United States
Environmental
Protection Agency

Contaminated Sediment Remediation Guidance for Hazardous Waste Sites

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NOTICE

This document provides 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 provides information 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, this document does 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 document suggests approaches that may be used at particular sites as appropriate, given site-specific circumstances. EPA made many changes to this document based on public comment on a draft document. Even though the document is now final, however, EPA welcomes 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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Executive Summary

In 2004, the U.S. Environmental Protection Agency (EPA) released the *Updated Report on The Incidence and Severity of Sediment Contamination in Surface Waters of the United States: National Sediment Quality Survey*, that identifies areas in all regions of the country where sediment may be contaminated at potentially harmful levels (U.S. EPA 2004a). Contaminated sediment has significantly impaired the navigational and recreational uses of rivers and harbors in the U.S. (NRC 1997 and 2001) and is a contributing factor in many of the 2,800 fish consumption advisories nationwide (U.S. EPA 2003a). As of 2001, EPA had decided to take action to clean up sediment at approximately 140 sites under the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) and additional sites under the Resource Conservation and Recovery Act [(RCRA), U.S. EPA 2001a]. The remedies for more than 65 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 remedy 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. Although aspects related to characterization and risk assessment are summarized, the guidance focuses on considerations regarding feasibility studies and remedy selection for sediment. 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 on specific aspects of contaminated sediment assessment and remediation.

Chapter 1, Introduction, describes the general backdrop for contaminated 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 water bodies containing contaminated sediment should be given understandable information about the safety of their activities, and be provided significant opportunities for involvement in the EPA's decision-making process for 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 water body 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 re-contamination. 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 contaminated 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, contaminant fate and transport, 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) and contaminant fate and transport (e.g., transformation and movement of contaminants) 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 verified models that are in the public domain, calibrated and validated 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), evaluating long-term effectiveness and permanence, estimating cost, and using institutional controls. Major remedies 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 each of the three major remedies (sediment removal, capping, and MNR) at every site where they might be appropriate. At large or complex sites, project managers have found that alternatives that combine a variety of approaches 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. When evaluating alternatives with respect to the long-term effectiveness and permanence criterion, it is important to remember that each of the three major remedies may be capable of reaching acceptable levels of long-term effectiveness and permanence, and that site-specific characteristics must be reviewed during the alternatives evaluation to ensure that the alternative selected will be effective in that environment. 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 remedy, and briefly discusses enhanced natural recovery through thin-layer placement. The chapter defines MNR as a remedy 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), ongoing processes that reduce risk from the contaminated sediment, 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. Evaluation of MNR should usually be based on site-specific data collected over a number of years, including multiple lines of evidence. Project managers should evaluate the long-term stability of the sediment bed and the mobility of contaminants within it. 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 risk reduction approach.

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 involving minimal disruption to the existing human and biological community. Because no construction or infrastructure is needed, it is generally much less disruptive to communities than active remedies. 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 remedies; and its effectiveness may be more uncertain than active remedies. As any risk reduction approach that takes a period of time to reach remediation goals, remedies that include MNR frequently rely upon institutional controls, such as fish consumption advisories, which may have limited effectiveness in controlling human exposure during the recovery period.

Chapter 5, In-Situ Capping, summarizes the major capping technologies and describes the site conditions that are important 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 that remains in place. Caps are generally constructed of clean sediment, sand, or gravel, but can also include geotextiles, liners, or the addition of material, such as organic carbon, to attenuate the flux of contaminants. A cap reduces risk through the following 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 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 not properly maintained or if contaminants move through the cap in significant amounts. Another potential disadvantage to in-situ capping may be that in some situations a preferred 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, staging, and disposal of dredged or excavated contaminated 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, staging, de-watering, water treatment, sediment transport, and sediment treatment, re-use, or disposal. Transport and disposal options for contaminated sediment are sometimes complex and controversial and should be discussed with stakeholders early in the project. In some cases, specialized methods of operation or equipment may be needed in order to minimize resuspension of sediment and transport of contaminants. Project managers should make realistic, site-specific predictions of residual contamination based on pilot studies or comparable sites. Where effective debris removal and over-dredging (removal of some clean sediment below the contaminated sediment) are possible, residual contamination is generally lower than where these practices are not possible. In some environments, excavation may lead to lower levels of residual contamination than dredging, although site preparation for excavation can be more complex due to the need for re-routing or draining the water body.

Chapter 6 also discusses the major advantages and disadvantages of contaminated sediment removal by dredging and excavation. One of the principal advantages of removing contaminated sediment from the aquatic environment is that, if cleanup levels are achieved, 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 also allows maximum flexibility regarding future use of a water body. Although remedies at sites with bioaccumulative contaminants usually require the development or continuation of fish consumption advisories for a period of time after removal, other types of institutional controls might not be necessary to protect a cap or layer of natural sedimentation. 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 the NCP's remedy selection framework, including applying the NCP expectations (40 CFR §300.430(a)(1)(iii)) to CERCLA contaminated sediment remedies, considering a no-action alternative, choosing among sediment remedies and comparing net risk reduction, 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 remedy for contaminated sediment should be based on careful consideration of the advantages and disadvantages of each available option and a comparison among them. This chapter includes two summary tables to help with this process: one describes site conditions especially conducive to each of the three major remedies for sediment (MNR, capping, dredging), and the other summarizes key differences between the three major remedies with respect to the NCP's nine remedy selection criteria. 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.

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. This chapter presents the key steps in designing and conducting a monitoring program at a sediment site, introduces some of the monitoring techniques available for physical, chemical, and biological measurements, and summarizes some of the factors to consider when monitoring remedies including 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. Project managers should ensure that adequate baseline data are available for comparison to monitoring data after a remedial action and that adequate background data are available, including any continuing off-site contaminant contributions. 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 to contribute to a better understanding of technology performance at the national level.

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1.0 INTRODUCTION

1.1 PURPOSE

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 federal and state project managers considering remedial response actions or non-time-critical removal actions under the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA), more commonly known as "Superfund." 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 may also be useful to other governmental organizations and potentially responsible parties (PRPs) that are conducting a sediment cleanup under CERCLA, RCRA, or other environmental statutes, such as the Clean Water Act (CWA) or the Water Resource Development Act (WRDA). The guidance may also be useful to members of the community and their technical representatives.

This guidance can be applied to contaminated sediment 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 storage/containment facilities, or roadside ditches is not addressed. This guidance addresses both in-situ and ex-situ remedies for sediment, including monitored natural recovery (MNR), in-situ capping, and dredging and excavation. However, the science and practice of sediment remediation are rapidly evolving, especially in the area of in-situ treatment options. This guidance is not intended to limit or delay innovative or developing approaches or technologies that may reduce risk from contaminated sediment.

Consideration of materials deposited in flood plains, whether considered soil or sediment, is an important factor in reducing risk in aquatic environments. Much of the general approach recommended in this guidance can be applied to contaminated flood plains, although the technical considerations are written with aquatic sediment in mind. Control of upland soils and other upland source materials is also critical to reducing risk in aquatic environments, but in general, existing guidance should be used for these materials [e.g., the U.S. Environmental Protection Agency's (EPA's) *Soil Screening Guidance* (U.S. EPA 1996a)]. However, flood plain soils which may be a source of contamination to surface water or sediment also require consideration of fate and transport issues.

Following this introductory chapter, the guidance presents sediment-specific issues to consider during remedial investigations (see Chapter 2) and feasibility studies (see Chapter 3), followed by chapters concerning the three major remedies for sediment management (see Chapter 4, Monitored Natural Recovery; Chapter 5, In-Situ Capping; and Chapter 6, Dredging and Excavation). The guidance then presents information on selecting sediment remedies (see Chapter 7); and on monitoring sediment sites (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 alternatives (e.g., the feasibility study stage of the Superfund process) and remedy selection.

1.2 CONTAMINATED SEDIMENT

For the purposes of this guidance, contaminated sediment is soil, sand, organic matter, or other minerals that accumulate on the bottom of a water body and contain toxic or hazardous materials at levels that may adversely affect human health or the environment (U.S. EPA 1998a). Contaminants adsorbed to soil or in other forms may wash from land, be deposited from air, erode from aquatic banks or beds, or form from the 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 water bodies. In this guidance, "water body" generally includes all of these environments. Some contaminants have both anthropogenic, or man-made, sources and natural sources (e.g., many metals and some organic compounds). This guidance addresses management of contaminants present above naturally-occurring levels that may cause an unacceptable risk to humans or to ecological receptors.

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 or outfall discharges into a water body from industrial facilities, waste water treatment plants, storm water discharges, or combined sewer overflows
- Chemical spills into a water body
- Surface runoff or erosion of soil from flood plains and other contaminated sources on land, such as waste dumps, chemical storage facilities, mines and mine waste piles, and agricultural or urban areas
- Air emissions from power plants, incinerators, pesticide applications, or other sources, that may be transferred to a water body through precipitation or direct deposition
- Up welling or seepage of contaminated ground water or non-aqueous phase liquids (NAPL) into a water body
- Direct disposal from docked and dry-docked ships, or release of contaminants from in-water structures and over-water structures or ship maintenance

Organic contaminants in sediment typically adsorb to fine 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. Pore water in sediment generally is interconnected with both surface water and ground water, although the degree of interconnection may change from place to place and with flow changes in ground water and surface water.

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

In 2004, the EPA released *The Updated Report on the Incidence and Severity of Sediment Contamination in Surface Waters of the United States* (U.S. EPA 2004a). 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 2004a). States have issued approximately 2,800 advisories limiting consumption of fish and wildlife, which cover about 33 percent of the nation's total lake acreage and 15 percent of the nation's total river miles, in addition to 100 percent of the Great Lakes, in part due to sediment contamination (U.S. EPA 2003a). 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)].

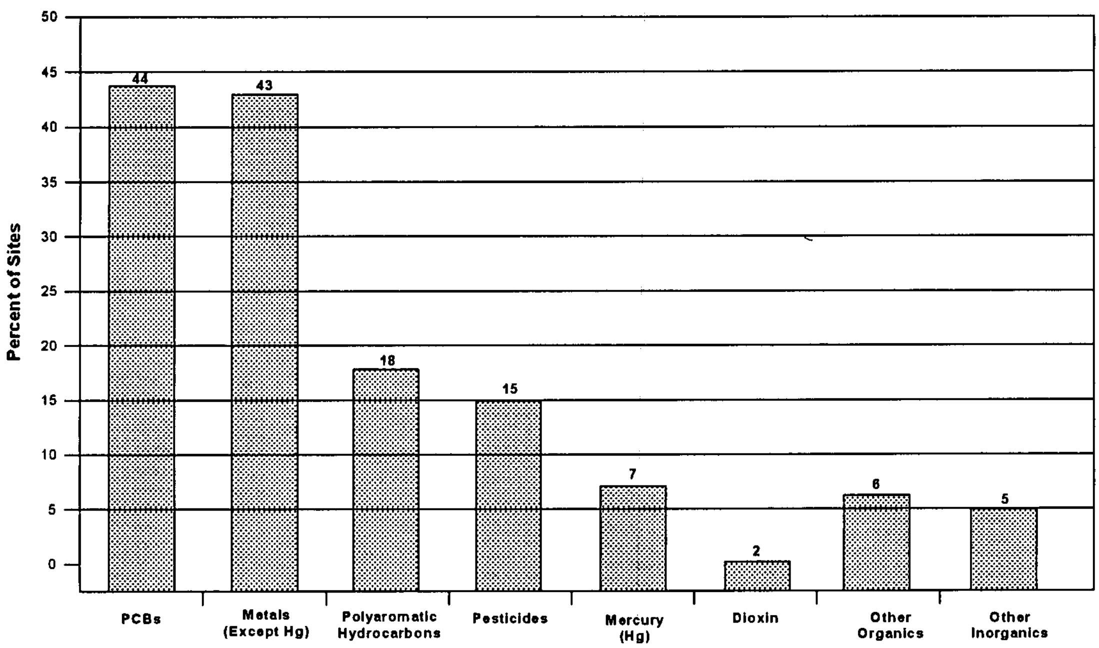
As of 2001, the Superfund program had decided to take an action to address sediment at approximately 140 sites (U.S. EPA 2001a). The remedies for more than 65 sites are large enough that they are being tracked at the national level [see the Office of Superfund Remediation and Technology Innovation's (OSRTI's) Contaminated Sediments in Superfund Web site at http://www.epa.gov/superfund/resources/sediment/sites.htm]. These sites include a wide variety of contaminants, as presented in Highlight 1-2.

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.

1.3 RISK MANAGEMENT PRINCIPLES AND REMEDIAL APPROACHES

Office of Solid Waste and Emergency Response (OSWER) Directive 9285.6-08, *Principles for Managing Contaminated Sediment Risks at Hazardous Waste Sites* (U.S. EPA 2002a, attached as Appendix A to this guidance), presents eleven risk management principles that 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. Although 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.

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



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

- Sediment sites may have a large number of sources, some of which can be ongoing and difficult to control
- The sediment environment is usually dynamic, and understanding the effect of natural forces and man-made events on sediment movement and stability, and contaminant transport, can be difficult
- Cleanup work in an aquatic environment is frequently difficult from an engineering perspective and may be 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 species or habitats
- For large sites, a number of communities with differing views and opinions may be affected
- There may be significant injuries to trustee resources at sediment sites

The eleven risk management 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 remedy selection criteria (Title 40 Code of Federal Regulations (40 CFR) §300.430(c)). The eleven principles are listed in Highlight 1-4 and are incorporated throughout this guidance. EPA's OSWER Directive 9285.6-11, supplements the eleven principles directive cited above by describing how the OSRTI Sediment Team and National Remedy Review Board are involved at large sediment sites (U.S. EPA 2004b). Copies of both directives can be found on the Superfund Web site at http://www.epa.gov/superfund/resources/sediment/documents.htm.

Highlight 1-4: Risk Management Principles Recommended for Contaminated Sediment Sites	
1.	Control sources early
2.	Involve the community early and often
3.	Coordinate with states, local governments, tribes, and natural resource trustees
4.	Develop and refine a conceptual site model that considers sediment stability
5.	Use an iterative approach in a risk-based framework
6.	Carefully evaluate the assumptions and uncertainties associated with site characterization data and site models
7.	Select site-specific, project-specific, and sediment-specific risk management approaches that will achieve risk-based goals
8.	Ensure that sediment cleanup levels are clearly tied to risk management goals
9.	Maximize the effectiveness of institutional controls and recognize their limitations
10.	Design remedies to minimize short-term risks while achieving long-term protection
11.	Monitor during and after sediment remediation to assess and document remedy effectiveness
Source: U.S. EPA 2002a	

1.3.1 Remedial Approaches

Highlight 1-5 lists the major remedies available for managing risks from contaminated sediment. Frequently, a final sediment remedy combines more than one type of approach.

Highlight 1-5: Remedial Approaches for Contaminated Sediment	
In-situ Approaches	**Ex-situ Approaches**
In-situ Capping: • Single-layer granular caps • Multi-layer granular caps • Combination granular/geotextile caps Monitored Natural Recovery: • Physical processes • Chemical processes • Biological processes Hybrid Approaches: • Thin layer placement of sand or other material to enhance recovery from natural deposition Institutional Controls: • Fish consumption advisories • Commercial fishing bans • Waterway or land use restrictions (e.g., no anchor or no wake zones; limitations on navigational dredging) • Dam or other structure maintenance agreements In-situ Treatment (under development): • Reactive caps • Additives/enhanced biodegradation	Dredging: • Hydraulic, mechanical, or combination/hybrid dredging • Treatment of dredged sediment and/or removed water • Disposal of dredged sediment or treatment residuals in upland landfill, confined disposal facility, or other placement • Backfill of dredged area, as needed or appropriate Excavation: • Water diversion or dewatering • Treatment of excavated sediment • Disposal of excavated sediment or treatment residuals in upland landfill, confined disposal facility, or other placement • Backfill of excavated area, as needed or appropriate

1.3.2 Urban Revitalization and Reuse

Revitalization of urban areas and returning land and water bodies to productive use have become increasingly important to the EPA's hazardous waste programs 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 consider the goals of local governments and other entities to revitalize use of waterfront property, harbors, and other water bodies. This may involve reviewing local land use plans and identifying potential partners such as land owners, elected officials, and local land and water planning and development agencies. It may lead to opportunities to consider remedies that take into account the views 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

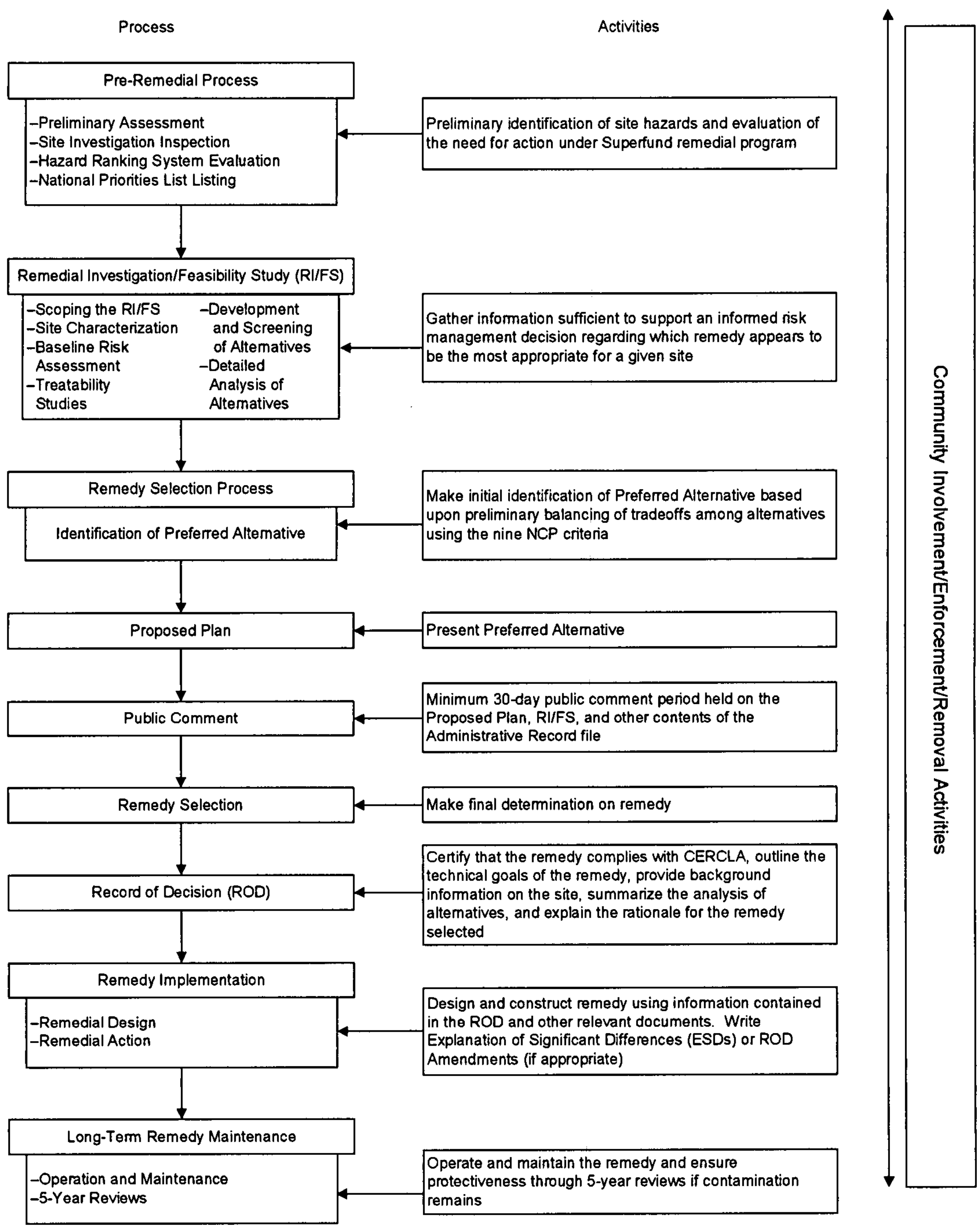
Decision making at sediment sites follows somewhat different processes depending on the scope of the problem, the entity conducting the work, and the legal authority under which it is conducted. While meeting all legal and regulatory requirements, it is the intent of the Agency to allow project managers the flexibility needed to make the most appropriate decisions at sediment sites.

1.4.1 Decision Process Framework

Remedial actions taken under CERCLA generally follow the Superfund remedial response process 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. Corrective actions under RCRA generally follow the RCRA remedial process laid out in the May 1, 1996 Advanced Notice of Proposed Rulemaking [(ANPR), 61 FR 19447].

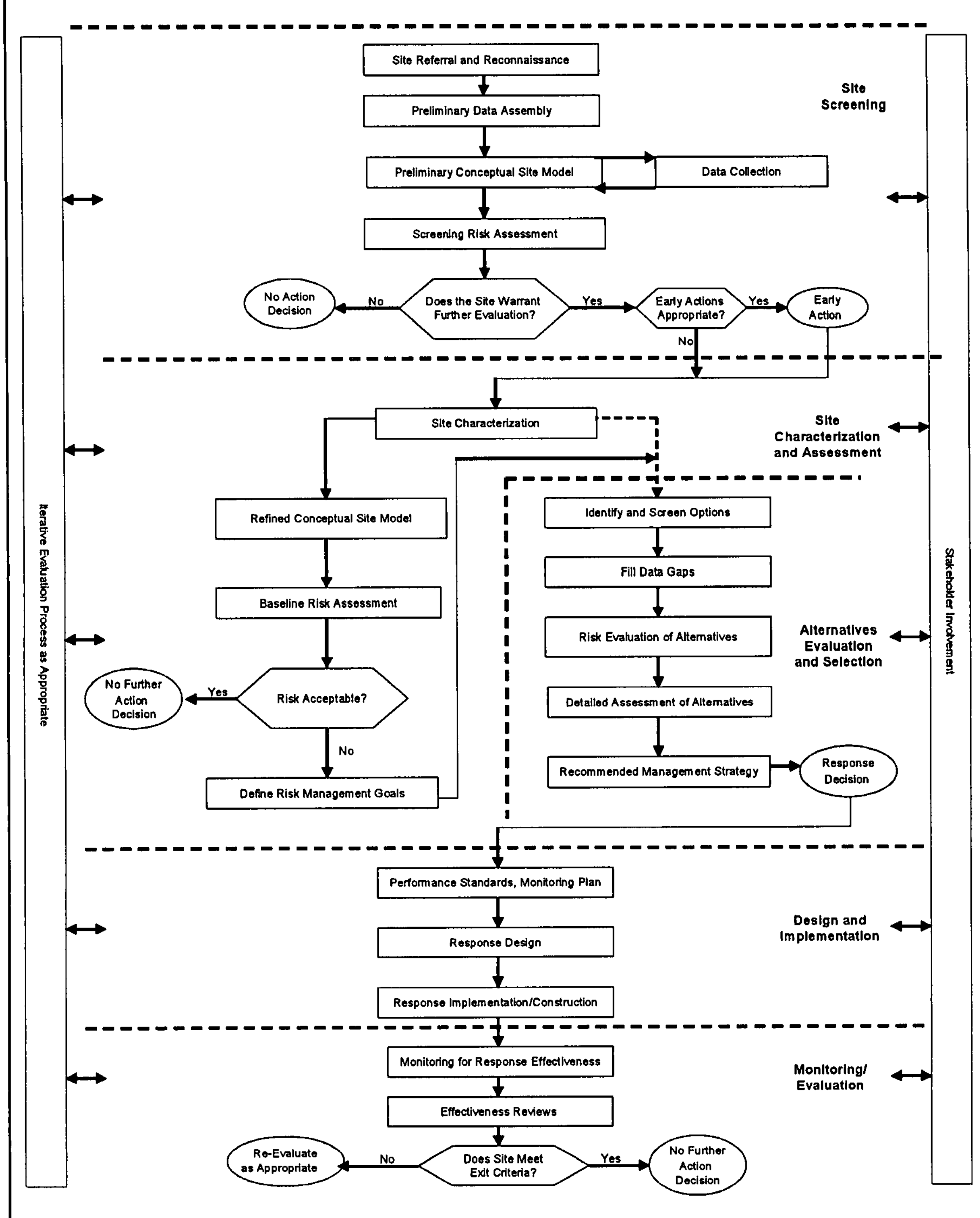
A general decision-making framework for sediment sites, *A Framework for Evaluating and Managing Contaminated Sediment Sites* (U.S. EPA et al. 2004, in prep.) is being developed by a team including representatives of the EPA, the U.S. Army Corps of Engineers (USACE), the U.S. Navy, and the National Oceanic and Atmospheric Administration (NOAA). This risk-based framework is being designed to provide an outline of activities and processes that should generally be considered when assessing and managing contaminated sediment sites. The joint-agency framework would not supersede any program-specific guidance, but is being designed to be used in conjunction with program-specific guidance. Highlight 1-7 presents the general outline of this framework.

Highlight 1-6: Superfund Remedial Response Process



Adapted from: U.S. EPA 1999a

Highlight 1-7: Hypothetical Framework for Cleanup of Contaminated Sediment



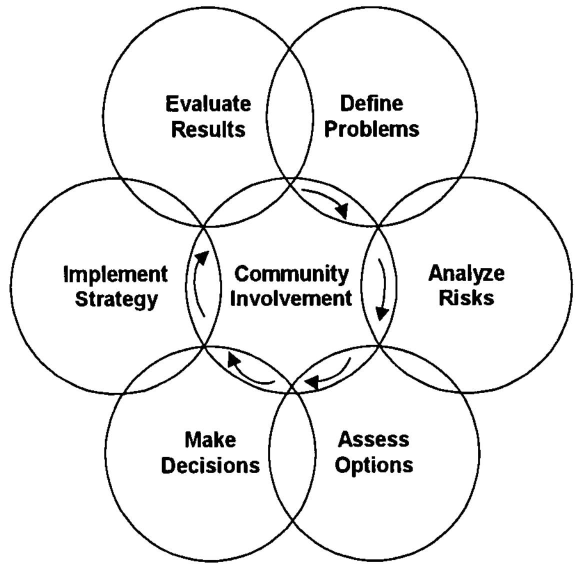
In the report, *A Risk-Management Strategy for PCB-Contaminated Sediments* (NRC 2001), the NRC recommended the use of the iterative decision-making approach shown in Highlight 1-8, adapted from The Presidential/Congressional Commission on Risk Assessment and Risk Management. EPA project managers should use this approach within the context of EPA's existing remedial process (Highlight 1-6). The NRC approach emphasizes the unique importance of community involvement throughout the decision-making process. This approach also emphasizes the usefulness of iteration if new information becomes available that changes the nature or understanding of the problem. It is not intended, however, to represent an endless loop. As noted by the NRC (2001): "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."

1.4.2 Technical Support

In 2002, EPA established the Contaminated Sediments Technical Advisory Group (CSTAG) to monitor the progress of, and provide advice regarding, a number of large, complex, or controversial contaminated sediment Superfund sites. For most sites, the group meets with the site team several times throughout the site investigation, response selection, and action implementation processes. Involving CSTAG at each major phase of a project provides additional technical support to the project team and ensures consistency with EPA's national sediment policies. General information about CSTAG and site-specific recommendations and responses are available at http://www.epa.gov/superfund/resources/sediment/cstag.htm.

In 2004, EPA established the Superfund Sediment Resource Center (SSRC) to make expert technical assistance available to EPA project managers of any Superfund sediment site. The SSRC has the capability of accessing expertise from the EPA's Office of Research and Development, the USACE, as well as private consultants and academic researchers. Information on how to access the SSRC is available through OSRTI's Contaminated Sediments in Superfund Web site at http://www.epa.gov/superfund/resources/sediment/ssrc.htm.

Highlight 1-8: National Research Council - Recommended Framework for Risk Management



Source: NRC 2001

1.5 STATE, TRIBAL, AND TRUSTEE INVOLVEMENT

State cleanup agencies and affected Indian tribes or nations at sediment sites or impacted downstream areas have an important role as co-regulators and/or affected parties and as sources of essential information at sediment sites. States are the lead agency at some sediment sites, or lead the cleanup of land-based source areas or particular operable units within a site. States and tribes are frequently an indispensable source of historic and current information about water body 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. At some sediment sites, states are also owners of aquatic lands, dams, or flood plains. Where this is the case, states have multiple roles at the site. At sediment sites, as for all sites, states (and local and tribal governments where applicable) should be involved early and often in the remedial investigation/feasibility study (RI/FS). Coordination with the state may be especially helpful in the development of the site conceptual model, risk assessment, and remediation goals. Additional coordination during Remedial Design/Remedial Action phases is also very important (e.g., an opportunity to consult during the engineering design following remedy selection and on other technical matters related to implementation or monitoring of the 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).

Where there is a potential for natural resource injuries and 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 have an opportunity to be involved throughout the investigation and remedy selection process at sites where they have jurisdiction and interest. 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), 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 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. When trustees are involved, project managers should consult them early in the RI/FS process regarding potential contaminant migration pathways, ecological receptors, and characteristics of the water body 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. 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).

1.6 COMMUNITY AND OTHER STAKEHOLDER INVOLVEMENT

Communication and outreach with the community and other stakeholders can pose unique challenges at sediment sites, especially at large sites on publically-used water bodies. Community Involvement Coordinators often have a critical role as part of the project team at these sites. Sediment sites that span large areas may present barriers to communicating effectively with different communities, local governments, and the private sector along the water body. People who live, work, and play adjacent to water bodies 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. Community members may have a wide variety of needs and wishes for current and future uses of the water body. Highlights 1-9 and 1-10 list some of the common community concerns about contaminated sediment and risk reduction methods for sediment. 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 1-9: Common Community Concerns about 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 1-10: Common Community Concerns about Sediment Cleanup

Concerns about MNR	Concerns about In-Situ Capping	Concerns about Dredging and Excavation
• Long time-frame for recovery • Ongoing human and ecological exposure during recovery period • Doubts about effectiveness/spreading of contamination due to flooding/other disturbance • Extended loss of resources and uses • Perception of "do nothing" remedy • Property value/ transferability concerns with leaving significant contamination in place	• Increased truck or rail traffic • Loss of resource/harvesting opportunities • Increased flooding • Disturbance of aquatic habitat • Cap material source issues • Loss of boat anchoring access • Doubts about effectiveness due to cap erosion, disruption, or contaminant migration through cap • Loss of privacy during construction • Recreation and tourism impacts during construction • Property value/transferability concerns with leaving significant contamination in place	• Increased truck or rail traffic • Noise, emissions, and lights at treatment and disposal facilities • Siting of new disposal facilities • Loss of capacity at existing disposal facilities • Loss of privacy during construction • Infrastructure needs on adjacent land • Recreation and tourism impacts • Access to private property • Property values near dredging, treatment and disposal facilities • Disturbance of aquatic habitat • Resuspension/spreading contamination during dredging

Existing community involvement and sediment guidance from EPA and elsewhere offer some guidelines for involving the community in meeting these and other concerns, as identified in Highlight 1-11.

Highlight 1-11: Community Involvement Guidance and Advice

EPA Office of Solid Waste and Emergency Response on Community Involvement (available at http://www.epa.gov/superfund/action/community/index.htm):

- *Early and Meaningful Community Involvement* (U.S. EPA 2001c)
- *Superfund Community Involvement Toolkit* (U.S. EPA 2003b)
- *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)
- *Incorporating Citizen Concerns into Superfund Decision Making* (U.S. EPA 2001d)

RCRA Community Involvement Guidance (available at http://www.epa.gov/epaoswer/hazwaste/ca/resource/guidance.htm, see list under "Public Involvement/Communication"):

- *RCRA Public Participation Manual*
- *RCRA Expanded Public Participation Rule* (60 FR 63417-34)
- *RCRA Corrective Action Workshop Communication Tools*

Office of Water on Communication of Fish Consumption Risks and Surveys (available at http://www.epa.gov/ost/fish):

- *Guidance for Conducting Fish and Wildlife Consumption Surveys* (U.S. EPA 1998c)
- *National Risk Communication Conference Held in Conjunction with the Annual National Forum on Contaminants in Fish* (May 6-8, 2001, conference proceedings available at http://www.epa.gov/waterscience/fish/proceedings.html)

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.

Point 1. Involve the Community and Other Stakeholders Early and Often

In addition to the requirements and recommendations regarding stakeholder involvement available in CERCLA §117 and the NCP, one of EPA's eleven principles for managing risk of contaminated sediment is to involve the community early and often. This is an important principle in relation to other stakeholders as well, including local governments, port authorities, and PRPs. 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 involvement allows necessary input from communities and other stakeholders and facilitates more comprehensive identification of issues and concerns early in the site management process.

Early community involvement enables EPA to learn what stakeholders, especially community members, think are important exposure pathways 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). 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.

Point 2. Build an Effective Working Relationship with the Community and Other Stakeholders

In addition to the requirements and recommendations regarding public outreach available in CERCLA §117 and the NCP, building partnerships with key community groups, the private sector, and other interested parties is critical to implementing a successful outreach 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 and other stakeholders at sediment sites. Project managers should consider the following advice as they formulate their outreach plans:

- Create realistic expectations up front for both public involvement and sediment cleanup;
- Where possible, instead of asking for extra meetings, 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 of which 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.

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

In addition to the requirements and recommendations regarding public outreach available in CERCLA §117 and the NCP, 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. One potential resource is a video prepared by EPA's Superfund office in 2003, to explain to communities the general remedial options for sediment.

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) capabilities. 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

The main purpose of investigating contaminated sediment, as with other media, generally is to determine the nature and extent of contamination in order to determine if there are unacceptable risks that warrant a response and, if so, to evaluate potential remedies. Investigations may be conducted by a number of different parties under a number of different legal authorities. Most of this chapter presents general information of potential use to any investigator. However, the language and program-specific references are drawn from the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) program, and at times, from the Resource Conservation and Recovery Act (RCRA) program.

Under CERCLA, the investigation process is known as a "Remedial Investigation" (RI). Under RCRA, the investigation process is known as a "RCRA Facility Investigation." The RI 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). The process in a RCRA corrective action is best described in Office of Solid Waste and Emergency Response (OSWER) Directive 9902.3-2A, *RCRA Corrective Action Plan* (U.S. EPA 1994a), and the May 1, 1996 Advanced Notice of Proposed Rulemaking [(ANPR) 61 FR 19447]. This chapter supplements these existing guidances by offering brief sediment-specific guidance about site characterization, risk assessment, 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.

2.1 SITE CHARACTERIZATION

The site characterization process for a contaminated sediment site should allow the project manager to accomplish the following general goals, at a scale and complexity appropriate to the site:

- Identify and quantify the contaminants present in sediment, surface water, biota, flood plain soils, and in some cases, ground water;
- Understand the vertical and horizontal distribution of the contaminants within the sediment and flood plains;
- Identify the sources of historical contamination and quantify any continuing sources;
- Understand the geomorphological setting and processes (e.g., resuspension, transport, deposition, weathering) affecting the stability of sediment;
- Understand the key chemical, and biological processes affecting the fate, transport, and bioavailability of contaminants;
- Identify the complete or potentially complete human and ecological exposure pathways for the contaminants;
- Identify current and potential future human and ecological risks posed by the contaminants;

- Collect data necessary to evaluate the potential effectiveness of natural recovery, in-situ capping, sediment removal, and promising innovative technologies; and

- Provide a baseline of data that can be used to monitor remedy effectiveness in all appropriate media (generally sediment, water, and biota).

The project manager, in consultation with technical experts and stakeholders, should develop site-specific investigation goals that are of an appropriate scope and complexity for the site. Systematic planning, dynamic work strategies, and, where appropriate, real-time measurement technologies may be especially needed at sediment sites. Combined, these three strategies are known as the "triad approach," described on EPA's Innovative Technologies Web site at http://www.cluin.org/triad. This approach attempts to summarize the best current practices in site characterization, in order to collect the "right" data, improve confidence in results, and save cost.

Data collection during the remedial investigation frequently has multiple uses, including human health and ecological risk assessment, identification of potential early actions, and remedy decision-making. It is important to involve all data users (e.g., risk assessors, modelers, as well as quality assurance/quality control (QA/QC) experts) early throughout data collection.

Data should be of a type, quantity, and quality to meet the objectives of the project. The EPA's data quality objective (DQO) process is one method to achieve this, as described below. Where other agencies (e.g., natural resource trustee agencies, state remediation agencies, and health departments) have an interest at the site, they should be consulted concerning decisions about DQOs so that collected data can serve multiple purposes, if possible. In addition, the community and other stakeholders (e.g., local governments and potentially responsible parties) should be consulted in these decision as appropriate.

2.1.1 Data Quality Objectives

The EPA's DQO process is intended to help project managers collect data of the right type, quality, and quantity to support site decisions. As described in *Guidance for the Data Quality Objective Process* (U.S. EPA 2000a), seven steps generally guide the process. The initial steps help assure that only data important to the decisions that need to be made are collected. The seven DQO steps include the following, with an example written in the context of a risk assessment:

1. *State the problem*. Example: There is current exposure of humans to site-related contaminants through eating fish.

2. *Identify the decision*. Example: Is the exposure causing an unacceptable risk?

3. *Identify inputs to the decision*. Examples: What are the appropriate fish species, receptor groups, and consumption rates to evaluate? What existing data are available and what must be collected? What is the toxicity of the contaminants to all receptor groups?

4. *Define boundaries of study.* Example: For purposes of the human health risk assessment, should the water body and the human population each be considered as a whole or in subparts?

5. *Develop a decision rule.* Example: If exposure at the upper 95 percent confidence limit for fish consumption of the recreational fisher population to the mean contaminant concentration of any one of the three most popular fish species exceeds a cancer risk range of 10^{-6} to 10^{-4} or a Hazard Index of 1, risk will be considered unacceptable.

6. *Specify limits on decision errors.* Example: What levels of uncertainty are acceptable for this decision, considering both false positive and false negative errors?

7. *Optimize the design for obtaining data.* Example: What is the most resource-effective fish sampling and analysis design for generating data that will meet the data quality objectives?

Similar hypotheses could be established for evaluating each approach being considered for the site, and for evaluating the effectiveness of the selected approach. The way in which the process is followed may vary depending on the decision to be made, from a thought process to a rigorous statistical analysis. Additional guidance provided in *EPA Requirements for Quality Assurance Project Plans* [(QAPPs), U.S. EPA 2001f) describes how DQOs are incorporated into QAPPs.

2.1.2 Types of Data

The types of data the project manager should collect are determined mostly by information needed to develop the conceptual site model, conduct the human health and ecological risk assessments, evaluate potential remedies, document baseline conditions prior to implementation of the remedy, and design and implement the selected remedy.

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. It is frequently important to understand the historical changes in some of these characteristics (e.g., water body bathymetry or contaminant distributions in surface and subsurface sediment, water, and biota). It may also be important to understand how characteristics change seasonally, and under various flow and temperature conditions. The relative importance of these types of data variabilities are dependent on the site. While sediment sites typically demand more types of data for effective characterization than other types of sites, the type and quantity of data required should be geared to the complexity of the site and the weight of the decision. In addition, the data acquisition process should not prevent early action to reduce risk when appropriate.

Site characterization should include collection of sufficient baseline data to be used to compare to monitoring data collected during and following implementation of the remedy in a statistically defensible manner. Additional sampling could be needed during remedial design, however, to establish reliable baseline data for the monitoring program. Chapter 8, Remedial Action and Long-Term Monitoring, provides a discussion of effective monitoring programs, much of which is also useful during the remedial investigation.

Highlight 2-1: Example Site Characterization Data for Sediment Sites		
Physical	**Chemical**	**Biological**
• Sediment particle size/distribution and mineralogy in cores • In-situ porosity/bulk density • Bearing strength • Specific gravity • Salinity profile of sediment cores • Geometry/bathymetry of water body • Turbidity • Temperature • Sediment resuspension and deposition rates • Depth of mixing layer/ degree and depth of bioturbation • Geophysical survey results • Flood frequencies, annual and event-driven hydrographs and current velocities • Tidal regime • Surface water/ground water interaction • Ground water flow regime	• Near-surface contaminant concentrations in sediment • Contaminant profiles in sediment cores • Contaminant concentrations in biota tissue • Contaminant concentrations in ground water • Total organic carbon (TOC) in sediment • Dissolved, suspended, and colloidal contaminant concentrations in surface water • Simultaneously extracted metals (SEM) in sediment • Acid volatile sulfide (AVS) in sediment • Non-contaminant chemical species that may affect contaminant mobility • Oxidation-reduction profile of sediment cores • pH profile in sediment cores • Carbon/nitrogen/ phosphorus ratio • Non-ionized ammonia concentration in sediment	• Sediment toxicity • Extent of recreational/commercial harvesting of fish/shellfish for human consumption • Extent of predators dependent on aquatic food chain (e.g., mink, otter, kingfisher, heron) • Abundance/diversity of benthic species and fishes • Abundance/diversity of emergent and submerged vegetation • Habitat stressor analyses • Contaminant bioavailability • Pathological condition, such as presence of tumors in fish • Presence of indicator species

Polychlorinated Biphenyl (PCB) Data

At this time, polychlorinated biphenyls (PCBs) are among the most common contaminant of concern at contaminated sediment sites. The term "PCB" refers to a group of 209 different chemicals sharing a similar structure of chlorinated biphenyl rings. The 209 PCB forms are called PCB congeners. Aroclors are commercial mixtures of PCB congeners, with each Aroclor made up of a certain percentage of chlorine. For example, Aroclor 1242 contains 42 percent chlorine. Release of an Aroclor into the environment may result in a change in its congener composition. As also discussed in Chapter 8, Remedial Action and Long-Term Monitoring, for sediment sites contaminated with PCBs, the National Research Council (NRC) states that total PCB concentrations determined by analyzing PCBs as Aroclors are prone to error, because the distribution of PCB congeners in Aroclors is altered considerably by physical, chemical, and biological processes after release into the environment (NRC 2001). EPA's Office of Water *Guidance for Assessing Chemical Contaminant Data for Use in Fish Advisories, Volume 1, Fish Sampling and Analysis, Third Edition* (U.S. EPA 2000b), also notes that individual PCB congeners may be preferentially enhanced in environmental media and in biota.

In 1996, EPA released its *PCB Cancer Dose-Response Assessment and Application to Environmental Mixtures* (U.S. EPA, 1996a, also referred to as the "PCB Cancer Reassessment"). The PCB Cancer Reassessment presented a new approach for assessing cancer risk from exposure to PCBs based on exposure pathways of concern and congener chlorination levels. The PCB Cancer Reassessment also acknowledged the importance of evaluating risk from dioxin-like PCB congeners in addition to risk from total PCBs. Dioxin-like PCB congeners are structurally similar to 2,3,7,8-tetrachlorodibenzo-*p*-dioxin (TCDD, or dioxin) and recent studies have found that these congeners exhibit similar toxic effects to dioxin (though they display lesser potency). Toxic Equivalency Factors (TEFs) relating the potency of these PCB congeners to the potency of dioxin were first published by the World Health Organization (WHO) in 1994, and later updated in 1998 (Van den Berg et al. 1998).

Characterizing PCB risk 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. Although Aroclor analysis can be useful for initial assessment of PCB concentrations, for risk assessment purposes NRC recommends that PCB sites should be characterized on the basis of specific PCB congeners and the total mixture of congeners found at each site. EPA currently provides congener-specific analyses through its Non-Routine Program under the Contract Laboratory Program (CLP), but it may, in the future, be available through its CLP routine analytical services. This service provides for analytical consistency, centralized contract administration, and sample tracking.

However, to the extent that it is determined that PCB congener-specific data are useful at a site, the project manager should not assume that this necessarily need be done for all samples collected. At times, only a subset of samples or sampling events may need congener analysis. Deciding how best to characterize 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. The decision about what method or methods to use for PCB analysis should be made on a site-specific basis. EPA's Superfund program is in the process of developing guidance on assessing human health risks posed by PCBs in contaminated soil. The guidance will be found at http://www.epa.gov/superfund/resources/pcb/index.htm. While the focus of the guidance is on human health risk from soils, the guidance is being designed to provide an analytical framework that can be used for selecting appropriate PCB analytical methods for ecological risks and for various media, such as soils, sediments, tissue and water. An appendix to the guidance will consist of a compendium of analytical methods for PCBs.

Metals Data

Currently, metals are also among the most common contaminant of concern at Superfund sediment sites. Concentrations of metals in sediment alone may not be good measures of metal toxicity. Because the bioavailablity of metals is frequently related to the concentration of sulfides in the sediment, it is important to analyze both acid volatile sulfides (AVS) and simultaneously extracted metals (SEM) in sediment with metals contamination. AVS controls the activity and availability of divalent metals in the pore ratios, and differences between AVS and SEM may be used to predict metal toxicity and availability in sediment (U.S. EPA 1996a). The AVS-SEM approach can be applied on a molar ratio (not concentration ratio) basis for copper, cadmium, nickel, lead, zinc, and on a half molar basis for silver. For chromium, if there is any SEM, it is assumed that the chromium is in the trivalent state and not bioavailable to cause effects (unlike hexavalent chromium which is bioavailable and toxic). The equilibrium-partitioning approach using AVS and SEM for predicting metals bioavailability is a useful tool for understanding the sequestration of selected metals, and research in this area is ongoing.

2.1.3 Background Data

Where site contaminants may also have natural or other anthropogenic (man-made) non-site-related sources, it may be important to establish background or reference site data for a site. When doing so, project managers should consult EPA's *Role of Background in the CERCLA Cleanup Program* (U.S. EPA 2002b), the *EPA ECO Update - The Role of Screening-Level Risk Assessments and Refining Contaminants of Concern in Baseline Ecological Risk Assessments* (U.S. EPA 2001g), and *Guidance for Comparing Background and Chemical Concentrations in Soil for CERCLA Sites* (U.S. EPA 2002c). Although the latter is written specifically for soil, many of the concepts may be applicable to contaminant data for sediment and biota. It should be noted that a comprehensive investigation of all background substances found in the environment usually will not be necessary at CERCLA sites. For example, radon background samples normally would not be collected at a chemically contaminated site unless radon, or its precursor was part of the CERCLA release.

Where applicable, project managers should consider continuing atmospheric and other background contributions to sites in order to adequately understand contaminant sources and establish realistic risk reduction goals (U.S. EPA 2002b). For baseline risk assessments, EPA recommends an approach that generally includes the evaluation of the contaminants that exceed protective risk-based screening concentrations (RBCs), including contaminants that may have natural or anthropogenic sources on and around the Superfund site under evaluation. However, when site-specific information demonstrates that a substance with elevated concentrations above RBCs originated solely from natural causes (i.e., is a naturally occurring substance and not release-related), that contaminant need not be carried through the quantitative analysis, but should be discussed in the risk characterization summary. The purpose here is to communicate potential risks to the public. The presence above RBC level indicates a potential environmental or health risk, and that information should be discussed at least qualitatively in the document. If data are available, the contribution of background to site conditions should be distinguished (U.S. EPA 2002b). This approach ensures a thorough characterization of risks associated with hazardous substances, pollutants, and contaminants at sites (U.S. EPA 2002b).

For risk management purposes, understanding whether background concentrations are high relative to the concentrations of released hazardous substances, pollutants, and contaminants may help risk managers make decisions concerning appropriate remedial actions (U.S. EPA 2002b). Generally, under CERCLA, cleanup levels are not set at concentrations below natural or anthropogenic background levels (U.S. EPA 1996a, 1997c, 2000c). If a risk-based remediation goal is below background concentrations, the cleanup level for that chemical may be established based on background concentrations.

In cases where area-wide contamination may pose risk, that are not appropriate to address under CERCLA, EPA may be able to help identify other programs or regulatory authorities that are able to address the sources of area-wide contamination, particularly anthropogenic sources (U.S. EPA 1996a, 1997c, 2000c). In some cases, as part of a response to address CERCLA releases of hazardous substances, pollutants, and contaminants, EPA may also address some of the background contamination that is present on a site due to area-wide contamination.

2.2 CONCEPTUAL SITE MODELS

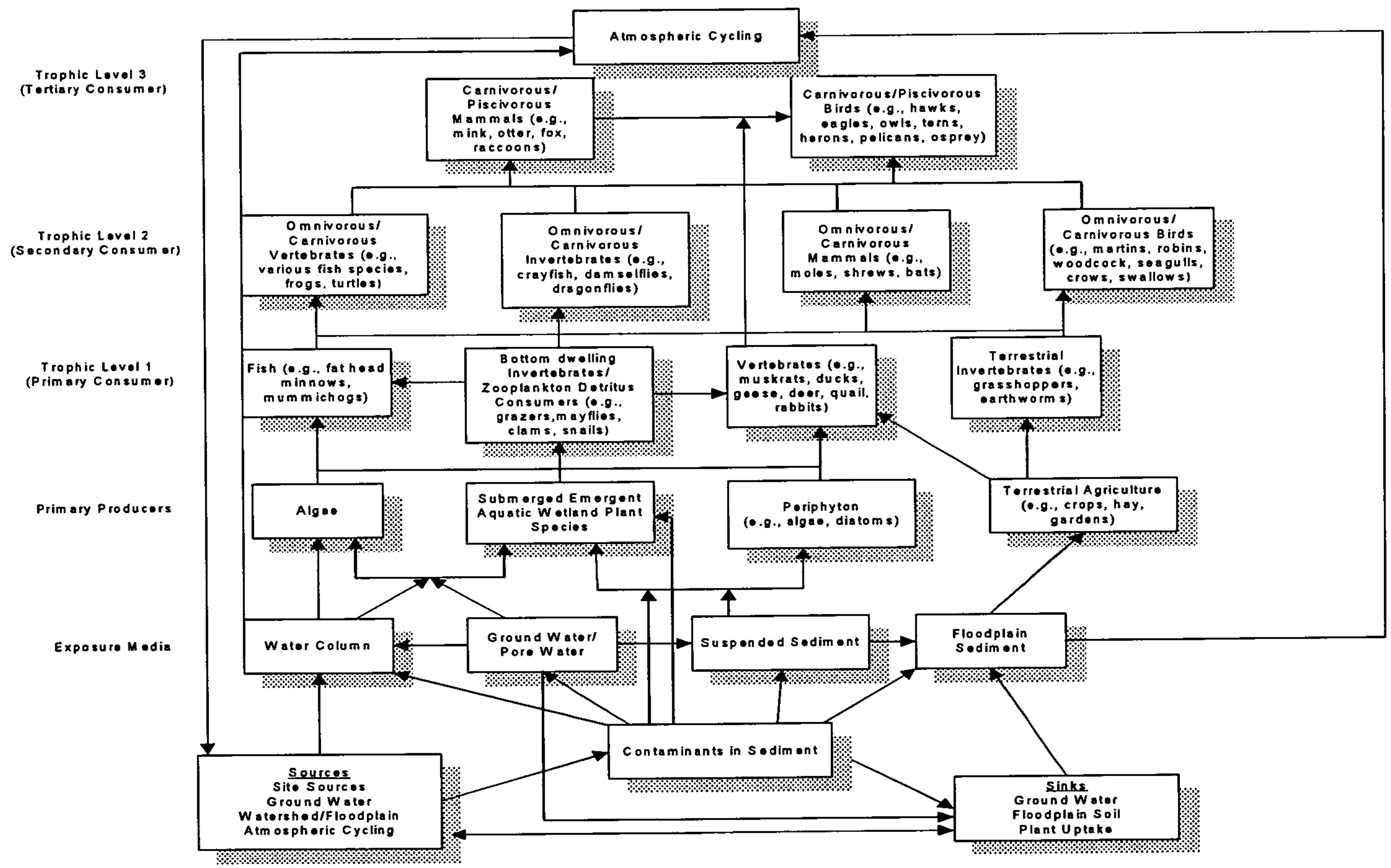
A conceptual site model generally is a representation of the environmental system and the physical, chemical, and biological processes that determine the transport of contaminants from sources to receptors. For sediment sites, perhaps even more so than for other types of sites, the conceptual site model is an important element for evaluating risk and risk reduction approaches. The initial conceptual site model can provide the project manager with a simple understanding of the site based on data available early in the investigation. Essential elements generally include information about contaminant sources, transport pathways, exposure pathways, and receptors. Summarizing this information in one place helps in testing assumptions and identifying data gaps and areas of critical uncertainty for additional investigation. Later, this conceptual model should be modified as additional source, pathway, and contaminant information is collected. A good conceptual site model is a valuable tool in evaluating the potential effectiveness of actions to reduce exposure of receptors to contaminants. Natural resource trustee agencies and other stakeholders may have information about the ecosystem that is important in developing the conceptual site model and it is recommended that they have input at this stage of the site investigation. Information gaps may be discovered in development of the conceptual site model that support collection of new data. Typical elements of a conceptual site model for a sediment site are shown in Highlight 2-2.

Highlight 2-2: Typical Elements of a Conceptual Site Model for Sediment

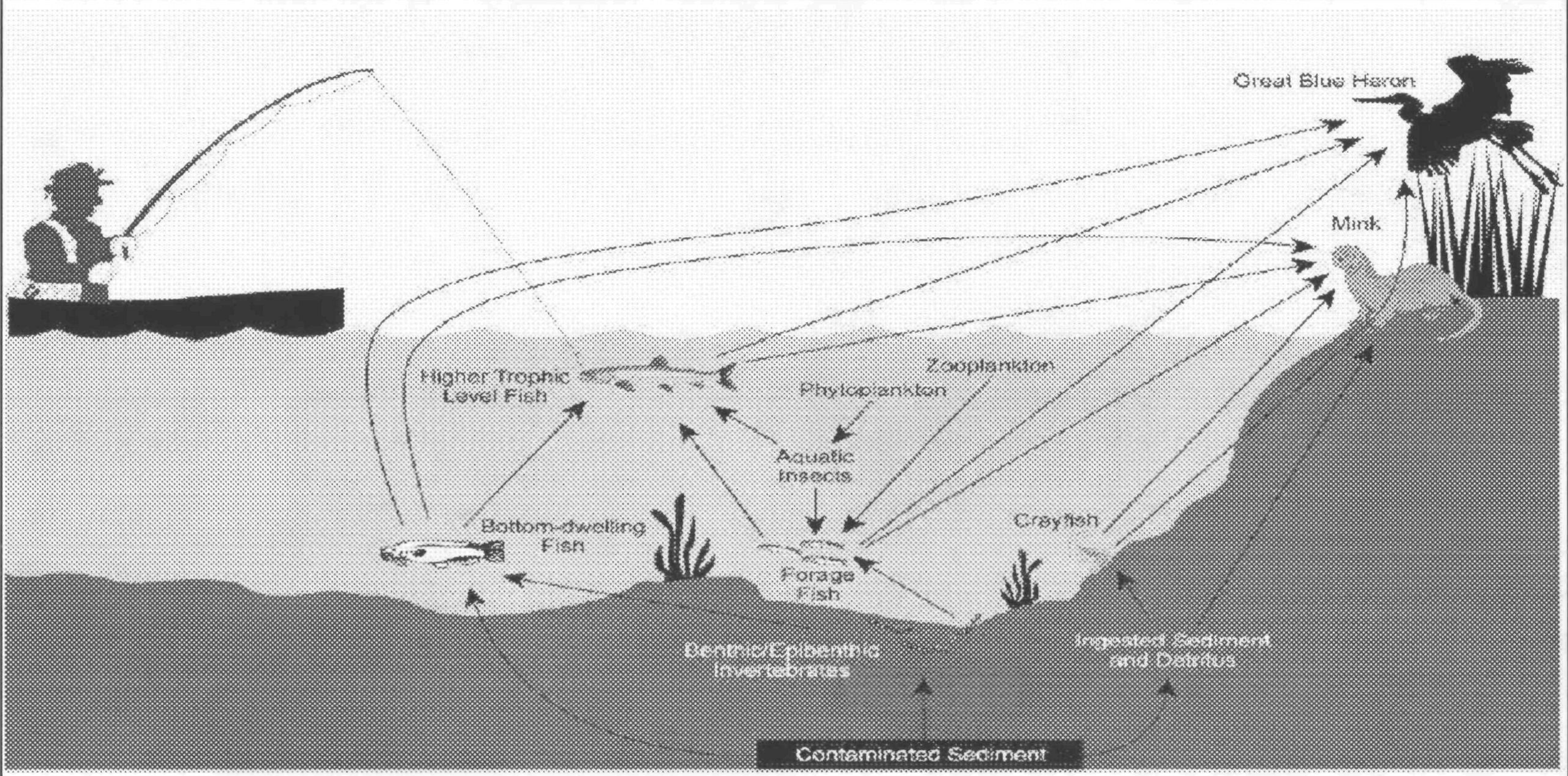
Sources of Contaminants of Concern: • Upland soils • Flood plain soils • Surface water • Ground water • Non-aqueous phase liquids and other source materials • Sediment "hot spots" • Outfalls, including combined sewer outfalls and storm water runoff outfalls • Atmospheric contaminants	Exposure Pathways for Humans: • Game fish/shellfish ingestion • Dermal uptake from wading, swimming • Water ingestion • Inhalation of volatiles Exposure Pathways for Biota: • Fish/shellfish ingestion • Benthic invertebrate activity • Direct uptake from water
Contaminant Transport Pathways: • Sediment resuspension • Surface water transport • Runoff • Bank erosion • Ground water advection • Bioturbation • Food chain	Human Receptors: • Recreational fishers • Subsistence fishers • Waders/swimmers/birdwatchers Ecological Receptors: • Bethic/epibenthic invertebrates • Bottom-dwelling fish • Pelagic fish • Mammals and birds (e.g., mink, otter, heron, bald eagle)

Project managers may find it useful to develop several conceptual site models that highlight different aspects of the site. At complex sediment sites, often three conceptual site models are developed, one for sources, release and media, and one each for human health and ecological receptors. Highlight 2-3, Highlight 2-4, and Highlight 2-5 present examples that focus on ecological and human health threats.

Highlight 2-3: Sample Conceptual Site Model Focusing on Ecological Threats

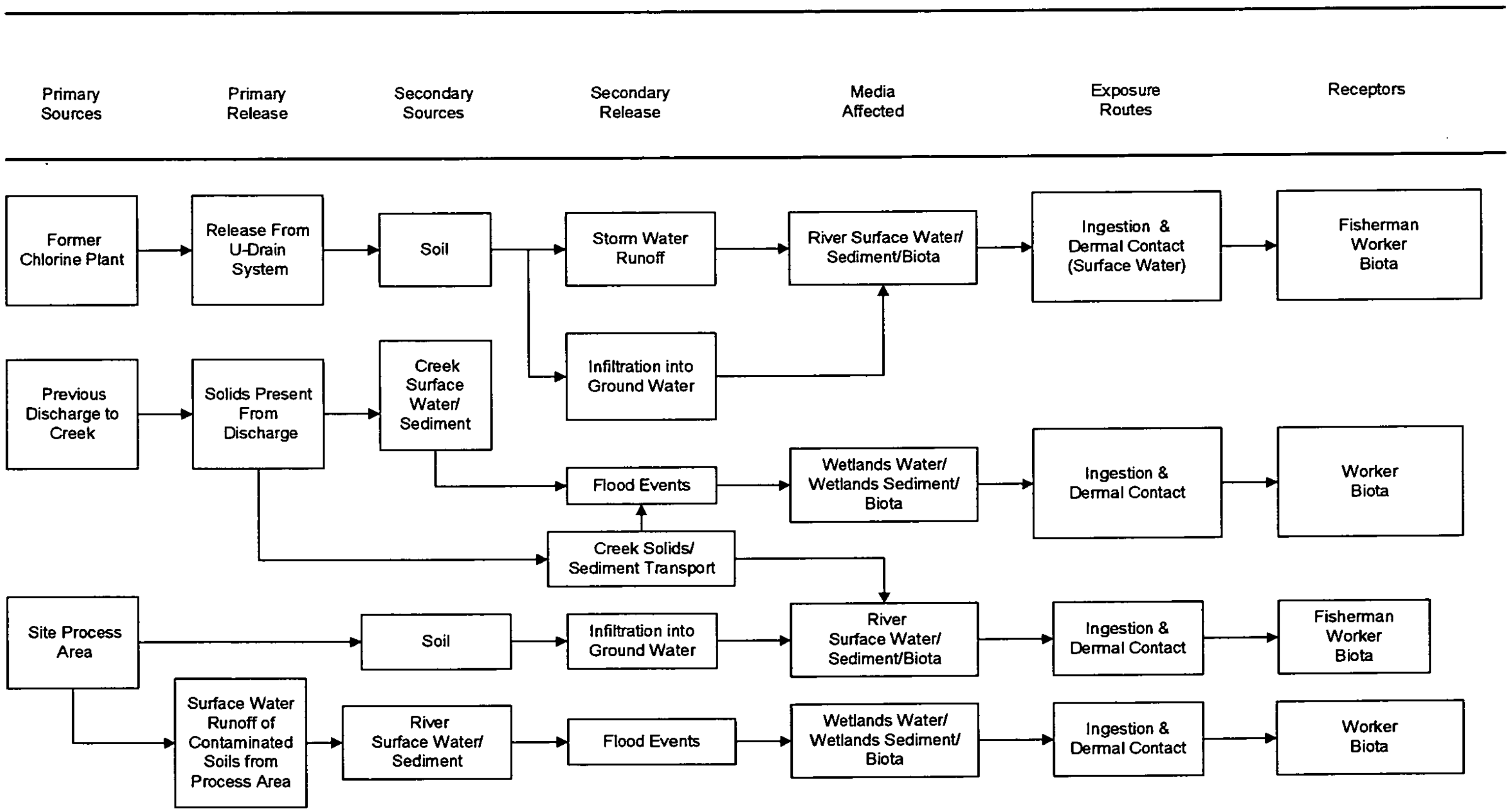


Highlight 2-4: Sample Pictorial-Style Conceptual Site Model Focusing on Human and Ecological Threats



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

Highlight 2-5: Sample Conceptual Site Model Focusing on Human Health Threats



2.3 RISK ASSESSMENT

Consistent with the National Oil and Hazardous Substances Pollution Contingency Plan (NCP), a human health risk assessment and an ecological risk assessment are performed at all contaminated sediment sites. In addition to assessing risks due to contaminated sediment, in many cases, risks from soil, surface water, ground water and air pathways may need to be evaluated as well. Generally, the human health risk assessment should consider the cancer risks and non-cancer health hazards associated with ingestion of fish and other biota appropriate to the site (e.g., shellfish, ducks); dermal contact with and incidental ingestion of contaminated sediments; inhalation of volatilized contaminants; swimming and possible ingestion of river water if it is used as a drinking water supply. Separate analyses should also consider risks from exposure to floodplains and may include direct contact, ingestion, and exposures to homegrown crops, beef and dairy products where appropriate. As with all RI data collection efforts, the scope of the assessments should be tailored to the complexity of the site and how much information is needed to reach and support a risk management decision. It is important to involve the risk assessors early in the process to assure that the information collected is appropriate for use in the risk assessment.

Risk assessments are designed to evaluate the potential threat to human health and the environment in the absence of any remedial action. Generally, they provide the basis for determining whether remedial action is necessary as well as the framework for developing risk-based remediation goals. Risk assessments should also provide information which can be used to evaluate risks associated with implementing various remedial alternatives which may be considered for the site. Detailed guidance on performing human health risk assessments is provided in a number of documents, most of which are available on EPA's Web site at http://www.epa.gov/superfund/programs/risk. The *Risk Assessment Guidance for Superfund,* also referred to as "RAGS" (U.S. EPA 1989) provides a basic plan for developing human health risk assessments. Specific guidance on the standardized planning, reporting, and review of risk assessments is provided at http://www.epa.gov/superfund/programs/risk/ragsd/index.htm.

Detailed guidance on performing ecological risk assessments is provided in *Ecological Risk Assessment Guidance for Superfund: Process for Designing and Conducting Ecological Risk Assessment,* also referred to as "ERAGS" (U.S. EPA 1997d). 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. As stated in the *Role of the Ecological Risk Assessment in the Baseline Risk Assessment* (U.S. EPA 1994b), the purpose of the ecological risk assessment is to "1) identify and characterize the current and potential threats to the environment from a hazardous substance release, 2) evaluate the ecological impacts of alternative remediation strategies, and 3) establish cleanup-levels in the selected remedy that will protect those natural resources at risk."

Although not EPA guidance, the recently released Navy guidance *Implementation Guide for Assessing and Managing Contaminated Sediment at Navy Facilities,* provides useful information on performing human health and ecological risk assessments at contaminated sediment sites [U.S. Naval Facilities Engineering Command (FEC) 2003].

2.3.1 Screening Risk Assessment

A screening risk assessment typically is performed to identify the contaminants of potential concern (COPCs) and the portions of a site that may present an unacceptable risk to human health or the environment. Currently, there are no widely accepted sediment screening values for human health risk from either direct contact with sediment or for eating fish or shellfish, although research is ongoing. For floodplain and beach soils, human health soil screening levels may be used. Widely-accepted screening values do exist for ecological risk from direct toxicity, although, similar to the situation for human health risk, screening values for risk to wildlife and fish from bioaccumulative contaminants have not yet been fully developed. Each of these issues is discussed further below. In cases where screening levels do exist, or may be developed in the future, it is very important for project managers to keep in mind that screening values are not designed to be used as default cleanup levels and generally should not be used for that purpose. In addition to their intended purpose, in some cases project managers may also find ecological screening values or human health screening level exposure assumptions useful for evaluating whether detection levels for sediment analytical work are sufficiently low to be useful for risk assessment.

When evaluating human health risks from direct contact with sediments and from bioaccumulative contaminants in fish and shellfish, RAGS (U.S. EPA 1989), and other risk guidance discussed above, should be followed to identify the COPC that may present an unacceptable risk. In general, if bioaccumulative contaminants are found in biota at levels above site background, they should not be screened out and should be carried into the baseline risk assessment.

When evaluating human health risk from direct contact with floodplain or beach soils, OSWER and several regions have soil screening values that may be useful. Human health soil screening levels (SSLs) for residential and industrial properties are available at http://www.epa.gov/superfund/resources/soil, which provde a generic approach and exposure assumptions for evaluation of risks from direct contact with soil.

When screening ecological risk to benthic biota from direct toxicity, project managers should consult EPA's Eco-Updates *EcoTox Thresholds* (U.S. EPA 1996c) and *The Role of Screening-Level Risk Assessment and Refining Contaminants of Concern in Baseline Ecological Risk Assessments* (U.S. EPA 2001g), which describes the process of screening COPC. The EPA equilibrium-partitioning sediment benchmarks (ESBs) available at http://www.epa.gov/nheerl/publications/ and the Superfund program's Ecotox Thresholds (ETs) available at http://www.epa.gov/superfund/programs/risk/eco_updt.pdf should be used as screening values for risk to benthic biota from direct toxicity. Other published sediment guidelines [e.g., National Oceanic and Atmospheric Administration (NOAA) Screening Quick Reference Tables (SQuiRTs), http://response.restoration.noaa.gov/cpr/sediment/squirt/squirt.html] can also be used as screening values Table 3-1 in the Navy guidance (U.S. Navy FEC 2003) also provides a list of citations for ecological screening values for sediment.

When screening ecological risks to terrestrial receptors from contaminated floodplain soils, the recently released OSWER Directive 9285.7-55, *Guidance for Developing Ecological Soil Screening Levels* [(Eco-SSLs), U.S. EPA 2003c, http://www.epa.gov/ecotox/ecossl/] should be used. Eco-SSLs for some receptors have been developed for aluminum, antimony, barium, beryllium, cadmium, cobalt, dieldrin, iron, and lead. Screening values for arsenic, chromium, copper, dichlorodiphenyltrichloroethane (DDT), manganese, polycyclic aromatic hydrocarbons (PAHs), pentachlorophenol, and vanadium are currently under development.

For ecological risk to wildlife or fish from food chain effects, widely-accepted screening values have not yet been fully developed. As for the human health risk assessment, if bioaccumulative contaminants are found in biota at levels above site background, they generally should not be screened out and should be carried into the baseline risk assessment for ecological risk as well.

2.3.2 Baseline Risk Assessment

At contaminated sediment sites with bioaccumulative contaminants, the human health exposure pathway driving the risk is usually ingestion of biota, most commonly the ingestion of fish by recreational anglers. Depending on the contaminant and the use of the site, however, there can also be significant risks from direct contact with the sediment, water, or floodplain soils, usually through dermal contact. At sites with non-bioaccumulative or non-biomagnifying contaminants, human health risk is usually driven by pathways involving direct contact.

Generally, the ecological risk assessment should consider the risks to invertebrates, plants, fish and wildlife from direct exposure and from food chain expsoures. The selection of appropriate site-specific 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 of the contaminants of potential concern to the assessment endpoints. PCBs, for example, bioaccumulate in food chains and can diminish reproductive success in upper trophic level species (e.g., mink, kingfishers) 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 usually would constitute the remediation goal.

2.3.3 Risks from Remedial Options

As part of the risk assessment, the short-term, and if appropriate, the long-term risks to human health and the environment from implementation of each of the considered remedial alternatives should be estimated and considered in the remedy selection process. For example, excavation of sediment and capping normally will remove or kill local biota utilizing the areas. These alternatives may also cause substantial short-term impacts on the biota that relied on the existing sediment bed for habitat or food. It is generally believed, however, that these impacts will be short lived, and the biota and habitats typically will recover in less than a year or two. Use of eco-friendly materials as backfill for dredging projects or as a final cap surface can greatly improve the likelihood of quick re-colonization by beneficial biota. The subject of implementation risks is discussed in more detail in the remedy-specific chapters of this guidance and in Chapter 7, Section 7.3, Comparing Net Risk Reduction.

2.4 CLEANUP GOALS

To select the most appropriate remedy for a site, it is important to develop clearly defined remedial action objectives (RAOs) and contaminant-specific remediation goals (RGs). RAOs generally are used in developing and comparing alternatives for a site and in providing the basis for developing more specific RGs, which in turn are used by project managers to select final sediment cleanup levels based on the other NCP remedy selection criteria. RAOs, RGs, and cleanup levels are dependent on each other and represent three steps along a continuum leading from remedial investigation/feasability study scoping to the selection of a remedial action that will be protective of human health and the environment, meet applicable or relevant and appropriate requirements (ARARs), and provide the best balance among the remaining NCP criteria.

2.4.1 Remedial Action Objectives and Remediation Goals

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 typically are derived from the conceptual site model (Section 2.2), and address the significant exposure pathways. RAOs may vary widely for different parts of the site based on the exposure pathways and receptors, regardless if these parts of the site are managed separately as operable units under CERCLA. 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 lead a project manager to develop different RAOs and RGs for each area that are protective of the different receptors.

The development of RAOs should also include a discussion of how they address all the unacceptable human health and ecological risks identified in the risk assessment. Examples of RAOs specific for sediment sites are included in Highlight 2-6. Sediment sites also may need RAOs for other media (e.g., soils, ground water, or surface water). When developing 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, complete biota recovery may depend on the cleanup of sources that are regulated under other authorities. The project manager may discuss these other actions in the record of decision (ROD) and explain how the site remediation is expected to contribute to meeting area-wide goals outside the scope of the site, such as goals related to watershed concerns, but RAOs should reflect objectives which are achievable from the site cleanup.

Highlight 2-6: Sample 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, wading, or swimming at the site to acceptable levels
- Reduce the risks to adults and children from ingestion of contaminated fish and shellfish taken from the site to acceptable levels

Ecological Risk:

- Reduce the toxicity to benthic aquatic organisms at the site to levels that are acceptable
- Reduce the risks to birds and mammals that feed on fish that have been contaminated from sediment at the site to levels that are acceptable

Generally, preliminary remediation goals (PRGs) that are protective of human health and the environment are developed early in the remedial investigation process based on readily available screening levels for both human health and ecological risks (although project managers should be aware that currently available screening levels for sediment are limited; see Section 2.3.1). Because there are very few ARARs specifically for sediment, these RGs are normally based on the site-specific risk assessment. Regions should note, however, some states do have standards for contaminated sediment (e.g., State of Washington) and others are developing them.

As more information is generated during the investigation, these PRGs should be replaced with site-specific RGs by incorporating an improved understanding of site conditions (e.g., site-specific information on fish ingestion rates and bioaccumulation of contaminants in sediment into biota; resource use; other human activities), and other site-specific factors, such as the bioavailability of contaminants. The completed human health and ecological risk assessments should identify appropriate RGs for each contaminant of concern in each medium of significance. RGs for sediment often address direct contact for humans and biota to the sediment as well as bioaccumulation through the food chain. The concentrations of bioaccumulative contaminants in fish are a function of both the sediment and water concentrations of the contaminant, and are, to some extent, species-dependent. The development of the sediment RGs may involve a variety of different approaches that range from the simple application of a bioaccumulation factor from sediment to fish or more sophisticated food chain modeling. The method used and the level of complexity in the back calculation from fish to sediment should be consistent with the approaches used in the human health and ecological risk assessments.

RGs should be represented as a range of values within acceptable risk levels so that the project manager may consider the other NCP criteria when selecting the final cleanup levels. For human health, general guidance is available regarding the exposure equations necessary to develop RG concentrations in various media for both cancer risks and non-cancer health hazards (see Section 2.3.) The development of the human health-based RGs should provide a range of risk levels (e.g., 10^{-6}, 10^{-5}, and 10^{-4} and a non-cancer Hazard Index of 1 or less depending on the health end points of the specific contaminants of concern.) The development of the ecologically-based RGs should also provide a range of risk levels based on the receptors of concern identified in the ecological risk assessment (see Section 2.3). Human health and ecological RGs should be developed through iterative discussions between the project manager, risk assessor, and modeler or other appropriate members of the team.

2.4.2 Cleanup Levels

At most CERCLA sites, RGs for human health and ecological receptors are developed into final, chemical-specific, sediment cleanup levels by weighing a number of factors, including site-specific uncertainty factors and the criteria for remedy selection found in the NCP at Title 40 Code of Federal Regulations (40 CFR) §300.430. These criteria include long-term effectiveness and permanence; reduction of toxicity, mobility and volume through treatment; short-term effectiveness; implementability; cost; and state and community acceptance. These criteria are discussed in detail in Chapter 3, Section 3.2, NCP Remedy Selection Criteria.

Uncertainty factors that may be relevant to consider include (among others) the reliability of inputs and outputs of any model used to estimate risks and establish cleanup levels, reliability of the potential approaches to achieve those results, and the likelihood of occurrence for the exposure scenarios being considered. Other technical factors include (among others) limitations of remedial alternatives and detection and quantification limits of contaminants in environmental media. It is especially important to assess technical achievability realistically, by considering both background levels of contamination and what has been achieved at similar sites elsewhere, so that achievable cleanup levels are developed. All of these factors, along with verified background concentrations of COC, 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 incorporating contaminant fate and transport processes, 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, for CERCLA actions, the ROD should include chemical-specific cleanup levels as provided in the NCP at 40 CFR §300.430(c)(2)(I)(A). The ROD should also indicate the approach that will be used to measure attainment of the cleanup levels. At many sediment sites, especially but not exclusively those with bioaccumulative contaminants, the attainment of sediment cleanup levels may not coincide with the attainment of RAOs. For example, this may be due to the length of time needed for fish or the benthic community to recover. Where cleanup levels have been achieved but progress towards meeting RAOs is not forthcoming as expected, the five-year review process, or where appropriate, a similar process conducted sooner than five years, should be used to assess whether additional actions are needed. Consistent with the NCP (40 CFR §300.430(f)(4)(ii)), where contaminants remain present above unlimited use and unrestricted exposure levels, 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 that should be collected for this review to be effective. As explained further in that chapter, the need for long-term monitoring is not limited to sites where five-year reviews are required. Most sites where contaminated sediment has been removed also should be monitored for some period to ensure that cleanup levels and RAOs are met and will continue to be met.

2.5 WATERSHED CONSIDERATIONS

A unique aspect of contaminated sediment sites is their relationship within the overall watershed, or drainage area, in which they are located. Within the watershed there often is a spectrum of issues that the project manager may need to consider. Foremost among them at many sites is to work with the state to ensure that fish consumption advisories are in place and well publicized. Project managers also should understand the role of the contaminated water body in the watershed, including the habitat or flood control functions it may serve, the presence of non-site-related contaminant sources in the watershed, and current and reasonably anticipated or desired future uses of the water body and surrounding land.

2.5.1 Role of the Contaminated Water Body

Most water bodies provide important habitat for spawning, migration, or food production for fish, shellfish, birds, and other aquatic and land-based animals. One significant 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 consideration when evaluating alternatives and establishing remediation goals for a site, as these fish populations may not show improvement if any link in their migratory route is missing, blocked, or toxic. For migratory species, it may be more appropriate to measure risk and remedy effectiveness in terms of risk to juveniles.

The size, topography, climate, and land use of a watershed, among other factors, may affect characteristics of a water body, such as water quality, sedimentation rate, sediment characteristics, seasonal water flows and current velocities, and the potential for ice formation. For example, watersheds with large wetland areas tend to 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.

Some sediment sites are located in watersheds with a large number of historical and ongoing point and non-point sources, from many potentially responsible parties. Where this is the case, it is especially important to attain expert assistance to plan site characterization strategies that are well suited to the complexity of the issues and designed to answer specific questions. In urban watersheds and others with a large number of ongoing sources, it may be beneficial for a broader group of stakeholders to participate in setting priorities for site characterization and remediation efforts. In these areas, it is especially important to consider background concentrations when developing remedial objectives and to evaluate the incremental improvement to the environment if an action is taken at a specific site in the watershed. Approaching management of a site within the watershed context provides an opportunity to better determine the needs and coordinate the sequence and schedule of cleanup activities in the watershed.

2.5.2 Water Body and Land Uses

Water body uses at sediment sites may include commercial navigation; commercial fisheries, shellfisheries, or aquaculture; boating, swimming, and other forms of recreation; other commercial or industrial uses; recreational or subsistence fishing or shellfishing; and other, less easily categorized uses. Most water bodies 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 performed by the U.S. Army Corps of Engineers (USACE). Other commercial or industrial uses of a site may include the presence of gravel pits, drinking water use, and industrial uses of water including cooling, washing, or waste water disposal.

The NCP preamble (55 *FR* 8710) states that both current and future land uses should be evaluated in assessing risks posed by contaminants at a Superfund site and discusses how Superfund remedies should be protective in light of reasonably anticipated future uses. 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 encourages early discussions with state and local land use planning authorities and the public, regarding reasonably anticipated future uses of properties associated with an National Priorities List (NPL) site. This coordination should begin during the scoping phase of the RI/FS, and ongoing coordination is recommended to ensure that any changes in expectations are incorporated into the remedial process.

There are additional factors the project manager should include in considering anticipated future uses 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 sediment Superfund or RCRA site as compared to an upland terrestrial site. A remediated sediment site may attract more recreational, subsistence, and cultural uses, 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 (generally as TBCs, see Chapter 3, Section 3.3 on ARARs) 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 master plans developed by port and harbor authorities for projections of future use. The USACE should also be contacted regarding future navigational dredging of federally maintained channels.

There may be more parties to consult about anticipated future use at large sediment sites as opposed to typical 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 may 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 should be considered when decision makers wish to understand the implications of different exposure scenarios. Especially where there is some uncertainty regarding the anticipated future uses, the project manager should compare the potential risks associated with several use scenarios.

The identification of appropriate future use assumptions during the baseline risk assessment and the feasibility study should allow the project manager to focus on developing protective, practicable, and cost-effective remedial alternatives. In addition, coordination with stakeholders on land and water body uses leads to opportunities to coordinate Superfund or RCRA remediation in conjunction 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 (PRPs) to settle natural resource damage claims in conjunction with the cleanup. However, as noted in Chapter 1, Section 1.5, State, Tribal, and Trustee Involvement, whether remediation and restoration are addressed concurrently is a site-specific decision that involves input from a number of different parties.

2.6 SOURCE CONTROL

Identifying and controlling contaminant sources is critical to the effectiveness of 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 water body 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 ground water or non-aqueous phase liquids (NAPLs) may continue to introduce contamination to a site. At sites with significant sediment mobility, areas of higher contaminant concentration may act as continuing sources for less-contaminated areas.

Some sources, especially those outside the boundaries of the Superfund or RCRA site, may best be handled under another authority, such as the CWA or a state program. These types of sites can present an opportunity for partnering with private industry and other governmental entities to identify and control sources on a watershed basis. Water bodies with sources outside the Superfund site also present a need to balance the desire for watershed-wide solutions with practical considerations affecting a subset of responsible parties. It can be difficult to determine the proper party to investigate sources outside the Superfund site, but the site RI/FS must be sufficient to determine the extent of contamination coming onto the site and its likely effect on any actions at the site. A critical question is whether an action in one part of the watershed is likely to result in significant and lasting risk reduction, given the probable timetable for other actions in the watershed.

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 ARARs, including the application of technology-based and water quality-based National Pollutant Discharge Elimination System (NPDES) permitting to achieve and maintain sediment cleanup levels. Source control actions may include the following, or other actions:

- Elimination or treatment of waste water discharges (e.g., installing additional treatment systems prior to discharge);
- Isolation or containment of sources (e.g., capping of contaminated soil) with attendant engineering controls;
- Pollutant load reductions of point and non-point sources based on a TMDL;
- Implementation of best management practices (e.g., reducing chemical releases to a storm drain line); and
- Removal or containment of mobile sediment hot spots.

EPA's Contaminated Sediment Management 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 state or local governments using combinations of voluntary and mandatory actions.

The identification of continuing sources and their potential to re-contaminate site sediment are essential parts of site characterization and the development of an accurate conceptual site model, whether or not source areas are part of the site itself. 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 to determine where to focus resources. Where sources are a part of the site, project managers should develop a source control strategy or approach for the site as early as possible in the process of site characterization. Where sources are outside the site, project managers should encourage the development of source control strategies by other authorities, and understand those strategies. Generally, a source control strategy should include plans for identifying, characterizing, prioritizing, and tracking source control actions, and for evaluating the effectiveness of those actions. It is also useful to establish milestones for source control that can be linked with sediment remedial design and cleanup actions. If sources are substantially controlled, it is very important to re-evaluate risk pathways to see if sediment actions are still needed. If sources are not substantially controlled, it is very important to include ongoing sources in the evaluation of what sediment actions may or may not be appropriate and what management goals are achievable for the site.

Generally, significant continuing upland sources (including ground water, NAPL, or upgradient water releases) should be controlled to the greatest extent possible before sediment cleanup. Once these sources are controlled, project managers should evaluate the effectiveness of the 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 sediment remediation is likely to significantly benefit human health and/or the environment after considering the risks caused by an unaddressed or ongoing source, it may be appropriate to conduct an action for sediment prior to completing all land-based source control actions.

2.7 PHASED APPROACHES AND EARLY ACTIONS

At some sediment sites, a phased approach to site characterization, remedy selection, or remedy implementation may be the best or only practical option. Phasing site characterization can be especially useful when risks are high, yet some important site-specific factors are unknown. Phasing in remedy selection and implementation may be especially useful at sites where contaminant fate and transport processes are not well understood or the remedy has significant implementation uncertainties. Phasing may also be useful where the effectiveness of source control is in doubt. By knowing the effectiveness of source control prior to implementing sediment cleanups, the risk of having to revisit re-contaminated areas is greatly reduced. High remedy costs, the lack of available services and/or equipment, and uncertainties about the potential effectiveness or the risks of implementing the preferred sediment management approach, can also lead to a decision to phase the cleanup.

Phasing can also be used at large, multi-source, multi-PRP sites with primarily historic contamination where contaminated sediment is still near the sources. In these types of sites, working with single responsible parties to address sediments with higher contaminant concentration near their sources may be an effective risk reduction measure, while the more complex decision making concerning less-contaminated downstream areas with mixed contaminants is ongoing.

Project managers are also encouraged to use an iterative approach, especially at complex sediment sites in order to provide additional certainty of information to support decisions. In general, this means testing of hypotheses and conclusions and reevaluating site assumptions as new information is gathered. This is an important component of updating the conceptual site model. 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. As noted in Chapter, Section 1.4, Decision-Making Process, an iterative approach should not be misconstrued as an endless loop.

Even before the sediment at a site is well characterized, if risk is obvious, it may be very important to begin to control significant ongoing land-based sources. It also may be appropriate to take other early or interim actions, followed by a period of monitoring, before deciding on a final remedy. Highlight 2-7 provides examples of early actions taken to control sources, minimize human exposure, control sediment migration, or reduce risk from sediment hot spots at contaminated sediment sites. Early or interim actions are frequently used to prevent human exposure to contaminants or to control sources of sediment contamination. However, such actions for sediment are less frequent. Early or interim actions may be appropriate for sediment to prevent migration or to reduce the current risk from a localized area of highly contaminated sediment. 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 that would present an immediate threat. At contaminated sediment sites, removal authority or state authorities have been used to implement many of the actions listed in Highlight 2-7. The NCP at 40 CFR §300.415 outlines criteria for using removal authority, as further explained in the EPA guidance and directives (U.S. EPA 1993a, U.S. EPA 1996d, 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.

2.8 SEDIMENT STABILITY AND CONTAMINANT FATE AND TRANSPORT

An important part of the remedial investigation at many sediment sites is an assessment of the extent of sediment and contaminant movement by processes and events in the past and a prediction about whether there is likely to be significant redistribution or transport in the foreseeable future. It is also important to characterize the potential movement of sediment and contaminants to accurately assess a range of risk management approaches. This characterization should include an assessment of sediment stability and contaminant fate and transport.

Highlight 2-7: Potential Examples of Early Actions at Contaminated Sediment Sites

Actions to prevent releases of contaminants from sources:

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

Actions to minimize human exposure to contaminants (coordinated with other appropriate agencies):

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

Actions to minimize further migration of contaminated sediment:

- Boating controls (e.g., vessel draft or wake restrictions to prevent propeller wash, anchoring restrictions)
- Excavating, dredging, capping, or otherwise isolating contaminated sediment hot spots

Actions taken to reduce risk from highly contaminated sediment hot spots:

- Capping, excavation, or dredging of localized areas of contaminated sediment that pose a very high risk

In most aquatic environments, surface sediment and any associated contaminants, move over time. The more important, and more complex issue is whether movement of contaminated sediment (surface and subsurface) or of contaminants alone is occurring or may occur at scales and rates that will significantly change their current contribution to human health and ecological risk. Addressing that issue requires an understanding of the role of natural processes that counteract sediment and contaminant movement and fate, such as natural sedimentation and armoring, and contaminant transformations to less toxic or less bioavailable compounds. For this reason, it is important for project managers to use technical experts to help in the analysis of sediment stability and contaminant mobility, especially where large amounts of resources are at stake.

Sediment movement is a complex topic also because it has both positive and negative effects on risk. For example, floods frequently transport both clean and contaminated sediment, which are subsequently deposited within the water body and on flood plains. This may spread contamination, isolate (through burial) other existing contamination, and lower concentrations of contaminants (through dilution) within the immediate site boundaries.

Both natural and man-made (anthropogenic) forces may cause sediment and contaminants to move. Highlight 2-8 lists examples of each.

Highlight 2-8: Potential Causes of Sediment and/or Contaminant Movement

Natural causes of sediment movement include:

- Routine currents in rivers, streams, and harbors
- Tides in marine waters and estuaries
- Floods generated by rainfall or snow-melt induced runoff from land surfaces
- Ice thaw and ice dam-induced scour
- Seiches (oscillation of lake elevation caused by sustained winds), especially in the Great Lakes
- Storm-generated waves and currents (e.g., hurricanes, Pacific cyclones, nor'easters)
- Seismic-generated waves (e.g., tsunamis)
- Earthquakes, landslides, and dam failures
- Bioturbation from micro- and macrofauna

Anthropogenic causes of sediment movement include:

- 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
- Boat propeller wash, ships' wakes, ship grounding or anchor dragging

Causes of dissolved contaminant movement without sediment movement include:

- Flow of ground water through sediment
- Molecular diffusion
- Gas-assisted transport

Many contaminated sediment sites are located in areas that are primarily depositional, or in areas where only a limited surface layer of sediment is routinely mobilized. In these fairly stable areas, other processes may contribute to sediment and contaminant movement. These include, for sediment, bioturbation, and for dissolved contaminants, ground water flow, molecular diffusion, and potentially, gas-assisted transport. Like erosion and deposition, these processes continue to operate after remedies are in place, so an understanding of whether or not they are likely to be significant ongoing contaminant transport pathways at a particular site is especially important for evaluating in-situ capping and monitored natural recovery alternatives.

There are a variety of empirical and modeling methods for evaluating sediment and contaminant movement and their consequences. The models normally rely upon site-specific empirical data for input parameters. Both empirical methods and models have limitations, so it is usually important to consider a variety of methods in evaluating a site and to compare the results. For large or complex sediment sites, project managers should approach an assessment of sediment and contaminant movement from the following aspects:

- A site-specific assessment of empirical site characterization data (see Section 2.8.1);
- A site-specific assessment of the frequencies and intensities of expected routine and extreme events which mobilize sediment (see Section 2.8.2);
- A site-specific assessment of ongoing processes that mobilize contaminants in otherwise stable sediment, such as bioturbation, diffusion, and advection (see Section 2.8.3); and
- A site-specific assessment of the expected consequences or results of sediment and contaminant movement (see Section 2.8.4).

As noted above, this assessment will frequently require the use of models. A wide variety of models are available, ranging from simple models with small numbers of input criteria to complex, multi-dimensional models that are data intensive. A discussion of model uses and selection is presented in Section 2.9.

Especially for larger sites, a "lines of evidence" approach should be used to evaluate the stability of the sediment bed and the contaminants within it for various areas of the water body. 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 to determine the source of the discrepancies and understand their significance. This approach is described in more detail in Chapter 4, Section 4.3, Lines of Evidence.

2.8.1 Data Collection

An assessment of sediment and contaminant movement begins with the collection of a variety of empirical data (i.e., data derived from field or laboratory observation). Although literature values may be available for some parameters, project managers are encouraged to collect site-specific information for the most important processes at the site (as identified in the conceptual site model), especially where large resources are at stake in decision making.

The vertical and horizontal sediment and contaminant distributions present at a site are a result of all of the routine and extreme, natural and anthropogenic processes that contribute to the physical, chemical, and biological attributes of a water body. Site conditions at the time of investigation generally reflect a combination of influences. Project managers should not assume that current conditions represent stable conditions when, in fact, sediment may be actively responding to recent or current forces and events. Conversely, project managers should not assume that a site or all areas of a site are unstable or contaminants are mobile at a scale or rate which significantly impacts risk. At many sites, the same areas of contamination persist over many years, despite some level of surface sediment and contaminant redistribution.

Processes that are important in terms of their larger scale influences on a watershed may be less important to the stability of sediment or mobility of contaminants in smaller, more isolated areas of a water body. Both scales of investigation may be important. For example, in some situations, the large scale rainstorms associated with hurricanes may greatly impact sediment loading to the water body, 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 flow-induced shear stress at the bottom of the water body during various conditions, and the cohesiveness of the upper sediment layers. In most environments, bottom shear stress is controlled by currents, waves, and bottom roughness (e.g., sand ripples, biologically formed mounds in fines). A preliminary evaluation of sediment stability should include at least site-specific measurements of surface water flow velocities and discharges, water body bathymetry, and surface sediment types (e.g., by use of surface grab samples).

In some cases, empirically measured erosion rates are lower than anticipated from simple models, due to natural armoring. Winnowing (suspension and transport) of fines from the surface layers of sediment is one common form of armoring. Others are listed in Highlight 2-9, including the effect known as "dynamic armoring", which describes the effect caused by suspended sediment or a fluff, floc, or low density mud layer (present in some estuaries and lakes) that decreases the expected erosion rate of underlying sediment.

Highlight 2-9: Principal Types of Armoring

Physical:

- Winnowing of fine grained materials, leaving larger-grained materials on surface
- Compaction of fine-grained sediment

Chemical:

- Chemical reactions and weathering of surface sediment

Dynamic:

- Suspended sediment dampening turbulence during high flow events

Biological:

- Physical protection and sequestration by rooted aquatic vegetation
- Mucous excretions of polychaetes
- Erosion-resistant fecal pellets or digested sediment

Sediment properties that affect cohesion and erosion in many sediment environments include bulk density, particle size (average and distribution), clay mineralogy, the presence of gas, and the organic content. It is not unusual for erosion rates to vary by 2 to 3 orders of magnitude spatially at a site, depending on currents, bathymetry, bioturbation, and other factors (e.g., pore water salinity). In a fairly uniform cohesive sediment core, erosion rates may drop several orders of magnitude with depth into the sediment bed, but in more variable cores this may not be the case.

Biological processes by macro- and microorganisms also affect sediment stability in multiple ways, both to increase erosion (e.g., gas generation and bioturbation by lowering bulk density) and to decrease erosion (e.g., aquatic vegetation, biochemical reactions which increase shear strength of sediment). The process of sediment mixing caused by bioturbation is discussed further in Section 2.8.3.

A wide variety of empirical methods is available to assess the extent of past sediment and contaminant movement. Highlight 2-10 lists some key examples. Each of these methods has advantages and limitations and generally none should be used in isolation. The help of technical experts is likely to be needed to determine which methods are most likely to be useful at a particular site.

2.8.2 Routine and Extreme Events

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 water body. In northern climates, formation of ice dams and ice scour are also routine events that may have significant effects on sediment. It is important to note that seasonal changes in water flow may also affect where erosion and deposition occur. Depending on the location of the site, (e.g., riverine areas, coastal/marine area, inland water bodies), different water body 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 flows and stages from nearby gauging stations and on other hydrodynamic forces. However, project managers should keep in mind that residential or commercial development in a watershed may significantly increase the impervious area and subsequently increase the frequency and intensity of routine flood events. While the intensity of most routine forces may be low, their high frequency may cause them to be an important influence on sediment movement within some water bodies.

Highlight 2-10: Key Empirical Methods to Evaluate Sediment and Contaminant Movement

Bathymetry (evaluates net change in sediment surface elevations)

- Single point/local area devices
- Transects/cross-sections (with known vertical and horizontal accuracy)
- Longitudinal river profiles along the thalweg (i.e., location of deepest depth)
- Acoustic surveys (with known vertical and horizontal accuracy)
- Comparison to dredging records, aerial photos, overall geomorphology

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

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

Sediment data (e.g., from continuous cores or surface samples):

- Patterns of grain-size distribution; sediment trend analysis (McLaren and Bowles 1985, McLaren et al. 1993, Pascoe et al. 2002)
- In-situ or ex-situ erosion measurement devices [e.g., SEDFLUME (Jepsen et al. 1997, McNeil et al. 1996), PES (Tsai and Lick 1986), Sea Carousel (Maa et al. 1993), or Inverted Flume (Ravens and Gschwend 1999)]
- Sediment water interface camera

Geochronology (evaluates continuity of sedimentation and age of sediment with depth in cores):

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

Geomorphological studies:

- Land and water body geometry and bathymetry; physical processes
- 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 and coastal seas)
- Sampling during the rising limb of a rain-event generated runoff hydrograph (frequently greatest erosion)

Dissolved contaminant movement:

- Seepage meters at sediment surface
- Gradients near water body

In contrast, some water bodies are significantly affected by short-term extreme forces that are much less common. 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 upland soil and erosion of sediment, which are then deposited in other areas of the water body or on flood plains when the flow slows during the falling limb of the runoff hydrograph. Scour of the sediment bed may also result from the movement of ice and/or natural or man-made debris during extreme flood events. To obtain a preliminary understanding of extreme event frequency at a site, it is important to examine both historical records (e.g., meteorological and flow records) and site characterization data (e.g., core data and bathymetry).

Floods are frequently classified by their probability of occurrence; for example 50-year, 100-year, 200-year, and probable maximum flood. Although 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. 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 not uncommon for multiple low probability events to happen more frequently than they are expected, especially when the hydrograph record used to determine these probabilities is not very long or where land use or climate is changing.

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. 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 that 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 on sediment and contaminant movement of a 100-year flood and other events or forces with a similar probability of occurrence (i.e., 0.01 in a year). A similar minimum probability of occurrence may be appropriate for analysis of other extreme events such as hurricanes and earthquakes. 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 2.9 of this chapter discusses modeling in more detail.

2.8.3 Bioturbation

In many cases, within stable sediment deposits, the most important natural process bringing contaminants to the sediment surface is bioturbation. Broadly speaking, bioturbation is the movement of sediment by the activities of aquatic organisms. Although this movement may be in many directions, it is the vertical mixing that is mainly of concern for project managers because it brings contaminants to the bed surface, where most exposures occur. 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 to interstitial/pore water or the water column. Many bottom-dwelling organisms 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 profile camera results, sediment cores, or other site characterization data that displays the cumulative results of bioturbation through time. It is also useful to be aware of the typical burrowing depths of aquatic organisms in environments similar to the site. Project managers should keep in mind however that population density has a tremendous effect on whether organisms present at the site may have a significant effect on the mixing zone. It is important to understand the depth of the mixing zone in the various environments at a site because, where sediment is physically stable and not significantly mobilized by ground water advection, contaminants below this zone are unlikely to contribute to current or future risk at a site.

Typically, the upper 15 to 20 centimeters of sediment contain the greatest number of organisms and activity, and are therefore of greatest interest when attempting to determine the depth of the mixing zone or when evaluating current exposure of biota to contaminants, although this depth can be greater, especially in marine environments. Highlight 2-11 provides examples of organisms that cause bioturbation, their activity type, and the general depth of the activity. 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. For example, the depth and effectiveness of bioturbation may be very different in a highly productive estuary and in a heavily used commercial boat slip.

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 - Salinity, water temperatures, depths, seasonal variation);
- Sediment type - Size distribution, organic and carbonate content, bulk density); and
- Organism type - Organisms either present and/or likely to recruit to and re-colonize the area).

Highlight 2-11: Sample Depths of Bioturbation Activity			
Organism	**Activity Type**	**Depth**	**Reference**
Freshwater			
Tubificid worm (oligochaete)	Burrowing/Feeding	0 - 3 cm	Matisoff, Wang and McCall 1999 Pennak 1978
Midge and Mayfly (insects)	Burrowing/Feeding	0 - 15 cm	Matisoff and Wang 2000 Pennak 1978
Crayfish (crustacean)	Burrowing	0 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 or dredging backfill material. Where bioturbation is likely to be a significant process, it is important to evaluate the depth over which it causes significant mixing, using site-specific data and assistance by technical experts, to assess alternative approaches for the site.

2.8.4 Predicting the Consequences of Sediment and Contaminant Movement

Depending on its extent, movement of sediment or contaminants may or may not have significant consequences for risk, cost, or other important factors at a specific site. A number of differing factors may be important in determining whether expected or predicted movements 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 exposure and risk. Where this information is not available or has significant uncertainty, models may also be very useful to help understand and predict changes. This analysis should include not only increased risk from contaminant releases to the immediate water body, 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.

Project managers should assess the impacts of contaminant release on potential receptors on a site-specific basis, using information generated during the baseline human health and ecological risk assessments. Where natural recovery is being evaluated, project managers should recognize that not only the rate of net sedimentation, but also the frequency of erosive episodes, can help determine the rate of recovery for surface sediment and biota. Where in-situ capping is being evaluated, project managers should recognize that some amount of erosion and sediment transport may be acceptable and can be incorporated into plans for remedial design and cap maintenance. Increased risk to human or ecological receptors due to contaminant releases during dredging may be a related analysis when considering dredging. Comparing the increased risks, costs, or other consequences of sediment disruption due to natural causes or the remedy itself also may be 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 sediment 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.

2.9 MODELING

This section briefly discusses the role of modeling in evaluating alternative remedies 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 (e.g., U.S. EPA 2004c and 2004d). Guidance on the recommended process to follow in making these decisions is given below. This section focuses on sediment transport models, but the general principles also apply to other models, such as food web models. Technical assistance is available to project managers from EPA's Superfund Sediment Resource Center (SSRC), where experts from inside and outside the Agency may be accessed. Additional research about contaminated sediment transport and food web modeling is underway at the Office of Research and Development (ORD) and project managers should monitor the Superfund sediment Web site at http://www.epa.gov/superfund/resources/sediment or contact their region's ORD Hazardous Substance Technical 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, have documented contaminant concentrations in sediment and biota, and often have fish consumption advisories already in place.

Models can be useful tools, even though they can be 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 is needed. Nevertheless, models are helpful in that they give, when properly applied, a more complete understanding of the transport and fate of contaminants than typically can be provided by empirical data (from field or laboratory) alone. Modeling of contaminated sediment, just as with other modeling, should follow a systematic planning and implementation process. 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., decades) or during episodic, high-energy events (e.g., 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 usually 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 indications for 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 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 by the model. Where it is not, information should be relayed to researchers so that the model can be modified or re-calibrated and lead to more accurate future predictions.

2.9.1 Sediment/Contaminant Transport and Fate Model Characteristics

A sediment/contaminant transport and fate model typically is a mathematical or conceptual representation of the movement of sediment and associated contaminants, and the chemical fate of those contaminants, as governed by physical, chemical and biological factors, in bodies of water. These models are inherently limited by our current understanding of the factors governing these process and our ability to quantify them (i.e., represent mathematically their interactions and effects on the transport and fate of sediment and contaminants). Even the most complex sediment model may be a relatively simplistic representation of the movement of sediment through natural and engineered water bodies. It may be 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 (i.e., breaking space and time into blocks) of the water body being modeled when using a numerical model; and

- The inability to realistically simulate geomorphological processes such as river meandering, bank erosion, and localized effects (e.g., due to natural debris or beaver dams).

Nevertheless, sediment/contaminant transport and fate models generally are useful tools when properly applied, although they are data intensive and require specialized expertise to apply and interpret. This type of model is one of several tools that could assist a remedial decision.

Currently, 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 2-12, and an example of a conceptual site model is presented in Highlight 2-13.

Highlight 2-12: Key Characteristics of the Major Types of Sediment/Contaminant Transport and Fate Models

Conceptual Model:

Identifies the following: 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.

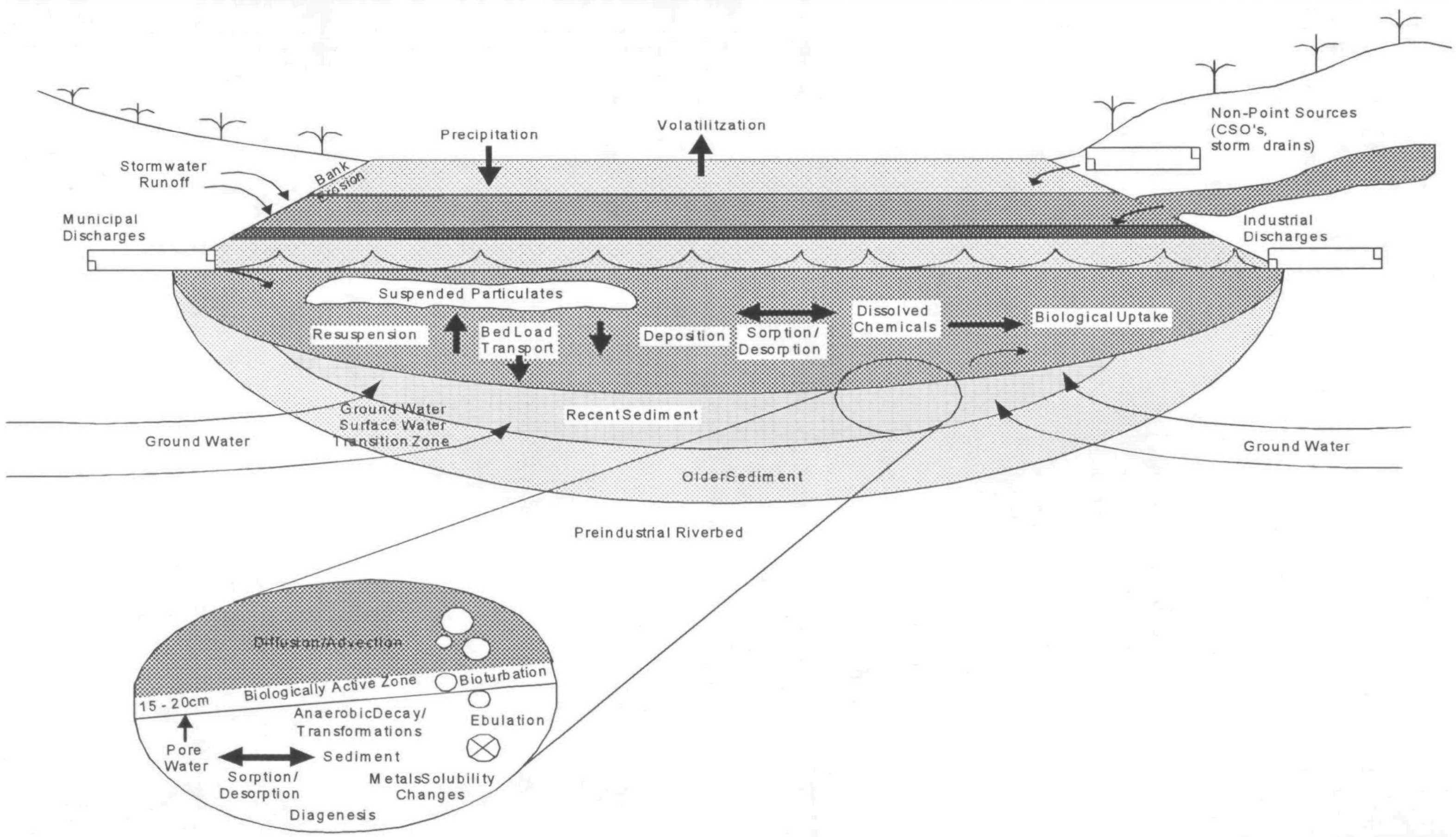
Regression Model:

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 of numerical techniques include finite difference and finite element methods. A numerical model is used when the processes being modeled are represented by nonlinear equations for which closed-form solutions do not exist.

Highlight 2-13: Sample Conceptual Site Model Focusing on Sediment-Water Interaction



Source: Modified from Sediment Management Workgroup (SMWG)

2.9.2 Determining Whether A Mathematical Model is Appropriate

Mathematical transport and fate 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, existing empirical data and new monitoring data may be sufficient to support a decision. A mathematical modeling study is usually not warranted 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 approaches. Mathematical modeling becomes especially important when the existing empirical data are insufficient to predict future scenarios.

Project managers should use the following series of questions to help guide the process of deciding whether to use a site-specific mathematical model:

- Have the questions or hypotheses that the model is intended to answer 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 all significant ongoing sources of 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 itself?

If the decision is made that some level of mathematical 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.

2.9.3 Determining the Appropriate Level of Model

When the decision is made that a mathematical model is appropriate at a site, project managers should generally consider three steps in determining what level of modeling to use. It is important to consider all three steps in order. In some cases, these three steps may be more useful when performed in an iterative fashion (for example, based on additional data analysis or from results obtained during Step 3, it may become apparent that the conceptual site model should be modified).

Step 1: Develop Conceptual Site Model

Development of a Conceptual Site Model (CSM) is recommended as the key first step in this process. As described in Section 2.2, a CSM identifies the processes and interactions that typically control the transport and fate of contaminants, including sediment associated contaminants. If this step is not performed, then the decision of what level of modeling is appropriate may be made with less than the requisite information that might be needed to make a scientifically defensible decision.

The development of a CSM usually 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) or Cowen et al. (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 significant processes and interactions that control the transport and/or fate of sediment contaminants, 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 and eliminate those types of models that do not have this capability from further consideration.

Mathematical models (in particular numerical models) that can simulate most of the processes that control the transport and fate of sediment and contaminants in water bodies (including a wide variety of physical, chemical, and biological processes) have been developed. Highlight 2-14 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:

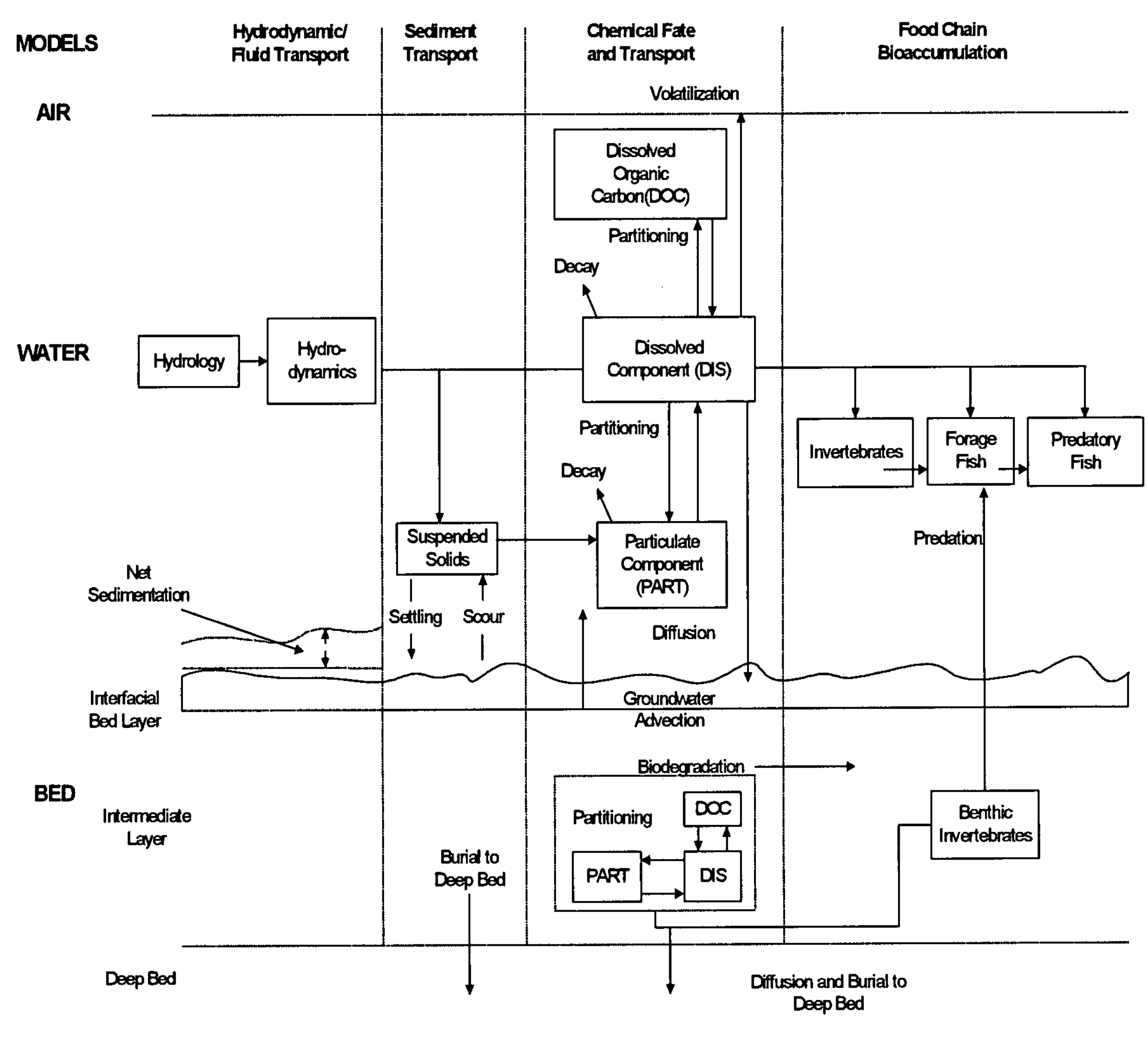
- *Land and air:* Physical processes that result in loading of contaminants to water bodies may include point discharges, overland flow (i.e., runoff), discharge of ground water, NAPL seeps, and air deposition;

- *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;

- *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

- *Water column and 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, biotransformation, and biological uptake.

Highlight 2-14: Sample Contaminant Exposure Modeling Framework



Source: NRC 2001

In Highlight 2-14 above and in other modeling discussions, generally "two-phase partitioning" refers to modeling the contaminant in two parts or phases: a bioavailable dissolved fraction and a generally non-bioavailable particulate fraction. In "three-phase partitioning," contaminant concentrations normally are considered in three phases: the bioavailable dissolved phase, a generally non-bioavailable dissolved organic carbon phase, and a generally non-bioavailable particulate organic carbon phase. A three-phase model usually is appropriate for waters in which internally produced organic material (e.g., produced in-situ) is a significant proportion of total solids as compared to other organic and inorganic matter 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 approaches, or develop and test new models or modules. This latter approach is a research and development level effort and normally should be avoided.

Examples of processes that cannot be dynamically simulated, even using state-of-the-art sediment transport models, may include 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 water body due to the failure of a river/stream bank, but this process normally 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 have been conducted by the EPA's National Exposure Research Laboratory (see U.S. EPA 2004c and U.S. EPA 2004d).

Where numerical models are used, the following components typically should be performed to yield a scientifically defensible modeling study: verification, calibration, validation, sensitivity analysis, and uncertainty analysis. The project manager should be aware that the terms "verification" and "validation" are frequently used interchangeably in modeling literature. These terms, for purposes of this guidance, mean:

- *Model verification*: Evaluating the model theory, consistency of the computer code with model theory, and evaluation of the computer code for integrity in the calculations. This should be an ongoing process, especially for newer models. Model verification should be documented, or the model or model component should be peer-reviewed by an independent party if it is new;

- *Model calibration*: Using site-specific information from a historical period of time to adjust model parameters in the governing equations (e.g., bottom friction coefficient in hydrodynamic models) to obtain an optimal agreement between a measured data set and model calculations for the simulated state variables;

- *Model validation*: Demonstrating that the calibrated model accurately reproduces known conditions over a different period of time with the physical parameters and forcing functions changed to reflect the conditions during the new simulation period, which is different from that used for calibration. The parameters adjusted during the calibration process should NOT be adjusted during validation. Model simulations during validation should be compared to the measured data set. If an acceptable level of agreement is achieved between the data and model simulations, then the model can be considered validated as an effective tool, at least for the range of conditions defined by the calibration and validation data sets. If an acceptable level of agreement is not achieved, then further analysis should be carried out to determine possible reasons for the differences between the model simulations and measured data during the validation period. The latter sometimes leads to refinement of the model (e.g., using a finer model grid) or to the addition of one or more physical/chemical processes that are represented in the model;

- Sensitivity analysis: This process consists of varying each of the input parameters by a fixed percent (while holding the other parameters constant) to determine how the predictions vary. The resulting variations in the state variables are a measure of the sensitivity of the model predictions to the parameter whose value was varied; and

- Uncertainty analysis: This process consists of propagating the relative error in each parameter (that was varied during the sensitivity analysis) to determine the resulting error in the model predictions. A probabilistic model (e.g., Monte Carlo Analysis) is one method of performing an uncertainty analysis (see guidance on Superfund's risk Web page at http://www.epa.gov/superfund/programs/risk). In general, while quantitative uncertainty analyses are possible and practical to perform with watershed loading models and food chain/web models, they are not so (at the current time) for fate and transport models.

The extent to which these components of a modeling study are performed using verified models can determine to a large degree the defensibility of the modeling project. If a verified model has not been sufficiently calibrated or validated for a specific site, and if sensitivity and uncertainty analyses have not been performed, then the modeling study may lack defensibility and be of little value. Where possible, project managers should use verified models that are in the public domain, calibrated and validated 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 publicly and may not have been verified. The interpretation of modeling results and the reliance placed on those results should heavily consider the extent of documented model verification, calibration, validation, sensitivity analysis, and uncertainty analysis performed.

2.9.4 Peer Review

It is EPA policy that a peer review of numerical models is often appropriate 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 1994c) and *Peer Review Handbook* (U.S. EPA 2000d) to determine whether a peer review of a model is appropriate and, if so, what type of peer review should be used. As a rule of thumb, when a model is being used outside the niche for which it was developed, is being applied for the first time, or is a critical component of a decision that is very costly, a peer review should be performed. In addition, project managers should refer to OSWER Directive 9285.6-08, *Principles for Managing Contaminated Sediments at Hazardous Waste Sites*, Principle 6 (U.S. EPA 2002a, see Appendix A).

EPA peer review guidance for models also notes that: "Environmental models 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" (U.S. 1994c). Peer reviewers advise the Agency regarding proper use and interpretation of a model; it is then the Agency's task to properly apply that advice to regulatory decisions.

Highlight 2-15 summarizes some important points to remember about modeling at sediment sites.

Highlight 2-15: Important Principles to Consider in Developing and Using Models at Sediment Sites

1. **Consider modeling results in conjunction with empirical data to inform site decision-making.** Mathematical models are useful tools that, in conjunction with site environmental measurements, can be used to characterize current site conditions, predict future conditions and risks, and evaluate the effectiveness of remedial alternatives in reducing risk. Modeling results generally should not be relied upon exclusively as the basis for cleanup decisions.

2. **Develop and refine a conceptual site model that identifies the key areas of uncertainty where modeling information may be needed.** When evaluating if a model is needed and in deciding which models might be appropriate, a conceptual site model should be developed that identifies the key exposure pathways, the key sediment and water-body characteristics, and the major sources of uncertainty that may affect the effectiveness of potential remedial alternatives (e.g., capping, dredging, and/or monitored natural recovery).

3. **Consider site complexity before deciding if a mathematical model is necessary.** Site complexity and controversy, available resources, project schedule, and the level of uncertainty in model predictions that is acceptable, are generally the critical factors in determining whether a simple, intermediate, or advanced level model should be developed and used. Potential remedy cost and magnitude of risk are generally less important, but they can significantly affect the level of uncertainty that is acceptable.

4. **Determine what model output data are needed to facilitate decision-making.** As part of problem formulation, the RPM should consider: 1) what site-specific information is needed to make the most appropriate remedy decision (e.g., degree of risk reduction that can be achieved, correlation between sediment cleanup levels and protective fish tissue levels, time to achieve risk reduction levels, degree of short-term risk), 2) what model(s) are capable of generating this information, and 3) how the model results can be used to help make these decisions. Site-specific data collection should concentrate on input parameters that will have the most influence on model outcome.

5. **Understand and explain model uncertainty.** The model assumptions, limitations, and the results of the sensitivity and uncertainty analyses should be clearly presented to decision makers and should be clearly explained in decision documents such as proposed plans and RODs.

6. **Conduct a complete modeling study.** If an intermediate or advanced level model is used in decision making, the following components should be included in every modeling effort:
   - Model verification (or peer-review if a new model is used)
   - Model calibration
   - Model validation
   - Sensitivity analysis
   - Uncertainty analysis

7. **Learn from modeling efforts.** If post-remedy monitoring data demonstrate that the remedy is not performing as expected (e.g., fish tissue levels are much higher than predicted), consider sharing these data with the modeling team to allow them to perform a post-remedy validation of the model. This could provide a basis for model enhancements that would improve future model performance at other sites. If needed, this information could also be used to re-estimate the time frame when RAOs are expected to be met at the site.

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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 the remedial action objectives (RAOs) for the site. This process lays the groundwork for proposing and selecting a remedy for the site that best eliminates, reduces, or controls risks to human health and the environment. The 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). The proposed plan and record of decision (ROD) process is described in the EPA's *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). 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 (ARARs), estimating cost, and implementing institutional controls. Chapters 4, 5, and 6 present more detailed guidance on evaluating alternatives based on the three major approaches for sediment: monitored natural recovery (MNR), in-situ capping, and dredging (or excavation) with treatment or disposal.

Although this chapter focuses on remedial alternatives for managing contaminated sediment, project managers beginning this stage of site management should keep in mind that the first step at almost every sediment site should be to implement measures to control any significant ongoing sources and to evaluate the effectiveness of those controls. Until this is done, appropriately evaluating alternatives for sediment may be difficult. However, it may be appropriate to evaluate implementation of interim sediment clean-up measures prior to completing source control in order to control further dispersal of sediment hot spots or reduce risks to human health and the environment due to sediment contamination.

In addition, project managers should keep in mind that flexibility is frequently important in the feasibility study process at sediment sites. Iterative or adaptive approaches to site management are likely to be appropriate at these sites. Also, project managers should consider pilot testing various approaches as part of the feasibility study process.

3.1 DEVELOPING REMEDIAL ALTERNATIVES FOR SEDIMENT

As described in Section 1.3.1 Remedial Approaches, there are typically three major approaches that can be taken to reduce risk from contaminated sediment when source control measures are insufficient to reduce risks: MNR, in-situ capping, and sediment removal by dredging or excavation. Hybrid approaches may combine these three. A fourth approach, in-situ treatment, is currently under development and may become a viable alternative in the future, especially in combination with in-situ caps. Highlight 1-5 in Chapter 1 briefly summarizes these major approaches for sediment sites.

Project managers should consider the following steps, which build on EPA's RI/FS Guidance by adding details specific to sediment, when developing alternatives at sediment sites:

1. Develop remedial action objectives specifying the contaminants and media of interest, exposure pathways, and remediation goals that permit a range of alternatives to be developed including each of the three major approaches (natural recovery, capping, and removal), and that consider state and local objectives for the site;

2. Identify estimated volumes or areas of sediment to which the approaches may be applied, taking into account the need for protectiveness as identified in the remedial action objectives and the biological, chemical and physical characteristics of the site;

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

4. Develop additional detail concerning known major constraints on each alternative, including the three major approaches at the site (e.g., need to maintain flow capacity for flood control, need to accommodate navigational dredging);

5. To the extent possible with information available at this stage of the FS, identify the time frame(s) in which the alternatives are expected to achieve cleanup levels and remedial action objectives; and

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

This process often 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 risk reduction goals. Typically, 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 approaches that may be available for contaminated sediment, generally project managers should evaluate each approach carefully, including the three major approaches (MNR, in-situ capping, and removal through dredging or excavation) at every sediment site at which they might be appropriate.

3.1.1 Alternatives which Combine Approaches

At sites with multiple water bodies or sections of water bodies with differing characteristics or uses, or differing levels of contamination, project managers have found that alternatives that combine a variety of approaches 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 examples of how different approaches might be combined into alternatives for evaluation at sediment sites:

- An alternative might combine a variety of dredging, transport, and disposal methods that remove differing volumes of contaminated sediment "hot spots," with capping or MNR for more widespread areas of lessor contamination;

- An alternative might combine armored in-situ capping of contaminated sediment which is more erodible or hot spot areas causing higher risk, with MNR for more highly depositional areas;

- An alternative might combine dredging in federal navigation channels or for areas where there is insufficient water depth to maintain navigation or flood capacity with a cap, with in-situ capping of flood plain, intertidal or under-pier areas where a less costly approach is desired; and
- An alternative might combine thin-layer placement (see Chapter 4, Monitored Natural Recovery) 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 at Title 40 Code of Federal Regulations (40 CFR) §300.430(e)(6) provides that the no-action alternative should be considered 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, such as under another ROD.

No-action or no-further-action alternatives normally do not include any treatment, engineering controls, or institutional controls but may include monitoring. For example, at a site where risk is acceptable (e.g., because contaminant levels in surface sediment and biota are low and the site is stable), but the site contains higher levels of contamination at depth, it may be advisable to periodically evaluate the continued stability of buried contaminants. A "no action" alternative may include monitoring of these buried contaminants. Project managers and others should not confuse this however with MNR, where natural processes are relied upon to reduce an unacceptable risk to acceptable levels. The difference is often the increased level and frequency of monitoring included in the MNR alternative and the fact that the MNR alternative includes a cleanup level and expected time frame for achieving that level. Project managers should normally evaluate both a No Action and an MNR alternative at sediment sites.

If a no-action or no-further action alternative does not meet the NCP's threshold criteria allowed in 40 CFR §300.430 (i.e., protection of human health and the environment and meeting applicable or relevant and appropriate requirements), it is not necessary to carry it though to the detailed analysis of alternatives. However, the 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

Generally, in-situ treatment is an approach that involves the biological, chemical, or physical treatment of contaminated sediment in place. This approach is currently under development by researchers. Although significant technical limitations exist currently, active laboratory, bench and field scale pilot studies may make it a viable alternative in the future. Project managers are encouraged to track the development of in-situ treatment methods. 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 altering the contaminants by converting them into a less bioavailable, 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 developing an effective in-situ delivery system to add and mix the needed levels of reagents to contaminated sediment is more problematic. The lack of an effective delivery system has also hindered the application of in-situ stabilization systems [National Research Council (NRC) 2001]. However, new developments may make this a more promising approach in the future.

Several EPA-funded bench and field studies in this area are underway. These include studies conducted by 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 and Southwest, currently 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.

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

Site	Technology Type	Contaminant
Jones Island CDF (Confined Disposal Facility)	Phytoremediation	Polycyclic aromatic hydrocarbons (PAHs) and PCBs
Milwaukee Harbor	Phytoremediation	PAHs and PCBs
Whatcom Waterway, Puget Sound	Electrochemical Oxidation	Mercury and PAHs
Anacostia River	Multiple Reactive Caps	PAHs and PCBs

3.2 NCP REMEDY SELECTION CRITERIA

The NCP at 40 CFR §300.430(e)(9) establishes a framework of nine criteria for evaluating remedies. These criteria address the requirements of the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA), and additional technical and policy considerations that are important for selecting remedial actions. Many of these criteria are also important for actions under the Resource Conservation and Recovery Act (RCRA).

The NCP at 40 CFR §300.430(e)(7) describes a method for screening potential alternatives prior to developing detailed alternatives when a number of alternatives are being considered at a site. Only the alternatives judged as the best or most promising following this screening should be retained for further development and 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 relatively limited number of approaches available for sediment, project managers generally should not screen out any of the major approaches early in the FS.

More detailed discussions of what should be addressed under each of the nine criteria can be found in the ROD Guidance (U.S. EPA 1999a) and the RI/FS Guidance (U.S. EPA 1988a). The following provides a summary of the nine criteria (U.S. EPA 1988a):

Threshold Criteria

- *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. In addition to ARARs, this criterion also commonly includes whether the alternative considers other criteria, advisories, and guidance that are to be considered at the site. This criterion is discussed further with respect to contaminated sediment in Section 3.3;

Balancing Criteria

- *Long-Term Effectiveness and Permanence*: This criterion includes an evaluation of the magnitude of human health and ecological risk from untreated contaminated materials 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. This criterion is discussed further with respect to contaminated sediment in Section 3.4;

- *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. This criterion is discussed further with respect to contaminated sediment in the chapters related to the individual remedies;

- *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. This criterion is discussed further with respect to contaminated sediment in the chapters related to the individual remedies;

- *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. It also considers 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. This criterion is discussed further with respect to contaminated sediment in the chapters related to the individual remedies;

- *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. This criterion is discussed further with respect to contaminated sediment in Section 3.5;

Modifying Criteria

- *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. This criterion is discussed further with respect to contaminated sediment in Chapter 1, Section 1.5; and

- *Community Acceptance*: This criterion includes an evaluation of the concerns of the public regarding the alternatives. It determines which component of the alternatives interested persons in the community support, have reservations about, or oppose. This criterion is discussed further with respect to contaminated sediment in Chapter 1, Section 1.6.

Additional guidance about how to apply these criteria to sediment alternatives is found throughout the guidance, as indicated above. In addition, Chapter 7, Remedy Selection Considerations, summarizes general considerations of each of the nine criteria with respect to the three major approaches.

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. In addition, on-site actions need to comply with the substantive portions of ARARs unless the ARAR is waived. ARARs may be waived only under limited circumstances. 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.

Sediment cleanup levels for response actions under CERCLA generally are based on site-specific risk assessments, but occasionally are based on ARARs. Project managers may also consider non-promulgated advisories or guidance issued by federal, state or tribal governments, frequently called TBC ("to be considered"). While TBCs may not be legally binding on their own, and thus do not have the same status as ARARs, TBCs can be used as a basis for making cleanup decisions. The project manager should refer to *CERCLA Compliance with Other Laws Manual* (U.S. EPA 1988b). Also, the preamble to the final NCP (55 *Federal Register* (*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 NCP at 40 CFR §300.515(b) for provisions dealing with tribal governments).

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. 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 actual and hypothetical examples of how remedial strategies have been adapted to comply with ARARs.

For more information about ARARs, the project manager should consult 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 1994d).

As part of the ARARs analysis, project managers, in consultation with the site attorney, should consider appropriate requirements promulgated under the Clean Water Act (CWA). As described in the examples in Highlight 3-2, federal water quality criteria as well as state-promulgated regulations including state water quality standards may be potential ARARs for surface water when water is discharged from dewatering or treatment areas or as effluent from CDFs. Furthermore, some states may have 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 CWA are planning tools designed to reduce contributing point and non-point sources of pollutants in water quality limited segments (WQLS). TMDLs calculate the greatest amount of loading of a pollutant that a water body can receive without exceeding CWA water quality standards. TMDLs are usually established by the states, territories, or authorized tribes and approved by the EPA. Effluent limits in point source national pollutant discharge elimination system (NPDES) permits should be consistent with the assumptions and requirements in a wasteload allocation in an approved TMDL.

Highlight 3-2: Examples of Potential ARARs for Sediment Sites		
Law or Regulation	**Description**	**Examples of How Remedial Strategies have been Adapted to Comply with ARARs**
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 to consider whether nationally recommended AWQC 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 that included treatment of water following dewatering sediment, EPA determined that a revised AWQC was a relevant and appropriate criteria for 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 that cannot be minimized must be mitigated.	Work at the ASARCO, Tacoma WA, National Priorities List (NPL) site included construction of an armored cap in the inter-tidal zone. Work at the Wyckoff/Eagle Harbor, WA, NPL site included construction of a sheet pile barrier wall to control subsurface non-aqueous phase liquid (NAPL) migration. To compensate for the loss of habitat, intertidal habitat was created in another part of these two sites. Work at the Lavaca Bay, TX site involved construction of a CDF with effluent discharge to the Bay. CDF effluent discharged to waters of the U.S. is defined as a dredged material discharge under Section 404.

Law or Regulation	Description	Examples of How Remedial Strategies have been Adapted to Comply with ARARs
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 a applicable. However, the site is located in a state where EPA implements the RCRA program, and the on-site cleanup action will comply with substantive requirements of a 404 permit. Thus the cleanup action is exempted from RCRA. This situation is explained in the description of the selected remedy in the ROD.
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.
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 during a window of time when juvenile salmon are not migrating through the area. Other in-water work will be performed outside of this window, using special conditions recommended by NMFS to minimize impacts to salmon.
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)).	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 sediment and dispose of the de-watered sediment and resulting liquid, as per the disposal requirements for PCB remediation waste. As dewatering is a physical means of separation, de-watered sediment is sampled to determine the disposal option, landfilling in either a municipal landfill or a TSCA chemical waste landfill, based

Law or Regulation	Description	Examples of How Remedial Strategies have been Adapted to Comply with ARARs
	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. The risk-based option under 761.61(c) would be expected to be selected most often at Superfund sites.	on the concentration of PCBs in the de-watered sediment. In general, if sediment containing PCBs is de-watered or physically separated, the separated solids and liquids can then be sampled to determine disposal options. Barring the occurrence of other contaminants, if PCBs in the separated sediment is below 50 ppm, federal standards allow these sediments to be taken to a municipal sanitary landfill. Generally, if PCB levels are greater than 50 ppm in the separated sediments, they would go to a TSCA chemical waste landfill and those greater than 500 ppm would be treated. Example 2. A PCB transformer is known to have broken open in the area of PCB-contaminated sediment prior to 1978, resulting in sediment, 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 for discharges to surface water. 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 designates 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 or waive 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.	A remedial alternative includes on-site upland disposal of dredged sediment. The feasibility study examines 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 State-promulgated and EPA-approved TMDLs. These allocations may be an applicable or a relevant and appropriate requirement, where such regulations exist, depending on whether the regulation specifically addresses the site as a discharge. Non-promulgated TMDLs may be a TBC.	A remedial dredging alternative includes an expected temporary increase in total suspended solids in the water body and residual contamination that provides a small continuing load to the water body. EPA consulted with the state TMDL program to determine whether TMDLs are a potential ARAR or TBC and how they interact with the alternative.
National Pollutant Discharge Elimination System (NPDES) Permit Regulations	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 on-site, the substantive requirements may be an applicable regulation.	A Superfund remedy includes ground water remediation with discharge of the water to surface water. EPA consulted with the state NPDES permit program to determine water treatment standards prior the discharge.

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. Project managers should work closely with regional EPA Water program 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*, 40 CFR Part 6, Appendix A. Although few Executive Orders provide requirements under federal environmental laws, making them ARARs, the Agency normally follows 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, which were written in furtherance of the National Environmental Policy Act (NEPA) and other environmental statutes. 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 for sediment 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 sediment in a small river, as the increased bottom elevation would increase the risk of flooding. Instead, the final EPA remedy called for dredging contaminated sediment 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 LONG-TERM EFFECTIVENESS AND PERMANENCE OF SEDIMENT ALTERNATIVES

This first of the five NCP balancing criteria is one of the most critical criteria in evaluating alternatives. As described in EPA's general RI/FS Guidance, the "long-term effectiveness and permanence" criterion includes an evaluation of two basic factors, magnitude of residual risk and the adequacy and reliability of controls for that residual risk. As applied to sediment, project managers should consider:

- <u>Magnitude of residual risk:</u> this factor is designed to assess the level of expected residual risk in the sediment after the completion of the remedy (i.e., after capping, dredging, in-situ treatment, or several years of MNR). The volume, toxicity, mobility, bioavailability, and propensity to bioaccumulate of the residuals should be considered in this evaluation; and

- <u>Adequacy and reliability of controls</u>: this factor is designed to assess the adequacy and expected long-term reliability of controls that can be used to manage post-remediation sediment residuals or untreated contamination that remains in the sediment. It may also include an assessment of the expected effectiveness of institutional controls, such as fish consumption advisories, to ensure that exposures are within protective levels. This factor also addresses the long-term reliability and the potential need to replace technical components such as a cap, backfill after dredging, or a slurry wall; and their risks posed should the remedy need replacement.

Developing answers to the following questions may help the project manager in evaluating the long-term effectiveness of alternatives:

- What is the level of human health and/or ecological risk after implementation?

- How much of the risk is due to sediment residuals versus unremediated areas of contamination?

- What is the likelihood that the planned cap, dredging approach, or MNR will meet the cleanup levels and RAOs?

- What type and degree of long-term management will be required?

- What are the requirements for operation and maintenance (O&M) and long-term monitoring?

- What is the potential need for replacing or modifying the technical components of the alternative?

- What is the magnitude of risk should the remedy fail?

- What is the degree of confidence that there are adequate controls to identify and prevent remedy failure?

- What are the uncertainties associated with the disposal of treatment residuals or dredge materials?

It is important to remember that each of the three major approaches may be capable of reaching acceptable levels of short-term effectiveness, long-term effectiveness, and permanence, and that site-specific characteristics should be reviewed during the alternatives evaluation to ensure that the selected alternative will be effective in that environment. Project managers should evaluate and compare the effectiveness of in-situ (capping and MNR) and ex-situ (dredging) alternatives under the conditions present at the site. There should not be a presumption that removal of contaminated sediments from a water body will necessarily meet these criteria better than capping or MNR. What constitutes an acceptable level of effectiveness and permanence is a site-specific decision that should also consider each of the other NCP remedy selection criteria. Each of the major approaches for sediment has its own remedy-specific considerations under this criteria. These are summarized below. Some aspects are discussed in more detail in the following remedy-specific chapters.

Monitored Natural Recovery

For a successful MNR remedy, the risk present at the time of remedy selection should be the same as baseline risk, but as natural processes progress, the risk should decrease with time. The level of risk reduction afforded by this remedy generally depends on what cleanup levels the natural processes are expected to be able to achieve in a reasonable time frame and the level of contamination which may continue to enter the system from any uncontrolled sources. Residual risk for an MNR alternative normally is the risk remaining after the remedial action has been concluded (i.e., after natural processes have reduced risks to acceptable levels). To evaluate the level of permanence and residual risk associated with an MNR alternative, the project manager might ask: "If MNR processes are currently proceeding at an acceptable rate, will that rate continue such that the residual risk will be low for the long-term"? This frequently is related to the stability of the sediment bed, or the chance that clean sediment overlying buried contaminants may be eroded to such an extent that an unacceptable risk from buried contamination is created in the future. Residual risk for an MNR remedy may also be related to the chance that ground water flow, bioturbation, or other mechanisms may move buried contaminants to the surface where they could cause unacceptable human or ecological exposure, even in otherwise stable, non-erosional sediment. However, erosion of some portions of a sediment bed, or some movement of contaminants through bioturbation, may not create an unacceptable risk; therefore, it is important to review such factors on a site-specific basis. Evaluating the adequacy of controls for these risks in an MNR remedy may include evaluating the ability of the monitoring plan to detect significant sediment erosion or contaminant movement, and evaluating the adequacy of any institutional controls that are relied upon to control erosion (e.g., dam or breakwater maintenance agreements).

In-Situ Capping

For a successful in-situ capping remedy, risk due to direct exposure to contaminated sediment in the capped area generally decreases rapidly, although risks may remain from un-capped areas. The level of risk reduction associated with this remedy generally depends on the action level selected for capping (i.e., what level of contamination will remain outside the capped area) and the level of contamination which may continue to enter the system from any uncontrolled sources. Residual risk, after the cap is in place, usually is related to the following: 1) short-term risk remaining from contaminants still in the food chain; 2) likelihood of cap erosion or disruption exposing contaminants; 3) likelihood of contaminants migrating through the cap; and 4) risks from contaminants remaining in uncapped areas. An evaluation of long-term effectiveness and permanence for capping also should include an evaluation of the ability to monitor the effectiveness of the cap and to replace or replenish components of the cap through time before any significant contaminant releases occur.

Dredging or Excavation

For a successful dredging or excavation remedy, risks within the site itself may increase due to increased exposure to contaminants released into the surface water during sediment removal, but this increase should be temporary and localized. After this time, risk should decrease. The speed of the decrease and the level of long-term risk reduction associated with this remedy generally depends on the action level and/or cleanup levels selected for sediment removal (i.e., what level of contamination will remain outside of the dredged/excavated area), the level of residual contamination in the area after dredging, and the level of contamination which may continue to enter the system from any uncontrolled sources. Residual risk, after the dredging or excavation is complete, usually is related to the following: 1) short-term risk remaining from contaminants still in the food chain; 2) risk from contaminated sediment left behind outside of the dredged or excavated areas; 3) risk from the residual contamination left in place after dredging (and backfilling if the remedy included this); and 4) risk posed by untreated contaminants and treatment residuals at their disposal location. Similar to capping, the evaluation should include the need to replace technical components of the remedy after remedial action is completed. For dredging or excavation, this usually focuses on technical components of any on-site disposal units and the need to replenish backfill material in the dredged areas.

Project managers should recognize that all approaches for sediment leave some contaminants in place after remedial actions are completed, whether buried beneath a natural sediment layer or engineered cap, left near the surface or mixed with backfill as residuals following dredging or excavation, or as low levels of contamination outside of areas that were capped or dredged. All of these residual contaminants are affected by a variety of natural processes that can disperse, contain or sequester them. As described above and in the three remedy-specific chapters of this guidance that follow, MNR, in-situ-capping, and sediment removal each may be capable of achieving acceptable levels of long-term effectiveness and permanence. Site-specific site characteristics should be reviewed to ensure that the selected alternative will provide long-term effectiveness at a particular site.

3.5 COST

Developing accurate 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 capital costs, annual and periodic O&M costs, and net present value (U.S. EPA and USACE 2000). A cost estimate prepared as part of the CERCLA cleanup process should not include potential claims for natural resource damages or potential restoration credits, but may include costs for mitigation of habitat lost or impaired by the remedial action, where appropriate.

3.5.1 Capital Costs

Capital costs are those expenditures that are needed to construct a remedial action (U.S. EPA and USACE 2000). 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. As indicated in the Highlight, capital costs may include construction monitoring and environmental monitoring before, during and immediately following the remedial action. Monitoring beyond that point should be considered part of O&M.

Highlight 3-3: Examples of Categories of Capital Costs for Sediment Remediation	
Categories	**Capital Costs**
General (may apply to several or all remedial approaches)	• 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 • Engineering needs during construction (not pre-construction design) • 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
In-situ Capping	• Cap materials – Material costs – Equipment and labor costs – Cost of mitigation if required under CWA §404 • Transport, storage, and placement of cap materials – Barge/tug lease costs – Stockpiling of cap material – Land use cost
Dredging or Excavation	• Dredging or excavation equipment and labor costs • Engineering controls to protect water quality (e.g., 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

Categories	Capital 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 • Engineering controls to protect water quality (e.g., process water and storm water runoff controls) • Disposal of treatment residuals
In-Water Contained Aquatic Disposal, In-Water or Upland Confined Disposal Facilities	• Land acquisition or use costs • Construction of disposal site and any associated disposal costs – Demolition of existing facilities – Excavation to support berm – Equipment and labor costs • Berm construction – Imported materials for berm – Equipment costs • Capping disposal site – Cap materials – Equipment and labor costs • Engineering controls to protect water quality • Cost of mitigation if required under CWA §404
Upland Landfill Disposal	• Land acquisition costs • Construction costs • Transportation costs • Tipping fees for regional landfill

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. Where site-specific costs are available from pilot studies or removal actions, they are likely to be the best source of realistic cost information. Where this is not available, actual costs from similar projects implemented at other sites is frequently the next best source of costs.

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. EPA's Office of Superfund Remediation and Technology Innovation (OSRTI) can help project managers locate sites where a similar approach has been implemented. The project manager also may find it useful to refer to the ARCS program (U.S. EPA 1994d) 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. Also, many of the local district U.S. Army Corps of Engineers (USACE) offices have extensive experience with dredging and in-water construction and may be an additional source of good cost information.

3.5.2 Operation and Maintenance Costs

O&M costs generally are those post-construction costs necessary to ensure or verify the continued effectiveness of a remedial action (U.S. EPA and USACE 2000). 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 generally are incurred as part of the Remedial Action phase of a project, while long-term O&M costs or long-term cap maintenance generally are part of the O&M phase of a project (U.S. EPA and USACE 2000). At Fund-lead sites it can be very important to differentiate these two cost categories because CERCLA has specific requirements that address paying for long-term O&M (CERCLA 104(c)(3))(See Section 3.5.4, State Cost Share). Some examples of categories that are generally considered short-term O&M at sediment sites include the following:

- Operation of sediment or water treatment facilities during the remedial action;
- Monitoring, sampling, testing, analysis, and reporting during the remedial action (some may be considered capital costs, see Section 3.5.1 above);
- Maintenance of in-situ cap or on-site disposal site during the shake-down period (e.g., one year);
- Maintenance of engineering site controls during shake-down period (e.g., one year);
- Cost overrun contingency; and
- Project management and support.

Some examples of categories that are generally considered long-term O&M at sediment sites include the following:

- Maintenance and monitoring of institutional controls;
- Long-term monitoring, sampling, testing, analysis, and reporting;
- Long-term maintenance of in-situ cap or on-site disposal unit; and
- Long-term maintenance of engineering site controls.

Additional issues related to long-term monitoring and maintenance of all three remedial approaches (MNR, capping, and dredging or excavation) are discussed in Chapter 8 of this guidance.

3.5.3 Net Present Value

The NCP also provides that an analysis of remedy net present value, or present worth, should be used [NCP §300.430(e)(9)(iii)]. 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). Although this may be appropriate in some circumstances, the blanket use of a 30-year period is no longer 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).

For sediment approaches that leave significant quantities of contaminated sediment in place, such as in-situ capping or monitored natural recovery based on natural burial, the actual monitoring period is likely to be longer than 30 years, although project managers are encouraged not to assume that monitoring in perpetuity will be necessary at every site. This is discussed further in Chapter 8, Remedial Action and Long-Term Monitoring.

The discount rate that should be used for this analysis is established by the Office of Management and Budget (OMB). Based on current Agency policy, as reflected in the 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. Project managers should be aware that this rate may not be the same as rates that various potentially responsible parties (PRPs) or federal facilities use for similar analyses. For example, some industries use a higher discount rate that includes an opportunity cost of capital when the pool of capital dollars is limited for a particular business. This typically will increase the net present value of alternatives with high long-term O&M costs in their analysis. 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.

3.5.4 State Cost Share

At Fund-lead sites, generally the state is responsible for ten percent of remedial action costs and 100 percent of long-term O&M costs (see 40 CFR 300.510(b) and (c)). Different requirements may apply if the facility was publicly operated at the time of disposal of hazardous substances and for federal facilities. Where O&M costs are significantly different between alternatives, this may add to differences of opinion about preferred alternatives. For the discussion to be based on the best available information, it is especially important that cost estimates be as accurate as possible, including costs of long-term O&M.

After a joint EPA/state inspection of an implemented Fund-financed remedial action, EPA may share, for a period of up to one year, in the cost of the operation of the remedial action to ensure that the remedy is operational and functional (40 CFR 300.510(c)(2)). Where this applies to sediment sites, it may mainly involve in-situ caps and on-site disposal facilities.

The RAOs of most sediment sites address sediment and biota. However, a few sediment site remedies may also include surface water restoration as a goal of the remedial action. The NCP specifies the following in 40 CFR 300.510(c)(2):

> In the case of the restoration of ground or surface water, EPA shall share in the cost of the state's operation of ground or surface water restoration remedial actions as specified in 40 CFR 300.435(f)(3).
>
> The NCP at 40 CFR 300.435(f)(3) specifies that:
>
> For Fund-financed remedial actions involving treatment or other measures to restore ground- or surface-water quality to the level that assures protection of human health and the environment, the operation of such treatment or other measures for a period of up to 10 years after the remedy becomes operational and functional will be considered part of the remedial action. Activities required to maintain the effectiveness of such treatment or other measures following the 10-year period, or after remedial action is complete, whichever is earlier, shall be considered O&M.

In 40 CFR 300.435(f)(3) and (4), the NCP also addresses when a restoration activity will be considered administratively "complete" for purposes of federal funding and discusses several actions that are excluded from consideration under this provision.

Where a sediment site includes surface water restoration as a goal, the project manager should consult with their Office of Regional Counsel to determine how these provisions apply to their site.

3.6 INSTITUTIONAL CONTROLS

The term "institutional control" (IC) generally refers to non-engineering measures intended to affect human activities in such a way as to prevent or reduce exposure to hazardous substances, often by limiting land or resource use. ICs can be used at all stages of the remedial 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 2000e) 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 2000f).

As explained in the OSWER Directive cited above (U.S. EPA 2000e), there are four general categories of ICs:

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, typically involve legal instruments placed in the chain of title of the site or property. Enforcement tools normally include provisions of CERCLA Unilateral Administrative Orders (UAOs), Administrative Orders on Consent (AOCs), or Consent Decrees (CD). Information devices are designed to provide information or notification to the public. The three most common types of ICs at sediment sites include fish consumption advisories and commercial fishing bans, waterway use restrictions, and land use restriction/structure maintenance agreements. Each of these is discussed in more detail below.

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 that 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 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. Information should be provided in appropriate languages to meet the needs of the impacted communities. However, project managers should be aware that consumption advisories are not enforceable controls and their effectiveness can be extremely variable. This is discussed further in Chapter 7, Remedy Selection Considerations.

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. In addition, 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 USACE, an opportunity for users of the waterway to comment, and, ultimately, deauthorization by Congress. The state also may have additional authority 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 an important mechanism to help ensure the overall protectiveness of a remedy.

Land Use Restrictions and Structure Maintenance Agreements

Where contamination remains in place, it may be necessary for the project manager to work with private parties, state land management agencies, or local governments 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 a remedy. 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, Title 33 United States Code (U.S.C.) Section 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. In addition, long-term maintenance of structures such as dams or breakwaters may be a necessary component of some sediment remedies. Where this is the case, it is important that project managers clarify how this maintenance is part of the remedy and who is responsible for it. Where maintenance decisions may change through time, contingencies may be needed for additional actions.

Highlight 3-4 summarizes some important points to remember about feasibility studies at sediment sites.

Highlight 3-4: Some Key Points to Remember about Feasibility Studies for Sediment

- Generally, project managers should implement and evaluate the effectiveness of major source control actions before finalizing the evaluation of alternatives for sediment.
- Generally, project managers should evaluate each of the three major approaches: MNR, in-situ capping, and removal through dredging or excavation, at every sediment site at which they might be appropriate.
- At sites with multiple water bodies or sections of water bodies with different characteristics or uses, alternatives that combine a variety of remedial approaches are frequently the most promising.
- MNR, in-situ capping, and sediment removal are each capable of achieving acceptable levels of long-term effectiveness and permanence. Site-specific site characteristics should be reviewed to ensure that the selected alternative will be effective at a particular site.
- Accurate cost estimates, including long-term O&M costs and, where appropriate, materials handling, transport, and disposal costs, are very important to a good comparison of alternatives. Actual costs from pilot projects at a site and at similar, completed sediment sites are among the best cost resources.
- Institutional controls can be used at all stages of the remedial process to reduce exposure to contamination. Project managers should consider the effectiveness and enforceability of controls used at their site and evaluate their role in risk reduction.

4.0 MONITORED NATURAL RECOVERY

4.1 INTRODUCTION

Monitored natural recovery (MNR) is a remedy for contaminated sediment that typically uses ongoing, naturally occurring processes to contain, destroy, or reduce the bioavailability or toxicity of contaminants in sediment. Not all natural processes result in risk reduction; some may increase or shift risk to other locations or receptors. Therefore, to implement MNR successfully as a remedial option, project managers should identify and evaluate those processes that contribute to risk reduction. MNR usually involves acquisition of information over time to confirm these potential risk-reduction processes. Implementation of MNR usually requires assessment, modeling, and monitoring to demonstrate risk reduction. Project managers should also be aware of the potential for combining natural recovery with engineering approaches, for example by installation of flow control structures to encourage deposition or by the placement of a thin layer of additional clean sediment or additives to enhance sorption or chemical transformation. These combined approaches are discussed further in Section 4.5, Enhanced Natural Recovery.

MNR may rely on a wide range of naturally occurring processes to reduce risk to human and/or ecological receptors. These processes may include physical, biological, and chemical mechanisms that act together to reduce the risk posed by the contaminants. Depending on the contaminants and the environment, this risk reduction may occur in a number of different ways. Highlight 4-1 lists the most common risk reduction processes. Processes which reduce toxicity through destructive processes or reduce bioavailability through increased sorption usually are preferable to mechanisms that reduce exposure through natural burial or mixing-in-place because the destructive/sorptive mechanisms generally have a higher degree of permanence. However, many contaminants which remain in sediment are not easily transformed or destroyed. For this reason, risk reduction due to natural burial through sedimentation is more common and can be an acceptable sediment management option. The last mechanism of the four most common processes, dispersion, typically is the least preferable basis for MNR because, while it may reduce risk in the source area, generally it increases contaminant loading to downstream areas. As reiterated in Chapter 7, Remedy Selection Considerations, project managers should carefully evaluate the effects of this increased loading on receiving bodies before selecting MNR where dispersion is the primary risk reduction mechanism, to ensure that it is not simply transferring risk to a new area. Project managers should be aware that at most sites, a variety of natural processes are occurring which may reduce risk. All mechanisms are valid as a part of a potentially viable basis for selection of MNR after all criteria have been weighed.

As used for purposes of this guidance, MNR is similar in some ways to the Monitored Natural Attenuation (MNA) remedy used for ground water and soils (U.S. EPA 1999d). The key difference between MNA for ground water and MNR for sediment is in the type of processes most often being relied upon to reduce risk. Whereas transformation of contaminants usually is the major attenuating process relied upon for contaminated ground water, these processes are frequently too slow for the persistent contaminants of concern in sediment to provide for remediation in a reasonable time frame. Therefore, isolation and mixing of contaminants through natural sedimentation is the process most frequently relied upon for contaminated sediment.

Highlight 4-1: General Hierarchy of Natural Recovery Processes for Sediment Sites

Many different natural processes may reduce risk from contaminated sediment, including the following, listed from generally most to least preferable, though all potentially acceptable, as a basis for selecting MNR:

A The contaminant is converted to a less toxic form through transformation processes, such as biodegradation or abiotic transformations

B Contaminant mobility and bioavailability are reduced through sorption or other processes binding contaminants to the sediment matrix

C 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

D Exposure levels are reduced by a decrease in contaminant concentration levels in the near-surface sediment zone through dispersion of particle-bound contaminants or diffusive or advective transport of contaminants to the water column or (see caveats in text regarding use of these processes for risk reduction)

The information needed to select an MNR remedy for sediment generally include the following:

- A detailed understanding of the natural processes that are affecting sediment and contaminants at the site;
- A predictive tool (generally based either on computer modeling or extrapolation of empirical data) to predict effects of those processes in the future;
- A means to control any significant ongoing contaminant sources;
- An evaluation of ongoing risks during the recovery period and exposure control, where possible; and
- The ability to monitor the natural processes and/or concentrations of contaminants in sediment or biota to see if recovery is occurring at the expected rate.

Some consider that all sediment site remedies are using natural recovery to some extent because natural processes are ongoing whether or not an active cleanup is underway [e.g., National Research Council (NRC) 2001]. It is true that natural processes in most cases will continue whether or not an active cleanup is underway, but these processes may either reduce, transfer, or increase risk. Natural processes may reduce residual risk following dredging or in-situ capping at many sites, and it is can be very valuable to monitor that further reduction in risk. However , it is also important for project managers to distinguish whether they are relying upon natural processes 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 and are expected to continue to reduce residual risks that are already at an acceptable level. Therefore, the key factors that normally distinguish MNR as a remedy are the presence of unacceptable risk, the ongoing burial or degradation/transformation, or dispersion of the contaminant, and the establishment of a cleanup level that MNR is expected to meet within a particular time frame.

MNR has been selected as a component of the remedy for contaminated sediment at about a dozen Superfund sites so far. Historically, at many sites it has been combined with dredging or in-situ capping of other contaminated sediment areas of a site. Although natural recovery has been observed in some areas (e.g., decreases in contaminant levels in sediment), long-term monitoring data on fish tissue are not yet available at most sites to document continued risk reduction. However, monitoring results from some areas are promising (e.g., U.S. EPA 2001h, U.S. EPA 2001i, Swindoll et al. 2000). MNR does not generally meet the Comprehensive Environmental Response, Compensation and Liability Act (CERCLA) §121(b)(1) preference for treatment. However, just as is the case with many traditional land remedies, if the proposed remedy meets other requirements, it can still be selected under CERCLA §121 and existing guidance. When contaminants left in place are above levels that allow for unlimited use and unrestricted exposure, five-year reviews generally are necessary (U.S. EPA 2001k).

Although each of the three major remedies (MNR, in-situ capping, and removal) should be considered at every site at which they might be appropriate, MNR should receive detailed consideration where the site conditions listed in Highlight 4-2 are present.

Highlight 4-2: Some Site Conditions Especially Conducive to Monitored Natural Recovery

- Risk is low to moderate
- Anticipated land uses or new structures are not incompatible with natural recovery
- Natural recovery processes have a reasonable degree of certainty to continue at rates that will contain, destroy, or reduce the bioavailability or toxicity of contaminants within an acceptable time frame
- Expected human exposure is low and/or can be reasonably controlled by institutional controls
- Site includes sensitive, unique environments that could be irreversibly damaged by capping or dredging
- Sediment bed is reasonably stable and likely to remain so
- Sediment is resistant to resuspension (e.g., cohesive or well-armored sediment)
- Contaminant concentrations in biota and in the biologically active zone of sediment are moving towards risk-based goals on their own
- Contaminants already readily biodegrade or transform to lower toxicity forms
- Contaminant concentrations are low and cover diffuse areas
- Contaminants have low ability to bioaccumulate

4.2 POTENTIAL ADVANTAGES AND LIMITATIONS

In most cases, the two key advantages of MNR are its relatively low implementation cost and its non-invasive nature. While costs associated with characterization and often, modeling, necessary to evaluate natural recovery can be extensive, the costs associated with implementing MNR are primarily associated with monitoring. However, implementation costs may also include the cost of implementing institutional controls and public education to increase the effectiveness of those controls. MNR typically involves no man-made physical 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 may include the fact that no construction or infrastructure is needed, and therefore it may be much less disruptive of communities than active remedies such as dredging or in-situ capping. No property should be needed for materials handling, treatment, or disposal facilities, and no contaminated materials should be transported through communities.

Two key limitations of MNR may be that it generally leaves contaminants in place and that it can be slow in comparison to active remedies. Any remedy that leaves untreated contaminants in place probably includes some risk of re-exposure of the contaminants. When MNR is based primarily on natural burial, there is some risk of buried contaminants being re-exposed or dispersed if the sediment bed is significantly disturbed by unexpectedly strong natural or man-made forces. The potential effects of re-exposure may be greater if high concentrations of contaminants remain in the sediment, and likewise, lower if contaminant concentrations or risks are low. There is also some risk of dissolved contaminants being transported to the surface water at levels that could cause unacceptable risk. The time frame for natural recovery may be slower than that predicted for dredging or in-situ capping. However, realistic estimates of the longer design and implementation time for active remedies should be factored in to the comparison. Like any remedy which takes a period of time to reach remediation goals, remedies that 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 usually have no ability to control ecological exposures.

Another limitation of MNR may be a high level of uncertainty associated with it. Major areas of uncertainty frequently include uncertainty related to predicting future sedimentation rates in dynamic environments and uncertainty related to the ability to predict rates of contaminant flux through stable sediment. It can be especially difficult to predict rates of natural recovery where contaminant levels and risks are already low because small additional factors become relatively more important. However, a higher level of uncertainty may be more acceptable in these situations as well.

4.3 LINES OF EVIDENCE

An evaluation of MNR as a potential remedy or remedy component should be supported with site-specific characterization, analysis, and usually, modeling. A variety of types of information, or lines of evidence, is usually needed. The lines of evidence approach for evaluation of natural attenuation of contaminants in soil and ground water can provide a general framework for evaluating MNR in sediments (e.g., U.S. EPA 1999d). Swindoll and his colleagues include a chapter on natural remediation of sediment which presents a useful summary discussion (Swindoll et al. 2000). EPA's Office of Research and Development (ORD) is in the process of drafting a technical resource document specifically for MNR in sediments and may also include suggested protocols.

As with the evaluation of any sediment alternative, an evaluation of MNR should be based on a thorough conceptual site model that includes current and future pathways of human and ecological exposure to the contaminants. This conceptual understanding should be based on site-specific data collected over a number of years and, for factors known to fluctuate seasonally, data collected during different seasons. Lines of evidence that can be used to construct a plausible case for the use of MNR include those listed in Highlight 4-3. It is important to note that not all lines of evidence or types of information are appropriate at every site, but generally, multiple lines of evidence are needed.

Highlight 4-3: Potential Lines of Evidence of Monitored Natural Recovery
• Characterization of historical sources of contamination and documentation that significant ongoing sources have been controlled
• Characterization of transport and fate processes for sediment and contaminants
• Compilation of sufficient historical record for contaminants in sediment to evaluate temporal trends of concentration, mass, or toxicity over time
• Compilation of sufficient historical trends in biological endpoint data to corroborate chemical data trends
• Development of an acceptable and defensible predictive tool(s) to allow prediction of future recovery and reduction in risk
Source: Adapted from Davis et al. 2003

Examples of types of site-specific information that could be collected to support the lines of evidence listed in Highlight 4-3 include the following:

- Contaminant concentrations in water column, sediment, and/or biota before and after source control or hot spot sediment remediation measures are implemented;
- Sediment core data demonstrating a trend in historical surface contaminant concentrations through time;
- Rates of sedimentation and erosion through time;
- Depth of the sediment mixing zone (e.g., due to bioturbation);
- Knowledge of contaminant transport into sediment or surface water from ground water advection or movement of non-aqueous phase liquids (NAPL);
- Extent of contaminant sorption to sediment and bioavailability to receptors;
- Extent of anaerobic/aerobic chemical or biotransformation occurring at the site; and
- Identification of bioaccumulation pathways from sediment to biota.

The amount of physical, biological, and chemical processes information needed to adequately assess the applicability of MNR is site specific. An important step in documenting the potential for MNR as a management alternative normally is to show that observed reductions in sediment and biological risks can reasonably be expected to continue into the future. In systems where the mechanisms causing the recovery is unknown, or where the fate and transport processes driving recovery may be complex and changing with time, simple extrapolation of historical trends may not be appropriate. In such cases, a well-constructed numerical model can be a useful tool for predicting future behavior of the system. This is discussed further in Chapter 2, Section 2.9 Modeling.

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 2000a) that is normally integrated within the remedial investigation and feasibility study (RI/FS). The DQO process is discussed in greater detail in Chapter 2, Section 2.1.1.

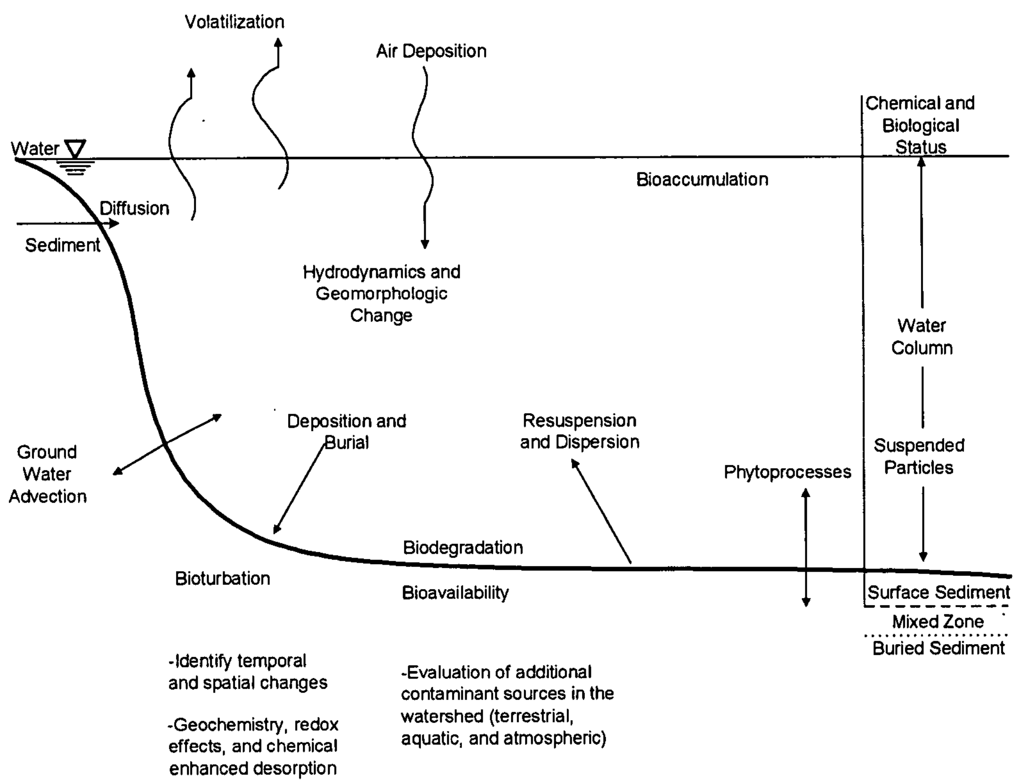
4.4 NATURAL RECOVERY PROCESSES

The success of MNR as a risk reduction approach typically is dependent upon understanding the dynamics of the contaminated environment and the fate and mobility of the contaminant in that environment. The natural processes of interest for MNR may include a variety of processes that, under favorable conditions, act without human intervention to reduce the mass, toxicity, mobility, or concentration of contaminants in the sediment bed. These natural processes may include the following:

- *Physical processes*: sedimentation, advection, diffusion, dilution, dispersion, bioturbation, volatilization;
- *Biological processes*: biodegradation, biotransformation, phytoremediation, biological stabilization; and
- *Chemical processes*: oxidation/reduction, sorption, or other processes resulting in stabilization or reduced bioavailability.

Highlight 4-4 illustrates some of the natural processes that the project manager should consider when evaluating MNR. With few exceptions, these processes interact in aquatic systems, sometimes increasing the risk-reduction effects of a process compared to what they might be for that process in isolation, and sometimes reducing those risk-reduction effects. 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 2001j), sustained burial processes remove contaminants from the bioavailable zone, but also can impede certain degradation processes, such as aerobic biodegradation. Likewise, contaminant sorption to sediment particles may both reduce bioavailability and reduce rates of contaminant transformation. In addition, in the case of mixed contaminants, the same natural process may result in very different environmental fates. When dealing with mixed contaminants at a site, care should be taken not to focus unduly on one contaminant without understanding the effects of natural processes on the other contaminants. Understanding the interactions between effects and prioritizing the significance of these effects to the MNR remedy should be part of a natural process analysis.

Highlight 4-4: Sample Conceptual Model of Natural Processes Potentially Related to MNR



4.4.1 Physical Processes

Generally, physical processes do not directly change the chemical nature of contaminants. Instead, physical processes may bury, mix, dilute, or transfer contaminants to another medium. Physical processes of interest for MNR include sedimentation, erosion, re-suspension, diffusion, dilution, dispersion, bioturbation, advection, and volatilization (including temperature-induced desorption of semi-volatiles). All of these processes may reduce contaminant concentrations in surface sediment, and thus reduce risk associated with the sediment. Sedimentation normally reduces risk physically by containing contaminants in place. Other physical processes, such as erosion, dispersion, dilution, bioturbation, advection, and volatilization may reduce contaminant concentrations in sediment as a result of transferring the contaminants to another medium or dispersing them over a wider area (e.g., via ground water or surface water). These processes may reduce, increase, or transfer the risk posed by the contaminants. As discussed previously in Section 4.1, project managers should carefully evaluate the effects of increased loading on receiving bodies before selecting MNR where dispersion is the primary risk reduction mechanism.

Physical processes in sediment can operate at vastly different rates. Some may occur faster than others, but may or may not have more impact on risk. In general, processes in which contaminants are transported by bulk movement of particles or pore water (e.g., erosion, dispersion, bioturbation, advection) occur at faster rates than processes in which contaminants are transported by diffusion or volatilization and, therefore, are frequently, but not always, 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. Some physical processes are continuous, and others seasonal or episodic. Depending on the environment, any of these types of processes (i.e., continuous, seasonal, or episodic) may have the most impact on natural recovery of a site. For example, project managers should not assume that episodic flooding will have a positive or negative effect on risk over an entire site. Flooding is most likely to cause erosion in some areas, while causing significant deposition in others.

Transport and deposition of cleaner sediment in a watershed may lead to natural burial of contaminated sediment in a quiescent environment. Natural burial may reduce the availability of the contaminants to aquatic plants and animals and, therefore, may reduce toxicity and bioaccumulation. The overlaying cleaner sediment also 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 water column. However, while bioturbation by burrowing organisms may promote mixing and dilution of contaminated sediment with the newly deposited cleaner sediment, for bioaccumulative contaminants it may also result in continued bioaccumulation into the food web until contaminant isolation occurs.

The long-term protectiveness provided by sedimentation depends upon the physical stability of the new sediment bed and the rates of movement of contaminants through the new sediment. Major events, such as severe floods or ice movements may scour the buried sediment, exposing contaminated sediment and releasing the contaminants into to the water column. Ground water that flows through the sediment bed also may transport dissolved contaminants into the water column. Depending upon their extent, processes such as these may extend the natural recovery period or, in some cases, inhibit it altogether. A site-specific evaluation of both sediment stability and contaminant mobility are important to evaluating MNR as a remedy. There are a variety of empirical and modeling methods to assess rates of various physical processes at specific sites. These are discussed in Chapter 2, Section 2.8, Sediment Stability and Contaminant Fate and Transport, and Section 2.9, Modeling.

4.4.2 Biological and Chemical Processes

Like most natural processes, biological processes also depend on site-specific conditions and are highly variable. During biodegradation, a chemical change is facilitated by microorganisms living in the sediment. 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. Some degradation of high molecular weight organic compounds occurs naturally 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 frequently occurs at depths of a few millimeters to a few centimeters where sediments have substantial organic content and conditions are quiescent, and may occur deeper in some circumstances. 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). However, this also reduces the availability of the contaminant to receptors living in the sediment and as well as at higher trophic levels.

Chemical processes in sediment are especially important for metals contaminants. 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.

Biochemical Processes for Polycyclic Aromatic Hydrocarbons (PAHs)

The class of hydrocarbons known as polycyclic aromatic hydrocarbons (PAHs) is a common contaminant in sediment and biota at Superfund sites. Many organisms are capable of accumulating PAH contaminants in their tissue, but biomagnification generally does not occur in vertebrate species (Suendel et al. 1994). Fish generally do not accumulate higher tissue PAH concentrations than their prey due to their ability to metabolize and eliminate PAH; however, the PAH metabolites may themselves cause chronic toxicity, such as reduced growth and reproduction and increased incidence of neoplasms in fish. The potential exists for biomagnification in some invertebrate species because of their lesser ability to metabolize and eliminate PAHs (Meador et al. 1995).

PAHs may be subject to physical, chemical and biological breakdown in the environment and where these processes are effective, may be especially amenable to natural recovery. The type of process which dominates may depend on time. For example, following a release of PAHs into the environment, physical–chemical processes such as dispersion, volatilization, and photodegredation may dominate. Where these processes are effective in attenuating the contaminants to less toxic levels, tolerant microbial species may cause further biodegradation. There is a wide variation in levels of microbial activity and rate of toxicity reduction, depending on the physical and chemical conditions of the site and the abundance of microbes and other species that influence biodegredation rates (Swindoll et al. 2000). PAHs biodegrade more quickly through aerobic than anaerobic processes, although the degradation rate usually decreases 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 1996d, Safe 1980).

Although low PAH degradation rates are often attributed to low bioavailability (see review by Reid et al. 2000), recent evidence reported by Schwartz and Scow (2001) demonstrates that it may be the lack of enzyme induction amongst the PAH-degrading bacteria that is responsible for low mineralization rates below a threshold PAH concentration. Other researchers have reported this phenomenon for PAHs (Ghiorse et al. 1995, Langworthy et al. 1998) and other aromatic organics (Zaidi et al. 1988, Roch and Alexander 1997). At elevated PAH concentrations in sediments, there is selective pressure for PAH-degrading bacteria, which can increase the capacity to naturally attenuate PAHs. However, there is uncertainty about whether and how fast this degradation may reach acceptable risk levels.

Biochemical Processes for Polychlorinated Biphenyls (PCBs)

Release of a PCB Aroclor (see PCB data information in Section 2.1.2, Types of Data) into the environment may result in a change in its congener composition. This is a result of the combined weathering effects and such processes as differential volatilization, solubility, sorption, anaerobic dechlorination, and metabolism, and results in changes in the composition of the PCB mixture in sediment, water, and biota over time and between trophic levels (NRC 2001).

Highly chlorinated congeners of PCBs may gradually partially dechlorinate naturally in anaerobic sediment (Brown et al. 1987, Abramowicz and Olsen 1995, Bedard and May 1996). In general, less-chlorinated PCBs bioaccumulate less than the highly chlorinated congeners, but are more soluble and, therefore, more readily transported into and within 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 (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 1996d, Harkness et al. 1993). Although desirable, it is unclear whether biologically mediated dechlorination of PCBs would be effective in achieving remedial objectives in a reasonable time frame and may result in the production of more toxic byproducts.

4.5 ENHANCED NATURAL RECOVERY

In some areas, natural recovery may appear to be the most appropriate remedy, 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 could consider accelerating the recovery process by engineering means, for example by the addition of a thin layer of clean sediment. This approach is sometimes referred to as "thin-layer capping" or "particle broadcasting." 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 as much 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. In most cases, natural materials (as opposed to manufactured materials) approximating common substrates found in the area should be used. 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.

Project managers might also consider the addition of flow control structures to enhance deposition in certain areas of a site. Enhancement or inception of contaminant degradation through additives might also be considered to speed up natural recovery. However, when evaluating the feasibility of these approaches, project managers should consult state and federal water programs regarding the introduction of clean sediment or additives to the water body. For example, in some areas, potentially erodible clean sediment already is a major non-point source pollution problem, especially in areas near sensitive environments such as those with significant sub-aquatic vegetation or shellfish beds.

4.6 ADDITIONAL CONSIDERATIONS

MNR is likely to be effective most quickly in stable depositional environments after source control actions and active remediation of any sediment hot spots have been completed. Where external sources were controlled many years previously and no discernable hot spot areas can be 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 remedies, effective source control is critical to reaching remedial objectives in a reasonable time frame and to preventing re-contamination.

As discussed in Chapter 7, Remedy Selection Considerations, when evaluating MNR, the short-term effects on human health and the environment during the recovery period (i.e., the baseline risks for the site) should be compared to the short-term effects of other approaches such as effects of resuspension of contaminants due to dredging and habitat changes caused by capping. Section 7.2, Considering Remedies, discusses the process of comparing short-term and long-term risks associated with various approaches in a net comparative risk analysis.

In most cases, the long-term effectiveness of MNR is dependent on the dynamic processes of mixing and burial over time remaining dominant over sediment resuspension or contaminant movement via advective flow or other mechanisms. Assessment of sediment stability and contaminant mobility are therefore very important at most sites. Some potential mechanisms for physical disruption of overlying cleaner sediment, such as keel drag or pipeline construction, may be amenable to human management. Others mechanisms for physical disruption, such as ice scour or flooding, may only be partly manageable or not manageable. The importance of contaminant movement through overlying sediment to surficial sediment and the overlying water depends on the chemical characteristics of the contaminant, physical characteristics of the sediment, and patterns of ground water flow. Both issues are also of concern for in-situ capping and discussed further in Chapter 2, Section 2.8, Sediment Stability and Contaminant Fate and Transport, in Chapter 5, In-Situ Capping, and in the U.S. Army Corps of Engineers (USACE) Technical Note, *Subaqueous Capping and Natural Recovery: Understanding the Hydrogeologic Setting at Contaminated Sediment Sites* (Winter 2002).

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 risk reduction approach at a contaminated sediment site. Generally, MNR should usually be used either in conjunction with source control or active sediment remediation or as a follow-up measure to an active remedy. For example, MNR may be an appropriate approach for some sediment sites after control of floodplain soils and NAPL seeps. At other sites, MNR may be an appropriate approach to control risk from areas of wide-spread, low-level sediment contamination, following dredging or capping of hot spots. MNR may also be an appropriate measure to reduce residual risk from dredging or excavation in cases where the active cleanup is not expected to achieve risk-based measures alone.

When considering the use of MNR as a follow-up measure, project managers should consider the change in conditions caused by the active remedy. As noted by the SAB (U.S. EPA 2001j): "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 remedies. However, the Agency recognizes that MNR may take longer to reach cleanup levels in sediment than dredging or in-situ capping and, therefore, may take longer to reach all remedial action objectives, such as contaminant reductions in fish. It is important to compare time frames on as accurate a basis as possible, including for example, accurate assessments of time for design and implementation of dredging or capping and realistic assumptions concerning dredging residuals. Factors that the project manager should consider in determining whether the time frame for MNR is "reasonable" include the following:

- The extent and likelihood 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 continue to be impacted 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 time frame prediction.

As with any remedy, project managers should carefully evaluate the uncertainties involved and consider the need for contingency measures, contingency remedies, or interim decisions where there is significant uncertainty about effectiveness. For MNR, as for other approaches which take a period of time to reduce risk, project managers should carefully consider how risks can be controlled during the recovery period. For sites with bioaccumulative contaminants, institutional controls such as fish consumption advisories are frequently needed to reduce human exposures during this period. In most cases, no institutional controls are possible for reducing ecological exposure during the recovery period. See Chapter 3, Section 3.6, Institutional Controls, and Chapter 7, Section 7.4, Considering Institutional Controls, for more information concerning institutional controls at sediment sites. Highlight 4-5 lists some important points to remember from this chapter.

Highlight 4-5: Some Key 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 reduce risk
- Evaluation of MNR usually should be based on site-specific data collected over a number of years. At some sites, this may include an assessment of seasonal variation for some factors
- Project managers should evaluate the long-term stability of the sediment bed, the mobility of contaminants within it, 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
- 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 risk reduction approach

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5.0 IN-SITU CAPPING

5.1 INTRODUCTION

For purposes of this guidance, in-situ capping refers to the placement of a subaqueous covering or cap of clean material over contaminated sediment that remains in place. Caps are generally constructed of granular material, such as clean sediment, sand, or gravel. A more complex cap design can include geotextiles, liners, and other permeable or impermeable elements in multiple layers that may include additions of material to attenuate the flux of contaminants (e.g., organic carbon). Depending on the contaminants and sediment environment, a cap is designed to reduce 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/or
- Chemical isolation/reduction of the movement of dissolved and colloidally transported contaminants into the water body.

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 component of the remedy for contaminated sediment at about a dozen Superfund sites as of 2001 and at additional, non-Superfund sites. At some sites, in-situ capping has served as the primary approach for sediment, and at other sites it has been combined with sediment removal (i.e., dredging or excavation) or monitored natural recovery (MNR) of other sediment areas. In-situ capping has not been implemented at many sites in states east of the Rockies, but has been successfully used at a number of sites in the Pacific Northwest, several of which were constructed over a decade ago (see site list at http://www.epa.gov/superfund/resources/sediment/sites.htm).

Variations of in-situ capping include installation of a cap after partial removal of contaminated sediment, innovative caps, which incorporate treatment components, and thin-layer placement, or particle broadcasting, to enhance natural recovery. Capping is sometimes considered following partial sediment removal where capping alone is not feasible due to a need to preserve water body depth for navigation or flood control, or where it is desirable to leave deeper contaminated sediment in place to preserve bank or shoreline stability following removals. There are a number of pilot studies underway to investigate in-situ caps which incorporate various forms of treatment (see Chapter 3, Section 3.1.3, In-Situ Treatment Alternatives). Application of thin layers of clean material may be used to enhance natural recovery through burial and mixing with clean sediment when natural sedimentation rates are not sufficient (see Chapter 4, Section 4.5, Enhanced Natural Recovery). Placement of a thin layer of clean material is also sometimes used to backfill dredged areas, where it mixes with dredging residuals and further reduces risk from contamination that remains after dredging. In this application, the material is not often designed to act as an engineered cap to isolate buried contaminants is therefore not considered in-situ capping in this guidance.

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 of 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), available on the Web at www.epa.gov/glnpo/sediment/iscmain and the *Assessment and Remediation of Contaminated Sediments (ARCS) Program Remediation Guidance Document* (U.S. EPA 1994d). Unless an effective treatment component is incorporated into the cap, in-situ capping does not generally meet the Comprehensive Environmental Response, Compensation and Liability Act (CERCLA) §121(b)(1) preference for treatment. However, just as is the case with many traditional land remedies, if the proposed remedy meets other requirements, it can still be selected under CERCLA §121 and existing guidance. When contaminants left in place are above levels that allow for unlimited use and unrestricted exposure, five-year reviews generally are necessary (U.S. EPA 2001k).

Although each of the three major remedies (MNR, in-situ capping, and removal) should be considered at every site at which they might be appropriate, capping should receive detailed consideration where the site conditions listed in Highlight 5-1 are present.

Highlight 5-1: Some Site Conditions Especially Conducive to In-Situ Capping

- Suitable types and quantities of cap material are readily available
- Anticipated infrastructure needs (e.g., piers, pilings, buried cables) are compatible with cap
- Water depth is adequate to accommodate cap with anticipated uses (e.g., navigation, flood control)
- Incidence of cap-disrupting human behavior, such as large boat anchoring, is low or controllable
- Weight of the cap can be supported by the underlying sediment without slope failure
- Expected human exposure is substantial and not well-controlled by institutional controls
- Long-term risk reduction outweighs habitat disruption, and/or habitat improvements are provided by the cap
- Hydrodynamic conditions (e.g., floods, ice scour) are not likely to compromise cap or can be accommodated in design
- Rates of ground water flow in cap area are low and not likely to create unacceptable contaminant releases
- Sediment has sufficient strength to support cap (e.g., has high density/low water content)
- Risk is moderate to high
- Contaminants have low rates of flux through cap
- Contamination covers contiguous areas (e.g., to simplify capping)

5.2 POTENTIAL ADVANTAGES AND LIMITATIONS

Two advantages of in-situ capping are that it can quickly reduce exposure to contaminants and that, unlike dredging or excavation, it requires less infrastructure in terms of material handling, dewatering, treatment and disposal. A well-designed and well-placed cap should provide fast reduction in exposure of fish and other biota to contaminated sediment and often also should provide a clean substrate for re-colonization by bottom-dwelling organisms. Changes in bottom elevation caused by a cap may create more desirable habitat, or specific cap design elements may enhance or improve habitat substrate. Another possible advantage is that the potential for contaminant resuspension and the risks associated with dispersion and volatilization of contaminated materials during construction are typically much lower for in-situ capping than for dredging operations. Most capping projects use conventional equipment and locally available materials, and may be implemented more quickly and may be less expensive than remedies involving removal and disposal or treatment of sediment.

In-situ capping may be less disruptive of communities than dredging or excavation. Although some local land-based facilities are often needed for materials handling, usually no dewatering, treatment or disposal facilities need to be located and no contaminated materials are transported through communities. Where clean dredged material is used for capping, a much smaller area of land facilities is needed.

The major limitation of in-situ capping is that the contaminated sediment is left in place in the aquatic environment where contaminants could be exposed or dispersed if the cap is significantly disturbed or if contaminants move through the cap in significant amounts. In addition, in some environments it is difficult to place a cap without significant contaminant losses from compaction and disruption of the underlying sediments. Also, although the cap is designed to reduce exposure of biota to the contaminated sediment, it is sometimes necessary to rely on institutional controls, which can be limited in terms of effectiveness and reliability, to protect people from eating fish that were previously contaminated and to protect the cap from disturbances such as keel drag.

Another potential limitation of in-situ capping may be that in some situations a preferred habitat may not be provided by the surficial cap materials. To provide erosion protection, it may be necessary to use coarse cap materials that are different from native soft bottom materials and thus can alter the biological community. In some cases, however, it may be desirable to select capping materials that discourage colonization by native deep-burrowing organisms to limit bioturbation.

5.3 EVALUATING SITE CONDITIONS

A good assessment of site-specific conditions typically is critical to understanding the expected feasibility and effectiveness of in-situ capping. Site conditions can 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.

5.3.1 Physical Environment

Aspects of the physical environment of an in-situ cap that should be considered include water body dimensions, depth and slope (bathymetry) of sediment bed, and flow patterns, including tides, currents, and other potential disturbances in cold climates, such as an ice scour. Existing infrastructure such as bridges, utility crossings, and other marine structures are discussed in Section 5.3.3.

The bathymetry of the site influences how far cap material will spread during placement and the cap's stability. Flatter bottom slopes should allow material to be placed more accurately, especially if capping material is to be placed hydraulically. Water depth also should influence 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.

The energy of flowing water 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 can affect dispersion during cap placement and can influence the selection of the equipment to be used for cap placement. Bottom currents can generate shear stresses that can 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 and flood-carrying capacity of the channel. Modeling studies may be useful to assess these changes in site conditions where they are likely to be significant. Project managers are encouraged to draft decision documents which include some flexibility in requirements for how a cap affects carrying capacity of a water body, while still meeting applicable or relevant and appropriate requirements (ARARs). For example, in some water bodies a cap may be appropriate even though it decreases the flood-carrying capacity, if that decrease is not significant. In depositional areas, the effect of new sediment likely to be deposited on the cap should be considered in predicting future flood-carrying capacity. Clean sediment accumulating on the cap can increase the isolation effectiveness of the cap over the long term and may also increase consolidation of the underlying sediment bed.

5.3.2 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 combination with the remediation goals and objectives, should determine 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, for example if it will extent beyond the cap surface and cause scouring. Side-scan sonar can be an effective tool to identify debris.

The chemical characteristics of the contaminated sediment are an important factor that may affect design or selection of a cap, especially if capping highly mobile or highly toxic sediment. Capping may change the uppermost layer of 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 in this upper zone. 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) become more soluble. Mercury becomes methylated through the action of anaerobic bacteria and highly chlorinated polychlorinated biphenyls (PCBs) may degrade to less chlorinated forms in an anaerobic environment. These issues are also discussed in Chapter 4, Section 4.4.2.

When contaminated sediments 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 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. The grain size of the capping material controls in part how these avenues are developed. Finer grained caps may develop fissures while coarser grained caps such as sands allow gas to pass through. However, a compensating factor in some cases is caused by the caps insulation ability, which can cause underlying sediments to stay cooler and thus reduce expected decomposition rates. Where gas generation is expected to be significant, these factors should be considered during cap design.

5.3.3 Waterway Uses and Infrastructure

If the site under consideration is adjacent to or within a water body used for navigation, recreation or flood control, the effect of cap placement on those uses should be evaluated. As described in Section 5.3.1, the flood carrying capacity of a water body could be reduced by a cap. 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 (e.g., seasonal, tidal, and wave) and the potential effects of vessel groundings on the cap. Potential cap erosion caused by propeller wash should be evaluated. Where circumstances dictate, an analysis should be conducted for activities which may affect cap integrity such as the potential for routine anchoring of large vessels. Anchoring by small recreational vessels typically would not compromise the integrity of most caps. Such activities may indicate the need for restrictions or a modification of the cap design to accommodate certain activities. It may be necessary to restrict fishing and swimming to prevent recreational boaters from dragging anchors across a cap. In some situations, partial dredging prior to cap placement may minimize these limitations of capping.

Other activities in and around the water body 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 lines) are commonly located in urban waterways. It may be necessary to relocate existing utility crossings under portions of water bodies if their deterioration or failure might impact cap integrity. More commonly however, pipes or utilities are left in place under caps, and long-term operation and maintenance plans include repair of cap damage caused by the need to remove, replace, or repair the pipes or utilities. 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 state or 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.

5.3.4 Habitat Alterations

In-situ capping alters the aquatic environment and, therefore, can affect aquatic organisms in a variety of ways. As is discussed further in Chapter 6, Dredging or Excavation, while a project may be designed to minimize habitat loss or degradation, or even to enhance habitat, both sediment capping and sediment removal and disposal do alter the environment. Where risks are low and there is the option of taking action or not, it is important to determine whether the potential loss of a contaminated habitat is a greater impact than the benefit of providing a new, modified but less contaminated habitat. 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. Through time, sedimentation and other natural processes will change the uppermost layer of the cap. 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 desirable 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 at some sites. 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 withstand 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.

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). Changes in bottom elevation may enhance or degrade desirable habitat, depending on the site.

Project managers should consult EPA staff working with the Clean Water Act, as well as natural resource trustees and USACE, 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 remedies are being considered which degrade aquatic habitat, substantive requirements may include minimizing the permanent loss of habitat and mitigating it by creation or restoration of a similar habitat elsewhere. However, it should not be assumed that in-situ caps result in a permanent loss of habitat; this is a site-specific decision. In addition, project managers should be aware that any mitigation related to meeting the substantive requirements of ARARs for the site, such as the Clean Water Act, may be independent of the Natural Resource Trustees' natural resource damage assessment process.

5.4 FUNCTIONAL COMPONENTS OF A CAP

As introduced in Section 5.1 of this chapter, generally caps generally are designed to fulfill three primary functions: physical isolation, stabilization/erosion protection, and chemical isolation. In some cases, multiple layers of different materials are used to fulfill these function and in some cases, a single layer may serve multiple functions. Project managers are encouraged to consider the use of performance-based measures for caps in remedy decisions, to preserve flexibility in how the cap may be designed to fulfill these functions.

5.4.1 Physical Isolation Component

The cap should be designed to isolate contaminated sediment from the aquatic environment. The physical isolation component of the cap should also include a component to account for consolidation of cap materials.

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. This serves two functions: 1) to decrease exposure of aquatic organisms to contaminants, and 2) to decrease the ability of burrowing organisms to move buried contaminants to the surface (i.e., bioturbation). To design a cap component for this second function, the depth of the effective mixing zone (i.e., the depth of effective sediment mixing due to bioturbation and/or frequent sediment disturbance) and the population density of organisms within the sediment profile should be evaluated and considered in selecting cap thickness. Although not usually a major pathway for contaminant release, project managers should also be aware of the potential for wetland/aquatic plants to penetrate a cap and create pathways for some contaminant migration. Especially in marine environments, the potential for colonization by deep burrowing organisms (e.g., certain species of mud shrimp) could lead to a decision to design a thicker cap. 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 2.8.3 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* (Clarke et al. 2001), provides information on designing in-situ caps and also provides many useful references on bioturbation. This document (DOER-C21) 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 their own weight. 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.

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 of the capping material or armor stone. The degree of consolidation should provide an indication of the volume of pore water that will be expelled through the contaminated layer and capping layer to the water column due to consolidation. The consolidation-driven advection of pore water should be considered in the evaluation of short-term contaminant flux. Also, consolidation may decrease the vertical permeability of the capped sediment and thus reduce long-term flux. 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, Palermo et al. 1998a, Liu and Znidarcic 1991).

5.4.2 Stabilization/Erosion Protection Component

This component of the cap is intended to stabilize both the contaminated sediment and the cap itself to prevent either from being resuspended and transported off site. The potential for erosion generally depends on the magnitude of the applied bed shear stresses due to river, tidal and wave-induced currents, turbulence generated by ships/vessels (due to propeller action and vessel draft), and sediment properties such as particle size, mineralogy and bed bulk density. At some sites, there is also the potential for seismic disturbance, especially where contaminated sediment or cap material are of low shear strength. These and other aspects of investigating sediment stability are discussed in Chapter 2, Section

2.8, Sediment Stability and Contaminant Fate and Transport. 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, 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 relatively 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 2.8, Sediment Stability and Contaminant Fate and Transport, in some circumstances, lower probability events should also be considered.

Another consideration for capping, especially capping of contaminated sediment with high organic content (e.g., wood processing sites) is whether significant gas generation due to anaerobic degradation will occur. Gas generation in sediment beneath the cap could either add significant uplift forces and threaten the physical stability of the overlying capping materials, or carry significant amounts of contaminants through the cap. Little has been documented in this area to date, but the possible influence of this process on cap effectiveness presents an uncertainty that the project manager should consider in the analysis of remedial alternatives.

5.4.3 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 dissolved contaminants by advection (flow of ground water or pore water) through the cap is possible, while movement of contaminants by molecular diffusion (movement across a concentration gradient) over long periods usually is inevitable. However, in assessing these processes, it is important to also assess the sorptive capacity of the cap material, which will act to retard contaminant flux through the cap, and the long-term fate of capped contaminants which may transform through time. Very slow releases of dissolved contaminants through a cap at low levels may not create an unacceptable risk. 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. Because of the uncertainties involved in predicting future flux rates over very long time periods, this guidance does not advocate a particular minimum rule of thumb for the appropriate time frame for design with respect to chemical isolation. In general, it is reasonable for the physical isolation component (i.e., physical stability) of a cap design to be based on a shorter time frame (e.g., a disruptive event with a more frequent recurrence interval) than the much longer time frames considered in design for chemical isolation (e.g., the time required for accumulation of contaminants in the cap material or that required to attain the maximum chemical flux through the cap), in part because erosion of small areas of a cap is easier to repair.

Nevertheless, 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 over the area to be capped (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 conductivity 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 through contaminated sediment, in-situ capping may not be an effective remedial approach without additional protective measures. Use of amended caps (caps containing reactive or sorptive material to sequester organic or inorganic contaminants) is one potential option that is undergoing pilot studies (see http://www.rtdf.org). More information on the interactions of ground water and in-situ caps can be found in the USACE Technical Note, *Subaqueous Capping and Natural Recovery: Understanding the Hydrogeologic Setting at Contaminated Sediment Sites* (Winter 2002).

Where non-aqueous phase liquids (NAPL) are present in part of an area to be capped, the process for potential contamination migration should be carefully considered. In situations where conventional cap designs are not likely to be effective, it may be possible to consider impervious materials (geomembranes, clay, concrete, steel, or plastic) or reactive materials for the cap design. Where this is done, however, care must be taken such that head increases along the edges of the impervious area do not lead to additional NAPL migration. Project managers are encouraged to draw on the experience of others who have conducted pilot or full scale caps in the presence of NAPL.

Laboratory tests can be used to calculate 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 models can evaluate the effectiveness of varying thicknesses of granular cap materials with differing properties [grain size and total organic carbon (TOC)]. The results generated by such models include flux rates to overlying water and sediment contaminant and pore water concentrations in the entire sediment and cap profile as a function of time. These results can be compared to remediation goals such as sediment action levels or applicable water quality criteria in overlying surface water, or interpreted in terms of a mass loss of contaminants as a function of time. Results could also be compared to similar calculations for other remediation technologies.

5.5 OTHER CAPPING CONSIDERATIONS

The general elements or components of an in-situ capping project include those listed below. A feasibility study to evaluate in-situ capping for a site should address each of the following:

- Identifying candidate capping materials that are physically and chemically compatible with the environment in which they will be placed;
- Evaluating geotechnical considerations including consolidation of compressible materials and potential interactions and compatibility among cap components;

- Assessing placement methods which will minimize short-term risk from release of contaminated porewater and resuspension of contaminated sediment during cap placement; and

- Identifying performance objectives and monitoring methods for cap placement and long-term assessment of cap and biota.

However, many of the aspects are often addressed in more detail during design.

These topics are discussed briefly below. In addition, project managers should refer to Chapter 8, Section 8.4.2 for a discussion of general monitoring considerations for in-situ capping, and to Chapter 3, Section 3.6 for a discussion of institutional controls that may relate to caps.

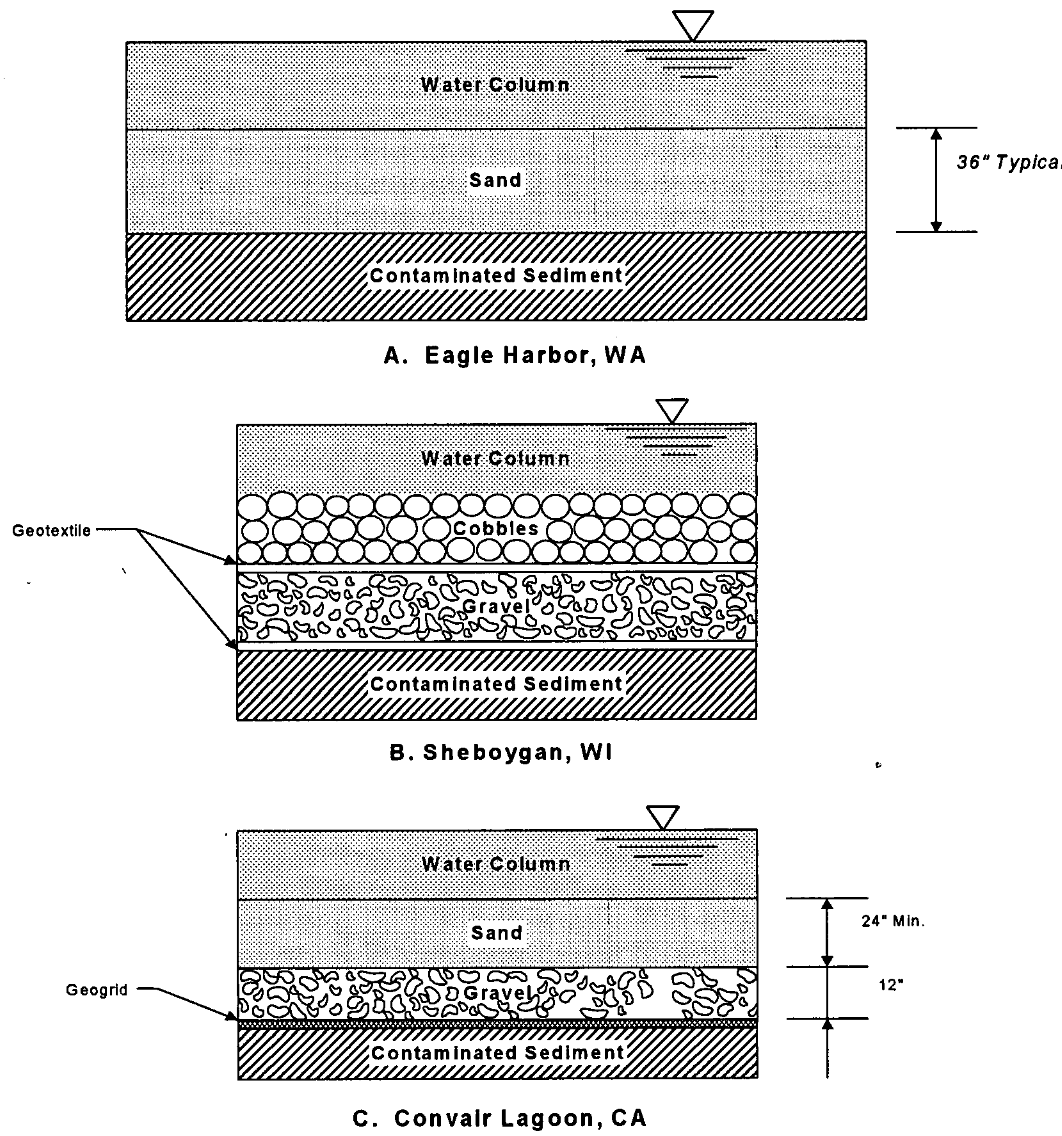
5.5.1 Identification of Capping Materials

Caps are generally composed of clean granular materials, such as upland sand-rich deposits or sandy sediment; 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 expected effects of bioturbation, consolidation, erosion, and other related processes on the short- and long-term chemical isolation of contaminants. For example, if the potential for erosion of the cap is significant, protection could be increased by increasing cap thickness or by engineering the cap to be more erosion-resistant, through use of cap material with larger grain size, or an armor layer. 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.

Specialized materials may be used to enhance the chemical isolation capacity or otherwise decrease the thickness of caps compared to sand caps. Examples include engineered clay aggregate materials (e.g., AquaBlok™), and reactive/adsorptive materials such as activated carbon, apatite, coke, organoclay, zero-valent iron and zeolite. Composite geotextile mats containing several of these materials (i.e., reactive core mats) are beginning to become available commercially.

Highlight 5-2 illustrates some examples of cap designs.

Highlight 5-2: Sample Cap Designs



Source: Modified from U.S. EPA 1998d

5.5.2 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 can become two additional geotechnical issues which may be important for cap effectiveness.

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 shear strength. Conventional geotechnical design approaches should, therefore, be applied with caution (for example, by building up a cap gradually over the entire area to be capped). Similarly, caps with flat transition slopes at the edges are not generally subject to a sliding failure normally evaluated by conventional slope stability analysis.

5.5.3 Placement Methods

A variety of equipment types and placement methods have been used for capping projects. The use of granular capping materials (i.e., sand, 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 usually have relatively little free water. Normally, these materials can be handled mechanically in a dry state until released into the water over the contaminated site. Mechanical methods (e.g., 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 some 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 sediment resuspension and contaminant releases during cap placement is important. Cap placement can resuspend some contaminated sediment. Contaminants can also be released to the water column from compaction of disruption of underlying sediments during cap placement. Both can lead to increased risks during and following cap placement. Applying cap material slowly and uniformly can minimize the amount of sediment disruption and resuspension. Therefore, designs should include plans to minimize and monitor impacts during and after construction.

5.5.4 Performance Monitoring

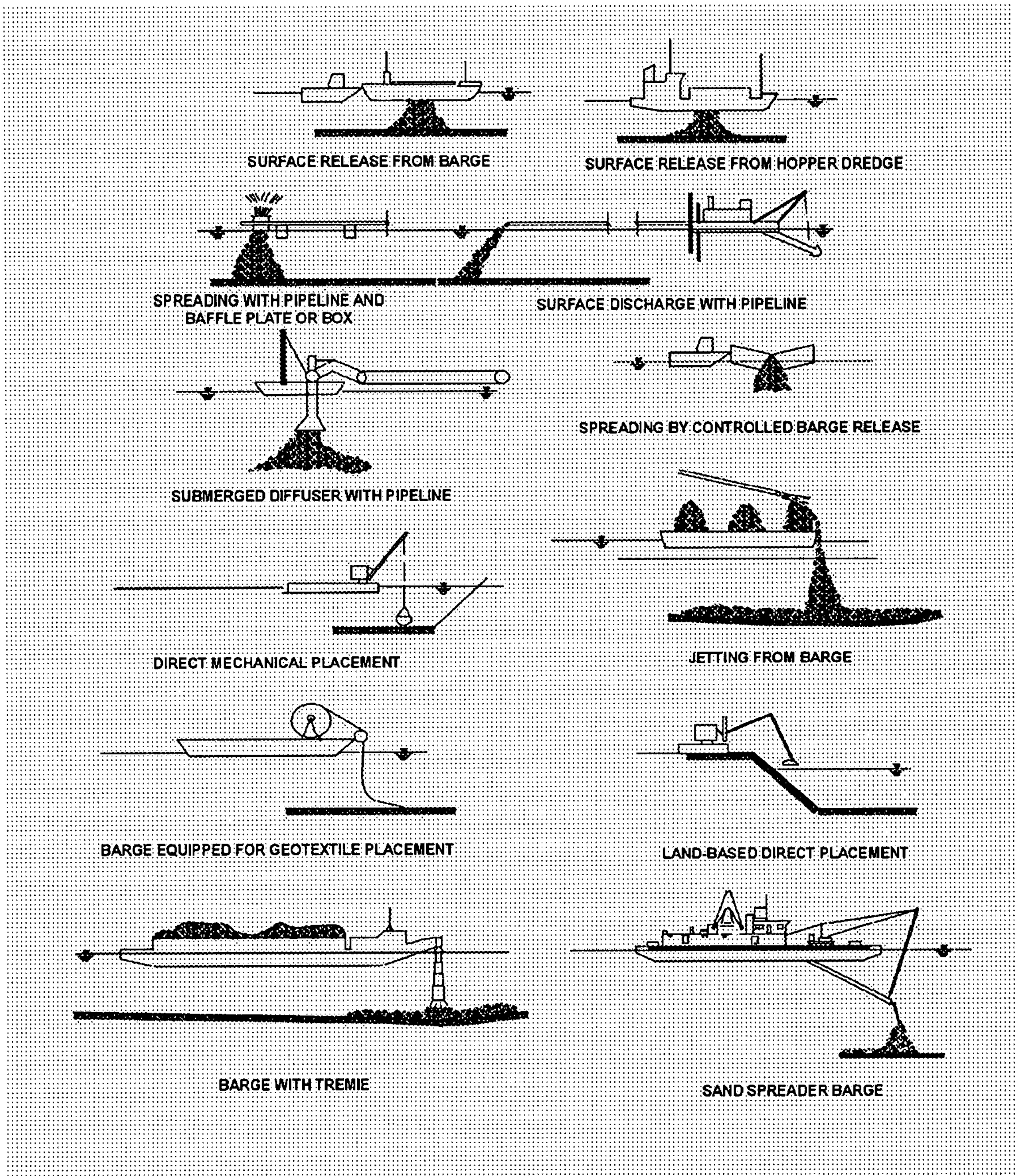
Performance objectives for an in-situ cap relate to its ability to provide sufficient physical and chemical isolation and stabilization of contaminated sediment. Broader remedial action objectives for the site such as decreases in contaminant concentrations in biota or reduced toxicity also should be monitored when applicable. The following processes should be considered when evaluating the performance of a cap, and in developing a cap monitoring program:

- Erosion or other physical disturbance of cap;
- Contaminant flux into cap material from underlying contaminated sediment (e.g., ground water advection, molecular diffusion);
- Contamination of cap surface from other sources (e.g., unremediated sediment, flood plains other land-based sources);
- Recolonization of cap surface and resulting bioturbation; and
- Recovery of biota related to remedial action objectives.

General considerations related to monitoring caps and an example of cap monitoring elements are presented in Chapter 8, Remedial Action and Long-Term Monitoring.

Performance monitoring of a cap should be related to the design standards and remedial action objectives related to the site. Generally, physical monitoring is conducted on a more frequent schedule than chemical or biological monitoring because it is less expensive to perform. Some processes (such as contaminant flux) are generally not assessed directly because some are very difficult to measure, but are assessed by measuring contaminant concentrations in bulk samples from the cap surface, in shallow cores into the surface layer of a cap, and by bathymetric surveys and various photographic techniques. It is often desirable to establish several permanent locational benchmarks so that repeated surveys can be accurately compared. In some cases, contaminant flux and the resulting contaminant concentration in surface sediment, cap pore water or overlying surface water can be compared to 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).

Highlight 5-3: Sample Capping Equipment and Placement Techniques



Source: U.S. EPA 1998d

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

Highlight 5-4: Some Key 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, sewer, electric and phone lines, and fuel pipelines
- Substrate and depth alteration from capping should be evaluated for effects on 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, flow variability including extreme events, and ice scour
- 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 such as seismic disturbances with a similar probability of occurrence
- Cap placement methods should be selected to minimize the resuspension of contaminated sediment and releases of dissolved contaminants from compacted 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 evaluate long-term integrity of the cap, recovery of biota, and evidence of re-contamination
- Periodic needs for maintenance should be expected for in-situ caps

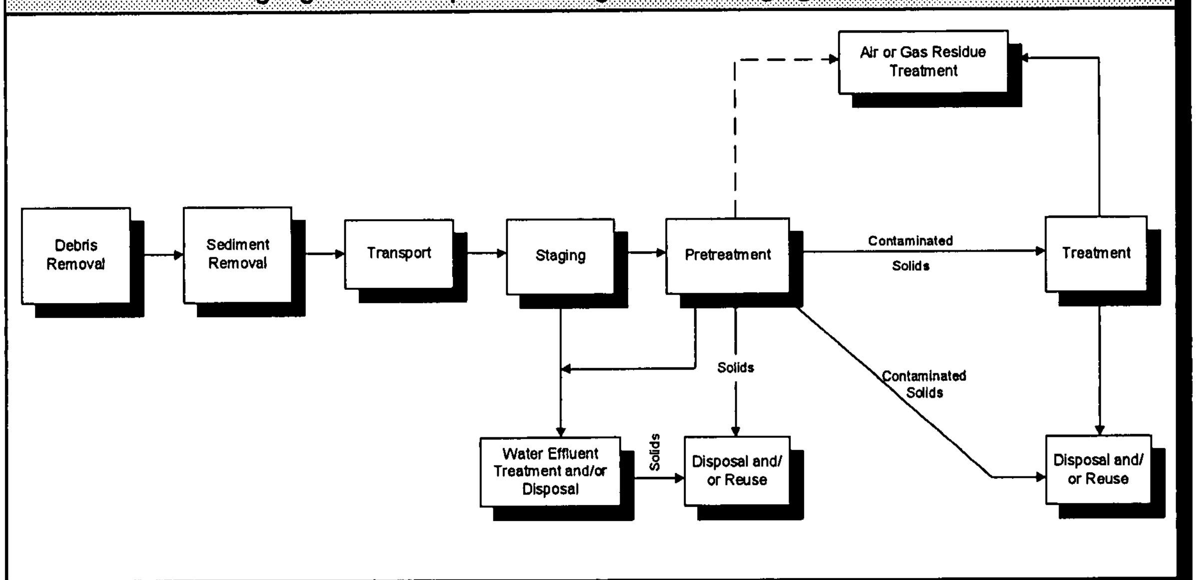
6.0 DREDGING AND EXCAVATION

6.1 INTRODUCTION

Dredging and excavation are the two most common means of removing contaminated sediment from a water body, either while it is submerged (dredging) or after water has been diverted or drained (excavation). Both methods typically necessitate transporting the sediment to a location for treatment and/or disposal. They also frequently include treatment of water from dewatered sediment prior to discharge to an appropriate receiving water body. Sediment is dredged on a routine basis at numerous locations for the maintenance of navigation channels. 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. Use of the term environmental dredging has evolved in recent years to characterize dredging performed specifically for the removal of contaminated sediment. Environmental dredging is intended to remove sediment contaminated above certain action levels while minimizing the spread of contaminants to the surrounding environment during dredging [National Research Council (NRC 1997)].

The key components to be evaluated when considering dredging or excavation as a cleanup method are removal, staging and transport, treatment (pre-treatment, treatment of decant, and/or dewatering effluents and sediment, if necessary), and disposal (liquids and solids). Highlight 6-1 provides an example flow diagram of the possible steps in a dredging or excavation alternative. The simplest dredging or excavation projects may consist of as few as three of the components shown in Highlight 6-1. More complex projects may include most or all of these components. Efficient coordination of each component is very important for a cost-effective cleanup. Project managers should recognize that, in general, fewer sediment rehandling steps leads to lower implementation risks and lower cost.

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



Sediment removal by dredging or excavation has been the most frequent cleanup method for sediment used by the Superfund program. Dredging or excavation has been selected as a cleanup method for contaminated sediment at more than 100 Superfund sites (some as an initial removal action). At about 15 to 20 percent of these sites, in-situ cleanup method [i.e., capping or monitored natural recovery (MNR)] were also selected for sediment at part of the site.

Project managers should also refer to the U.S. Environmental Protection Agency's (EPA's) *Assessment and Remediation of Contaminated Sediments (ARCS) Program Remediation Guidance Document* (U.S. EPA 1994d), and *Handbook: Remediation of Contaminated Sediments* (U.S. EPA 1991b), the NRC's *Contaminated Sediments in Ports and Waterways: Cleanup Strategies and Technologies* (NRC 1997), and Palermo and colleagues' *Operational Characteristics and Equipment Selection Factor for Environmental Dredging* (in press) for detailed discussions of the processes and technologies available for dredging and excavation.

Although each of the three major remedies (MNR, in-situ capping, and removal) should be considered at every site at which they might be appropriate, sediment removal by dredging or excavation should receive detailed consideration where the site conditions listed in Highlight 6-2 are present.

Highlight 6-2: Some Site Conditions Especially Conducive to Dredging or Excavation

- Risk is high
- Suitable disposal sites are available and nearby
- Suitable area is available for staging and handling of dredged material
- Existing shoreline areas and infrastructure (e.g., piers, pilings, buried cables) can accommodate dredging or excavation needs
- Navigational dredging is scheduled or planned
- Water depth is adequate to accommodate dredge but not so great as to be infeasible; or excavation in the dry is feasible
- Maneuverability and access not unduly impeded by piers, pilings, or other structures
- Expected human exposure is substantial and not well-controlled by institutional controls
- Long-term risk reduction of sediment removal outweighs sediment disturbance and habitat disruption
- Water diversion is practical, or current velocity is low or can be minimized, to reduce resuspension and downstream transport during dredging
- Contaminated sediment is underlain by clean sediment (so that over-dredging is feasible)
- Sediment contains low incidence of debris (e.g., logs, boulders, scrap material) or is amenable to effective debris removal prior to dredging or excavation
- High contaminant concentrations cover discrete areas
- Contaminants are highly correlated with sediment grain size (to facilitate separation and minimize disposal costs)

6.2 POTENTIAL ADVANTAGES AND LIMITATIONS

One of the advantages of removing contaminated sediment from the aquatic environment often is that, if it achieves cleanup levels for the site, it 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 future exposure and transport of contaminants.

Another potential advantage of removal of contaminated sediment is the flexibility it may leave regarding future use of the water body. In-situ cleanup methods such as monitored natural recovery and capping frequently need institutional controls that limit water body uses. Although remedies at sites with bioaccumulative contaminants usually require the development or continuation of fish consumption advisories for a period of time after removal, other types of institutional controls might not be necessary to protect a cap or layer of natural sedimentation.

Another possible advantage, where dredging residuals are low, concerns the time to achieve remedial action objectives. Active cleanup methods such as sediment removal and, particularly, capping may reduce risk more quickly and achieve remedial action objectives faster than would be achieved by natural recovery. (However, in comparing time frames between approaches, it is important to include accurate estimates of the time for design and implementation of active approaches.) Also, although it is not often cost-effective and therefore not often selected, sediment removal is presently the only cleanup method that can allow for treatment and/or beneficial reuse of dredged or excavated material. (Caps that incorporate treatment measures, sometimes called "active" caps, are currently under development by researchers. See Chapter 3, Section 3.1.3.)

There are also significant potential limitations to sediment removal. Implementation of dredging or excavation is usually more complex and costly than MNR or in-situ capping because of the removal technologies themselves (especially in the case of dredging) and the need for transport, staging, treatment (where applicable), and disposal of the dredged sediment. Treatment technologies for contaminated sediment frequently offer implementation challenges because of limited full-scale experience and high cost. In some parts of the country, disposal capacity may be limited in existing municipal or hazardous waste landfills and it may be difficult to locate new local disposal facilities. Dredging or excavation may also be more complex and costly than other approaches due to accommodation of equipment maneuverability and portability/site access. Operations and effectiveness may be affected by utilities and other infrastructures, surface and submerged structures (e.g., piers, bridges, docks, bulkheads, or pilings), overhead restrictions, and narrow channel widths.

Another possible limitation of sediment removal is the high level of uncertainty associated with estimating the extent of residual contamination left following removal. No removal technology can remove every particle of contaminated sediment, and especially where work is conducted under water, there can be significant residual contamination. 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. Residuals may also be greater in very shallow waters and when dredging sediments with high water contents. These complicating factors can make the sediment removal process and achievement of risk-based remediation goals difficult and costly. Dredging residuals have been underestimated at many existing sites, even when obvious complicating factors were not present. For some sites, this has resulted in not meeting cleanup levels or remedial action objectives.

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

Finally, like for in-situ capping, disruption of the benthic environment normally is unavoidable during dredging or excavation and usually 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 often has advantages over dredging for the following reasons:

- Excavation equipment operators and oversight personnel can much more easily see the removal operation. Although in some cases diver-assisted hydraulic dredging or video-monitored dredging can be used, turbidity, safety and other technological constraints typically make it necessary for dredging to be performed without visual assistance;

- Removal of contaminated sediment is usually more complete (i.e., residual contamination tends to be lower);

- Far fewer waterborne contaminants are released when the excavation area has been dewatered; and

- In-water bottom conditions (e.g., debris) and sediment characteristics (e.g., grain size and specific gravity) typically require much less consideration.

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. For example, cofferdams, sheet pile walls, or other diversions/exclusion structures would need to be fabricated and installed. Maneuvering around diversion/exclusion structures may be required because either earth moving equipment cannot access the site or double handling may be required to move material outside of the site. In addition, excavation generally is limited to relatively shallow areas.

6.3 SITE CONDITIONS

6.3.1 Physical Environment

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

- Bathymetry, slope of the sediment surface and water depth;
- Currents and tides;
- Bottom conditions, especially the presence of debris and large rocks both on top of and within the sediment bed;
- Depth to and (un)evenness of bedrock or hard bottom (e.g., stiff glacial till);
- Sediment particle size distribution, degree of consolidation, and shear strength;
- Thickness and vertical delineation of contaminated sediment;
- Distance between dredging and disposal locations;
- The presence and maintenance condition of structures such as piers, pilings, cables, or pipes; and
- Land access to water body.

Additionally, sediment removal may change the hydrodynamics and slope stability of the remediation area. These changes should be evaluated to insure that the removal activity does not cause bank or structural instability, shoreline facility damages, or other adverse effects in or near the removal operation that are unacceptable.

Thorough horizontal and vertical characterization of both the physical and chemical sediment characteristics and characteristics of other physical debris present on top of or buried in the sediment bed at the site normally is needed during the remedial investigation to evaluate the feasibility, cost, and potential effectiveness of dredging or excavation. The results of this characterization should 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, Section 2.1, Site Characterization.

There are several tests that may help provide the project manager with needed information for feasibility study or design of dredging, treatment, or disposal methods. In addition, the time and cost needed to conduct engineering and environmental testing should be considered. The project manager should refer to *Evaluation of Dredged Material Proposed for Disposal at Island, Nearshore or Upland Confined Disposal Facilities - Testing Manual* (USACE 2003) and *Evaluation of Dredged Material Proposed for Discharge in Waters of the U.S. - Testing Manual (Inland Testing Manual)* (U.S. EPA and

USACE 1998) for further information. In addition, 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).

6.3.2 Waterway Uses and Infrastructures

Any evaluation of the feasibility of a dredging or excavation project should consider impacts to existing and reasonably anticipated future uses of a waterway. Waterway uses that may need to be considered when evaluating a sediment removal alternative include the following:

- Navigation (commercial, military, recreational);
- Residential/commercial/military moorage;
- Flood control;
- Recreation;
- Fishing (subsistence, commercial, recreational);
- 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 dredge disposal sites; and
- Moorage and anchorage areas.

Evaluation of the feasibility of a sediment removal project should include an analysis of whether impacts to these potential uses may be avoided or minimized both during construction and in the long term.

6.3.3 Habitat Alteration

The project manager should consider the impact of habitat loss or alteration in evaluating a dredging or excavation alternative. As is also discussed in Chapter 5, In-Situ Capping, while a project may be designed to minimize habitat loss, or even enhance habitat, sediment removal and disposal, as well as sediment capping, do alter the environment. 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 forested 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. 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. Appropriate coordination with natural resource agencies typically will assist the project manager in determining the extent of impacts that a dredging project may have on 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.

6.4 EXCAVATION TECHNOLOGIES

Excavation of contaminated sediment generally involves isolating the contaminated sediment from the overlying water body by 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 streams, shallow rivers and ponds, or near shore areas.

Prior to pumping out the water, the area can be isolated using one or more of the following:

- Sheet piling;
- Earthen dams;
- Coffer dams;
- Geotubes, inflatable dams;
- Rerouting the water body using temporary dams or pipes; or
- Permanent relocation of the water body.

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 6-3 shows an example of where this has been used. If a stream is split down its center, then one side of the stream may be excavated in the dry, after pumping out the trapped water. 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. Sheet piling may not be feasible where bedrock or hard strata are present at or near the bottom surface. Where sheet piling is used to isolate a dredging or excavation action, project managers should consider potential hydraulic impacts of the diverted flow. Such diversion in most cases will increase natural flow velocity, which may scour sediment outside the diversion wall. If the sediment is also contaminated, as is likely to be the case, the increased dispersion of the sediment should be considered in design choices. Temporarily rerouting a water body with dams is sometimes done for small streams or ponds (Highlight 6-4). This includes the use of temporary dams to divert the water flow allowing excavation of now "dry" 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.

Highlight 6-3: Example of Excavation Following Isolation Using Sheet Piling

Source: Pine River/Velsicol, EPA Region 5

Once isolated, standing water within the excavation area will need to be removed. Although 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 water body. Management of water within the confined area is another 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. Where sediment is soft, support of the excavation equipment in the dewatered area can be problematic because underlying materials may not have the strength to support equipment weight. This also may reduce excavation depth precision. Both factors should be accounted for in design. When the excavation activities are complete, temporary dam(s) or sheet piling(s) are removed and the water body is restored to its original hydraulic condition.

Highlight 6-4: Examples of Permanent or Temporary Rerouting of a Water Body

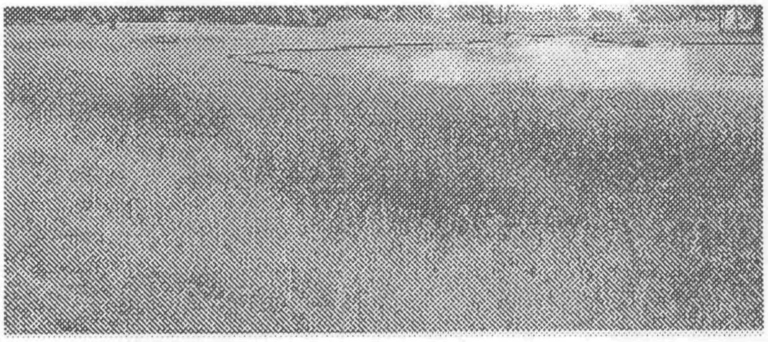
A: Permanent River Relocation – Triana/Tennessee River Site

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 total DDT (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 total DDT 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 total DDT concentrations in fish and water continue to decline.

B: Temporary ReRouting 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

Another less common type of excavation project involves permanent relocation of a water body (also shown in Highlight 6-4). This, for example, was accomplished at the Triana/Tennesee River Superfund Site in Alabama and is being implemented at the Moss-American Superfund Site in Wisconsin. The initial phases of such a project may be similar to excavation projects that temporarily reroute a water body. However, in a permanent stream relocation project, a replacement stream is constructed and then the original water body is excavated or capped and converted into an upland area. Because the original water body is covered over, direct exposure to residual contamination is generally 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.

6.5 DREDGING TECHNOLOGIES

For purposes of this guidance, dredging means the removal of sediment from an underwater environment, typically using floating excavators called dredges. Dredging involves mechanically 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 removing the dredged material. Some dredges employ pneumatic (compressed air) systems to pump the sediment out of the waterway (U.S. EPA 1994d); however, these have not generally gained acceptance on environmental dredging projects.

6.5.1 Mechanical Dredging

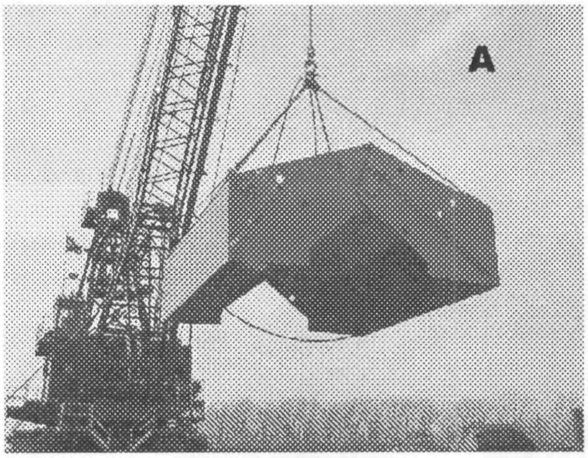
The fundamental difference between mechanical and hydraulic dredging equipment is the form in which the sediment is removed. Mechanical dredges offer the advantage of removing the sediment at nearly the same solids content and, therefore, volume as the in-situ material. Little additional water is entrained 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. However, the water that is present in the bucket above the sediment must either be collected, managed, and treated, or be permitted to leak out, which generally leads to higher contaminant losses during dredging.

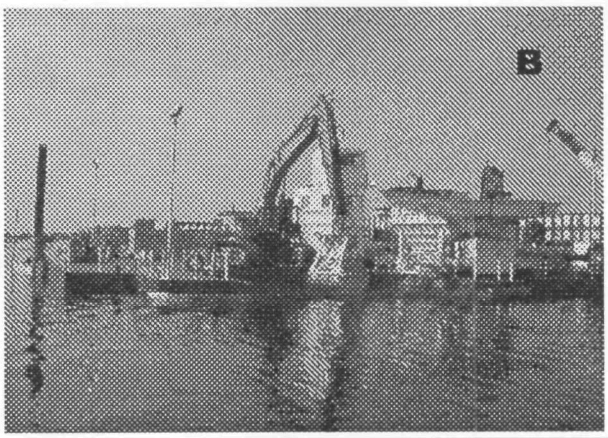
The mechanical dredges most commonly used in the U.S. for environmental dredging are the following (Palermo et al. *in press*):

- Clamshell: Conventional clamshell dredges, wire supported, conventional open clam bucket, circular shaped cutting action;
- Enclosed Bucket: Wire supported, near watertight or sealed bucket as compared to conventional open bucket (recent designs also incorporate a level cut capability as compared to a circular-shaped cut for conventional buckets, for example, the Cable Arm and Boskalis Horizontal Closing Environmental Grab); and
- Articulated Mechanical: Backhoe designs, clam-type enclosed buckets, hydraulic closing mechanisms, all supported by articulated fixed-arm (e.g., Ham Visor Grab, Bean Hydraulic Profiling Grab (HPG), Toa High Density Transport, and the Dry Dredge).

The mechanical dredge types listed above reflect equipment used for environmental dredging and generally readily available in the U.S. The enclosed bucket dredges were designed to address a number of issues often raised relative to remedial dredging including contaminant removal efficiency and minimizing sediment resuspension. However, redesigned dredging equipment may not be cost-effective at every site. For example, in some environments an enclosed bucket may be most useful for soft sediment but may not close efficiently on debris. A conventional clamshell dredge may have greater leverage and be able to close on or cut debris in some cases. However, material mounded over the top may be resuspended. An articulated mechanical dredge may have advantage in stiffer sediment since the fixed-arm arrangement can push the bucket into the sediment to the desired cut-level, and not rely on the weight of the bucket for penetration. Highlight 6-5 shows two examples of mechanical dredges including a type used at New Bedford Harbor.

Highlight 6-5: Examples of Mechanical Dredges





Note: A = Cable Arm Corp. dredge cutterhead (Source: Cable Arm, Corp.)
B = Bean Company Horizontal Profiling Grab (HPG) dredge, New Bedford Harbor Site (Source: Barbara Bergen, U.S. EPA)

6.5.2 Hydraulic Dredging

Hydraulic dredges remove and transport sediment in the form of a slurry through the inclusion or 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 1994d). The excess water is usually discharged as effluent at the treatment or disposal site and often needs 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 hydraulic dredges most commonly used in the U.S. for environmental dredging are the following (Palermo et al. in press):

- Cutterhead: Conventional hydraulic pipeline dredge, with conventional cutterhead;

- Horizontal Auger: Hydraulic pipeline dredge with horizontal auger dredgehead (e.g., Mudcat);

- Plain Suction: Hydraulic pipeline dredge using dredgehead design with no cutting action, plain suction (e.g., cutterhead dredge with no cutter basket mounted, Matchbox dredgehead, articulated Slope Cleaner, Scoop-Dredge BRABO, etc.);

- Pneumatic: Air operated submersible pump, pipeline transport, either wire supported or fixed-arm supported (e.g., Japanese Oozer, Italian Pneuma, Dutch "d", Japanese Refresher, etc.);

- Specialty Dredgeheads: Other hydraulic pipeline dredges with specialty dredgeheads or pumping systems (e.g., Boskalis Environmental Disc Cutter, Slope Cleaner, Clean Sweep, Water Refresher, Clean Up, Swan 21 Systems, etc.); and

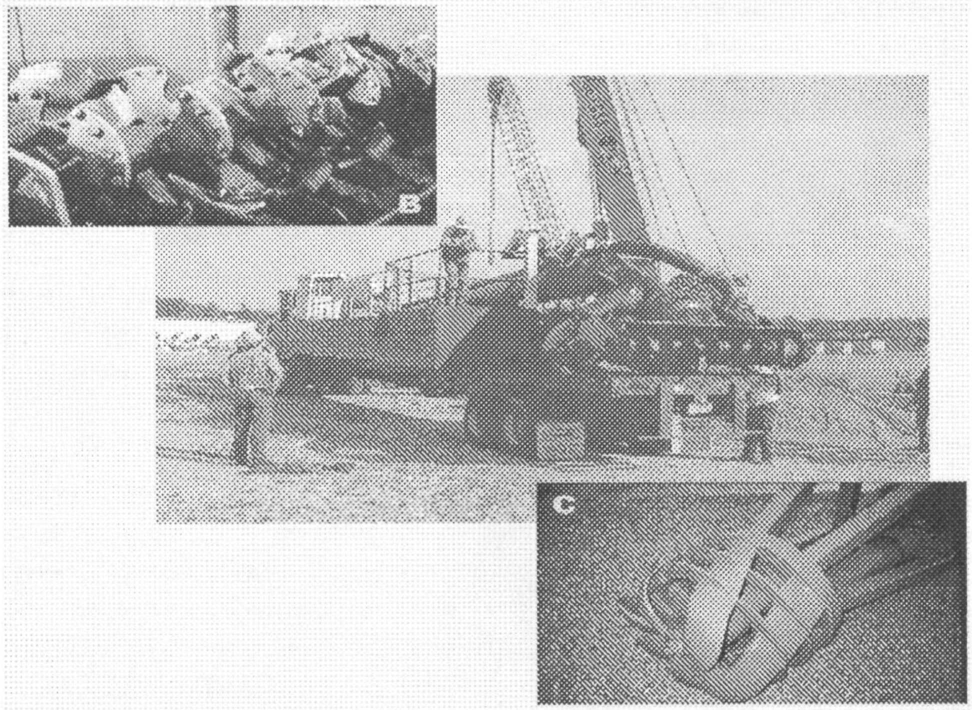
- Diver Assisted: Hand-held hydraulic suction with pipeline transport.

Some of the hydraulic dredges included above have been specifically developed to reduce resuspension during the removal process. As with modified mechanical dredges, project managers should be aware that there may be tradeoffs in terms of production rate and ability to handle debris with many of these modifications. Highlight 6-6 presents examples of hydraulic dredges.

6.5.3 Dredge Equipment Selection

The selection of appropriate dredging equipment is essential for an effective environmental dredging operation. The operational characteristics of the three types of mechanical and five types of hydraulic dredges presented in the guidance sections above are listed in Highlights 6-7a and 6-7b (Palermo et al. in press). This information was reviewed by an expert panel and attendees at a special session on environment dredging at the Meeting of the Western Dredging Association (WEDA XXI) and 33rd Annual Texas A&M Dredging Seminar in Houston, Texas. The operational characteristics and selection factors have been drawn from information compiled for the public review draft of this guidance as well as earlier published reviews of dredge characteristics. Quantitative operational characteristics (both capabilities and limitations) are summarized for conditions likely to be encountered for many environmental dredging projects. The numbers are not representative of all dredge designs and sizes available, but represent those most commonly used for environmental dredging. Qualitative selection factors for each dredge type are presented based on the best professional judgement and interpretation of readily available data. Site-specific results and supporting references are available in Palermo and colleagues' *Operational Characteristics and Equipment Selection Factors for Environmental Dredging* (Palermo et al. in press).

Highlight 6-6: Examples of Hydraulic Dredges



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

The information in Highlights 6-7a and 6-7b is intended to help project managers make initial assessments of dredge capabilities, and screen equipment types for evaluation at a Feasibility Study stage or for pilot field testing. It is not intended as a guide for final equipment selection for remedy implementation. There are many site specific circumstances that dictate which equipment type is most appropriate for any given situation, and each type can be applied in different ways to adapt to site conditions. In addition, because new equipment is being continuously developed, project managers will need to consult with experts who are familiar with the latest technologies. Experience has shown that an effective environmental dredging operation also 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.

Highlight 6-7a: Example Environmental Dredging Operational Characteristics and Selection Factors[1]

EQUIPMENT TYPE[2]

	Mechanical Dredges (2 to 8 cubic meter buckets)			Hydraulic/Pneumatic Dredges (15 to 30 cm pump sizes)						Dry Excavation
	Conventional Clamshell (Wire)[3]	Enclosed Bucket (Wire)[4]	Articulated Mechanical (Fixed Arm)[5]	Cutter-head[6]	Horizontal Auger[7]	Plain Suction[8]	Pneumatic[9]	Specialty[10]	Diver[11]	Various Mechanical Excavators[12]
OPERATIONAL CHARACTERISTICS[13]										
Operating Production Rate (m^3/hr)[14]	48 (2 m^3 bucket) 95 (4 m^3 bucket) 143 (6 m^3 bucket) 193 (8 m^3 bucket)			23 (15 cm pump) 41 (20 cm pump) 64 (25 cm pump) 93 (30cm pump)			Site Specific	Equipment Specific	10	Site Specific
Percent Solids (by weight)[15]	Near In-Situ	Near In-Situ	Near In-Situ	5	5	5	15 or higher	Equipment Specific	<5	In-Situ or greater
Vertical Operating Accuracy (cm)[16]	15	15	10	10	10	10	15	10	–	5
Horizontal Operating Accuracy (cm)[17]	10	10	10	10	10	10	10	10	–	5
Maximum Dredging Depth (m)[18]	Stability Limitations	Stability Limitations	15	15	5	15	45	15	30	Stability Limitations
Minimum Dredging Depth (m)[19]	–	–	–	1	0.5	1	5	1	0.5	–

	EQUIPMENT TYPE[2]									
	Mechanical Dredges (2 to 8 cubic meter buckets)			Hydraulic/Pneumatic Dredges (15 to 30 cm pump sizes)						Dry Excavation
	Conventional Clamshell (Wire)[3]	Enclosed Bucket (Wire)[4]	Articulated Mechanical (Fixed Arm)[5]	Cutter-head[6]	Horizontal Auger[7]	Plain Suction[8]	Pneumatic[9]	Specialty[10]	Diver[11]	Various Mechanical Excavators[12]
EQUIPMENT SELECTION FACTORS[20]										
Sediment Resuspension[21]	Low	High	High	Medium	Medium	High	High	High	High	High
Contaminant Release Control[22]	Low	High	High	Medium	Medium	Medium	Medium	Medium	High	High
Residual Sediment/ Cleanup Levels[23]	Low	Medium	Medium	Medium	Medium	Medium	Medium	Medium	High	High
Transport by Pipeline[24]	Medium	Medium	Medium	High	High	High	High	High	High	Medium
Transport by Barge[25]	High	High	High	Medium	Medium	Medium	Medium	Medium	Low	High
Positioning Control in currents/wind/ tides[26]	High	High	High	High	Medium	High	High	High	Medium	High
Maneuverability[27]	High	High	High	Low	Low	Low	Low	Low	High	High
Portability/ Access[28]	High	High	High	High	High	High	High	Medium	High	High
Availability[29]	High	High	High	High	High	High	Medium	Medium	High	High

EQUIPMENT TYPE[2]										
	Mechanical Dredges (2 to 8 cubic meter buckets)			Hydraulic/Pneumatic Dredges (15 to 30 cm pump sizes)						Dry Excavation
	Conventional Clamshell (Wire)[3]	Enclosed Bucket (Wire)[4]	Articulated Mechanical (Fixed Arm)[5]	Cutter-head[6]	Horizontal Auger[7]	Plain Suction[8]	Pneumatic[9]	Specialty[10]	Diver[11]	Various Mechanical Excavators[12]
Debris/Loose Rock/ Vegetation[30]	High	High	High	Low	Low	Low	Low	Low	Low	High
Hardpan/Rock Bottom[31]	Low	Low	Low	Low	Low	Medium	Medium	Medium	High	High
Flexibility for Varying Conditions[32]	High	High	Medium	High	Medium	Low	Low	Low	Low	High
Thin Lift/Residual Removal[33]	Low	Medium	Medium	Medium	High	High	High	High	High	High

Highlight 6-7b: Footnotes for Example Environmental Dredging Operational Characteristics and Selection Factors	
1	This table provides general information to help project managers initially assess dredge capabilities, and screen and select equipment types for evaluation at the feasibility study stage or for pilot field testing. This table is NOT intended as a guide for final equipment selection for remedy implementation. There are many site-specific, sediment-specific, and project-specific circumstances that will dictate which equipment is most appropriate for any given situation, and each equipment type can be applied in different ways to adapt to site and sediment conditions. In addition, because new equipment is being continuously developed, project managers will need to consult with experts who are familiar with the latest technologies. For additional information on development and technical basis for the entries in this table refer to: Palermo, M., N. Francingues, and D. Averett. 2005. Operational Characteristics and Equipment Selection Factors for Environmental Dredging. Journal of Dredging Engineering, Western Dredging Association, in preparation.
2	Equipment types shown here are considered the most commonly used for environmental dredging in the U.S. Other dredge types are available. Equipment used for environmental dredging is usually smaller in size than that commonly used for navigation dredging. Information presented here is tailored for mechanical bucket sizes from 3 to 10 cubic yards (about 2 to 8 cubic meters), and hydraulic/pneumatic pump sizes from 6 to 12 inches (about 15 to 30 cm). Larger sizes are available for many equipment types.
3	Clamshell – conventional clamshell dredges, wire supported, conventional open clam bucket.
4	Enclosed bucket – wire supported, near watertight or sealed bucket usually incorporating a level cut capability.
5	Articulated Mechanical – backhoe designs, clam-type enclosed buckets, hydraulic closing mechanisms, all supported by articulated fixed-arm.
6	Cutterhead – conventional hydraulic pipeline dredge, with conventional cutterhead.
7	Horizontal auger – hydraulic pipeline dredge with horizontal auger dredgehead.
8	Plain Suction – hydraulic pipeline dredge using dredgehead design with no cutting action.
9	Pneumatic – air operated submersible pump, pipeline transport, either wire supported or fixed-arm supported.
10	Specialty Dredgeheads – other hydraulic pipeline dredges with specialty dredgeheads or pumping systems
11	Diver assisted – hand-held hydraulic suction with pipeline transport.
12	Dry Excavation – conventional excavation equipment operating within dewatered containments such as sheet-pile enclosures or cofferdams.
13	OPERATIONAL CHARACTERISTICS are shown as quantitative entries, reflecting capabilities and limitations of dredge types, and are solely a function of the equipment itself.
14	Production rate – in-situ volume of sediment removed per unit time. Rates shown are for production cuts as opposed to "cleanup passes" and are for active periods of operation under average conditions. Rates for two bucket or pump sizes are shown for comparison. For mechanical dredges, the rates were calculated assuming 80% bucket fill with a bucket cycle time of 2 minutes. For hydraulic dredges, the rates were calculated assuming in-situ sediment 35% solids by weight, 5% solids by weight for slurry, and pump discharge velocity of 10 feet/sec. The rate shown for diver-assisted assumes a maximum pump size of 15 cm and roughly 50% efficiency of diver effort while working. Production rate for dry excavation is would be largely dictated by the time required to isolate and dewater the areas targeted for excavation. A variety of factors may influence the effective operating time per day, week, or season, and should be considered in calculating times required for removal.
15	Percent solids by weight – ratio of weight of dry solids to total weight of the dredged material as removed, expressed as a percentage. Percent solids for mechanical dredging is a function of the in-situ percent solids and the effective bucket fill (expressed as a percentage of the bucket capacity filled by in-situ sediment as opposed to free water), and near in-situ percent solids is possible for production cuts. A wide range of percent solids for hydraulic dredges is reported, but 5% solids can be expected for most environmental dredging projects.

Highlight 6-7b: Footnotes for Example Environmental Dredging Operational Characteristics and Selection Factors	
16	Vertical operating accuracy – the ability to position the dredgehead at a desired depth or elevation for the cut and maintain or repeat that vertical position during the dredging operation. Although positioning instrumentation is accurate to within a few centimeters, the design of the dredge and the linkages between the dredgehead and the positioning system will affect the accuracy attainable in positioning the dredgehead. A vertical accuracy of cut of about 15 cm (one-half foot) is considered attainable for most project conditions. Fixed arm equipment holds some advantage over wire-supported in maintaining vertical operating accuracy. The accuracies achievable for sediment characterization should be considered in setting performance standards for environmental dredging operating accuracy (both vertical and horizontal).
17	Horizontal operating accuracy – the ability to position and operate the dredgehead at a desired location or within a desired surface area. Considerations are similar to those for vertical accuracy.
18	Maximum dredging depth – physical limitation to reach below a given depth. Wire-supported buckets or pumps can be deployed at substantial depths, so the maximum digging depth is limited by stability of the excavation. Reach of fixed arm supported buckets or hydraulic dredges is limited by the length of the arm or ladder. Conventional backhoe equipment is limited to about 15 meters reach. Smaller hydraulic dredges are usually designed for a maximum dredging depth of about 15 meters. Hydraulic dredges also have a limiting depth of removal of about 50 feet due to the limitation of atmospheric pressure, but this limitation can be overcome by addition of a submerged pump on the ladder. The table entries should NOT be considered as hard and fast limits. Larger dredge sizes and designs are available for deeper depths.
19	Minimum dredging depth – constraints on draft limitations of some floating dredges or potential loss of pump prime for hydraulic dredges. Such limitations can be managed if the dredge "digs its way into the area". For smaller dredges, these limitations are at approximately the 1-meter water depth. Pneumatic dredges require a minimum water depth of about 5 meters for efficient pump operation.
20	SELECTION FACTORS are shown as qualitative entries, reflecting the potential performance of a given dredge type, and are a function of both the capability of the equipment type and the site and/or sediment conditions. Entries defined as follows: (High) - indicating the given dredge type is generally suitable or favorable for a given issue or concern, (Medium) - indicating the given dredge type addresses the issue or concern, but it may not be preferred, and (Low) - indicating the given dredge type may not be a suitable selection for addressing this issue or concern.
21	Sediment Resuspension – potential of a given dredge type in minimizing sediment resuspension. Clamshell (Low) - Circular-shaped cutting action, cratered bottom subject to sloughing, open bucket design subject to washout and spillage, scows and workboats working in shallow areas. Enclosed Bucket (High) - Seal around the lips of the bucket and an enclosed top when in the shut position, level cut design minimizes sloughing. Articulated Mechanical (High) - Less resuspension as compared to conventional clamshell dredges. Cutterhead/ Horizontal Auger (Medium) - Conventional cutterhead dredges and horizontal augers result in less resuspension as compared to conventional clamshell dredges. May be fitted with hoods or shrouds to partially control resuspension. Plain Suction/ Pneumatic (High) - No mechanical action to dislodge the material. Specialty (High) - Although designs vary, all the so-called specialty dredges have features specifically intended to reduce resuspension. Diver (High) - Precision of diver assisted hydraulic dredging, the smaller size of the dredgeheads used, and inherently slow speed of operation. Dry Excavation (High) - Completely isolates the excavation process from the water column.
22	Contaminant Release Control - the inherent ability to control sediment resuspension and dissolved and volatile releases for the given equipment type and associated operation. Clamshell (Low) - can be operated such that the excavation and water column exposure of the bucket is within a silt curtain containment or enclosure, however, high suspended solids within the silt curtain may be released when the curtain is moved. Enclosed bucket/ Articulated Mechanical (Medium) - can be operated such that the excavation and water column exposure of the bucket is within a silt curtain enclosure with relatively small footprint. Enclosed buckets act as a control to greatly reduce resuspension within the enclosures and potential for release. Cutterhead/ Plain suction/ Horizontal auger/ Pneumatic/ Specialty Dredgeheads/ (Medium) - capable of transporting the material directly by pipeline, minimizing exposure to the water column and to volatilization. Can be operated within enclosures, but the footprint of such enclosures would necessarily be larger than that for mechanical dredges. Diver assisted (High) - scale of diver-assisted dredging would seldom require contaminant release controls. Dry Excavation (High) - Dewatering of the dredging area effectively eliminates dissolved releases. Sediment surface exposed to the atmosphere has lower volatile emission rates as compared to the same surface ponded with elevated suspended sediment concentrations.

Highlight 6-7b: Footnotes for Example Environmental Dredging Operational Characteristics and Selection Factors	
23	Residual sediment/ Cleanup Levels – efficiency of the dredge is in removing material without leaving a residual, and potentially meeting a cleanup criterion. Clamshell (Low) - high potential to leave residual sediment because of the circular-shaped cutting action and the tendency to leave a cratered bottom subject to sloughing. Enclosed bucket/ Articulated Mechanical/ Cutterhead/ Horizontal auger/ Plain Suction/ Pneumatic/ Specialty Dredgeheads (Medium) - all dredges with active dredgeheads and/or movement in contact with the bottom sediment will leave some residual sediment. The control offered by the articulated arm provides an advantage for removal of thin residual layers. Diver assisted (High) - hand-held action of diver-assisted work has a low potential for generating residual sediment. Dry Excavation (High) - any fallback of sediment excavated under dry conditions can be readily observed and managed.
24	Transport by Pipeline -compatibility of the dredge with subsequent transport by pipeline. Clamshell/ Enclosed bucket/ Articulated Mechanical (Medium) - All mechanical dredges remove material at near in-situ density, and additional reslurry and rehandling equipment must be employed to allow for pipeline transport. Cutterhead/ Plain suction/ Horizontal auger/ Pneumatic/ Specialty Dredgeheads/ Diver Assisted (High) - All hydraulic and pneumatic dredges are designed for pipeline transport. Dry Excavation (Medium) - Additional reslurry and rehandling equipment must be employed to allow for pipeline transport.
25	Transport by barge – compatibility of the dredge with subsequent transport by barge. Clamshell/ Enclosed bucket/ Articulated Mechanical (High) - material excavated with mechanical dredges is close to in-situ density and may be directly placed in barges for transport. Cutterhead/ Plain suction/ Horizontal auger/ Pneumatic/ Specialty Dredgeheads/ Diver Assisted (Medium) - barge transport of hydraulically dredged material is inefficient. Although pneumatic and some specialty dredges are capable of removing soft sediments at high water content, intermittent operation for change-out of barges will significantly reduce efficiency. Dry Excavation (High) - material excavated in the dry may be placed directly in barges using conveyers or front-end loaders.
26	Positioning Control in currents/wind/tides – ability of the dredge to hold a desired position of the dredgehead horizontally with current, wind, or vertically with fluctuating tides. Clamshell/ Enclosed bucket/ Articulated Mechanical (High) - operate with spuds or jack-up piles and are inherently stable against movement by normal winds and currents. Cutterhead/ Plain suction/ Specialty Dredgeheads (High) - equipped with spuds and use "walking spud" method of operation inherently stable against movement by normal winds and current. Horizontal auger (Medium) - free floating and operate using an anchor and cable system, subject to movement with longer anchor sets. Pneumatic (High) - operate from spudded barges or platforms and are inherently stable against movement by normal winds and currents. Diver assisted (Medium) - ability of divers to maintain a desired position will be hampered by currents. Dry Excavation (High) - not affected by wind and currents.
27	Maneuverability – ability of the dredge to operate effectively in close proximity or around utilities and other infrastructure, narrow channel widths, surface and submerged obstructions, and overhead restrictions. Clamshell/ Enclosed bucket/ Articulated Mechanical (High) - buckets are wire supported or fixed-arm articulated and may be operated close in to infrastructure and within tightly restricted areas. Cutterhead/ Plain suction/ Horizontal auger/ Pneumatic/ Specialty Dredgeheads (Low) - swinging action of the walking spud method of operation for hydraulic pipeline dredges and the need for long anchor and cable setup for horizontal auger dredges limits their ability to operate near infrastructure or within tightly restricted areas. Diver assisted (High) - can be conducted close to infrastructure and within tightly restricted areas. Dry Excavation (High) - containments for dry excavation can be designed for areas near infrastructure and tightly restricted areas may be completely contained.
28	Portability/Access – ability of the dredge to pass under bridges, through narrow channels, or to be transported by truck and easily launched to the site. Clamshell/ Enclosed bucket/ Articulated Mechanical/ Cutterhead/ Plain suction/ Horizontal auger/ Pneumatic/ Diver assisted/ Dry Excavation (High) - dredge types considered here are the smaller size and are generally truck transportable. Specialty Dredgeheads (Medium) - some specialty dredge designs are too large for truck transport.
29	Availability – This factor refers to the potential availability of dredges types to contractors and the potential physical presence of the equipment in the U.S. Clamshell/ Enclosed bucket/ Articulated Mechanical/ Cutterhead/ Plain suction/ Horizontal auger/ Pneumatic/ Diver assisted/ Dry Excavation (High) - Most dredge types are readily available. Specialty Dredgeheads (Medium) - Some specialty dredges are only available through one contractor, or may be subject to restrictions under the Jones Act.

Highlight 6-7b: Footnotes for Example Environmental Dredging Operational Characteristics and Selection Factors	
30	Debris/Loose Rock/Vegetation – susceptibility of a given dredge type to clogging by debris and subsequent loss of operational efficiency. Clamshell/ Enclosed bucket/ Articulated Mechanical (High) - mechanical dredges can effectively remove sediments containing debris, although leakage may result. Mechanical equipment is the only approach for debris-removal passes. Cutterhead/ Plain suction/ Horizontal auger/ Pneumatic/ Specialty Dredgeheads (Low) - subject to clogging by debris and are incapable of removing larger pieces of loose rock and larger debris. Loose rock and large debris can also cause inefficient sediment removal. Diver assisted (Low) - presence of logs and large debris may present dangerous conditions for diver-assisted dredging. Although divers can remove sediment from around large debris or rocks, this type of operation would be inefficient. Dry Excavation (High) - dry excavation allows use of conventional excavation equipment. Leakage from buckets caused by debris is not a consideration for dry excavation.
31	Hardpan/ Rock Bottom – ability of a dredge type to efficiently remove a sediment layer overlying hardpan or rock bottom without leaving excessive residual sediment. Clamshell/ Enclosed bucket/ Articulated Mechanical/Cutterhead/ Horizontal auger (Low) - closing action of buckets and cutting action of dredgeheads result in problems maintaining a desired vertical cutting position and would tend to leave behind excessive residual sediment. Power associated with articulated mechanical has advantage in removing hard materials. Plain suction/ Pneumatic/ Specialty Dredges (Medium) - lack an active closing or cutting action and can operate over an uneven hard surface, although removal efficiency may be low. Diver assisted (High) – may be the most effective approach for precise cleanup of a hard face, since the divers can feel the surface and adjust the excavation accordingly. Dry Excavation (High) - allows the visual location of pockets of residual remaining on an uneven hard surface.
32	Flexibility for Varying Conditions – flexibility of a given dredge type in adapting to differing conditions, such as sediment stiffness, variable cut thicknesses, and the overall ability to take thick cuts. Clamshell/ Enclosed bucket (High) - buckets are capable of taking thin cuts or thicker cuts in proportion to the bucket size, and bucket sizes can be easily switched. Articulated Mechanical (Medium) - ability to change bucket sizes for articulated mechanical is limited. Cutterhead (High) - capable of taking variable cut thicknesses by varying the burial depth of the cutter. Different cutterhead sizes or designs can be used to adapt to changing cut thicknesses or sediment stiffness. Horizontal auger (Medium) - designed for a set maximum cut thickness, and attempts to remove thick cuts may result in plowing actions with excessive resuspension and residual. Plain suction/ Pneumatic (Low) - no cutting action limits ability to take thicker cuts or remove stiffer materials. Specialty Dredgeheads (Low) - specialty dredges are designed for a specific application and have limited flexibility. Diver assisted (Low) - removal is limited to thin cuts. Dry Excavation (High) - allows use of a full range of conventional excavation equipment.
33	Thin lift/ residual removal – ability of a given dredge type to removal thin layers of contaminated material without excessive overdredging. Clamshell (Low) - circular shaped cut not suited to efficient removal of thin layers. Enclosed bucket/ Articulated Mechanical (Medium) - level cutting action is capable of removing thin layers, but the buckets would only be partially filled, resulting in inefficient production and higher handling and treatment costs. Cutterhead/ Horizontal Auger (Medium) - capable of removing thin layers, but the percent solids is reduced under these conditions. Plain suction/ Pneumatic (High) -well suited for removal of thin lifts, especially loose material such as residual sediment. Specialty Dredgeheads (High) - some specialty dredges are designed specifically for removal of thin lifts. Diver assisted (High) - precision of diver-assisted dredging is well suited for removal of thin layers, especially residuals. Dry Excavation (High) - allows for a precise control of cut thickness, amenable to removal of thin layers.

6.5.4 Dredge Positioning

An important 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, in order to avoid a more than necessary amount of over-dredging and excess handling of uncontaminated sediment. Video cameras are sometimes useful in monitoring dredging operations, although turbidity effects and lack of spatial references may present limitations to their use. The working depth of the dredgehead may be measured using acoustic instrumentation and by monitoring dredged slurry densities. In addition, surveying software 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 (see e.g., St.

Lawrence Centre 1993). Digital positioning systems are also available that enable dredge operators to follow a complex sediment contour (see e.g., Van Oostrum 1992).

Depending on site conditions (e.g., currents, winds, tides), the horizontal position of the dredge may need to be continuously monitored during dredging. Satellite- or transmitter-based positioning systems, such as differential global positioning systems (DGPS) can 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. The accuracies achievable for sediment characterization should be considered in setting performance standards for environmental dredging vertical and horizontal operating accuracy (Palermo et al. in press). However, project managers should not develop unrealistic expectations of dredging accuracy. Contaminated sediment cannot 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. Accurately dredging to pre-established cut-lines is an important component of meeting remedial action objectives, but alone is not generally sufficient for meeting them. The section below describes the equally important factors of controlling dredging losses and residual contamination.

6.5.5 Predicting and Minimizing Resuspension, Contaminant Release and Transport During Dredging

Sediment resuspension and unwanted contaminant release and transport in the water body arise due to a variety of activities associated with a dredging remedy. These frequently include resuspension caused by operation of the dredgehead, by operation of work boats and tug boats, and by deployment and movement of control measures such as silt screens or sheet piles. Contaminated sediment may also be lost from barges used during the dredging operation. 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 (so that resuspended sediment is later redeposited and dredged) should be an important consideration. Storm events may also result in transport of contaminants beyond the dredging area. Use of containment barriers to limit transport of resuspended contaminated sediment is discussed in Section 6.5.6 of this guidance.

When evaluating the resuspension effects of dredging, it is important to compare these 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, and consider the length of time over which dredging-related contaminant releases would occur. In general, two types of contaminant release are associated with resuspended sediment: particulate and dissolved. Particulate release refers to the transport of contaminants associated with the particle phase. Dissolved refers to the release of dissolved contaminants from the particles into the water column. This form of release is significant because dissolved contaminants are the most readily bioavailable. Consequently, resuspension can result in the release of bioavailable organic and inorganic contaminants into the water column which may cause toxicity or enhanced bioaccumulation. Research is currently being performed to address the risk associated with resuspension at contaminated sites. Until further guidance is available, at most sites, it is important to monitor resuspension during dredging to evaluate its effects on water quality. Project managers should be aware that most engineering measures implemented to reduce resuspension also reduce dredging efficiency. Estimates of production rates, cost, and project time-frame, should take these measures into account.

Some contaminant release and transport during dredging is inevitable and should be factored into the alternatives evaluation and planned for in the remedy design. Releases can be minimized by choice of dredging equipment, dredging less area and/or using certain operational procedures (e.g., slowing the dredge clamshell descent just before impact with the sediment bed.) A careful assessment of all causes of resuspension is necessary to realistically predict the likely contaminant releases during a dredging operation. The magnitude of sediment resuspension and resulting transport of contaminants during a dredging operation is influenced by many factors, including:

- Physical properties of the sediment [e.g., grain size distribution, organic carbon content, Acid Volatile Sulfides (AVS) concentration];
- Vertical distribution of contaminants in the sediment;
- Water velocity and degree of turbulence;
- Type of dredge;
- Methods of dredge operation;
- Skill of operators;
- Extent of debris;
- Water salinity; and
- Extent of workboat/tugboat activity.

To adequately compare various remedies for a site, to the extent possible, project manager should estimate the magnitude of these releases, either by comparison to dredging projects in similar environments or by performing early actions or pilot studies during the feasibility study. However, at present, no fully verified empirical or predictive tools are available to accurately quantify the predicted releases. As research in predicting resuspension and contaminant release associated with dredging progresses, project managers should watch for verified methods to be developed to assist in this estimate. Although the degree of resuspension will be site-specific, recent analyses of field studies and available predictive models of the mass of sediment resuspended range from generally less than one percent of the mass dredged (Hays and Wu 2001, Palermo and Averett 2003) to between 0.5 and 9 percent (NRC 2001). The methods contained in EPA's *Estimating Contaminant Losses from Components of Remediation Alternatives for Contaminated Sediments* (U.S. EPA 1996f), may be useful to estimate the dredgehead component of resuspension losses. To the extent possible, total dredging losses should be estimated on a site-specific basis and considered in the comparison of alternatives during the feasibility study.

If conventional clamshell dredges are unacceptable due to anticipated losses, a special purpose dredge may be considered. These dredges generally resuspend less material than conventional dredges, but associated costs may be greater and they also may not be usable in the presence of significant debris or obstructions. 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). Other factors unrelated to resuspension, such as maneuverability requirements, hydrodynamic conditions, or others listed in Section 6.5.3 above, may also 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, while also ensuring that the project can be implemented in a reasonable time frame. 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 to better understand and control effects of resuspension during future cleanup actions.

Another potential route of contaminant release during dredging or excavation may be the volatilization of contaminants, either near the dredge or excavation site or in a holding facility like a confined disposal facility (CDF) (Chiarenzeli et al. 1998). At sites with high concentrations of volatile contaminants, dredging or excavation may present special challenges for monitoring and operational controls if they may pose a potential risk to workers and the nearby community. This exposure route may be minimized by reducing dredging production rates so that resuspension is minimized. Covering the surface of the water with a physical barrier or an absorbent compound may also 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 of PCBs during dredging to background levels, see *Report on the Effects of the Hot Spot Dredging Operations: New Bedford Harbor Superfund Site, New Bedford, MA* (U.S. EPA 1997e and available at http://www.epa.gov/region01/superfund/sites/newbedford/47203.pdf). In addition, the CDF that the dredged sediment was pumped into was fitted with a plastic cover that effectively reduced 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 dewatering), and other control measure should be taken as needed (e.g., foam).

6.5.6 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, cofferdams, and bubble curtains (U.S. EPA 1994d, Francingues 2003). 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 may increase, at least temporarily, residual contaminant concentrations inside the barrier compared to what it would have been without the barriers.

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 1993c) 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.

Sheet pile containment structures are more likely to provide reliable containment of resuspended sediment than silt screens or curtains, although at significantly higher cost and with different technological limitations. Where water is removed on one side of the wall, project managers should be aware of the hydraulic loading effects of water level variations inside and outside of these walls. Project managers should also be aware of the increased potential for scour to occur around the outside of the containment area, and the resuspension that will occur during placement and removal of these structures. In addition, use of sheet piling may significantly change the carrying capacity of a stream or river and make it temporarily more susceptible to flooding.

Oil booms are appropriate for sediment that may likely release oils or floatables (such as light non-aqueous-phase liquids, or LNAPL) 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 1994d). However, booms do not aid in retaining the soluble portion of floatables [e.g., polycyclic 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. 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 site conditions dictate the need for minimal transport of suspended sediment, for example when dredging hot spots of high contaminant concentration.

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 and 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). At some sites, changes in dredging operating procedures may offer more effective control of resuspension than containment barriers.

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

- Significant currents;
- High winds;
- Changing water levels, such as tidal fluctuation;
- Excessive wave height, including ship wakes; and
- Drifting ice and debris.

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 isolate the dredging operation effectively 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. To be effective, barriers should be deployed around the dredging operation and remain in place until the operation is completed, although it may need to be opened to allow transport of barges in and out of the dredge site, which may release some resuspended contaminants. 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.

6.5.7 Predicting and Minimizing Dredging Residuals

All dredging operations leave behind some residual contamination in sediment. Similar to resuspension releases discussed above, the extent of that residual contamination is dependent on a number of factors including:

- Type and size of dredging equipment;
- Amount of contaminated sediment resuspended by the dredging operation;
- Extent of controls on dispersion of resuspended sediment (e.g., silt curtains, sheet piling);
- Surface and sub-surface contaminant concentrations in the area to be dredged;

- Contaminant concentrations in surrounding un-dredged areas;
- Characteristics of underlying sediment or bedrock (e.g., whether over-dredging is feasible);
- Extent of debris, obstructions or confined operating area (e.g., which may limit effectiveness of dredge operation); and
- Skill of operators.

Project managers should factor a realistic estimate of dredging residuals into their evaluation of alternatives which include dredging. Field results to date for completed environmental dredging pilots and projects suggest that average post-dredging residual contamination levels in the past have often not met desired cleanup levels. However, aside from past experience, there is no commonly accepted method to predict accurately the exact degree of residual contamination likely to result from use of a given dredge type to remove a given sediment type under given site conditions. Additional guidelines are needed in this area and are likely to be developed in the future. Generally, residual concentrations would be expected to be higher where average contaminant concentrations in the sediment are higher. Residual contamination also tends to be higher where over-dredging is not possible and where substantial debris is present in the dredged area. Limitations of site or technology such as these should be factored into the comparison of alternatives and selection of the best risk reduction alternative for the site.

To achieve cleanup levels, additional passes of the dredge may be needed to achieve the desired results. Placement of a thin layer of clean material designed to mix with underlying sediment or the addition of reactive/sorptive materials to surface sediment can also be used to reduce the residual contamination. Project managers should consider developing a contingency remedy if there is sufficient uncertainty concerning the ability to achieve low cleanup levels. Where a contingency remedy involves containment of residuals by in-situ capping, project managers should consider whether containment without dredging may be a more cost-effective solution.

When conducting post-dredging sampling to confirm residual contamination levels, it is important to differentiate samples taken within and outside of the dredged area, and to report both a dredged area residual and a wider residual contaminant concentrations. The former is usually essential for assessing whether dredging is capable of meeting desired results at the site, and the latter is usually essential for assessing contaminant levels to which biota will be exposed at the site overall and in assessing the likelihood of achieving all remedial action objectives.

6.6 TRANSPORT, STAGING, AND DEWATERING

After removal, sediment often is transported to a staging or rehandling area for dewatering (if necessary), and further processing, treatment, 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, staging, or rehandling site. Sediment may then be transported for pretreatment, treatment, and/or ultimate disposal (U.S. EPA 1994d). As noted previously, where possible, project managers should design for as few rehandling operations as possible, in order to decrease risks and cost. Project managers should also consider community concerns regarding these operations (e.g., odor, noise, lighting, and other issues). Health and safety plans should address both workers and community members.

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 reslurried from barges and pumped into nearshore disposal sites by pipeline;

- Barge: A rehandling facility located on shore is a commonly considered option. With a rehandling 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 rehandling facility;

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

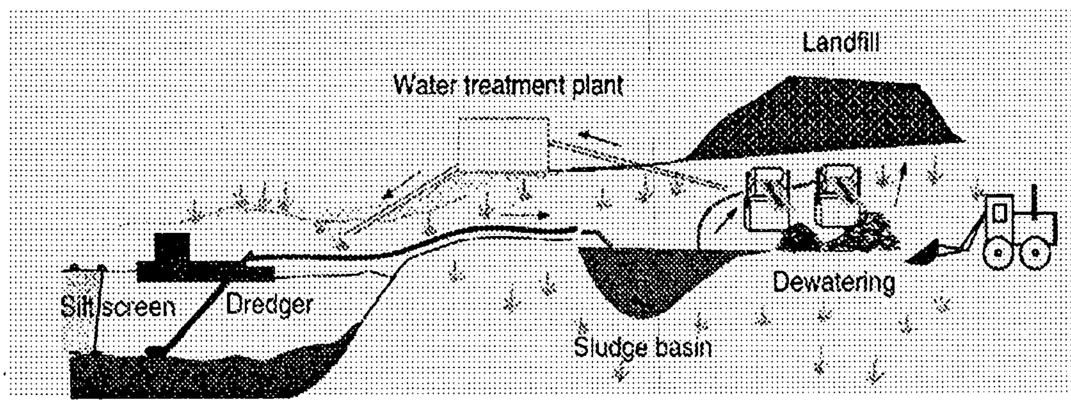
- Railcar: Rail spurs may be constructed to link rehandling/treatment facilities to the rail network. Many licensed landfills have rail links, so long-distance transport by rail is generally an option; and/or

- Truck/Trailer: Dredged material can be rehandled 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. Project managers should consider the compatibility of the dredge with the subsequent transport of the dredged sediment. For example, hydraulic and pneumatic dredges produce contaminated dredged-material slurries that can be transported by pipeline to either a disposal or rehandling site. Mechanical removal methods typically produce dense, contaminated material that is hauled by barge, railcar, truck/trailer, or conveyor systems. The feasibility, costs of transportation, and need for additional equipment are frequently influenced by the scale of the remediation project (Churchward et al. 1981, Turner 1984, U.S. EPA 1994e).

Temporary storage of contaminated sediment may also be necessary in order to dewater it prior to upland disposal or to allow for pretreatment and equalization prior to treatment. For example, a temporary CDF may be designed to store dredged 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 staging (e.g., pumping onto a barge with frequent off-loading) or more permanent disposal (e.g., moving the sediment to a land-based CDF where it may be dewatered and treated). A typical dewatering schematic is shown in Highlight 6-8.

Highlight 6-8: Sample of Dredging Dewatering Process



Depending upon the quality of the water after it is separated from sediment and upon applicable or relevant and appropriate requirements (ARARs), it may be necessary to treat water prior to discharge. Where water treatment is required, it can be a costly segment of the dredging project and should be included in cost estimates for the alternative. Water treatment costs may also affect choices regarding dredging operation and equipment selection, as both can affect the amount of water entrained.

The project manager should consider potential contaminant losses to the water column and atmosphere during transport, dewatering, temporary storage, or treatment. For example, conventional mechanical dredging methods and equipment often rely on gravity dewatering of the sediments on a dredge scow, with drainage water and associated solids flowing into the surrounding water. Project managers should evaluate what engineering controls are necessary and cost-effective, and include these controls in planning and design. Implementation risks, both to workers and to the community, differ significantly between the various transport methods listed above. These risks should be evaluated and included when comparing alternatives. Best management practices for protection of water quality should also be followed.

The risks associated with a temporary storage or staging sites are similar to those associated with CDFs, as discussed in Section 6.8.2. 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.

6.7 SEDIMENT TREATMENT

For the majority of sediments removed from Superfund sites, treatment is not conducted prior to disposal, although pretreatment, such as particle size separation to distinguish between hazardous and non-hazardous waste disposal options, is common. Although EPA prefers treatment for principal threat waste, at present it is not frequently selected for sediment, generally due to concerns related to cost, effectiveness, and/or (for on-site operations) community preferences. However, treatment of sediment is the best option in some circumstances and innovations in ex-situ or in-situ treatment technologies may make treatment a more viable cost-effective option at additional sediment sites in the future. Especially for contaminated sediment that is considered a principal threat waste, project managers should evaluate at least one alternative that includes treatment of the dredged sediment.

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. 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 (NRC 1997). The base of experience for treatment of contaminated sediment is still limited. Each component of a potential treatment train is discussed below.

6.7.1 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's *Assessment and Remediation of Contaminated Sediments (ARCS) Program Remediation Guidance Document* (U.S. EPA 1994d).

6.7.2 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. 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. The following treatment technologies are among those which might be considered for evaluation.

<u>Bioremediation</u>

Generally, bioremediation is the process in which microbiological processes are used to degrade or transform contaminants to less toxic or nontoxic forms. In recent years, it has been demonstrated as a technology for destroying some organic compounds in sediment. The project manager should refer to EPA (1994d), Myers and Bowman (1999), and Myers and Williford (2000) for a summarization of bioremediation technologies and their application under site-specific conditions.

<u>Chemical Treatment</u>

Generally, 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 and colleagues (1990) reviewed several general categories of chemical treatment. Of the categories reviewed, treatments including chelation, dechlorination, and oxidation (of organic compounds) were considered most promising.

<u>Extraction/Washing</u>

Generally, 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 following fractions: 1) particulate solids; 2) water; and 3) concentrated organic contaminants. The concentrated organics are removed from the separator for post-process treatment. Extraction or washing also may generate large volumes of contaminated wastewater that generally must be treated prior to discharge.

Immobilization or Solidification/Stabilization

Generally, 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 1994d). 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). Another form of immobilization, chemical stabilization, minimizes the solubility of metals primarily through the control of pH and alkalinity. Chemical stabilization of organic compounds also may be possible (Barth et al. 2001, Wiles and Barth 1992, Myers and Zappi 1989).

Thermal Treatment

Generally, 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 generally effective for destroying organic contaminants but are also expensive and have significant energy costs. Generally, thermal treatment does not destroy toxic metals.

Particle Size Separation

Generally, particle size separation involves separation of the fine material from the coarse material by physical screening. A site demonstration of the Bergman USA process resulted in the successful separation of less than 45 micron fines from washed coarse material and a humic fraction (U.S. EPA 1994f). As previously noted, 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

Generally, treatment of process effluents means treatment of liquid, gas, or solid residues and 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. Generally 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.

Pilot and full-scale treatment processes have been conducted at a number of sites, although there is limited experience at Superfund sites. Where treatment has been used at Superfund sites, the most common treatment method is immobilization by solidification or stabilization. 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 1993d). Specific applications, limitations, specifications, and efficiencies of many sediment treatment processes are discussed in the ARCS Program's *Remediation Guidance Document* (U.S. EPA 1994d). The NY/NJ

Harbor Project is an example of a large-scale demonstration of a number of dredged decontamination technologies, (see Highlight 6-9.)

Highlight 6-9: NY/NJ Harbor - An Example of 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. The patented washing system has been demonstrated capable of decontaminating sediments containing high quantities of silt and clay.

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 that can be used to produce an architectural tile.

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

Potential sediment treatment technologies will 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

- *EPA National Risk Management Research Laboratory (NRMRL) 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 on CD from the EPA's National Risk Management Research Laboratory in Cincinnati, Ohio, 45268. Contact information may be found at http://www.epa.gov/ORD/NRMRL/treat.htm.

6.7.3 Beneficial Use

Beneficial use may be an appropriate management option for treated or untreated sediment resulting from environmental dredging projects. Significant cost saving may be realized if physical and chemical properties of the sediment allow for beneficial use, especially where disposal options are costly. For example, at Rouge River/Newburgh Lake, Michigan, a Great Lakes Area of Concern, significant cost savings were realized by using lightly contaminated dredged sediment as daily cover at a local sanitary landfill, where it did not pose risk within the landfill boundary. However, beneficial use of dredged or excavated sediment has only been implemented infrequently to date for remedial projects, mainly due to lack of cost-effective uses in most instances. Where beneficial use is considered, the contaminant levels and environmental exposure, including considerations of future land use, should be assessed.

Options for beneficial use may include the following:

- Construction fill;
- Sanitary landfill cover as in the above example;
- Mined lands restoration (e.g., Bark Camp Mine Reclamation Project http://www.dep.state.pa.us/dep/DEPUTATE/MINRES/BAMR/bark_camp/barkhomepage.htm);
- Subgrade cap material or subgrade in a restoration fill project (topped with clean sediment or other fill);
- Building materials (e.g., architectural tile, see Highlight 6-9); and
- Beach nourishment (for a clean sand fraction).

A series of technical notes on beneficial uses of contaminated material has been developed by the USACE (Lee 2000), and the USACE maintains a Web site of beneficial use case studies which is currently available at http://www.wes.army.mil/el/dots/budm/budm.html. 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 addition, Barth and associates evaluated beneficial reuse using several availability tests in an effectiveness protocol (Barth et al. 2001).

In some cases, a CDF (see description in Section 6.8.2) can be integrated with site reuse plans to both reduce environmental risk and simultaneously foster redevelopment in urban areas and brownfields sites. For example, at the Sitcum Waterway cleanup project in Tacoma, Washington, contaminated sediment was placed in a near shore fill in the Milwaukee Waterway, which was then developed into a container terminal. 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 SEDIMENT DISPOSAL

For purposes of this guidance, 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 typically is a major cost and logistical component of any dredging or excavation alternative. The identification of disposal locations can often be the most controversial component of planning and implementing a dredging remedy and therefore should be considered very early in the Feasibility Study.

Contaminated sediment is typically managed in upland sanitary landfills, or hazardous or chemical waste landfills, and less frequently, in CDFs, or contained aquatic disposals (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. As noted below, all disposal options have the potential to create some risk. These risks may result from routine practices (such as worker exposure and physical risks and volatilization), while other risks may result from unintended events, such as transportation accidents and contaminant losses at the disposal site. All potential risks should be considered when comparing alternatives. The ARCS Program's *Remediation Guidance Document* (U.S. EPA 1994d) provides a discussion of the available disposal technologies for sediment, 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.

6.8.1 Sanitary/Hazardous Waste Landfills

Existing commercial, municipal, or on-site sanitary and hazardous waste landfills are the most widely used option for disposal of dredged or excavated sediment and pre-treatment/treatment residuals from environmental dredging and excavation. Landfills also are sometimes constructed on-site for a specific dredging or excavation project. 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.

Due to typical restrictions on liquids in landfills, most sediment should be dewatered 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). As also explained in the section on ARARs in Chapter 2, if sediment containing PCBs are dewatered or physically separated, the dewatered solids and resulting liquids can then be sampled to determine disposal options. Baring the occurrence of other contaminants, if PCBs in the dewatered or separated sediment is below 50 ppm, generally, it can be taken to a municipal sanitary landfill, those greater than 50 ppm generally are taken to a TSCA chemical waste landfill, while those greater than 500 ppm generally are treated.

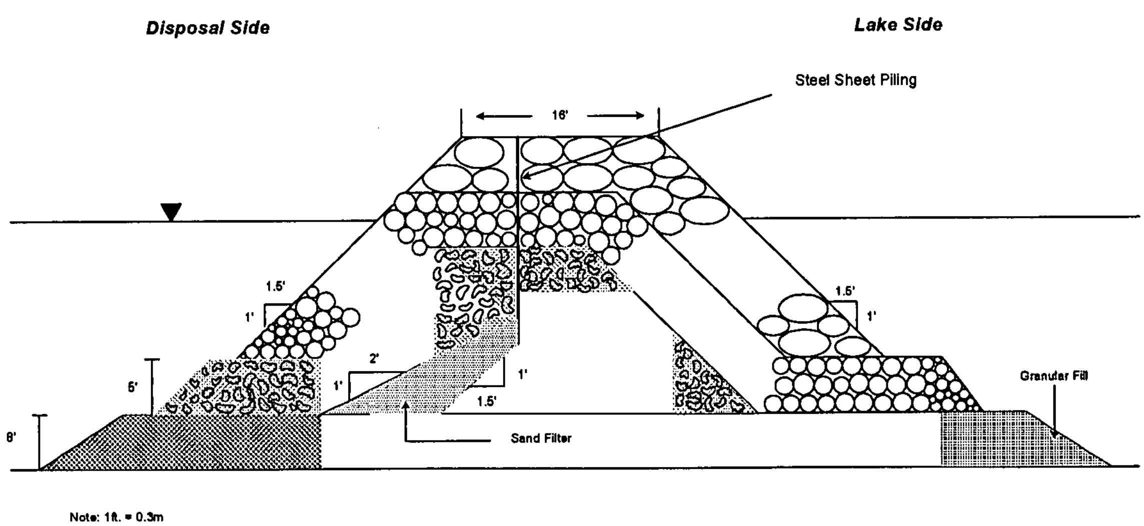
6.8.2 Confined Disposal Facilities

CDFs are engineered structures enclosed by dikes and specifically designed to contain contaminated sediment. With the exception of combined navigational/environmental dredging projects, CDFs have not been widely used for environmental dredging sites, due in part to siting considerations and risk concerns. However, they have been used to meet the needs of specific sites, as have other innovative in-water fill disposal options, for example the filling of a previously used navigational waterway or slip to create new container terminal space (e.g., Hylebos Waterway cleanup and Sitcum Waterway cleanup in Tacoma, Washington). In some cases, new nearshore habitat has also been created as mitigation for the fill.

Under normal operations of a CDF, 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 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 6-10. CDFs may be located either upland (above the water table), near-shore (partially in the water), or completely in the water (island CDFs). There are several documents available containing thorough descriptions, technical considerations, and costs associated with CDFs (U.S. EPA 1996f, U.S. EPA 1994d, U.S. EPA 1991b, and Averett et al. 1990). Additionally, Black and Veatch are describing a history and evaluation of the design and performance of CDFs used for navigational dredging projects in the Great Lakes Basin, including a review and discussion of relevant contaminant loss and contaminant uptake studies (Black and Veatch, in prep).

Highlight 6-10: Cross Section of a Typical Confined Disposal Facility Dike with a Filter Layer



Note: Adapted from US. EPA 1998d

6.8.3 Contained Aquatic Disposal

For purposes of this guidance, contained aquatic disposal is a type of subaqueous capping in which the contaminated dredged sediment is placed into a natural or excavated depression elsewhere in the water body. A related form of disposal, known as level bottom capping, places the dredged sediment on a level bottom elsewhere in the water body, where it is capped. These disposal options are only very rarely considered for environmental dredging projects, largely due to risk concerns. However, there may be instances in which both other disposal options and capping contaminated sediments in-situ are infeasible. In these instances, it may be appropriate to evaluate CADs. The depression used in the case of a CAD should provide lateral containment of the contaminated material, and also should have 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 1994d).

6.8.4 Losses from Disposal Facilities

Evaluation of a new on-site 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, seepage through the bottom and 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 has also developed a contaminant pathway testing and evaluation manual for CDFs (USACE 2003). 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 1994d, 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 may be lost to the water column or air during placement of the contaminated sediment, seepage of pore water during the initial consolidation of the sediment following placement, and by any of the risk pathways common to in-situ caps, such as through erosion of the cap or movement of contaminants through the cap (see Chapter 5, In-Situ Capping). Whatever disposal options are evaluated, the effects of contaminant losses during construction and in the long term should be considered.

Highlight 6-11 presents some general points to remember from this chapter.

Highlight 6-11: Some Key Points to Remember When Considering Dredging and Excavation

- Source control should be generally implemented to prevent re-contamination
- A dredging or excavation alternative should include details concerning all phases of the project, including sediment removal, staging, dewatering, water treatment, sediment transport, and sediment treatment, reuse, or disposal
- Transport and disposal options may be complex and controversial; investigate options early and discuss them with stakeholders
- In predicting risk reduction effects of dredging or excavation of deeply buried contaminants remember that current risk, and therefore current biota exposure, normally is related only to contaminants that are bioaccessible
- Environmental dredging should be conducted to take advantage of methods of operation, and in some cases specialized equipment, that minimize resuspension of sediment and transport of contaminants
- Project managers should conduct a site-specific assessment or pilot study of anticipated sediment resuspension, contaminant release and transport, and its potential ecological impacts, prior to full scale dredging
- Project managers should make realistic, site-specific predictions of residual contamination based on pilot studies or comparable sites. Where over-dredging is not possible, be aware that residual contamination is generally higher than where this practice is possible
- Excavation (conducted after water diversion) often leads to lower levels of residual contamination than dredging (conducted under standing water)
- The use of experienced operators and oversight personnel skilled in environmental 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

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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 many project managers at the remedy selection stage. The program 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 (Title 40 Code of Federal Regulations (40 CFR) §300.430(a)(1)(i)). Superfund remedies must also be cost-effective and use permanent solutions to the maximum extent practicable (Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) §121(b)). The best route to meeting these and other requirements, as well as 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. Although decision making in the face of imperfect knowledge is often necessary, it may be appropriate to postpone a final decision if there is significant doubt about the proposed action's ability to reduce site risks substantially in light of the potential magnitude of costs associated with addressing certain sediment sites.

This guidance addresses many considerations and uncertainties in the context of the Superfund program's blueprint, the National Oil and Hazardous Substances Pollution Contingency Plan (NCP).

Consistent with the 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* (U.S. EPA 2002a), included in this guidance as Appendix A, 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 remedy for contaminated sediment should be based on a careful consideration of the advantages and limitations of available approaches and a balancing of tradeoffs among alternatives. This and other risk management principles that apply at the remedy selection stage are discussed further in Section 7.6, Conclusions.

EPA's *Rules of Thumb for Superfund Remedy Selection* (U.S. EPA 1997c, also referred to as the "Rule of Thumb Guidance") 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. In addition, this guidance discusses how remedy selection may also be applicable to the Resource Conservation and Recovery Act (RCRA) Corrective Action Program. For more information on the two cleanup programs, the project manager should refer to Office of Solid Waste and Emergency Response (OSWER) Directive 9200.0-25 *Coordination Between RCRA Corrective Action and Closure and CERCLA Site Activities* (U.S. EPA 1996g).

Decisions regarding remedy selection should also consider pertinent recommendations from stakeholders, which frequently include the local community, local government, states, tribes, and responsible parties. Remediation may significantly impact day-to-day activities of residents and recreation-seekers, and operations of commercial establishments near the water body for extended periods. Stakeholders should be involved when designing and scheduling remedial operations, not just during the remedy selection process. Documenting and communicating how and why remedy decisions are made are very important tasks at sediment sites. For guidance on documenting remedy decisions under 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 provides 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 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 CERCLA §121, as well as technical and policy considerations that have proven to be important for selecting among remedial alternatives. The nine criteria analysis is comprised of the following two steps: 1) an evaluation of all alternatives 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 limitations). 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, use 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.

The NCP provides that each remedial action selected shall be cost-effective, provided that it first satisfies the threshold criteria (40 CFR 300.430(f)(ii)(D)). Cost-effectiveness is determined by evaluating three of the five balancing criteria: 1) long-term effectiveness and permanence; 2) reduction of toxicity, mobility, or volume of hazardous substances through treatment; and 3) short-term effectiveness. A remedy typically is considered cost effective when its cost is proportional to its overall effectiveness. As described in the Preamble to the NCP, more than one alternative may be considered cost-effective (55 *Federal Register* (*FR*) 8728, March 8, 1990). The relationship between overall effectiveness and cost is examined across all alternatives to identify which options afford effectiveness proportional to their cost. The evaluation of an alternative's cost effectiveness usually is concerned with the reasonableness of the relationship between the effectiveness afforded by each alternative and its costs when compared to other available options (U.S. EPA 1999a). For some complex sediment sites, there may be a high degree of uncertainty about the predicted effectiveness of various remedial alternatives. Where this is the case, it is especially important to identify and factor that uncertainty into site decisions.

The NCP lists six "expectations" that EPA generally considers in developing appropriate remedial alternatives at Superfund sites (40 CFR §300.430(a)(1)(iii)). Highlight 7-1 discusses how the six expectations may be relevant for sites with contaminated sediments. Generally, the expectations are addressed by seeking the best balance of trade-offs among the alternatives evaluated.

Highlight 7-1: NCP Remedy Expectations and Their Potential Application to Contaminated Sediment
The EPA expects to use treatment to address the principal threats posed by a site, wherever practicable: • In general, wastes, including contaminated sediment, may be considered a principal threat where toxicity and mobility combine to pose a potential human health risk of 10^{-3} or greater for carcinogens (U.S. EPA 1991c). For these areas, project managers should evaluate an alternative that includes treatment. However, the practicability of treatment, and whether a treatment alternative should be selected, should be evaluated against the NCPs nine remedy selection criteria. Based on available technology, treatment is not considered practicable at most sediment sites
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 for every sediment site that includes low-level threat waste. Where a containment alternative is clearly not appropriate for a detailed evaluation, project managers should evaluate ex-situ containment (i.e., disposal without treatment). It should be recognized that in-situ containment can also be effective for principal threat wastes, where that approach represents the best balance of the NCP nine remedy selection criteria
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 that combine various approaches for different parts of the site. For a broader discussion on this topic, refer to Chapter 3, Section 3.1.1, Alternatives that Combine Approaches
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 (e.g., dam or breakwater maintenance) are frequently a part of sediment alternatives, especially where contaminated sediment is left in place, or where remedial goals in fish tissue cannot be met for some time. See Chapter 3, Section 3.6, 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 may result in less cost and performance data, frequently due to limited field application. Additional cost and performance data may be needed for many sediment remedies, and field demonstrations of new techniques and approaches especially may be needed, including both innovative in-situ and ex-situ technologies. Although most innovations for sediment remedies are currently in the research phase, as they become available, RPMs should consider using them

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 surface water contamination. Where this is the case, ground water migration prevention may be very important to a successful sediment cleanup and to protect benthic biota. Ground water restoration may also be needed in order to return the ground water to a beneficial use

7.2 CONSIDERING REMEDIES

If the baseline risk assessment determines that contaminated sediment presents an unacceptable risk to human health or the environment, remedial alternatives should be developed to reduce those risks to acceptable levels. As discussed in Chapter 3, Section 3.1, Developing Remedial Alternatives for Sediment, due to the limited number of approaches available for contaminated sediment, generally, project managers should evaluate each of the three major approaches: monitored natural recovery (MNR), in-situ capping, and removal through dredging or excavation, at every sediment site where they might 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. 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 choices between areas of the site and how they are best suited to particular cleanup methods, rather than a simple one-size-fits-all choice between approaches for the entire site.

Project managers should keep in mind that deeper contaminated sediment that is not currently bioavailable or bioaccessible, and that analyses have shown to be stable to a reasonable degree, do not necessarily contribute to site risks. The decision whether or not to leave buried contaminated sediment in place should include an analysis of several factors, including the potential for erosion due to natural or anthropogenic forces, and the effectiveness of any institutional controls to limit disturbance. In some cases, the most appropriate approach may be long-term monitoring, with contingency actions, if necessary.

To assist project managers in evaluating cleanup options, two summary highlights are presented below. They are not requirements or expectations for the use of the three approaches.

Highlight 7-2 provides general site, sediment, and contaminant characteristics that are especially conducive to each of the three common sediment approaches. This highlight is intended as a general tool for project managers as they look more closely at particular approaches when most of these characteristics are present. It is important to remain flexible when evaluating sediment alternatives and consider approaches that at first may not appear most appropriate for a given environment. When an approach is selected for a site which has one or more site characteristics or conditions that appear problematic, 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: Some Site Conditions Especially Conducive to Particular Remedial Approaches for Contaminated Sediment

Characteristics	Monitored Natural Recovery	In-situ Capping	Dredging/Excavation
General Site Characteristics	Risk is low to moderate Anticipated land uses or new structures are not incompatible with natural recovery Natural recovery processes have a reasonable degree of certainty to continue at rates which will contain, destroy, or reduce the bioavailability or toxicity of contaminants within an acceptable time frame	Risk is moderate to high Suitable types and quantities of cap material are readily available Anticipated infrastructure needs (e.g., piers, pilings, buried cables) are compatible with cap Water depth is adequate to accommodate cap with anticipated uses (e.g., navigation, flood control) Incidence of cap-disrupting human behavior, such as large boat anchoring, is low or controllable	Risk is high Suitable disposal sites are available and nearby Suitable area is available for staging and handling of dredged material Existing shoreline areas and infrastructure (e.g., piers, pilings, buried cables) can accommodate dredging or excavation needs Navigational dredging is scheduled or planned Water depth is adequate to accommodate dredge but not so great as to be infeasible; or excavation in the dry is feasible Maneuverability and access not unduly impeded by piers, pilings, or other structures
Human and Ecological Environment	Expected human exposure is low and/or reasonably controlled by institutional controls Site includes sensitive, unique environments that could be irreversibly damaged by capping or dredging	Expected human exposure is substantial and not well-controlled by institutional controls Long-term risk reduction outweighs habitat disruption, and/or habitat improvements are provided by the cap	Expected human exposure is substantial and not well-controlled by institutional controls Long-term risk reduction of sediment removal outweighs sediment disturbance and habitat disruption
Hydrodynamic Conditions	Sediment bed is reasonably stable and likely to remain so	Hydrodynamic conditions (e.g., floods, ice scour) are not likely to compromise cap or can be accommodated in design Rates of ground water flow in cap area are low and not likely to create unacceptable contaminant releases	Water diversion is practical, or current velocity is low or can be minimized, to reduce resuspension and downstream transport during dredging

Characteristics	Monitored Natural Recovery	In-situ Capping	Dredging/Excavation
Sediment Characteristics	Sediment is resistant to resuspension, e.g., cohesive or well-armored sediment	Sediment has sufficient strength to support cap (e.g., has high density/low water content)	Contaminated sediment is underlain by clean sediment (so that over-dredging is feasible) Sediment contains low incidence of debris (e.g., logs, boulders, scrap material) or is amenable to effective debris removal prior to dredging or excavation
Contaminant Characteristics	Contaminant concentrations in biota and in the biologically active zone of sediment are moving towards risk-based goals on their own Contaminants already readily biodegrade or transform to lower toxicity forms Contaminant concentrations are low and cover diffuse areas Contaminants have low ability to bioaccumulate	Contaminants have low rates of flux through cap Contamination covers contiguous areas (e.g., to simplify capping)	High contaminant concentrations cover discrete areas Contaminants are highly correlated with sediment grain size (i.e., to facilitate separation and minimize disposal costs)

Highlight 7-3 may assist project managers in evaluating cleanup options. For convenience these comparisons are organized around the NCP's nine remedy selection criteria. This highlight is intended only to 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 the ROD Guidance (U.S. EPA 1999a) and EPA's *Guidance for Conducting Remedial Investigations and Feasibility Studies under CERCLA* (U.S. EPA 1988a, commonly referred to as the "RI/FS Guidance"). The example criterion components column used in Highlight 7-3 below are adapted from the RI/FS Guidance and are intended only as examples of some of the components that may be considered when evaluating each remedy selection criterion.

Highlight 7-3: Examples of Some Key Differences Between Remedial Approaches for Contaminated Sediment				
NCP Remedy Selection Criteria	**Example Criterion Components**	**Monitored Natural Recovery**	**In-Situ Capping**	**Dredging/Excavation**
Overall Protective-ness	N/A	Relies upon natural processes for protection May provide low level of short-term protection, but may provide potentially acceptable long-term protection	Relies upon adequate cap placement and maintenance for protection May provide moderate to high level of protection, depending upon areal extent and design of cap	Relies upon effective removal and low residual levels for protection May provide moderate to high level of protection, depending on residual. May not be as protective in the short term as capping (due to resuspension and residuals) but may provide high long-term protection in areas with acceptable residuals or in areas favorable to additional natural recovery
Compliance with Applicable or Relevant and Appropriate Require-ments (ARARs)	N/A	Generally, only chemical-specific ARARs apply (these would also apply to other approaches)	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 See Chapter 3, Section 3.3 for additional example 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 See Chapter 3, Section 3.3, for additional example ARARs

NCP Remedy Selection Criteria	Example Criterion Components	Monitored Natural Recovery	In-Situ Capping	Dredging/Excavation
Long-Term Effective-ness and Permanence	**Magnitude of Risk Reduction and Residual Risks**	May provide low to high level of risk reduction and residual risk, depending on processes being relied upon and site-specific characteristics that might prevent long-term isolation or destruction of contaminants	May provide moderate to high level of risk reduction and 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	May provide moderate to high level of risk reduction and low to moderate residual risk, depending on effectiveness of dredging and use of backfill material May provide low (upland) to moderate (in-water) residual risk for sediments and treatment residuals contained at controlled disposal sites
	Adequacy and Reliability of Controls for Residual Risk	May provide low control, but potentially acceptable, depending on processes being relied upon and site-specific conditions May provide moderate ability to control physical disturbance due to human activity via institutional controls; may provide little ability to control physical disturbance due to natural forces May provide no ability to control advection and diffusion of contaminants through overlying cleaner sediment, where this is of concern	May provide moderate to high control, depending on cap stability and contaminant migration through cap May provide 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 May provide some ability to control effects of advective flow and diffusion rates through cap design	May provide high control due to removal of contaminants, if residual contamination is below cleanup levels May provide high control if residual risk from contaminants remaining in place is similar to MNR May leave residual risks at upland disposal sites that are easily controlled; at in-water sites control can be more complex
	Need for Five-Year Reviews	Five-year reviews probably would be required for most sites due to waste left in place and possible continuing need for use restrictions	Five-year reviews probably would be required for most sites due to waste left in place and possible continuing need for use restrictions	Five-year review generally required for dredged site, at least until cleanup levels and remedial action objectives are met and site is available for unrestricted use Reviews 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	**N/A**	No treatment is involved	Typically, no treatment is involved Research is ongoing concerning the combination of innovative in-situ treatment components within a cap	Most often, no sediment treatment is involved. Sediment can be treated if cost-effective; stabilization is most common form Potential exists for beneficial reuse of dredged sediment Water treatment can reduce TMV of contaminants where significant quantities of toxics are removed from the water
Short-Term Effective-ness	**Environ-mental Impacts During Remedy Implemen-tation**	No additional impact to bottom-dwelling ecological community from the remedy itself Impacts of contaminated sediment on environment continue but should gradually decline until protection is achieved	May provide high impact to bottom habitat in area of cap; potential for re-colonization is site specific. Cap design can facilitate re-colonization in some cases May provide low potential for impacts from releases to the environment during cap placement and initial consolidation	May provide high impact to bottom habitat in dredged area; potential for re-colonization generally good, but site specific. Backfill design can facilitate re-colonization in some cases There could be moderate potential for impacts to biota from release during dredging; releases partially controllable by physical barriers and by selection and operation of dredging equipment

NCP Remedy Selection Criteria	Example Criterion Components	Monitored Natural Recovery	In-Situ Capping	Dredging/Excavation
Short-Term Effective-ness (cont.)	**Community and Worker Protection During Remedy Implementa-tion**	There should be no additional health impacts to community from the remedy itself; pre-existing impacts will continue but should gradually decline until protection is achieved May provide moderate ability to control community impacts from fish/shellfish ingestion and, where applicable, direct contact with contaminated sediment, through consumption advisories and use restrictions There should be minimal impacts on workers from monitoring activities There should be no additional local community disruption beyond existing condition	There should be low potential for health 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 Staging needs for cap placement may disrupt local community during placement	There should be low to moderate potential for health impacts to community and workers from contaminant release during dredging, staging, 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 Dredged materials and water handling or treatment needs may disrupt local community
	Time Until Protection Is Achieved	Generally, longest time to achieve protection, depending on rates of natural processes and bioavailability of the contaminants Time to achieve protection is frequently highly uncertain	Generally, shortest time to achieve protection Complete biota recovery could take several years Generally, most certainty concerning time to achieve protection	Time to achieve protection varies significantly depending on the size and complexity of the project Complete biota recovery could take several years Time frame generally more uncertain than for capping due to difficulty of predicting 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 Where site-specific conditions allow, should be relatively easy to implement a different remedy if MNR is not effective Methods for monitoring sediment cleanup levels are relatively well established	Cap placement methods are generally well-established; ability to construct a cap depends on a number of factors including, 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 site-specific conditions, and degree of monitoring and maintenance Relatively easy to repair cap in case of localized erosion or disruption, but can be difficult or costly to implement sediment removal if cap is not effective Methods for monitoring cap integrity and contaminant migration within cap are relatively well established	Dredging and excavation methods are generally well-established; technical feasibility of dredging depends mainly on accessibility, extent of debris and obstructions, and the ability to over-dredge Disposal in upland landfills is a well-established technique; in-water disposal methods are less well-established and may require greater monitoring; technical feasibility generally depends on distance to the disposal site, ease of dewatering, and slope and geotechnical stability of disposal site Reliability should be higher for excavation than dredging; reliability of dredging depends on site-specific conditions and skill of equipment operators Transport of sediment to disposal site may present costly technical and/or public policy challenges Where site-specific conditions allow, should be relatively easy to re-dredge, cap or implement MNR if remedy is not effective, but cost consequences can be high 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
Implement-ability (cont.)	**Administra-tive Feasibility**	State-regulated institutional controls, including fish consumption advisories where contaminants are bioaccumulative, 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 long-term controls on waterway use Where contaminants are bioaccumulative, fish consumption advisories frequently needed for a period of years to decades. Length of time generally depends on residual contamination outside of capped area	Dredging and excavation plan should be coordinated with other agencies to ensure compatibility with other waterway uses and habitat concerns during the removal operation Fish consumption advisories frequently needed for a period of years to decades, where contaminants are bioaccumulative. Length of time generally depends on residual contamination within and outside of dredged area 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 if not available locally Specialized cap placement equipment may be needed in some environments, but are generally available Availability of suitable cap material staging areas is critical and can be problematic for some sites (e.g., some urban areas)	Environmental dredging and excavation equipment is generally available, although availability may be a problem for large projects. Specialized equipment may need to be constructed for special situations Availability of suitable dredged material staging, separation, and, where required, water treatment capacity is critical and can be problematic for some sites (e.g., some urban areas) Availability of a suitable disposal facility with adequate capacity is critical and can be problematic for some sites (e.g., where local disposal is infeasible or high volumes are involved)

NCP Remedy Selection Criteria	Example Criterion Components	Monitored Natural Recovery	In-Situ Capping	Dredging/Excavation
Cost	**N/A**	Generally, no capital cost Long-term monitoring costs typically continue until cleanup levels and remedial action objectives are met. Length of long-term monitoring is generally dependent on assurance of sediment stability	Capital costs generally higher than MNR and lower than dredging/ excavation Long-term maintenance and monitoring costs generally higher than MNR and dredging/ excavation Long-term monitoring costs typically continue until cleanup levels and remedial action objectives are met. Length of long-term operation and maintenance (O&M) period dependent on time necessary to verify long-term stability of cap and lack of significant contaminant fluxes through cap	Capital costs generally higher than MNR or capping and more difficult to estimate accurately Long-term monitoring costs generally lower than MNR and capping Long-term monitoring costs typically continue until cleanup levels and remedial action objectives are met. Length of long-term O&M period dependent on extent of residual contamination and use of on-site disposal

NCP Remedy Selection Criteria	Example Criterion Components	Monitored Natural Recovery	In-Situ Capping	Dredging/Excavation
State Acceptance and Community Acceptance	**N/A**	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 objections to a "do nothing" remedy, leaving contamination in place, possible spread of contaminants during flooding or other disruption; uncertainties of predicting rates of natural burial; and a potentially lengthy period of fish consumption advisories	Commonly identified benefits include use of an active remedy with no disposal issues, generally moderate cost, and potentially faster biota recovery than MNR or dredging due to rapid placement of exposure barrier Commonly identified concerns include leaving contamination in place, temporary disruption to local residents and businesses, increased truck, rail or barge traffic during capping; temporarily reduced recreational access; potentially long-term reduction of navigational waterway access; reduced access to buried utilities, possible long-term anchoring or other waterway use restrictions, and costs to potentially responsible parties (PRPs) and/or state during O&M	Commonly identified benefits include removing contaminants from waterway, possible treatment of contaminants, faster biota recovery than MNR, increased/restored navigational depth, decreased flooding, and lack of use limitations after completion Commonly identified concerns include temporary disruption to local residents and businesses, contaminant releases during dredging, temporary reduction of recreational and navigational waterway access during dredging; siting of and risks from local disposal facilities; increased truck, rail, or barge traffic during dredging, and a period of fish consumption advisories, generally longer than for capping but shorter than for MNR

7.3 COMPARING NET RISK REDUCTION

Each approach to managing contaminated sediment has its own potential uncertainties and relative risks. The concept of comparative net risk reduction was discussed by the National Academy of Sciences Committee of the NRC as a method to ensure that all positive and negative aspects of each sediment management approach were appropriately considered at contaminated sediment sites. The Committee states that (NRC 2001):

> All remediation technologies have advantages and disadvantages when applied at a particular site, and it is critical to the risk management that these be identified individually and as completely as possible for each site. For example, managing risks from contaminated sediment in the aqueous environment might result in the creation of additional risks in both aquatic and terrestrial environments... Removal of contaminated materials can adversely impact existing ecosystems and can remobilize contaminants,

> resulting in additional risks to humans and the environment. Thus, management decisions at a contaminated sediment site should be based on the relative risks of each alternative management action... For a site, it is important to consider "overall" or "net" risk in addition to specific risks.

Project managers are encouraged to use the concept of comparing net risk reduction between alternatives as part of their decision-making process for contaminated sediment sites, within the overall framework of the NCP remedy selection criteria. Consideration should be given not only to risk reduction associated with reduced human and ecological exposure to contaminants, but also to risks introduced by implementing the alternatives. The magnitude of risk associated with each alternative generally is extremely site-specific, as is the time frame over which implementation risks may apply to the site. Evaluation of both implementation risk and residual risk are existing important parts of the NCP remedy selection process. By evaluating these two concepts in tandem, additional information may be gained for remedy selection. Highlight 7-4 provides examples of factors that should be evaluated by project managers in this comparative evaluation.

Highlight 7-4: Sample Factors for Comparative Evaluation of Net Risk Reduction

Factors Potentially Reducing Risk

- Reduced exposure to bioavailable/bioaccessible contaminants
- Removal of bioavailable/bioaccessible contaminants
- Removal or containment of buried contaminants that are likely to become bioaccessible

Factors Potentially Continuing or Increasing Risk

For MNR:

- Continued exposure to contaminants already at sediment surface and in food chain
- Potential for undesirable changes in the site's natural processes (e.g., lower sedimentation rate)
- Potential for contaminant exposure due to erosion or human disturbance

For In-Situ Capping:

- Contaminant releases during capping
- Continued exposure to contaminants currently in the food chain
- Other community impacts (e.g., accidents, noise, residential or commercial disruption)
- Worker risk during transport of cap materials and cap placement
- Releases from contaminants remaining outside of capped area
- Disruption of benthic community

For Dredging or Excavation:

- Contaminant releases during sediment removal, transport, or disposal
- Continued exposure to contaminants currently in the food chain
- Other community impacts (e.g., accidents, noise, residential or commercial disruption)
- Worker risk during sediment removal and handling
- Residual contamination following sediment removal
- Releases from contaminants remaining outside dredged/excavated area
- Disruption of benthic community

7.4 CONSIDERING INSTITUTIONAL CONTROLS

Institutional controls (ICs) such as fish consumption advisories, fishing bans, ship draft/anchoring/wake controls, or structural maintenance agreements for dams or breakwaters are common parts of sediment remedies (see Chapter 3, Section 3.6, Institutional Controls). 40 CFR §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 2000e). 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. For some federal facilities in the CERCLA program, the IC implementation details (i.e., the specific IC mechanism) should be placed in the ROD. The program manager should refer to EPA's *Guidance on the Resolution of the Post-ROD Dispute* (U.S. EPA 2003d) for guidelines describing and documenting ICs in Federal Facility RODs, Remedial Designs, Remedial Action Workplans, and Federal Facility Agreements/Interagency Agreements.

Reliability and effectiveness of ICs are of particular concern with sediment alternatives, whether they are used alone or in combination with MNR, 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 are unlikely to 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, see Appendix A).

Implementing and overseeing ICs can often be more difficult at sediment sites where control of the water body may involve multiple entities and a single landowner is not present to provide oversight and enforcement. As for other types of sites, at sediment sites, project managers should review ICs during the five-year review. Where a water body 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 water body, 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 2000e). Additional guidance on other aspects of ICs is under development by EPA.

7.5 CONSIDERING NO-ACTION

The ROD Guidance, Section 8.1, 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 however may include monitoring. For example, sediment may pose no current or potential threat to human health or the environment; however, uncertainties concerning that evaluation may 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 an 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, an MNR remedy generally needs more intensive monitoring to show that contaminant concentrations are being reduced by anticipated mechanisms at the predicted rates.

7.6 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), 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 evaluate each of the three major remedies (i.e., MNR, in-situ capping, and removal through dredging or excavation) at every sediment site at which they might be appropriate.

Controlling any continuing sources of contaminants is an important factor for any sediment remedy (U.S. EPA 2002a). Where source control is uncertain, cannot be achieved, or is outside the scope of the remedial action, project managers should consider the potential for re-contamination and factor that potential into the remedy selection process and into the long-term monitoring plan for the site. 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; in such situations, careful consideration should be given as to whether the uncontrolled sources will cause the early action to be ineffective.

At many sites, but especially at large sites, the project manager should consider a combination of sediment approaches 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 water body (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 erosion or contaminant transport is a potential concern. Typically, it is not sufficient to assume that a site as a whole is depositional or erosional. 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 for which no field records are available and for predicting future stability.

The project manager should include in the remedy selection process a clear analysis of the uncertainties involved, including uncertainties concerning the predicted effectiveness of various alternatives and the time frames for achieving cleanup levels and remedial action objectives. 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 cleanup levels and remedial action objectives are met. Sediment remedies should not only include monitoring of surficial sediment immediately following implementation of the action, but also should include long-term monitoring of sediment to assess changes in residual contamination and possible re-contamination, and monitoring of fish or other relevant biota recovery data. Without these data, an assessment of the long-term effectiveness of the remedy is difficult and five-year reviews may be difficult to perform acurately. Additional monitoring data may help not only to assess the site, but to help build a body of knowledge that will decrease uncertainties in decision-making at future sites. Chapter 8, Remedial Action and Long-Term Monitoring, discusses these and other general monitoring considerations for contaminated sediment sites.

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8.0 REMEDIAL ACTION AND LONG-TERM MONITORING

This chapter provides a recommended approach to developing an effective monitoring plan at contaminated sediment sites. A monitoring plan is recommended for all types of sediment remedies, both during and after remedial action in order to evaluate how effective the remedy is in meeting the clean-up levels for the site and the remedial action objectives (RAOs). Monitoring data are also needed to complete the five-year review process at sites where they are required.

For Fund-lead sites that are subject to a state cost share, it may be necessary to distinguish monitoring that is part of the remedial action phase of a remedy from monitoring that is associated with the operation and maintenance (O&M) phase of the remedy. Distinguishing these two is a site-specific decision. Project managers may find it useful to refer to Chapter 3, Section 3.5.2, Operation and Maintenance Costs for suggestions about what types of activities are frequently associated with long-term O&M as distinguished from similar activities that are typically conducted during the remedial action itself.

This chapter is based on a lot of the information in the framework presented in EPA's new "Monitoring Guidance," Office of Solid Waste and Emergency Response (OSWER) Directive 9355.4-28 *Guidance for Monitoring at Hazardous Waste Sites: Framework for Monitoring Plan Development and Implementation* (U.S. EPA 2004e). Project managers are encouraged to consult the Monitoring Guidance for more detailed information about the monitoring framework and how it incorporates EPA's Data Quality Objective (DQO) process. This chapter presents more specific guidance for monitoring of sediment sites; however, many technical details are outside the scope of this chapter. More specific guidance on particular monitoring topics is under development by EPA to assist project managers.

8.1 INTRODUCTION

As described in EPA's Monitoring Guidance (U.S. EPA 2004e), monitoring may be viewed as "the collection and analysis of repeated observations or measurements to evaluate changes in condition and progress toward meeting a management objective." Monitoring should include the collection of field data (i.e., chemical, physical, and/or biological) over a sufficient period of time and frequency to determine the status at a particular point in time and/or trend over a period of time in a particular environmental parameter or characteristic, relative to clearly defined management objectives. The data, methods, and endpoints should be directly related to the RAOs and clean-up levels or goals for the site.

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 baseline site data should have been collected during the remedial investigation or site characterization phase. 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 anticipate expected post-remedy monitoring needs in order to ensure that adequate baseline data are collected to allow comparisons to future data sets. It is important to note that data collection is a dynamic and iterative process.

Project managers should ensure that agreements with contractors or responsible parties concerning remedial design and remedial action include requirements for development of an appropriate monitoring plan. The need for environmental monitoring and how the data will be used to measure performance against clean-up levels and RAOs should be discussed early in the remedial design process. Where institutional controls are part of the remedy, this discussion should also include implementation and, where appropriate, monitoring plans for those controls. Having an early discussion of the monitoring needs as they relate to any engineering performance standards for the particular remedies should allow the project manager sufficient time to resolve logistical or other implementation issues long before the monitoring program is put in place. This discussion during remedial design is also important to determine whether sufficient baseline data have been collected so that both the remedial action and long-term monitoring data can be easily compared to pre-remedy conditions.

At sediment sites, it is also frequently necessary to continue collecting background data from upstream or other reference areas away from the direct influence of the site. This can be especially important where there are uncertainties or potentially changing conditions in background areas, for example, where upstream urban storm water runoff or other possible continuing sources of contamination could impact a remedy.

During the remedial design phase, it is also important to develop a clear understanding of how the monitoring data will be used in the post-remediation decision process, and to ensure that reviews of the monitoring results are conducted in a timely fashion so additional actions can be taken when necessary. In this way, the monitoring data should become a key element of the decision process both in terms of whether the clean-up levels and RAOs are being met and whether additional management actions are warranted.

Although sediment sites vary widely in size and complexity, monitoring typically requires a higher degree of planning at sediment sites than some other types of sites for the following reasons:

- Sediment sites often involve more than one affected medium (e.g., sediment, surface water, biota, and floodplain soils) and multiple contaminants of concern;
- Contaminants at sediment sites are often from a variety of sources, some of which may be outside of the site in question;
- Sediment sites may require monitoring over large areas and in a variety of physical and ecological settings;
- The spatial and temporal variabilities of aquatic sediment and biota can be great; and
- For sites with bioaccumulative contaminants, the relationship between contaminant levels in sediment and biota is frequently complex.

An especially important issue for project managers at large sites is the need to monitor both the effectiveness of individual sediment actions and the ability of achieving overall site RAOs. Frequently, the monitoring parameters at large sites are different. For example, where contaminants from multiple sources are indistinguishable, it may be necessary to find unique parameters for monitoring effectiveness of individual actions. However, it also may be very important to monitor parameters that may be responding to multiple sources or areas of a site, such as some fish species. Key steps for developing and implementing a monitoring plan for sediment sites and some potential monitoring techniques and approaches for sediment remedies are discussed in the remainder of this chapter.

Highlight 8-1 lists some key questions that should be answered before developing a monitoring plan.

Highlight 8-1: Key Questions For Environmental Monitoring
• What is the purpose of the monitoring?
• Are detection limits adequate to meet the purpose of the monitoring?
• Are there likely to be other factors, such as non site-related releases, beside the cleanup that will influence the monitoring results, and are these well understood?
• How often should monitoring take place, and how long should it continue?
• Can the monitoring results be readily placed into searchable, electronic databases and made available to the project team and others?
• Is it clear who is responsible for reviewing the monitoring data and what the triggers are for identifying important trends (positive or negative) in the results?
• What are the most appropriate methods for analyzing the monitoring data? Should these be based on statistical tests or other quantitative analysis? Will there be sufficient data to support these statistical measures?
• Is there agreement on what actions will be taken should the monitoring data indicate the following: 1) the site appears to be improving and the RAOs are likely to be met; or 2) the site does not appear to be improving and the RAOs are not likely to be met?
• How will the results be communicated to the public, and who is responsible for doing this?

8.2 SIX RECOMMENDED STEPS FOR SITE MONITORING

Monitoring is conducted at contaminated sediment sites for a variety of reasons, but primary among them are the following: 1) to assess compliance with design and performance standards (e.g., monitoring sediment resuspension or contaminant release during dredging, measuring cap thickness during and after cap placement); 2) to assess short-term remedy performance and effectiveness in meeting sediment cleanup levels; and/or 3) to evaluate long-term remedy effectiveness in achieving remedial action objectives and in reducing human health and/or environmental risk.

When developing a monitoring plan, it is important to review the record of decision (ROD) and all supporting documents for the site. The ROD generally should contain numerical cleanup levels and/or action levels for sediment and sometimes for other media, and narrative RAOs that relate more directly to reducing risk. These form the basis of the monitoring plan. RODs or other site documents may also contain specific performance criteria or objectives for the short-term and long-term performance of the remedy that should be incorporated into the monitoring plan.

EPA's Monitoring Guidance (U.S. EPA 2004e) describes certain key steps that are recommended in developing and implementing a monitoring plan. These steps are listed in Highlight 8-2 and explained briefly along with sediment site examples in the following text. This guidance was developed for use at all hazardous waste sites, not just Superfund sites, and therefore, uses the term "site activity" to apply to implementation of removal actions, remedial actions, institutional controls, or habitat mitigation.

Highlight 8-2: Recommended Six-Step Process for Developing and Implementing a Monitoring Plan

Step 1. Identify Monitoring Plan Objectives

- Evaluate the site activity
  - Identify the activity objectives
  - Identify the activity endpoints
  - Identify the activity mode of action
- Identify monitoring objectives
- Obtain stakeholder input

Step 2. Develop Monitoring Plan Hypotheses

- Develop monitoring conceptual models
- Develop monitoring hypotheses and questions

Step 3. Formulate Monitoring Decision Rules

Step 4. Design the Monitoring Plan

- Identify data needs
- Determine monitoring plan boundaries
- Identify data collection methods
- Identify data analysis methods
- Finalize the decision rules
- Prepare monitoring quality assurance project plans (QAPPs)

Step 5. Conduct Monitoring Analyses and Characterize Results

- Conduct data collection and analysis
- Evaluate results per the monitoring DQOs (developed in Steps 1-4) and revise data collection and analysis as necessary
- Characterize analytical results and evaluate relative to the decision rules

Step 6. Establish the Management Decision

- Monitoring results support the decision rule for site activity success
  - Conclude the site activity and monitoring
- Monitoring results do not support the decision rule for site activity success but are trending toward support
  - Continue the site activity and monitoring
- Monitoring results do not support the decision rule and are not trending toward support
  - Conduct causative factor and uncertainty analysis
  - Revise site activity and/or monitoring plan and implement

Source: U.S. EPA 2004e

Step 1. Identify Monitoring Plan Objectives

Generally, the most important element in developing an effective monitoring plan is for the project manager to identify clear and specific monitoring objectives. Identifying appropriate monitoring objectives includes examining the intended outcomes of the action and the methods used to achieve that outcome at the site. Inadequate or vague monitoring objectives can lead to uncertainty about why the monitoring is being conducted and how the data will be used. Furthermore, funding for monitoring is often limited. Specifying objectives helps to focus the experimental design and ensure that the most useful information is collected. When identifying monitoring objectives other than those already established in decision or enforcement documents, the project manager should involve participants from all concerned stakeholders [e.g., public, natural resource trustees, state agencies, potentially responsible parties (PRP)].

In general, physical and chemical objectives or endpoints are less costly and more easily measured and interpreted than biological objectives or endpoints, and therefore may be more appropriate where quick decisions are needed. However, the ability of physical and chemical endpoints to quantify changes in ecological risk may be less direct than biological measurements, for example where risk is due to direct contact with multiple contaminants. In this case, toxicity tests or bioassessments may provide an integrated measurement of the cumulative effects of all contaminants and, therefore, can be a better assessment of ecological risks in some situations. Conversely, where the primary risk is due to humans and wildlife eating fish, chemical endpoints in fish may be most appropriate.

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, typically 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. Although no single endpoint can quantify all possible risks, a combination of physical, chemical, and biological endpoints usually provides the best overall approach for measuring risk reduction.

> **Example:** In the ROD, EPA established a remedial action objective of reducing polychlorinated biphenyl (PCB) concentrations in fish tissue to levels that would eliminate the need for a fish consumption advisory for PCBs (for this site, 0.05 ppm). To achieve this objective, EPA selected a cleanup level of 0.5 ppm total PCBs in sediment. The short-term objective of the monitoring program is to monitor PCB concentrations in sediment until the cleanup level is met and the long-term objective of the monitoring program is to monitor PCB concentrations in fish tissue until the remedial action objective is met.

Step 2. Develop Monitoring Plan Hypotheses

Typically, monitoring hypotheses represent statements and/or questions about the relationship between a site activity, such as sediment remediation and one or more expected outcomes (U.S. EPA 2004e). The development of the monitoring hypotheses is analogous to the problem formulation step (Step 1) of the DQO process (U.S. EPA 2000a). The monitoring hypothesis may be generally stated as

"The site activity has been successful in reaching its stated goals and objectives," or in question form, as "Has the site activity reached its stated goals and objectives"?

Example: Has the PCB concentration in sediment reached the cleanup level of 0.5 ppm? Has the PCB concentration in fish tissue reached the remedial goal of 0.05 ppm?

Step 3. Formulate Monitoring Decision Rules

Once monitoring objectives and hypotheses are agreed upon and stated explicitly, the next step should be to identify specific decision rules that will be used to assess whether the objectives are met. A decision rule normally is an "if... then..." statement that defines the conditions that would cause the decision maker to choose an action. In a monitoring plan, the decision rules should establish criteria for continuing, stopping, or modifying the monitoring or for taking an additional response action. Four main elements of a decision rule usually are: 1)the parameter of interest; 2)the expected outcome of the remedial action; 3)an action level, the basis on which a monitoring decision will be made; and 4) alternative actions, the monitoring decision choices for the specified action (U.S. EPA 2004e).

Another factor the project manager should consider when developing decision rules is the time frame under which they will operate. For example, when dredging highly contaminated sediment, a real-time monitoring program could be established to analyze water samples 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, the time frame should be explicitly stated and understood by all the participants.

Examples: A decision rule could be established to require certain actions if suspended sediment or contaminant concentration in the surface water due to releases from dredging exceed certain criteria. A decision rule could be established to assess whether the sediment cleanup level of 0.5 ppm PCBs has been reached, defined as an average of 0.5 ppm PCBs in each of ten grids over the. A decision rule could be established to assess whether progress is being made toward the remedial action objective of reduced PCB concentrations in fish tissue by establishing an interim goal of achieving two ppm in fish tissue within five years, after which monitoring frequency will be revisited. PCB concentrations in fish species "A" will be measured on a specific frequency (e.g., annually) that is commensurate with the relevant species' uptake and depuration rates.

Step 4. Design the Monitoring Plan

The fourth recommended step for the project manager is to identify the monitoring design for collecting the necessary data. Design considerations include identifying data needs; determining monitoring boundaries (frequency, location, duration); identifying data collection methods; and identifying data analysis methods, including uncertainty analysis. EPA requires that a systematic planning approach be used to develop acceptance or performance criteria for all environmental data collection and use. The Agency's DQO process is a planning approach normally appropriate for sediment sites (U.S. EPA 2000a). Quality assurance project plans (QAPPs) or their equivalent are also needed for environmental data collection and use.

The spatial and temporal aspects of a monitoring plan typically 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. Generally, the more dynamic the conditions, the more frequently sampling is necessary to accurately represent conditions. However, a less costly alternative can be to use data endpoints which respond to cumulative, longer-term conditions, where appropriate.

Selecting a statistical approach to use in evaluating the data is another important aspect of the monitoring program design. Data are sometimes collected in a manner that is incompatible with or insufficient for the statistical tests used to analyze the data. For example, the amount of data required to reliably establish a trend in data typically is significantly more than that required to compare point-in-time data. Especially for critical decisions, project managers should seek expert advice in order to design a sampling program that will yield statistically defensible results. One potential method, power analysis, is described in *Biostatistical Analysis* (Zar 1999).

Another crucial element of developing a monitoring plan is cost. Generally, it is more cost-effective to collect less of the "right" data than it is to collect more of the "wrong" data. Following these key steps to design a monitoring plan should help project managers determine what the "right" data are. Project managers may also find it useful to consider the use of indicator or surrogate parameters that correlate with those of primary interest, as a supplement to primary parameters that are especially costly or problematic to collect.

Finally, this step of monitoring plan development should ensure that there are mechanisms in place for modifying the plan based on new information.

> **Example:** From the remedial investigation data, we know that smallmouth bass spend most of their time in the contaminated area and spawn in late spring. 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 four-year old female bass will be collected in the early spring, before spawning, in each of these areas. A power analysis on baseline data indicated 20 fish would allow the project team to discern a 0.5 ppm or greater change in tissue concentration with 0.25 ppm confidence intervals (90 percent). However, given cost considerations, only ten samples will be analyzed immediately and the other 20 archived for further analyses pending the results.

Step 5. Conduct Monitoring Analyses and Characterize Results

The next recommended step in developing a monitoring plan includes data collection and analysis, evaluating analytical results, and addressing data deviations from the monitoring DQOs. At this point, the project manager should evaluate the data with regard to the monitoring hypotheses, the DQOs, and the monitoring decision rules developed in previous steps. At this step, decision rules should be implemented that may call for continuing, stopping, or modifying the monitoring or for taking additional action at the site monitored.

In addition, the project manager should communicate data and results to the appropriate audiences. 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 of understanding. 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.

> **Example:** At this point, three years of fish tissue data have been collected, analyzed, and validated. The decision criterion for this monitoring objective was to reduce the PCB concentrations in fish tissue to two ppm within five years. The data show that after the third year, fish tissue concentrations have decreased significantly but the averages are still above two ppm; however, the higher levels are restricted to a relatively small area and most fish are below two ppm. The results are summarized and presented to the stakeholders. Due to the declining trend, the decision is made that the monitoring objective is expected to be met within five years and the fourth year monitoring effort can be skipped.

<u>Step 6. Establish the Management Decision</u>

The final step of a monitoring plan should be an extension of Step 5, to evaluate monitoring results and uncertainties and come to a decision regarding any changes in site activities or changes in the monitoring plans that may be appropriate at this time.

> **Example:** Due to the declining trend, the decision is made that the monitoring objective is expected to be met within five years and the fourth year monitoring effort can be skipped.

An outline of the six steps and suggested subparts is shown in Highlight 8-2. 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 guidance (U.S. EPA 2000a) to supplement this outline when preparing a sediment site monitoring program.

8.3 POTENTIAL MONITORING TECHNIQUES

This section provides a brief overview of the types of monitoring techniques and data endpoints that the project manager should consider when developing a monitoring plan. The endpoints to select depend on the requirements in the decision and/or enforcement documents, as well as more general considerations related to the cleanup methods selected and the phase of the operation, as discussed in previous sections. For complex sites, frequently a combination of physical, chemical, and biological methods and a tiered monitoring plan, as described above, is the best approach to determine whether a sediment remedy meets sediment cleanup levels, remedial objectives or goals, and associated performance criteria both during remedial action and in the long term. Monitoring, sampling, and analysis methods are constantly being improved based on research and increased field experience. Project managers should watch for new methods and, where they offer additional accuracy or lower cost but also allow for data to be compared to existing data, consider using them.

Generally, physical and chemical endpoints are easier to measure and interpret than biological endpoints. In the case of human health risk, chemical measurements are most often used to assess risk. In contrast, measurement of the biological community is a direct but often complex measurement for monitoring changes in 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 2001k) and *Managing and Sampling and Analyzing Contaminants in Fish and Shellfish* (U.S. EPA 2000g) for more detailed information.

Biological endpoints (e.g., toxicity tests) typically 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 are designed to 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, typically occur over long periods of time and normally 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 long-term effectiveness of a remedial action in achieving the RAOs.

8.3.1 Physical Measurements

Physical testing at a site may include measurements of erosion and/or deposition of sediment, ground water advective flow, particle size, surface water flow rates, and sediment homogeneity/heterogeneity. Potential types of physical data and their uses 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 resuspended during dredging and during placement of in-situ caps;

- Bathymetry Data: Uses include evaluating post-capping or post-dredging bottom elevations for comparison to design specifications, and evaluating 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 measuring 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 surficial zone and/or deeper sediment), evaluating biodegradation, contaminant partitioning to the pore water, and concentrations of total organic carbon. Potential sampling tools and environmental monitoring methods used in support of chemical measurements include the following:

- *Sediment Grab Samplers:* Uses include collection of samples for 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;

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

- *Seepage Meters:* Uses include measurement of contaminant flux into the water column.

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;

- <u>*Toxicity Testing:*</u> Uses include measurement of acute and long-term lethal or sublethal effects of contaminants on organisms to help establish protective range of remediation goals;

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

- <u>*Caged Fish/Invertebrate Studies:*</u> 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

- <u>*Sediment Profile Camera Studies:*</u> 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.

The interpretation of fish tissue results and their relationship to sediment contaminant levels can be especially complex. Potential complications may relate to questions of home range, lipid content, age, feeding regime, contaminant excretion rates, and other factors. Especially at low contaminant concentrations, these variabilities can make understanding the relationship between trends in sediment and biota concentrations especially difficult.

Fact sheets are under development at EPA concerning biological monitoring at sediment sites, including:

- An approach for using biological measures to evaluate the short-term and long-term remedial effects at Superfund sites; and

- Using bioaccumulation information from biota sediment accumulation factors (BSAFs) and food chain models to access ecological risks and to develop sediment remediation goals.

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 plan will likely include a combination of techniques to measure short and long term success. At many sediment sites, monitoring of source control actions is an important first step.

8.4.1 Monitoring Natural Recovery

Generally, monitoring is an essential component of a remedy that includes monitored natural recovery (MNR), as normally contaminants are left in place without protection from physical or biological disturbances. Monitoring continued effectiveness of source control actions can be especially important at MNR sites. Depending on the quality of existing trend data, MNR remedies may require more intensive monitoring early in the recovery period, which may be relaxed if predicted recovery rates are being attained. Also, there may be a need to collect additional data after an intensive disturbance event.

Monitoring of natural recovery often tests the hypothesis that natural processes are continuing to operate at a rate that is expected to reduce contaminant concentrations in appropriate media such as biota to an acceptable level in a reasonable time frame. Other measures of reduced risk may also be appropriate for a site. In most cases, monitoring involves measuring natural processes indirectly or measuring the effects of those processes. 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 surface sediment and biota; and
- Measures of biota recovery (e.g., sediment toxicity, benthic community size and/or diversity).

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 2001j), Section 3.4, 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.

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 has been disturbed or transported and the extent to which that disturbance has caused a release of contaminants and increased exposure. The project manager should design the monitoring plan to handle the relatively quick turnaround times needed to effectively monitor disruptive events. However, interpretation of these data in terms of increased risk should take into account the length of time organisms may be exposed to higher levels of contaminant concentrations.

The project manager should include periodic comparisons of monitoring data to rates of recovery expected for the site in an MNR monitoring program. Where predictions were based on modeling, the project manager should make monitoring results available to researchers in order to conduct field validation of the model. 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. For example, a contingency for additional evaluation or additional work may be triggered by an increasing or insufficiently decreasing trend in contaminant concentrations in sediment, surface water, or biota at specified locations. Where contingencies for additional work 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.

Following attainment of cleanup levels and remedial action objectives, monitoring may still be needed at some MNR sites. For sites where natural recovery is based on burial with clean sediment, continued monitoring may be necessary in order to assess whether buried contaminants remain buried after an intensive disturbance event. This monitoring should continue until the project team has reasonable confidence in the continued effectiveness of the remedy.

8.4.2 Monitoring In-Situ Capping

Generally, 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, and of cap performance during an initial period. It may also include monitoring of broader remedial action objectives such as recovery of the benthic community or of contaminant levels in fish. Long-term monitoring for capping generally includes continued monitoring of cap performance and maintenance activities, and continued monitoring of remedial action objectives. In some cases (e.g., Fund-lead sites) it may be necessary to distinguish monitoring that is part of remedial action from monitoring that is part of O&M. This should be a site-specific decision. Highlight 8-3 lists sample elements of monitoring an in-situ cap.

As shown in Highlight 8-3, a variety of monitoring equipment and methods can be used for capping projects during both remedial action and long-term monitoring. Decisions about what monitoring to require should be site-specific and also depend on decision and enforcement document requirements. In general, bathymetric surveys to determine cap thickness and stability over time, sediment core chemistry (including surface sediments and upper portion of cap) to confirm physical and chemical isolation and test for recontamination, and some form of biological monitoring are needed for most capping projects. Specialized equipment, such as seepage meters, diffusion samplers (e.g., peepers and semi-permeable membrane devices), sediment profile cameras, sediment traps, or use of caged organisms, may also be useful in some cases.

Construction monitoring for capping normally 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 cores, 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.

Biological monitoring in the initial period following cap construction may include monitoring of the benthic community 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 are also likely to be needed.

Highlight 8-3: Sample Cap Monitoring Phases and Elements

Monitoring Phase	Element	Component	Analysis	Frequency/Location
Cap Construction	Cap material quality and size	Cap material sampling	Physical properties, size	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
	Sediment displacement	Sediment samples	Chemical properties of sediment	Sediment bed near cap boundaries
Cap Performance	Re-colonization	SPC Benthic community analysis	Layer thickness Re-colonization, 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

Long-term monitoring of in-situ capping sites 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 low projected rate and concentration. It is also frequently desirable to include ongoing monitoring for recontamination of the cap surface and non-capped areas 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 a significant 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 effective monitoring of expected disruptive events.

Cap maintenance is generally limited to the repair and replenishment of the erosion protection layer in potentially 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 maintain isolation of the contaminated sediment. These types of management options are usually 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 generally is an essential component of a remedy that includes dredging or excavation. 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. Following dredging or excavation, the residual sediment contamination should also be monitored. Additional monitoring following sediment removal may include monitoring of sediment toxicity or benthic community recovery or, for bioaccumulative contaminants, tissue concentrations in fish or shellfish, as well as continued monitoring of any on-site disposal facilities and monitoring sediment and/or biota for recontamination.

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:

- Surface water monitoring at the dredging site and any in-water disposal sites (e.g., total suspended solids, total and dissolved contaminant concentrations, caged fish toxicity, caged mussel intake);
- Monitoring of dredging/excavation residuals at the sediment surface to determine whether cleanup levels are met;
- 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 disposal of dredged sediment or treatment residuals.

A thorough monitoring plan will normally enable project managers to make design or construction changes in order to ensure that the spread of contamination to uncontaminated areas of the water body, sensitive habitats, or adjacent human populations is minimized during dredging, transport, treatment, or disposal. Depending on the contaminants present and their tendency to volatilize or bioaccumulate, the project manager should consider water, air, and biological sampling in the monitoring plan.

Generally, a monitoring plan for dredging should include collecting data to test the effectiveness of silt curtains, dredge operating practices, and any other measures used to control sediment resuspension or sediment or contaminant transport. 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, although in some cases it may be a appropriate to use a tiered approach with analysis of dissolved compounds triggered by exceedances of threshold criteria for total compounds or for suspended solids. Also, where contaminants may be volatile, project managers should consider including air sampling. 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 baseline data for contaminant concentrations in water and, where appropriate, in air. This should ensure 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 not met.

Following dredging, it is usually essential for project managers to conduct monitoring in order to determine whether cleanup levels in sediment are achieved. Initial sampling should be analyzed rapidly, so that contingency actions, such as additional dredging, excavation, or backfilling, can be implemented quickly if cleanup levels have not been met.

Following sediment removal, it is usually necessary for the project manager to conduct long-term monitoring to ensure that the dredged or excavated area is not re-contaminated by additional sources or by disturbance of any residuals that remain above cleanup levels. Long-term monitoring is usually necessary to provide data to determine whether remedial action objectives are met, and may be necessary for a period of time following remedial action to provide confidence that the objectives will remain met.

If an in-water or upland disposal facility is constructed on-site as part of the remedy, it should also 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 on-site 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 re-vegetation or re-colonization by plant and animal communities, and their potential uptake of contaminants.

Highlight 8-4 lists important points to remember related to monitoring sediment sites.

Highlight 8-4: Some Key Points to Remember About Monitoring Sediment Sites

- A monitoring plan may be important for all types of sediment remedies, both during and following any physical construction, to ensure that exposure pathways and risks have been adequately managed
- The development of monitoring plans should follow a systematic planning process that identifies monitoring objectives, decision criteria, endpoints, and data collection, analysis, and data interpretation 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
- Where background conditions may be changing or where uncertainty exists concerning continuing off-site contaminant contributions to a site, it is likely to be necessary to continue collecting data from upstream or other reference areas for comparison to site monitoring data
- Monitoring needs include both monitoring of construction and operation and monitoring intended to measure whether cleanup levels in sediment and remedial action objectives for biota or other media 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 measurement methods and quick turnaround analysis methods with real-time feedback are especially useful during capping and dredging operations to identify potential problems which may be corrected as the work progresses
- After completion of remedial action, long-term monitoring may be 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 Trustees* (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.

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