials (U.S. EPA 1994b).

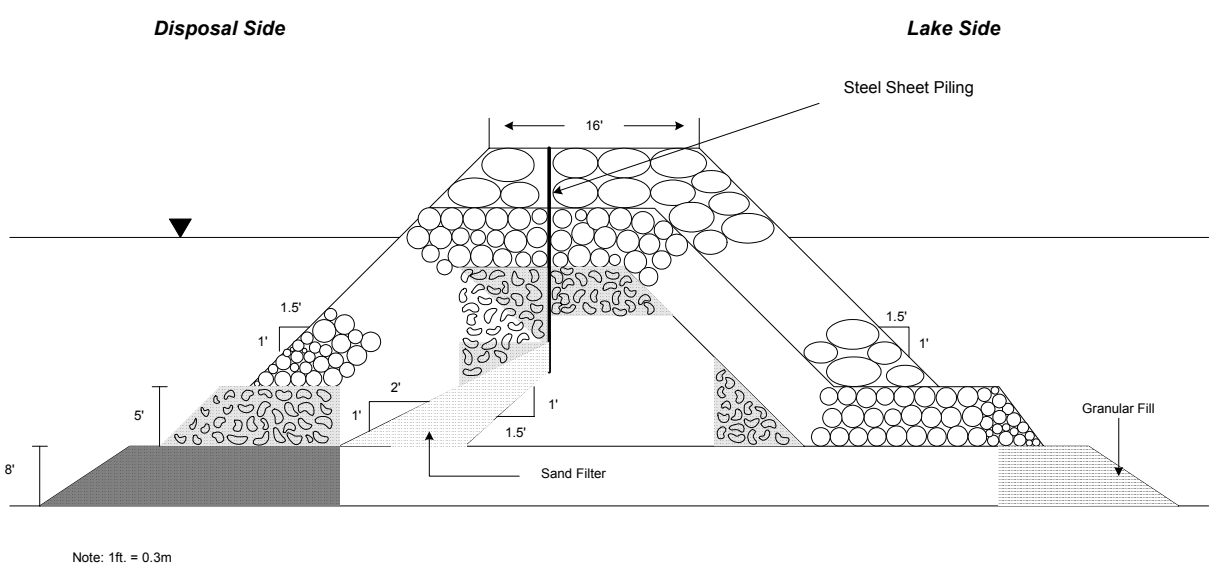
Due to the restriction on liquids in landfills, most dredged material should be de-watered and/or stabilized/solidified before disposal in a landfill. Temporary placement in a CDF or pretreatment using mechanical equipment may therefore be necessary (Palermo 1995).

6.7.2 Confined Disposal Facilities

CDFs are engineered structures enclosed by dikes and specifically designed to retain dredged solids and associated contaminants. Under normal operations, water is discharged over a weir structure or allowed to migrate through the dike walls while solids are retained within the CDF. Typically effluent guidelines or discharge permits govern the monitoring requirements of the return water. Details regarding the engineering design of CDFs to include sizing to retain solids are available in the U.S. Army Corps of Engineers (USACE) engineer manual, *Confined Disposal of Dredged Material* (USACE 1987).

A cross-sectional view of a typical nearshore CDF dike design is shown in Highlight 6-13. CDFs may be located either upland (above the water table), near-shore (partially in the water), or completely in the water (island CDFs). EPA (1996f), EPA (1994b), EPA (1991b), and Averett et al. (1990) contain thorough descriptions, technical considerations, and costs associated with CDFs. Additionally, Black and Veatch (in preparation) contains a history and evaluation of the design and performance of CDFs in the Great Lakes Basin, including a review and discussion of relevant contaminant loss and contaminant uptake studies.

Highlight 6-13: Cross Section of a Confined Disposal Facility Dike with a Filter Layer



Note: Adapted from US. EPA 1998d

6.7.3 Contained Aquatic Disposal

Contained aquatic disposal is a type of subaqueous capping in which the contaminated dredged material is placed into a natural or excavated depression. The depression provides lateral containment of the contaminated material, and also has the advantage of requiring less maintenance and being more resistant to erosion than level-bottom capping. The depression for the CAD cell may be excavated using conventional dredging equipment or natural or historically dredged depressions may be used. Uncontaminated material excavated from the depression may subsequently be used for the cap (U.S. EPA 1994b). The design of a CAD option for a sediment remedy should be approached in the same way as a CAD project design for dredged material disposal and cap designs for in-situ capping (U.S. EPA 1998d, Palermo et al. 1998a, and Palermo 1997). A major consideration is the selection of the appropriate methods for placement of the contaminated material and subsequent placement of the cap. Community acceptance and local land use laws are also important considerations in the siting and placement of CADs.

6.7.4 Losses From Disposal Facilities

Evaluation of a disposal facility for placement of contaminated sediments should include assessment of contaminant migration pathways and incorporation of management controls in the facility design as needed. Landfill disposal options may have short-term releases which include spillages during transport and volatilization to the atmosphere as the sediment is drying. As for any disposal option, longer-term releases depend in large part on the characteristics of the contaminants and the design and maintenance of the facility.

For CDFs, contaminants may be lost via effluent during filling operations, surface runoff due to precipitation, leachate through the bottom, seepage through the dike wall, volatilization to the air, and uptake by plants and animals. The USACE has developed a suite of testing protocols for evaluation of each of these pathways (U.S. EPA and USACE 1992), and these procedures are included in ARCS guidance for estimating contaminant release (U.S. EPA 1996f). The USACE is developing a comprehensive contaminant pathway testing and evaluation manual for CDFs (USACE in preparation). Depending on the likelihood of contaminants leaching from the confined sediment, a variety of dike and bottom linings and cap materials may be used to minimize contaminant loss (U.S. EPA 1991b, U.S. EPA 1994b, Palermo and Averett 2000). CDFs for sediment remediation projects are more likely to need control measures such as bottom or sidewall liners or low permeability dike cores than would CDFs constructed for navigation dredged material.

For CADs, contaminants maybe lost to the water column during placement of the contaminated sediment, and advection of pore water during the initial consolidation of the sediment following placement and capping. Volatilization may also occur at both CDFs and CAD sites during placement. Whatever disposal options are evaluated, the effects of contaminant losses during construction and in the long term should be considered.

6.7.5 Beneficial Use

Beneficial use of dredged or excavated sediment has been implemented infrequently to date as a dredge material management option in association with environmental cleanup. Although not normally considered a disposal option, in special situations, beneficial use may be an appropriate management option for lightly contaminated or treated sediment resulting from environmental dredging projects.

Significant cost saving may be realized if physical and chemical properties of the sediment allow for beneficial use. In each case, the contaminant levels and environmental exposure, including considerations of future land use, should be assessed. For example, at Newburgh Lake, Michigan, significant cost savings were realized by using lightly contaminated dredged material as daily cover at a local sanitary landfill, where the presence of the dredged material did not pose risk within the landfill boundary. Options for beneficial use may include the following:

- Beach nourishment (for a clean sand fraction);
- Construction fill;
- Sanitary landfill cover as in the above example;
- Mined lands restoration (e.g., http://www.dep.state.pa.us/dep/DEPUTATE/MINRES/BAMR/bark_camp/barkhomepage.htm);
- Subgrade cap material (topped with clean sediment or other fill); or
- Building materials (e.g., architectural tile, see Highlight 6-11).

A series of technical notes on beneficial use of contaminated material is currently being developed by the USACE (Lee 2000). Use of contaminated materials from CDFs (to include treated material) is a major thrust of the USACE Dredging Operations and Environmental Research (DOER) program (http://www.wes.army.mil/el/dots/doer/).

In some cases, a CDF can be integrated with site reuse plans to both reduce environmental risk and simultaneously foster redevelopment in urban areas and Brownfield sites. For example, at the Sitcum Waterway cleanup project in Tacoma, Washington, contaminated sediment was placed in a near shore fill, which was then developed into a container storage area. Also, there may be innovative and environmentally protective ways to reuse dredged contaminated sediments in habitat restoration projects (e.g., placement of lightly contaminated material over highly contaminated materials to build up elevations necessary for final placement of clean emergent marshlands).

6.8 SITE CONSIDERATIONS

6.8.1 Physical Environment

Several aspects of the physical environment may make dredging more or less difficult to implement. In the remedial investigation, the following types of information should be collected, as they will affect the type of equipment selected and potentially the feasibility of dredging:

- Bathymetry, slope of the sediment surface and water depth;
- Currents and tides;
- Bottom conditions, especially the presence of debris and large rocks;

- Depth to and (un)evenness of bedrock or hard bottom (e.g., stiff glacial till);
- Sediment particle size distribution and degree of consolidation;
- Thickness of contaminated sediment;
- Distance between dredging and disposal locations;
- The presence of structures such as piers, pilings, cables, or pipes; and
- Land access to waterbody.

Additionally, sediment removal may change the hydrodynamics and slope stability of the remediation area. These changes need to be evaluated to insure that the removal activity does not cause instability or other adverse effects on the system.

6.8.2 Sediment Characteristics

Thorough horizontal and vertical characterization of both the physical sediment characteristics and the contaminants at the site is needed during the remedial investigation to evaluate the feasibility of dredging or excavation. The results of this characterization will help determine the area, depth, and volume to be removed, and the volume of sediment requiring treatment and/or disposal. Some aspects of sediment characterization are discussed in Chapter 2, Remedial Action Considerations.

There are several tests that may help provide the project manager with needed information for design of dredging, treatment, or disposal methods. The project manager should refer to Highlight 6-14 for a summary of the most commonly used tests. In addition, the time and cost needed to conduct engineering and environmental testing should be considered. Several guidance documents on estimating contaminant losses from dredging and disposal have been developed by the EPA and USACE. The project manager should refer to *Estimating Contaminant Losses from Components of Remediation Alternatives for Contaminated Sediments* (U.S. EPA 1996f), *Evaluation of Dredged Material Proposed for Discharge in Waters of the U.S. - Testing Manual (Inland Testing Manual)* (U.S. EPA and USACE 1998) and *Evaluation of Dredged Material Proposed for Disposal at Island, Nearshore or Upland Confined Disposal Facilities - Testing Manual* (USACE in preparation) for further information.

6.8.3 Waterway Uses and Infrastructures

Removal of contaminated sediment has the advantage of potentially imposing fewer limitations on waterway uses than capping or monitored natural recovery alternatives. However, any evaluation of the feasibility of a dredging or excavation project should consider impacts to existing and potential future

Highlight 6-14: Dredging/Disposal Feasibility Tests

Test	Description	Data Utilization	Reference
Atterberg Limits	Determines the percent moisture content that sediment changes from a solid to a semi-solid (shrinkage limit), a semi-solid to a plastic (plastic limit), and a plastic to a liquid (liquid limit).	Used in conjunction with other physical properties to determine the potential physical behavior of the sediment during remediation; for example, at moisture contents greater than the liquid limit, the sediment may behave and flow like a viscous liquid.	Spigolon 1993
Pancake Column Leach Test (PCLT)	Water is passed through a sample of the dredged material; after passing through the dredged material, the water is analyzed for contaminant concentrations.	Used with mass transport modeling to estimate the long-term water quality impact and contaminant flux in a confined disposal site.	Brannon et al. 1994
Dredged Material Slurry Settling Tests	Sediment slurry/coagulant mixtures are added to a settling column; height of the sediment/water interface is measured at specific time intervals over a period of time.	Performed to observe the settling behavior of sediment; aids in design of particle settling basins, confined disposal facilities, and sediment dewatering system.	USACE 1987
Effluent Elutriate Test	Aqueous extract is prepared from a sediment/water mixture that is mixed and allowed to settle; the extract is analyzed for its contaminant concentrations (Settling time = Estimated CDF water retention time).	Used to estimate the amount of contaminants that may be released during hydraulic filling of a confined disposal facility.	USACE WES 1998
Moisture Content	A measure of the amount of moisture in a soil sample, calculated as: (wet weight - dry weight)/(dry weight); commonly used in engineering and geological applications.	Used in conjunction with other physical properties when designing and sizing remediation components.	ASTM D2216
Particle Size Distribution	Particles are separated into various size classes, such as sand, silt, clay, by passing them through a series of fine-meshed sieves.	Determines the relative amounts of silts, sands, and clay materials in sediment; has a wide range of implications for pretreatment, treatment, etc.	Spigolon 1993
Specific Gravity	Measurement of the weight of a volume of sediment compared to the same volume of water.	Useful in determining how quickly sediment will sink in water; useful in design sediment dewatering and particle size separation systems.	U.S. EPA and USACE 1998
Standard Elutriate Test	An aqueous extract is prepared from a sediment/water mixture that is allowed to settle for one hour, centrifuged, and decanted; extract is analyzed for its contaminant concentrations.	Used to estimate the amount of contaminants that may be released during dredging and open water disposal.	U.S. EPA and USACE 1977

uses of a waterway. Waterway uses that should be considered when selecting a dredging with treatment or disposal alternative include the following:

- Navigation (commercial, military, recreational);
- Residential/commercial/military moorage;
- Flood control;
- Recreation;

- Fishing;
- Water supply, such as presence of intakes;
- Storm water or effluent discharge outfalls;
- Use by fish and wildlife, especially sensitive or important aquatic habitats;
- Waterfront development;
- Utility crossings;
- Existing disposal sites; and
- Anchorage areas.

Evaluation of the feasibility of a sediment removal project should include an analysis of whether impacts to these uses may be avoided or minimized both during construction and in the long term. For dredge or fill projects being considered within or adjacent to a navigation or flood control channel, the long- and short-term effects of the project on the functions of the channel should be considered. The acceptable draft of vessels allowed to navigate over a contained aquatic disposal should consider water level fluctuations (seasonal, tidal, and wave) and the potential effects of grounding on a cap. Because of the potential erosion caused by propeller wash, restrictions on propeller size and/or vessel draft may be necessary. Anchoring or bottom trawling should not be allowed at locations on or near the contained aquatic disposal site to avoid disturbance of a cap.

6.8.4 Habitat Alteration

The project manager should consider the potential impact of habitat loss or alteration in evaluating a dredging or excavation alternative. While a project may be designed to minimize habitat loss, or even enhance habitat, sediment removal and disposal does alter the environment. However, it is important to determine whether the loss of a contaminated habitat is a greater impact than the benefit of providing a new, modified but less contaminated habitat. For example, a sediment removal alternative may or may not be appropriate where extensive damage to an existing upland or wetland will occur. If the contaminated sediment in the wetland is bioavailable and may be impacting wildlife populations, the short-term disruption of the habitat may be warranted to limit ongoing long-term impacts to wildlife. In this instance, the contaminated habitat as an attractive nuisance may more than offset its positive functional values. On the other hand, if the wetland is functioning properly and is not acting as a contaminant source to the biota and the surrounding area, it may be appropriate to leave it intact rather than remove it. Deliberations as to whether to alter wetland and aquatic habitats should be a routine component in the remedial decision process, and each site offers its own unique considerations. Coordination with natural resource agencies will assist the project manager in determining if the dredging project may impact aquatic organisms or their habitat, and how to minimize these impacts.

Another consideration is avoidance of short-term ecological impacts during dredging. This may involve timing the project to avoid water quality impacts during migration and breeding periods of

sensitive species or designing the dredging project to minimize suspended sediment during dredging and disposal.

Habitat impacts are also important when evaluating disposal options. Near shore habitat is often the most sensitive and important habitat to aquatic organisms, and, in many cases, has already been adversely affected by human activity. Filling these areas should be considered only if no other options with less adverse effect on the aquatic environment are available. Examples of projects where filling of wetlands was deemed appropriate to achieve cleanup goals include the Bailey Waste site in Texas City, Texas, where the Record of Decision (ROD) called for filling in marsh areas to make a causeway for excavation equipment to access contaminants that extended from the shoreline out into the marsh. At the New Bedford Harbor, Massachusetts site, a dewatering facility may be constructed in a shoreline area which may also be available for port activities in the future. New Bedford decisions preserve an extensive salt marsh system on the opposite side of the estuary.

Highlight 6-15 presents some general points to remember from this chapter.

Highlight 6-15: Points to Remember When Considering Dredging and Excavation

- Source control generally should be implemented to prevent re-contamination
- A dredging or excavation alternative should include details concerning all phases of the project, including sediment removal, transport, and treatment or disposal options
- Transport and disposal options may be complex and controversial; start investigating options early and discuss them with stakeholders
- In predicting risk reduction effects of dredging or excavation of deeply buried contaminants, the project manager should remember that biota will only respond to removal of contaminants that are bioavailable
- Environmental dredging should be conducted to take advantage of new equipment and methods of operation which minimize resuspension
- Project managers should conduct a site-specific assessment of anticipated sediment resuspension, contaminant release and transport, and its potential ecological impacts prior to dredging
- Project managers should make realistic assumptions regarding residual contamination. Where over-dredging is not possible, residual contamination is generally higher than where this practice is possible
- Excavation (conducted in the dry) often leads to lower levels of residual contamination than dredging (conducted under water)
- The use of experienced operators and oversight personnel skilled in dredging or excavation technologies as well as other phases of the project is very important to an effective cleanup
- A dredging or excavation project should be monitored during implementation to assess resuspension and transport of contaminants, immediately after implementation to assess residuals, and after implementation to measure long-term recovery of biota and test for re-contamination

7.0 REMEDY SELECTION CONSIDERATIONS

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7.0 REMEDY SELECTION CONSIDERATIONS

> "No two sites are identical and therefore the risk-management strategy will vary from site to site...The strategy selected should be one that actually reduces overall risk, not merely transfers the risk to another site or another affected population. The decision process necessary to arrive at an optimal management strategy is complex and likely to involve numerous site-specific considerations."
>
> "Management decisions must be made, even when information is imperfect. There are uncertainties associated with every decision that need to be weighed, evaluated, and communicated to affected parties. Imperfect knowledge must not become an excuse for not making a decision."

In these two statements from the National Research Council's (NRC's) *A Risk Management Strategy for PCB-Contaminated Sediments* report (NRC 2001), the NRC identifies some of the key challenges faced by project managers of many sites at the remedy selection stage. The goal of the Superfund remedy selection process is to select remedies that are protective of human health and the environment, that maintain protection over time, and that minimize untreated waste (NCP §300.430(a)(1)). However, the best route to overall risk reduction depends on a large number of site-specific considerations, some of which may be subject to significant uncertainty. This guidance has attempted to address many of those considerations and uncertainties, in the context of the Superfund program's implementing regulation, the National Oil and Hazardous Substances Pollution Contingency Plan (NCP).

Each of the risk management principles in the U.S. Environmental Protection Agency's (EPA's) *Principles for Managing Contaminated Sediment Risks at Hazardous Waste Sites* [included in this guidance as Appendix A, (U.S. EPA 2002a)] is important to consider for achieving a successful sediment cleanup. Several of the principles apply more directly to the remedy selection stage, especially Principle 7: "Select site-specific, project-specific, and sediment-specific risk management approaches that will achieve risk-based goals." Any decision regarding the specific choice of a risk management strategy for contaminated sediment should be based on careful consideration of the advantages and disadvantages of available options and a balancing of tradeoffs among alternatives. This and other risk management principles which apply at the remedy selection stage are discussed further in section 7.5, Conclusions.

EPA's *Rules of Thumb for Superfund Remedy Selection* (U.S. EPA 1997d) is another helpful guidance for project managers to review when selecting remedies at sediment sites. The Rules of Thumb guidance describes key principles and expectations, interspersed with "best practices" based on program experience and policies. This guidance also discusses how remedy selection may also be applicable to the Resource Conservation and Recovery Act (RCRA) Corrective Action Program. For more information the project manager should see OSWER Directive 9200.0-25 *Coordination Between RCRA Corrective Action and Closure and CERCLA Site Activities* (U.S. EPA 1996g).

Documenting and communicating how and why remedy decisions are made are very important at sediment sites. For guidance on documenting remedy decisions under the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) project managers should refer to EPA's *A Guide*

to Preparing Superfund Proposed Plans, Records of Decision, and other Remedy Selection Documents, also referred to as the "ROD Guidance" (U.S. EPA 1999a).

7.1 NCP REMEDY SELECTION FRAMEWORK

In the NCP, EPA establishes a series of expectations (see Highlight 7-1) to reflect the principal requirements of CERCLA §121 and to help focus the remedial investigation/feasibility study (RI/FS) on appropriate cleanup options. EPA also developed nine criteria for evaluating remedial alternatives to ensure that all important considerations are factored into remedy selection decisions. Chapter 3, Feasibility Study Considerations, outlines the NCP's nine remedy selection criteria in section 3.2. These criteria are derived from the statutory requirements of Section 121, as well as technical and policy considerations that have proven to be important for selecting among remedial alternatives. The nine criteria analysis comprises two steps: 1) an evaluation of each alternative with respect to each criterion; and 2) a comparison among the alternatives to determine the relative performance of the alternatives and identify major trade-offs among them (i.e., relative advantages and disadvantages). Ultimately, the remedy selected must be protective of human health and the environment, attain (or waive) applicable or relevant and appropriate requirements (ARARs), be cost effective, utilize permanent solutions and alternative treatment technologies or resource recovery technologies to the maximum extent practicable, and satisfy a preference for treatment or provide an explanation as to why this preference was not met.

Cost effectiveness is determined by comparing an alternative's cost to its effectiveness as determined by the following: 1) its long-term effectiveness and permanence; 2) its ability to reduce toxicity, mobility, or volume of hazardous substances, pollutants or contaminants through treatment; and 3) its short-term effectiveness (U.S. EPA 1999a). A remedy is considered cost effective when its cost is proportional to its overall effectiveness as demonstrated though a comparison among alternatives. It is important to note that more than one alternative can be cost effective, and that the Superfund program does not mandate the selection of the most cost-effective alternative, or the least-costly alternative that is also cost effective. The evaluation of an alternative's cost effectiveness is concerned only with the reasonableness of the relationship between the effectiveness afforded by each alternative and its costs when compared to other available options.

Highlight 7-1 discusses how the six NCP remedy selection expectations (NCP §300.430(a)(1)(iii)) may be relevant for sites with contaminated sediments. Generally, the expectations are addressed by selecting the alternative that provides the best balance of trade-offs among the alternatives evaluated.

7.2 CONSIDERING CLEANUP METHODS

If the baseline risk assessment indicates that contaminated sediment threatens (or may threaten) human health or the environment, remedial alternatives should be developed to eliminate, reduce, or manage those threats. In considering the range of alternatives to develop during the FS, the project manager should explore the most promising or likely cleanup methods given site-specific characteristics or conditions. As discussed in Chapter 3, section 3.1, Developing Sediment Alternatives, due to the limited number of cleanup methods available for contaminated sediment, generally, project managers should evaluate each of the three major cleanup methods: monitored natural recovery (MNR), in-situ capping, and removal through dredging or excavation, at every sediment site at

Highlight 7-1: NCP Remedy Expectations and Their Application to Contaminated Sediment

The EPA expects to use treatment to address the principal threats posed by a site, wherever practicable:

- Contaminated sediment is frequently a source material and subject to this expectation regarding principal threat waste. See EPA (1991e) for definition of principal threat waste. In general, project managers should evaluate an alternative which includes treatment where toxicity and mobility combine to pose a potential human health risk of 10^{-3} or greater for carcinogens (U.S. EPA 1991e). However, the practicability of treatment, and whether a treatment alternative should be selected, should be evaluated against the NCP nine remedy selection criteria

The EPA expects to use engineering controls, such as containment, for waste that poses a relatively low long-term threat or where treatment is impracticable:

- Containment options for sediment generally focus on in-situ capping. Where possible, a project manager should evaluate in-situ capping, or other engineering controls, for every sediment site that includes low-level threat waste. Where an in-situ capping alternative is clearly not appropriate, project managers should consider ex-situ containment. Where monitored natural recovery is expected to be achieved through burial with clean sediment, it may also be considered a containment option

The EPA expects to use a combination of methods, as appropriate, to achieve protection of human health and the environment:

- Large or complex contaminated sediment sites or operable units frequently require development of alternatives which combine various cleanup methods for different parts of the site. For a broader discussion on this topic, refer to Chapter 3, section 3.1.1, Alternatives That Combine Cleanup Methods

The EPA expects to use institutional controls such as water use and deed restrictions to supplement engineering controls as appropriate for short- and long-term management to prevent or limit exposure to hazardous substances, pollutants, or contaminants:

- Institutional controls such as fish consumption advisories, fishing bans, ship draft/anchoring/ wake controls, or structural maintenance requirements are frequently necessary as part of sediment alternatives, especially where contaminated sediment is left in place, or where remedial objectives in fish tissue cannot be met for some time. See Chapter 3, section 3.5, Institutional Controls, for additional discussion

The EPA expects to consider using innovative technology when such technology offers the potential for comparable or superior treatment performance or implementability, fewer or lesser adverse impacts than other available approaches, or lower costs for similar levels of performance than demonstrated technologies:

- Innovative technologies are technologies whose limited number of applications result in a lack of cost and performance data, frequently due to limited field application. Additional cost and performance data are needed for many sediment remedies and field demonstrations of new techniques and approaches are especially welcome, including both innovative in-situ and ex-situ treatment technologies and innovative technologies applied to in-situ capping or enhancements to natural recovery

The EPA expects to return reusable ground waters to their beneficial uses wherever practicable, within a time frame that is reasonable given the circumstances for the site. When restoration of ground water to beneficial uses is not practicable, EPA expects to prevent further migration of the plume, prevent exposure to the contaminated ground water, and evaluate further risk reduction:

- Ground water may be a continuing source of sediment and water contamination. Where this is the case, ground water restoration and migration prevention may be very important to a successful sediment cleanup

which they may be appropriate. Depending on site-specific conditions, contaminant characteristics, and/or health or environmental risks at issue, certain methods or combinations of methods may prove more promising than others. In reality, each site and the various sediment areas within it presents a unique combination of circumstances that should be considered carefully in selecting a comprehensive site-wide cleanup strategy. At large or complex sediment sites, the remedy decision frequently involves not a simple choice between cleanup methods but a choice between what areas of the site are best suited to a particular method.

To assist project managers in evaluating cleanup options two highlights are presented below. Highlight 7-2 provides general site, risk and contaminant characteristics that are generally consistent with each of the three common sediment cleanup methods. Highlight 7-3 lists key differences between the cleanup methods.

The site characteristics in Highlight 7-2 are intended as a general tool to suggest that project managers look more closely at particular methods when these characteristics are present. They are not requirements or expectations for the use of the three cleanup methods. It is important to remain flexible when evaluating sediment alternatives and consider cleanup methods which may not at first appear ideal for a given environment. When a cleanup method is selected for which some site characteristic is not ideal, additional engineering or institutional controls may be available to enhance the remedy. Some of these situations are discussed in the remedy-specific chapters (Chapters 4, 5, and 6).

Highlight 7-2: Site Conditions Generally Consistent with Selection of Common Sediment Cleanup Methods

Characteristics	Monitored Natural Recovery	In-situ Capping	Dredging/Excavation
General Site Characteristics	Low rates of fish/shellfish consumption. Critical resources not likely to be impacted if some contaminants released if sediment bed disturbed. Stable land uses in watershed; no plans for upstream structures which would trap sediment. Source control achieved or well underway.	Nearby source of suitable cap material, of sufficient quantity for area of contamination. High rates of fish/shellfish consumption, such as subsistence fishing community. Critical resources not likely to be impacted if some contaminants released if cap disturbed. Source control achieved or well underway.	Nearby disposal site for dredged material. Available area for staging and handling of dredged material. High rates of fish/shellfish consumption, such as subsistence fishing community. Navigational dredging required. Source control achieved or well underway.

Characteristics	Monitored Natural Recovery	In-situ Capping	Dredging/Excavation
General Physical/Chemical Environment	Consistent sediment deposition with high rate of burial. Low probability of contaminant dispersal to sensitive environment without active remedy. Reducing environment for metals contamination. Low rates of ground water influx that may increase contaminant migration through clean sediment.	Shallow slopes and relatively level bottom topography. Sufficient post-capping water depth to maintain flow capacity during floods or necessary navigational depths. Low rates of ground water influx that may increase contaminant migration through cap. Insufficient or inconsistent rates of natural burial.	Contaminated sediment underlain by clean soft sediment rather than hardpan or bedrock (to facilitate over-dredging). Few piers, pilings, or other structures to impede maneuverability. High probability of contaminant dispersal to sensitive environment without removal.
General Ecological Environment	Sensitive, unique environment which should not be disturbed by an active cleanup.	Ecological community recolonizes cap or relocates to neighboring areas.	Ecological community recolonizes dredged area or relocates to neighboring areas.
Hydrodynamic Conditions	Consistently stable sediment bed over long periods, including low incidence of natural sediment disruptive events and sediment-disruptive human activity.	Low enough incidence of natural disruptive events for practical design and maintenance of cap. Low or controllable incidence of cap-disruptive human behavior, such as large boat anchoring.	Water diversion practical, or current velocity low or can be minimized to reduce resuspension and downstream transport during dredging. Where near-water disposal is used, low enough incidence of natural disruptive events for practical design and maintenance of disposal site.
Sediment Characteristics	Highly cohesive or well-armored sediment.	Sufficient shear strength to support cap. High density/low water content sediment.	Low incidence of debris, logs, or boulders, or effective removal prior to dredging or excavation.
Contaminant Characteristics	High rates of biodegradation or transformation to lower toxicity forms. Low contaminant concentrations covering diffuse areas. Low ability to bioaccumulate.	Contaminants with low rates of flux through cap. Contamination covers contiguous areas.	High contaminant concentrations covering discrete areas. Contaminants highly correlated with sediment grain size (to facilitate separation and minimize treatment costs).

Some of the key differences between cleanup methods are presented in Highlight 7-3. For convenience these comparisons are organized around the NCP's nine remedy selection criteria. This highlight is intended to only identify some of the general differences between these three remedy types, not as an example of an actual comparative alternatives analysis for a site. An actual site alternatives analysis would typically include more complex alternatives and many site-specific details, as described in *A Guide to Preparing Superfund Proposed Plans, Records of Decision, and other Remedy Selection Decision Documents*, also referred to as the "ROD Guidance," (U.S. EPA 1999a) and *Guidance for Conducting Remedial Investigations and Feasibility Studies under CERCLA*, also referred to as the "RI/FS Guidance" (U.S. EPA 1988a). The example criterion components used in Highlight 7-3 below are taken from the RI/FS Guidance and are intended as only examples of some of the components that may be considered when evaluating that remedy selection criterion.

Highlight 7-3: Examples of Some Key Differences Between Sediment Cleanup Methods

NCP Remedy Selection Criteria	Example Criterion Components	Monitored Natural Recovery	In-Situ Capping	Dredging/Excavation
Overall Protective-ness		Relies upon natural processes for protection. Low level of short-term protection, but potentially adequate long-term protection.	Relies upon adequate cap placement and maintenance for protection. Moderate to high level of protection, depending upon areal extent of cap.	Relies upon effective removal and low residual levels for protection. Moderate to high level of protection, depending on residual. May not be as protective in the short term as capping (due to residuals) but potentially high long-term protection.
Compliance with Applicable or Relevant and Appropriate Require-ments (ARARs)		Generally, only chemical-specific ARARs apply (these would also apply to other cleanup methods).	Generally, the Clean Water Act (CWA) §404 (regulates discharge of dredged or fill materials into waters of the U.S.) and the Rivers and Harbors Act (prohibits obstruction or alteration of a navigable waterway) are ARARs.	Generally, CWA §404 and the Rivers and Harbors Act are ARARs. Generally, treatment facilities and in-water disposal sites should meet substantive requirements of the CWA §§404 and 401 for discharge of effluents into waters of the U.S. Generally, RCRA is an ARAR for disposal in solid or hazardous waste landfills. For polychlorinated biphenyl (PCB) sites, the Toxic Substances Control Act (TSCA) may be an ARAR.

NCP Remedy Selection Criteria	Example Criterion Components	Monitored Natural Recovery	In-Situ Capping	Dredging/Excavation
Long-Term Effective-ness and Permanence	**Long-Term Effectiveness and Magnitude of Residual Risks**	Low to high long-term effectiveness and residual risk, depending on processes being relied upon (e.g., burial or degradation).	Moderate to high long-term effectiveness and generally low to moderate residual risk, depending on cap design, placement, construction, and maintenance to address site characteristics that might otherwise prevent long-term isolation of contaminants.	Moderate to high long-term effectiveness and low to moderate residual risk, depending on amount of residual contamination. Low (upland) to moderate (in-water) residual risk for sediments and treatment residuals contained at controlled disposal sites.
	Permanence and Adequacy and Reliability of Controls for Residual Risk	Low (except in case of degradation or dilution), but potentially adequate, permanence. Moderate ability to control physical disturbance due to human activity via institutional controls (ICs); little ability to control physical disturbance due to natural forces. Little to no ability to control advection and diffusion of contaminants through overlying cleaner sediment, where this is of concern.	Moderate to high permanence, depending on cap stability and contaminant migration through cap. Low to moderate ability to control physical disturbance due to human and natural forces through cap design and moderate ability to control disruption through institutional controls. Some ability to control effects of advective flow and diffusion rates through cap design.	Highly permanent due to removal of contaminants. Control of residual risk from contaminants remaining in place is similar to MNR. Residual risks at upland disposal sites easily controlled; at in-water sites control can be more complex.
	Need for Five-Year Reviews	Perpetual review required for most sites due to waste left in place and possible continuing need for use restrictions.	Perpetual review required for most sites due to waste left in place and possible continuing need for use restrictions.	Review generally required for dredged site until cleanup levels and remedial action objectives are met and site is available for unrestricted use. Perpetual review generally required for on-site disposal facilities.

NCP Remedy Selection Criteria	Example Criterion Components	Monitored Natural Recovery	In-Situ Capping	Dredging/Excavation
Reduction of Toxicity, Mobility, and Volume (TMV) Through Treatment		No treatment is involved.	Presently no treatment is involved. Future potential for combining innovative treatment components within an in-situ cap.	Sediment can be treated if cost-effective; stabilization is most common form. Future potential for innovative treatment and re-use of dredged materials. Water treatment can reduce TMV of contaminants where significant quantities of toxics are removed from the water.

NCP Remedy Selection Criteria	Example Criterion Components	Monitored Natural Recovery	In-Situ Capping	Dredging/Excavation
Short-Term Effective-ness	**Community and Worker Protection During Remedy Implementa-tion**	Impacts to community continue but gradually decline until protection is achieved. Moderate ability to control impacts from fish/shellfish ingestion and, where applicable, direct contact with contaminated sediment, through ICs. Minimal impacts on workers from monitoring activities.	Low potential for impacts to community and workers from contaminant releases during cap placement; engineering controls may minimize these releases; worker protection generally available. Increased truck or rail traffic for transport of cap material may impact workers and the community.	Low to moderate potential for impacts to community and workers from contaminant release during dredging, transport, and disposal; engineering controls may minimize these releases; worker protection generally available. Increased truck or rail traffic for transport of dredged material may impact workers and the community.
	Environ-mental Impacts During Remedy Implemen-tation	Impacts to environment continue but gradually decline until protection is achieved. Bottom-dwelling ecological community left intact, although may be impaired.	Low potential for impacts from releases to the environment during cap placement and initial consolidation; impact of aquatic releases partially controllable through equipment selection and placement techniques. Majority of bottom-dwelling ecological community smothered; potential for re-colonization variable. Cap design can facilitate re-colonization in some cases.	Low to moderate potential impacts to environment during dredging; releases partially controllable by physical barriers and by selection and operation of dredging equipment. Majority of bottom-dwelling ecological community removed; potential for re-colonization variable. Backfill design can facilitate re-colonization in some cases.
	Time Until Protection is Achieved	Generally, longest time to achieve protection, depending on rates of natural processes and bio-availability of the contaminants. Time to achieve protection is frequently highly uncertain.	Generally, shortest time to achieve protection, although biota recovery may still take several years.	Time to achieve protection varies significantly depending on the size and complexity of the project. Time frame generally more uncertain than for capping due to unknown extent of residual contamination.

NCP Remedy Selection Criteria	Example Criterion Components	Monitored Natural Recovery	In-Situ Capping	Dredging/Excavation
Implement-ability	**Technical Feasibility**	Generally, no construction is required. Reliability can be uncertain in some environments due to uncertain rates of natural processes and uncertainties concerning sediment stability. Relatively easy to implement a different remedy in case of remedy failure. Methods for monitoring sediment cleanup levels are relatively well-established, although certain natural processes themselves can be difficult to monitor directly.	Cap placement methods are generally well-established; constructability depends mainly on water depth and currents, slope and geotechnical stability of underlying materials, and stability of the cap itself during and after construction. Reliability generally high, depending on environment and degree of monitoring and maintenance Relatively easy to repair cap in case of remedy failure, but relatively difficult to implement a different remedy. Methods for monitoring cap itself are relatively well-established, although certain processes, such as through-cap advective flow, can be difficult to monitor directly.	Dredging and excavation methods are generally well-established; technical feasibility of dredging depends mainly on accessibility, extent of obstructions, and the ability to over-dredge. Disposal in upland landfills is well-established; in-water disposal methods are less well-established and require greater monitoring; technical feasibility generally depends on slope and geotechnical stability of disposal site, distance to the disposal site, and ease of dewatering. Reliability higher for excavation than dredging; reliability of dredging depends on environment and skill of equipment operators. Transport of sediment to disposal site may present costly technical/and or administrative challenges. Relatively easy to re-dredge or implement a different remedy in case of remedy failure. Monitoring methods for sediment cleanup levels and short-term releases from dredging are relatively well-established.

NCP Remedy Selection Criteria	Example Criterion Components	Monitored Natural Recovery	In-Situ Capping	Dredging/Excavation
	Administra-tive Feasibility	State-regulated ICs, including fish consumption advisories, are frequently needed for a longer period than for other remedies.	Containment in public waters can require long-term coordination with state and local regulators due to potential need for permanent controls on waterway use.	Dredging and excavation plan should be coordinated with other agencies to ensure compatibility with other waterway uses and habitat concerns during the removal operation. Disposal siting often requires intensive coordination with several government agencies and the public.
	Availability of Services, Materials, Capacities, and Equipment	Monitoring and analytical services are generally readily available.	Location and suitability of capping material source is critical and can be problematic. Specialized cap placement equipment may be needed in some environments, but are generally available.	Environmental dredging and excavation equipment is generally available, although availability may be a problem for large projects and specialized equipment may need to be constructed for special situations. Availability of a suitable disposal facility with adequate capacity is critical and can be problematic.
Cost		Generally, no capital cost. Operation and maintenance (O&M) costs (e.g., monitoring) generally continue in perpetuity.	Capital costs generally higher than MNR and lower than dredging or excavation. O&M costs generally higher than MNR and dredging/excavation and generally continue in perpetuity.	Capital costs generally higher than MNR or capping. O&M costs generally higher than MNR and less than capping; O&M period limited unless on-site disposal is used.

NCP Remedy Selection Criteria	Example Criterion Components	Monitored Natural Recovery	In-Situ Capping	Dredging/Excavation
State Acceptance and Community Acceptance		Commonly identified benefits include lack of disruption to local residents, lack of disruption to aquatic and terrestrial animal and plant life, and low cost. Commonly identified concerns include leaving contamination in place, possible spread of contaminants during flooding or other disruption; uncertainties of predicting burial rates; and a potentially lengthy period of fishing bans or fish consumption advisories.	Commonly identified benefits include use of an active remedy with no disposal issues, generally moderate cost, and potentially faster biota recovery due to relatively rapid placement of exposure barrier. Commonly identified concerns include leaving contamination in place, disruption to local residents and businesses, increased truck, rail or barge traffic, recreational and navigational waterway access, access to buried utilities, possible long-term anchoring or other waterway use restrictions, and a period of fishing bans or fish consumption advisories.	Commonly identified benefits include removing contaminants from waterway, possible treatment of contaminants, potentially faster biota recovery, and increased/restored navigational depth, decreased flooding, and lack of use limitations after completion. Commonly identified concerns include disruption to local residents and businesses, releases during dredging, recreational and navigational waterway access during dredging, siting of and risks from local disposal facilities, increased truck, rail, or barge traffic, and a period of fishing bans or fish consumption advisories.

7.3 CONSIDERING INSTITUTIONAL CONTROLS

Institutional controls such as fish consumption advisories, fishing bans, ship draft/anchoring/wake controls, or structural maintenance requirements, are common parts of sediment remedies (see Chapter 3, section 3.5, Institutional Controls). NCP §300.430(a)(1)(iii)(D) contains the following general EPA expectations with respect to ICs. These expectations generally apply to all Superfund sites, including sediment sites:

- EPA expects to use institutional controls such as water use and deed restrictions to supplement engineering controls as appropriate for short- and long-term management to prevent or limit exposure to hazardous substances, pollutants, or contaminants;

- Institutional controls may be used during the conduct of the RI/FS and implementation of the remedial action and, where necessary, as a component of the completed remedy; and

- The use of institutional controls shall not be substituted for active response measures (e.g., treatment and/or containment of source material, restoration of

ground waters to their beneficial uses) as the sole remedy unless such active measures are determined not to be practicable, based on the balancing of trade-offs among alternatives that is conducted during the selection of remedy.

EPA policies concerning ICs are explained in *Institutional Controls: A Site Manager's Guide to Identifying, Evaluating, and Selecting Institutional Controls at Superfund and RCRA Corrective Action Cleanups* (U.S. EPA 2000c). In addition to considering the NCP expectations concerning ICs, the project manager should determine what entities possess the legal authority, capability and willingness to implement, and where applicable, monitor, enforce, and report on the status of the IC. An evaluation should also be made of the durability and effectiveness of any proposed IC. The objectives of any ICs contained in the selected alternative should be clearly stated in the ROD or other decision document together with any relevant performance standards. While the specific IC mechanism need not be identified, the types of ICs envisioned should be discussed in sufficient detail to support a conclusion that effective implementation of the ICs can reasonably be expected.

Reliability and effectiveness of ICs are of particular concern with sediment alternatives, whether they are used alone or in combination with monitored natural recovery, in-situ capping, or sediment removal. Project managers should recognize that ICs generally cannot protect ecological receptors, or prevent disruption of an in-situ cap by bottom-dwelling organisms. In addition, in many cases ICs have been only partially effective in modifying human behavior, especially in the case of voluntary or advisory controls. Although fish consumption advisories can be an important component of a sediment remedy, it should be recognized that they may not be entirely effective in eliminating exposures. Where advisories or bans are relied upon to reduce human health risk for long periods, public education, and where applicable, enforcement by the appropriate agency, are critical. This point is emphasized in Principle 9 of EPA's risk management principles for sediment: "Maximize the effectiveness of institutional controls and recognize their limitations" (U.S. EPA 2002a).

Implementing and overseeing ICs can often be more difficult at sediment sites where control of the waterbody may involve multiple entities and a single landowner is not present to provide oversight and enforcement. If a waterbody is privately owned, the landowner may not be in a position to prevent disruptions, such as grounding of vessels or anchor drag, even if ICs are in place. Where a waterbody is owned or controlled by local, state, or federal government entities, their regulations and guidance should be consulted to determine what governmental controls can be used to restrict the use of the waterbody, and the regulatory or administrative process to enforce such a restriction. In complex situations it may be useful to layer a number of different ICs as discussed in *Institutional Controls: A Site Manager's Guide to Identifying, Evaluating, and Selecting Institutional Controls at Superfund and RCRA Corrective Action Cleanups* (U.S. EPA 2000c).

7.4 CONSIDERING NO-ACTION

Selecting a "no-action" remedy is appropriate when no engineering controls (e.g., in-situ cap, dredging or excavation), ICs, or treatment are warranted at a site or a portion of a site. The ROD Guidance indicates that a no-action remedy may be appropriate in the following situations:

- When the site or operable unit poses no current or potential threat to human health or the environment;

- When CERCLA does not provide the authority to take remedial action; or

- When a previous response(s) has eliminated the need for further remedial response [often called a "no-further action" alternative].

Generally, if ICs are necessary to control risks caused by a contaminant of concern at a site, a no-action remedy is not appropriate. For example, if fish consumption advisories or fishing bans are necessary to control risks from contaminants of concern at a site, a no-action remedy for sediment is not appropriate, even if the advisories or bans are already in place. Instead, a remedy should be considered that includes at least the institutional control (e.g., advisories or bans), and, if appropriate, other actions for sediment or other media.

A no-action ROD may however include monitoring. For example, sediment may pose no current or potential threat to human health or the environment; however, uncertainties concerning that evaluation make it wise to continue some level of monitoring. In this case, a no-action ROD that includes monitoring may be an appropriate remedy. It is important to note that this is different from a MNR remedy where current or expected future risk is unacceptable and natural processes are being relied upon to reduce that risk to an acceptable level within a reasonable time frame. Although a no-action remedy may require long-term monitoring, a MNR remedy generally needs more intensive monitoring to show that contaminant concentrations are being reduced by anticipated mechanisms at the predicted rates.

7.5 CONCLUSIONS

The focus of remedy selection should be on selecting the alternative which represents the best overall risk reduction strategy for the site according to the NCP nine remedy selection criteria. As discussed in the OSWER Directive 9285.6-08 *Principles for Managing Contaminated Sediment Risks at Hazardous Waste Sites* (U.S. EPA 2002a), the EPA's policy has been and continues to be that there is no presumptive remedy for any contaminated sediment site, regardless of the contaminant or level of risk. Generally, as discussed in Chapter 3, Feasibility Study Considerations, project managers should consider each of the three major cleanup methods (i.e., monitored natural recovery, in-situ capping, and removal through dredging or excavation) at every sediment site where they may be appropriate.

Controlling any continuing sources of contaminants is an important component of any sediment remedy (U.S. EPA 2002a). Where source control is uncertain or cannot be achieved, project managers should consider the potential for re-contamination and factor that potential into the remedy selection process. However, project managers should note that delaying an action to complete source control may not always be wise. Early actions in some areas may be appropriate as part of a phased approach to address site-wide contamination even if sources are not fully controlled initially.

At many sites, but especially at large sites, the project manager should consider a combination of sediment cleanup methods as the most effective way to manage the risk. This is because the characteristics of the contaminated sediment and the settings in which it exists, are not usually homogeneous throughout a waterbody (NRC 2001). As discussed in the remedy-specific chapters of this guidance, when evaluating alternatives, project managers should include realistic assumptions concerning residuals and contaminant releases from in-situ and ex-situ remedies, the potential effects of those residuals and releases, and the length of time a risk may persist. In addition to considering the impacts of each alternative on human health and ecological risks, the project manager should assess the societal and

cultural impacts of each alternative on the community and the opportunities for site reuse and redevelopment.

The project manager should include a scientific analysis of sediment stability in the remedy selection process for all sites where sediment disturbance is a potential concern. Typically, it is not sufficient to assume that a site as a whole is stable or unstable. Generally, as discussed in Chapter 2, Remedial Investigation Considerations, project managers should make use of available empirical methods for evaluating sediment stability, especially when there are significant differences between alternatives. At large or complex sites, and sites with limited historical data, project managers may also consider using a numerical model for evaluating events where no field records are available and for predicting future stability.

The project manager should include in the remedy selection process a clear understanding of the uncertainties involved, including uncertainties concerning the predicted effectiveness of various alternatives and the time frames for achieving remedial goals in the remedy selection process. Project managers should quantify, as far as possible, the uncertainty of important factors in the remedy decision. Where it is not possible to quantify uncertainty, the project manager should use a sensitivity analysis to determine which apparent differences between alternatives are most likely to be significant.

The project manager should monitor all sediment remedies during and after implementation to determine if the actions are effective and if all remedial goals are met. Sediment remedies should not only include monitoring of surficial sediment immediately following implementation of the action, but also include long-term monitoring of sediment to assess movement of residuals and possible re-contamination, and monitoring of fish or other relevant biota recovery. Without these data, an assessment of the long-term effectiveness of the remedy is difficult. Additional monitoring data helps not only to assess the site, but also helps project managers determine the future conditions and practices that lead to the least impacts in the short term and most effective sediment remedies in the long term. Chapter 8, Remedial Action and Long-Term Monitoring, discusses these and other general monitoring considerations for sediment sites.

8.0 REMEDIAL ACTION AND LONG-TERM MONITORING

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8.0 REMEDIAL ACTION AND LONG-TERM MONITORING

This chapter provides an approach to developing an effective monitoring program at contaminated sediment sites. A monitoring program is recommended for all types of sediment remedies, both during the remedial action phase and over the long term [i.e., during the operation and maintenance (O&M) phase] to ensure that all sediment risk and exposure pathways at a site have been and continue to be adequately managed by the remedy. The goals of this chapter are the following:

- To provide a consistent definition of monitoring for this guidance and identify some of the complexities associated with monitoring at contaminated sediment sites;
- To present the key elements of a contaminated sediment site monitoring program;
- To introduce some of the monitoring techniques available for physical, chemical, and biological measurements; and
- To present some of the factors to consider when monitoring cleanups using monitored natural recovery (MNR), in-situ capping, or dredging/excavation.

In addition to the guidance presented in this chapter, the project manager should consider applicable or relevant and appropriate requirements (ARARs), such as the Clean Water Act (CWA), Resource Conservation and Recovery Act (RCRA), Toxic Substances Control Act (TSCA), state/tribal laws, and to be considered (TBC) criteria, in developing a site-specific monitoring program.

8.1 INTRODUCTION

For the purposes of this guidance, monitoring is the collection of field data (i.e., chemical, physical, and/or biological) over a sufficient period of time and frequency to determine the status and/or trend in a particular environmental parameter or characteristic. Environmental monitoring should not produce only a “snapshot in time” of the parameter of interest. Rather it should involve repeated sampling over time to define the trends in the parameter(s) of interest relative to clearly defined management objectives and goals.

Environmental sampling and analysis is typically conducted during all phases of the Superfund process to address various questions. By the time a project manager is implementing a remedial action or writing a monitoring plan, a considerable amount of site data should have been collected during the remedial investigation or site characterization phase and during remedial design. In the site characterization phase, sampling is performed to determine the nature and extent of contamination, to develop the information necessary to assess risks to human health and the environment, and to assess the feasibility of remedial alternatives. During site characterization, the project manager should consider expected monitoring needs during and after the remedial action to ensure that data are collected describing baseline conditions for comparison to future data sets. It is important to note that data collection is a dynamic process.

The project manager should review the existing site characterization data in the remedial design phase to determine whether adequate data have been collected to provide a baseline for remedial action

and/or long-term monitoring. It may be necessary to collect additional data in the design phase to serve this purpose. At sediment sites it is also frequently necessary to continue collecting data from upstream or other reference areas away from the direct influence of the site, for comparison to site monitoring data. This can be especially important where there is uncertainty or potentially changing conditions in background areas, for example, where upstream urban storm water runoff or other continuing sources of contamination could impact a remedy.

Although sediment sites vary widely in size and intricacy, monitoring may be especially complex at sediment sites for the following reasons:

- Sediment sites often involve more than one affected medium (e.g., sediment, surface water, air, ground water, and continuing contaminant sources, such as wastewater effluents) and may have more than one contaminant of concern;

- Sediment sites may require monitoring over very large areas;

- Sediment sites may occur in a large variety of environmental settings (e.g., marine, estuarine, riverine, lacustrine, etc.), each of which may require different monitoring strategies;

- Sediment sites often include multiple human health exposure pathways (e.g., recreational use, commercial and subsistence fishing, drinking water);

- Sediment sites may include complex ecosystems involving multiple ecological receptors (e.g., benthic, aquatic, terrestrial, and avian biota) and hence require multiple monitoring measurement endpoints; and

- The spatial and temporal variabilities of both physical and chemical sediment characteristics can be great. In particular, the spatial and temporal variabilities of both sediment and contaminant transport are often greater than for less mobile media such as contaminated soil, for example, located on the flood plains.

These potential complexities make it especially important at sediment sites to systematically plan for monitoring. Key general elements for monitoring sediment sites, some potential monitoring techniques and approaches for sediment remedies are discussed in the remainder of this chapter. More specific guidance is under development by the U.S. Environmental Protection Agency (EPA) to assist project managers with the following aspects of sediment site monitoring:

- Using sediment toxicity tests and chemical analyses when assessing baseline ecological risks and when monitoring remedy effectiveness;

- Using benthic assessment field studies when assessing baseline ecological risks and when monitoring remedy effectiveness;

- Using biota tissue data, biota sediment accumulation factors (BSAFs), and simple food chain models when assessing baseline ecological risks and when monitoring remedy effectiveness; and

- Monitoring for resuspension, contaminant transport, and residuals during and after dredging.

8.2 KEY ELEMENTS FOR SEDIMENT SITE MONITORING

Monitoring can be conducted at contaminated sediment sites for a variety of reasons, but primary among them are the following: 1) to assess operational effectiveness (e.g., monitoring sediment resuspension rates during dredging, measuring cap thickness during and after installation); and/or 2) to evaluate remedy effectiveness and document long-term human health and environmental benefits. No all-inclusive monitoring blueprint exists because sediment sites can be quite different, both with respect to types of contaminants [e.g., polychlorinated biphenyls (PCBs), metals] and physical characteristics (e.g., lakes, rivers, estuaries). However, certain key elements are important for a well-designed monitoring program, independent of the site or the remedial stage. These key elements are presented below in text and outline form. Following each element, a brief hypothetical example is provided to illustrate how the project manager might apply each element to a cleanup scenario.

When creating a monitoring program following the key elements below, it is important to review the record of decision (ROD) for the site. The ROD generally should contain cleanup levels for sediment, remediation goals for biota, and narrative remedial action objectives (RAOs) which can then be applied to the monitoring program, especially Elements 1 through 3 below. If the cleanup levels and remediation goals are very specific, some of the work in Elements 1 through 3 will already be completed.

<u>Element 1: Monitoring Objective Identification</u>

The most important element in developing an effective monitoring program is for the project manager to identify clear and specific monitoring objectives. These objectives generally will support the remediation goals, remedial action objectives for the site which are often risk-based (e.g., reduce fish tissue concentrations) and should be in the ROD. Inadequate or vague monitoring objectives can lead to criticism about what was monitored and why. Furthermore, funding for monitoring is often limited. Specifying objectives help to focus the experimental design and ensure that the most useful information is collected.

When identifying monitoring objectives other than those established in the ROD, the project manager should involve participants from all concerned groups [e.g., public, natural resource trustees, state agencies, potentially responsible parties (PRP)]. This participation does not necessarily imply the continuous involvement of the stakeholders; rather, it provides an opportunity for their input into developing the monitoring objectives. In some instances, more direct involvement is warranted by certain groups (e.g., natural resource trustees) to ensure that all needs/concerns are incorporated into the overall monitoring objectives. Whether involvement is direct or indirect, the purpose is for the project manager to bring all stakeholder viewpoints to the decision making process. In general, the focus of any specific monitoring program should be to determine the status and/or trend in those environmental parameters or characteristics of interest relative to clearly defined management objectives and goals.

Example: In River X, fish were found to have very high concentrations of PCBs in their tissue. These concentrations were determined to pose both human health and ecological risks. A remediation goal of reducing PCB concentrations in fish tissue to 0.05 parts per

million (ppm), was documented in the ROD. The subsequent monitoring program would monitor PCB concentrations in fish tissue along River X until this goal is reached.

Element 2: Decision/Evaluation Criteria

Once monitoring objectives are agreed upon and stated explicitly, the next step for the project manager is to identify specific decision criteria to assess whether the objectives are met. Criteria can be based on physical, chemical, and/or human health or environmental goals. Examples could include a physical criterion to limit contaminant net transport, a chemical criterion to limit contaminant concentrations in the water column, and/or a biological criterion to lower fish tissue concentrations to a specific value. Furthermore, additional criteria may relate to engineering and/or construction (e.g., cap stability or thickness).

Another factor the project manager should consider when developing decision criteria is the time frame for assessing those criteria. If the potential risks are high, the time frame for assessing decision criteria may need to be short. For example, when dredging severely contaminated sediment, a real-time monitoring program could be established to analyze water samples on a time frequency basis before proceeding with the next day's dredging. In contrast, the time frame required to assess a long-term monitoring objective (e.g., to lower fish tissue concentrations) would be longer. In either case, it is essential that the time frame be explicitly stated and understood by all the participants.

Example: With the remediation goal to reduce PCB concentrations in fish tissue to 0.05 ppm, the explicit monitoring decision criterion is to meet and interim goal of 2 ppm in fish tissue. Furthermore, this goal is expected to be met within a five year period, after which monitoring frequency may be revisited.

Element 3: Endpoint identification

Once the decision criteria have been identified, the next key element in this framework is to determine the information required to evaluate those criteria. Again, the more clearly the goals and criteria are stated initially, the easier it is to identify the appropriate endpoints. In general, physical (e.g., transport) and chemical (e.g., water quality criteria) endpoints are easier to interpret than biological endpoints (e.g., benthic community diversity). However, the ability of physical and chemical endpoints to quantify ecological risk is usually less direct than biological measurements. For example, contaminated sediment usually contains a suite of chemicals, and it is virtually impossible to analyze for all of them. Also, chemicals can act additively, thus increasing the ecological risks beyond those indicated by single chemical measurements. Biological endpoints (e.g., toxicity tests) provide an integrated measurement of the cumulative effects of all contaminants and, therefore, can be a better assessment of ecological risks.

When identifying appropriate endpoints, it is important for the project manager to ensure that the measure employed matches the time frame established for the criteria. For example, acute toxicity tests quantify short-term effects on an organism; therefore, this type of test may be appropriate for operational monitoring (e.g., monitoring during remedial dredging), where it can be performed in a short period of time. Other biological endpoints, such as changes in community species diversity, occur over long periods of time and may be more appropriate for use in a long-term monitoring program designed to look at ecological recovery. While no single endpoint can quantify all possible risks, a combination of

physical, chemical, and biological endpoints usually provides the best overall approach for measuring risks.

> **Example:** Given that the decision criterion is 2 ppm in fish tissue, PCB concentrations in fish species A will be measured every X months to evaluate whether the interim goal has been met.

Element 4: Monitoring Program Design and Data Collection

At this point monitoring objectives, criteria, and endpoints have been identified. The fourth key element for the project manager is to identify the monitoring design for collecting endpoint data (e.g., determining where and how often to collect those data). Design considerations include quality assurance, spatial and temporal factors, statistical design, and cost. The time spent initially to develop an effective and efficient monitoring design is often the best way to maximize the utility of the information collected (i.e., it is more effective to collect less of the "right" data than it is to collect more of the "wrong" data).

EPA requires a systematic planning approach to develop acceptance or performance criteria for all environmental data collection. The Agency's data quality objective (DQO) process is a planning approach appropriate for sediment sites (U.S. EPA 2000e). Quality assurance project plans (QAPPs) are also required. The formation and documentation of a rigorous quality assurance/quality control (QA/QC) program ensures the validity of the results for EPA and others and reenforces subsequent conclusions.

The spatial and temporal aspects of a monitoring program define where and when to collect samples. In general, sampling locations should be based on the areal extent and magnitude of the contaminated sediment and the propensity for the contaminants to move, either through transport (e.g., remediation, natural events) or through the food chain. Sampling station locations are site-specific and depend on the endpoints and decision criteria selected. It is also important for the project manager to consider how frequently to collect samples. Generally, the more dynamic the conditions, the more frequently sampling should occur.

Selecting a statistical approach to use is another important aspect of the monitoring program design. Data are sometimes collected in a manner that is incompatible with the statistical tests used to analyze the data. Project managers should identify factors such as data representativeness, sample replication, biased versus unbiased sampling designs, etc., when designing the monitoring program. The DQO process can be particularly helpful in this regard. Failure to take this step can result in the need to resample or modify decisions, all of which might be avoided through effective statistical considerations early in the design phase.

Finally, in reality, cost often drives data collection. For example, frequently the question asked is, "How many chemistry samples can I collect with my $50,000 budget?" The more correct philosophy should be, "Given that I have a $50,000 budget, what are the most appropriate samples to collect?" To reiterate, it is more cost-effective to collect less of the "right" data than it is to collect more of the "wrong" data. The monitoring program design will determine what the "right" data are.

> **Example:** From the remedial investigation (RI) data we know that Fish A overwinters in the contaminated area. The proposed sampling plan would consist of overlying an unbiased sampling grid onto a map of the contaminated area of River X as well as in the

areas upstream and downstream of the site. Based on available funding, it is decided that 30 fish will be collected in the Spring in each of these areas. However, given cost considerations, only 10 samples will be analyzed immediately and the other 20 archived for further analyses pending the results. The DQO process is used and a QA/QC plan is developed, as well as a health and safety plan (HASP).

Element 5: Data Analysis and Management

The last key element of a monitoring program is data analysis and dissemination. At this point, the project manager evaluates the data relative to the status and trends of multiple endpoints as well as comparing it to the decision criteria to determine if the interim goal and remediation goals are met. In addition, the project manager should communicate data, results, and conclusions to the appropriate audience. Frequently, the importance of communicating the results is underestimated. Because information is often provided to individuals with various levels of technical expertise, it should be comprehensible at multiple levels. Complex scientific data are not often easily understood by those without a technical background and ineffective data communication often leads to skepticism about the conclusions. Therefore, it is important that the project manager consider the audience and present results in multiple formats. To those less familiar with the technical presentation of data, information can be presented in easily understood visual formats [e.g., geographic information system (GIS)]. This approach maximizes the effective dissemination of information to the greatest number of individuals, thus increasing the probability that the conclusions will be understood and believed.

A final consideration is the physical location of data storage, that is, who will maintain the data and who will have access to it. Data stored electronically are much easier to manipulate graphically and/or reevaluate than data filed on handwritten sheets; however, data securing should also be considered.

Example: At this point, three years of fish tissue data have been collected, analyzed, and have passed the QA/QC evaluation. The decisions criterion for this monitoring objective was to reduce the PCB concentrations in fish tissue to 2 ppm. The data show that the after the third year, fish tissue concentrations are still above 2 ppm; however, the highest levels are restricted to a relatively small area. The results are summarized and presented to the original participating agencies. Due to the high fish tissue concentrations in certain areas, the project manager decides to analyze the additional 20 samples to better characterize the contamination. After examining the additional data, the decision is made that the monitoring objective has not been met and continued monitoring at the current frequency is necessary.

An outline of the five key elements and suggested subparts is shown in Highlight 8-1. It should be noted that the following outline essentially follows EPA's DQO process, with modification, for ease of application to a contaminated sediment site. Project managers should refer to the DQO process to supplement this outline when preparing a sediment site monitoring program.

Highlight 8-1: Outline of Key Elements for Sediment Site Monitoring

1. Monitoring Objective Identification (Ex: Reduce fish PCB concentrations to remediation goal of 0.05 ppm)
   - a. Site summary
     - i. Background information
   - b. Participants
     - i. Federal
     - ii. State
     - iii. Trustees
     - iv. Public
     - v. PRPs
   - c. Human risks
     - i. Exposure
       - (1) Air
       - (2) Water
       - (3) Sediment
       - (4) Biota
   - d. Ecological risks
     - i. Transport
     - ii. Exposure
     - iii. Bioaccumulation

2. Decision/Evaluation Criteria (Ex: Reduce fish PCBs to interim goal of 2 ppm in 5 years)
   - a. Existing criteria
     - i. ARARs
   - b. Site-specific criteria
     - i. Risk-based criteria
     - ii. Technology-based criteria (e.g., cap thickness)
   - c. Milestones (Time frame for assessing criteria)
     - i. Real time
     - ii. Annual
     - iii. Post remediation

3. Endpoint Identification (Ex: PCB tissue residues in fish species A)
   - a. Measures and methods
     - i. Physical
       - (1) Resuspension
       - (2) Transport
     - ii. Chemical
       - (1) Bioavailable sediment concentrations
       - (2) Biota tissue concentration
     - iii. Biological
       - (1) Chronic toxic effects
       - (2) Food chain effects

4. Monitoring Program Design and Data Collection (Ex: 30 fish collected in the Spring at multiple locations and times)
   - a. Temporal considerations
     - i. Meteorological factors
     - ii. Time frame for data collection
   - b. Spatial considerations
     - i. Strategic locations relative to transport, exposure, health, etc.
   - c. Statistical considerations
     - i. Replication
     - ii. Representativeness
     - iii. Biased vs. Unbiased sampling
   - d. Cost
     - i. Number of samples
       - (1) Tiered approach
         - 1. Worst areas first with most intensive monitoring
         - 2. Scale back in less contaminated areas
   - e. Feedback loop
     - i. Ability to modify the experimental design based on new information
   - f. DQO process and QA/QC plan
   - g. HASP

5. Data Analysis and Management (Ex: Fish residues are greater than 2 ppm after 3 years, requiring continued long-term monitoring at current frequency)
   - a. Data analysis
     - i. QA/QC evaluation
     - ii. Statistical evaluation to compare data with decision criteria to evaluate if goals met
   - b. Data dissemination
     - i. Audience
       - (1) Managers
       - (2) State and local governments
       - (3) Public
       - (4) Scientific literature
     - ii. Type
       - (1) Electronic (e.g., web site)
       - (2) Hard copy (e.g., fact sheets)
       - (3) Public meetings

8.3 POTENTIAL MONITORING TECHNIQUES

This section provides a brief overview of the types of monitoring techniques and endpoints that the project manager should consider during and following implementation of a sediment cleanup. The exact measurements depend on the cleanup methods selected and the phase of the operation as discussed in previous sections. In general, a combination of physical, chemical, and biological methods and a tiered monitoring protocol/sampling plan, as described above, is the best approach to determine whether a sediment remedy meets remedial objectives and associated performance criteria both during remedial action and in the long term.

Generally, physical (e.g., transport) and chemical (e.g., sediment concentrations) endpoints are easier to measure and interpret than biological (e.g., species abundance) endpoints. In the case of human health risk, chemical measurements are most often used to assess risk (e.g., mercury in fish tissue). In contrast, measurement of the biological community is a direct but often complex measurement for monitoring response to changed ecological risk. Caged organisms (e.g., *Macoma*, or mussels) at the site

over a defined time frame can identify changes in bioavailable concentrations of many contaminants. Collection of fish and tissue analysis can address both human health and ecological response of the system, if both needs are considered during design of the sampling and analysis plan. The project manager should refer to Office of Water's *Methods for Collection, Storage, and Manipulation of Sediments for Chemical and Toxicological Analyses* (U.S. EPA 2001j) and *Managing and Sampling and Analyzing Contaminants in Fish and Shellfish* (U.S. EPA 2000f) for more detailed information.

Biological endpoints (e.g., toxicity tests) provide an integrated measurement of the cumulative effects of all contaminants. When using biological endpoints, it is important for the project manager to ensure that the biological test employed fits the intended criteria. For example, acute toxicity tests quantify short-term effects on an organism; therefore, this type of test may be appropriate when monitoring for short-term impacts of a remedy. Other biological endpoints, such as changes in community species diversity, occur over long periods of time and are more appropriate for use in a long-term monitoring program designed to look at ecological recovery. While no single endpoint can quantify all possible risks, project managers should consider a combination of physical, chemical, and biological endpoints to provide the best overall approach for assessing the short- and long-term success of a remedial action.

8.3.1 Physical Measurements

Physical testing at a site may include measurements of erosion and/or deposition of sediment, pore water analysis, ground water advective flow analysis, particle size analysis, surface water flow rates, and sediment homogeneity/heterogeneity. Potential types of physical monitoring data and their uses also include the following:

- *Sediment Geophysical Properties:* Uses include fate and transport modeling, determination of contaminant bioavailability, and habitat characteristics of post-cleanup sediment surface;

- *Water Column Physical Measurements (e.g., turbidity, total suspended solids):* Uses include monitoring the amount of sediment resuspension during dredging and during placement of in-situ caps;

- *Global Positioning Systems (GPS) Data:* Uses include maintaining accuracy of navigation for repetitive sampling;

- *Bathymetry Data:* Uses include evaluation of post-capping or post-dredging bottom elevations for comparison to design specifications and evaluation of sediment stability during natural recovery;

- *Side Scan Sonar Data:* Uses include remote sensing to monitor the distribution of sediment types and bedforms;

- *Settlement Plate Data:* Uses include monitoring changes in cap thickness over time and measurement of cap consolidation;

- *Sediment Profile Camera Data:* Uses include monitoring of changes in thin layering within sediment profiles, sediment grain sizes, bioturbation and oxidation depths, and the presence of gas bubbles; and

- *Subbottom Profiler Data:* Uses include remote sensing measurement of changes in sediment surface and subsurface layers, bioturbation and oxidation depths, and presence of gas bubbles.

8.3.2 Chemical Measurements

Chemical testing may include sediment chemistry (both the upper biological zone and/or deeper sediment), evaluating biodegradation, contaminant partitioning to the pore water, and concentrations of total organic carbon. Potential environmental monitoring methods used in support of chemical measurements include the following:

- *Sediment Grab Samplers:* Uses include measurement of surface sediment chemistry;

- *Coring Devices (e.g., vibracore, gravity piston, or drop tube samplers):* Uses include obtaining a vertical profile of sediment chemistry, or detection of contaminant movement through a cap or through a layer of naturally deposited clean sediment;

- *Direct Water Column Measurements (probes):* Uses include measurement of parameters such as pH and dissolved oxygen in the water column;

- *Surface Water Samplers:* Uses include measurement of chemical concentrations (dissolved and particulate) in water or contaminant releases to the water column during construction; and

- *Semi-Permeable Membrane Devices:* Uses include measurement of dissolved contaminants at the sediment-water interface.

For sediment sites contaminated with PCBs, the National Research Council (NRC) recommends that PCB sites be characterized and remedies for PCBs be monitored on the basis of specific PCB congeners and the total mixture of congeners that exist at each site, rather than on the basis of total PCBs or Aroclors [(i.e., commercial PCB mixtures) NRC 2001]. EPA's Office of Water, in *Guidance for Assessing Chemical Contaminant Data for Use in Fish Advisories, Volume 1, Fish Sampling and Analysis, Third Edition* (U.S. EPA 2000g) indicates that analyses for PCBs as Aroclors can result in significant error in determining total PCB concentrations and that the distribution of PCB congeners in Aroclors is altered considerably by physical, chemical, and biological processes after release into the environment. Characterizing PCB risk and monitoring PCB remedies on a congener-specific basis allows for an accounting of the differences in physicochemical, biochemical, and toxicological behavior of the different congeners in type and magnitude of effects and, therefore, in risk calculations.

However, deciding how best to characterize and monitor a PCB site is a complex issue due in part to issues related to dioxin-like PCBs, the lack of congener-specific toxicological data, the need for comparing present and previously-collected data, and the cost of congener-specific analyses. As of July 2002, OERR has non-routine analytical service contracts in place for PCB congener analyses. As of

September 2003, EPA will provide this service through the contract laboratory program to meet more extensive quality assurance requirements.

8.3.3 Biological Measurements

Biological testing can include toxicity bioassays, examining changes in the biological assemblages at sites, either to document problems or evaluate restoration efforts, and/or determining toxicant bioaccumulation and food chain effects. Potential types of biological monitoring data and their uses also include the following:

- *Benthic Community Analysis:* Uses include evaluations of population size and diversity, and monitoring of recovery following remediation;

- *Toxicity Testing:* Uses include measurement of lethal or sublethal effects of contaminants on organisms in order to help establish protective range of remediation goals;

- *Tissue Sampling:* Uses include measurement of bioaccumulation, modeling trophic transfer potential, and estimating food web effects;

- *Caged Fish/Invertebrate Studies:* Uses include monitoring change in uptake of contaminants by biota from the sediment or water column to measure the effect of the remedy on bioaccumulation rates; and

- *Sediment Profile Camera:* Uses include indirect measurement of macroinvertebrate recolonization, for example, measuring population density of polychaetes by counting the number of burrow tubes per linear centimeter along the sediment-water interface.

8.4 REMEDY-SPECIFIC MONITORING APPROACHES

The following sections discuss monitoring issues particular to natural recovery, in-situ capping, and dredging or excavation. Many sediment remedies involve a combination of cleanup methods, and for these remedies, the monitoring program will likely include a combination of techniques to measure short- and long-term success. In general, the project manager should consider monitoring which takes place during construction or at any time before construction specifications, cleanup levels, and remedial action objectives are met, to be part of remedial action and the long-term operation and maintenance phase of the remedy.

8.4.1 Monitoring Natural Recovery

Monitoring is an essential component of a remedy that includes MNR, as contaminants are left in place, generally, without physical protection from physical or biological disturbances. Remedial action monitoring for MNR can extend for a long period of time. It generally includes all monitoring up until cleanup levels and remedial action objectives are met (i.e., the recovery period). Long-term monitoring (i.e., during the O&M phase) generally includes all monitoring following attainment of cleanup levels and remedial action objectives (i.e., continued monitoring to ensure recovery is maintained). MNR remedies generally require more intensive monitoring early in the recovery period, which may be relaxed if

predicted recovery rates are being attained. An exception may be in the case of an intensive disturbance event.

Remedial Action Monitoring

Remedial action monitoring of natural recovery should test the claim that the numerous relevant processes are indeed operating to isolate or eliminate the contaminants of concern. Monitoring should focus on the natural processes which are relied upon to reduce risk. In some cases it may be possible for the project manager to monitor the process itself, but in most cases, monitoring involves measuring the process indirectly or measuring the effects of that process. As a sound strategy for monitoring natural recovery the project manager should consider monitoring the following:

- Direct or indirect measures of natural processes (e.g., sediment accumulation rates, degradation products, sediment and contaminant transport);
- Contaminant levels in sediment (e.g., of the bioavailable zone and, where appropriate, at depth); and
- Measures of biota recovery (e.g., benthic organism population size and diversity and/or, for bioacumulative contaminants, contaminant levels in other trophic level indicator species).

EPA's Science Advisory Board (SAB), in its May 2001 report, *Monitored Natural Attenuation: USEPA Research Program - An EPA Science Advisory Board Review* (U.S. EPA 2001i), section 3.4, under "Summary of Major Research Recommendations," indicates the need for the development of additional monitoring methods to quantify attenuation mechanisms, contaminated sediment transport processes, and bioaccumulation to support footprint documentation and analysis of permanence. EPA is aware of these research needs and plans to address some of these topics in ongoing and future work.

In developing monitoring plans for MNR, project managers should also consider the likelihood of movement of contaminants by advective flow of water through the contaminated sediment, either into surface water or into surrounding ground water. In addition, movement by molecular diffusion over long time periods is inevitable. The project manager should consider these processes for both remedial action and long-term monitoring plans.

For areas that may be subject to sediment disruption, the project manager should conduct more extensive monitoring when specified disruptive events (e.g., storms or flow stages of a specified recurrence interval or magnitude) occur in order to evaluate whether buried contaminated sediment is being disturbed or transported and the extent to which that disturbance is causing release of contaminants and increased risk. The project manager should design the monitoring plan to handle the relatively quick turnaround times needed to effectively monitor expected disruptive events. This disturbance-related monitoring may be appropriate during both remedial action and long-term monitoring.

The project manager should include periodic comparisons of monitoring data to rates of recovery expected for the site in a MNR monitoring program. Where predictions were based on modeling, the project manager should use monitoring results to verify and/or adjust model assumptions and to rerun model predictions. Where contingency remedies or triggers for additional work are part of a remedy

decision, the project manager should design the monitoring plan to help determine whether those triggers are met. Examples triggers include the following:

- Contaminant concentrations in sediment, surface water, or biota at specified locations that exhibit an increasing or insufficient decreasing trend;
- Changes in land and/or surface water/ground water use may adversely affect the protectiveness of the remedy;
- Insufficient sedimentation rates; and
- Occurrence of a flood or storm that scours the sediment and exposes previously buried contaminants.

Where contingencies are triggered, the project manager may need to include measures such as additional source control, additional institutional controls, the placement of a thin layer of clean sediment to enhance natural recovery, or an active cleanup such as dredging or capping.

Long-Term Monitoring

Following completion of the remedial action, long-term monitoring is frequently needed at MNR sites. The term "long-term monitoring" is somewhat confusing for MNR remedies because the remedial action phase generally takes a long time period by itself. Long-term monitoring (i.e., monitoring during the O&M phase) for MNR remedies is monitoring after cleanup levels and remedial action objectives have been achieved. For sites where natural recovery is based on burial with clean sediment, continued monitoring generally is necessary after cleanup levels and remedial action objectives have been achieved in order to assess whether buried contaminants remain in place and are not bioavailable. Many of the factors discussed above concerning disruptive event monitoring and other issues apply to this stage of monitoring as well.

8.4.2 Monitoring In-Situ Capping

Monitoring is an essential component of a remedy that includes in-situ capping. Remedial action monitoring for capping generally includes monitoring of construction and placement, initial cap performance, and monitoring of any broader remedial action objectives such as fish recovery. Long-term monitoring (i.e., during the O&M phase) for capping generally includes continued monitoring of cap performance and monitoring of maintenance activities. Long-term monitoring may also include periodic monitoring to ensure that broader remedial action objectives continue to be met. Monitoring of a cap is also used to guide cap maintenance plans and modify future monitoring schedules and activities. Highlight 8-2 lists example elements of cap monitoring.

Highlight 8-2: Example Cap Monitoring Phases and Elements

Monitoring Phase	Element	Component	Analysis	Frequency/Location
Cap Construction	Cap material quality	Cap material sampling	Physical properties	5% of loads
	Cap thickness and areal extent	Bathymetry Subbottom profile	Thickness of cap layers Areal extent of cap	Baseline Initial placement Final surveys over entire area
		Sediment profile camera (SPC)	Thickness of cap layers	Baseline Initial placement Defined grid for remaining cells
		Cores	Layer thickness and physical properties Chemical properties for baseline	Defined grid
	Sediment resuspension	Plume tracking Acoustic Doppler Current Profile (ADCP) Water column samples	Suspended sediment Water column chemistry	5% of load placements
Cap Performance	Recolonization	SPC Benthic Community Analysis	Layer thickness Recolonization, population size and diversity	Defined grid - frequency determined by local information about recolonization rates
	Physical isolation	Subbottom profile Bathymetry Cores	Layer thickness	Annual checks in some cases Surveys over entire area every five years
	Chemical isolation	Cores Peepers Seepage meters	Physical properties Sediment chemistry Pore water chemistry	Defined grid every five years
Severe Event Response	Cap integrity	Subbottom profile SPC Cores		Following major storms or earthquakes

As shown in Highlight 8-2, a variety of monitoring equipment and methods can be used for capping projects during both remedial action and long-term monitoring. Two common approaches are the use of bathymetric surveys to determine cap thickness and stability over time and the analysis of sequential cores taken through the cap to confirm physical and chemical isolation. Specialized equipment, such as seepage meters, diffusion samplers (e.g., peepers and semi-permeable membrane devices), and sediment profile cameras, can also be considered. To ensure physical isolation of contaminated sediment, measurements of bathymetry of the capped area, cap/component thickness, colonization by bottom-dwelling organisms, and sedimentation through sediment traps can be conducted. Elements for measuring contaminant migration may include chemical analysis of cap materials, collection chambers, air-filled (vapor diffusion) or solvent-filled (peepers) bags, and caged fish. Seepage meters can also be used to measure advective flow rates and pore water flux.

In developing monitoring plans for caps, project managers should also consider the likelihood of movement of contaminants by advective flow water through the cap and the contaminated sediment, either into surface water or into surrounding ground water. In addition, movement by molecular diffusion over long time periods is inevitable. Both remedial action and long-term monitoring plans should consider these processes.

Remedial Action Monitoring

As mentioned above, remedial action monitoring for capping generally includes monitoring of construction, initial cap performance monitoring, and monitoring of any broader remedial action objectives such as recovery of the bottom-dwelling benthic community, fish/shellfish, or other higher trophic level biota.

Construction monitoring for capping is designed to measure whether design plans and specifications are followed in the placement of the cap and to monitor the extent of any contaminant releases during cap placement. During construction, monitoring results can be used to identify modifications to design or construction techniques needed to meet unavoidable field constraints. Construction monitoring frequently includes interim and post-construction cap material placement surveys. Appropriate methods for monitoring cap placement include bathymetric surveys, sediment core sampling, sediment profiling camera, and chemical resuspension monitoring for contaminants. For some sites, visual observation in shallow waters or surface visual aids, such as viewing tube or diver observations, can also be useful.

More broadly, remedial action monitoring of a cap should be designed to evaluate whether all remedial action objectives have been met. Biological testing may include the type and quantity of organisms that may recolonize the capped site and the bioturbation behavior of benthic organisms. Where contaminants are bioaccumulative, fish or other biota edible tissue or whole body monitoring may also be recommended.

Long-Term Monitoring

Following completion of the remedial action, long-term monitoring is important to ensure that the cap is not being eroded or significantly compromised (e.g., penetrated by submerged aquatic vegetation, ground water recharge, or bioturbation) and that chemical contaminant fluxes that ultimately do move

through the cap to surface water do so at the projected rate and concentration. It is also frequently desirable to include ongoing monitoring for recontamination of the cap surface from other sources.

For areas that may be subject to cap disruption, more extensive monitoring should be triggered when specified disruptive events (e.g., storms or flow stages of a specified recurrence interval or magnitude) occur, in order to evaluate whether the cap was disturbed and whether any disturbance caused release of contaminants and increased risk. Additional monitoring for the effects of tidal and wave pumping and boat propeller wash is also recommended. In general, the project manager should monitor cap integrity both routinely and following all storm/flood events that approach the design storm magnitude envisioned by the cap's engineers. As for other types of sediment remedies, the project manager should design the monitoring plan to handle the relatively quick turnaround times needed to effectively monitor expected disruptive events.

Cap maintenance is generally limited to the repair and replenishment of the erosion protection layer in high erosion areas where this is necessary. Project managers should consider the ability to detect and quickly respond to a loss of the erosion protection layer when evaluating a capping alternative. Seasonal limitations, such as ice formation or closure of navigation structures (locks), can limit the ability to monitor in-situ caps after a significant erosion event. This can also limit the project manager's ability to respond if maintenance is needed.

Capping remedies frequently include provisions for actions to be taken in the case that one or more cap functions are not being met. Options for modifying the cap design may or may not be available. If monitoring shows that the stabilization component is being eroded by events of lesser magnitude than planned, or the erosive energy at the capping site was underestimated, then eroded material can be replaced with more erosion-resistant cap material. If monitoring indicates that bottom-dwelling organisms are penetrating the cap in significant numbers, then project managers should consider placing additional cap material on top of the cap to inhibit cap colonization. These types of management options are feasible where additional cap thickness, and the resulting decrease in water depths at the site, does not conflict with other waterway uses. Where a cap has been closely designed to a thickness that will not limit waterway use (i.e., recreational or commercial navigation), the options for modifying a cap design after construction can be limited.

8.4.3 Monitoring Dredging or Excavation

Like all sediment remedies, monitoring is an essential component of a remedy that includes dredging or excavation. Remedial action monitoring for this type of remedy generally includes construction and operational monitoring of the dredging or excavation, transport, dewatering, any treatment, transport, and any on-site disposal placement. Remedial action monitoring for dredging or excavation also includes monitoring of residual contamination and monitoring of all broader remedial action objectives such as bottom-dwelling community recovery or fish and shellfish recovery. Long-term monitoring (i.e., during the O&M phase) for dredging or excavation generally includes continued monitoring of any on-site disposal facilities and monitoring sediment and/or biota for recontamination.

<u>Remedial Action Monitoring</u>

Remedial action monitoring for dredging or excavation generally includes a comprehensive monitoring program for all potential routes of contaminant exposure during various phases of the

operation. Depending on the levels of contamination and the selected methods of dredging/excavation, transport, treatment or disposal, potential construction and operational monitoring may include the following:

- Water quality monitoring at the dredging and disposal sites;
- Monitoring of dredging residuals;
- Effluent quality monitoring after sediment dewatering and/or treatment;
- Air monitoring at the dredge, transport, on-site disposal, and treatment sites; and
- Monitoring of on-site treatment residuals.

A thorough operational monitoring plan, including effective containment barriers, will help project managers to ensure that contamination is not spread during dredging, transport, treatment, or disposal to uncontaminated areas of the waterbody, sensitive habitats, or adjacent human populations. The project manager should consider water, air, and biological sampling in the remedial monitoring plan. This is dependent on the predominant contaminants of concern and the tendency for the contaminant to volatilize or bioaccumulate.

Generally, project managers should design remedial action monitoring for dredging to test the effectiveness of silt curtains, operational controls, and any other measures used to control total suspended solids from sediment resuspension. In most cases the project manager should include sampling upgradient of the dredging operation and both inside and outside of any containment structures. Generally this sampling should also include dissolved compounds in the water column. Also, where contaminants may be volatile, project managers should include air sampling. As discussed in Chapter 6, section 6.8.2, Sediment Characteristics, several tests and models have been established by the EPA and the U.S. Army Corps of Engineers (USACE) to predict contaminant losses from dredging. At highly contaminated sites, it may be necessary for the project manager to conduct a pilot study on a small area to determine if the sediment may be removed without causing unacceptable risks to adjacent human populations or adjacent benthic habitat. This information can help to determine what containment barriers or dredging methods work best and what performance standards are achievable at the site. The project manager should compare monitoring results to a pre-operational baseline for contaminant concentrations in air and water. This ensures that effects due to dredging may be separated and evaluated from natural perturbations, such as tide and storm influence. The project manager should develop contingency plans to guide changes in operation where performance standards are exceeded.

Following dredging, it is essential for project managers to determine whether cleanup levels in sediment and remediation goals for all media, including biota, are achieved through sediment monitoring. Initial sampling should be analyzed rapidly, so that contingency actions, such as additional dredging or backfilling, can be implemented quickly if cleanup levels have not been met. A post-dredging monitoring program should be designed by the project manager to measure whether the remedy has been successful in managing the risks at the site. The project manager should design the monitoring program for dredging sites to provide data that demonstrates that all food chain risks and other sediment exposure pathways have been managed or controlled and any on-site disposal facilities are operating effectively to isolate contaminants from the environment.

Long-Term Monitoring

Following completion of the remedial action, it is necessary for the project manager to conduct long-term monitoring to ensure the dredged area is not re-contaminated by additional sources or by disturbance of any residuals which remain above cleanup levels. Long-term monitoring of any on-site disposal facilities is also necessary.

If an in-water or upland disposal facility is constructed on-site as part of the remedy, it should be monitored to ensure that it remains intact and that there are no unacceptable contaminant releases in the long term. Monitoring is recommended to resolve whether contaminants are leaking through the bottom or walls of the confined disposal facility (CDF) or landfill, and that any surface cap remains intact to ensure protection from infiltration. Depending on the type of disposal site and the nature of the contamination, long-term disposal site monitoring may include the following:

- Seepage from the CDF containment cells to surrounding surface water;
- Ground water monitoring;
- Surface water run-off monitoring;
- Monitoring of disposal area cap integrity; and
- Monitoring of revegetation or recolonization by plant and animal communities, and their potential uptake of contaminants.

Highlight 8-3 lists important points to remember related to monitoring sediment sites.

Highlight 8-3: Points to Remember About Monitoring Sediment Sites

- A monitoring program is important for all types of sediment remedies, both during the remedial action and over the long term to ensure that sediment risk and exposure pathways at a site have been adequately managed and remain so
- The development of monitoring plans should follow a systematic planning process that identifies monitoring objectives, decision criteria, endpoints, and data collection and analysis methods
- Before implementing a remedial action, project managers should review baseline data and collect additional data if needed to ensure that an adequate baseline exists for comparison to monitoring data
- Remedial action monitoring includes both construction/operational monitoring and monitoring intended to measure whether cleanup levels and remedial action objectives have been met
- Monitoring plans should be designed to evaluate whether performance standards of the remedial action are being met and should be flexible enough to allow revision if operating procedures are revised
- Field methods/quick turnaround with real-time feedback are useful, especially during the remedial action to predict or identify potential problems
- After completion of remedial action, long-term monitoring is important to watch for recontamination, to assess continued containment of buried or capped contaminants, and to monitor dredging residuals and on-site disposal facilities

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CONTAMINATED SEDIMENT REMEDIATION GUIDANCE FOR HAZARDOUS WASTE SITES:

APPENDIX A: PRINCIPLES FOR MANAGING CONTAMINATED SEDIMENT RISKS AT HAZARDOUS WASTE SITES

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UNITED STATES ENVIRONMENTAL PROTECTION AGENCY
WASHINGTON, D.C. 20460
Feb. 12, 2002

OFFICE OF
SOLID WASTE AND EMERGENCY
RESPONSE

OSWER Directive 9285.6-08

MEMORANDUM

SUBJECT: Principles for Managing Contaminated Sediment Risks at Hazardous Waste Sites

FROM: Marianne Lamont Horinko ***/s/ Marianne Lamont Horinko***
Assistant Administrator

TO: Superfund National Policy Managers, Regions 1 - 10
RCRA Senior Policy Advisors, Regions 1 - 10

I. PURPOSE

This guidance will help EPA site managers make scientifically sound and nationally consistent risk management decisions at contaminated sediment sites. It presents 11 risk management principles that Remedial Project Managers (RPMs), On-Scene Coordinators (OSCs), and RCRA Corrective Action project managers should carefully consider when planning and conducting site investigations, involving the affected parties, and selecting and implementing a response.

This guidance recommends that EPA site managers make risk-based site decisions using an iterative decision process, as appropriate, that evaluates the short-term and long-term risks of all potential cleanup alternatives consistent with the National Oil and Hazardous Substances Pollution Contingency Plan's (NCP's) nine remedy selection criteria (40 CFR Part 300.430). EPA site managers are also encouraged to consider the societal and cultural impacts of existing sediment contamination and of potential remedies through meaningful involvement of affected stakeholders.

This guidance also responds in part to the recommendations contained in the National Research Council (NRC) report discussed below.

II. BACKGROUND

On March 26, 2001, the NRC published a report entitled *A Risk Management Strategy for PCB-Contaminated Sediments*. Although the NRC report focuses primarily on assessment and remediation of PCB-contaminated sediments, much of the information in that report is applicable to other contaminants. Site managers are encouraged to read the NRC report, which may be found at http://www.nrc.edu.

In addition to developing these principles, OSWER, in coordination with other EPA offices (Office of Research and Development, Office of Water, and others) and other federal agencies (Department of Defense/U.S. Army Corps of Engineers, Department of Commerce/National Oceanic and Atmospheric Administration, Department of the Interior/U.S. Fish and Wildlife Service, and others) is developing a separate guidance, *Contaminated Sediment Remediation Guidance for Hazardous Waste Sites* (Sediment Guidance). The Sediment Guidance will provide more detailed technical guidance on the process that Superfund and RCRA project managers should use to evaluate cleanup alternatives at contaminated sediment sites.

While this directive applies to all contaminants at sediment sites addressed under CERCLA or RCRA, its implementation at particular sites should be tailored to the size and complexity of the site, to the magnitude of site risks, and to the type of action contemplated. These principles can be applied within the framework of EPA's existing statutory and regulatory requirements.

III. RISK MANAGEMENT PRINCIPLES

1. Control Sources Early.

As early in the process as possible, site managers should try to identify all direct and indirect continuing sources of significant contamination to the sediments under investigation. These sources might include discharges from industries or sewage treatment plants, spills, precipitation runoff, erosion of contaminated soil from stream banks or adjacent land, contaminated groundwater and non-aqueous phase liquid contributions, discharges from storm water and combined sewer outfalls, upstream contributions, and air deposition.

Next, site managers should assess which continuing sources can be controlled and by what mechanisms. It may be helpful to prioritize sources according to their relative contributions to site risks. In the identification and assessment process, site managers should solicit assistance from those with relevant information, including regional Water, Air, and PCB Programs (where applicable); state agencies (especially those responsible for setting Total Maximum Daily Loads (TMDLs) and those that issue National Pollutant Discharge Elimination

System (NPDES) permits); and all Natural Resource Trustees. Local agencies and stakeholders may also be of assistance in assessing which sources can be controlled.

Site managers should evaluate the potential for future recontamination of sediments when selecting a response action. If a site includes a source that could result in significant recontamination, source control measures will likely be necessary as part of that response action. However, where EPA believes that the source can be controlled, or where sediment remediation will have benefits to human health and/or the environment after considering the risks caused by the ongoing source, it may be appropriate for the Agency to select a response action for the sediments prior to completing all source control actions. This is consistent with principle #5 below, which indicates that it may be necessary to take phased or interim actions (e.g., removal of a hot spot that is highly susceptible to downstream movement or dispersion of contaminants) to prevent or address environmental impacts or to control human exposures, even if source control actions have not been undertaken or completed.

2. Involve the Community Early and Often.

Contaminated sediment sites often involve difficult technical and social issues. As such, it is especially important that a project manager ensure early and meaningful community involvement by providing community members with the technical information needed for their informed participation. Meaningful community involvement is a critical component of the site characterization, risk assessment, remedy evaluation, remedy selection, and remedy implementation processes. Community involvement enables EPA to obtain site information that may be important in identifying potential human and ecological exposures, as well as in understanding the societal and cultural impacts of the contamination and of the potential response options. The NRC report (p. 249) "recommends that increased efforts be made to provide the affected parties with the same information that is to be used by the decision-makers and to include, to the extent possible, all affected parties in the entire decision-making process at a contaminated site. In addition, such information should be made available in such a manner that allows adequate time for evaluation and comment on the information by all parties." Through Technical Assistance Grants and other mechanisms, project managers can provide the community with the tools and information necessary for meaningful participation, ensuring their early and continued involvement in the cleanup process.

Although the Agency has the responsibility to make the final cleanup decision at CERCLA and RCRA sites, early and frequent community involvement facilitates acceptance of Agency decisions, even at sites where there may be disagreement among members of the community on the most appropriate remedy.

Site managers and community involvement coordinators should take into consideration the following six practices, which were recently presented in OSWER Directive 9230.0-99 *Early*

and Meaningful Community Involvement (October 12, 2001). This directive also includes a list of other useful resources and is available at http://www.epa.gov/superfund/pubs.htm.

(1) Energize the community involvement plan.
(2) Provide early, proactive community support.
(3) Get the community more involved in the risk assessment.
(4) Seek early community input on the scope of the remedial investigation/feasibility study (RI/FS).
(5) Encourage community involvement in identification of future land use.
(6) Do more to involve communities during removals.

3. Coordinate with States, Local Governments, Tribes, and Natural Resource Trustees.

Site managers should communicate and coordinate early with states, local governments, tribes, and all Natural Resource Trustees. By doing so, they will help ensure that the most relevant information is considered in designing site studies, and that state, local, tribal, and trustee viewpoints are considered in the remedy selection process. For sites that include waterbodies where TMDLs are being or have been developed, it is especially important to coordinate site investigations and monitoring or modeling studies with the state and with EPA's water program. In addition, sharing information early with all interested parties often leads to quicker and more efficient protection of human health and the environment through a coordinated cleanup approach.

Superfund's statutory mandate is to ensure that response actions will be protective of human health and the environment. EPA recognizes, however, that in addition to EPA's response action(s), restoration activities by the Natural Resource Trustees may be needed. It is important that Superfund site managers and the Trustees coordinate both the EPA investigations of risk and the Trustee investigations of resource injuries in order to most efficiently use federal and state resources and to avoid duplicative efforts.

Additional information on coordinating with Trustees may be found in OSWER Directive 9200.4-22A *CERCLA Coordination with Natural Resource Trustee*s (July 1997), in the 1992 ECO Update *The Role of Natural Resource Trustees in the Superfund Process* http://www.epa.gov/superfund/programs/risk/tooleco.htm), and in the 1999 OSWER Directive 9285.7-28 P *Ecological Risk Assessment and Risk Management Principles for Superfund Sites* (also available at the above web site). Additional information on coordinating with states and tribes can be found in OSWER Directive 9375.3-03P *The Plan to Enhance the Role of States and Tribes in the Superfund Program* (http://www.epa.gov/superfund/states/strole/index.htm).

4. Develop and Refine a Conceptual Site Model that Considers Sediment Stability.

A conceptual site model should identify all known and suspected sources of contamination, the types of contaminants and affected media, existing and potential exposure pathways, and the known or potential human and ecological receptors that may be threatened. This information is frequently summarized in pictorial or graphical form, backed up by site-specific data. The conceptual site model should be prepared early and used to guide site investigations and decision-making. However, it should be updated periodically whenever new information becomes available, and EPA's understanding of the site problems increases. In addition, it frequently can serve as the centerpiece for communication among all stakeholders.

A conceptual site model is especially important at sediment sites because the interrelationship of soil, surface and groundwater, sediment, and ecological and human receptors is often complex. In addition, sediments may be subject to erosion or transport by natural or man-made disturbances such as floods or engineering changes in a waterway. Because sediments may experience temporal, physical, and chemical changes, it is especially important to understand what contaminants are currently available to humans and wildlife, and whether this is likely to change in the future under various scenarios. The risk assessor and project manager, as well as other members of the site team, should communicate early and often to ensure that they share a common understanding of the site and the basis for the present and future risks. The May 1998 EPA *Guidelines for Ecological Risk Assessment* (Federal Register 63(93) 26846-26924, http://www.epa.gov/superfund/programs/risk/tooleco.htm), the 1997 Superfund Guidance *Ecological Risk Assessment Guidance for Superfund: Process for Designing and Conducting Ecological Risk Assessments* (EPA 540-R-97-006, also available at the above web site), and the 1989 *Risk Assessment Guidance for Superfund (RAGS), Volume 1, Part A* (EPA 540-1-89-002, http://www.epa.gov/superfund/programs/risk/ragsa) provide guidance on developing conceptual site models.

5. Use an Iterative Approach in a Risk-Based Framework.

The NRC report (p. 52) recommends the use of a risk-based framework based on the one developed by the Presidential/Congressional Commission on Risk Assessment and Risk Management (PCCRARM, 1997, *Framework for Environmental Health Risk Management*, Vol. 1, as cited by NRC 2001). However, as recognized by the NRC (p. 60): "The framework is intended to supplement, not supplant, the CERCLA remedial process mandated by law for Superfund sites."

Although there is no universally accepted, well-defined risk-based framework or strategy for remedy evaluation at sediment sites, there is wide-spread agreement that risk assessment should play a critical role in evaluating options for sediment remediation. The Superfund program uses a flexible, risk-based framework as part of the CERCLA and NCP process to adequately characterize ecological and human health site risks. The guidances used by the

RCRA Corrective Action program (http://www.epa.gov/correctiveaction/resource/guidance) also recommend a flexible risk-based approach to selecting response actions appropriate for the site.

EPA encourages the use of an iterative approach, especially at complex contaminated sediment sites. As used here, an iterative approach is defined broadly to include approaches which incorporate testing of hypotheses and conclusions and foster re-evaluation of site assumptions as new information is gathered. For example, an iterative approach might include pilot testing to determine the effectiveness of various remedial technologies at a site. As noted in the NRC report (p. 66): "Each iteration might provide additional certainty and information to support further risk-management decisions, or it might require a course correction."

An iterative approach may also incorporate the use of phased, early, or interim actions. At complex sediment sites, site managers should consider the benefits of phasing the remediation. At some sites, an early action may be needed to quickly reduce risks or to control the ongoing spread of contamination. In some cases, it may be appropriate to take an interim action to control a source, or remove or cap a hot spot, followed by a period of monitoring in order to evaluate the effectiveness of these interim actions before addressing less contaminated areas.

The NRC report makes an important point when it notes (p. 256): "The committee cautions that the use of the framework or other risk-management approach should not be used to delay a decision at a site if sufficient information is available to make an informed decision. Particularly in situations in which there are immediate risks to human health or the ecosystem, waiting until more information is gathered might result in more harm than making a preliminary decision in the absence of a complete set of information. The committee emphasizes that a 'wait-and-see' or 'do-nothing' approach might result in additional or different risks at a site."

6. Carefully Evaluate the Assumptions and Uncertainties Associated with Site Characterization Data and Site Models.

The uncertainties and limitations of site characterization data, and qualitative or quantitative models (e.g., hydrodynamic, sediment stability, contaminant fate and transport, or food-chain models) used to extrapolate site data to future conditions should be carefully evaluated and described. Due to the complex nature of many large sediment sites, a quantitative model is often used to help estimate and understand the current and future risks at the site and to predict the efficacy of various remedial alternatives. The amount of site-specific data required and the complexity of models used to support site decisions should depend on the complexity of the site and the significance of the decision (e.g., level of risk, response cost, community interest). All new models and the calibration of models at large or complex sites should be peer-reviewed consistent with the Agency's peer review process as described in its Peer Review Handbook (EPA 100-B-00-001, http://www.epa.gov/ORD/spc/2peerrev.htm).

Site managers should clearly describe the basis for all models used and their uncertainties when using the predicted results to make a site decision. As recognized by the NRC report (p. 65), however, "Management decisions must be made, even when information is imperfect. There are uncertainties associated with every decision that need to be weighed, evaluated, and communicated to affected parties. Imperfect knowledge must not become an excuse for not making a decision."

7. Select Site-specific, Project-specific, and Sediment-specific Risk Management Approaches that will Achieve Risk-based Goals.

EPA's policy has been and continues to be that there is no presumptive remedy for any contaminated sediment site, regardless of the contaminant or level of risk. This is consistent with the NRC report's statement (p. 243) that "There is no presumption of a preferred or default risk-management option that is applicable to all PCB-contaminated-sediment sites." At Superfund sites, for example, the most appropriate remedy should be chosen after considering site-specific data and the NCP's nine remedy selection criteria. All remedies that may potentially meet the removal or remedial action objectives (e.g., dredging or excavation, in-situ capping, in-situ treatment, monitored natural recovery) should be evaluated prior to selecting the remedy. This evaluation should be conducted on a comparable basis, considering all components of the remedies, the temporal and spatial aspects of the sites, and the overall risk reduction potentially achieved under each option.

At many sites, a combination of options will be the most effective way to manage the risk. For example, at some sites, the most appropriate remedy may be to dredge high concentrations of persistent and bioaccumulative contaminants such as PCBs or DDT, to cap areas where dredging is not practicable or cost-effective, and then to allow natural recovery processes to achieve further recovery in net depositional areas that are less contaminated.

8. Ensure that Sediment Cleanup Levels are Clearly Tied to Risk Management Goals.

Sediment cleanup levels have often been used as surrogates for actual remediation goals (e.g., fish tissue concentrations or other measurable indicators of exposure relating to levels of acceptable risk). While it is generally more practical to use measures such as contaminant concentrations in sediment to identify areas to be remediated, other measures should be used to ensure that human health and/or ecological risk reduction goals are being met. Such measures may include direct measurements of indigenous fish tissue concentrations, estimates of wildlife reproduction, benthic macroinvertebrate indices, or other "effects endpoints" as identified in the baseline risk assessment.

As noted in the NRC report (p. 123), "The use of measured concentrations of PCBs in fish is suggested as the most relevant means of measuring exposures of receptors to PCBs in contaminated sediments." For other contaminants, other measures may be more appropriate.

For many sites, achieving remediation goals, especially for bioaccumulative contaminants in biota, may take many years. Site monitoring data and new scientific information should be considered in future reviews of the site (e.g., the Superfund five-year review) to ensure that the remedy remains protective of human health and the environment.

9. Maximize the Effectiveness of Institutional Controls and Recognize their Limitations.

Institutional controls, such as fish consumption advisories and waterway use restrictions, are often used as a component of remedial decisions at sediment sites to limit human exposures and to prevent further spreading of contamination until remedial action objectives are met. While these controls can be an important component of a sediment remedy, site managers should recognize that they may not be very effective in eliminating or significantly reducing all exposures. If fish consumption advisories are relied upon to limit human exposures, it is very important to have public education programs in place. For other types of institutional controls, other types of compliance assistance programs may also be needed (e.g., state/local government coordination). Site managers should also recognize that institutional controls seldom limit ecological exposures. If monitoring data or other site information indicates that institutional controls are not effective, additional actions may be necessary.

10. Design Remedies to Minimize Short-term Risks while Achieving Long-term Protection.

The NRC report notes (p. 53) that: "Any decision regarding the specific choice of a risk management strategy for a contaminated sediment site must be based on careful consideration of the advantages and disadvantages of available options and a balancing of the various risks, costs, and benefits associated with each option." Sediment cleanups should be designed to minimize short-term impacts to the extent practicable, even though some increases in short-term risk may be necessary in order to achieve a long-lasting solution that is protective. For example, the long-term benefits of removing or capping sediments containing persistent and bioaccumulative contaminants often outweigh the additional short-term impacts on the already-affected biota.

In addition to considering the impacts of each alternative on human health and ecological risks, the short-term and long-term impacts of each alternative on societal and cultural practices should be identified and considered, as appropriate. For example, these impacts might include effects on recreational uses of the waterbody, road traffic, noise and air pollution, commercial fishing, or disruption of way of life for tribes. At some sites, a comparative analysis of impacts such as these may be useful in order to fully assess and balance the tradeoffs associated with each alternative.

11. Monitor During and After Sediment Remediation to Assess and Document Remedy Effectiveness.

A physical, chemical, and/or biological monitoring program should be established for sediment sites in order to determine if short-term and long-term health and ecological risks are being adequately mitigated at the site and to evaluate how well all remedial action objectives are being met. Monitoring should normally be conducted during remedy implementation and as long as necessary thereafter to ensure that all sediment risks have been adequately managed. Baseline data needed for interpretation of the monitoring data should be collected during the remedial investigation.

Depending on the risk management approach selected, monitoring should be conducted during implementation in order to determine whether the action meets design requirements and sediment cleanup levels, and to assess the nature and extent of any short-term impacts of remedy implementation. This information can also be used to modify construction activities to assure that remediation is proceeding in a safe and effective manner. Long-term monitoring of indicators such as contaminant concentration reductions in fish tissue should be designed to determine the success of a remedy in meeting broader remedial action objectives. Monitoring is generally needed to verify the continued long-term effectiveness of any remedy in protecting human health and the environment and, at some sites, to verify the continuing performance and structural integrity of barriers to contaminant transport.

IV. IMPLEMENTATION

EPA RPMs, OSCs, and RCRA Corrective Action project managers should immediately begin to use this guidance at all sites where the risks from contaminated sediment are being investigated. EPA expects that Federal facility responses conducted under CERCLA or RCRA will also be consistent with this directive. This consultation process does not apply to Time-Critical or emergency removal actions or to sites with only sediment-like materials in wastewater lagoons, tanks, storage or containment facilities, or drainage ditches.

Consultation Process for CERCLA Sites

To help ensure that Regional site managers appropriately consider these principles *before* site-specific risk management decisions are made, this directive establishes a two-tiered consultation procedure that will apply to most contaminated sediment sites. The consultation process applies to all proposed or listed NPL sites where EPA will sign or concur on the ROD, all Non-Time-Critical removal actions where EPA will sign or concur on the Action Memorandum, and all "NPL-equivalent" sites where there is or will be an EPA-enforceable agreement in place.

Tier 1 Process

Where the sediment action(s) for the entire site will address more than 10,000 cubic yards or five acres of contaminated sediment, Superfund RPMs and OSCs should consult with their appropriate Office of Emergency and Remedial Response (OERR) Regional Coordinator at least 30 days before issuing for public comment a Proposed Plan for a remedial action or an Engineering Evaluation/Cost Analysis (EE/CA) for a Non-Time-Critical removal action.

This consultation entails the submission of the draft proposed plan or draft EE/CA, a written discussion of how the above 11 principles were considered, and basic site information that will assist OERR in tracking significant sediment sites. If the project manager has not received a response from OERR within two weeks, he or she may assume no further information is needed at this time. EPA believes that this process will help promote nationally consistent approaches to evaluate, select and implement protective, scientifically sound, and cost-effective remedies.

Tier 2 Process

This directive also establishes a new technical advisory group (Contaminated Sediments Technical Advisory Group–CSTAG) that will monitor the progress of and provide advice regarding a small number of large, complex, or controversial contaminated sediment Superfund sites. The group will be comprised of ten Regional staff and approximately five staff from OSWER, OW, and ORD. For most sites, the group will meet with the site manager and the site team several times throughout the site investigation, response selection, and action implementation processes. For new NPL sites, the group will normally meet within one year after proposed listing. It is anticipated that for most sites, the group will meet annually until the ROD is signed and thereafter as needed until all remedial action objectives have been met. The specific areas of assistance or specific documents to be reviewed will be decided by the group on a case-by-case basis in consultation with the site team. For selected sites with an on-going RI/FS or EE/CA, the group will be briefed by the site manager some time in 2002 or 2003. Reviews at sites with remedies also subject to National Remedy Review Board (NRRB) review will be coordinated with the NRRB in order to eliminate the need for a separate sediment group review at this stage in the process.

Consultation Process for RCRA Corrective Action Facilities

Generally, for EPA-lead RCRA Corrective Action facilities where a sediment response action is planned, a two-tiered consultation process will also be used. Where the sediment action(s) for the entire site will address more than 10,000 cubic yards or five acres of contaminated sediment, project managers should consult with the Office of Solid Waste's Corrective Action Branch at least 30 days before issuing a proposed action for public comment. This consultation entails the submission of a written discussion of how the above 11 principles

were considered, and basic site information that will assist OSW in tracking significant sediment sites.

If the project manager has not received a response from OSW within two weeks, he or she may assume no further information is needed. States are also encouraged to follow these procedures. For particularly large, complex, or controversial sites, OSW will likely call on the technical advisory group discussed above.

EPA also recommends that both state and EPA project managers working on sediment contamination associated with Corrective Action facilities consult with their colleagues in both RCRA and Superfund to promote consistent and effective cleanups. EPA believes this consultation would be particularly important for the larger-scale sediment cleanups mentioned above.

EPA may update this guidance as more information becomes available on topics such as: the effectiveness of various sediment response alternatives, new methods to evaluate risks, or new methods for characterizing sediment contamination. For additional information on this guidance, please contact the OERR Sediments Team Leader (Stephen Ells at 703 603-8822) or the OSW Corrective Action Programs Branch Chief (Tricia Buzzell at 703 308-8632).

NOTICE: This document provides guidance to EPA Regions concerning how the Agency intends to exercise its discretion in implementing one aspect of the CERCLA and RCRA remedy selection process. This guidance is designed to implement national policy on these issues. Some of the statutory provisions described in this document contain legally binding requirements. However, this document does not substitute for those provisions or regulations, nor is it a regulation itself. Thus it cannot impose legally binding requirements on EPA, states, or the regulated community, and may not apply to a particular situation based upon the circumstances. Any decisions regarding a particular situation will be made based on the statutes and regulations, and EPA decision-makers retain the discretion to adopt approaches on a case-by-case basis that differ from this guidance where appropriate. Interested parties are free to raise questions and objections about the substance of this guidance and the appropriateness of the application of this guidance to a particular situation, and the Agency welcomes public input on this document at any time. EPA may change this guidance in the future.

cc: Michael H. Shapiro
Stephen D. Luftig
Larry Reed
Elizabeth Cotsworth
Jim Woolford

Jeff Josephson, Superfund Lead Region Coordinator, USEPA Region 2
Carl Daly, RCRA Lead Region Coordinator, USEPA Region 8
Peter Grevatt
NARPM Co-Chairs
OERR Records Manager, IMC 5202G
OERR Documents Coordinator, HOSC 5202G
RCRA Key Contacts, Regions 1 - 10

CONTAMINATED SEDIMENT REMEDIATION GUIDANCE FOR HAZARDOUS WASTE SITES:

APPENDIX B: USGS 100-YEAR FLOOD FACT SHEET

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Fact Sheet 229-96

The "1OO-Year Flood"

(Larger Version, 149K GIF)

Photo by Geff Hinds, Tacoma News Tribune

Flood designations are based on statistical averages, *not* on the number of years between big floods.

The estimates are only as good as the available data. Flood designations are updated as more data are collected or when the conditions change in a river basin.

BIG FLOODS COULD HAPPEN AGAIN IN WASHINGTON DURING ANY YEAR

Rivers across the Nation seem to be rising to record flood levels almost every year. In Washington, more than one 100-year flood has happened on a few rivers in just the past several years. How can 100-year floods happen so often?

WHY DON'T THESE FLOODS HAPPEN EVERY 100 YEARS?

The term "100-year flood" is misleading because it leads people to believe that it happens only once every 100 years. The truth is that an uncommonly big flood can happen any year. The term "100-year flood" is really a statistical designation, and there is a **1-in-100 chance** that a flood this size will happen during any year. Perhaps a better term would be the "1-in-100 chance flood."

The actual number of years between floods of any given size varies a lot. Big floods happen irregularly because the climate naturally varies over many years. We sometimes get big floods in successive or nearly successive years with several very wet years in a row.

HOW ARE FLOODS DESIGNATED?

Scientists collect data and study past floods to get a minimum of 10 years of information about the river;

a longer record provides a better estimate of the "1-in-100 chance flood." Scientists use statistics and observe how frequently different sizes of floods occurred, and the average number of years between them, to determine the probability that a flood of any given size will be equalled or exceeded during any year.

MANY FLOOD DESIGNATIONS WILL CHANGE OVER TIME

As more data are collected, or when a river basin is altered in a way that affects the flow of water in the river, scientists re-evaluate the frequency of flooding. Dams and urban development are examples of some man-made changes in a basin that affect floods.

THE USGS COLLECTS ESSENTIAL DATA FOR UNDERSTANDING FLOODS

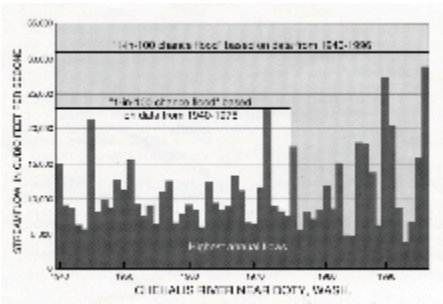
Scientists at the USGS measure streamflow in rivers across the State during every major flood. After flood waters recede, the USGS may be funded to locate and survey "high-water marks" where debris and mud lines indicate the highest extent of flood waters. These post-flood surveys are used to estimate maximum flows at sites that could not be reached during the floods and also to map the areas covered by the floods.

Streamflow data that have been collected since 1975 on the Chehalis River near Doty indicate that the estimated streamflow of "1-in-100 chance flood" is higher than it was 20 years ago.

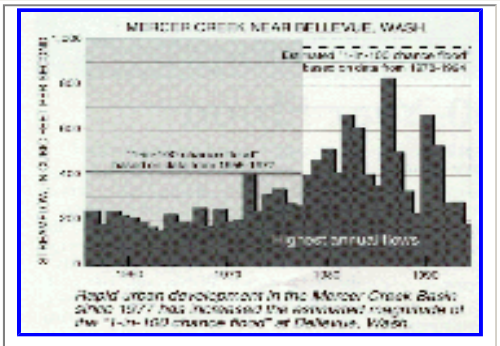
The eariler flood designation was accurate on the basis of the data that were available at the time; more large floods happened after 1975 than from 1940-1975.

The change in the flood designation after 20 years of additional data collection highlights the importance of continued river monitoring.

Annual peak flow data for 1995 and 1996 are provisional and may change.



(Larger Version, 182K GIF)



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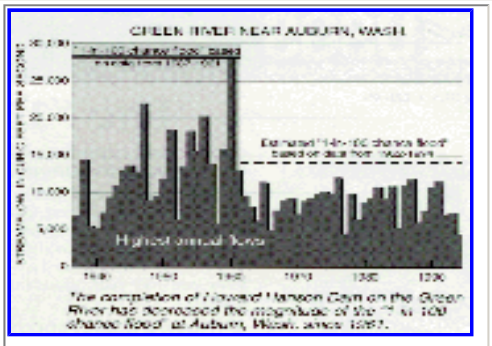
Rapid urban development in the Mercer Creek Basin since 1977 has increased the estimated magnitude of the "1-in-100 chance flood" at Bellevue, Wash.



(Larger Version, 182K GIF)

The completion of Howard Hanson Dam on the Green River has decreased the magnitude of the "1-in-100 chance flood" at

Auburn, Wash. since 1961.

DO YOU LIVE ON THE FLOODPLAIN?

The areas affected by past floods have been mapped by the Federal Emergency Management Agency and many other government agencies. Because of continuing changes in river channels and land use in many basins, the maps may not reflect current information for your area. Inquire at your City or County Building or Planning Department.

If you live on the designated floodplain, the chances are about 1 in 2 that you will experience a flood during your lifetime. Prepare for a flood as you would for any natural disaster, and make evacuation plans for your family.

FLOODS WILL CONTINUE TO HAPPEN

Although we can lessen effects of some floods, they are part of the natural cycle of every river and benefit instream habitats by moving material downstream and renewing streambeds. As floods get bigger and spread farther, flood waters slow and deposit sediment on the floodplain. This natural process created valuable farmlands in river valleys of the Pacific Northwest over thousands of years.

Glossary of Flood Terms

A **flood** is any relatively high streamflow that overtops the natural or artificial banks of a river.

Discharge is another term for streamflow; it is the measured volume of water that moves past a point in the river in a given amount of time. Discharge is usually expressed in cubic feet per second.

One **cubic foot per second** (cfs) is about 450 gallons per minute. The average discharge of the Columbia ~ River in September at The Dalles, Oregon, is about 120,000 cfs, which would fill the Seattle Kingdome in less than 10 minutes. The average discharge of the Puyallup River in September is about 1,700 cfs at Puyallup, Wash.

The **floodplain** is the relatively flat lowland that borders a river, usually dry but subject to flooding. Floodplain soils actually are former flood deposits.

The *average* number of years between floods of a certain size is the **recurrence interval** or **return period.** The *actual* number of years between floods of any given size varies a lot because of the naturally changing climate.

A **hydrograph** is a graph that shows changes in discharge or river stage over time. The time scale may be in minutes, hours, days, months, years, or decades.

The **river stage** is the height of the water in the river, measured relative to an arbitrary fixed point.

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from U.S. Department of the Interior, U.S. Geological Survey, Fact Sheet FS-229-96

For more information contact any of the following:

The U.S. Geological Survey has served the public and Federal, State, and local goverments since 1879 by collecting, analyzing, and publishing detailed information about the Nation's mineral, land, and water resources. The USGS has been studying the water resources of Washington State since the turn of the century. This information is in a variety of map, book, electronic, and other formats and is available by contacting:

U.S. Geological Survey
1201 Pacific Ave., #600
Tacoma, WA 98402
(206) 593-6510
Fax: (206) 593-6514
Email:dc_wa@usgs.gov

Selected data and interpretive reports are available on the USGS Washington "home page" on the World Wide Web at http://wwwdwatcm.wr.usgs.gov/

CONTAMINATED SEDIMENT REMEDIATION GUIDANCE FOR HAZARDOUS WASTE SITES:

APPENDIX C: RADIOMETRIC DATING OF SEDIMENT

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RADIOMETRIC DATING OF SEDIMENT

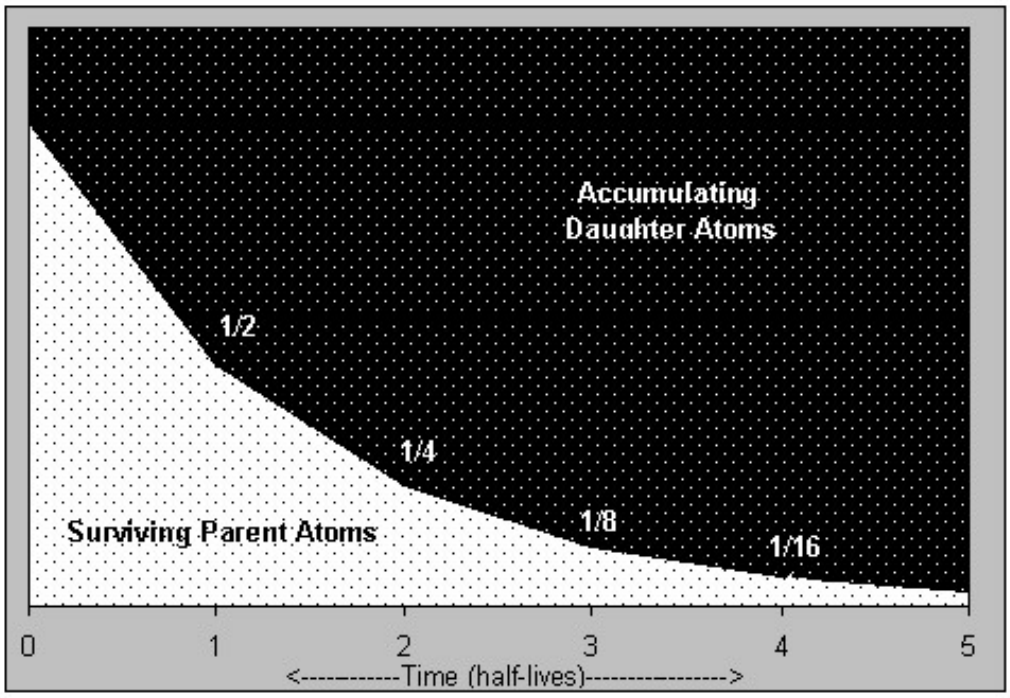
C.1 BACKGROUND

Radiometric dating is a technique that has been in use for decades in fields as diverse as geology and archeology. This technique relies on measuring the known rate of isotope decay, or half-life, as a function of time and depth of sampling. Briefly stated, when the half-life of a radionuclide is known, then observing the distribution of the radionuclide and its breakdown products along a sample core can provide significant insight into the chronology of soil formation within the sample core.

C.2 RADIOMETRIC DATING

The purpose of this section is to describe the process of radioactive decay and its relationship to radiometric dating. Highlight D-1 depicts the decay of a hypothetical parent isotope and the formation of a radiogenic daughter. With time, the decay of a radioactive parent produces radiogenic daughter atoms within the material in which the isotope resides (i.e., soil, sediment, etc). Knowing the decay rate of the parent, the time since the parent material was formed can be measured in terms of the ratio of daughter and parent nuclides in the material. In Highlight D-1, it can be seen that this ratio is unique for any point in time.

Highlight C-1: Radioactive Decay of a Parent Isotope and Radiogenic Formation of a Daughter Isotope



The accuracy of this method of dating relies on two assumptions. First, the system in which radioactive decay occurs must be closed. In order for this method to produce accurate assessments of time, it is important that neither parent nor daughter atoms have been introduced or removed by factors other than radioactive decay. This assumption is more important when daughter atoms have been introduced from outside the system, than when parent atoms have an external origin. When daughter atoms are introduced from sources outside of the system, the ratio of daughter to parent isotopes increases and estimates of the age of material will be too large. The violation of this assumption and its resolution will play an important role in estimating sedimentation rates and is discussed in detail in the next section. The second assumption is that no daughter atoms were present in the system when the parent isotope was formed. Again, the failure of this assumption would result in dating estimates that were larger than the actual age of the material.

There are three major systems of radioactive decay that have been used for radiometric dating (Eicher 1976). A system is usually identified by its parent-daughter (or granddaughter) relationship, such as the potassium-argon, rubidium-strontium, and uranium-lead. Within each system, different isotopes may be used as geochronometers, such as potassium-40, rubidium87, uranium-235 and uranium-238 and the daughter products may be chosen based on physical characteristics, such as solubility and half-life.

There are a large number of unstable isotopes that could be used for radiometric dating of sediments, but many may be unsuitable for such an application. Some of the reasons for unsuitability include very long or short half-lives, ubiquity in nature, solubility in water, or poor understanding of their physical characteristics. The selection of a radionuclide for radiometric dating should depend on the following five requirements (USGS 1998):

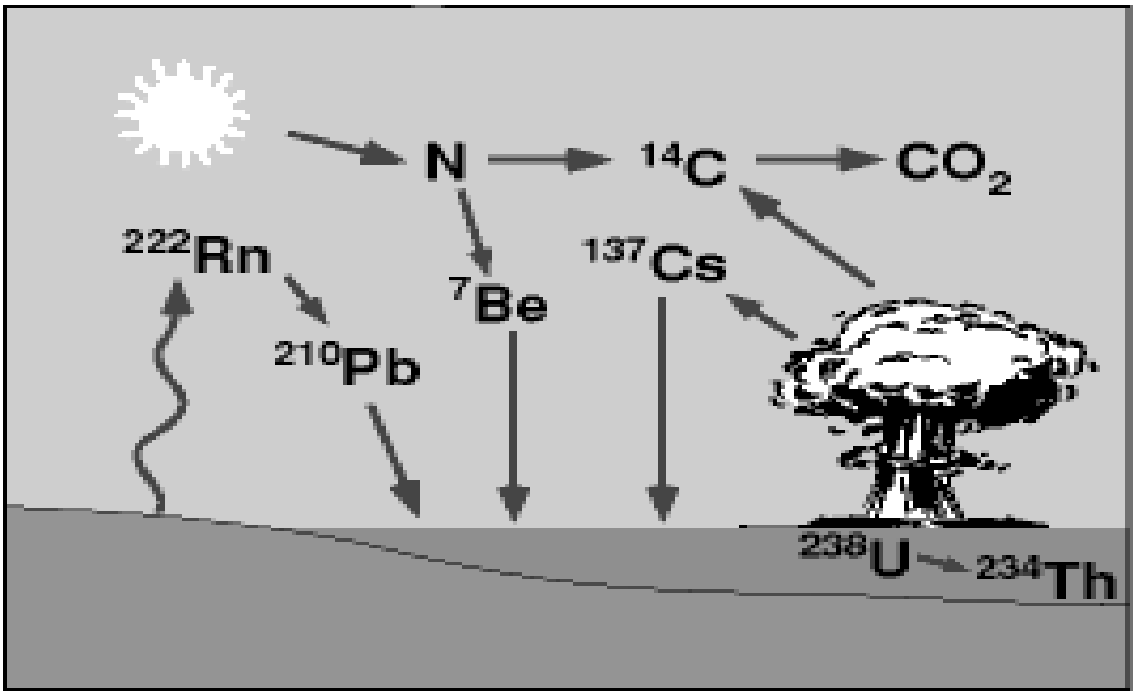
- The chemistry of the isotope (element) is known;
- The half-life is known;
- The initial amount of the isotope per unit of substrate is known or accurately estimated;
- The only change in concentration of the isotope is due to radioactive decay; and
- In order to be useful, it must be relatively easy to measure.

Given these requirements, four isotopes are commonly used to measure sedimentary dynamics over a time period from 100 to 150 years: Beryllium-7 (^{7}Be), Carbon-14 (^{14}C), Cesium-137 (^{137}Cs), and Lead-210 (^{210}Pb). The following sections describe each of these radionuclides and their use in radiometric dating of sediments (USGS 1998). Highlight C-2 presents a graphical representation of the radioactive decay chains for each of these isotopes.

<u>Beryllium-7</u>

^{7}Be is a naturally produced radioisotope that is formed by cosmic ray bombardment of atmospheric nitrogen (N) and oxygen (O). It is removed from the atmosphere through precipitation. Beryllium is a highly reactive element and becomes rapidly and tightly bound to sediments. ^{7}Be has a half-life of 53 days, which makes it effective for dating sediments of an age of about 1 year. Detection of its presence is a reliable indicator that the substance was in contact with the atmosphere within the past

Highlight C-2: Radioactive Decay of Common Isotopes



year. This information is important, as it can be used to calibrate other radiometric dating methods to date and define sedimentary behavior.

Carbon-14

^{14}C is produced in the Earth's atmosphere by the interaction of cosmic ray particles with nitrogen (N), oxygen (O), and carbon (C). Of these elements, nitrogen is the most important in terms of the amount of ^{14}C produced. ^{14}C was also produced by thermonuclear activity (bomb testing), which contributed significantly to ^{14}C levels in the atmosphere, reaching a peak in 1963 (Northern Hemisphere) and 1964 (Southern Hemisphere). All ^{14}C produced is rapidly oxidized to CO_2 and is assimilated into the carbon cycle. ^{14}C has a half-life of 5,730 years and has an effective range of applicability of 100 to 70,000 years for dating organic material. The amount of bomb-produced carbon is determined by comparing present radiocarbon activity to 1950 carbon activity, the date established by convention as the baseline for all radiocarbon dating. Post-1952 carbon values are reported as a percentage of modern (that is, 1950) carbon, and denoted as ^{14}C.

Cesium-137

Cesium has only one naturally occurring stable isotope, ^{133}Cs. The radiogenic isotope ^{137}Cs has been used in hydrologic studies. ^{137}Cs is produced from detonation of nuclear weapons and emissions from nuclear power plants. Beginning in 1954 with the commencement of nuclear testing, ^{137}Cs was released into the atmosphere where it is absorbed readily into solution and returns to earth in the form of precipitation. Once ^{137}Cs enters the ground water, it is deposited on soil surfaces and is removed from the landscape primarily by particle transport. As a result, the input function of these isotopes can be estimated as a function of time. The resulting activities of ^{137}Cs in sediments can thus be used to understand the

history of sediments by dating cores and estimating rates of sediment deposition and thus erosion within the watershed.

^{134}Cs and ^{135}Cs have also been used in hydrology as a measure of cesium output by the nuclear power industry. This isotope is used because, while it is less prevalent than either ^{133}Cs or ^{137}Cs, both are be produced solely by nuclear reactions.

Lead-210

^{210}Pb, with a half-life of 22.3 years, is ideal for most ecosystem studies. A member of the ^{238}U series, ^{210}Pb forms by the decay of its intermediate gaseous parent, radon-222. ^{222}Rn, formed by the decay of radium, escapes into the atmosphere by recoil or by diffusion, and rapidly decays to form ^{210}Pb. This isotope has a residence time in the atmosphere of about 10 days before it is removed by precipitation. The highly reactive lead is then rapidly adsorbed to and incorporated into the depositing sediment. ^{210}Pb is also formed within sediments by the decay of ^{226}Ra. Dates of sediment deposition are calculated by determining the decrease in ^{210}Pb activity at each selected sediment interval; this decrease is a function of time. If the initial concentration of ^{210}Pb is known, or is estimated using ^{7}Be data, then the "age" of a sediment interval can be calculated.

C.3 RADIOMETRIC DATING FOR ESTIMATING SEDIMENTATION RATES

Radiometric dating in a lacustrine, estuarine, or marine setting is marked primarily for its violation of one of the primary assumptions, that the "system" is closed and there is no introduction nor loss of daughter products through other than radiogenic transformation of the parent material already present in the material. The system is defined as that area of sediments which are under evaluation. Such an area may be a river reach, a tidal wetland, or any other natural hydrologic catchment area. The accumulation of sediments in any such area will involve the introduction of both parent and daughter isotopes which were formed upstream in the migratory sediments' original location. Thus, when a core is taken from an area of interest, the core will contain not only the isotopes that were deposited through aerial deposition within the catchment area but also isotopes that were transported into the area as a result of sedimentary deposition. Some isotopes also form within the material of interest, itself, as a result of radiogenic decay of parent material that was already present in the material of interest. For example, ^{210}Pb can be deposited in sediments as precipitation, but it also forms as a daughter product from the radiogenic decay of ^{226}Ra within the sediments. Thus, within a system in which ^{210}Pb is used as a geochronometer there are two original sources of ^{210}Pb, and then the ^{210}Pb that has been introduced into the system as a result of sedimentation. Dating such cores requires integrating information from multiple sources or making a series of assumptions. The accuracy of the effort will be sensitive to any assumptions that are made, and independent verification of the radiometric dating will greatly improve its accuracy.

Methods have been developed, primarily by the U.S. Geologic Survey (USGS), to inventory, or separate out the various contributing sources of isotopes to a natural catchment area. First, there are multiple sources of data related to the rates of aerial deposition of many isotopes. Depending on the isotope, institutions such as universities or government agencies, have performed many studies, some long-term, directed at measuring rates of aerial deposition of radioactive isotopes. For instance, in the South Florida area, the University of Miami has tracked aerial deposition of ^{210}Pb and ^{137}Cs for nearly a decade. Under the 1996 Comprehensive Test Ban Treaty, several organizations collect and monitor information on ^{137}Cs deposition at numerous sites in the U.S. Other organizations are interested in radiometric dating to support archeological and paleontological investigations. These sources of

information may be used to establish rates of aerial deposition of the isotope to be used in the radiometric dating of sediments.

The second source of an isotope maybe its formation within the sediments of concern. In such cases, the parent material can be directly measured. Using known rates of radioactive decay, an estimate of the amount of daughter product that would be produced by the radiogenic decay of the parent can be generated. This level of daughter product material is often called the "supported" amount of the isotope, or the amount of an isotope that should be present given the amount of the parent material present.

The final source of an isotope within a natural catchment area is that which is introduced through sedimentation, or transported into the system from sources upstream. This is the amount of sediment that is most of interest to site managers at sites whose remedies include natural capping. The amount of sediment being transported into a system can be measured by the amount of isotope that is present but could not have been produced within the system, given the amount of parent material present. Often, this amount is called the "unsupported" amount of the isotope.

Radiometric dating of a catchment system requires establishing an inventory of the isotope present and the related daughter products and determining the amount of the inventory that can be attributed to 1) aerial deposition, 2) in situ formation, and 3) sedimentary transport. Given that the first two can be either estimated based on studies of the local area or directly measured, the amount of the third component can only be attributed to sedimentation.

Important Considerations

There are some factors of which investigators using radiometric dating methods should be aware. Some to consider will include the following:

- First, if no studies are available to establish rates of aerial deposition, then assumptions should be made. Such assumptions should be based on as much relevant information as possible, and the accuracy of the dating method will be sensitive to the validity of those assumptions. For instance, if the assumption underestimates the rate of aerial deposition, then the radiometric dating method will overestimate the amount of sediment being transported into the catchment area and the estimated rate of sedimentation will be too high;
- Second, investigators should be aware that sediment deposition is a dynamic process that reflects not only hydrologic events but also is influenced by man-made events. Furthermore, sedimentation occurs not as a homogeneous, continuous process, but in pulses over time. Therefore, extrapolating results across event short periods of time may result in inaccurate results. For example, in a rapid depositional environment, such as portions of the Chesapeake Bay where rapid urban development is clearing large tracts of land quickly, sedimentation rates may fluctuate significantly over periods as short as one to two years. Therefore, the core intervals that are used for dating should be small enough to account for such variations, usually one to five centimeters;
- Third, relying solely on measurements of isotope activity without taking into account the quality and characteristics of the sediments in which the measurements are made can significantly influence the radiometric dating results. For example, in catchment areas with little or no mixing of sediments, fine-grained sediments settle into fine laminate structures. Concentrations of isotopes within these fine laminate structures may be significantly higher than within laminates of coarser-grained materials, such as sand, and

radioactive measurements will also be higher. Thus, without taking into account that material in which the isotope has been deposited, the radiometric method will underestimate the age of the sediments; and

- Fourth, information about significant geologic, ecological, or anthropogenic events should be considered and integrated into the radiometric dating when appropriate. Large-scale housing or industrial construction over extended periods of time can introduce significant quantities of recently-deposited isotopes into the system as a result of erosion of unprotected soils. Similar information can used to benchmark ^{137}Cs levels in sediments. Knowledge of the half-life of ^{137}Cs, and that ^{137}Cs was introduced into the environment as a result of atomic bomb testing in the mid-1950s can be used to validate date estimates using ^{210}Pb as a chronometer. For example, during a study conducted by the USGS in Lake Ponchatrain, Louisiana, using ^{210}Pb as the geochronometer, the method showed that the bottom of the cores taken near the input from the Mississippi River were of about 150 years of age. However, additional testing of the material at the bottom of the cores indicated the presence of ^{137}Cs, which has only been present in the environment since the mid-1950s. A USGS study of the South Florida Bay area used the introduction of the Australian Pine to benchmark ^{210}Pb levels in core samples taken in peat soils. The introduction of the Australian Pine occurred during the early 1900s. Because of the minimal mixing that can be expected in such soils, investigators were able to establish appropriate rates of supported isotope activity with a significant degree of accuracy.

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