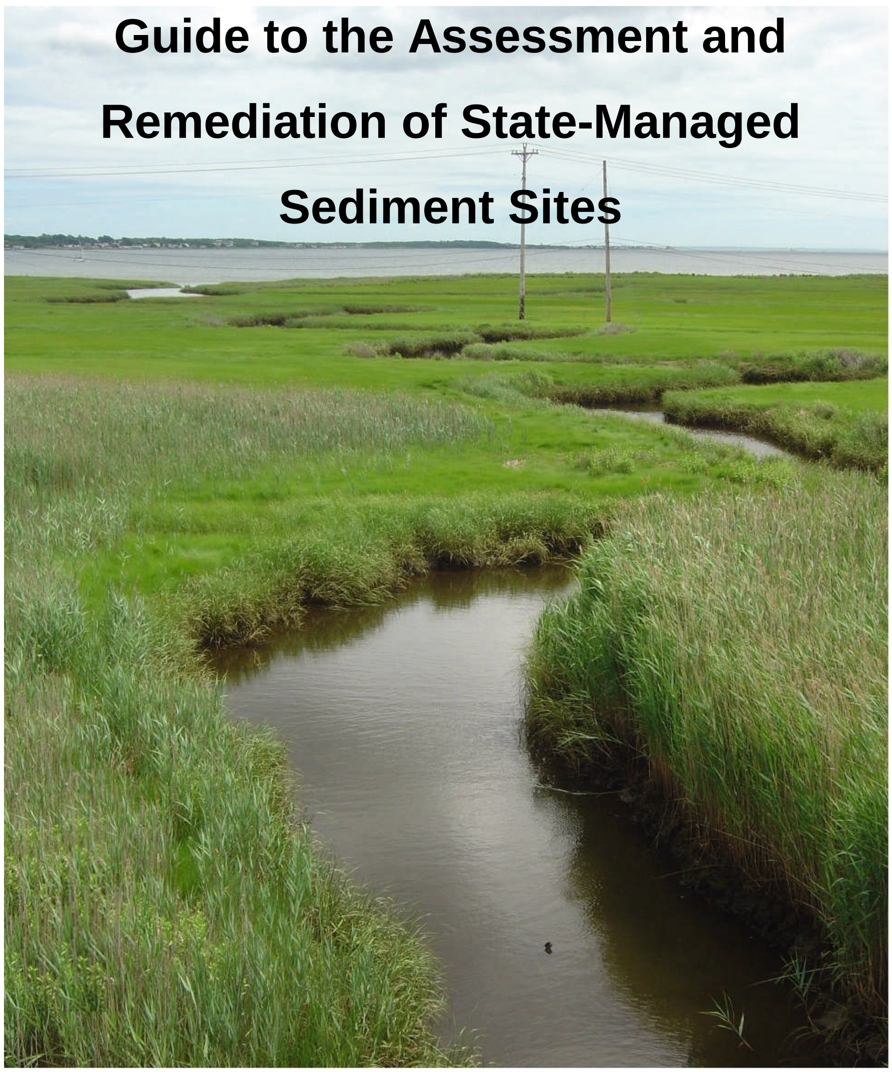
Association of State and Territorial

ASTSWMO

Solid Waste Management Officials

Guide to the Assessment and Remediation of State-Managed Sediment Sites



Sediments Focus Group

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It is important to note that this document does not establish any official opinions, positions, preferences, or recommendations by ASTSWMO or by any individual ASTSWMO member or their respective State or region.

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Abbreviations and Acronyms

ARAR - Applicable or Relevant and Appropriate Requirement
ASTSWMO - Association of State and Territorial Solid Waste Management Officials
ATSDR - Agency for Toxic Substances and Disease Registry
AWQC - Ambient Water Quality Criteria
BAZ - Biologically Active Zone
BSAF - Biota - Sediment Accumulation Factor
CAD - Confined Aquatic Disposal
CCL - Construction Completions List
CDFs - Confined Disposal Facilities
CERCLA - Comprehensive Environmental Response, Compensation, and Liability Act
COE - U.S. Army Corps of Engineers
COPCs - Chemicals of Potential Concern
CPP - Citizen Participation Plan
CWA - Clean Water Act
DDT - Dichlorodiphenyltrichloroethane
DETs - Diffusion Equilibration in Thin Films
EPA - U.S. Environmental Protection Agency
EPCs - Exposure Point Concentration
FERC - Federal Energy Regulatory Commission
HHRA - Human Health Risk Assessment
HI - Hazard Index
HQ - Hazard Quotient
HRS - Hazard Ranking System
IZ - Isolation Zone
MNA - Monitored Natural Attenuation
NCP - National Contingency Plan
NFESC - Naval Facilities Engineering Service Center
NOAA - National Oceanic and Atmospheric Administration
NOAEL - No Observable Adverse Effects Level
NPL - National Priorities List
O&M - Operation and Maintenance
PA/SI - Preliminary Assessment/Site Inspection
PAHs - Polycyclic Aromatic Hydrocarbons
PCBs - Polychlorinated Biphenyls
PCDDs - Polychlorinated Dibenzodioxins
PCDFs - Polychlorinated Dibenzofurans
PEPs - Potential Exposure Pathways
PRPs - Potential Responsible Parties
RAGS - Risk Assessment Guidance for Superfund

RAOs - Response Action Objectives
RCRA - Resource Conservation and Recovery Act
RD/RA - Remedial Design/Remedial Action
RfD - Reference Dose
RI/FS - Remedial Investigation/Feasibility Study
RL - Remediation Level
ROCs - Receptors of Concern
ROD - Record of Decision
RTDF - Remediation Technologies Development Forum
SMDPs - Scientific Management Decision Points
SPAWAR - Space and Naval Warfare Systems Command
SPMDs - Semi-Permeable Membrane Devices
SQC - Sediment Quality Criteria
TEFs - Toxic Equivalency Factors
TMDL - Total Maximum Daily Load
UCL - Upper Confidence Limit
VOCs - Volatile Organic Chemicals

Guide to the Assessment and Remediation of State-Managed Sediment Sites

Section I. Introduction

Recently, groups such as the U.S. Army Corps of Engineers (COE) (Ref. I.1), COE Center for Contaminated Sediments (Ref. I.2), U.S. Environmental Protection Agency (EPA) (Ref. I.3), and the Sediment Management Work Group (Ref. I.4), Remediation Technologies Development Forum (RTDF) (Ref. I.5), SedWeb (Ref. I.6) have completed reference and guidance materials or have web sites on sediment site issues. Much of the focus of these groups has been directed at larger, complex sites, such as Federal Superfund Sites. The Association of State and Territorial Solid Waste Management Officials (ASTSWMO) Sediments Focus Group has developed this paper which presents issues related to State sediment sites, which are typically smaller than those listed on the National Priorities List (NPL). State sediment sites can offer unique and complex challenges, such as the limited resources of the State remedial programs and smaller, less financially viable responsible parties. Often States have to assess and remediate smaller sediment sites, which can often present the same difficult challenges as larger sites. This requires States to be resourceful and develop creative mechanisms to motivate and cooperatively accomplish cleanup. This resource may also help the States with the issues related to any required post remedial activities, such as Operation and Maintenance, on Superfund Sites.

This paper is designed to provide State remedial project managers with information sources and issues related to sediment assessment and remediation. Because previous work, especially that by the COE and EPA, regarding large sites may be helpful, it will often serve as a starting point for a State program (see Appendix A for a Summary of EPA's Superfund Remediation Process). The intent of this paper is not to repeat work done by others. However, to the extent that previous sediment guidance and reference materials can be helpful, they will be summarized and referenced. Where possible in this paper, references and web pages are hyperlinked for easier access.

Section I.1 What is ASTSWMO?

ASTSWMO (Ref. I.1.1) is an organization supporting the environmental agencies of the States and trust territories. ASTSWMO focuses on the needs of State hazardous waste programs; non-hazardous municipal solid waste and industrial waste programs; recycling, waste minimization, and reduction programs; Superfund and State cleanup programs; waste management and cleanup activities at federal facilities, and underground storage tank and leaking underground storage tank programs. The Association's mission is briefly stated: "To Enhance and Promote Effective State and Territorial Waste Management Programs, and Affect National Waste Management Policies."

The Sediments Focus Group is part of the CERCLA and Brownfields Research Center Subcommittee. The Focus Group's mission is to create opportunities for the States to exchange information and to assist in the development of new approaches for contaminated sediment assessment and remediation, as well as to influence national sediment cleanup guidance and policy.

Section I.2 Challenges of Sediment Sites

Assessment, risk management, and remedial decisions for sediment involve more complex scientific and policy concerns than the traditional soil-based exposure scenario. Contaminated sediment may occur in a wide variety of aquatic environments including rivers, streams, intermittent streams, roadside ditches, wetlands, ponds, lakes, reservoirs, harbors, estuaries, bays, intertidal zones, and oceans. Unlike land-based sites, sediment sites are often complex, large and diverse (e.g., mixed use, numerous sources), particularly where large coastal water bodies are impacted. Since multiple government entities and programs (e.g., CERCLA, RCRA, CWA, TMDL State remediation and wastewater permitting programs, local governments, port authorities) may be involved in data gathering, risk assessment, risk management, and remedial decisions affecting these large sites, effective communication and coordination can be a daunting task. There may also be significant natural resource damages of interest at sediment sites as well as local stakeholder interests (fishermen, environmental and public interest groups). Conversely, at small sediment sites, the State remedial project manager must quantify the magnitude of the problem, often with limited financial resources. Regardless of the size of the site, the State remedial project manager needs to have a thorough understanding of available sediment assessment and remediation guidance, expertise needed for the assessment and remediation, and be able to locate funding sources, and interpret environmental laws.

Sediments are often impacted by a multitude of contaminants and may have a different mix of sources for each chemical of concern. This creates difficulties in tracking sources of contamination, and can also result in ubiquitous, regional "background" levels of anthropogenic contaminants that are difficult to separate from site-specific sources. Contaminants at a site may have been transported long distances from many potential sources, making it particularly difficult to identify contaminant sources. Additionally, natural background chemicals may also be present at relatively high concentrations. Often sources of contaminants may be continuous. Remediation decisions must recognize that sediments may become recontaminated without effective source control. Thus it may be technically impracticable to return impacted sediments to background conditions.

The simple fact that sediments are under water makes their sampling, assessment, and remediation technically challenging and costly. While soils and groundwater are often geographically removed from the receptors to be protected, it is generally unavoidable to affect ecological receptors during a sediment remediation effort. Because sediment remediation activities themselves may harm ecological receptors/habitat, remediation proposals often include a natural recovery option. Risks associated with the exposure of more impacted sediments due to dramatic events (i.e. floods, storm surges) must be integrated into the risk management decisions.

Contaminated sediments have the potential to pose both human and ecological risks. Risks associated with direct toxicity and the bioaccumulative effects of sediment contaminants should be considered. Because multiple communities and trophic levels can be at risk, evaluating ecological risks associated with impacted sediment can be far more complex than an evaluation of human health risks. If a water body is not used for recreation or drinking water and is not a fishery, risks to humans are not assessed. Given the uncertainties involved in assessing ecological risks, and the often-transient nature of wildlife receptor exposure, remediation for the sake of ecologically protective endpoints alone is often a difficult sell. Because the benthic community is in direct contact with sediments and is near the base of the food chain, cleanup targets for this community can be orders of magnitude lower than those in most soil sites. Where this community is the risk driver, communicating the importance of "protecting worms" can be a particular challenge for the risk manager.

For all of these reasons, the costs associated with sediment assessment and cleanup can be significantly over that needed to address the same chemicals in impacted soil and groundwater. Additionally, the benefits associated with a clean "land-based" site are certainly quantifiable from an economic and real estate standpoint. In contrast, assessing the economic benefit of clean sediment can be a much muddier task.

Section I.3 Purpose of the Guidance

Toxic and bioaccumulative chemicals have been known to concentrate at high levels in sediments due to their physical and chemical properties. Many of these chemicals have been banned from use in North America for over 30 years (i.e. DDT and PCBs), yet detection of these chemicals in sediments above human and ecological risk criteria still occurs at the present time. When sediments remain undisturbed, they can act as sinks for these toxic substances, concentrating them. During environmental events (e.g., precipitation, anoxia, storm surges), sediment contaminants are released and become a source of pollution, producing ecological and human health risks as well as economic impacts in some areas.

The EPA has historically provided guidance on the assessment and remediation of contaminated sediments in freshwater ecosystems (see Sections IV and VI), which compiles an abundance of information available on this topic. However, most of this information is directed towards federal lead contaminated sediment sites dealing with larger volumes of sediment, not typical of State managed sediment sites. Further, many impacted sites exist in coastal environments associated with urban industrial areas.

This document is intended to provide States and Trust Territories with information regarding the assessment and remediation of State managed sediment sites. In this sediment paper, state remedial project managers will find the information and tools necessary to effectively assess and select an appropriate remedial action for smaller contaminated sediment sites in which they are responsible for cleanup and/or oversight. These sites are not necessarily addressed by the federal Superfund program.

The State of Washington, for instance, developed cleanup regulations for State managed sites under the authority of a citizen-mandated toxic waste cleanup law called the Model Toxic Control Act (Ref. I.3.1). The regulation for this Act is the Washington Sediment Management Standards (Ref. I.3.2) that establishes sediment quality standards and procedures for controlling sources and conducting site assessment and cleanup of freshwater, low salinity and marine sediment sites in that State. Supporting guidance describes site specific sampling schemes, field sampling protocols, methods of analysis for chemistry and biological effects, etc. which may assist other States in various stages of sediment management at their own sites.

Section I.4 Overview of the Guidance

The paper addresses the following topics, by section. Section II lists general considerations when planning and implementing a sediment remediation project. Funding for sediment assessment and remediation can be an issue at small, State-lead contaminated sediment sites, and this also addressed in Section II. Section III describes guidance and issues related to site characterization and human and ecological risk assessment. Available resources and common assessment issues are presented. Section IV describes the development of remedial goals for sediments. Section V focuses on sediment remediation and monitoring approaches. Various remedial actions, including capping, dredging, and natural attenuation are highlighted. Section VI describes various post-remedial issues, namely performance monitoring and institutional controls.

Section II. General Considerations in Planning and Implementing Sediment Assessment and Remediation Projects

Some of the general steps discussed in this section can be found in U.S. EPA Guidance of Conducting Remedial Investigations and Feasibility Studies Under CERCLA (Ref. II.1), and various State guidance documents for remedial action in the environment (see Section III). Following the CERCLA RI/FS Guidance is an important consideration for seeking cost recovery or if federal funding becomes available in the future. Depending on the scope of the project, it will also be necessary to identify stakeholders, funding sources and other resources available to complete the project.

Section II.1 Steps in Planning and Implementing Sediment Assessment and Remediation Projects

Several steps have been identified for planning a contaminated sediment project that involves multiple stakeholders:

1. Define the problems and clarify goals of the project.
2. Gather information.
3. Develop action alternatives to meet goals.
4. With input of stakeholders, decide on a plan based on a preferred alternative.
5. Define how to measure success.
6. Implement the chosen plan.
7. Evaluate results using defined success benchmarks.
8. If needed repeat from Step 1.

In Step 1, it is essential to identify the appropriate stakeholders (i.e. interested persons, government, business, and environmental organizations) in the beginning of the process in order to gain comprehensive input for defining problems and setting goals. In Step 2, interested stakeholders will provide information critical to developing acceptable alternatives and may recommend gathering additional information. Step 3 is the assembling of an appropriate range of alternatives to meet project goals. In Step 4, stakeholder involvement may be conducted through such measures as the issuance of a Proposed Remedial Action Plan for public comment, and subsequent issuance of a Record of Decision. Keeping stakeholders informed helps build trust and a more productive dialogue when input is needed on major decisions. Concurrently, Step 5 should evaluate the measure of success to meet the project goals. For contaminated sediment sites, this can involve contaminant levels in the various media (i.e. water, sediment and biota) and habitat replacement, as appropriate. Implementing the chosen plan in Step 6 involves designing and constructing the chosen alternative while meeting applicable or relevant and appropriate requirements. Step 7 involves evaluating the measures of success after the chosen alternative has been implemented. In Step 7, the measure of success is evaluated for the project at periodic intervals. If the measures of success fail to meet their projected goals at an appropriate time interval, it could be necessary to repeat these steps.

Important Factors to Consider When Involving Stakeholders

For a typical project to remediate a sediment area of concern, the lead agency might start by identifying known problems in the area, such as historical or current industrial discharges, sample results, loss of diversity of plant or animal life, or loss of human use for water supply or recreation. The lead agency should reach out first for input from its own programs, and then those of other interested government agencies (local, State, or federal), and finally, to the public.

Identifying interested public members through meetings or surveys could elicit comments and concerns from individuals, environmental organizations, industry, sporting clubs, property owners, civic or neighborhood associations, and many others. This input should be used to further focus the goals for remediation of the area of concern. These goals might be to restore habitats, improve water quality and recreation opportunities, or ensure sustainable commerce and industry.

These “kickoff outreach” efforts can be used to form a project-specific contacts list of interested members of the public and other organizations. Those with an especially active interest, and ability to review project deliverables, could form a community advisory team.

Formation of advisory teams is a valuable next step after goal definition. An “internal” or “technical” advisory team would consist of government agencies with a jurisdiction or interest in the project. These might include other States or federal agencies, EPA, COE, the U.S. Fish and Wildlife Service, and others. This technical team would be invited to review and comment on reports prior to their release for public comment.

A “community” advisory team would consist of organizations that could conduct another tier of review and could assist the lead agency in gathering public comments at large on critical reports.

A Citizen Participation Plan (CPP) also known as a Community Relations Plan, should be developed at the beginning of the project once most of the interested parties are identified. Some States require community participation in the remedial process. State regulations and guidance should be consulted. The CPP should include:

- Brief history and background about the site including the area(s) of concern and reason for the project;
- Purpose of the plan, which should solicit community input and provide information though-out the project;

- Timeline of project events and deliverables;
- Associated timeline of major points for communication with the public (e.g. status reports) public review periods, and scheduled public meetings;
- Project contacts for the lead agency including the remedial project manager, a person skilled at human health risk communication and a community relations person;
- Describe means for communicating with the public such as Fact Sheets, E-mail lists, Web Page, Radio, TV, and newspapers;
- Document repositories (local libraries or municipal offices where interested persons can read project documents); and
- List of interested and affected people and organizations, including municipal, State and federal officials. Before listing individuals and non-government organizations, they should be asked if they want to be included in the CCP. However, to protect privacy, mailing and phone lists of private individuals should only be kept by the project manager and/or community relations person.

A CPP offers several advantages to the project manager, to include, a basis for scoping and budgeting public outreach for the project; a record of public participation; and a practical reference for community contacts. The CPP offers the public an overview of the project and documents the times at which they can expect opportunities for input. Early in the project, the written plan allows the public an opportunity to identify inadequacies or omissions in planned outreach. If the remedial process takes a long time, the CPP and any mailing lists should be updated periodically.

Resources

The following resources may be useful when involving stakeholders:

- Managing Lakes and Reservoirs, North American Lake Management Society, Third Ed., 2001. (Ref. II.1.1)
- *Citizen Participation in New York's Hazardous Waste Site Remediation Program: A Guidebook*, New York State Department of Environmental Conservation, June 1998, (Document currently being replaced, check NYDEC website for replacement www.dec.ny.gov.) (Ref. II.1.2)
- Superfund Community Involvement Handbook (Ref. II.1.3)

Section II.2 Identify Funding Sources

Funding is critical to the assessment and remediation of contaminated sediment sites. It is best for State's to identify the Potential Responsible Parties (PRPs) as soon as possible, preferably after site discovery. Project managers should consult with their agency's legal department and/or State's attorney general office to start enforcement. If PRPs are identified and they have the ability to pay, States will typically attempt to negotiate with the PRPs. If successful, the State and PRPs will reach agreement on who will do the work at the site. Sometimes, the PRPs will settle with the State and pay "cash out" for the remedial activities. If negotiations fail, the State has the option of taking the PRPs to court. If the state is successful in the court, the PRPs can be forced to perform or pay for the remedial activities. Project managers should understand that PRP negotiations and court actions could take a long time and be resource intensive for the State.

If PRPs cannot be identified, or negotiations and court actions fail, the State may have the option to use State funds to remediate the site. The State's ability to perform the remediation will depend on the financial resources of the State and the capability of the State's environmental agency.

If the State cannot perform the remedial activities at a sediment site, the State could ask federal government agencies for assistance. Likely sources of potential funding include:

- U.S. Environmental Protection Agency (Ref. I.2.1)
- U.S. Coast Guard National Pollution Fund Center (Ref. II.2.2)
- Office of Surface Mining, Abandoned Mine Land Program (Ref. II.2.3)

Important Factor to Consider
States usually deal with sites not addressed by federal funding on a case by case basis. Internal State programs should decide the best and most appropriate funding mechanism available. When dedicated funding is not available, the State agency may consider requesting funding through the State budget process or other appropriate mechanism.

Section III. Characterization and Ecological and Human Health Risk Assessment

Section III.1 Overview of the Conceptual Site Model and Risk Assessment

When characterizing ecological or human health risks, the first step is building the conceptual site model. For contaminated sediment sites, the remedial project manager will need access to a team of experts, including chemists, geologists, hydrologists, toxicologists, and field biologists, to prepare and review a conceptual site model (Section III.2). The conceptual site model includes the identification of potential chemicals of concern (Section III.4), human and ecological receptors of concern, and potential exposure pathways (Section III.5). The complexity and comprehensiveness of the conceptual site model should be gauged by the contaminants of concern, spatial extent, and degree of sediment contamination. For example, at a "small" site, where the extent of contamination is limited and where the cost of additional study would exceed the cost of remediating to generic screening values (i.e., see Soil Screening Guidance Quick Reference Fact Sheet (Ref. III.1.1), it may be most efficient to limit the assessment to the most exposed receptors of concern (e.g., benthic invertebrates). Once a conceptual site model is prepared, surface water, sediment, or tissue-based ecological and human health protective screening levels can be compared to site conditions (as directed by the conceptual site model). Screening values that should be evaluated include sediment quality criteria (see Section III.3) and risk-based values developed in the human health and ecological risk assessment (see Sections III.6 through III.8).

The objectives and role of the screening and risk assessment process in contaminated sediment site assessments are further outlined in this section. The screening process is iterative. Conservative or protective screening values protective of each ecological or human receptor potentially exposed to sediment contamination are compared to site chemistry data.

Important Factors to Consider When Planning Site Characterization and Risk Assessment

- Build an assessment team.
- Involve all stakeholders, including the natural resource trustee agencies.
- Define the extent of the problem, including identification of contaminants of concern and the spatial extent of contamination.
- Determine resources needed.
- Perform iterative assessments, each building on the findings of the other.
- The conceptual site model, if not appropriately developed, can lead to unnecessary and costly contaminated site assessment and cleanup, or, conversely, under-protective and resource damaging remedial actions (or inaction).

Resources

The following resources may be useful in conducting risk assessments:
Ecological Risk Assessment

- U.S. Army Corps of Engineers (Ref. I.1)
- U.S. Navy Ecological Risk Assessment Guidance and Resources (Ref. III.1.2)
- Oak Ridge Laboratory (Ref. III.1.3)
- Tri-Services Ecological Risk Assessment Workgroup (Ref. III.1.4)
- U.S. EPA Guidelines for Ecological Risk Assessment (Ref. III.1.5)
- U.S. EPA Ecological Risk Assessment for Superfund: Process for Designing and Conducting Ecological Risk Assessments (Ref. III.1.6)
- U.S. EPA Guidance Manual to Support the Assessment of Contaminated Sediments in Freshwater Ecosystems (Ref. III.1.7)
- State of Alaska Ecological Risk Assessment Guidance (Ref. III.1.8)
- State of California Ecological Risk Assessment Guidance (Ref. III.1.9)

- Commonwealth of Massachusetts Risk Assessment Guidance (Ref. III.1.10)
- State of Minnesota Risk Assessment Guidance (Ref. III.1.11)
- State of Oregon Ecological Risk Assessment Guidance (Ref. III.1.12)
- State of Texas Ecological Risk Assessment Guidance (Ref. III.1.13)
- Wisconsin Sediment Risk Assessment Guidance (Ref. III.1.14)

Human Health Risk Assessment

- U.S. EPA Risk Assessment Guidance for Superfund, Vol. 1 Human Health Evaluation Manual (Part A) (Ref. III.1.15)
- U.S. EPA Tools for Human Health Risk Assessment (Ref. III.1.16)
- State of California Human Health Human Risk Assessment (Ref. III.1.17)
- State of Virginia Voluntary Remediation Program Risk Assessment Guidance Home Page (Ref. III.1.18)
- Ohio EPA Property Specific Risk Assessment Procedures (Ref. III.1.19)
- Ohio EPA Phase II Property Assessment for the Voluntary Action Program (Ref. III.1.20)

Other Site Characterization Issues

Groundwater/surface water interaction can be an important factor in designing sediment contamination investigations and corrective actions in shallow freshwater, estuarine and coastal environments. Upward flux of groundwater can cause advective transport of contaminants from contaminated sediments to surface water. Also, a post-remediation sediment surface (e.g. dredged or capped) can be re-contaminated by groundwater plume transport from upland or deeper sediment sources.

Important Factors to Consider

- **Preferential groundwater discharge due to heterogeneity of the aquatic sediments and the underlying geologic units** - Groundwater does not discharge evenly across the bottom of a surface water body, but instead discharges in certain areas preferentially. Factors affecting the location of these high discharge zones may include variations in permeability and porosity, both vertically and horizontally. It is important to identify the areas where groundwater discharges to the surface water in order to fully evaluate sediment contamination variation across the site and to appropriately design the remedy.
- **Seasonal effects on groundwater flux** - In some settings, groundwater flux may vary seasonally as a result of spring thaw, seasonal precipitation patterns, etc. The investigation should factor in consideration of this variability in order to adequately evaluate the impact groundwater flux may have both on contaminant concentrations and final remedy design.
- **Long-term surface water stage changes** - Some water bodies experience significant, long-term changes in water levels. Historic information should be

gathered regarding water levels at the site, and consideration should also be given to foreseeable causes of future water level variations. This information should be factored into the site characterization and final remedy design.

- **Gas production in sediments and ebullition (bubble generation) causing contaminant transport and preferential pathways** - At sites with high organic-content sediments, bacterial activity often generates significant volumes of methane and other gases. Migration of these gases through the sediments can create preferential pathways for contaminant transport, and should be considered when investigating the site. Formation of gases by bacterial decay is often highly dependent on temperature, geochemistry, etc., and may be eliminated as a concern with proper remedy engineering to control for one or more of these factors. Additional information on evaluating and modeling gas production in sediments is available at the following: Gas Production in Sediment Layers (Ref III.1a.1), Contaminated Sediment (Ref III.1a.2), and Gas Enhanced Transportation from Contaminated Sediments at Stryker Bay, Duluth (Ref III.1a.3).
- **Upland sources of contamination transported to sediments by groundwater** - Upland sources may have been the cause of the sediment contamination, or may act as an on-going or future source of contamination to the sediments. This must be evaluated to ensure that a remediated site does not become recontaminated.
- **Tidal, seiche and surge effects on groundwater/surface water flux** - The effects on contaminant migration in sediments caused by relatively rapid and regular water level changes such as tides, seiche, or surge, are not yet well understood. It has been suggested that such water level fluctuations may create a "pumping" effect that causes greater migration of contaminants than would normally be expected. At marine sites, tidal fluctuations may also affect the sediment pore water chemistry as saline and fresh waters mix. At sites with large scale water level variations, their impact on both contaminant migration and final remedial design should be considered.

Potential Biologically Active Zone (BAZ) of Sediments

The BAZ is the upper layer of the sediment in which both plants and benthic organisms are active. It is necessary to understand the site specific BAZ to determine both the depth to investigate potentially contaminated sediments and the thickness of post-remediation sediments that must meet cleanup goals to remain protective for human and ecological receptors.

In addition to toxicity to benthic organisms, aquatic plants can uptake contaminants through their root systems causing direct toxicity, or transferring them up the food chain. Their root systems and root channels can also cause preferential groundwater flux. Similarly, benthic organisms can burrow into contaminants, creating pathways for contaminant migration or transfer up the food chain.

Important Factors to Consider for Potential BAZ Depth Determination

- Sediment substrate type affects the depths to which benthic organisms and aquatic plant roots can penetrate.
- Benthic invertebrate burrowing and bioturbation depths are generally shallow (usually the upper 15 cm), however, most aquatic and benthic communities include some species or individuals that penetrate to deeper depths. This must be evaluated on a site specific basis.
- Crustaceans (such as crayfish, ghost shrimp, etc.), amphibians, and reptiles (such as turtles), may burrow to depths significantly deeper than those reached by benthic invertebrate communities. Again, this must be evaluated on a site specific basis.
- In near shore sediments, burrowing of mammals such as muskrats, beavers, etc., may penetrate to significant depths near banks and shorelines.
- Aquatic vegetation types and rooting depths.
- Surface water light penetration controls the depths of water in which aquatic vegetation will grow and how abundant the vegetation will be.
- Sediment erosion and deposition potential.

Section III.2 Building the Conceptual Site Model

The goal of the conceptual site model is to assess and integrate the chemical, physical, and biological characteristics of a site, including identification of source areas, contaminant fate and transport, chemicals of concern, receptors of concern, and potential exposure pathways. The presence of a contaminant in sediments does not necessarily indicate there are significant ecological or human health risks to warrant a remedial action. The U.S.EPA Contaminated Sediment Guidance for Hazardous Waste Sites (Ref III.2.1), U.S. EPA Sediment Assessment and Remediation Guidance (Section III.2.2), and other state and federal risk assessment guidance (see Section III.3) provide overviews of how to prepare and present a conceptual site model for a contaminated sediments site.

Important Factors to Consider When Collecting Data to Support the Conceptual Site Model

- Use accepted quality assurance/quality control procedures for collecting and analyzing samples.
- Use accepted laboratory methods and achieve environmentally protective analytical reporting/detection limits.
- Prepare data quality objectives.
- Find Expertise – the project team should include experienced geologists, hydrologists, chemists, toxicologists and field biologists.
- Data needs for identifying source areas, ground water transport modeling, or sediment transport modeling may be different from those needed in the risk assessment. The project manager should meet with the risk assessors and

agree upon sampling and data needs for the risk assessment.

- Site media to assess includes sediment, sediment pore water, surface water, and groundwater. Biota also may be sampled as discussed in Section III.8 (Exposure Assessment). Environmental transport pathways that should be considered include sediment suspension, sediment deposition, groundwater flow to sediment pore water and to surface water, and/or transfer of contaminants from water and sediment to biota.

Section III.3 Sediment Quality Guidelines or Criteria

Many states possess sediment quality guidelines or sediment quality criteria (SQC) that specify numerical limits for chemical contaminants allowed in sediments. These criteria are often based on protection of benthic or sediment-dwelling invertebrate populations (see listing below), however, they are not necessarily protective for all potential ecological or human chemical exposures. Guidance for measuring and selecting chemicals of potential concern (COPCs) in the SQC screening or risk assessment process is described in Section III.4c. If no state or federal-specific SQC exist for a given COPC, the SQC is not protective of a receptor of concern identified in the site conceptual model (e.g., fish, bird, mammal, human), or the concentration of a COPC exceeds an SQC, an ecological or human health risk assessment may be necessary. See Figure 1 for a presentation of applicable decision criteria. Note that SQCs developed by a given State may not be acceptable or relevant to another State. It is recommended that the appropriate State officials be contacted to determine the applicability of any proposed sediment screening criteria to be used.

Important Factors to Consider

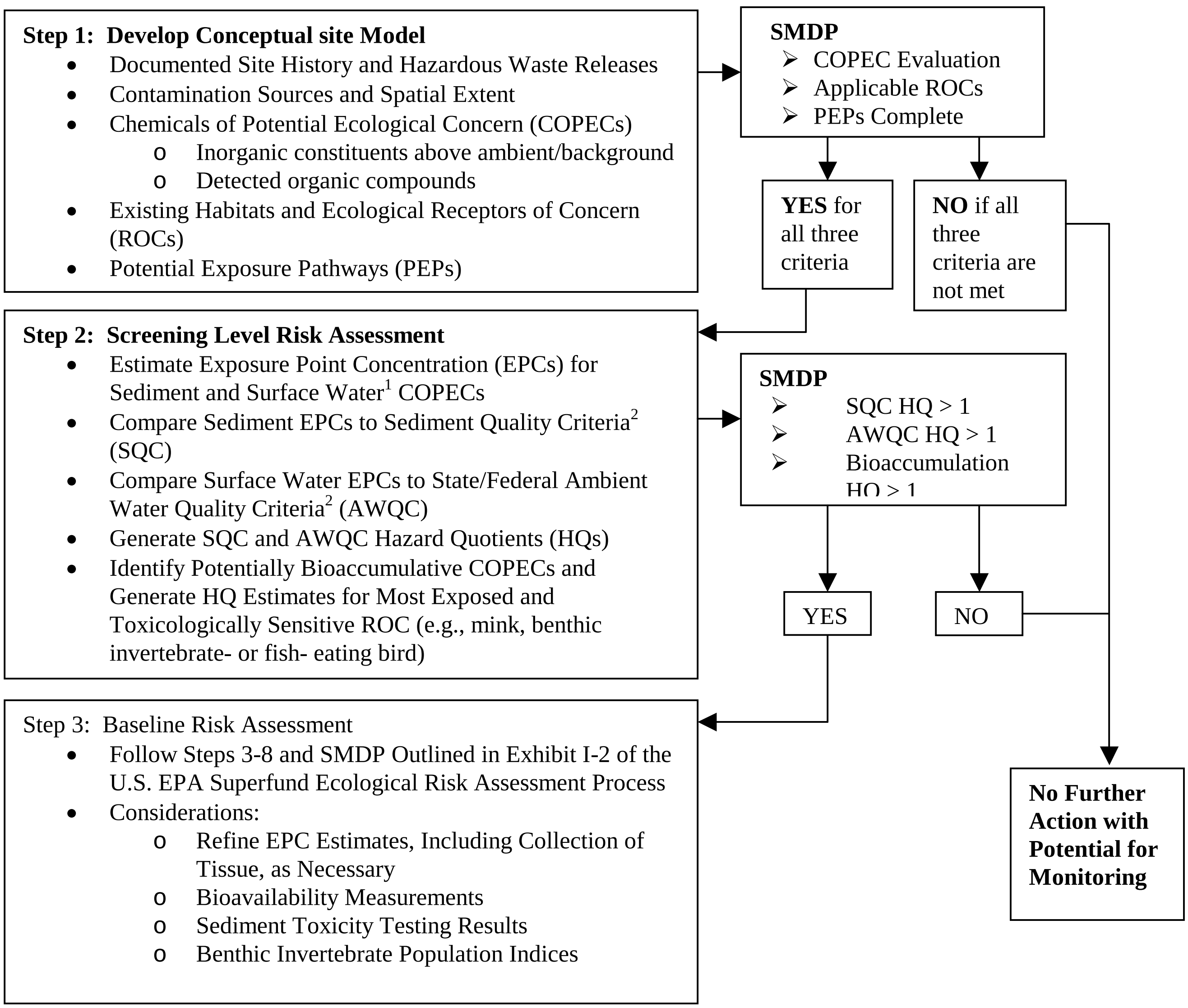
- Many SQC are only protective of the benthic invertebrate community.
- A human health and ecological risk assessment may need to be performed based on exceedances of the SQC, the types of chemicals present (e.g., chemicals or inorganic constituents that bioaccumulate), and receptors of concern.
- Sediment and surface water analytical detection limits must be lower than applicable SQC (see Section III.4).
- Exceedance of a SQG by a given constituent or multiple constituents does not necessarily indicate an ecological or human health risk is certain. The risk assessor may recommend laboratory or in situ toxicity testing and/or tissue collection to validate whether an exceedance of a SQC is of concern.
- Most SQC are designed to protect benthic invertebrates. The risk assessor, based on the horizontal and vertical extent of sediment contamination, the chemicals or inorganic constituents present, the degree of contamination, and the habitat and ecological receptors present or potentially present, may need to consider risks to other species, including plants, fish, reptiles,

amphibians, birds, and mammals. Similarly, if contamination is widespread, recreational or subsistence uses of the water body should be considered and human health risks and hazards assessed.

- For human health risk assessment, only two states (Virginia and Texas) were identified as having screening levels based on direct contact with sediment. Two states (Florida and New York) were identified as having screening levels based on bioaccumulation to the human food chain. In general, any detected contaminant that is considered an important bioaccumulative compound should be carried through to the quantitative risk assessment.

Figure 1. SEDIMENT ECOLOGICAL RISK ASSESSMENT PROCESS

(Adapted from and Supplementary to Exhibit I-2 from the Eight Step Ecological Risk Assessment Process for Superfund, U.S. EPA, 1997) (Ref. III.3.1)



SMDP = Scientific Management Decision Point

1. See U.S. EPA Guidance for Calculating Exposure Point Concentrations (2002) (Ref. III.3.2)
2. See Section IV. 3

Resources

The following resources may be useful:

- Use of Sediment Quality Guidelines and Related Tools for the Assessment of Contaminated Sediments SETAC Pellston Workshop (Ref. III.3.3)
- State of Alaska Guidance Sediment Quality Options (Ref. III.3.4)
- State of Florida Sediment Quality Guidance Inland Waters (Ref. III.3.5)
- Commonwealth of Massachusetts Revised Sediment Screening Values (Ref. III.3.6)
- State of New York DEC Division of Fish, Wildlife and Marine Resources Technical Guidance for Screening Contaminated Sediments (Ref. III.3.7)
- State of Wisconsin Consensus Based Sediment Quality Guidelines (Ref. III.3.8)
- State of Washington Sediment Standards, Chapter 173-204 WAC Marine Chemical Criteria (Ref. III.3.9)
- State of Washington Freshwater Sediment Criteria (Ref. III.3.10)
- State of Washington Human Health Sediment Criteria (Ref. III.3.11)
- State of Washington Bibliography of Sediment Management Documents (Ref. III.3.12)
- State of Texas Risk Reduction Program Development of Human Health Sediment PCLs (contact Recreation only) (Ref. III.3.13)
- State of Texas Guidance for Determining Surface Waster and Sediment PCLs Includes some exposure factors for the Contact recreation pathway (Ref. III.3.14)
- State of Virginia Voluntary Remediation Program Risk Assessment Guidance Home Page (Ref. III.3.15)
- Ohio EPA Property Specific Risk Assessment Procedures (Ref. III.3.16)
- Ohio EPA Phase II Property Assessment for the Voluntary Action Program (Ref. III.3.17)

Section III.4 Identification of Chemicals of Concern

Sediment, surface water, and in some cases, plant or wildlife tissue samples, should be collected from in or near the water body of concern. Methods for measuring, identifying, and selecting chemicals of concern are further described in this section.

Section III.4a Sediment and Surface Water Sampling

The EPA and several states have guidance for sediment and surface water sampling methods. Applicable guidance and some important factors to keep in mind when sampling are summarized below.

Important Factors to Consider When Collecting Field Samples

- The collection and manipulation of sediments and surface water can change their chemical and physical characteristics. Collect and preserve sediment samples in a manner that maintains their integrity.
- Assure that discrete or composite sediment sampling is performed to meet data quality objectives specified for the human health or ecological risk assessment.
- When sampling sediments, use procedures that minimize disturbance. If possible, avoid wading or boat prop wash when sampling. Collect downstream samples first and continue upstream.
- For human health risk assessment purposes, sample at potential exposure points where people are most likely to wade, swim or fish.
- If bioaccumulation modeling will be done, collect sediment samples to measure particle size distribution samples and total organic carbon.
- How deep should sediment samples be collected? Most organisms inhabit or feed within the oxic (oxygen containing) layer of sediments. The depth of this layer can vary widely, depending on the characteristics of the water body of concern (e.g., from one centimeter to 30 centimeters). Sediment samples must be collected within this surface layer to assess human health and ecological risks.
- Deeper sediment samples should also be collected to delineate the vertical and horizontal extent of contamination. Consideration should be given for the several marine/estuarine species, which burrow to depths far greater than 30 centimeters in sediment. For example, the west-coast geoduck clam (*Panopea abrupta)* may burrow to depths of 1 meter (Fisheries and Oceans Canada, 2002) (Ref. III.4a.1). The ghost shrimp (*Callianassa californiensis*) and blue mud shrimp (*Upogebia pugettensis*) create complex and multidimensional burrows up to depths of 75 and 45 centimeters, respectively (COE, 1989) (Ref. III.4a.2). The California mudflat worm (*Urechis caupo*) creates U-shaped burrows that average 36 centimeters in depth (as cited in Julian et. al., 2001) (Ref. III.4a.3).
- Sediment contaminant concentrations will tend to be higher in areas of finer grain particles and higher organic carbon content. Since these types of sediments are more likely to be in depositional zones, deeper samples may be needed. Although deeper sediments may not be currently available to human or ecological receptors, they should be assessed as if they could be exposed in the future by dredging or severe storms.
- The sampling strategy for a sediment site should be driven by the conceptual site model. Considerations for the types and locations of samples are the physical characteristics of the water body, the fate and transport of the chemicals, and the receptors and exposure pathways. If the water body is contaminated with bioaccumulative substances, tissue sampling may be needed in addition to sampling the sediments themselves.

Resources
The following resources may be useful when collecting samples from the field:

- U.S. EPA Environmental Response Team SOP 2016 (Ref. III.4a.4)
- Superfund Program Representative Sampling Guidance, Vol. 5: Surface Water and Sediment (Ref. III.4a.5)
- U.S. EPA Method for Collection, Storage and Manipulation of Sediments for Chemical and Toxicological Analysis: Technical Manual (Ref. III.4a.6)
- Guidance for Sampling and Analyzing for Organic Contamination in Sediments (Ref. III.4a.7)
- Ohio EPA Sediment Sampling Guide and Methodologies (Ref. III.4a.8)
- State of Minnesota Contaminated Sediment Resource Page (Ref. III.4a.9)
- State of Wisconsin Sediment Sampling Guidelines (Ref. III.4a.10)
- State of Washington Dept. of Ecology Sediment Management Guidance (Ref. III.4a.11)
- State of Washington Puget Sound Protocols and Guidelines (Ref. III.4a.12) for environmental sampling and analysis of water, sediment and tissue

Section III.4b Investigation Methods – Groundwater Upwelling and Porewater Sampling

Investigation methods will depend on site specific conditions, but the following list provides some useful tools and techniques developed for sediment sites:

- Use traditional on-shore and off-shore piezometers and monitoring wells.
- Mini-piezometers can provide a quick means for obtaining hydraulic gradients between surface water and pore water, between different depths within the sediments, and/or laterally across the site. Water can be withdrawn at various depths for chemical profiling. Standard operating procedures for mini-piezometers can be found in Porewater Sampling from a Micro Point or Mini Piezometer (Ref. III.4b.1).
- Implanted piezometer points for a permanent or semi-permanent installation of a piezometer point, using direct push technology. This technology leaves the point in the sediment at the desired depth(s) and attached to a flexible tube that can be run to a convenient location. This style of piezometer provides head data, and potentially, a water sampling port, while eliminating the need for an above surface casing. See Geoprobe Systems Web Page (Ref. III.4b.2).
- Vibrating wire piezometers and pressure transducers provide real-time data of head and/or pore water pressure. Vibrating wire piezometers can be installed "sacrificially" directly in the sediment (i.e. no casing, not retrieved when project is completed), while pressure transducers are generally installed inside a casing. The following web links provide more information on vibrating wire piezometers: VW Piezometers (Ref. III.4b.3), CEP VW Piezometers (Ref. III.4b.4), and 4500 Series VW Piezometers Pressure

Transducers (Ref. III.4b.5).

- Sediment/surface water interface flux meters (manual and automated) can be of a very simple design (Lee D.R., 1977) (Ref. III.4b.6) or automated systems using ultrasonic or electromagnetic flow meters (see Development of a Benthic-Flux Chamber) (Ref. III.4b.7). They can provide data on the direction, rate, and volume of groundwater flux into or out of the sediments.
- In most areas, sediment and surface water temperature profiling can provide a high contrast between surface water and groundwater temperatures. Mapping vertical variations in temperature at depth across the site can help locate areas of preferential groundwater discharge through sediments. This can be done easily by using direct-reading thermal probes.
- Gas production and ebullition studies and modeling are conducted at sites where gas production may play a major role in contaminant migration, or may affect the integrity of the final remedial design. Collection of gas in a gas flux meter allows determination of the gas chemistry and rate of its production, which may be important to remedial design.
- Aquatic vegetation mapping has been used in some areas to provide information on preferential groundwater discharge areas. Aquatic vegetation may vary across the site based on variations in surface water–groundwater interactions, particularly if there are significant differences in the water chemistry or dissolved oxygen content between the surface water and groundwater.

Other In Situ Sampling Devices

Diffusion Samplers - The diffusion sampler consists of a deionized water-filled bag with a low-density polyethylene diffusion membrane to collect water samples. VOCs in the sediment pore water diffuse into the deionized water contained in the sampling bag. The bags can be deployed in sediments at the desired depth, and this provides a simple hot- spot screen. The membrane may be pierced in the sediments.

Pore-Water Peepers - This is a passive diffusion sampler consisting of small chambers with membrane or mesh walls that are buried in the sediments, where interstitial waters are allowed to infiltrate. These require deployment by hand and an equilibration period. Only dissolved constituents are sampled. The membrane may become clogged and only small sample volumes may be collected.

Gel Samplers - Diffusion Equilibration in Thin Films (DET) are comparable with peeper systems except that the diffusive equilibrium is attained between solutes in the pore water and a thin film of gel. The thinness of the gel (≤ 1 mm) results in faster diffusive equilibration than with traditional peepers or dialysis cells.

Semi-Permeable Membrane Devices (SPMDs) - These devices are deployed in the sediment. Following field deployment, the devices are dialyzed and analyzed. Lipid content of the membrane is intended to mimic the bioconcentration of organic contaminants in fat tissues of biota. Biofouling can impede uptake. The device relies on diffusion and sorption to accumulate analytes in the sampler. Samples are a time-integrated representation of conditions at the sampling point over the deployment period.

Push Point Samplers - The push point sampler has a small diameter core barrel with a lance tip and a "T" type handle. The small diameter barrel has holes drilled in the side at the bottom to allow water to enter. A solid plastic rod is placed in the barrel to prevent water and sediment from entering the sampler during pushing. When the sampling section of the barrel has been driven/pushed to the desired depth, the rod is withdrawn allowing pore water to enter. The water sample is withdrawn with syringe and tubing or a peristaltic pump.

Additionally, the Space and Naval Warfare Systems Command and Naval Facilities Engineering Service Center are working with Cornell University to develop techniques for assessing contaminated ground-water discharge into coastal environments. Two of these tools, the Trident probe and the UltraSeep meter [see Coastal Contaminant Migration Monitoring (Ref. III.4b.8) and New Tools Improves Assessment of Contaminated Ground Water and Surface Water Interaction (Ref. III.4b.9)] can be used to identify areas of groundwater release into surface water, and to quantify flow rates and contaminant levels. The Trident is a multi-sensor probe that allows rapid screening of the offshore area to identify potential discharge zones based on conductivity and temperature contrast, and/or site-specific chemical tracers. Differences in observed conductivity and temperature indicate areas where groundwater discharge is occurring. The probe can also be used to collect interstitial water samples for chemical analysis. The UltraSeep is a continuously-logging seepage meter with flow proportional water sampling capability. The UltraSeep, makes direct measurements of advective flux and contaminant concentrations at a particular location.

Resources

- U.S. EPA is preparing a groundwater/surface water interactions guidance publication that will be added to their EcoUpdate series. Check that website for availability ECO Update Bulletin Series (Ref. III.4b.10)
- Field Study of the Fate of Arsenic, Lead, and Zinc at the Groundwater/Surface-Water interface (Ref. III.4b.11)
- Proceedings of the Ground-Water/Surface-Water Interactions Workshop Part1, Part2, Part3 (Ref. III.4b.12)
- A Review of Methods for Assessing Nonpoint Source Contaminated Ground-Water Discharge to Surface Water. (Ref. III.4b.13)

Section III.4c Food Chain Sampling

Tissue samples should be collected when bioaccumulative compounds are potential contaminants of concern, a large area of sediments is contaminated (e.g., greater than 5 acres), and the water body supports edible aquatic organisms. A list of important bioaccumulative compounds is contained in the document Bioaccumulation Testing and Interpretation for the Purpose of Sediment Quality Assessment: Status and Needs
(Ref. III.4c.1). At a minimum, collect samples from a bottom feeder and a predator fish species that is typically consumed by humans or predatory animals. Since the species consumed by humans or predatory animals tend to be migratory, it is often difficult to link contaminant levels back to a particular site. If one of the objectives of the sampling event is to assess bioaccumulation from site contaminated sediment, a sessile species or species with a limited range close to the site should also be collected. Edible shellfish should be collected from estuarine and marine sediments. Many sediment contaminants are lipophilic. Therefore species with a higher lipid content will tend to have higher concentrations of contaminants and are a good option for tissue sample collection. When collecting fish, filet samples should be collected and the percent lipids should be determined. The remainder of the fish sample can be analyzed and used in the ecological risk assessment, where needed, or for subpopulations that consume whole fish.

Important Factors to Consider When Assessing Bioaccumulation

- One or more samples should be collected up-gradient of the probable source or from an appropriate reference sample location in the same or similar watershed to help determine whether contaminants may be coming from an up-gradient source or are naturally occurring (i.e., inorganic constituents).
- Sample species with high site fidelity are likely to spend most of their lifespan in the area of the contaminated sediments.
- The background or reference samples should be taken from an area with similar physical characteristics of the site but with no influence from the site.

Issues

- PCBs, dioxins, and furans - Analysis of PCBs, dioxin, and furan congeners is recommended when performing a risk assessment. The use of Aroclor data is likely to underestimate total PCBs and does not address the toxicity of dioxin-like congeners. For further information see applicable references below.
- Mercury - The methylated form of mercury is more toxic and bioaccumulative. Inorganic and metallic mercury tend to form alkyl mercury compounds in sediments. The presence of sulfur-reducing bacteria, low pH, and anaerobic conditions favor the methylation of mercury. Therefore most of the mercury detected in fish tissue samples is methyl mercury. It is

appropriate to sample tissues for total mercury and assume that it is methyl mercury for risk assessment purposes.

Resources

The following additional resources may be useful:

- Guidance for Assessing Chemical Contaminant Data for Use In Fish Advisories Volume 1: Fish Sampling and Analysis – 3rd Edition (Ref. III.4c.2)
- PCB Cancer Dose-Response Assessment and Application to Environmental Mixtures (Ref. III.4c.3)
- L. Valoppi et al., 2000, *Use of PCB congener and homologue analysis in ecological risk assessment* (Ref. III.4c.4)
- The World Health Organization Reevaluation of Human and Mammalian Toxic Equivalency Factors for Dioxins and Dioxin-Like Compounds (Ref. III.4c.5)
- ATSDR Toxicological Profile for Mercury (Ref. III.4.c.6)

Section III.4d Selecting Chemicals of Potential Ecological and Human Health Concern

Once the analytical results have been received the data should be reviewed to insure that it is appropriate for use in SQC comparisons or for performing the risk assessment. See Risk Assessment Guidance for Superfund (RAGS) (Ref. III.1.15) for a general discussion of data evaluation. Some of the issues that should be considered are the appropriateness of the analytical methods, the adequacy of the sample quantitation limits, useability of qualified data, and the results of blank samples.

Important Factors to Consider

- Organic chemicals, particularly those which are potentially bioaccumulative (e.g., log octanol-water partition coefficient greater than 4), and inorganic constituents that exceed local background concentrations and SQCs (see Section III.3) should be carried through to the risk assessment.
- When screening and selecting potential inorganic constituents of concern, limiting the assessment to those constituents significantly elevated above background or ambient concentrations is recommended. The California Environmental Protection Agency (Ref. III.4d.1) provides guidance in this matter, as well as subjective and quantitative statistical approaches for identifying inorganic constituents of concern in soils and sediments. The U.S. Navy Facilities Command (Ref. III.4d.2) has also developed a guidance document for characterizing background conditions at sediment sites. If a screening value is exceeded, the assessment may be further refined to account for site-specific conditions, including bioavailability, receptor site-use factors, or measured site-specific exposure data (e.g., tissue concentrations

of chemicals of concern in plants, invertebrates or fish).

Resources
See Section III.1 for additional resources.

Section III.5 Identifying Receptors of Concern and Complete Exposure Pathways

The conceptual site model and the human and ecological risk assessments must identify receptors of concern and the environmental exposure pathways to these receptors. This section discusses the process of identifying ecological and human receptors of concern and relevant exposure pathways.

Section III.5a Ecological Receptors of Concern

As applicable, the risk assessment must identify species representative of, and critical to the functioning of, fresh or salt water habitats, including those found in ponds, lakes, streams, rivers, estuaries, or near shore coastal marine areas. A biological survey of the site, including a literature review and direct site observations, should be performed

Important Factors to Consider When Selecting Ecological Receptors of Concern

- Qualified field biologists are needed to perform the survey.
- A thorough review of site conditions should include literature review, and possibly field surveys, for potential threatened or endangered species present in the investigation area.
- The potential for the site to support state or federally-protected threatened or endangered species must be evaluated.
- Surveys should be conducted over more than one season (e.g., summer, spring, winter) to capture changes in plant and animal abundance and migration.
- If the site in question supports threatened or endangered species habitat, or threatened and endangered species are observed following biological surveys, then the applicable natural resource trustees should be notified.

Resources
See Section III.1 for additional resources.

Section III.5b Human Health Receptors of Concern

The following are some of the human receptor populations that should be considered in the human health risk assessment.

- Residential/General Population;
- Recreators (e.g., swimmers, beachgoers);
- Subsistence Fisherman;
- Sport or Recreational Fisherman (marine and freshwater anglers); and
- Commercial/Industrial Workers.

Important Factors to Consider
- Site-specific information regarding the use of the waterbody should be used whenever possible. State or local natural resource agencies may be able to provide information on the use of the site for recreation or fishing.
- Federal or State fishing restrictions (see Section VI.2b) are not always followed and should not necessarily be a rationale for eliminating a receptor from the risk assessment.

Resources
See Section III.1 for additional resources.

Section III.5c Identification of Complete Ecological and Human Health Exposure Pathways

RAGS (Ref. III.1.15) defines an exposure pathway as consisting of four elements: (1) a source and mechanism of chemical release, (2) a retention or transport medium (or media in cases involving media transfer of chemicals), (3) a point of potential human or ecological contact with the contaminated medium (referred to as the exposure point), and (4) an exposure route (e.g., ingestion) at the contact point.

Ecological Exposure Pathways
Ecological receptors can be exposed to sediment contaminants by direct contact (i.e., surface or dermal exposures) or by incidental ingestion of sediment. Organisms also can be exposed indirectly to sediment contaminants by desorption from sediment to surface water and by consumption of contaminated prey (i.e., through bioaccumulation).

Resources
See Section III.1 for additional resources.

Important Factors to Consider
- Because of their sessile nature, macrophytes (e.g., rooted aquatic plants) and benthic invertebrates may be highly exposed to sediment contaminants. For this reason, the benthic invertebrate community is a primary receptor group that is evaluated in the SQC screen and/or in the risk assessment.
- Depending on the extent of sediment contamination, indirect exposure pathways (e.g., invertebrate or fish consumption) may need to be addressed

in the risk assessment.

Issues

- For wildlife receptors such as birds and mammals, inhalation and dermal exposures are considered far less significant exposure routes than ingestion. Typically only ingestion exposures are estimated in the risk assessment (see U.S. EPA EcoSSL Guidance 2005). (Ref. III.5c.1)
- Some species may consume large amounts of sediment during feeding or foraging (Beyer et. al., 1994) (Ref. III.5c.2). Incidental sediment ingestion is a significant exposure pathway that must be quantitatively evaluated whenever avian and mammalian wildlife risks are assessed.

Human Health Exposure Pathways

Direct contact with sediment may occur during recreational activities such as fishing, boating, swimming, and wading. If the site impacts sediments where any of these activities occur or may occur in the future, direct contact exposure should be evaluated. In addition, commercial/industrial workers at marinas and shipyards and those involved with dredging operations could also be exposed to contaminated sediments. Exposure by dermal contact and inadvertent ingestion are the principle exposure routes and should be assessed. In some cases exposure through inhalation should also be included.

Indirect Contact may involve the consumption of shellfish, fish, and/or birds (see Section III.8.a)

Important Factors to Consider

- The types of contaminants present and the types of activities at the site will determine the exposure routes that should be evaluated.
- Even chemicals with relatively low volatility such as PCBs may become volatile during storms or activities that disturb the sediments. Also, PCBs are more volatile at higher temperature and if sediments are not covered by water, as in tidal location. Because PCB volatility has been a concern at the New Bedford Harbor Superfund Site, PCBs in air have been monitored, see Current Monitoring Data New Bedford Harbor Superfund Site (Ref III.5.c.3).

Resources

See Section III.1 for additional resources.

Section III.6 Characterizing Ecological Risks of Contaminated Sediment Sites

Ecological risk assessment is a process to systematically organize and evaluate data, information, assumptions, and uncertainties to help understand and predict the relationships between chemical stressors and ecological effects. The goal of the ecological risk assessment is to provide the remedial project manager with information useful for environmental decision-making. The primary role of the ecological risk assessment is to identify plants and animals potentially at risk from exposure to sediment- and sediment pore water-associated contaminants.

For each receptor or species of concern, the risk assessment specifies assessment endpoints. Assessment endpoints identify the environmental attributes or species considered critical to the function of a biological community or population. Measurement endpoints (e.g., screening values or toxicity criteria) are the metrics or parameters used to evaluate the effects of the chemicals of concern on the selected assessment endpoints. Ecological hazard is characterized by comparing predicted exposure rates to the selected screening values. Depending on the receptors and exposure pathways identified in the conceptual site model, sediment screening-level ecological risk assessment should include consideration of the assessment and measurement (screening value) endpoints.

Section III.6a Protection of the Plant Community

Plants are the bases of the food chain for most freshwater and marine ecosystems. Potential hazards to free-floating aquatic plants are often adequately addressed by comparing surface water contaminant concentration data to the federal ambient water quality criteria and state water quality objectives protective of aquatic life. Potential hazards to wetland-associated plants or aquatic macrophytes (i.e., rooted aquatic plants) from contaminants in sediments or surface water are rarely quantified in ecological risk assessments. Aquatic macrophytes provide critical nutrient recycling functions, habitat, and food in freshwater wetland, estuarine wetlands or near-coastal ecosystems. Since no sediment screening criteria exist for these species, it is usually assumed that existing sediment screening criteria that are protective of benthic invertebrates or fish will be protective of aquatic macrophytes. However, according to Lewis et. al., *Wetland Plant Seedlings as Indicators of Near-Coastal Sediment Quality: Interspecific Variation* (Ref. III.6a.1), using rooted aquatic macrophyte 7 to 28-day toxicity growth bioassays showed that numerical SQC protective of invertebrates did not predict the various phytoinhibitory and phytostimulatory effects of a variety of sediments contaminated with metal and organic constituents above invertebrate-based SQC.

Plant Screening Values

Regarding free-floating plant species (e.g., algae), one should compare surface water concentrations to State water quality objectives or federal ambient water quality criteria protective of freshwater or saltwater aquatic life. Most states have water quality objectives protective of aquatic life.

Resources

For federal and State criteria and other methods, see:

- U.S. EPA Water Quality Standards Resource Page (Ref. III.6a.2) includes web links to state and federal criteria
- Oak Ridge National Laboratory Screening Benchmarks for Aquatic Biota (Ref. III.6a.3)
- Macrophytic (rooted) vegetation (e.g., cattails, eel grasses): no screening values available. Consult other sources, including reviews of available toxicity data for aquatic plants:
- Lytle, J.S. and T.F. Lytle, 2001. *Use of Plants for Toxicity Assessment of Estuarine Ecosystems*, (Ref. III.6a.4)
- Mohan, B.S. and B.B. Hosetti,1999. *Aquatic Plants for Toxicity Assessment*, (Ref. III.6a.5)

Section III.6b Protection of the Invertebrate Community

Similar to aquatic plants, benthic (sediment-dwelling) invertebrates provide key nutrient recycling functions and serve as a food source to higher trophic level organisms. Because of their life history, benthic invertebrates are closely associated with sediment contaminants and may be adversely affected by exposure. As mentioned in Section III.3, many State sediment quality guidelines, objectives or criteria are protective of benthic invertebrate populations.

Invertebrate Screening Values

Free-floating species (e.g., zooplankton) may be treated similarly as free-floating plants (see Section III.6a).

For benthic species (e.g., amphipods) compare sediment contaminant concentrations to threshold effect and probable effect levels.

In addition to chemical screening levels, potential hazards to invertebrate populations can be assessed using bioassessment approaches. For example, the U.S. EPA provides guidance for conducting surveys related to invertebrate species richness and abundance, and that may be used as metrics for the health of a given water body.

Resources

- NOAA Screening Quick Reference Tables (Ref. III.6b.1) provides fresh and saltwater specific values
- MacDonald, D.D., Ingersoll, C.G., and T.A. Berger, 2000. *Development and Evaluation of Consensus-Based Sediment Quality Guidelines for Freshwater Ecosystems,* (Ref. III.6b.2)
- U.S. EPA Biological Assessment and Biocriteria (Ref. III.6b.3)

Section III.6c Protection of Fish Populations

Apart from their critical role in the function of many aquatic ecosystems, fish are also a valued economic and recreational resource. In some cases a contaminated sediment site may support or provide habitat for State or federally protected species. State water quality objectives and federal ambient water quality criteria are protective of aquatic life and are generally protective of fish life (see above screening value web links). However, NOAA has recently issued fish-specific SQC for polycyclic aromatic hydrocarbons, PCBs, and tributyl tins which can be compared to site concentrations. Residue effects concentrations can also be combined with the Biota - Sediment Accumulation Factor (BSAF) values to estimate safe sediment concentrations that are protective of fish. However, given the limited availability of both, there is considerable uncertainty associated with this approach.

Resources

Fish Screening Values

- NOAA Sediment Quality Criteria Protective of Fish (Ref. III.6c.1)

Residue Effects Databases and Studies

- Beckvar, N., Dillon, T.M., and Read, L.B, 2005. *Approaches For Linking Whole-Body Fish Tissue Residues Of Mercury Or DDT To Biological Effects Thresholds*, (Ref. III.6c.2)
- Jarvinen, A.W. and G.T. Ankley, 1999. *Linkage of Effects to Tissue Residues: Development of a Comprehensive Database for Aquatic Organisms Exposed to Inorganic and Organic Chemicals*, (Ref. III.6c.3)
- U.S. Army Corps of Engineers/U.S. EPA Residue-Effects Database (ERED) (Ref. III.6c.4)

Section III.6d Protection of Amphibian and Reptile Populations

Besides the embryonic and juvenile life stages of amphibians, very little ecotoxicological information or screening values exist for assessing potential sediment risks to amphibians (e.g., frogs) and reptiles (e.g., turtles, snakes). Because of the lack of this information, most sediment ecological risk assessments assume that screening values protective of invertebrates, fish, birds, or mammals are protective of amphibians and reptiles. Depending on the complexity of the site, levels of contamination, and amphibian or reptile species present (e.g., State or federally protected), the risk assessment may include assessment endpoints for these species. Usually assessment endpoints for these species will not be selected at small state-lead sediment sites unless a threatened or endangered amphibian species is potentially affected by site chemicals of concern.

Resources

Amphibian Screening Values

- A Database of Reptile and Amphibian Toxicology Literature (RATL) (Ref. III.6d.1)
- Sparling, D.W., Linder, G., and C. A. Bishop, 2000. *Ecotoxicology of Amphibians and Reptiles,* (Ref. III.6d.2)
- Amphibian toxicity data for water quality criteria chemicals. United States Environmental Protection Agency. EPA/600/R-96/124. (Ref. III.6d.3)

Section III.6e Protection of Bird and Mammal Populations

Species which incidentally ingest large amounts of sediment such as shorebirds and certain waterfowl [Beyer et al,1994 (Ref. III.5c.3) and Hui and Beyer, 998 (Ref. III.6e.1)] that may be exposed to contaminants which accumulate in plants, invertebrates, and fish (e.g., shorebirds, waterfowl, heron, and mink) should be selected as assessment endpoints in the ecological risk assessment. We recommend sites that encompass more than 25 % of the home or foraging range of a resident bird or mammal species be evaluated in the risk assessment. Methods include toxicity reference values, life history parameters, and ingestion rates for screening ecological risks to these species are provided in the ecological risk assessment guidance resources listed in Section III.7. For birds and mammals, estimates of exposure through sediment ingestion and through consumption of contaminated food items are very similar to those summarized in the human health risk discussion below (see Section III.8).

Ecological risk or hazard is expressed as a Hazard Quotient (HQ) or Hazard Index (HI). A HQ represents the value obtained by dividing the predicted exposure rate by the selected toxicity screening value. A HI represents the summation of HQ for each Chemicals of Potential Concern (COPC) identified (i.e., cumulative hazard). Since most sediment assessments include more than one COPC, the HI is almost always calculated. A HQ or HI above 1 indicates the potential for ecological risk.

For bird and mammal screening values see methods for derivation in the ecological risk assessment guidance as provided in Section III.1.

Section III.6f Important Factors to Consider When Characterizing Ecological Risks

- Sediments, either directly or indirectly, provide habitat for a variety of ecological receptors, not just benthic invertebrates.
- Few commonly accepted sediment screening values exist for plants, fish, amphibians, reptiles, birds, or mammals.
- Assessment and measurement endpoints should be prepared that focus and

define the level of effort in the risk assessment.

- Risk assessment is an iterative process, moving from very conservative to more refined exposure and toxicity assumptions.
- Sediment contaminants will have varying degrees of bioavailability; validation of screening level findings is often necessary.

Issues

- Ambient Water Quality Criteria are protective of free-floating plant (i.e., algal) species. SQC for rooted, aquatic macrophytes are not available. Aquatic macrophytes may provide critical breeding and spawning habitat in some aquatic ecosystems (e.g., coastal estuaries). If the conceptual site model indicates aquatic macrophytes are receptors of concern, the risk assessor must consider alternative methods for assessing potential risks to these species, including toxicity testing, residue analysis, and reference versus assessment site survey methods (e.g., percent coverage, density, stem length, rhizome length, plant mass).
- Exceedance of an invertebrate-based screening criterion does not necessarily indicate that surface water or sediment toxicity is certain. Surface water or sediment toxicity testing should be performed to validate the findings.
- Survey methods and protocols for assessing the health of benthic invertebrate communities are available [see the U.S. EPA Bioassessment and Biocriteria (Ref. III.6f.1)]. These methods are also useful for validating whether exceedance of a screening criterion is significant. These methods may be less sensitive measures of chemical stressor effects than toxicity testing.
- Very few sediment screening values exist for fish. While ambient water quality criteria are generally protective of surface water exposures, sediments may also be an important direct or indirect exposure pathway to fish. Bioaccumulation of inorganic or organic compounds in fish should be considered in the context of both the adverse effects of the compound to the fish itself, and the adverse effects of the compound to other species that eat fish, including humans.
- Many sediment-associated contaminants of concern (e.g., PAHs, PCBs, organochlorine pesticides, and metals) cause measurable changes in biochemical, histopathological, and physiological function in plants, invertebrates, amphibians, reptiles, birds, or mammals. These parameters, measured pre- and post- remediation, provide a sensitive and reproducible means by which remedy effectiveness can be measured. For fisheries resources, Anderson et al, 1997 (Ref. III.6f.2) provides a suite of biological indicator measurements that integrate the responses of fish to multiple chemical stressors and that are cost effective relative to many types of contaminant analyses. A good example of a biological indicator endpoint

with linkage to sediment-associated contaminants is the incidence and severity of tumors in fish. For example, Baumann, P.C. and Harshbarger, J.C., 1995 (Ref. III.6f.3) showed a rapid decrease in the incidence of liver tumors in fish following the removal of PAHs from a riverine system.

- There is a large body of literature for early-life stage exposures of amphibians to water; however, no generally accepted or standardized screening values are available. No screening values are available for reptiles or adult amphibians. If amphibians or reptiles are selected as receptors of concern, often the risk assessor assumes, by default, that protection of other species (e.g., invertebrates, fish, birds, mammals) will be protective of amphibians and reptiles. In special cases where risks to amphibians and reptiles are further investigated (i.e., threatened or endangered species issues), a review of the literature and the data sources listed in Section III.6d are highly recommended. Toxicity testing with surrogate amphibian or reptile species is another means of indirectly assessing potential risks.
- Related to wildlife exposure assumptions, the risk assessor must review the literature and estimate feeding rates, incidental sediment ingestion rates, and dietary preferences (e.g., invertebrate, fish, amphibian dietary items) for each wildlife species assessed. Primary sources are the U.S. EPA Wildlife Exposure Handbook (Ref. III.6f.4) and Nagy, 2001 (Ref. III.6f.5); however some State-specific information may exist (e.g., OEHHA Cal/Eco Tox Database) (Ref. III.6f.6). In a screening level assessment, the risk assessor should assume a "worst case" exposure scenario where an animal would consume a diet of the maximally exposed dietary item (i.e., food item with the highest measured or predicted concentration of a given chemical or concern) and incidentally ingest sediment within the most contaminated sediments area. Incidental sediment ingestion, since it does not contribute to the caloric needs of an animal, should be considered as a separate mass of ingested material and not as a portion of the total mass of material required to meet its caloric needs.
- Wildlife toxicity criteria are available from a number of sources including the U.S.EPA EcoSSLs (2005) (Ref. III.6f.7) and the U.S. EPA Region 9 BTAG (Ref. III.6f.8). It is important that the resource agencies and the responsible parties agree on the exposure methods and toxicity criteria used in the risk assessment. In a screening level assessment, the risk assessor compares the estimated exposure rate to a no observable adverse effects level (NOAEL) toxicity value. Toxicity criteria, for the most part, are developed in standard laboratory or toxicity test species including mice, rat, quail, and mallard. If there is a large difference in body weight between the laboratory test species and the wildlife species of concern, an allometric conversion of the toxicity value may be conducted (Sample and Arenal, 1999) (Ref. III.6f.9).

Section III.7 Risk Management Decision-Making Criteria for Ecological Risk Assessment

Depending on the spatial extent and severity of contamination, the screening process may identify receptors potentially at risk. As previously mentioned, the number of assessment endpoints in the risk assessment may be limited for small sites. As shown in Figure 1, the risk assessment process proceeds in a series of steps, with each successive step building on the previous findings. The risk assessment process starts with the development of a conceptual site model (Step 1). When a screening-level risk assessment (Step 2) suggests potential ecological hazards (i.e., a sediment quality or hazard quotient greater than one, where the site maximum exposure concentration for a given contaminant of concern is divided by the sediment quality criterion or toxicity reference value), a validation study or baseline risk assessment (Step 3) may be recommended to reduce uncertainty in the findings. A weight or lines-of-evidence approach (e.g., Burton et al. 2002) (Ref. III.7.1) should be used to summarize and integrate various measurement endpoint findings and relate those findings to each selected assessment endpoint. Figure 1 also shows scientific management decision points (SMDPs) (EPA, 1997) (Ref. III.7.2). SMDPs are reached at the end of each step in the risk assessment process. Given the constraints of time, money, and the size and complexity of a contaminated sediment site, the State remedial project manager may choose the level of effort expended in the risk assessment. For example, it may be more cost-effective to remediate a contaminated sediment site than to perform a rigorous baseline ecological risk assessment. Finally, preliminary remedial action objectives that are supportive of the assessment endpoints selected should be provided in the final risk assessment.

Important Factors to Consider When Making Ecological Risk Management Decisions

- The selected remedial alternate (including no action) should be reviewed and accepted by the natural resource trustee agencies.

Issues

- SDMPs are critical decision points in the risk assessment and remedial investigation process. It may be more cost effective to remediate a small contaminated sediments site than conduct extensive biological sampling, toxicity testing, or surveys. Conversely, for a large contaminated site, further toxicity testing, biological sampling and survey information are critical.
- Ecological decisions made with the information provided in the ecological risk assessment should be based on a supporting evidence analysis (see documents in Section III.1). Information that should be synthesized and evaluated in the analysis includes the:
    - o magnitude of the HQ or HI;

- toxicological endpoint of the toxicity value used to calculate the HQ or HI;
- identified chemicals of concern and potential exposure pathways;
- persistence and bioaccumulation potential of chemical(s) of concern;
- range of representative species evaluated, including the presence of endangered species;
- life history, home range and foraging habits of representative species of concern;
- uncertainty contained in exposure models;
- estimated and/or field-verified exposure point concentrations (e.g., related to food chain transfer);
- estimated and potentially field-verified toxicity evaluations; and
- magnitude of any uncertainty factors used to develop the final toxicity value.

Resources

See Section III.1 for additional resources.

Section III.8 Characterizing Human Health Risks of Contaminated Sediment Sites

The human health risk assessment (HHRA) process involves four major steps. The steps are: 1) data collection and evaluation; 2) exposure assessment; 3) toxicity assessment; and 4) risk characterization. A closely related, but separate, step is risk management. The HHRA for sediment sites follows these same steps. Data collection and evaluation were discussed in Section III.4. Some of the issues related to exposure assessment were discussed in Section III.5. The remaining steps in the process are discussed below with emphasis on topics that are unique to State sediment sites.

Section III.8a Exposure Assessment

Exposure assessment involves identifying potential receptors and exposure pathways and quantifying chemical intake. There are two main pathways for human exposure to contaminated sediment. These are direct contact and ingestion of contaminants that have accumulated in edible tissue of aquatic organisms. Other exposure pathways, such as inhalation, are typically far less significant than ingestion.

The equations for assessing oral (inadvertent ingestion) and dermal exposure to sediments are shown below.

Oral $CDI = [C_S \times IR \times CF \times FI \times EF \times ED]/[BW \times AT]$

Dermal CDI = [C_S x CF x SA x ABS x EF x ED x AF]/[BW x AT]

Where,

CDI =	Chronic Daily Intake (mg/kg-day)
C_S =	Exposure Point Concentration in Sediment (mg/kg)
IR =	Ingestion Rate of Sediment (mg/day)
CF =	Conversion Factor (kg/mg)
FI =	Fraction Ingested from Contaminated Source unit less
EF =	Exposure Frequency (days/year)
ED =	Exposure Duration (years)
BW =	Body Weight (kg)
AT =	Averaging Time (days)
SA =	Skin Surface Area Available for Contact (cm^2/day)
ABS =	Absorption Factor (unit less)
AF =	Sediment to Skin Adherence Factor (mg/cm^2)

A few States have default values for sediment exposure factors (see the references for Texas (Ref.III.3.12) and Virginia (Ref.III.3.13) in Section III.3). In addition, U.S. EPA Exposure Factors Handbook (Ref. III.8a.1) and dermal guidance may be helpful in determining the exposure factor inputs to these equations. In general, the exposure point concentration should be an Upper Confidence Limit (UCL) on the arithmetic average. EPA's ProUCL software, Software for Calculating Upper Confidence Limits (Ref. III.8a.2) is a tool for calculating UCLs.

Resources

The following resources may be useful:

- U.S. EPA Risk Assessment Guidance for Superfund Part E, Supplimental Guidance for Dermal Risk Assessment (Ref. III.8a.3)
- Calculating Upper Confidence Limits for Exposure Point Concentrations at Hazardous Waste Sites (Ref. III.8a.4)

Food Chain Bioaccumulation

Where sediment contamination exists in waters that support edible aquatic organisms, the potential for food chain bioaccumulation should be assessed. The preferred method for assessing this pathway is by direct measurement of concentrations in the tissue. The equation for assessing exposure by this pathway is:

CDI = [C_b x IR_bx EF x ED]/[BW x AT]

Where,

C_b =	Exposure Point Concentration in Biota (mg/kg)
IR_b =	Ingestion Rate of Biota (kg/day)

Several States have default values for the exposure factors used in this equation (see the references for Texas (Ref.III.3.12) and Virginia (Ref.III.3.13) in Section III.3). In addition, the U.S. EPA Exposure Factor Handbook, Chapter 10, Intake of Fish and Shellfish (Ref. III.8a.1) has fish ingestion values for various scenarios. Depending on the receptor (e.g., subsistence fisherman, recreational fisherman), different rates of fish or edible shellfish consumption may be appropriate.

Resources

The following resource may be useful:

- Chemical in Fish: Consumption of Fish and Shellfish in California and the United States (Ref. III.8a.5)

When tissue data are not available, a biota-sediment accumulation factor (BSAF) may be used to estimate the C_b factor in the above equation. The BSAF relates the lipid normalized concentration in the biota to the organic carbon normalized concentration in sediment. C_b is calculated using:

$$C_b = C_S \times BSAF$$

The reference below contains BSAFs for fish tissue for some heavy metal and non-polar organic compounds. Also see the food chain bioaccumulation guidance listed above.

- The Incidence and Severity of Sediment Contamination in the Surface Waters of the United States, National Sediment Quality Survey, 2nd Edition, Appendix C (Ref. III.8a.6)

Important Factors to Consider When Estimating BSAFs

- To reduce uncertainty and strengthen the findings of the risk assessment, site-specific, empirically determined BSAFs, are usually preferred over literature-derived values. However, for smaller sites with limited resources, literature values may be useful in determining whether bioaccumulation is a concern.
- Whenever possible, site specific exposure factors based on local fishing patterns should be used in the risk assessment. Use of generic default exposure factors may underestimate risk when the area is used regularly for subsistence fishing. Note that the use of defaults values could overestimate the risk for small sites or areas with limited access.

Section III.8b Toxicity Assessment

The toxicity of the COPCs is expressed as the reference dose (RfD) for non-carcinogens and the slope factor for carcinogens. Some COPCs have both carcinogenic and non-carcinogenic effects. Both should be assessed. Values for

RfDs and slope factors should be obtained according to the following hierarchy.

1. U.S. EPA Integrated Risk Information System (IRIS) (Ref. III.8b.1)
2. EPA's Provisional Peer Reviewed Toxicity Values (PPRTV) (State project managers should contact their EPA Regional Risk Assessor for access.)
3. Other, including:
   California EPA Office of Environmental Health Hazard Assessment Toxicity Criteria Database (Ref. III.8b.2)
   Agency for Toxic Substances and Disease Registry (Ref. III.8b.3)
   Health Effects Assessment Summary Tables (Not on-line, states should contact their EPA Regional Risk Assessor)

Important Factors to Consider When Characterizing Human Health Risks

- Be aware that some states (e.g., California) may require their slope factors or RfDs be the primary values used in the toxicity evaluation.
- Toxicity factors are updated periodically. Check U.S. EPA Integrated Risk Information System (IRIS) (Ref. III.8b.1) to verify the most current value.

Section III.8c Risk Characterization

The risk characterization step of the process combines information collected during the exposure assessment with information collected during the toxicity assessment. For carcinogens, risk is expressed as a unit less probability of developing cancer over a lifetime. Carcinogenic risk is calculated as:

Risk = CDI x slope factor

The risk for individual carcinogens should be summed to get a total carcinogenic risk.

For non-carcinogens, risk is expressed as the HQ, where

HQ = CDI/RfD

The HQs for chemicals affecting the same target organ should be summed to calculate the HI.

In addition to the numerical expressions of risk, the risk characterization section should also include a discussion of the uncertainties associated with each step of the process.

Section III.8d Risk Management

The purpose of the risk assessment is to provide managers with information to decide whether an action needs to be taken at the site. For carcinogens, the acceptable risk range is generally between 10^{-6} to 10^{-4}. Different States will have different target risks within that range. For non-carcinogens, an HI that exceeds 1 is generally considered unacceptable. If the risks exceed the targets, some type of remedial action will be needed. If an action is needed, cleanup levels should be calculated by solving for the concentration term in the risk equations that were presented in the previous section. If both the direct contact and the bioaccumulation pathways are applicable to the site, remediation levels (RLs) for both pathways should be assessed, and the lower of the two RLs should be chosen. RLs for both carcinogenic and non-carcinogenic effects should be calculated and the lower of the two values should be chosen.

The RLs for direct contact with sediment is calculated using:

$$RLs = 1/[(1/RL_{dermal})+(1/RL_{oral})]$$

Cancer $RL_{oral} = [TR \times BW \times AT]/[EF \times ED \times (IRs/10^6) \times CSF]$

$RL_{dermal} = [TR \times BW \times AT]/[CSF \times SA \times AF \times ABS \times EF \times ED \times CF]$

Non-cancer $RL_{oral} = [THQ \times RfD \times BW \times AT]/[EF \times ED \times (IR/10^6)]$

$RL_{dermal} = [THQ \times RfD \times BW \times AT]/[SA \times AF \times ABS \times EF \times ED \times CF]$

Where,
TR = Target risk
THQ = Target hazard quotient

The RLs for bioaccumulation is calculated using:

$$RLs = C_b \times BSAF$$

Cancer $C_b = [TR \times BW \times AT]/[EF \times ED \times (IR_b/CF) \times CSF]$

Non-cancer $C_b = [THQ \times RfD \times BW \times AT]/[EF \times ED \times (IR/1000)]$

Where,
CF = conversion factor in g/kg

The following sections will address the different types of remedial actions that are appropriate for addressing contaminated sediments.

Section IV Developing Remedial Goals

A remedial goal, sometimes referred to as a RL, is a target chemical concentration or level of toxicity at which the exposure hazard is eliminated or reduced to an acceptable level. The RL is the concentration to which a contaminant or toxicity is reduced via cleanup.

A cleanup study, or remedial investigation/feasibility study, should be completed before remedial goals are proposed for a contaminated sediment site. Stakeholders must be involved early and often in the process for a realistic and effective remedy to be accomplished. To address cost and technical feasibility, areas and volumes requiring remediation must be estimated and preliminary screening of remedial options performed (see Section III.1.). Then considerations of net environmental benefits, cost, and technical feasibility must be balanced.

Remedial goals must be developed taking net environmental effects, cost, and technical feasibility into consideration. Given these factors, specific chemical contaminant concentrations cleanup goals are usually developed between an optimum no-effects level and a pre-established cleanup trigger level. Remedial options must be weighed and balanced to arrive at and systematically evaluate the sensibility of proposed remedial goals. They should be as close as practicable to the remedial goal, but in no case higher than the cleanup trigger level, and attainable in consideration of environmental effects, technical feasibility, and cost. The remedial goal must also meet all legally applicable federal, State, and local requirements. At CERCLA sites, in the state of Washington, for instance, sediment cleanups must comply with sediment quality standards established in the *Chapter 173-204* (Ref. I.3.1)*,* as an Applicable or Relevant and Appropriate Requirement (ARAR) (see below for further explanation).

Site-specific remedial goals may be developed using a three-step process. First, information from the cleanup study is analyzed to determine the potential for natural recovery and the volumes or areas of sediment that require cleanup. Second, the factors affecting the net environmental benefits, cost, and technical feasibility of the full range of remedial goals are identified. Finally, net environmental benefits, costs, and technical feasibility are weighed to determine an optimal remedial goal within the possible range of goals. Based on this information, sediment cleanup levels (remedial action objectives), are established on a site-specific basis within an allowable range of contamination.

The potential for natural recovery for each contaminant at the site is determined. The rate of natural recovery will be affected by the rate that contaminants are introduced into the environment by ongoing sources. If sources of contaminants to the site have been inactive for at least five years and historical sediment data are available for that time period, it may be possible to estimate natural recovery rates empirically using data collected during the hazard assessment and chemistry data collected during the cleanup study. If sources are ongoing or have recently ceased, or if historical sediment data are not available, a model may be used to estimate natural recovery in sediments. Such models incorporate site specific factors including source loading and sediment deposition rates. The bounds of uncertainty should be understood and described if a model is used.

Environmental benefits are the short- and long-term environmental and human health benefits resulting from a cleanup action. The net environmental benefit is that resulting from a cleanup action minus the short- and long-term impacts to the environment and human health that also result directly from the cleanup action. Net environmental benefit is, therefore, a measure of the actual benefits to be gained from cleanup of a site, considering both the positive and negative effects of cleanup on human health and the environment. Important benefits include the reduction of acute or chronic toxic effects and reduction of cancers and genetic defects in humans and the environment. Important impacts include the destruction or disturbance of benthic and aquatic communities and/or habitats.

Costs are monetary expenditures associated with cleanup of a site. Types of costs include the costs of planning, capital, materials, and labor required to perform the cleanup, and the costs of monitoring and maintaining the containment structures for wastes remaining onsite. Compared to net environmental benefits, the costs of cleanup are relatively easy to identify and estimate.

Technical feasibility is the ability of a remedial option to be implemented at a site. Components of technical feasibility include the option's ability to reduce volume, toxicity, or mobility of contaminants, the option's short- and long-term effectiveness, and the reliability of the technologies involved. Additional considerations include the availability of capping materials or disposal sites, and permit requirements. The federal Clean Water Act allows States to approve, condition, or deny projects proposed to be built in wetlands or in other waters of the United States. Projects that may result in a discharge to these waters must first receive a permit from one of several State and/or federal agencies. Section 401 of the Clean Water Act requires that applicants for those permits first receive certification from the State that the proposed project will meet State water quality standards and other aquatic protection regulations. Any conditions of the State's certification become conditions of the federal permit. The federal agency cannot issue its permit until the certification is approved, conditioned, or waived by the State. For dredging projects in the State of Washington, for example, applicants receiving a section 404 permit from the U.S. Army Corp of Engineers, a Coast Guard permit, or license from the Federal Energy Regulatory Commission (FERC), are required to obtain a section 401 water quality certification from the Department of Ecology. Issuance of a certification means that Ecology anticipates that the applicant's project will comply with State water quality standards and other aquatic resource protection requirements under Ecology's authority. The 401 Certification can cover both the construction and operation of the proposed project.

Methods for weighing net environmental benefit, cost, and technical feasibility range from subjective and qualitative narrative methods to highly complex economic analyses using a total value approach. Methods focus on a comparison of costs and net environmental benefits with technical feasibility brought into consideration during the evaluation of remedial options as a basis for developing preliminary costs and benefits.

The final remedial option is then selected to accomplish a remedial goal that is protective of human health and the environment as possible given the above considerations.

ARARs - The 1986 Superfund Amendments and Reauthorization Act adopted a provision in the National Contingency Plan (NCP) that remedial actions must meet ARARs, unless waived. Criteria for a State requirement to qualify as an ARAR are that it should be: a State law; an environmental or facility siting law; promulgated; more stringent than the federal requirement; identified in a timely manner; and consistently applied. The State of Washington, for example, has legally promulgated sediment quality and cleanup standards that are consistently recognized as ARARs by EPA for application at CERCLA sites in that State. Differences occur between the State and EPA occasionally over whether the state regulation in its entirely or only specific portions of it are applicable to CERCLA sites. Coordination between the State and federal agencies at an early stage on the identification of ARARs is critical to reach agreement and officially document the ARARs in planning documents (i.e., during the Feasibility Study).

State Standards - To establish a consistent approach for assessing and remediating sediment contamination, the State of Washington, for example, adopted the Washington Sediment Management Standards Chapter 173-204 (Ref. I.3.2) in 1991. This regulation provides chemical concentration and biological criteria by which sediment contamination is assessed and remediated in the State of Washington. The U.S. Environmental Protection Agency subsequently approved the Sediment Management Standards as water quality standards for application in the State of Washington, and they are routinely considered ARARs at CERCLA sites in that State.

An excerpt follows that describes sediment remediation goals in Washington State. Note that the terminology varies from that above, but is defined for implementation purposes:

WAC 173-204-570. Sediment cleanup standards.

(1) Applicability and purpose. This section establishes the sediment cleanup standards requirements for cleanup actions required under authority of Chapter 90.48 and/or 70.105D Revised Code of Washington (RCW), and/or this chapter, and describes the process to determine site-specific cleanup standards.

(2) Cleanup objective. The sediment cleanup objective shall be to eliminate adverse effects on biological resources and significant health threats to humans from sediment contamination. The sediment cleanup objective for all cleanup actions shall be the sediment quality standards as defined in WAC [173-204-320](#) through [173-204-340](#), as applicable. The sediment cleanup objective identifies sediments that have no acute or chronic adverse effects on biological resources, and which correspond to no significant health risk to humans, as defined in this chapter.

(3) Minimum cleanup level. The minimum cleanup level is the maximum allowed chemical concentration and level of biological effects permissible at the cleanup site to be achieved by year ten after completion of the active cleanup action.

(a) The minimum cleanup levels criteria of WAC [173-204-520](#) shall be used in evaluation of cleanup alternatives per the procedures of WAC [173-204-560](#), and selection of a site cleanup standard(s) per the procedures of this section.

(b) The Puget Sound marine sediment minimum cleanup level is established by the following:

(i) Sediments with chemical concentrations at or below the chemical criteria of Table III shall be determined to meet the minimum cleanup level, except as provided in (b)(iv) of this subsection; and

(ii) Sediments with chemical concentrations that are higher than the chemical criteria of Table III shall be determined to exceed the minimum cleanup level, except as provided in (b)(iii) of this subsection; and

(iii) Sediments with biological effects that do not exceed the levels of WAC [173-204-520(3)](#) shall be determined to meet the minimum cleanup level; and

(iv) Sediments with biological effects that exceed the levels of WAC [173-204-520(3)](#) shall be determined to exceed the minimum cleanup level; and

(v) Sediments which exceed the sediment minimum cleanup level human health criteria or the other toxic, radioactive, biological, or deleterious substances criteria or the nonanthropogenically affected criteria of WAC [173-204-520](#) as determined by the department, shall be determined to exceed the minimum cleanup level.

(4) Sediment cleanup standard. The sediment cleanup standards are established on a site-specific basis within an allowable range of contamination. The lower end of the range is the sediment cleanup objective as defined in subsection (2) of this section. The upper end of the range is the minimum cleanup level as defined in subsection (3) of this section. The site specific cleanup standards shall be as close as practicable to the cleanup objective but in no case shall exceed the minimum cleanup level. For any given cleanup action, either a site-specific sediment cleanup standard shall be defined, or multiple site unit sediment cleanup standards shall be defined. In all cases, the cleanup

standards shall be defined in consideration of the net environmental effects (including the potential for natural recovery of the sediments over time), cost and engineering feasibility of different cleanup alternatives, as determined through the cleanup study plan and report standards of WAC 173-204-560.

(5) All cleanup standards must ensure protection of human health and the environment, and must meet all legally applicable federal, state, and local requirements.

Federal Guidance - EPA's 2002 Memo, Principles for Managing Contaminated Sediment Risks at Hazardous Waste Sites (Ref. IV.1) included 11 Risk Management Principles for managing contaminated sediment risks at hazardous waste sites. These are:

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.*

Resources

The following resources may be useful for determining remedial goals:

- Development of Cleanup Action Alternatives that include Remediation Levels (Ref. IV.2)
- Sediment Cleanup Standards User Manual (Ref. IV.3)

Section V Remediation

Section V.1 Types of Remediation

The process of sediment site remediation should be addressed in the same manner as any other site, by using a State remedial or EPA's federal Superfund program.

Sediment remediation information can be found at the COE Web Page (Ref. V.1.1) and EPA's Contaminated Sediment Guidance for Hazardous Waste Sites (Ref. III.2.1).

Sediment site remediation is typically different than soil or groundwater remediation. Sediments are located in water and/or near shore areas. The remedial activities at a sediment site can be difficult because of staging near, in, or on the water.

Sediment site remedial options typically include dredging, excavation, capping, in-situ treatment, bioremediation, natural attenuation, and/or enhanced natural attenuation. Depending on the size, complexity, and contamination distribution; often more than one option can be used at the same time to achieve site cleanup goals. Each remedial option is briefly discussed below.

Section V.1a Dredging

Dredging typically involves the hydraulic or mechanical removal of sediments, see Ref II.2.1 (page 6-9), COE Dredge Web Page (Ref. V.1a.1), COE Dredging Operations & Environmental Research (DOER) (Ref. V.1a.2), COE Dredge Operations Technical Support (DOTS) (Ref. V.1a.3), and dredging animations at Take a Trip Through a Dredge! (Ref. V.1a.4).

Typically, hydraulic dredges (such as, cutterhead, horizontal auger, and plain suction) have devices to cut into the sediment (see Picture 1). Once the sediment is loose, then the dredge pump will pull the sediment and surrounding water into the dredge. The fluidized sediment are placed into a temporary scow or pumped via pipeline to a temporary or permanent facility.

Mechanical dredging is performed with a dredging bucket that is lowered (dropped) into the sediments (see Picture 2). While being raised, the dredge bucket closes and collects the sediment. The sediments are then placed into a scow for later disposal. Types of mechanical dredges include conventional clamshell and enclosed bucket. Also, some new types of mechanical dredge systems can also move sediments hydraulically with a pump(s) via a pipeline.

Picture 1: Hydraulic Dredge

Picture 2: Mechanical Dredge

Issues

- **Sediment Properties** – It is essential to understand the chemical and physical properties of the contaminated sediment's properties as much as possible before dredging. The selection of the optimal type of dredge equipment and disposal options can depend on the sediment properties. The type, size, and density of the sediment materials can limit the use of hydraulic dredging (i.e. dense material has limits in being pumped in a pipeline). Also, the grain size of the sediment will determine how prone it is to re-suspension during dredging. The finer-grained the sediments, the greater concern for re-suspension and movement of contaminants off-site.
- **Contamination Levels and Location** - Knowing the levels and locations (area and depth) of contamination is important to minimize the amount of under or over dredging of contaminated sediments because of the additional costs. A certain amount of over dredging is generally expected to ensure that the remedial objectives are achieved. More over-dredging is expected at sites where contaminant concentrations varies with depths, in small areas, and/or sites with variable bottom contours.
- **Location of Utilities, Debris, Boulders, and Bedrock** - It is extremely important to locate any utilities (such as, gas, electricity, water, sewer, and phone), debris, boulders, and bedrock before deciding to dredge. All of these may limit the amount of dredging that is possible in any given area. These types of obstructions can damage dredging equipment. Hitting and damaging a gas or electrical line could potentially be hazardous to the dredge operators. Depending on the amount and type, smaller size debris can be managed (see below "Sediment Re-suspension Caused by Debris Removal").

- **Field Trials** - Because of the expense of dredging, it is important to consider a field trial(s) for all large scale dredging projects, to ensure the dredge and other required equipment is appropriate for the remedy. Typically, it costs much more to re-start a project, than to consider contingencies before hand.
- **Changes to Bottom Typography** - Dredging will lower and change the bottom typography of the remaining surface. These changes are most dramatic at shoreline, near shore, an/or in shallow areas (such as, making tidal areas into subtidal). The depth and the water velocity can affect the type of plant and animal communities. Dredging can cause the complete removal of plant and animals. These changes can be mitigated by replacement of soils and plants in near shore and wetland areas. Depending on the site specific locations, replacement may not be necessary because plant and animals will return naturally. Consult with appropriate regulatory agency for mitigation or permit requirements**.**
- **Sediment Re-suspension Caused by Dredge** - Because of the nature of dredging, sediment movement will occur during dredging, see *Estimating Dredging Sediment Resuspension Sources* (Ref. V.1a.7), Assessment of Potential Impacts of Dredging Operations Due to Sediment Resuspention (Ref. V.1a.8), and, Summary of Measurement Protocols for Sediment Resuspended from Dredging Operations (Ref. V.1a.9). Re-suspension of sediments at highly contaminated sites may result in dredging residue that exceeds site remediation goals. Particular care should be taken at such sites to minimize re-suspension or over-dredge to achieve cleanup goals. Hydraulic dredging, in most cases, has been shown to have less sediment movement. However, both types of dredging operations will have some losses because of the dredging. Also, there may be additional sediment movement from the support activities. Depending on the depth of the dredging, propeller prop wash can disturb the sediment enough to move sediment. Sediments can also be moved because of placement and removal of anchors and spuds, and the removal of debris. Proper positioning of equipment can minimize sediment suspension from prop wash, and anchor and spud placement. Generally, increasing the depth of water can reduce or eliminate the re-suspension from prop wash. If possible, dredging should start upstream and finish downstream. This approach is most useful at a river location.
- **Sediment Re-suspension Caused by Debris Removal** - Sediments can be re-suspended because of the debris removal. Debris removal can be difficult depending on the amount and type (size, shape, weight.) of material (see Picture 3). Debris is sometime removed before dredging starts and is generally required before hydraulic dredging. If debris is not removed it can affect dredging production and significantly increase sediment losses material (see Picture 4). When removing debris or dredging near piers and pilings, care should be taken to avoid pulling on ropes and/or cables that may be attached to the piers or pilings because these could be damaged.

For more on Debris Removal see Equipment and Processes for Removing Debris and Trash from Dredged Material (Ref. V.1a.10).

Picture 3: Debris

Picture 4: Debris in Dredge

- **Sediment Re-suspension after Dredging** - Sediment sites can have contamination spread over large areas. Because of this and the high cost, dredging is generally limited to areas of the largest contaminant concentration(s). This can result in potentially large less contaminated area(s) that are not remediated. Sediment re-suspension can occur at various times after dredging and be the result of sloughing, windrowing, re-suspension, and unidentified target material. It is very difficult to accurately predict the contaminant concentration and thickness of dredge residue left after utilizing various dredging technologies. Therefore, if dredging is selected as a sediment remediation method, a plan to manage residual contamination should be developed. Post dredging and long term monitoring should be performed to evaluate residual contaminant levels post remediation and determine dredging effectiveness.

Additional Factors to Consider to Minimize Re-suspension

- **Hydraulic Dredging Percent Solids and Production Rates** - The potential for re-suspension and leaving contaminated residue is reduced by reducing the percent solids in the dredge slurry and increasing the production rates. However, this can significantly increase the volume of dredge water that must be treated and handled. The dredging operation should be designed to minimize re-suspension, while taking cost of water treatment into consideration.
- **Cutter Head Design and Swing Rate** – The type of cutter head affects the amount of re-suspension that occurs, and the faster the swing rate of the head the more sediment will be suspended in the water column. However, slow swing rates will also prolong the dredging activity. Again, the dredging operation should be designed to minimize re-suspension as much as possible, while taking the cost of dredging time into consideration.

Possible Methods for Residue Management to Minimize Re-suspension

- **Multiple Pass Dredging** – Multiple pass dredging can remove contaminant residue left by deposition of sediments suspended in the initial dredging operation. The cost of multiple pass dredging should be balanced against the additional contaminant reduction achieved.
- **Over-Dredge Allowances** – Setting a specific over-dredge allowance for a dredge contractor may minimize residual contamination that is a result of missed target material. By doing this, a dredge contractor may be more likely to achieve a specified "neat line" elevation without being penalized for minimal over dredging.
- **Environmental-specific Mechanical Dredge Buckets** - These types of dredge buckets have gasket sealed joints and hydraulic pressure release valves that are specifically designed to minimize sediment suspension during mechanical dredging. Bucket rinse tanks are also used to remove sediment from the bucket between each scoop.
- **Specially Designed Cutter Heads and Shrouds** - This type of cutter head dredge may control re-suspension of sediments and reduce residual contamination.
- **Silt Curtains** - Depending on the site conditions, silt curtains may be appropriate to control sediment movement. Silt curtains are most effective if they can be placed once, since placement and removal of silt curtains can cause sediment re- suspension. Generally, silt curtains work best if they are not in contact with the bottom, which can cause sediment suspension in tidal and faster moving river locations. For more on silt curtains see Silt Curtains as a Dredging Project Management Practice (Ref. V.1a.10).
- **Post Dredge Cover or "Dilution Cap"** - This can be utilized where residue management efforts are not expected to meet site remediation goals, a post-dredge cover or "dilution cap" can provide the means to reduce potential exposures to the residual contamination.

Resources

- Innovations in Dredging Technology: Equipment, Operations, and Management – April 2000 (Ref. V.1a.5)
- Innovations in Dredging Technology: Equipment, Operations, and Management – February 2000 (Ref. V.1a.6)

Section V.1b Excavation

Sediments can be removed by excavation from the upland shoreline or by isolating an area to make it dry with dams or sheetpile walls. Besides excavation equipment, sediment transport equipment (typically trucks) will be required. Sometimes in river or stream excavations, the river is blocked upstream and downstream. This will generally require the water to be diverted around the area being excavated.

Specialized equipment (i.e. vehicles with low impact tires) and mats should be used to minimize damage to wetland areas. Generally, excavation when the ground is frozen can help limiting the damage to the non-contaminated areas from equipment. Typically, restoration of vegetation and wetlands are done at the locations of contamination removal and damaged areas caused by vehicles and equipment.

Section V.1c Capping

Capping involves covering sediments with the proper type and amount of material to prevent the movement of contamination. Typically, a cap should be placed in a location where the cap will not move (i.e. low flow areas) nor interfere with access to utilities or structures. Cap design and construction will need to include a variety of considerations. The physical properties of the sediment in the area to be capped needs to be determined prior to cap placement. The proper placement of the cap material is critical to the success of the remediation. Generally, cap material is placed slowly over the contaminated area to prevent contamination migration. The more unstable the contaminated area, the slower the initial cap placement will need to be. Sometimes caps are placed in layers (or lifts) and each layer is allowed to consolidate. The cap material has to be the correct size and density range to prevent the cap and contaminated material from moving. Sometimes heavier material is placed on the top to protect the cap. The cap has to be correct thickness to ensure the contaminated sediments are isolated and to prevent the contaminants from migrating through or around the cap.

Unless the contaminated area is deep, capping is generally not done near navigation areas. Any capped area should be monitored to determine that there is no contamination migration through or around the edge of the cap.

Issues

- **Changes to Bottom Typography -** Capping will change the bottom typography of the surface. This is most important in navigational channels and at shoreline, near shore, or shallow areas. The depth and the velocity of the water can affect the type of plant and animal communities. Capping in shallow areas can cause significant changes to the plant and animal habitats. Depending on the site specific locations, replacement may not be necessary because plant and animals may return naturally. Consult with appropriate regulatory agency for mitigation requirements. Marine charts may need to be updated depending on the extent of impact to navigational area.
- **Potential Biologically Active Zone (BAZ) of Sediments** - The BAZ is the upper layer of the sediment in which both plants and benthic organisms are active. It is necessary to understand the site specific BAZ to determine the

thickness of post remediation sediments that must meet cleanup goals to remain protective for human and ecological receptors. For a capping remedy, the lower portion of the cap material is often referred to as the Isolation Zone (IZ). The IZ is the portion of the cap that prevents the underlying contamination from moving by advection or diffusion into the BAZ above the acceptable protective level. The BAZ-portion of the cap becomes the new ecological substrate for benthic invertebrates and rooted aquatic plants. Aquatic plants can uptake contaminants through their root systems causing direct toxicity or transferring them up the food chain. Their root systems and root channels can also cause preferential groundwater flux. Similarly, benthic organisms can burrow into contaminants, creating pathways for contaminant migration or transfer up the food chain. Therefore, the BAZ and IZ must be properly scaled to prevent site flora and fauna from encountering site contaminants.

- **Ice and Freeze/Thaw Effects on Sediments -** Ice movement and freeze/thaw events can have a substantial affect on soft sediments and cap materials. Ice push and ice heave due to wind driven movement, thermal expansion, or currents can affect contaminated sediment distribution and cause substantial damage to in-situ remedial caps. Also, the freeze/thaw process can cause ice intrusion, ice wedges, matrix alterations, and permeability/hydraulic conductivity changes.
- **Factors to consider when evaluating potential for ice effects include:**
  - Wind fetch distances,
  - Basin characteristics,
  - Snow cover (thermal insulation),
  - Temperature fluctuation, and
  - Existing evidence of ice damage or ice push events

Resources

The following resources may be useful:

- U.S. EPA Guidance for In-Situ Subaqueous Capping of Contaminated Sediments (Ref. V.Ic.1)
- Equipment and Placement Techniques for Subaqueous Capping (Ref. V.Ic.2)
- Guidance for Subaqueous Dredged Material Capping (Ref. V.Ic.3)
- Hazardous Substance Research Center South & Southwest In-situ Capping Primer (Ref. V.Ic.4)
- Subaqueous Capping and Natural Recovery: Understanding the Hydrogeology setting at Contaminated Sediment Sites (Ref. V.Ic.5)
- Subaqueous Cap Design: Selection of Bioturbation Profiles, Depths, and Process Rates (Ref. V.Ic.6)

Section V.1d In-Situ Remediation

In-situ remediation involves an active remedy in-place. This type of remedy is best suited for contaminants that can be broken down chemically or biologically (see Section V.1e), absorbed, or encapsulated. In general, these types of remedies are not considered fully developed. However, there have been several pilots study tests of these types of remedies.

Section V.1e Bioremediation

Depending on the type of contamination (i.e., materials that will degrade within a reasonable time frame), bioremediation can be utilized to beak down the contaminants. Typically, additional nutrients or specific microbes are required to perform bioremediation. Bioremediation has been more successful in certain soil and groundwater remediation scenarios than sediment remediation. Bioremediation will not reduce metal contamination. Because of the extra cost of moving sediments and biological treatment systems, bioremediation is generally done in-situ. A monitoring program may include sediment sampling, and monitoring the contamination levels and any breakdown products resulting from the bioremediation.

Issues

- **Selection of Bacteria** - The selection of the correct type of bacteria is critical to successful bioremediation. The type(s) of contaminant(s) will dictate the type of bacteria. Because the final breakdown products must be less toxic than the original contaminants, the mechanism of the breakdown process must be understood. It is also important that all intermediate breakdown products not be significantly toxic or more mobile than the original contaminant(s). The bacteria selected must not be toxic to local plants and animals, or humans. A laboratory study should be conducted to determine the breakdown mechanism and final breakdown products. A pilot study at the site should be done before attempting large scale bioremediation because field conditions can be significantly different than laboratory conditions.

Section V.1f Natural Attenuation

Natural attenuation is also known as Monitored Natural Attenuation (MNA). EPA describes the natural attenuation processes to "…include a variety of physical, chemical, or biological processes that, under favorable conditions, act without human intervention to reduce the mass, toxicity, mobility, volume, or concentration of contaminants in soil or groundwater. These *in-situ* processes include biodegradation; dispersion; dilution; sorption; volatilization; radioactive decay; and chemical or biological stabilization, transformation, or destruction of contaminants."

from Use of Monitored Natural Attenuation at Superfund, RCRA Corrective Action, and Underground Storage tank Sites (Ref. V.1f.1). MNA requires modeling and monitoring to prove its effectiveness as a remedy.

Resources

The following resource may be useful:

- Development of DoD Guidance for Monitored Natural Recovery at Contaminated Sediments Sites (Ref. V.1f.2)

Section V.1g Enhanced Natural Attenuation

Enhanced natural attenuation involves minimal human intervention to dilute contaminant concentrations by adding a "thin layer cap" and then letting the *in-situ* natural processes take place as described in the previous paragraph. The "thin layer cap" does not actually isolate the underlying sediment contamination, but effectively reduces it to immediately limit the exposure hazard. As with capping, considerations should include placing the "thin layer cap" in areas of minimal or no flow potential, and non-navigational areas. As with MNA, a monitoring program is needed to determine the remedy's effectiveness.

Resources

- In-Water and Riparian Management of Sediment and Dredge Material (Ref. V.1h.1) **-** Intended for management of sediments from channel (navigational) dredging, this document provides guidance to minimize the impact of contaminated sediments during dredging, and through underwater or shoreline burial. Numerical screening values are included for select contaminants.

Section V.2 Monitoring During Remedial Actions

The goals and objectives of monitoring during contaminated sediment remedial actions are to ensure protection of human health and the environment. Monitoring may involve sediment, water and biota sampling depending on the type of remedial action. The monitoring should be designed to address any corrective actions that may be needed during the remedial action.

Various types of monitoring should be considered during sediment remedial activities, such as, environmental, equipment performance, and confirmatory monitoring. Environmental monitoring is encouraged during the time of the remedial action to ensure that human health and the environment are adequately protected during these periods. Performance monitoring is done to ensure that the remedial equipment is working optimally and to ensure that permit conditions/performance standards are being achieved. Conformation monitoring is typically conducted immediately after active remedial activities are completed, in order to confirm that the remedial goal(s) and necessary permit conditions have been attained. Conformation monitoring can be done as sections of the site are remediated.

Monitoring plans should be developed prior to the remedial action and contain the following elements: 1) a sampling and analysis plan which details the parameters, such as sampling frequency and methods; 2) data analysis and evaluation procedures to be used to demonstrate and confirm that remedial action goals are met and to evaluate data trends (i.e. Quality Assurance/Quality Control); 3) justification for these procedures, including a description of any statistical methods to be employed; and 4) a contingency plan of action in the event that monitoring data indicate the remedial action is out of compliance and appropriate modifications are needed.

Providing real-time monitoring during remedial action for chemical constituents is challenging. In general, chemical monitoring results will lag remedial actions by a day or more. Many sediment remediation projects have attempted, using a surrogate, to generate a relationship to actual chemical constituents. The most common real-time parameters measured are Total Suspended Sediment, Total Suspended Solids, and turbidity. An important point to consider is that each sediment site will be different and so it is not possible to describe or use a generic monitoring program. Each monitoring plan should be developed based on site specific conditions and the chemical contaminants of concern.

Typically, three types (or a combination) of remedial actions are possible at contaminated sediment sites. The following discusses potential monitoring considerations during remediation of contaminated sediment sites.

Monitoring for post remedial activities is found in Section VI.

Section V.2a Design Sampling and Monitoring During Dredging

Typically, design and post-dredging sediment sampling is performed. The design sediment sampling is used to more accurately determine the depth and locations that require dredging. This is not necessarily the same as the sampling used in assessment, which is used to determine if a site requires a remedial action. The design (or pre-dredge) sampling is particularly important because a large amount of over dredging can significantly increase the amount of sediment to be processed and disposed, thus increasing the cost. Also, dredging is generally disruptive of the ecosystem at and near the dredging location, so limiting the dredging to exactly what is required can help limit any unnecessary ecological damage. Post-dredging sediment sampling should be done to confirm that the dredging was completed and that cleanup goals have been achieved. Depending on the post dredging sampling results adding dredging may be required.

The main concern with monitoring while dredging generally deals with the re-suspension of sediments (clean and contaminated). Monitoring chemical constituents and physical parameters (i.e. turbidity) sampling can be used to evaluate and regulate re-suspension caused by dredging. The sampling location to demonstrate compliance should be chosen carefully and allow a mixing zone.

Issues

- **Monitoring Frequency** - Real-time monitoring for turbidity is performed at the dredge and designated locations near the dredge. This information is used to evaluate and control dredging. Analytical results for chemical constituents will likely take 24 hours (or more) after the sampling is performed. Costs can be considerably higher for faster results. Close evaluation of dredging should be performed to allow for correct interpretation of the results. Sampling frequency should be decided based on the chemical constituents and site specific concerns. The monitoring should be used to evaluate project compliance. One alternative would be to gather more sampling data during the start of the project and reduce the frequency once dredging is at a consistent production rate. This would provide a basis to modify the monitoring frequency (increasing or decreasing) based on actual data. The sampling location to demonstrate compliance should be chosen carefully and allow for a mixing zone.
- **Monitoring Factors** - Factors to consider while monitoring included: depth of dredging; cleanup goals for chemical constituents; controlling the rate of dredging to maintain water quality goals; and measuring quantity of sediment and the chemical contaminants removed.

Section V.2b Monitoring During Capping

Monitoring during capping should include measuring the re-suspension of capping materials and contaminated materials, the thickness of the cap, and chemical constituents in the biologically active layer. The biologically active layer will depend on the organism(s) and substrate present.

Issues

- **Monitoring Area and Thickness** - Evaluation of the caps effectiveness should be performed during capping. The cap thickness should be monitored during the capping and compared to the minimum cap thickness to ensure the remedial goals are achieved. Cleanup goals for chemical constituents after the cap has been placed should be established.
- **Water Quality** - A major issue during capping can be trying to maintain water quality goals. The rate of cap placement may help in maintaining water quality (i.e., a slower rate of placement may cause fewer water quality concerns).

- **Real Time Monitoring** - The results of real-time monitoring of chemical constituents may be at least 24 hours after sampling is performed, and the cost for faster turnaround of results is much higher. Care should be taken when considering the amount of real-time monitoring to be performed.

Section V.2c Monitoring for Monitored Natural Recovery or Monitored Natural Attenuation

A monitoring plan should be developed that includes monitoring for chemical constituents, biological testing, and physical parameters for site specific conditions. The goal of this monitoring is to test the hypothesis that natural processes are continuing to perform at a rate that is expected to reduce contaminant concentrations in media (sediment, water or biota) to an acceptable level in a reasonable time frame. Monitoring results should be compared to any models used in determining that Monitored Natural Attenuation or Recovery was the appropriate remedy.

Where the cleanup action includes engineered controls or institutional controls, the monitoring may need to include not only measurements but also documentation of observations on the performance of these controls.

Resources

- Evaluation of Dredged Material Plumes Physical Monitoring Techniques (Ref. V.2.1)
- Acoustic Monitoring of Dredging-Related Suspended-Sediment Plumes (Ref. V.2.2)
- Improving Methods for Correlating Turbidity and Suspended Solids for Monitoring (Ref. V.2.3)

Section V.3 Disposal Capacity and Cost of Dredged/Excavated Material

Disposal capacity and the cost of disposal often play a major role in decisions made for sites in the later phases of cleanup, namely the feasibility phase, which identifies potential cleanup and disposal alternatives for contaminated material. These alternatives include confined aquatic disposal, confined near-shore disposal and upland disposal options, all of which have unique considerations and costs.

Section V.3a Sediment Disposal

Once dredged or excavated, sediments need to be properly disposed. If sediments are disposed in off site facilities (i.e. soil or hazardous waste landfills), the facility's requirements need to be met. Some States have restrictions on placing sediments in landfills because of the physical properties of sediment (i.e. consolidation can be a concern with sediment). The project manager should check the facility license requirements and/or appropriate State regulations. Because of the high cost, contaminated sediments are typically not disposed in Hazardous Waste (RCRA) facilities.

If sediments are disposed on site, Confined Disposal Facilities (CDFs) and Confined Aquatic Disposal (CAD) facilities are potential options. A CDF can be placed adjacent to the shoreline or be made into an island. Because a CDF is a disposal facility, the CDF should be constructed and maintained properly to ensure lasting effectiveness. One potential benefit of a CDF is the creation of potential land for marine or conservation uses. A CAD is created by:

1. Removing any top contaminated sediments;
2. Removing the clean material (typically sediment or sand) and properly disposing of the clean material;
3. Placing the contaminated sediments into the CAD; and
4. Placing clean cap material on the top of the CAD. (There are some CADs that are not capped).

Once created, a CAD should be considered a permanent facility. CAD locations can potentially be limited. CADs placed in navigational channels would need to be constructed so the top of the CAD will not interfere with future navigational dredging or be disturbed by navigational activities (i.e., dropping anchors, prop wash). The project manager should check any appropriate State/federal regulations regarding all onsite disposal facilities for contaminated sediments or off site disposal of any clean material or contaminated material.

Resources

- Confined Disposal Facility (CDF) Containment Features: A Summary of Field Experience (Ref. V.3a.1)
- Overview of Processes Affecting Contaminant Release form Confined Disposal Facilities (Ref. V.3a.2)
- Liner Design Guidance for Confined Disposal Facility Leachate Control (Ref. V.3a.3)

Section V.4 Beneficial Use

With the large volumes of material dredged for all purposes, including maintenance of navigation, there is considerable interest in beneficial use of dredged sediment as an alternative to in-water, shoreline or upland disposal. The cost savings from beneficial use of sediment dredged for remedial purposes could facilitate another remedial project. Dredged sediments, depending on their physical properties, can be used in place of conventional sand, gravel, commercial fill, or topsoil, or as feedstock for production of Portland cement or lightweight aggregate in kilns. Contaminants of concern for the remedial project may not preclude one or more of these beneficial use options. Possibilities for beneficial use should be considered alongside any remedial alternative (including dredging). Early data gathering and risk evaluation will facilitate acceptance of beneficial use both on the governmental and public levels.

Resources

The following resource may be useful:

- Dredged material Characterization Tests for Beneficial Use Suitability (Ref. V.4.1)
- Screening Tests for Assessing the Bioreclamation of Dredged Material (Ref. V.4.2)
- Determining Recovery Potential of Dredged Material for Beneficial Use – Soil Separation Concepts (Ref. V.4.3)
- Determining Recovery Potential of Dredged Material for Beneficial Use – Site Characterization; Prescriptive Approach (Ref. V.4.4)
- Determining Recovery Potential of Dredged Material for Beneficial Use – Site Characterization: Statistical Approach (Ref. V.4.5)
- Reclamation and Beneficial Use of Contaminated Dredge Material: Implementation Guidance for Select Options (Ref. V.4.6)

Section V.5 Permitting Requirements and Compensatory Mitigation Projects

Most sediment remediation projects involving dredging, capping, or sediment disposal require obtaining multiple permits from authorities such as the U.S. Army Corps of Engineers, State Natural Resource Agencies, U.S Fish and Wildlife Service, and other local governmental units (such as conservation agents). Often the permits or substantive requirements will require that on-site or off-site mitigation projects be completed to compensate for loss or conversion of habitat types and ecological services.

Meeting the permitting conditions or substantive requirements will vary by region and State. It is particularly important to open communication early with any and all relevant local, State, federal (and sometimes tribal) agencies in order to include compliance with these requirements in the project timeline and work plan. The following are important factors and considerations:

- Wetland delineation
- Wetland and aquatic vegetation surveys
- Aquatic invertebrate assemblage and abundance surveys
- Substrate type and quality before and after remediation/restoration
- Ecosystem functions and values assessment
- Remediation/restoration effects on commercial and recreational navigation
- Existing land use and land use planning/zoning

- Water Quality Certification
- Historic or Cultural Resources

Resources

- Environmental Windows Associated with Dredging Operations (Ref. V.5.1)

Section VI Post-Remedy Considerations

Remedy alternatives, other than off-site contaminant removal below any risks, may require post-remedial considerations such as, Operations and Maintenance (O&M), monitoring, and possible contingency actions to assure that ARARs, RAOs, and Cleanup Levels that apply to the alternative are fully achieved and maintained over time. These post construction activities may be subject to approval by the federal or State agencies. The types of post-construction activities will depend on the remedy used. The following sections discuss some aspects of post-construction activities.

A monitoring plan should be developed to include monitoring for chemical constituents, biological testing, and physical parameters for site specific conditions. Where the cleanup action includes engineered controls or institutional controls, the monitoring may need to include not only measurements but also documentation of observations on the performance of these controls. Long-term monitoring should be required if on-site disposal, such as a confined aquatic disposal or capping is the selected cleanup action. These measures should follow a regular schedule until residual contaminant concentrations no longer exceed remedial goals for an established period, and standards have been attained.

While the main focus of this paper is sediment sites that have State oversight. States could also have O&M obligations (include monitoring) at EPA Fund lead Superfund Sites (NPL). So even at Superfund Sites, States may find the following information useful. Also, if contaminants are left on-site, the EPA is required to perform a review (i.e. Five Year Review) for protectiveness and compliance with ARARs at least every five years.

Section VI.1 Post-Remedy Considerations for Dredging

A remedy involving off-site disposal of dredged sediment should require the least post-construction monitoring, O&M, and contingency actions due to the substantial reduction of long-term risk resulting from the mass removal of contaminated sediment from the site. However, biota may need to be monitored after dredging to determine if the biota that was disturbed during dredging has recovered.

Section VI.2 Post-Remedy Considerations for Capping

Remedy alternatives involving on-site capping and containment of contaminated sediments will be expected to meet ARARs, RAOs, and cleanup levels for the duration of storage or containment of contaminated sediments at the site. Thus, such remedy alternatives will require long-term monitoring to confirm that RAOs and cleanup levels are being met, and to detect non-compliance. They will also require O&M of the capping and containment structures to assure long-term integrity and functionality of the remedy. Finally, such remedies will also require planning and implementation of contingency actions to respond to circumstances where the integrity or functionality of the remedy may be compromised.

Long-term monitoring requirements that would apply to on-site capping and containment of contaminated sediments could include, among other things, monitoring to assure that the CAD and/or cap meets RAOs, cleanup levels and ARARs as discussed in this Section, by collecting and analyzing sediment, biota, and sediment pore water using equilibrium calculation and groundwater samples. Details of long-term monitoring requirements will be set forth in the O&M Plan. The O&M Plan should include an estimate of the cost to carry out the long-term monitoring activities required by the plan.

Because the caps should be sufficiently designed to prevent potential migration of impacted groundwater migration to surface water, monitoring of the groundwater monitoring adjacent to the cap would not be required. Where caps are not present adjacent to upland areas of contamination, ground water monitoring to demonstrate protectiveness of surface water will be necessary.

An O&M plan will be required for all remedy alternatives, which sets forth the measures that will be taken to assure the maintenance, integrity and functioning of the remedy components in order to provide long-term protection of public health and the environment. The plan will include, as appropriate for the alternative that is selected, maintenance requirements for the CAD, caps, post-remediation bathymetry, habitat substrate, benthic invertebrate recolonization, and wetland establishment. The O&M plan must include a cost estimate for performing the activities included in the O&M plan.

In addition, a contingency action plan will be required for a remedy that involves on-site, long-term capping or containment of contaminated sediments. The contingency action plan must provide for specific measures that will be taken to promptly and appropriately address circumstances and events that are not addressed by routine O&M and that pose a substantial threat to the continuing integrity and protectiveness of the remedy. At a minimum, the contingency action plan should include the following requirements:

- If bulk sediment or calculated pore water in the cap or biota fails to meet the RAOs and cleanup levels, the following contingency actions will be implemented:

- A work plan to further determine the extent and magnitude of the exceedance must be submitted to the agency within 30 days of documented noncompliance.
- A remedial plan to bring the sediment remedy back into long-term compliance must be submitted to the agency within 90 days of documented noncompliance. The plan must consider potential permitting and mitigation issues for the recommended actions.

- Implementation of the remedial plan shall commence within 30 days after approval of the plan by the agency, which may include modifications deemed reasonable and necessary by the agency.

The contingency action plan must include estimates of the cost to carry out the activities required by it. Contingency action does not include complete replacement of any major remedy component with a different component. If such complete replacement becomes necessary, it should be considered an additional remedial action subject to the selection process applicable under Superfund and any other governing legal documents.

Resources

See Section V.1c for references on post-construction capping.

Section VI.3 Post-Remedy Considerations for On-Site Disposal Facilities

Long-term monitoring should be required for on-site disposal facilities, such as an in- water CADs or shore CDFs. CAD monitoring can be similar to cap monitoring (see Section V.1c), since it is the same type of remedy. CAD monitoring should include measuring cap thickness and may included chemical and biota monitoring. CDF monitoring should include leachate or groundwater monitoring of the chemicals of concern. CDFs should be inspected regularly to make sure the structure is sound, particular if the CDFs are in areas with severe weather. All on-site disposal options should be inspected after any major weather event such as a hurricane or tornado.

Resources

- Overview of Processes Affecting Contaminant Release from Confined Disposal Facilities (Ref. VI.3.1)

Section VI.4 Institutional Controls

Institutional controls are measures undertaken to limit or prohibit activities that may interfere with the integrity of an interim action or cleanup action or that may result in exposure to hazardous substances at a site.

Where the cleanup action includes engineered controls or institutional controls, the monitoring may need to include not only measurements but also documentation of observations on the performance of these controls. Long-term monitoring should be required if on-site disposal, such as a CDF or capping, is the selected cleanup action. These measures should follow a regular schedule until residual contaminant concentrations no longer exceed remedial goals for an established period.

Section VI.4a Protection of Remedy

A remedy could be made protective by placing activities and uses limitations on the land and/or water. For example, with near-shore or upland disposal facilities, restrictions could limit or eliminate construction activities, digging, and/or other activities that may disturb the contaminated materials in the disposal facilities. A deed restriction or notice may be adequate for an upland property. For in-water remedies, such as cap or CADs, restrictions can be more difficult because of ownership issues (i.e., typically States may have trusteeship or ownership for in-water locations). Placing the restricted areas on navigational charts may help keep boats out of the cap or area of concern. Also, navigational buoys and/or warning flags may help in warning boats.

Effective institutional controls require proper monitoring and in some cases, may require enforcement. The State or local authorities should know what the controls require and have the ability to take enforcement actions.

Section VI.4b Fishing Restrictions

One typical institutional control to protect human health is to place restrictions or bans on fishing (including shellfishing) in contaminated areas. Sometimes, instead of a complete ban, warnings are placed on locations and types of fishing. Generally, placement and maintenance of appropriate signs are an important component of fish restrictions. Signs need to be posted using multiple native languages. Use of signs with symbols and words are generally used. Signs and lettering should be large enough to be seen from a distance.

Issues

- **Placing Fish Restriction** - Placement of restrictions is typically a State or local issue. State environmental or health agencies generally have regulatory powers to place restrictions. Some communities also have the ability to restrict shellfishing through local ordinances.
- **Monitoring and Enforcing Restrictions** - Generally, the main problems with fishing restrictions are with the monitoring and enforcement. Typically, State and local governments do a good job enforcing shellfishing restrictions. Most coastal communities have shellfish wardens, which can be financed by shellfish licenses. Other types of fishing enforcement can be difficult because of due to the lack of local jurisdiction or enforcement authorities.

States can have difficulties with monitoring and enforcement due to limited staff and the large size of the areas for which they are responsible.

- **Maintaining Signs** - Placement of warning signs can have limited affect. Signs should be placed where they can not be stolen or damaged. Signs need to be periodically monitored to make sure they are in the right place and the sign has not faded in the sun.
- **Educational Programs** - Depending on the type of fishing (e.g., subsistence, recreational, or commercial) an educational program can be helpful in enforcing about the fishing restriction, see the New Bedford Harbor Superfund Site Fish Smart Campaign (Ref VI.4b.1). Commercial fishermen typically have the best incentive to comply with fishing restrictions, since non-compliance could mean the loss of their license. Compliance by recreational or part-time fishermen often depends on agency outreach. Subsistence fishermen can be low income and/or from immigrant communities that either can not understand the risks or warning signs.

References and Web Links

Section I.	**Introduction**
I.1	U.S. Army Corps of Engineers (COE) Environmental Laboratory Web Page, http://el.erdc.usace.army.mil/index.cfm
I.2	U.S. Army Corps of Engineers (COE) Center for Contaminated Sediments Web Page, http://el.erdc.usace.army.mil/dots/ccs/
I.3	U.S. Environmental Protection Agency (EPA) Superfund Sediment Resource Center Web Page, http://www.epa.gov/superfund/resources/sediment/ssrc.htm
I.4	Sediment Management Work Group (SMWG) Web Page, http://www.smwg.org/
I.5	Remediation Technologies Development Forum (RTDF) Sediments Remediation Action Team Web Page, http://www.rtdf.org/public/sediment/default.htm
I.6	Hazardous Substance Research Centers (HSRC)/South & Southwest, Georgia Tech Research Corporation Web Page, http://www.sediments.org/
Section I.1.	**What is ASTSWMO?**
I.1.1	Association of State and Territorial Solid Waste Management Officials (ASTSWMO) Web Page, http://www.astswmo.org/
Section I.3	**Purpose of the Guidance**
I.3.1	Model Toxic Control Act, State of Washington, http://www.ecy.wa.gov/programs/tcp/smu/sediment.html
I.3.2	*Sediment Management Standards* (Chapter 173-204 WAC), The Washington State Department of Ecology, http://www.ecy.wa.gov/biblio/wac173204.html
Section II.	**General Considerations in Planning and Implementing Sediment Assessment and Remediation Projects**
II.1	*Guidance of Conducting Remedial Investigations and Feasibility Studies Under CERCLA*, EPA 540/G-89/004, OSWER 9355.3-01, Oct 1988, http://www.epa.gov/superfund/resources/remedy/pdf/540g-89004-s.pdf
Section II.1	**Steps in Planning and Implementing Sediment Assessment and Remediation Project**
II.1.1	*Managing Lakes and Reservoirs,* North American Lake Management Society, Third Ed., 2001
II.1.2	*Citizen Participation in New York's Hazardous Waste Site Remediation Program: A Guidebook*, New York State Department of Environmental Conservation, June 1998, (Document currently being revised check website for updated version www.dec.ny.gov)
II.1.3	*Superfund Community Involvement Handbook*, EPA 540-K-01-003, April 2002, http://www.epa.gov/superfund/tools/cag/ci_handbook.pdf

Section II.2 Identify Funding Sources

II.2.1 U.S. Environmental Protection Agency (EPA) Superfund Web Page, http://www.epa.gov/superfund/

II.2.2 U.S. Coast Guard National Pollution Funds Center Web Page, http://www.uscg.mil/hq/npfc/About Us/index.htm

II.2.3 Office of Surface Mining, Abandoned Mine Land Program Web Page, http://www.osmre.gov/aml/intro/zintro2c.htm

Section III.1 Overview of the Conceptual Site Model and Risk Assessment

III.1.1 EPA, 1996. *Soil Screening Guidance Quick Reference Fact Sheet*, EPA/540/F-95/041, December 1996, http://www.epa.gov/superfund/resources/soil/fact_sht.pdf

Ecological Risk Assessment

III.1.2 U.S. Navy Ecological Risk Assessment Guidance and Resources Web Page, http://web.ead.anl.gov/ecorisk/methtool/

III.1.3 *Ecological Risk Analysis: Guidance, Tools and Applications*, Oak Ridge National Laboratory Web Page, http://www.esd.ornl.gov/programs/ecorisk/ecorisk.html

III.1.4 Tri-Services Ecological Risk Assessment Workgroup (TSERA-WG) Web Page, http://chppm-www.apgea.army.mil/erawg/

III.1.5 *Guidelines for Ecological Risk Assessment*, EPA/630/R095/002F, April 1998, http://cfpub.epa.gov/ncea/cfm/recordisplay.cfm?deid=12460

III.1.6 *Ecological Risk Assessment Guidance for Superfund: Process for Designing and Conducting Ecological Risk Assessments – Interim Final*, EPA 540-R-97-006, OSWER 9285.7-25, PB97- 963211, June 1997, http://www.epa.gov/oswer/riskassessment/ecorisk/ecorisk.htm

III.1.7 *Guidance Manual to Support the Assessment of Contaminated Sediments in Freshwater Ecosystems, Volume I – An Ecosystem-Based Framework for Assessing and Managing Contaminated Sediments*, EPA-905-B02-001-A, December 2002, http://www.cerc.usgs.gov/pubs/sedtox/volumeI.pdf

III.1.8 *Ecological Risk Assessment Guidance*, Alaska Department of Environmental Conservation, Spill Prevention and Response Division, Series 1, Fact Sheet #9, February 2004, http://www.state.ak.us/dec/spar/csp/guidance/eco_risk.pdf

III.1.9 State of California Ecological Risk Assessment Guidance, http://www.dtsc.ca.gov/AssessingRisk/index.cfm#Ecological_Risk_Assessment http://www.oehha.org/ecotox/documents/

III.1.10 State of Massachusetts Risk Assessment Guidance http://www.mass.gov/dep/cleanup/laws/rc3.pdf

III.1.11 State of Minnesota Risk Assessment Guidance, http://www.pca.state.mn.us/cleanup/riskbasedoc.html

III.1.12 State of Oregon Ecological Risk Assessment Guidance, http://www.deq.state.or.us/wmc/cleanup/ecocover.htm

III.1.13 State of Texas Ecological Risk Assessment Guidance, http://www.tceq.state.tx.us/remediation/eco/eco.html

III.1.14 State of Wisconsin Sediment Risk Assessment Guidance http://www.dnr.state.wi.us/org/water/wm/wqs/sediment/assessment/

Human Health Risk Assessment

III.1.15 *Risk Assessment Guidance for Superfund, Volume 1 Human Health Evaluation Manual (Part A)*, Dec 1989, EPA/540/1-89/002, http://www.epa.gov/oswer/riskassessment/ragsa/index.htm

III.1.16 *USEPA Tools for Human Health Risk Assessment*, http://www.epa.gov/oswer/riskassessment/toolthh.htm

III.1.17 *State of California Human Health Risk Assessment Guidance,* http://www.dtsc.ca.gov/AssessingRisk/index.cfm - Human Risk Assessment

III.1.18 State of Virginia Voluntary Remediation Program Risk Assessment Guidance Home Page, http://www.deq.virginia.gov/vrprisk/homepage.html

III.1.19 Ohio EPA Property Specific Risk Assessment Procedures http://www.epa.state.oh.us/derr/vap/docs/rule_9.pdf

III.1.20 Ohio EPA Phase II Property Assessment for the Voluntary Action Program, http://www.epa.state.oh.us/derr/vap/docs/rule_7.pdf

Section III.1a Other Site Characterization Issues

III.1a.1 *Gas Production in Sediment Layers*, for Dutch Ministry of Public Works, 1998, WL Delft Hydraulics Web Page, http://www.wldelft.nl/cons/appl/soilwati/gp-sedlay.html

III.1a.2 *Contaminated Sediments*, for Dutch Ministry of Public Works, 1998, WL Delft Hydraulics Web Page, http://www.wldelft.nl/cons/area/mse/gassed.html

III.1a.3 *Gas Enhanced Transportation from Contaminated Sediment at Stryker Bay, Duluth*, WL Delft Hydraulics Web Page, http://www.wldelft.nl/proj/pdf/4uk00225.scherm.pdf

Section III.2 Building the Conceptual Site Model

III.2.1 *Contaminated Sediment Remediation Guidance for Hazardous Waste Sites*, EPA-540-R-05-012, OSWER 9355.0-85, December 2005, http://www.epa.gov/superfund/resources/sediment/pdfs/guidance.pdf

Section III.3 Sediment Quality Guidelines or Criteria

III.3.1 *Ecological Risk Assessment in Superfund – An Overview of the Eight Step Process*, EPA, 1997, http://www.epa.gov/region5superfund/ecology/html/8stepera.html

III.3.2 EPA. 2002. *Calculating Upper Confidence Limits for Exposure Point Concentrations at Hazardous Waste Sites,* Office of Emergency and Remedial Response, U.S. Environmental Protection Agency, Washington, D.C. 20460, OSWER 9285.6-10, December

III.3.3 *Use of Sediment Quality Guidelines and Related Tools for the Assessment of Contaminated Sediments SETAC Pellston Workshop*, http://www.cerc.usgs.gov/pubs/sedtox/wg0_setac_sqg_summary.pdf

III.3.4 State of Alaska, http://www.state.ak.us/dec/spar/csp/guidance/sediment_quality_options.pdf

III.3.5 State of Florida SQGs, http://www.cerc.usgs.gov/pubs/sedtox/sqags_for_florida_inland_waters_01_03.pdf

III.3.6 State of Massachusetts - Revised Sediment Screening Values, http://www.mass.gov/dep/water/laws/ecoturss.pdf
III.3.7 State of New York NYSDEC Division of Fish, Wildlife and Marine Resources, January 25, 1999. Technical Guidance for Screening Contaminated Sediments, http://www.dec.ny.gov/docs/wildlife_pdf/seddoc.pdf
III.3.8 State of Wisconsin Consensus-Based Sediment Quality Guidelines, http://dnr.wi.gov/org/aw/rr/technical/cbsqg_interim_final.pdf
III.3.9 State of Washington Sediment Management Standards, Chapter 173-204 WAC Marine Chemical Criteria, http://www.ecy.wa.gov/programs/tcp/smu/sed_chem.htm
III.3.10 State of Washington Freshwater Sediment Criteria, http://www.ecy.wa.gov/biblio/0309088.html
III.3.11 State of Washington Human Health Sediment Criteria, http://www.ecy.wa.gov/biblio/97114s.html
III.3.12 State of Washington Bibliography of Sediment Management Documents, http://www.ecy.wa.gov/programs/tcp/smu/sed_pubs.htm
III.3.13 *Texas Risk Reduction Program Development of Human Health Sediment PCLs* (contact recreation only), http://www.tceq.state.tx.us/assets/public/remediation/trrp/hhsedpcls.pdf
III.3.14 *Texas Guidance for Determining Surface Water and Sediment PCLs – Includes some exposure factors for the contact recreation pathway*, http://www.tceq.state.tx.us/comm_exec/forms_pubs/pubs/rg/rg-366_trrp_24.html
III.3.15 Virginia Voluntary Remediation Program Risk Assessment Guidance Web Page, http://www.deq.state.va.us/vrprisk/
III.3.16 Ohio EPA Phase II Property Assessment for the Voluntary Action Program, http://www.epa.state.oh.us/derr/vap/docs/rule_7.pdf
III.3.17 Ohio EPA Property Specific Risk Assessment Procedures, http://www.epa.state.oh.us/derr/vap/docs/rule_9.pdf

Section III.4a Sediment and Surface Water Sampling

III.4a.1 Fisheries and Oceans Canada. 2002. *Invertebrates - Geoduck Clam*, http://www-comm.pac.dfo po.gc.ca/publications/speciesbook/invertebrates/geoduck.html
III.4a.2 COE, 1989. *Ghost Shrimp and Blue Mud Shrimp*, U.S. Army Corps of Engineers, Coastal Ecology Group, Waterways Experiment Station and the U.S. Fish and Wildlife Service, Biological Report 82(11.93), January, 1989
III.4a.3 Julian et al, 2001. Julian, D., Chang, M.L., Judd, J.R., and Arp, A.J., *Influence of environmental factors on burrow irrigation and oxygen consuption in the mudflat invertebrate Urechis caupo*, Marine Biology, 139:163-173, 2001.
III.4a.4 U. S. EPA Environmental Response Team SOP 2016, http://www.ert.org/products/2016.PDF
III.4a.5 *Superfund Program Representative Sampling Guidance, Volume 5: Surface Water and Sediment*, http://www.ert.org/products/SF-WATR1.PDF
III.4a.6 *U.S. EPA - Methods for Collection, Storage and Manipulation of Sediments for Chemical and Toxicological Analyses: Technical Manual*, http://www.epa.gov/waterscience/cs/collection.html

III.4a.7 *Guidance for Sampling and Analyzing for Organic Contamination in Sediments*, http://yosemite.epa.gov/water/owrccatalog.nsf/0/fc8188cfac30a68285256b0600723b2f?OpenDocument

III.4a.8 Ohio EPA Sediment Sampling Guide and Methodologies, http://www.epa.state.oh.us/dsw/guidance/sedman2001.pdf

III.4a.9 State of Minnesota Contaminated Sediment Resource Page, http:/www.pca.state.mn.us/water/sediments/links-assessment.html

III.4a.10 State of Wisconsin Sediment Sampling Guidance http://www2.bren.ucsb.edu/~keller/courses/esm223/SedimentSamplingGuidelines.htm

III.4a.11 State of Washington Dept. of Ecology Sediment Management Guidance http://www.ecy.wa.gov/programs/tcp/smu/sediment.html

III.4a.12 State of Washington *Puget Sound Protocols and Guidelines* http://www.psat.wa.gov/Publications/protocols/protocol.html

Section III.4b Investigation Methods

III.4b.1 *Porewater Sampling from a Micro Push Point or Mini Piezometer*, SOP #SRC OGDEN-01, July 13, 2001, http://www.epa.gov/region8/r8risk/pdf/r8-src_src-ogden-01.pdf

III.4b.2 Geoprobe® Systems Web Page, http://geoprobe.com/products/tools/soil_gas/implantdesc.htm

III.4b.3 VW Piezometers, http://www.slopeindicator.com/instruments/piezo-vw.html

III.4b.4 CEP VW Piezometers, http://www.sensor123.com/piezo_vw.htm

III.4b.5 4500 Series VW Piezometers Pressure Transducers, http://www.geokon.com/products/datasheets/4500.pdf

III.4b.6 Lee D.R., 1977 *A device for measuring seepage flux in lakes and estuaries,* Limnology and Oceanography, v. 22, no. 1, p. 140-147

III.4b.7 *Development of a Benthic-Flux Chamber for Measurement of Ground-Water Seepage and Water Sampling for Mercury Analysis at the Sediment-Water Interface*, http://pubs.usgs.gov/sir/2004/5298/pdf/SIR2004-5298.pdf.

III.4b.8 SSC San Diego. 2003. *Coastal Contaminant Migration Monitoring: The Trident Probe and UltraSeep System - Hardware Description, Protocols, and Procedures*, Space and Naval Warfare Systems Center, San Diego, Technical Report 1902, June 2003, http://www.spawar.navy.mil/sti/publications/pubs/tr/1902/tr1902cond.pdf

III.4b.9 *New Tools Improve Assessment of Contaminated Ground Water and Surface Water Interaction*, EPA Technology News and Trends Newsletter, May 2005, http://www.clu-in.net/products/newsltrs/tnandt/view.cfm?issue=0505.cfm#3

III.4b.10 U.S. EPA Eco Update series Web Site, http://www.epa.gov/oswer/riskassessment/ecoup/index.htm

III.4b.11 *Field Study of the Fate of Arsenic, Lead, and Zinc at the Ground-Water/ Surface-Water Interface*, EPA/600/R-05/161, December 2005, http://www.epa.gov/ada/download/reports/600R05161/600R05161.pdf

III.4b.12 *Proceedings of the Ground-Water/ Surface-Water Interactions Workshop*. Solid Waste and Emergency Response, EPA/542/R-00/007, July 2000, http://www.epa.gov/tio/download/remed/gwsw/gwsw_part1.pdf http://www.epa.gov/tio/download/remed/gwsw/gwsw_part2.pdf http://www.epa.gov/tio/download/remed/gwsw/gwsw_part3.pdf

III.4b.13 *A Review of Methods for Assessing Nonpoint Source Contaminated Ground-Water Discharge to Surface Water*, Office of Water, EPA 570/9-91-010, April 1991

Section III.4c Food Chain Sampling

III.4c.1 *Bioaccumulation Testing and Interpretation for the Purpose of Sediment Quality Assessment: Status and Needs*, http://www.epa.gov/waterscience/cs/biotesting/

III.4c.2 *Guidance for Assessing Chemical Contaminant Data for Use In Fish Advisories Volume 1: Fish Sampling and Analysis - Third Edition,* http://www.epa.gov/ost/fishadvice/volume1/index.html

III.4c.3 *PCB Cancer Dose-Response Assessment and Application to Environmental Mixtures,* http://www.epa.gov/pcb/pubs/pcb.pdf

III.4c.4 L. Valoppi et al., 2000. *Use of PCB congener and homologue analysis in ecological risk assessment*, Environmental toxicology and risk assessment: Recent achievements in environmental fate and transport: Ninth volume, ASTM STP 1381. F. Price et al., eds. ASTM, West Conshohocken PA

III.4c.5 Martin Van den Berg et al., 2006. *The 2005 World Health Organization Reevaluation of Human and Mammalian Toxic Equivalency Factors for Dioxins and Dioxin-like Compounds.* Toxicol Sci., 93(2):223-41 http://www.ncbi.nlm.nih.gov/entrez/query.fcgi?cmd=Retrieve&db=PubMed&dopt=Citation&list_uids=16829543 (abstract only)

III.4c.6 *Toxicological Profile for Mercury, Agency for Toxic Substances and Disease Registry*, CAS# 7439-97-6, March 1999, http://www.atsdr.cdc.gov/toxprofiles/tp46.html

Section III.4d Selecting Chemicals of Potential Ecological and Human Health Concern

III.4d.1 The California Environmental Protection Agency http://www.dtsc.ca.gov/AssessingRisk/backgrnd.cfm

III.4d.2 *Guidance for Environmental Background Analysis Volume II: Sediment*, NFESC User's Guide UG-2054-ENV, Naval Facilities Engineering Command, April 2003, http://web.ead.anl.gov/ecorisk/related/documents/Final_BG_Sediment_Guidance.pdf

Section III.5c Identification of Complete Ecological and Human Health Exposure Pathways

III.5c.1 U.S. EPA EcoSSL Guidance 2005

III.5c.2 Beyer et al, 1994. Beyer, W. Nelson, E.E. Connor, and S. Gerould, *Estimates of Soil Ingestion by Wildlife*, Journal of Wildlife Management 58(2): 375-382, 1994

III.5c.3 *New Bedford Harbor Superfund Site Current Monitoring Data*, USEPA Region I Web Page, http://www.epa.gov/ne/nbh/data.html

Section III. 6a Protection of the Plant Community

III.6a.1 Lewis, M.A., Weber, D.E., and R.S. Stanley, 2000. *Wetland Plant Seedlings as Indicators of Near-Coastal Sediment Quality: Interspecific Variation,* Marine Environmental Research 50:535-540

III.6a.2 U.S. EPA Water Quality Standards Resource Web Page, http://www.epa.gov/waterscience/standards/

III.6a.3 *Oak Ridge National Laboratory Screening Benchmarks for Aquatic Biota,* http://www.esd.ornl.gov/programs/ecorisk/documents/tm96r2.pdf

III.6a.4 Lytle, J.S. and T.F. Lytle, 2001. *Use of Plants for Toxicity Assessment of Estuarine Ecosystems*, Environmental Toxicology and Chemistry 20(1):68-83.

III.6a.5 Mohan, B.S. and B.B. Hosetti,1999. *Aquatic Plants for Toxicity Assessment*, Environmental Research Section *A* 81:259-274.

Section III. 6b Protection of the Invertebrate Community

III.6b.1 *National Oceanic and Atmospheric Administration (NOAA) Screening Quick Reference Tables (SQuiRTs)* http://response.restoration.noaa.gov/cpr/sediment/squirt/squirt.html

III.6b.2 MacDonald, D.D., Ingersoll, C.G., and T.A. Berger. 2000. Development and Evaluation of Consensus-Based Sediment Quality Guidelines for Freshwater Ecosystems. *Archives of Environmental Contamination and Toxicology* 39:20-31.

III.6b.3 U.S. EPA Biological Assessments and Biocriteria Webpage, http://www.epa.gov/waterscience/biocriteria/technical/

Section III. 6c Protection of Fish Populations

III.6c.1 NOAA Sediment Quality Criteria Protective of Fish http://www.nwfsc.noaa.gov/research/divisions/ec/ecotox/whitepapers.cfm

III.6c.2 Beckvar, N., Dillon, T.M., and Read, L.B., 2005. Approaches For Linking Whole-Body Fish Tissue Residues Of Mercury Or DDT To Biological Effects Thresholds, *Environmental Toxicology and Chemistry*, 24(8):2094–2105.

III.6c.3 Jarvinen, A.W. and G.T. Ankley, 1999. *Linkage of Effects to Tissue Residues: Development of a Comprehensive Database for Aquatic Organisms Exposed to Inorganic and Organic Chemicals.* Society of Environmental Toxicology and Chemistry Press, Pensacola, Florida. 358 p.

III.6c.4 U.S. Army Corps of Engineers/U.S. Environmental Protection Agency Environmental Residue-Effects Database (ERED), http:/el.erdc.usace.army.mil/ered/

Section III. 6d Protection of Amphibian and Reptile Populations

III.6d.1 B.D. Pauli, J.A. Perrault and S.L. Money, 2000, *RATL: A Database of Reptile and Amphibian Toxicology Literature,* National Wildlife Research Centre, Canadian Wildlife Service, Environmental Conservation Branch, Technical Report Series Number 357, Catalogue No. CW69-5/357E-IN, Minister of Public Works and Government Services Canada, http://dsp-psd.communication.gc.ca/Collection/CW69-5-357E.pdf

III.6d.2 Sparling, D.W., Linder, G., and C. A. Bishop, 2000*. Ecotoxicology of Amphibians and Reptiles,* SETAC Press, Society of Environmental Toxicology and Chemistry, Pensacola, Florida, 904 pp.

III.6d.2 USEPA. 1996. *Amphibian toxicity data for water quality criteria chemicals*, United States Environmental Protection Agency, EPA/600/R-96/124.

Section III. 6e Protection of Bird and Mammal Populations

III.6e.1 Hui, C.A., and Beyer, W.N., 1998. *Sediment ingestion of two sympatric shorebird species,* The Science of the Total Environment, 224:227-233.

Section III. 6f Important Factors to Consider When Characterizing Ecological Risks

III.6f.1 U.S. EPA Bioassessment and Biocriteria Web Page, http://www.epa.gov/waterscience/biocriteria/

III.6f.2 Anderson, M. J., Barron, M. G, Diamond S. A., Lipton, J., and Zelikoff, J. T. 1997. *Biomarker Selection for Restoration Monitoring of Fishery Resources, Environmental Toxicology and Risk Assessment: Modeling and Risk Assessment (Sixth Volume)*, ASTM STP 1317, F. James Dwyer, Thomas R. Doane, and Mark L. Hinman, Eds., American Society for Testing and Materials, pp. 333-359.

III.6f.3 Baumann, P.C. and Harshbarger, J.C., 1995. *Decline of Liver Neoplasms in Wildbrown Bullhead Catfish after Coking Plant Closes and Environmental PAHs Plummet,* Environmental Health Perspectives, 103:168-170.

III.6f.4 U.S.EPA *Wildlife Exposure Handbook* (1993) http://cfpub.epa.gov/ncea/cfm/wefh.cfm?ActType=default

III.6f.5 Nagy, 2001. Nagy KA., *Food requirements of wild animals: Predictive equations for free-living mammals, reptiles, and birds*, Nutrition Abstracts and Reviews, Series B: Livestock Feeds and Feeding Oct;71(10): 1R-12R.

III.6f.6 OEHHA Cal/Eco Tox Database, http://www.oehha.org/cal_ecotox/

III.6f.7 U.S.EPA EcoSSLs (2005)

III.6f.8 U.S. EPA Region 9 BTAG, http://www.dtsc.ca.gov/AssessingRisk/upload/Eco_Btag-mammal-bird-TRV-table.pdf

III.6f.9 Sample, B.E. and Arenal, C.A. 1999. *Allometric models for interspecies extrapolation of wildlife toxicity data,* Bull, Environ. Contam. Toxicol., 62:653-663.

Section III.7 Risk Management Decision-Making Criteria for Ecological Risk Assessment

III.7.1 Burton et al. 2002. Burton, G.A., Jr., G. E. Batley, P.M. Chapman, V.E. Forbes, E.P. Smith, T. Reynoldson, C.E. Schlekat, P.J. den Besten, A.J. Bailer, A.S. Green and R.L. Dwyer, *A Weight-of-Evidence Framework for Assessing Sediment (Or Other) Contamination: Improving Certainty in the Decision-Making Process*, Human and Ecological Risk Assessment 8:1675-1696.

III.7.2 EPA, 1997. *Ecological Risk Assessment Guidance for Superfund: Process for Designing Conducting Ecological Risk Assessments. Interim Final*, EPA/540/R-97/006, June.

Section III.8a Exposure Assessment

III.8a.1 *Exposure Factors Handbook* http://cfpub.epa.gov/ncea/cfm/recordisplay.cfm?deid=12464&CFID=2162302&CFTOKEN=30643033

III.8a.2 *Risk Assessment Guidance for Superfund Part E, Supplemental Guidance for Dermal Risk Assessment* http://www.epa.gov/oswer/riskassessment/ragse/index.htm

III.8a.3 *Calculating Upper Confidence Limits for Exposure Point Concentrations at Hazardous Waste Sites*, http://www.hanford.gov/dqo/training/ucl.pdf

III.8a.4 *Software for Calculating Upper Confidence Limits* http://www.epa.gov/nerlesd1/tsc/software.htm

III.8a.5 OEHHA, 2001. *Chemicals in fish: Consumption of fish and shellfish in California and the United States*, Office of Environmental Health Hazard Assessment, California Environmental Protection Agency. October. http://www.oehha.org/fish/special_reports/fishy.html

III.8a.6 USEPA, 1997. *Exposure Factors Handbook, Chapter 10, Intake of Fish and Shellfish*, EPA/600/P-95/002Fb, http://www.epa.gov/ncea/efh/pdfs/efh-chapter10.pdf

III.8a.7 *The Incidence and Severity of Sediment Contamination in the Surface Waters of the United States, National Sediment Quality Survey, 2nd Edition*, Appendix C http://www.epa.gov/waterscience/cs/report/2004/nsqs2ed-complete.pdf

Section III.8b Toxicity Assessment

III.8b.1 Integrated Risk Information System (IRIS), http://www.epa.gov/iris/

III.8b.2 California EPA Office of Environmental Health Hazard Assessment Toxicity Criteria Database, http://www.oehha.ca.gov/risk/chemicalDB//index.asp

III.8b.3 Agency for Toxic Substances and Disease Registry, http://www.atsdr.cdc.gov/mrls.html

Section IV Developing Remedial Goals

IV.1 Principles for Managing Contaminated Sediment Risks at Hazardous Waste Sites, EPA Memorandum, OSWER Directive 9285.6-08, February 12, 2002, http://www.epa.gov/superfund/resources/remedy/pdf/92-85608-s.pdf

IV.2 *Development of cleanup action alternatives that include remediation levels,* Washington State Model Toxics Control Act Cleanup Regulation, Chapter 173-340 WAC, Part III, subsection –355, February 12, 1991, http://www.ecy.wa.gov/biblio/wac173340.html

IV.3 *Sediment Cleanup Standards User Manual*, Washington Dept. of Ecology, Sediment Management Unit June 1993, http://www.ecy.wa.gov/biblio/scum2.html

Section V.1 Types of Remediation

V.1.1 U.S. Army Corps Environmental Laboratory Cleanup/Remediation Web Page, http://el.erdc.usace.army.mil/research.cfm?Topic=enveng-cleanup&Option=List

Section V.1a Dredging

V.1a.1 U.S. Army Corps Environmental Laboratory Dredge Web Page, http://el.erdc.usace.army.mil/research.cfm?Topic=enveng-dredg&Option=List

V.1a.2 U.S. Army Corps Dredging Operations & Environmental Research (DOER), http://el.erdc.usace.army.mil/programs.cfm?Topic=doer&Option=Program

V.1a.3 U.S. Army Corps Dredging Operations Technical Support (DOTS), http://el.erdc.usace.army.mil/programs.cfm?Topic=dots&Option=Program

V.1a.4 U.S. Army Corps Dredging Operations Technical Support Program, Take a Trip Through a Dredge!, http://el.erdc.usace.army.mil/dots/trip.html

V.1a.5 *Innovations in Dredging Technology: Equipment, Operations, and Management*, ERDC TR-DOER-5, U.S. Army Corps of Engineers, April 2000, http://el.erdc.usace.army.mil/elpubs/pdf/trdoer5.pdf

V.1a.6 *Innovations in Dredging Technology: Equipment, Operations, and Management,* ERDC TN-DOER-T1, U.S. Army Corps of Engineers, February 2000, http://el.erdc.usace.army.mil/elpubs/pdf/doert1.pdf

V.1a.7 *Estimating Dredging Sediment Resuspension Sources*, TN-DOER-E6, U.S. Army Corps of Engineers, March 1999. (Document currently being amended.)

V.1a.8 *Assessment of Potential Impacts of Dredging Operations Due to Sediment Resuspension*, ERDC TN-DOER-E9, U.S. Army Corps of Engineers, May 2000, http://el.erdc.usace.army.mil/elpubs/pdf/doere9.pdf

V.1a.9 *Summary of Measurement Protocols for Sediment Resuspended from Dredging Operations*, ERDC TN-DOER-D8, U.S. Army Corps of Engineers, July 2006, http://el.erdc.usace.army.mil/elpubs/pdf/doerd8.pdf

V.1a.10 *Equipment and Processes for Removing Debris and Trash from Dredged Material*, ERDC TN-DOER-C17, U.S. Army Corps of Engineers, August 2000, http://el.erdc.usace.army.mil/elpubs/pdf/doerc17.pdf

V.1a.11 *Silt Curtains as a Dredging Project Management Practice*, U.S. Army Engineer Research and Development Center, Vicksburg, MS. ERDC TN-DOER-E21, U.S. Army Corps of Engineers**,** September 2005, http://el.erdc.usace.army.mil/elpubs/pdf/doere21.pdf

Section V.1c Capping

V.1c.1 *EPA Guidance for In-Situ Subaqueous Capping of Contaminated Sediments*, 1998, http://www.epa.gov/glnpo/sediment/iscmain/

V.1c.2 *Equipment and Placement Techniques for Subaqueous Capping*, ERDC TN-DOER-R9, U.S. Army Corps of Engineers, September 2005, http://el.erdc.usace.army.mil/dots/doer/pdf/doerr9.pdf

V.1c.3 *Guidance for Subaqueous Dredged Material Capping*, TR DOER-1, U.S. Army Corps of Engineers, June 1998, http://el.erdc.usace.army.mil/dots/doer/pdf/trdoer1.pdf

V.1c.4 *Hazardous Substance Research Centers South & Southwest In-situ Capping Primer*, 2006, http://www.hsrc-ssw.org/cap-primer.html

V.1c.5 *Subaqueous Capping and Natural Recovery: Understanding the Hydrogeologic Setting at Contaminated Sediment Sites*, ERDC TN-DOER-C26, U.S. Army Corps of Engineers, July 2002, http://el.erdc.usace.army.mil/elpubs/pdf/doerc26.pdf

V.1c.6 *Subaqueous Cap Design: Selection of Bioturbation Profiles, Depths, and Process Rates*, ERDC TN-DOER-C21, U.S. Army Corps of Engineers, August 2001, http://el.erdc.usace.army.mil/elpubs/pdf/doerc21.pdf

Section V.1f Natural Attenuation

V.1f.1 Use of Monitored Natural Attenuation at Superfund, RCRA Corrective Action, and Underground Storage Tank Sites, OSWER Directive 9200.4-178P, April 21, 1999, http://www.epa.gov/tio/download/reg/d9200417.pdf

V.1f.2 *Development of DoD Guidance for Monitored Natural Recovery at Contaminated Sediment Sites*, Fact Sheet ER-0622, Environmental Security Technology Certification Program, http://www.estcp.org/Technology/ER-0622-FS.cfm

Section V.1h Enhanced Natural Attenuation

V.1h.1 *In-Water and Riparian Management of Sediment and Dredged Material,* Division of Water TOGS 5.1.9:, New York State Department of Environmental Conservation, November 2004, http://www.dec.ny.gov/docs/water_pdf/togs519.pdf

Section V.2 Monitoring During Remedial Actions

V.2.1 *Evaluation of Dredged Material Plumes Physical Monitoring Techniques*, ERDC TN-DOER-E5, U.S. Army Corps of Engineers, December 1998, http://el.erdc.usace.army.mil/elpubs/pdf/doere5.pdf

V.2.2 *Acoustic Monitoring of Dredging-Related Suspended-Sediment Plumes*, ERDC TN-DOER-E7, U.S. Army Corps of Engineers, April 2000, http://el.erdc.usace.army.mil/elpubs/pdf/doere7.pdf

V.2.3 *Improved Methods for Correlating Turbidity and Suspended Solids for Monitoring*, ERDC TN-DOER-E8, U.S. Army Corps of Engineers, June 2000, http://el.erdc.usace.army.mil/elpubs/pdf/doere8.pdf

Section V.3a. Sediment Disposal

V.3a.1 *Confined Disposal Facility (CDF) Containment Features: A Summary of Field Experience*, ERDC TN-DOER-C18, U.S. Army Corps of Engineers, August 2000, http://el.erdc.usace.army.mil/elpubs/pdf/doerc18.pdf

V.3a.2 *Overview of processes affecting contaminant release from confined disposal facilities*, DOTS Contract Report D-92-1, U.S. Army Corps of Engineers, January 1992, http://el.erdc.usace.army.mil/elpubs/pdf/crd92-1.pdf

V.3a.3 *Liner Design Guidance for Confined Disposal Facility Leachate Control*, ERDC TN-DOER-C18, U.S. Army Corps of Engineers, December 2004 http://el.erdc.usace.army.mil/elpubs/pdf/doerr6.pdf

Section V.4 Beneficial Use

V.4.1 *Dredged Material Characterization Tests for Beneficial Use Suitability*, ERDC TN-DOER-C2, U.S. Army Corps of Engineers, May 1999, http://el.erdc.usace.army.mil/elpubs/pdf/doerc2.pdf

V.4.2 *Screening Tests for Assessing the Bioreclamation of Dredged Material*, ERDC TN-DOER-C4, U.S. Army Corps of Engineers, May 1999, http://el.erdc.usace.army.mil/elpubs/pdf/doerc4.pdf

V.4.3 *Determining Recovery Potential of Dredged Material for Beneficial Use - Soil Separation Concepts*, ERDC TN-DOER-C13, U.S. Army Corps of Engineers, July 2000, http://el.erdc.usace.army.mil/elpubs/pdf/doerc13.pdf

V.4.4 *Determining Recovery Potential of Dredged Material for Beneficial Use - Site Characterization; Prescriptive Approach*, ERDC TN-DOER-C14, U.S. Army Corps of Engineers, July 2000, http://el.erdc.usace.army.mil/elpubs/pdf/doerc14.pdf

V.4.5 *Determining Recovery Potential of Dredged Material for Beneficial Use - Site Characterization: Statistical Approach*, ERDC TN-DOER-C15, U.S. Army Corps of Engineers, July 2000, http://el.erdc.usace.army.mil/elpubs/pdf/doerc15.pdf

V.4.6 *Reclamation and Beneficial Use of Contaminated Dredged Material: Implementation Guidance for Select Options*, ERDC TN-DOER-C12, U.S. Army Corps of Engineers, February 2000, http://el.erdc.usace.army.mil/elpubs/pdf/doerc12.pdf

Section V.5 Permitting Requirements

V.5.1 *Environmental Windows Associated with Dredging Operations*, ERDC TN-DOER-E2, U.S. Army Corps of Engineers, December 1998, http://el.erdc.usace.army.mil/elpubs/pdf/doere2.pdf

Section VI.3 Post-Remedy Considerations for Capping for On-site Disposal Facilities

VI.3.1 *Overview of Processes Affecting Contaminant Release from Confined Disposal Facilities*, CD-D-92-1, U.S. Army Corps of Engineers, January 1992, http://el.erdc.usace.army.mil/elpubs/pdf/crd92-1.pdf

Section VI.4b Fishing Restrictions

VI.4b.1 New Bedford Harbor Superfund Site Fish Smart Campaign Web Page, http://www.epa.gov/region01/nbh/fishsmart.html

Appendix A: Summary of EPA's Superfund Remediation Process

A.1 EPA's Web Page, http://www.epa.gov/superfund

A.2 *CERCLA/Superfund Orientation Manual,* Oct 1992, EPA/542/R-92/005 http://www.epa.gov/superfund/resources/remedy/pdf/542r-92005-s.pdf

A.3 *Guidance for Performing Preliminary Assessments Under CERCLA*, September 1991, EPA/540/G-91/013, OSWER Publication 9345.0-01A, http://www.epa.gov/superfund/sites/npl/hrsres/ - PA%20Guidance

A.4 *Guidance for Performing Site Inspections Under CERCLA; Interim Final*, September 1992, EPA540-R-92-021, OSWER Directive 9345.1-05, http://www.epa.gov/superfund/sites/npl/hrsres/ - PA%20Guidance

A.5 *Hazard Ranking System Guidance Manual,* Interim Final, November 1992, http://www.epa.gov/superfund/sites/npl/hrsres/ - PA%20Guidance

A.6 *Hazard Ranking System; Final Rule* (55 FR 51532), Federal Register, December 14, 1990, http://www.epa.gov/superfund/sites/npl/hrsres/ - PA%20Guidance

A. 7 *A Guide to Preparing Superfund Proposed Plans, Record of Decision, and Other Remedial Selection Decision Documents*, July 1999, EPA 540-R-98-031, OSWER 9200.1-23P, http://www.epa.gov/superfund/resources/remedy/rods/

A.8 *Remedial Design/Remedial Action Handbook*, June 1995, EPA 540/R-95-059, OSWER 9355.0-04B, http://www.epa.gov/superfund/whatissf/sfproces/rdrabook.htm

A.9 *Close Out Procedures for National Priorities List Sites*, OSWER Directive 9320.2-09A-P, January 2000, http://www.epa.gov/superfund/resources/closeout/index.htm

A.10 *Superfund Post Construction Completion, An Overview*, June 2001, EPA 540-F-01-009, OSWER 9355.0-79FS, http://www.epa.gov/superfund/action/postconstruction/pcc_over.pdf

A.11 *Superfund Post Construction Completion Activities, An Overview*, June 2001, EPA 540-F-01-010, OSWER 9355.0-80FS, http://www.epa.gov/superfund/action/postconstruction/pcc_act.pdf

A.12 *Operation and Maintenance in the Superfund Program*, May 2001, EPA 540-F-01-004, http://www.epa.gov/superfund/resources/sheet.pdf

A.13 *Close Out Procedures for National Priorities List Sites*, January 2000, OSWER Directive 9320.2-09A-P, http://www.epa.gov/superfund/resources/closeout/index.htm