7.0 REMEDY SELECTION CONSIDERATIONS

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7.0 REMEDY SELECTION CONSIDERATIONS

> "No two sites are identical and therefore the risk-management strategy will vary from site to site...The strategy selected should be one that actually reduces overall risk, not merely transfers the risk to another site or another affected population. The decision process necessary to arrive at an optimal management strategy is complex and likely to involve numerous site-specific considerations."

> "Management decisions must be made, even when information is imperfect. There are uncertainties associated with every decision that need to be weighed, evaluated, and communicated to affected parties. Imperfect knowledge must not become an excuse for not making a decision."

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

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

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

Documenting and communicating how and why remedy decisions are made are very important at sediment sites. For guidance on documenting remedy decisions under the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) project managers should refer to EPA's *A Guide* *to Preparing Superfund Proposed Plans, Records of Decision, and other Remedy Selection Documents*, also referred to as the "ROD Guidance" (U.S. EPA 1999a).

7.1 NCP REMEDY SELECTION FRAMEWORK

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

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

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

7.2 CONSIDERING CLEANUP METHODS

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

7.3 CONSIDERING INSTITUTIONAL CONTROLS

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

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

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

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

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

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

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

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

7.4 CONSIDERING NO-ACTION

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

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

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

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

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

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

7.5 CONCLUSIONS

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

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

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

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

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

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

8.0 REMEDIAL ACTION AND LONG-TERM MONITORING

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8.0 REMEDIAL ACTION AND LONG-TERM MONITORING

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

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

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

8.1 INTRODUCTION

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

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

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

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

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

- Sediment sites may require monitoring over very large areas;

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

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

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

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

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

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

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

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

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

8.2 KEY ELEMENTS FOR SEDIMENT SITE MONITORING

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

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

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

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

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

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

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

Element 2: Decision/Evaluation Criteria

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

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

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

Element 3: Endpoint identification

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

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

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

Element 4: Monitoring Program Design and Data Collection

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

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

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

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

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

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

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

Element 5: Data Analysis and Management

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

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

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

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

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

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

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

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

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

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

8.3 POTENTIAL MONITORING TECHNIQUES

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

Generally, physical (e.g., transport) and chemical (e.g., sediment concentrations) endpoints are easier to measure and interpret than biological (e.g., species abundance) endpoints. In the case of human health risk, chemical measurements are most often used to assess risk (e.g., mercury in fish tissue). In contrast, measurement of the biological community is a direct but often complex measurement for monitoring response to changed ecological risk. Caged organisms (e.g., *Macoma*, or mussels) at the site over a defined time frame can identify changes in bioavailable concentrations of many contaminants. Collection of fish and tissue analysis can address both human health and ecological response of the system, if both needs are considered during design of the sampling and analysis plan. The project manager should refer to Office of Water's *Methods for Collection, Storage, and Manipulation of Sediments for Chemical and Toxicological Analyses* (U.S. EPA 2001j) and *Managing and Sampling and Analyzing Contaminants in Fish and Shellfish* (U.S. EPA 2000f) for more detailed information.

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

8.3.1 Physical Measurements

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

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

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

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

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

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

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

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

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

8.3.2 Chemical Measurements

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

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

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

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

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

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

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

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

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

8.3.3 Biological Measurements

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

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

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

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

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

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

8.4 REMEDY-SPECIFIC MONITORING APPROACHES

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

8.4.1 Monitoring Natural Recovery

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

Remedial Action Monitoring

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

- Direct or indirect measures of natural processes (e.g., sediment accumulation rates, degradation products, sediment and contaminant transport);

- Contaminant levels in sediment (e.g., of the bioavailable zone and, where appropriate, at depth); and

- Measures of biota recovery (e.g., benthic organism population size and diversity and/or, for bioacumulative contaminants, contaminant levels in other trophic level indicator species).

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

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

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

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

- Contaminant concentrations in sediment, surface water, or biota at specified locations that exhibit an increasing or insufficient decreasing trend;

- Changes in land and/or surface water/ground water use may adversely affect the protectiveness of the remedy;

- Insufficient sedimentation rates; and

- Occurrence of a flood or storm that scours the sediment and exposes previously buried contaminants.

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

Long-Term Monitoring

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

8.4.2 Monitoring In-Situ Capping

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

Highlight 8-2: Example Cap Monitoring Phases and Elements

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

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

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

<u>Remedial Action Monitoring</u>

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

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

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

<u>Long-Term Monitoring</u>

Following completion of the remedial action, long-term monitoring is important to ensure that the cap is not being eroded or significantly compromised (e.g., penetrated by submerged aquatic vegetation, ground water recharge, or bioturbation) and that chemical contaminant fluxes that ultimately do move through the cap to surface water do so at the projected rate and concentration. It is also frequently desirable to include ongoing monitoring for recontamination of the cap surface from other sources.

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

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

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

8.4.3 Monitoring Dredging or Excavation

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

Remedial Action Monitoring

Remedial action monitoring for dredging or excavation generally includes a comprehensive monitoring program for all potential routes of contaminant exposure during various phases of the operation. Depending on the levels of contamination and the selected methods of dredging/excavation, transport, treatment or disposal, potential construction and operational monitoring may include the following:

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

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

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

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

Long-Term Monitoring

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

If an in-water or upland disposal facility is constructed on-site as part of the remedy, it should be monitored to ensure that it remains intact and that there are no unacceptable contaminant releases in the long term. Monitoring is recommended to resolve whether contaminants are leaking through the bottom or walls of the confined disposal facility (CDF) or landfill, and that any surface cap remains intact to ensure protection from infiltration. Depending on the type of disposal site and the nature of the contamination, long-term disposal site monitoring may include the following:

- Seepage from the CDF containment cells to surrounding surface water;

- Ground water monitoring;

- Surface water run-off monitoring;

- Monitoring of disposal area cap integrity; and

- Monitoring of revegetation or recolonization by plant and animal communities, and their potential uptake of contaminants.

Highlight 8-3 lists important points to remember related to monitoring sediment sites.

Highlight 8-3: Points to Remember About Monitoring Sediment Sites

- A monitoring program is important for all types of sediment remedies, both during the remedial action and over the long term to ensure that sediment risk and exposure pathways at a site have been adequately managed and remain so

- The development of monitoring plans should follow a systematic planning process that identifies monitoring objectives, decision criteria, endpoints, and data collection and analysis methods

- Before implementing a remedial action, project managers should review baseline data and collect additional data if needed to ensure that an adequate baseline exists for comparison to monitoring data

- Remedial action monitoring includes both construction/operational monitoring and monitoring intended to measure whether cleanup levels and remedial action objectives have been met

- Monitoring plans should be designed to evaluate whether performance standards of the remedial action are being met and should be flexible enough to allow revision if operating procedures are revised

- Field methods/quick turnaround with real-time feedback are useful, especially during the remedial action to predict or identify potential problems

- After completion of remedial action, long-term monitoring is important to watch for recontamination, to assess continued containment of buried or capped contaminants, and to monitor dredging residuals and on-site disposal facilities

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