4.0 MONITORED NATURAL RECOVERY

4.1 INTRODUCTION

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

MNR may rely on a wide range of naturally occurring processes to reduce risk to human and/or ecological receptors. These processes may include physical, biological, and chemical mechanisms that act together to reduce the risk posed by the contaminants. Depending on the contaminants and the environment, this risk reduction may occur in a number of different ways. Highlight 4-1 lists the most common risk reduction processes. Natural processes that reduce toxicity through transformation or reduce bioavailability through increased sorption are usually preferable as a basis for remedy selection to mechanisms that reduce exposure through natural burial or mixing-in-place because the destructive/sorptive mechanisms generally have a higher degree of permanence. However, many contaminants that remain in sediment are not easily transformed or destroyed. For this reason, risk reduction due to natural burial through sedimentation is more common and can be an acceptable sediment management option. Dispersion is the least preferable basis for remedy selection based on MNR. While dispersion may reduce risk in the source area, it generally increases exposure to contaminants and may result in unacceptable risks to downstream areas or other receiving water bodies. As reiterated in Chapter 7, Remedy Selection Considerations, project managers should carefully evaluate the effects of this increased exposure and risk to receiving water bodies before selecting MNR where dispersion is one of the risk reduction mechanisms, to ensure that it is not simply transferring risk to a new area. Project managers should be aware that at most sites, a variety of natural processes are occurring that may reduce risk.

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

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

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

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

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

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

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

To select a MNR remedy, the project manager generally should consider the need for the following:

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

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

MNR has been selected as a component of the remedy for contaminated sediment at approximately one dozen Superfund sites so far. Historically, at many sites MNR has been combined with dredging or in-situ capping of other areas of a site. Although natural recovery following effective source control has been observed (e.g., decreases in sediment contaminant levels, sediment toxicity, and shellfish tissue contaminant levels), long-term monitoring data on fish tissue are not yet available at most sites to document continued risk reduction (see e.g., Magar et al. 2003). However, monitoring results documented at some sites are promising (e.g., Patmont et al. 2003, U.S. EPA 2001g, U.S. EPA 2001h, Swindoll et al. 2000). When hazardous substances left in place are above levels that allow for unlimited use and unrestricted exposure, a five-year review pursuant to Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) §121(c) may be required (U.S. EPA 2001i).

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

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

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

4.2 POTENTIAL ADVANTAGES AND LIMITATIONS

In most cases, the two key advantages of MNR are its relatively low implementation cost and its non-invasive nature. While costs associated with site characterization and modeling can be extensive, the costs associated with implementing MNR are primarily associated with monitoring. However, implementation costs may also include the cost of implementing institutional controls and public education to increase the effectiveness of those controls. MNR typically involves no man-made physical disruption to the existing biological community, which may be an important advantage for some wetlands or sensitive environments where the harm to the ecological community due to sediment disturbance may outweigh the risk reduction of an active cleanup.

Other advantages of MNR may include no construction or infrastructure is needed, and may, therefore, be much less disruptive of communities than active remedies such as dredging or in-situ capping. No property should be needed for materials handling, treatment, or disposal facilities, and no contaminated materials should be transported through communities.

Two key limitations of MNR may include it generally leaves contaminants in place and that it can be slow in reducing risks in comparison to active remedies. Any remedy that leaves untreated contaminants in place probably includes some risk of reexposure of the contaminants. When MNR is based primarily on natural burial, there is some risk of buried contaminants being reexposed or dispersed if the sediment bed is significantly disturbed by unexpectedly strong natural or man-made (anthropogenic) forces. The potential effects of reexposure may be greater if high concentrations of contaminants remain in the sediment, and likewise, lower if contaminant concentrations or risks are low. There is also some risk of dissolved contaminants being transported to the surface water at levels that could cause unacceptable risk. The time frame for natural recovery may be slower than that predicted for dredging or in-situ capping. However, time frames for various alternatives may overlap when uncertainties are taken into account. In addition, realistic estimates of the longer design and implementation time for active remedies should be factored in to the comparison. Like any remedy that takes a period of time to reach remediation goals, remedies that include MNR frequently rely upon institutional controls, such as fish consumption advisories, to control human exposure during the recovery period. These controls may have limited effectiveness and usually have no ability to reduce ecological exposures.

Major areas of uncertainty frequently noted for MNR include the ability to 1) predict future sedimentation rates in dynamic environments and 2) predict rates of contaminant flux through stable sediment. It can be especially difficult to predict rates of natural recovery where contaminant levels and risks are already low because small additional factors become relatively more important. However, a higher level of uncertainty may be more acceptable in these situations as well.

4.3 NATURAL RECOVERY PROCESSES

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

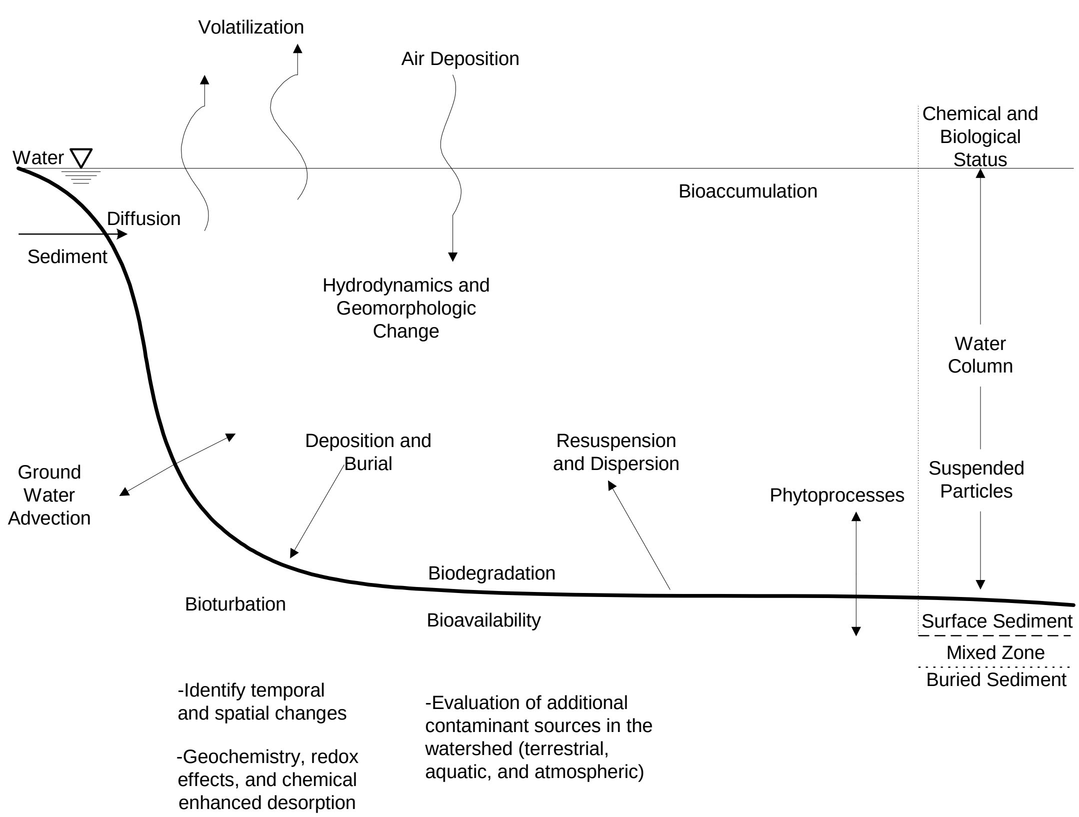
- *Physical processes*: Sedimentation, advection, diffusion, dilution, dispersion, bioturbation, volatilization;

- *Biological processes*: Biodegradation, biotransformation, phytoremediation, biological stabilization; and

- *Chemical processes*: Oxidation/reduction, sorption, or other processes resulting in stabilization or reduced bioavailability.

Highlight 4-3 illustrates some of the natural processes the project manager should consider when evaluating MNR. With few exceptions, these processes interact in aquatic systems, sometimes increasing the risk-reduction effects of a process compared to what they might be for that process in isolation, and sometimes reducing those risk-reduction effects. For example, as recognized by the U.S. Environmental Protection Agency's (EPA) Science Advisory Board (SAB) Environmental Engineering Committee, *Monitored Natural Attenuation: USEPA Research Program - An EPA Science Advisory Board Review* (U.S. EPA 2001j), sustained burial processes remove contaminants from the bioavailable zone, but can also impede certain degradation processes, such as aerobic biodegradation. Likewise, contaminant sorption to sediment particles may reduce both bioavailability and rates of contaminant transformation. In addition, in the case of mixed contaminants, the same natural process may result in very different environmental fates. When dealing with mixed contaminants at a site, the project manager should not focus unduly on one contaminant without understanding the effects of natural processes on the other contaminants, including breakdown products. Understanding the interactions between effects and prioritizing the significance of these effects to the MNR remedy should be part of a natural process analysis.

Highlight 4-3: Sample Conceptual Model of Natural Processes Potentially Related to MNR



4.3.1 Physical Processes

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

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

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

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

4.3.2 Biological and Chemical Processes

Like most natural processes, biological processes also depend on site-specific conditions and are highly variable. During biodegradation, a chemical change is facilitated by microorganisms living in the sediment. One of the important limitations to the usefulness of biodegradation as a risk-reduction mechanism is that the greater the molecular weight of the organic contaminants, the greater partitioning to sorption sites on sediment particles (Mallhot and Peters 1988) and the lower the contaminant availability to microorganisms. Some degradation of high molecular weight organic compounds occurs naturally in soil and sediment with anaerobic and aerobic microorganisms (Brown et al. 1987, Abramowicz and Olsen 1995, Bedard and May 1996, Shuttleworth and Cerniglia 1995, Cerniglia 1992, Seech et al. 1993). Degradation rates vary with depth in sediment partly due to the change from aerobic or anaerobic conditions. This changes frequently occur at depths of a few millimeters to a few centimeters where sediments have substantial organic content and conditions are quiescent, and may occur deeper in some circumstances. Longer residence times of contaminants in the sediment (aging) also usually result in increased sequestration (Luthy et al. 1997, Dec and Bollag 1997). These processes reduce the availability of the organic compounds to microorganisms and, therefore, reduce the extent and rates of biodegradation (Luthy et al. 1997, Tabak and Govind 1997). However, this can also reduce the availability of the contaminant to receptors living in the sediment and as well as at higher trophic levels.

Chemical processes in sediment are especially important for metals. 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 resulting from changes in redox potential that can affect the bioavailability of metal and organic metal compounds. Formation of relatively insoluble metal sulfides under reducing conditions can often 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 also affected by the biological community.

<u>Biochemical Processes for Polycyclic Aromatic Hydrocarbons (PAHs)</u>

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

PAHs may be subject to physical, chemical and biological breakdown in the environment and where these processes are effective, may be especially amenable to natural recovery. The type of process that dominates may depend on time. For example, following a release of PAHs into the environment, physical-chemical processes such as dispersion, volatilization, and photodegredation may dominate. Where these processes are effective in attenuating the contaminants to less toxic levels, tolerant microbial species may cause further biodegradation. There is a wide variation in rates of biodegradation and toxicity reduction, depending on the levels of microbial activity and the physical and chemical conditions of the site (Swindoll et al. 2000). PAHs biodegrade more quickly through aerobic than anaerobic processes, although the degradation rate usually decreases as the number of aromatic rings increases (Shuttleworth and Cerniglia 1995, Cerniglia 1992, Seech et al. 1993). While biodegradation of PAHs may occur under anaerobic conditions, PAHs usually persist longer in anaerobic sediment compared to aerobic environments (U.S. EPA 1996d, Safe 1980).

Although low PAH degradation rates are often attributed to low bioavailability (see review by Reid et al. 2000), evidence reported by Schwartz and Scow (2001) demonstrates that it may be the lack of enzyme induction amongst the PAH-degrading bacteria that is responsible for low rates below a threshold PAH concentration. Other researchers have reported this phenomenon for PAHs (Ghiorse et al. 1995, Langworthy et al. 1998) and other aromatic organics (Zaidi et al. 1988, Roch and Alexander 1997). At elevated PAH concentrations in sediment, there is selective pressure for PAH-degrading bacteria, which can increase the capacity to attenuate PAHs naturally. However, there is uncertainty about whether and how fast this degradation may reach acceptable risk levels. Because of the variation among sites, site-specific studies may be needed to resolve uncertainties concerning degredation rates and whether these rates will contribute to recovery within an acceptable time frame.

Biochemical Processes for Polychlorinated Biphenyls (PCBs)

Release of a PCB Aroclor (see PCB data information in Chapter 2, Section 2.1.2, Types of Data) into the environment may result in a change in its congener composition. This is a result of the combined weathering effects and such processes as differential volatilization, solubility, sorption, anaerobic dechlorination, and metabolism, and results in changes in the composition of the PCB mixture in sediment, water, and biota over time and between trophic levels (NRC 2001).

Highly chlorinated congeners of PCBs may gradually partially dechlorinate naturally in anaerobic sediment (Brown et al. 1987, Abramowicz and Olsen 1995, Bedard and May 1996). In general, less-chlorinated PCBs bioaccumulate less than the highly chlorinated congeners, but are more soluble and, therefore, more readily transported into and within the water column than highly chlorinated PCBs. The less chlorinated PCBs exhibit significantly less potential human carcinogenic and dioxin-like (coplanar structure) toxicity (Abramowicz and Olsen 1995, Safe 1992), but may be transformed in humans into forms with potential for other toxicity (Bolger 1993).

Aerobic processes may then biodegrade the less chlorinated PCB congeners (Flanagan and May 1993, Harkness et al. 1993). The sediment concentrations of other chemicals and the total organic content tend to control these processes. However, little evidence exists that lower chlorinated congeners under the anaerobic or anoxic conditions found in most sediment are significantly transformed. Therefore, these partially dechlorinated organics tend to accumulate and persist (U.S. EPA 1996d, Harkness et al. 1993). Although desirable, it is unclear whether biologically mediated dechlorination of PCBs would be effective in achieving remedial objectives in a reasonable time frame and may result in the production of more toxic byproducts.

4.4 EVALUATION OF NATURAL RECOVERY

An evaluation of MNR as a potential remedy or remedy component should generally focus on considering, at a minimum, the following questions:

- Is there evidence that the system is recovering?
- Why is the system recovering or not recovering?
- What is the pattern of recovery or non-recovery expected in the future?

This evaluation should be supported with a variety of types of site-specific characterization data and, often, modeling. The lines of evidence approach for evaluation of natural attenuation of contaminants in soil and ground water can provide a general framework for evaluating MNR in sediment (e.g., U.S. EPA 1999d). Swindoll and his colleagues include a chapter on natural remediation of sediment that presents a useful summary discussion (Swindoll et al. 2000). EPA's Office of Research and Development (ORD) is in the process of drafting a technical resource document specifically for MNR in sediments and may also include suggested protocols. In addition, members of the joint industry–EPA Sediments Action Team of the Remedial Technologies Development Forum (RTDF) has developed a series of working papers on MNR that can be found at http://www.rtdf.org/public/sediment/mnrpapers.htm (Davis et al. 2003, Dekker et al. 2003, Erickson et al. 2003, Magar et al. 2003, Patmont et al. 2003).

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

Highlight 4-4: Potential Lines of Evidence of Monitored Natural Recovery

- Long-term decreasing trend of contaminant levels in higher trophic level biota (e.g., piscivorous fish)
- Long-term decreasing trend of water column contaminant concentrations averaged over a typical low-flow period of high biological activity (e.g., trend of summer low flow concentrations)
- Sediment core data demonstrating a decreasing trend in historical surface contaminant concentrations through time
- Long-term decreasing trends of surface sediment contaminant concentration, sediment toxicity, or contaminant mass within the sediment

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

- Identification and characterization of ongoing sources of contamination;
- Characterization of sediment types (e.g., bed mapping) and stratigraphic structure of the sediment bed;
- Evaluation of historical and current contaminant levels in biota and surface water;
- Evaluation of geomorphology, long-term accretion, and erosion;
- Evaluation of sequestration mechanisms (e.g., sorption, precipitation) and rates of degradation or transformation;
- Determination of the depth of the surface mixed layer;
- Measurement of suspended solids and contaminant transport during high-energy (e.g., storm) events;
- Measurement of sediment erosion properties and impacts of ice on sediment transport;
- Evaluation of impacts of ground water advection or movement of non-aqueous phase liquids (NAPL); and
- Development of a tool to allow prediction of future recovery and risk reduction (e.g., sediment and contaminant fate and transport modeling).

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

Integration of the data quality objective (DQO) process with risk evaluation can help identify which natural processes are most critical to the evaluation of MNR at a site. Generally, the identification of MNR data needs and preparation of study design can be structured similarly to the DQO process (U.S. EPA 2000a) that is normally integrated within the remedial investigation and feasibility study (RI/FS). The DQO process is discussed in greater detail in Chapter 2, Section 2.1.1.

4.5 ENHANCED NATURAL RECOVERY

In some areas, natural recovery may appear to be the most appropriate remedy, yet the rate of sedimentation or other natural processes is insufficient to reduce risks within an acceptable time frame. Where this is the case, project managers may consider accelerating the recovery process by engineering means, for example by the addition of a thin layer of clean sediment. This approach is sometimes referred to as “thin-layer placement” or “particle broadcasting.” Thin-layer placement normally 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 typically different than the isolation caps discussed in Chapter 5, In-situ Capping, because it is not designed to provide long-term isolation of contaminants from benthic organisms. While thickness of an isolation cap can range up to several feet, the thickness of the material used in thin layer placement could be as little as a few inches. The grain size and organic carbon content of the clean sediment to be used for thin-layer placement should be carefully considered in consultation with aquatic biologists. In most cases, natural materials (as opposed to manufactured materials) approximating common substrates found in the area should be used. Clean sediment can be placed in a uniform thin layer over the contaminated area or it can be placed in berms or windrows, allowing natural sediment transport processes to distribute the clean sediment to the desired areas.

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

4.6 ADDITIONAL CONSIDERATIONS

MNR is likely to be effective most quickly in depositional environments after source control actions and active remediation of any high risk sediment have been completed. Where external sources were controlled many years previously and no discernable high risk sediment areas can be identified, yet site risks remain unacceptable, it may be questionable whether natural processes alone will reduce risks satisfactorily in the future. At these sites, it can be especially important to evaluate the effectiveness of previous source control actions and to evaluate potential additional active sediment source control or remediation methods for selected areas. For MNR, as for other sediment remedies, effective source control is often critical to reaching remedial objectives in a reasonable time frame and to preventing re-contamination.

As discussed in Chapter 7, Remedy Selection Considerations, when evaluating MNR, the short-term effects on human health and the environment during the recovery period (i.e., the baseline risks for the site) should be compared to the short-term effects of other approaches such as effects of resuspension of contaminants due to dredging and habitat changes caused by capping. Section 7.3, Considering Remedies, discusses the process of comparing short-term and long-term risks associated with various approaches in a net comparative risk analysis.

In most cases, the long-term effectiveness of MNR is dependent on the dynamic processes of mixing and burial over time remaining dominant over sediment resuspension or contaminant movement via advective flow or other mechanisms. Assessment of sediment and contaminant fate and transport are, therefore, very important at most sites. Some potential mechanisms for physical disruption of overlying cleaner sediment, such as keel drag or pipeline construction, may be amenable to human management controls. Others mechanisms for physical disruption, such as ice scour or flooding, may be only partly manageable or not manageable. The importance of contaminant movement through overlying sediment to surficial sediment and the overlying water can depend on several factors, including the chemical characteristics of the contaminant, physical characteristics of the sediment, and patterns of ground water flow. These issues can also be of concern for in-situ capping and are discussed further in Chapter 2, Section 2.8, Sediment and Contaminant Fate and Transport, in Chapter 5, In-Situ Capping, and in the U.S. Army Corps of Engineers (USACE) Technical Note, *Subaqueous Capping and Natural Recovery: Understanding the Hydrogeologic Setting at Contaminated Sediment Sites* (Winter 2002). In general, the presence of processes, such as erosion or ground water flow, that cause release of contamination to the water column should not eliminate consideration of MNR as a remedy; instead, they should lead to evaluation of the consequences of those processes on exposure and risk.

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

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

MNR should be considered when it would meet remedial objectives within a time frame that is reasonable compared to active remedies. However, the Agency recognizes that MNR may take longer to reach cleanup levels in sediment than dredging or in-situ capping and, therefore, may take longer to reach all remedial action objectives, such as contaminant reductions in fish. It is important to compare time frames on as accurate a basis as possible, including for example, accurate assessments of time for design and implementation of dredging or capping and realistic assumptions concerning dredging residuals. Where possible, estimates of the uncertainty in the recovery time frame associated with each alternative should also be made. Factors that the project manager should consider in determining whether the time frame for MNR is “reasonable” include the following:

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

- The value of ecological resources that may continue to be impacted during the recovery period;

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

- The uncertainty associated with the time frame prediction.

As with any remedy, project managers should carefully evaluate the uncertainties involved and consider the need for contingency measures, contingency remedies, or interim decisions where there is significant uncertainty about effectiveness. For MNR, as for other approaches which take a period of time to reduce risk, project managers should carefully consider how risks can be controlled during the recovery period. For sites with bioaccumulative contaminants, institutional controls such as fish consumption advisories are frequently needed to reduce human exposures during this period. In most cases, no institutional controls are possible for reducing ecological exposure during the recovery period. See Chapter 3, Section 3.6, Institutional Controls, and Chapter 7, Section 7.5, Considering Institutional Controls, for more information concerning institutional controls at sediment sites. Highlight 4-5 lists some important points to remember from this chapter.

Highlight 4-5: Some Key Points to Remember When Considering Monitored Natural Recovery

- Source control should be generally implemented to prevent recontamination

- MNR frequently includes multiple physical, biological, and chemical mechanisms that act together to reduce risk

- Evaluation of MNR should be usually based on site-specific data collected over a number of years. At some sites, this may include an assessment of seasonal variation for some factors

- Project managers should evaluate the long-term stability of the sediment bed, the mobility of contaminants within it, and the likely ecological and human health impacts of disruption

- Multiple lines of evidence are frequently needed to evaluate MNR (e.g., time-series data, core data, modeling)

- Thin-layer placement of clean sediment may accelerate natural recovery in some cases

- Contingency measures should be included as part of an MNR remedy when there is significant uncertainty that the remedial action objectives will be achieved within the predicted time frame

- Generally, MNR should be used either in conjunction with source control or active sediment remediation

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