4.0 MONITORED NATURAL RECOVERY

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4.0 MONITORED NATURAL RECOVERY

4.1 INTRODUCTION

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

- Exposure levels are reduced by a decrease in contaminant concentration levels in the near-surface sediment zone through burial or mixing-in-place with cleaner sediment;

- The contaminant is converted to a less toxic form through destructive processes, such as biodegradation or abiotic transformations; or

- Contaminant mobility and bioavailability are reduced through increased sorption to the sediment matrix.

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

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

- A detailed understanding of the natural processes that are affecting sediment and contaminants at the site;

- Conceptual and predictive modeling (either using computer modeling or another method) to predict effects of those processes in the future;

- A means to control any significant ongoing contaminant sources;

- A means to control contaminant exposure during the recovery period (to the extent possible); and

- The ability to monitor the natural processes and their effects to see if recovery is occurring.

MNR has been selected as a cleanup method for contaminated sediment at about a dozen Superfund sites so far. It usually (although not always) is combined with dredging or in-situ capping of other areas of a site. In general, project managers should evaluate each of the three major cleanup methods: MNR, capping, and removal through dredging or excavation, at every sediment site at which they may be appropriate. Some consider that all sediment site remedies are using “natural recovery” because natural processes are ongoing whether or not an active cleanup is underway (e.g., NRC 2001). Although it is true that natural processes will continue to reduce residual risk at many sites, it is important for project managers to distinguish whether they are relying upon MNR to reduce risk to an acceptable level (i.e., using MNR as a remedy), or simply noting the fact that natural processes are ongoing at a site. The key factors that distinguish MNR as a remedy are the presence of unacceptable risk, the ongoing burial or degradation/transformation of the contaminant, and the establishment of a cleanup level that MNR is expected to meet in a particular time frame. Although partial natural recovery has been noted in many areas (e.g., decreases in contaminant levels in fish), there is not yet a body of literature documenting complete recovery. However, monitoring results from some areas are promising (e.g., U.S. EPA 2001f, U.S. EPA 2001g, Swindoll et al. 2000).

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

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

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

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

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

4.2 ADVANTAGES AND DISADVANTAGES

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

Other advantages of MNR include the fact that no construction or infrastructure is needed, and it is therefore much less disruptive of communities than active cleanup methods such as dredging or in-situ capping. No property is needed for materials handling, treatment, or disposal facilities, and no contaminated materials are transported through communities.

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

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

4.3 NATURAL RECOVERY PROCESSES

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

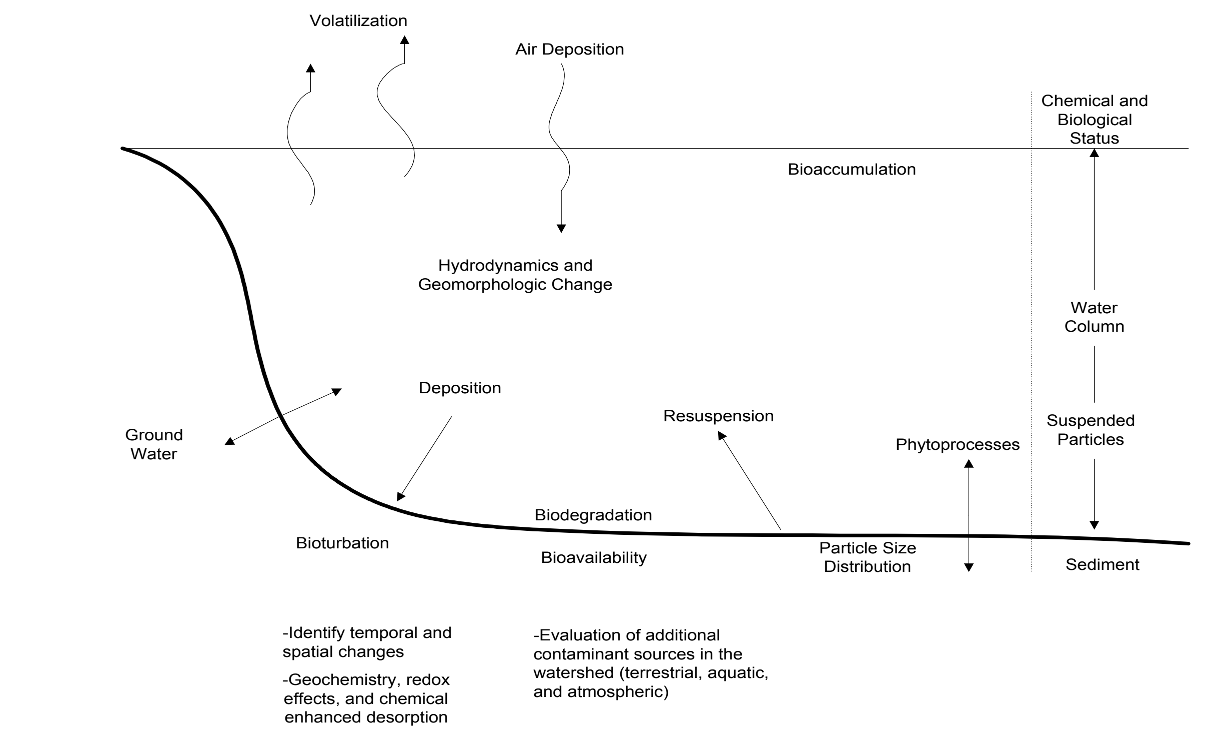
- Physical processes (e.g.,sedimentation, advection, diffusion, dilution, bioturbation, volatilization);
- Biological processes (e.g., biodegradation, biotransformation, phytoremediation, biological stabilization); and
- Chemical processes (e.g., oxidation/reduction, stabilization, sorption).

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

4.3.1 Physical Processes

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

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



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

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

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

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

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

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

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

4.3.2 Biological Processes

In biological processes such as biodegradation (or the more general term of biotransformation), a chemical change is facilitated by microorganisms living in the sediment. Biological processes depend on site-specific conditions and are highly variable. One of the important limitations to the usefulness of biodegradation as a risk-reduction mechanism is that the greater the molecular weight of the organic contaminants, the greater partitioning to sorption sites on sediment particles (Mallhot and Peters 1988) and the lower the contaminant availability to microorganisms. Degradation of high molecular weight organic compounds occurs naturally, but slowly, in soil and sediment with anaerobic and aerobic microorganisms (Brown et al. 1987, Abramowicz and Olsen 1995, Bedard and May 1996, Shuttleworth and Cerniglia 1995, Cerniglia 1992, Seech et al. 1993). Degradation rates vary with depth in sediment partly due to the change from aerobic or anaerobic conditions. This changes occurs at depths of a few millimeters to a few centimeters where sediments have substantial organic content and conditions are quiescent. Longer residence times of contaminants in the sediment (aging) also usually results in increased sequestration (Luthy et al. 1997, Dec and Bollag 1997). These processes reduce the availability of the organic compounds to microorganisms and, therefore, reduce the extent and rates of biodegradation (Luthy et al. 1997, Tabak and Govind 1997).

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

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

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

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

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

4.3.3 Chemical Processes

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

4.4 LINES OF EVIDENCE

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

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

- Documentation that any ongoing sources of contamination have been controlled;

- Time series data for sediment and biota that demonstrate a clear and meaningful trend of decreasing contaminant concentration, mass, or toxicity over time;

- Core data demonstrating a predictable rate of sedimentation or contaminant transformation;

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

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

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

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

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

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

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

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

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

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

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

EPA guidance on the DQO process describes in detail all of the seven steps and provides examples of how each step can be applied (U.S. EPA 2000e). Data needs for evaluation of MNR can be logically coordinated via the DQO process with risk assessment and other data needs of the site characterization.

4.5 ENHANCED NATURAL RECOVERY

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

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

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

4.6 CONCLUSIONS

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

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

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

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

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

- The extent of human exposure to contaminants during the recovery period, and if controlled by institutional controls, the effectiveness of those controls;

- The value of ecological resources that may be impacted by contaminant releases during the recovery period;

- The societal, cultural, and economic resources affected during the recovery period;

- The time frame in which affected portions of the site may be needed for future uses which will be available after MNR has achieved cleanup levels; and

- The uncertainty associated with the prediction

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

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

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

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

5.0 IN-SITU CAPPING

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5.0 IN-SITU CAPPING

5.1 INTRODUCTION

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

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

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

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

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

Much has been written about subaqueous capping of contaminated sediment. The majority of this work has been performed by, or in cooperation with, the U.S. Army Corps of Engineers (USACE). Comprehensive technical guidance on in-situ capping as a cleanup method for contaminated sediment can be found in the U.S. Environmental Protection Agency's (EPA) *Assessment and Remediation of Contaminated Sediment (ARCS) Program Guidance for In-Situ Subaqueous Capping of Contaminated Sediments* (U.S. EPA 1998d) and the *Assessment and Remediation of Contaminated Sediments (ARCS) Program Remediation Guidance Document* (U.S. EPA 1994b). Unless an effective treatment component is incorporated into the cap, in-situ capping generally does not meet CERCLA §121(b)(1) preference for treatment. When contaminants left in place are above levels that allow for unlimited use and unrestricted exposure, a five-year review generally is necessary (U.S. EPA 2001h).

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

Highlight 5-1: General Site Conditions Appropriate for In-Situ Capping

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

5.2 ADVANTAGES AND DISADVANTAGES

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

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

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

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

5.3 COMPONENTS OF CAPPING TECHNOLOGY

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

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

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

5.3.1 Identification of Capping Materials

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

5.3.2 Physical Isolation Component

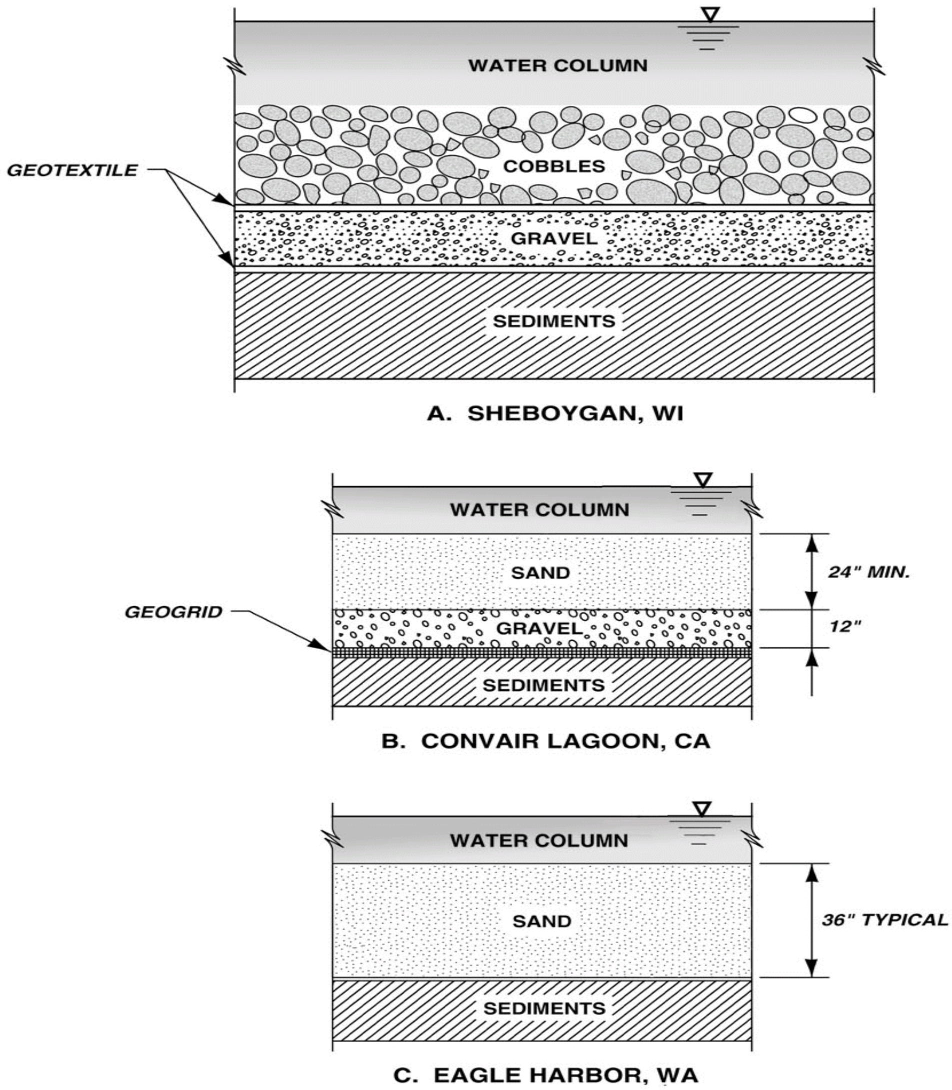
The cap should be designed to isolate sediment contaminants from the aquatic environment. The physical isolation component of the cap includes separate subcomponents for isolation and consolidation.

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

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

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

Highlight 5-2: Example Cap Designs



Source: U.S. EPA 1998d

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

5.3.3 Stabilization/Erosion Protection Component

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

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

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

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

5.3.4 Chemical Isolation Component

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

Both advective and diffusive processes should be considered in cap design. If a ground water/surface water interaction study indicates that advection is not significant at a given location (e.g., migration of ground water upward through the cap would not prevent attaining the remedial action objectives), the cap design may only need to address diffusion and the physical isolation and stabilization of the contaminated sediment. In this case, it may not be necessary to design for dissolved and/or colloidally facilitated transport due to advection (Ryan et al. 1995). In contrast, where ground water flow upward through the cap is expected to be significant, the hydraulic properties of the cap should also be determined and factored into the cap design. These properties should include the hydraulic conductivities of the cap materials, the contaminated sediment, and underlying clean sediment or bedrock. According to a USACE laboratory study, ground water flow velocities exceeding 10^{-5} cm/sec potentially result in conditions in which equilibrium partitioning processes essential to cap effectiveness could not be maintained (Myers et al. 1991). Such conditions should be carefully considered in the cap design. In areas with high rates of ground water flow discharges through contaminated sediment, in-situ capping may not be an effective remedial approach without additional protective measures. More information on the interactions of ground water can be found in the USACE Technical Note, *Subaqueous Capping and Natural Recovery: Understanding the Hydrogeologic Setting at Contaminated Sediment Sites* (USACE 2002).

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

5.3.5 Geotechnical Considerations

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

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

5.3.6 Placement Methods and Performance Monitoring

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

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

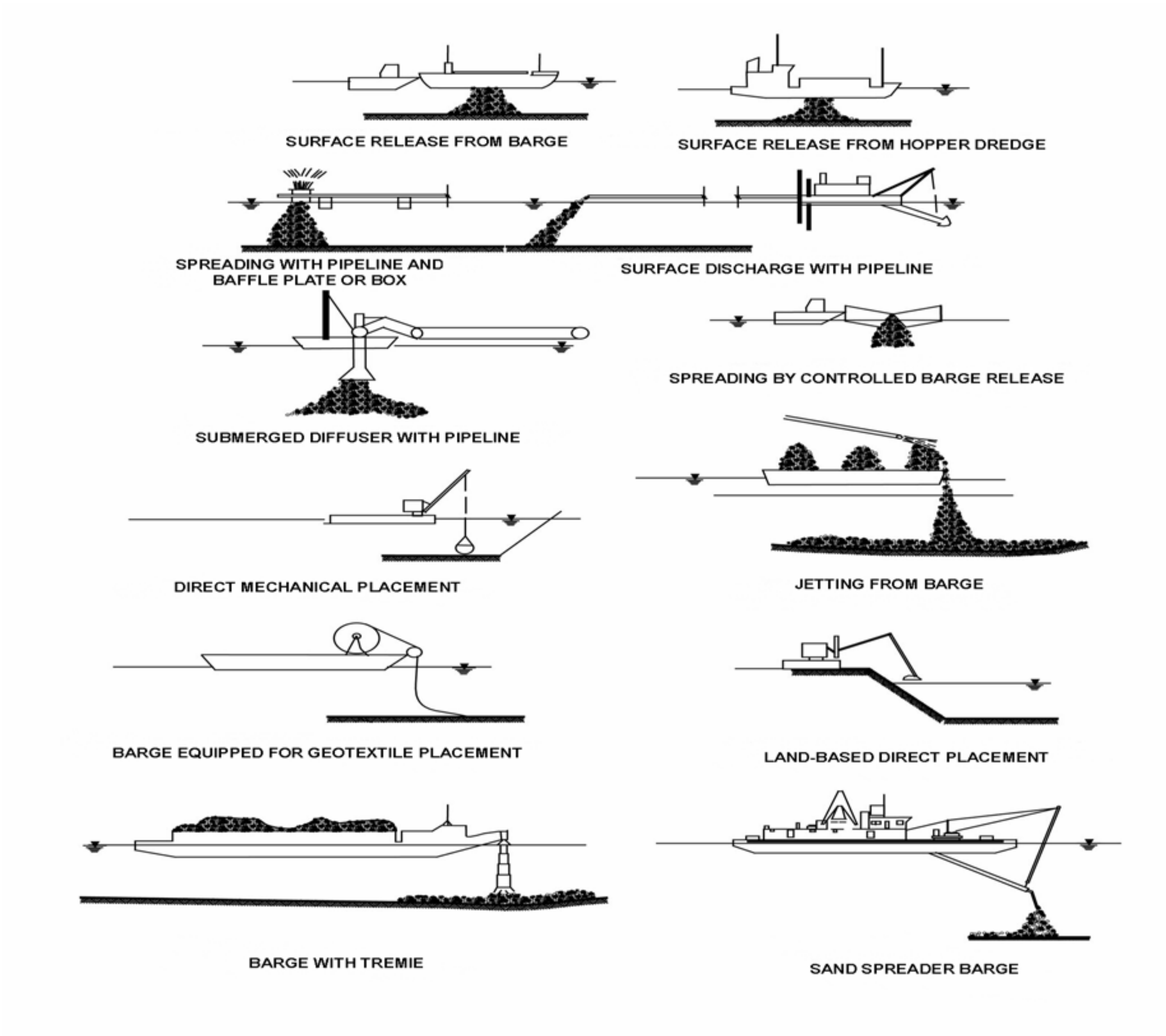
Monitoring of both placement and performance of in-situ caps are important. Cap placement can resuspend some contaminated sediment, leading to contaminant release and increased risks during and following cap placement. Therefore, designs should include plans to mitigate and monitor impacts during and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

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

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

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

Highlight 5-3: Example Capping Equipment and Placement Techniques



Source: U.S. EPA 1998d

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

5.4 EVALUATING SITE CONDITIONS

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

5.4.1 Physical Environment

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

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

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

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

5.4.2 Sediment Characteristics

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

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

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

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

5.4.3 Waterway Uses and Infrastructure

If the site under consideration is adjacent to or within a navigation, recreation or flood control channel, the effect of cap placement on those functions of the channel should be evaluated. Effects of cap placement on habitat function of a waterbody are discussed in the following section. Cap placement may have the beneficial effect of restoring habitat, but it also decreases the water depth and cross-sectional area of the channel. The flow carrying capacity of a channel and the navigable depth could also be reduced. If water depths are reduced in a harbor or river channel, some commercial and recreational vessels may have to be restricted or banned. The acceptable draft of vessels allowed to navigate over a capped area depends on water level fluctuations (seasonal, tidal, and wave) and the potential effects of vessel groundings on the cap. Due to potential cap erosion caused by propeller wash, engine size restrictions could also be needed. Generally, anchoring should not be allowed at locations on or near a cap. It may be necessary to restrict fishing and swimming to prevent recreational boaters from dragging anchors across a cap. In some situations, dredging prior to cap placement may minimize these adverse impacts of cap construction.

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

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

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

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

5.4.4 Habitat Alterations

In-situ capping alters the aquatic environment and, therefore, affects aquatic organisms. Habitat considerations are especially important when evaluating materials for the uppermost layers of a cap. Sandy sediment and stone armor layers are often used to cap areas with existing fine-grained sediment. Although the capped areas are already affected by contamination, the new substrate can change the habitat for benthic organisms. At least initially, changes in organic carbon content of the capping material may change the feeding behavior of benthic organisms in the capped area. Generally, the uppermost cap layers become a substrate for re-colonization. Where possible, caps should be designed to provide habitat for these organisms. In some cases it is possible to provide a habitat layer over an erosion protection layer by filling the interstices of armor stones with materials such as crushed gravel. In some cases, natural sedimentation processes after cap placement can create desirable habitat characteristics. For example, placement of a rock cap in some riverine systems can result in a final cap surface that is similar to that which previously existed because the rock may become embedded with sands/silts through natural sedimentation.

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

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

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

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

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