Association of State and Territorial

ASTSWMO

Solid Waste Management Officials

Framework for Long-Term Monitoring of Hazardous Substances at Sediment Sites

Sediments Focus Group

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Executive Summary

The primary purpose of long-term monitoring is to determine whether a remedial action was successful in minimizing environmental and human health risks. The long-term monitoring plan is developed to acquire data to determine whether the various components of the remedy are performing successfully based on the remedial goals and objectives of the project. The long-term monitoring plan's goals and objectives should be consistent with the remedial decision document.

Similar to remedial goals, monitoring goals need to be established. The design and implementation of a long-term monitoring plan should be considered during the remedial Feasibility Study (FS) when various alternatives (i.e., active or passive sediment remediation strategies) are selected. Remedial goals and objectives selected following the FS will form the basis for the long-term monitoring plan's goals and objectives.

Included in this paper are methods and resources for long-term monitoring of physical, chemical, and biological attributes at contaminated sediment sites. These methods provide a quantifiable means by which the remedy's effectiveness can be evaluated. Examples are included of methods that are appropriate for monitoring the effectiveness of various remedies, such as capping, dredging, confined disposal, enhanced natural recovery, in situ treatment, monitored natural attenuation, institutional controls, and no action.

Because most sediment site remedial actions do not involve the elimination of all risks associated with a site, it is important to establish baseline conditions both before and after remedial action. Essential components of a long-term monitoring plan include a summary of the baseline physical, chemical, and biological conditions before remediation; the goals and objectives of the monitoring plan; a site conceptual model; all data collection and evaluation methods; and relevant decision criteria. The pre-remediation and post-remediation data sets should be compatible to allow effective comparisons during long-term monitoring.

A long-term monitoring plan is not designed to simply assess the success or failure of a remedy. Physical, chemical, or biological changes in site conditions over the monitoring period may require adaptability in the plan. Contingency planning within the long-term monitoring plan provides flexibility to address changing site over time. Decision rules within a long-term monitoring plan should establish specific criteria for continuing, prolonging, modifying, or terminating data collection activities. In some cases, sediment monitoring may justify further response or remedial action, consistent with the regulatory framework of the remedial action.

Large arrays of physical, chemical, and biological monitoring techniques are available

for consideration by the remedial project manager. These monitoring techniques should not be mutually exclusive. Monitoring plans should include concurrent measures of physical, chemical, and biological conditions pre- and post-remediation to provide multiple lines-of-evidence for both determining and communicating whether a remedial action was effective.

Biological monitoring is necessary to ensure that the remedy is meeting ecological recovery goals for emergent and submergent aquatic plants, benthic invertebrates, amphibians, fish, birds, mammals, and other species. The long-term monitoring plan should set recovery goals and benchmarks and include consideration of the monitoring and control of invasive species. Provided that flexibility has been written into the long-term monitoring plan, biological monitoring may be reduced or phased out as recovery goals and benchmarks are met.

Also included in this paper are several case studies in which a monitoring plan was developed and various methods were used to evaluate the remedy's effectiveness. Rather than focus on the success or failure of a selected remedial alternative, each case study details which aspects of the monitoring strategy were critical in assessing the effectiveness of the selected remedy.

In summary, the implementation of a long-term monitoring plan should gather information to ensure that a contaminated sediment site's remedial goals and objectives are being achieved; inform project managers for management decisions regarding the protectiveness of human health and the environment; and provide a quantifiable means to evaluate future changes to the long-term monitoring plan or the selected remedy, if needed.

Section I. Introduction

The Association of State and Territorial Solid Waste Management Officials (ASTSWMO) Sediments Focus Group produced the "Guide to the Assessment and Remediation of State-Managed Sediment Sites" (ASTSWMO, 2007), which presents issues and information related to state sediment sites. This paper is a framework or guide that expands on that effort by discussing the issues related to post-remediation long-term monitoring at sediment sites. Because sediment sites and the types of remediation used at them can be complex, any monitoring decisions will need to consider these complexities to be effective.

This guide addresses both active and passive types of remedies, as well as any restored resources. Active remedies include capping, dredging, confined disposal, enhanced natural recovery, and various in situ methods (e.g., activated carbon). A passive remedy generally involves Monitored Natural Recovery (MNR). Sediment remedies also may include the primary restoration of sediment-associated habitats, such as wetlands. A long-term monitoring plan must consider the selected remedy, site size, and level of residual contamination. If a natural resource, such as a wetland, is damaged and restored as the result of the remediation, monitored recovery of that resource may need to be considered as well. Finally, a long-term monitoring plan should allow for contingencies.

The purpose of this guide is to address the components of a successful monitoring plan. It is not intended to address the pros or cons of various types of sediment remediation strategies; rather, it is designed to provide state project managers with information sources and examples of issues related to the establishment of successful long-term monitoring programs for sediment remediation sites.

Section I.1 What is ASTSWMO?

ASTSWMO is an organization supporting the environmental agencies of state and trust territories. ASTSWMO focuses on the needs of state hazardous waste programs; non-hazardous municipal solid waste and industrial waste programs; recycling, waste minimization, and reduction programs; Superfund and state cleanup programs; waste management and cleanup activities at federal facilities; and underground storage tank and leaking underground storage tank programs. The association's mission, briefly stated, is: "To enhance and promote effective state and territorial waste management programs, and affect national waste management policies."

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

Section I.2 Purpose of Long-Term Monitoring at Sediment Sites

The main purpose of long-term monitoring is to determine whether the remedial action has been successful. Accordingly, the primary goal of a monitoring program is to determine whether the various components of the remedy are performing successfully. Absent a monitoring program, this may be difficult, if not impossible, to determine. A monitoring program should not only be designed to evaluate the success or failure of a remedy, it should also be designed to address deficiencies throughout the remedial process so that changes can be implemented as necessary. Long-term monitoring may also be necessary to determine the next step(s) of the remedy for partially completed or staged remedial actions.

Similar to remedial goals, monitoring goals need to be established. A monitoring plan should be designed to determine whether those monitoring goals are being achieved. Aside from the overall goal of determining whether a remedy is successful, monitoring goals can determine the success of such components as: continued remedy protectiveness; adequate habitat recovery; and proper maintenance of on-site disposal facilities. The selection of monitoring goals will depend on the type and scope of the remedy selected. The goals and objectives of long-term monitoring plan should be established as early as possible, even at the FS stage.

Generally, most sediment site remediation efforts do not involve the removal of all contamination, or elimination of all risks associated with a site. For this reason, establishing baseline conditions both before and after remediation is important. For an active remedy, monitoring should take into consideration at least four factors: 1) the extent (area and levels) and persistence of residual contamination remaining at the site (for both the remediated and non-remediated locations); 2) the existence of on-site disposal facilities (such as confined disposal facilities, confined aquatic disposal facilities, and caps); 3) the biological resources restored or replaced; and, potentially, 4) the site bathymetry. These considerations are important to establish a post-remediation baseline, which, over time, can be used to evaluate the success of the remedy. The baseline is particularly important if there are any potentially significant contaminant sources that have not been remediated or are suspected to remain on or near the site. Controlling ongoing sources must be a top priority at contaminated sediment sites.

Natural resource trustees will probably be interested in the monitoring plans and results at sediment sites. Coordination of the monitoring plan with natural resource trustees is recommended, as sharing data will save time and money for both the remedial agency and the natural resource agency by not duplicating efforts.

Section I.3 Overview of the Framework

This paper addresses the following topics by section. Section II describes the essential components and organization of a long-term sediment monitoring plan. The long-term monitoring plan should be designed to determine whether a contaminated sediment site's remedial goals and objectives have been achieved, and to inform management's decisions and the public. Section III provides methods and resources for monitoring the physical, chemical, and biological attributes of sediments. These methods provide quantifiable means by which the remedial project manager can demonstrate the effectiveness of the selected remedy. Section IV details monitoring considerations and examples of methods that are appropriate for monitoring the effectiveness of various remedies, including capping, dredging, confined disposal, enhanced natural recovery, in situ treatment, monitored natural attenuation, institutional controls, or no action. Changes in site conditions over the monitoring period may require adaptability in the plan. Section V highlights several case studies in which a monitoring plan was developed and various methods were used to evaluate the remedy's effectiveness. Each case study details aspects of the monitoring strategy which were critical in assessing the effectiveness of the selected remedy. Section VI provides a summary of recommendations and conclusions.

Section II. Components of Long-Term Monitoring Plan

A long-term monitoring plan for contaminated sediment sites should describe the information and methods necessary to evaluate changes following remediation. This section provides a general overview of the basic components. If additional information is needed, the references at the end of the section can be used to obtain more guidance regarding long-term monitoring plan development.

A monitoring plan is developed based on the remedial goals and objectives of the project. Prior to monitoring, pre-remediation baseline site data and information should be collected during the site investigation. The pre-remediation and post-remediation data sets should be compatible to allow for effective comparisons during long-term monitoring. The components of a long-term monitoring plan include:

1. Project Background And Pre-Remedial Baseline Conditions
2. Long-Term Monitoring Plan Goals and Objectives
3. Conceptual Site Model
4. Monitoring Decision Rules
5. Monitoring Plan
6. Data Evaluation and Interpretation
7. Management Decisions

Each of these components is discussed in the following subsections.

Section II.1 Project Background and Pre-Remedial Baseline Conditions

The project background identifies and describes site conditions based on the supporting documentation for the site. It will include the relevant site description and release pathways, along with a summary of the biological resources present at the site and contaminant concentrations found in the various media (sediment, water and biota). Pre-remedial baseline conditions are the levels of contaminants and other relevant information found in the different media prior to the start of remediation. Post-remedial baseline conditions are also important to determine the levels of contaminants and other relevant information in the short term following remediation. Long-term monitoring should begin after the selected sediment remedial action is complete.

Section II.2 Long-term Monitoring Goals and Objectives

Long-term monitoring goals and objectives can be developed as soon as remedial action objectives are selected in the FS. The long-term monitoring plan's goals and objectives are then used to evaluate the sediment remediation project following completion of the selected remedial action. These specific monitoring goals and objectives examine the remedial action objectives and endpoints (physical, chemical and biological) following remediation or no action. Monitoring goals and objectives should be clear and specific to evaluate the conditions following the sediment remediation; they are generally linked to sediment, water and biota monitoring. For example, a long-term monitoring goal might be to determine whether a contaminant in fish or shellfish tissue declines following a remedial action. Similarly, a long-term monitoring objective might be to measure polychlorinated biphenyls (PCBs) in largemouth bass fillet tissue every year over a five year period.

Section II.3 Conceptual Site Model

The conceptual site model describes and organizes relationships between sediment remediation activities (including MNR) and expected future conditions. The conceptual site model for long-term monitoring is a useful tool for describing the working hypothesis between sediment remediation and expected outcomes.

The monitoring plan should develop questions to evaluate how the remedy is performing in the period following remedial action. The monitoring will measure contaminants and conditions in environmental media to evaluate how well the sediment remediation is meeting the remedial goals described in the decision document, or the Record of Decision.

A long-term monitoring question for sediment remediation could be generally stated as "Has the sediment remediation chosen for the site reached the stated goals and objectives?"

For example, specific questions that should be addressed through the long-term monitoring plan are:

- What are the contaminant levels (i.e., in water, sediment, biota) following remediation or monitored natural recovery?

- What are the contaminant levels over time (i.e., what are the long-term trends 3, 5 and 7 years after the action)?

- What frequency of monitoring should be used?

- Have biological systems/biota recovered based on some quantifiable or qualitative metrics?

Section II.4 Monitoring Decision Rules

The long-term monitoring plan should identify specific decision rules to evaluate whether remedial goals and objectives are addressed. Decision rules use "if… then…" statements to define a particular condition, allowing the decision maker to choose an action. Decision rules for long-term monitoring should establish site specific criteria to continue, stop or modify the long-term monitoring, or recommend taking additional response action. The main elements of a decision rule are: the parameter of interest; the expected outcome; an action level; the basis on which a monitoring decision will be made; and monitoring decision choices (USEPA, 2004a). The timeframe to attain long-term monitoring objectives should be understood by the participants and stakeholders.

Section II.5 Monitoring Plan

The long-term monitoring plan should detail all sample collection and analysis methods. For example, sampling and analysis plans should be developed to answer the questions posed in Section II.3. Data quality objectives (DQO) should be determined while the sampling plan is being developed. The EPA uses the data quality objective process in planning for monitoring and provides guidance on developing DQOs for projects (USEPA, 2000a). When preparing the monitoring plan, a Quality Assurance Project Plan (QAPP) (USEPA, 2002) or its equivalent should be included. A QAPP describes the necessary quality assurance procedures, quality control activities, and other technical activities that will be followed for the specific project.

The plan should be designed to obtain data at a frequency that meets the needs of the project. The nature and extent of contamination identified during pre-remedial conditions will help to determine what sampling and where it will be performed. In addition, the project's remedial goals and objectives identify the important endpoints that will be assessed.

The amount and complexity of sampling will depend on the site and on the type of sediment remediation completed. In general, larger sediment remediation projects may require more complex surveys or sampling activities over the long-term than a smaller sediment project. Institutional controls at sediment remediation projects may require additional or complimentary monitoring. For example, fish consumption advisories require fish tissue sampling and analysis to determine if the advisory can be modified. Ultimately, it is important to assess the endpoints that will be useful for evaluating site conditions and making decisions.

Section II.6 Data Evaluation and Interpretation

The next component involves organizing the analytical data, evaluating the results, and addressing any deviations from the monitoring plan. The data evaluation should present the analytical results in a format useable for that particular project. This portion of the monitoring plan should describe how the results will be evaluated in relation to the long-term monitoring goals and objectives, conceptual site model, and decision rules described above. Long-term monitoring may continue, cease, or be modified. Additional response actions may be indicated as well.

The results of long-term monitoring should be communicated to the appropriate stakeholders in a variety of formats, including detailed paper and electronic reports as well as non-technical booklets and presentations suitable for the general public.

Section II.7 Management Decisions

The long-term monitoring plan may need to be modified based on an evaluation of the actual results. Such decisions will generally be site-specific and depend on the information and data gathered. Before sampling begins, the long-term monitoring plan should establish criteria for continuing, stopping, or modifying the monitoring plan, or for evaluating additional response actions.

More information regarding development of long-term monitoring plans can be found in USEPA, 2000a; USEPA, 2001a; USEPA, 2001b; USEPA, 2002; USEPA, 2004a; and USEPA, 2005.

Section III Overview of Physical, Chemical, and Biological Monitoring Methods Applicable to Sediments

This section details methods for monitoring and sampling various physical, chemical, and biological components of sediments. These methods should be considered when preparing a long-term monitoring plan. Depending on the chemical of concern and the selected remedial alternative, physical, chemical, and biological measurements can be selected and incorporated into the plan. In many cases, these measurements can be taken concurrently, in co-located areas, to establish whether remedial action goals and objectives are being achieved.

Section III.1 Sediments

Section III.1.i Physical Characteristics

An analysis of the physical characteristics of sediment will provide important information that can be used to assess contaminant bioavailability, chemical speciation, sediment deposition, and sediment transport processes. Typical analyses include pH (pore water), redox potential (Eh), particle size distribution, total solids, specific gravity, and bulk density. Some of these parameters are described in more detail below. A variety of methods for measuring a sediment’s physical characteristics have been published and widely used for a number of years and can be found in Plumb, 1981; Page, et al., 1982; Folk, 1980; USEPA, 1995; USEPA, 2001a; Loring and Rantala, 1992; and Mudroch and Azcue, 1995.

- Particle size distribution - The frequency of size ranges of mineral particles that make up the sediment, which is usually described in percentages of gravel, sand, silt, and clay. This information can be used to predict sediment erodibility, contaminant binding capacity, and sediment treatability.

- Total solids (percent water or moisture content) - A gravimetric determination of the organic and inorganic material remaining in a sample after it has been dried at a specific temperature. This information can be used to convert concentrations of contaminants in sediment from a wet weight to a dry weight basis.

- Specific gravity - The ratio of the mass of a given volume of material to an equal volume of distilled water at the same temperature. The specific gravity of a sediment sample can be used to predict the behavior (i.e., dispersal and settling characteristics) of sediments.

- Wet (bulk) density - The mass of a water-sediment mixture per unit volume. This parameter can be used to predict sediment erosion potential/ cohesion and the ability to support a cap.

Particle size may be an important consideration since the highest concentrations of contaminants are often associated with smaller-sized sediment particles. Therefore, it is necessary to decide whether a sediment sample should be sieved and what particle size class should be analyzed for the contaminants of concern. This is important because the concentration data will be used by the environmental agency for ecological risk assessment and setting cleanup goals, and because the most biologically available contaminants are usually associated with the smallest sediment particles.

Section III.1.ii Chemical Characteristics

Chemical monitoring can be designed to evaluate concentrations of sediment contaminants (in the upper biological surficial zone, deeper sediment, and/or pore water), contaminant bioavailability, contaminant biodegradation, contaminant partitioning to pore water, and specific phases of contaminants. Sediments should be sampled and analyzed for contaminants to assess the effectiveness of the remedy/removal action and to characterize sediments recently deposited at the site and elsewhere as a result of deposition of resuspended sediments. Certainly, monitoring to assess sediment chemical stability is of key importance.

Additional chemical parameters include salinity and hardness (pore water), organic carbon, ammonia (pore water), nitrate, ammonia nitrogen, total phosphorus, total sulfide, acid volatile sulfide (AVS), and simultaneously extracted metals (SEM). Methods for the chemical evaluation of sediment are discussed in PSEP, 1996; APHA, 1995; and USEPA, 2001a.

Section III.1.iii Measures of Sediment Erodibility and Stability

At sites where natural recovery is based on burial with clean sediment, continued monitoring may be necessary to assess whether contaminants remain buried after a significant disturbance event. Methods of monitoring the placement of engineering controls will be needed, including bathymetric surveys, sediment cores, sediment profile imaging, and chemical resuspension monitoring of contaminants. Tools for monitoring sediment physical stability are of key importance; some of these are discussed in more detail below. Sediment stability assessment is generally discussed in Bohlen and Erickson, 2006.

- Bathymetric data - Useful for evaluating post-capping or post-dredging bottom elevations for comparison to design specifications, and evaluating sediment stability during natural recovery. Bathymetric analysis can track bed elevation changes with time, but typically cannot provide sufficient vertical resolution (within a few centimeters) over a short period of time (Magar and Wenning, 2006). General references for bathymetric survey methods include Ingham, 1994; Lurton, 2002; and US COE, 2002a.

- Settlement plate data - Useful for monitoring changes in cap thickness over time and measuring cap consolidation. This data can also be used as a measure of sediment deposition and to characterize recently deposited sediments.

- Sediment profile camera data - Useful for monitoring changes in thin layering within sediment profiles, cap thickness, sediment grain sizes, bioturbation and oxidation depths (benthic recolonization), and the presence of gas bubbles.

- Critical sheer stress data - Useful for tracking sediment stability, erosion potential, and contaminant resuspension. Shear stress can be measured directly using in situ or ex situ erosion measurement devices. In situ measurement devices include the Sea Carousel (Maa et al., 1995) or the Inverted Flume (Ravens and Gschwend 1999); ex situ devices include the SED Flume (McNeil et al., 1996; Roberts et al., 1998), the ASSET Flume (Roberts et al., 2003), the SEAWOLF Flume (Jepsen et al., 2002), and the Shaker/PES Flume (Tsai and Lick, 1986). Direct measurements of sediment shear strength may be necessary with more cohesive sediments. Measurement devices and references are discussed in Magar and Wenning, 2006. Widely used devices, their uncertainties and applicabilities, are also discussed in Jepsen, 2006.

Section III.1.iv Sediment Sampling

There are two basic techniques for sediment sampling: grab sampling for surface and near surface sediments, and coring. Sediment core data is used to obtain a vertical profile of sediment chemistry and to detect contaminant movement through a cap or through a layer of naturally deposited clean sediment. Core samples can also be used for sediment dating, determining sediment deposition and erosion rates, and source identification and control. Core data can be used to track contaminant trends over time, which is important when determining the appropriateness of MNR as a remedy. Coring devices include conventional hand corers, vibracorer, gravity piston corer, and drop tube samplers. The choice of corer design depends on factors such as the objectives of the sampling program, sediment volumes required for testing, sediment type, water depth, sediment depth, and currents or tides. A gravity corer may be limited to cores of 1-2 meters in depth, depending on sediment grain size, degree of sediment compactness, and the velocity of the drop. For penetration greater than 2 meters, a vibratory corer or a piston corer is generally preferable.

Grab samplers can be used to collect sediment samples for sediment chemistry analyses and toxicity tests. The samples can also be sieved to evaluate the benthic invertebrate community. There are many types of grab sampling devices; the Van Veen, Ponar, Petersen, and Birge-Ekman are the most commonly used. A grab sampler is lowered to the bottom of the water body where it penetrates the sediment-water interface and then closes. The device is then raised to the surface with the intact sediment sample. Grab samplers vary in penetration depth and the surface area sampled, but they are typically used when large volumes of sediment are needed, and consolidated, large-grained sediments are expected to be encountered. Although grab samplers can sample a larger surface area than most coring devices, they exhibit relatively shallow depth penetration. Caution must be exercised when collecting and interpreting sediment grab samples, as the deployment and capture of sediments will disturb existing sediment structure. Also, the jaws of the grab sampling device often do not close properly due to stones or debris. Sediment sampling techniques are discussed in Mudroch and MacKnight, 1994; Ohio EPA, 2001; TCEQ, 2003; USEPA, 2001a; USEPA 2003; Radtke, 2005; ASTM, 2006; and ASTM, 2008.

Section III.2 Surface Water

Surface water monitoring during remedial action and over the long term may be appropriate at some sites. Typical water chemistry measurements include dissolved oxygen, turbidity, conductivity, salinity, nitrate, pH, sulfate, hardness, alkalinity, organic carbon, total dissolved solids, and total suspended solids (TSS). Also, all target analytes identified in the sediment should initially be considered potential targets for water analysis. These analyses are important to assess the bioavailability of contaminants within the water column, and to track the possibility of releases to the water column during the remedy implementation and over the long term. TSS and turbidity information can be used to monitor the amount of sediment resuspended during dredging and during placement of in situ caps or other remedies. General water chemistry parameters are also important in assessing the potential for biological recovery in the impacted area.

General information for surface water sampling and analysis can be found in Nollet, 2007; TCEQ, 2003; and USGS, 2006. Additionally, a number of field and lab manuals are available on the U.S. EPA's Environmental Monitoring and Assessment Program (USEPA_EMAP) website. Approved U.S. EPA Clean Water Act analytical methods (test procedures) are provided at their website (USEPA_Clean_Water_Act).

Section III.3 Pore Water

Section III.3.i Analyses

Depending on the initial exposure pathways of concern, it may be appropriate to monitor the sediment pore water (or interstitial water) to assess contaminant bioavailability, biodegradation, contaminant partitioning to the pore water, and contaminant ground water flux, particularly for mobile chemicals at sites with the potential for groundwater upwelling following sediment remediation. In general, chemical concentrations in sediment pore water can provide better estimates of chemical bioavailability because concentrations in pore water more accurately reflect the bioavailable fraction. Certainly, if elevated pore water concentrations or pore water toxicity were of concern in sediments before remediation, pore water should be sampled and analyzed to track the remedy's effectiveness. Pore water can be sampled and analyzed for sediment contaminants as well as other factors that affect contaminant bioavailability and toxicity, including dissolved oxygen, salinity, hardness, pH, Eh, organic carbon, ammonia, nitrate, ammonia nitrogen, total phosphorus, and total sulfide.

Section III.3.ii Sampling and Extraction Techniques

There are a number of techniques for obtaining sediment pore water samples. In situ sampling methods include diffusion samplers, suction, and gel membrane/ion exchange resins. Although there are different types of diffusion samplers (dialysis bags, peepers, vapor diffusion bags, and semi-permeable membrane devices), the general idea is that pore water solutes diffuse through a membrane into collection chambers containing distilled or clean water of appropriate hardness or salinity. The chambers are placed within the sediment and the pore water is allowed to infiltrate into the chambers over a period of time. There are a variety of suction devices, including piezometers, syringes, BAT™ samplers, push-point samplers, and the Navy's Trident probe, which can be used to actively collect pore water. With suction devices, pore water is collected in a container after a vacuum is applied to draw the pore water through a filter, separating liquid and solid phases. In situ methods are preferable for maintaining the chemical integrity of a sample, however, they generally provide only small volumes of water and are sometimes difficult to deploy. Many of these sampling methods, along with their advantages and disadvantages, are summarized on the U.S. EPA's CLU-IN website (USEPA, 2004b).

Ex situ pore water sampling is often necessary when large sample volumes are needed, rapid sampling is needed, or in situ sampling is not practical. Once a sediment sample has been collected, ex situ methods for pore water sampling include centrifugation and squeezing. Extraction in the laboratory, just prior to analysis, is preferable. For centrifugation, sediment samples are rotated at high speeds until the liquid and particulate phases are separated. Pressure squeezing of a sediment sample involves the collection of pore water after passing it through a mechanical squeezer and then through a filter. Vacuum filtration and gas pressurization are similar ex situ extraction techniques.

It is very difficult to remove a pore water sample from sediment without altering the chemistry of the organic and inorganic constituents. Adams, et al., 2003, provide an excellent review on the effects of sampling, extraction, storage, handling, and toxicity testing on pore water chemistry, as well as the advantages and disadvantages of different sample manipulation techniques. Sampling methods are discussed in USEPA, 2001a; Chapman, et al., 2002; and Mudroch and Azcue, 1995.

Section III.3.iii Monitoring

Sediment pore water monitoring over the long term may be appropriate at some sites, depending on the nature of the exposure pathway of concern (elevated pore water contaminant concentrations and/or pore water toxicity to aquatic biota), and the type of remediation at the site. Monitoring surficial sediment pore water following dredging, in the event that changes in redox conditions result in dissolution of contaminants from residually impacted sediments, is recommended.

Pore water monitoring should be considered following placement of various capping materials as a remedy. If sand was used as a cap, pore water monitoring is recommended, since the lower sorptive capacity of sand may provide less effective attenuation of contaminant exposure than burial by natural sediment. If groundwater flux through contaminated sediment has been a problem, monitoring of the cap pore water should be considered. Pore water in the cap should also be monitored to ensure that impacted sediment pore water has not migrated into the cap as a result of cap-induced sediment compaction. These analyses can be performed over time to assess long-term cap performance.

If the cap is constructed with lower permeability materials, in situ pore water extraction and monitoring have the potential to create preferential pathways for contaminant migration. In those cases, a pore water monitoring methodology that minimizes disturbance of the cap, such as Solid Phase Micro Extraction (SPME), should be considered. See related discussion in Section IV.3.iii (Capping).

Section III.4 Biological Monitoring

Biological monitoring may serve as an integral component of sediment remediation monitoring. Biological monitoring methods offer a means to assess whether organisms living in or relying upon sediments are exposed to contaminants remaining in the ecosystem following a remedial action, whether those exposures have been mitigated, and/or whether those exposures continue to be deleterious. Depending on the type and degree of sediment contamination, biological indices may be selected at various time intervals to demonstrate whether a remedial action has met targeted remedial goals.

For the purposes of sediment investigations, biological monitoring can be subdivided into four general areas that provide the following types of information.

Section III.4.i Biological Surveys

Annual biological surveys or reconnaissance activities, including determination of the presence/absence, percent cover, diversity, and/or abundance of various organisms, can be used to document the recovery of an impacted aquatic ecosystem. The sensitivity or ability of the survey to detect a measurable change is dependent on the selected organism or community to be monitored and the primary contaminants of concern in the remedial assessment.

For a general overview of biological survey methods for various aquatic ecosystems, see the Handbook of Biodiversity Methods: Survey, Evaluation and Monitoring (Hill et al., 2005). One of the most frequently used sediment assessment techniques is for determining benthic (sediment-dwelling) invertebrate species' diversity and abundance, commonly known as the Benthic Macroinvertebrate Index (BMI). The U.S. Environmental Protection Agency (USEPA_Biocriteria) compiles methods for this and other bioassessment techniques to determine the presence, condition, and numbers of types of aquatic organisms in freshwater, estuarine, and near-shore coastal aquatic ecosystems.

Section III.4.ii Sediment Toxicity Assays

Sediment toxicity testing, in the laboratory or in situ, can be used to assess the recovery of an impacted aquatic ecosystem. A number of different bioassays are available for assessing the residual effects of contaminants left in place or documenting the recovery of an impacted sediment environment. Testing protocols for have been developed for plants, invertebrates, fish, and amphibians that have a close association with water and sediments.

Some resources for planning and conducting sediment toxicity assays are provided in USEPA 2001a; USEPA, 2000b and Cal/EPA, 2004.

Toxicity testing should be considered at least annually, at the same time of year, to evaluate changes in sediment toxicity over time. A sediment's physical characteristics, as well as seasonal variations in surface water conditions (i.e., dissolved oxygen, salinity, temperature, pH), should be considered when designing an appropriate monitoring program.

Section III.4.iii Measurement of Tissue Contaminant Concentrations

Tissue concentrations of contaminants in sediment-associated organisms can be used to monitor whether concentrations of sediment contaminants have increased, decreased, or remained the same following a remedial action. Tissue concentrations can provide an important line-of-evidence in establishing the efficacy of a remedial action, in particular for bioaccumulative contaminants. Tissue concentrations in plants, invertebrates, and fish can also be compared to various toxicological benchmarks or fishing advisory levels to make inferences relating to the potential toxicity of contaminants to the organisms themselves or to organisms that consume them.

Sources of information for planning and conducting tissue monitoring can be found in USEPA, 2000b; USEPA, 2000c, and USEPA, 2008 .

Tissue monitoring should be considered at least on an annual basis to evaluate changes in sediment contamination. The types of organisms to be collected will depend upon the contaminants of concern and their concentrations in sediment. Often, organisms exhibiting a high lipid content (i.e., fish or mussels) are preferable because of their propensity to accumulate highly lipophilic contaminants such as PCBs, dioxins, methyl mercury, and organochlorine pesticides. Seasonality (i.e., changes in tissue lipid content) and surface water conditions (i.e., salinity, temperature, and pH) may affect bioaccumulation in animals, therefore these parameters should also be considered when designing an appropriate monitoring program. Tissue types (i.e., whole body, filet, blood, organs) to be analyzed should be selected depending upon the chemicals of concern in the sediment, the exposure pathways to be evaluated (i.e., human consumption or food chain bioaccumulation), and the endpoint of concern (i.e., fish health advisory, organ damage, tumors, organism health).

Section III.4.iv Biological Indicators of Organism Health

Biological indicators or "biomarkers" of an organism's health can be used to monitor the recovery of an exposed population. As related to contaminated sediments, organism health is most often assessed and monitored to provide a metric for and to document the recovery of an exposed population. Biological indicators of health have been developed for plants, invertebrates, fish, birds, and mammals. The selection of an appropriate species to monitor will depend on the contaminants of concern, the amount of contamination, and the degree to which organism has been exposed.

Recently, the University of California proposed a multilevel approach linking subtle biochemical, toxicological, and histopathological effects to population-level endpoints in a variety of estuarine plant and animal species. A summary of their approach and research can be found at Pacific Estuarine Ecosystem Indicator Research (PEEIR) Consortium.

For further information related to biological indicators, see Adams, 2002; Anderson et al., 1997; Baumann and Harshbarger, 1995; Huggett et al., 1992; Van der Oost et al., 2003; Stein et al., 1992; and Teh et al., 1997.

Animal health monitoring should be considered at least on an annual basis to evaluate changes in sediment biological effects. Seasonality and surface water conditions (i.e., salinity, temperature, and pH) can affect many health endpoints (i.e., enzyme levels, protein expression, histopathology) and should therefore be considered when designing an appropriate monitoring program.

Section III.4.v Biological Monitoring Summary

Biological survey, toxicity, and wildlife health information can inform the sediment remedial manager as to the efficacy of the selected remedial alternative and clearly demonstrate to the public the benefits of the selected remedial action. As mentioned previously, the establishment of baseline conditions is crucial for implementing a biological monitoring plan. Ideally, biological survey, toxicity, and wildlife health information should be collected before the selected remedial action commences and monitored at least annually.

The information provided in Section III.4 is not intended to provide a full review of scientific literature, but to provide a background from which a remedial project manager can consider various biological monitoring methods. We strongly recommend that any proposed biological monitoring plan be designed and reviewed with input from wildlife and fisheries biologists, ecotoxicologists, and ecological risk assessors.

Section IV Considerations for Long-Term Monitoring of Remedy Performance

This Section covers the long term monitoring aspects of the various types of remedies, including No Action, Monitored Natural Recovery, and various active remedies.

Section IV.1 No Action Alternative

A no-action alternative may be selected for a site when a determination is made that no additional remedial work is required. Typically, a no-action alternative is employed at a site that has been fully investigated, the sediment contamination is not adversely affecting human health or the environment, contamination levels are below regulatory guidance or standards, and the site is stable. The regulatory agency has reviewed the site information and has made the decision that no additional remedial work is needed. The decision of no-action may cause the site to receive regulatory closure, in which case, it will not require any additional monitoring.

Section IV.2 Monitored Natural Recovery

Monitored natural recovery (MNR) uses ongoing, naturally occurring processes to contain, destroy, or reduce the bioavailability and toxicity of contaminants in sediments (Magar and Wenning, 2006). These processes should have been identified through previous investigations and documented in the remedial decision document. MNR may be a part of an active sediment remedy or it may be the selected remedy with no active remediation. Once these processes are understood, long-term monitoring should ensure that risk reduction continues over time. A MNR decision may be made because the environmental agency believes site conditions will improve over time and that more aggressive remedial action is not needed. A long-term monitoring program is the most reliable way to assess whether the MNR decision is sound.

The MNR long-term monitoring at contaminated sediment sites should evaluate the naturally occurring processes that reduce the risk to human and ecological receptors. The endpoints chosen and measured will be important indicators in evaluating how well the MNR is performing. These endpoints will typically be contaminant and media specific. For example, if PCBs were the contaminant of concern, the long-term monitoring for MNR would target PCB levels in biota, water, and sediments over time.

Some sediment remediation projects have used computer models to predict future conditions for MNR at sediment sites (Davis, et al., 2004). The data previously gathered at the site can be used to evaluate future model projections at the start of the long-term monitoring. Additional data gathering should be performed if the use of the computer models will continue during the long-term monitoring period. However, depending on the site and the endpoints measured, it may not be necessary to continue to use the computer models for MNR.

Long-term monitoring at MNR sites should be sufficient to evaluate the site conditions for periodic reviews (such as 5 years) after the remedial action has been completed and/or the monitored natural recovery period has started.

The remedial action's objectives and goals will help determine which endpoints should be in the long-term monitoring plan for MNR. The long-term monitoring plan's endpoints should be similar to those evaluated in determining the feasibility of MNR as a remedy. The plan will depend on the processes that drive the recovery.

The long-term monitoring plan should include verification that the contaminant source has been successfully eliminated or controlled. Some typical considerations for sediments, biota, and surface water are included below.

Sediments

If MNR is dependent on the burial of contaminated sediments, the monitoring plan should include measures of sediment deposition and erosion, and a contingency for monitoring after major storm events to ensure that buried sediments have not been uncovered or resuspended (Erickson, et al., 2004). See Section III.1.iii for a discussion of monitoring for sediment erodibility and stability.

If the remedial action objectives (RAOs) are based on sediment contaminant levels, the sediments should be monitored periodically to determine whether the predicted contaminant reductions are occurring. See Section III.1.iv for a discussion of sediment monitoring techniques and considerations. If MNR is dependent on chemical transformation to achieve remediation goals, monitoring of the breakdown products of the contaminants should be included. For PCBs, it is important to measure specific congeners rather than Aroclor mixtures since weathering will change the congener profile and impact the toxicity of the mixture (NRC, 2001). It is also important to measure individual polycyclic aromatic hydrocarbons (PAHs) since low molecular weight PAHs may decrease quickly while higher molecular weight compounds are more persistent, which will change the toxicity of the mixture (Magar, et al., 2004).

Biota

Contaminant levels in biota should be monitored periodically to determine whether predicted reductions are occurring. If the site risk driver is due to human consumption of fish and/or shellfish, tissue analyses of those organisms will be needed. The same considerations noted above regarding chemical transformation processes also apply to tissue sampling. If the site's risk is due to direct consumption of contaminated sediments by ecological receptors or food web interactions, tissue sampling will also be needed. In addition, toxicity tests and biological surveys may be helpful in demonstrating the natural recovery of the ecosystem. See Section III.4 for a discussion of biological monitoring. Note that ecological recovery may not occur as quickly as sediment concentration reductions, so biological monitoring may need to continue longer than sediment monitoring (Patmont, et al., 2004).

Water

If the sediment RAOs for MNR are based on contaminant levels in surface water, those levels should be monitored periodically to determine whether the predicted reductions are occurring. They should be measured over a variety of flow conditions (i.e., high, low and storm event) if possible. If the risk assessment was based on sediment pore-water concentrations, pore water samples should also be collected periodically. See Sections III.3 and III.4 for discussions of surface water and pore water sampling techniques and considerations.

In addition to the considerations noted above, a monitoring plan should address the possibility of the transfer of contamination from the site to downstream sediments or other media, possibly through dispersion or erosion. When this happens concentrations may decrease at the site but overall risk would not necessarily be reduced.

The long-term monitoring program will be used to evaluate the MNR decision. Monitoring data taken over time will allow the evaluation of trends. Project managers and decision makers can use the trend data to determine whether improvements can be demonstrated over an acceptable timeframe, or if a different remedy needs to be evaluated for the protection of human health and the environment. The site specific data obtained from the long-term monitoring program is critical for making these decisions.

Section IV.3 Monitoring Considerations for Active Remedies

This section discusses methods of monitoring active remedies, such as capping and dredging/excavating (with or without on-site disposal of contaminated sediments), enhanced natural recovery, and in situ treatment. Because these types of remedies generally do not involve the complete removal of contaminated sediments, some level of residual contamination will remain and require some level of monitoring. Also, because of the environmental impacts of active remedies, the habitat of the site will probably need to be monitored to determine whether ecological recovery is sufficient.

Generally, monitoring can include both habitat surveys and tests of chemical, biological, and physical parameters (see Section III). The types, amounts, and frequency of testing will depend on the goals of the monitoring program. These measures should follow a regular schedule until residual contaminant concentrations no longer exceed remedial goals, standards have been attained, and/or ecological resources have been adequately restored. When the cleanup action includes institutional controls or restrictions, the continued implementation of these controls should be monitored. Long-term monitoring should also be required if the remedy includes on-site contaminated sediment disposal, such as Confined Aquatic Disposal (CAD), shoreline Confined Disposal Facility (CDF), or capping.

Section IV.3.i Dredged Locations

Dredged locations usually require the least post-construction monitoring, as the mass removal of contaminated sediment should result in a substantial reduction of long-term risk. The goal of dredging should not only be to remove the risk of contaminants, but also, if possible, to restore or enhance the biota in the dredged area. If the dredged sediments are disposed of on site, in CADs or CDFs, additional monitoring will be required (see Section IV.3.iv). For additional information on dredge monitoring see USEPA, 2005.

Section IV.3.i.a Biota

Depending on the extent of dredging and the type of biota removed, biota may need to be monitored (see Section III.4) to determine if it has recovered. Monitoring can include both surveys and analyses of tissue concentrations. Surveys may include both plant and animal species. Unless there is a particular reason (i.e., restoration of a wetland or evaluation of a special-status plant such as eel grass), plant surveys are generally less important than animal surveys. Most surveys should evaluate the types of species and their density and health. Surveys should be performed for any species that is replaced after dredging, such as shellfish. Replacement is not typically done for migratory species that should return as soon as their food sources return. Chemical and health monitoring (Section III) of biota should be performed to determine if there are impacts from any remaining residual contamination or contamination spread from other, non-remediated, areas.

The extent of the biota surveys should reflect the size of the area dredged and the contamination levels in the less contaminated areas that are not remediated. If the area dredged is relatively small or in a location that does not normally have significant ecological resources, biota monitoring may be eliminated. Also, if the contamination has been completely removed or it has been established that the residual contamination poses no risk, chemical monitoring can be eliminated.

If the dredged areas are limited and there are significantly large areas that were not remediated, biota sampling should be considered to determine whether the remedial action was adequate and cleanup goals were achieved.

An important consideration for biota monitoring may be the physical and chemical characteristics of the remaining surface sediments. Sediment contaminants tend to adhere to fine-grained and organic materials, which are more likely to be at the sediment's surface. That is the typical depth for remedial dredging. Once dredged, the new surficial sediments may not have the same physical and chemical characteristics as the pre-dredged sediments. For this reason, the biota may not resemble similar but non-impacted locations. Any biota monitoring proposed should consider that possibility when selecting the type of organisms to be monitored. Important sediment parameters include grain size and carbon content; species that tend to live in the sediment will be the most impacted if it is physically different after dredging. If the depth of dredging was shallow and the dredged area is normally an area of deposition, these sediment impacts may not be long lasting.

Biota monitoring should also consider the depth of the water after remediation. Plant and animal species may change if there is a significant change in the water's depth, amount, and/or direction of currents and tides (see Section IV.3.i.d for shoreline changes considerations). A biota monitoring proposal should consider these potential impacts. Typically, remedial dredging is limited to surface contamination, thus a change in water depth would not be a consideration for deeper in-water dredging.

Section IV.3.i.b Sediment Contamination

Generally, analyses of contaminant levels in sediments after dredging (see Section III.1) should be limited, unless there are large amounts (in size or concentration levels) of residual contamination and there are significantly large less-impacted areas remaining. The more contamination remaining after dredging is completed, the more monitoring should be performed. Generally, deeper locations and low energy locations are the most appropriate for contaminant monitoring, since these are the most likely areas of sediment deposition.

In the event that there still are known or suspected releases of contaminants after dredging, sediment sampling should be ongoing to confirm that the remedial goals are still being met.

Section IV.3.i.c Sediment Replacement

Sometimes clean material is placed over the dredged area to restore water levels to appropriate depths. This is especially important for shoreline locations (see Section IV.3.i.d) and alluvial streams. For dredged areas in deeper water, certain materials may be used to cap residual contaminated sediments (see Section IV.3.iii). If possible, replacement materials should be physically similar to the material removed. Monitoring of replaced areas should include measurements of water depth and the thickness of the replacement materials (see Section III.1.iii).

Section IV.3.i.d Shoreline and Wetland Locations

Typically, dredging and/or excavation remediation in or near shoreline, shallow, and wetland areas require significantly more monitoring than deeper in-water dredged areas. Plant and animal species tend to be more abundant and diverse in shoreline and wetland areas, thus it is generally a good environmental practice or permit requirement to replace, and if possible, restore, these areas to their pre-impacted conditions. Replacement of a wetland may not be possible or appropriate in some dredged locations, in which case, alternative locations for wetland replication may be necessary and would then require monitoring.

Monitoring of replaced areas should include surveys of the biota and the replacement materials at those shoreline and wetland areas. Biota surveys should include the survival and growth rate of replaced plants, and the type and number of animal species replaced or returning to the area. Also, monitoring of invasive species of both plants and animals should be performed to determine if follow up action is needed.

The monitoring of replacement materials at shoreline and wetland areas is also important because these locations may be less stable and less resistant to extreme weather events and tides after dredging, therefore, they should be monitored for erosion (see Section III.1.iii). Even where these areas have been returned to pre-dredged conditions, it may take time for the new material to consolidate and have stability similar to the removed sediments. If the replacement materials consolidate too much, it may be necessary to add more material to maintain the restored area at the desired elevations and contours. Replaced areas should be monitored on a regular schedule until they have achieved the same stability as the original location. At a minimum, all locations with replaced material should be inspected after the first significant weather and tide events to ensure that the replaced material has not significantly moved or eroded.

Time series photographs or videos can be useful ways to evaluate the replaced areas over time so that vegetation and replaced material stability can be tracked.

Section IV.3.ii Enhanced Natural Recovery

Enhanced natural recovery for sediment sites is the process of increasing sedimentation rates by directly applying thin layers of sediment or installing structures that increase natural sedimentation in the aquatic environment. Sedimentation is an uncertain factor that has the potential to affect the success of a selected remedy. Enhanced natural recovery is an attempt to control natural factors such as water flow and sediment retention. Here the remedy attempts to enhance natural processes and parameters, resulting in less stress on the sediment environment. An enhanced natural recovery program should take into account the sedimentation rate of the system. Based on that information, sediment enhancement is usually achieved through the direct application of sediment in an area, or the construction of hydraulic flow controls such as berms, earthen dams, or flow gates. The physical, chemical, and biological monitoring methods cited in Section IV.2 for monitored natural recovery are also applicable to enhanced natural recovery actions.

Section IV.3.iii Capping

Capping of contaminated sediments is typically considered a permanent remedy. However, because contamination is contained on-site, long-term (if not permanent) monitoring will be required to confirm that cleanup goals are being achieved. Long-term monitoring should confirm the integrity of the cap, including: 1) that the contamination remains contained; 2) that the capping material stays at the appropriate location and the appropriate cap thickness; 3) that biota is re-established on and around the cap, if appropriate; and 4) that all institutional controls are maintained. Also, monitoring of the less contaminated, non-remediated areas may be appropriate depending on the amounts of contamination and the level of risks remaining.

Monitoring of the cap material may include monitoring of the surface contours and cap thickness. Because capping is generally not precise and can result in a varying cap thickness, it is important to evaluate the cap at multiple locations. Typically, the middle of the cap is monitored to confirm that it is thick enough to remain protective and that significant contaminant migration or burrowing animals are not causing contaminant releases. The areas at the edge of the cap should be monitored to ensure that the contaminated material was not forced out during cap placement and that the cap material is not significantly migrating.

Because of consolidation (the cap becomes thinner without loss of material), the time directly after the cap materials are placed is generally when the most cap movement occurs. Therefore, a cap should be monitored more frequently and at more locations immediately after its installation. Cap thickness monitoring can be reduced once the cap material is stable. Where water is shallow above a cap, the cap should be monitored after any major weather event to determine if any cap material has moved.

Other cap monitoring may include biota and contamination monitoring (see Section III.4). Sometimes return of the habitat to a pre-capped state is a remedial goal. Here monitoring may include surveys of the types and densities of species. If biota monitoring does not show significant improvement, vegetation planting or seeding may be needed. Contaminant monitoring of both biota (typically for less mobile animals such as shellfish) and cap material can determine whether the cap is not preventing the release of contamination. Cap material at and below the surface should be sampled. Samples collected below the cap's surface can be used to determine whether contaminants are migrating through the cap. Samples collected at the surface can help determine whether the cap is being contaminated from other locations that were not remediated. Samples collected below the cap's surface can be used to determine whether contamination has migrated up through the cap.

Institutional controls and/or environmental restrictions may be required components for this type of on-site disposal remedy. See Section IV.5 for these considerations.

For additional information on cap monitoring see USEPA, 2005; US COE, 1998; and US COE, 2002b.

Section IV.3.iv On-Site Disposal Facilities

Long-term monitoring should be required for all on-site disposal facilities, including in-water Confined Aquatic Disposal (CAD) and on-shore Confined Disposal Facilities (CDF). Institutional controls and/or environmental restrictions may be required components of any on-site disposal remedy. See Section IV.5 for these considerations. The long-term monitoring considerations applicable to caps also apply to on-site disposal facilities (see Section IV.3.iii).

Section IV.3.iv.a Confined Aquatic Disposal

Long-term CAD monitoring should include measuring cap thickness and contamination consolidation. Depending on the density of the contaminated material placed into the CAD (i.e., how much bulking has already occurred), a cap is generally not placed until the contaminated material has had a chance to consolidate. The uncapped material is monitored to determine the appropriate time to place a cap. Placing cap material on unconsolidated contaminated sediment could cause the contaminated material to mix with the cap, causing the cap to be less effective. Monitoring for this mixing effect is important soon after the cap is placed to determine if additional cap material will be required to meet remedial goals. Surface water monitoring for sediment contaminants can be used to determine whether there is a release of contaminants while the cap and contaminated sediments are consolidating.

If the cap is designed to be higher than the original surface (i.e. depth of water is less after the CDF construction), then the monitoring can be similar to a capping remedy as described in Section IV.3.iii. For these types of caps, monitoring material lost from the cap and contaminant migration are important. If the top of the CAD cap is below the surrounding area (such as, placed in a navigational channel), then the loss of cap material should be less of a concern, and the cap should be monitored primarily for contaminant migration.

Section IV.3.iv.b Confined Disposal Facility

Long-term CDF monitoring should include groundwater monitoring to determine the extent of any contaminant release. Groundwater monitoring should be more frequent while the contaminated sediments are consolidating since this is when the greatest release may occur. Once the sediments consolidate, less sampling should be needed. Any increase in groundwater contaminant concentrations once the sediments have consolidated could indicate that the CDF has failed and is not adequately containing the contamination.

CDFs should be inspected regularly to ensure that their structure remains sound. If the CDF is made from steel or other types of metals, the corrosion rates of those metals should be monitored. If the CDF has a vertical face and is in contact with water, the water line should be inspected, since that is where the most wear might occur. Any

CDF that is used to dock vessels should have its face inspected for potential damage. If a CDF is made from gravel and stones (i.e., a bermed facility), it should be checked for any consolidation, loss, or movement of the gravel and stones.

CDFs should be inspected after any major weather event, such as a hurricane or tornado. If a CDF is damaged, repairs should be made a soon as possible to prevent/limit contamination releases.

For additional information on CDF monitoring see USEPA, 2005 and US COE, 1992.

Section IV.3.v In-Situ Treatment

In situ treatment of sediments involves a remedy in which sediments are amended in place in a way that reduces or eliminates the toxicity or bioavailability of contaminants. For example, in situ treatment with activated carbon (AC) has been proposed to reduce the biological uptake of PCBs from sediments. Cho et al. (2007) conducted a preliminary pilot-scale study to assess the challenges of using AC under field conditions. The study was conducted at Hunters Point Shipyard (San Francisco, USA) to assess the effectiveness of AC in sequestering PCBs found in near-shore sediments. Approximately 500 kg of AC was placed into a 34.4 m^2 plot to a depth of 1 ft. A biological monitoring program was initiated to assess the effectiveness of the treatment. Following 7 months of treatment, a 28-day PCB bioaccumulation test was initiated in field-deployed clams, *Macoma nasuta*, exposed to AC-amended and non-AC-amended sediments. Bioaccumulation in the amended sediments was approximately half of the bioaccumulation resulting from exposure to the untreated sediment. Further studies are planned to compare the effectiveness of two large-scale sediment-AC mixing devices and will include both unmixed and mixed-only control plots. Biological monitoring will play an important role in determining whether this technology can be scaled up to treat large volumes of sediment, and whether the treatments result in reestablishment of a viable benthic invertebrate community.

Physical, chemical, and biological monitoring methods described in Section IV.2 are applicable to in situ treatment actions. In the case of treatment of PCB contaminated sediments with AC, tissue PCB levels, representative of organisms within various levels of the food chain, should be monitored over the duration of the plan.

Section IV.4 Responding to New Site Information

A long-term monitoring plan is typically implemented toward the end of a site remediation effort. The environmental agency usually has a good understanding of the site, chemicals of concern, sediment migration rates, and biological resources. Unfortunately, new information can always arise, as demonstrated in the Ciba case study attached to this guide (Appendix I). Usually the new information comes from a newly discovered contaminant or from another source that was not properly delineated. Another possibility may be the discovery of a biological resource, such as a threatened or endangered species, that was not previously believed to be present at the site. Such discoveries may change remedial action decisions for the site. If new information is discovered, a modification of the long-term monitoring plan will be warranted. The environmental agency will need to gather enough information to decide whether the current monitoring plan should be continued or modified. The new information may result in the need for further evaluation or modification of the remedy as appropriate in the remedy decision document.

Section IV.5 Monitoring the Effectiveness of Administrative Actions, Institutional Controls and Environmental Restrictions

Typically, when contamination is left onsite, either in onsite disposal facilities or as the result of unremediated residual contamination, institutional controls and/or environmental restrictions are necessary to ensure that the remedy is protective. Institutional controls are measures undertaken to limit or prohibit activities that may interfere with the integrity of an interim or cleanup action, or that may result in exposure to hazardous substances at a site. These may include fishing prohibitions or advisories, restrictions on dredging, and navigational warnings. Any remedy that includes administrative actions should also include a method of ensuring that controls remains in place as long as needed. This is particularly important if the entity responsible for issuing and implementing the institutional control is different from the agency issuing the decision document for the site. The decision document and monitoring plan should clearly state who is responsible for implementing the institutional control and how it will be tracked.

Section IV.5.i Fishing Advisories, Restrictions, or Bans

One typical institutional control to protect human health is the issuance of advisories, restrictions, or bans on fishing (including shell fishing) in contaminated areas. These actions may be needed for in-water disposal, capping remedies, and MNR. Sometimes, instead of a complete ban, advisories are placed on locations and types of fishing. These actions usually require monitoring, enforcement, and continuous communication with local or state authorities, as well as inspection, replacement, and maintenance of any warning signs. Warning signs should reflect the languages of the local community, especially newer immigrants. In many cases the state health department is the agency responsible for issuing the advisory or ban, while the state environmental agency is responsible for implementing the decision document. It is important to designate who will monitor and document that the restriction remains in place, such as by having a reporting requirement in the monitoring plan. The monitoring plan should also include inspections of signage to ensure that anglers are aware of the restrictions.

While it is possible to monitor and verify that a restriction and its signage remain in place, it is more difficult to monitor whether the restriction is effective in preventing people from eating contaminated fish and shellfish. One method for evaluating this is to conduct surveys of anglers to determine whether they consume the fish that they catch.

The references listed below include examples of surveys used to monitor anglers' awareness of and compliance with fishing restrictions (USEPA, 2000d; Gibson and McClaffertty, 2005; Harris and Jones, 2008).

Section IV.5.ii Waterway and Land Use Restrictions

When an engineering control such as a cap, a CDF, or a CAD (see Section IV.3.iii and IV.3.iv) is the selected remedy, institutional controls may also be needed to protect the integrity of the remedy. For near-shore or upland disposal facilities, restrictions might limit or eliminate certain construction activities, digging, and/or other activities that may disturb the contaminated materials in the disposal facilities. A deed restriction or notice may be adequate for an upland property, but for in-water remedies, such as capping or CADs, restrictions may be more difficult due to ownership issues. Typically, States have trusteeship or ownership of in-water locations, but locations on the shoreline or water area are owned by other parties.

Administrative actions may also include restrictions on vessel traffic and anchoring, or easements for installation of utilities and other in-water construction such as boat ramps, retaining walls, and marinas. These restrictions should be placed on navigational charts. Navigational buoys and/or warning flags will also help in warning boaters about caps or other areas of concern. The agencies responsible for enforcing these restrictions are likely to be local permitting offices or State resource agencies and not the agencies responsible for implementing the decision document. The monitoring plan should include provisions to inspect and document that prohibited activities are not taking place and that prohibited structures have not been built. Again, it is important to designate the entity that will be responsible for the monitoring and reporting.

Other potential restrictions for in-water disposal or capping remedies may include restrictions on the placement of utilities such as electrical wires, phone lines, and water and sewer lines. These types of restrictions may require continuous communication with local authorities, such as building or public works departments.

Section V Case Studies

The case studies presented in the appendix are intended to illustrate the importance of an effective long-term monitoring plan through discussion of actual site successes and the lessons that were learned. These case studies represent a variety of impacted sediment sites at both inland and coastal locations, and reflect sites with both human health and ecological pathway concerns. The contaminants of concern include metals, PCBs, polychlorinated terphenyls, and PAHs.

While developing long-term monitoring plans, the case studies selected highlight the importance of: establishing numerical or otherwise measurable goals with clear endpoints, data compatibility that allows for meaningful comparisons over time, baseline (pre-remedy) sampling, source monitoring, selection of key indicator species as measures of ecological recovery, designing a plan that has contingencies to address unforeseen circumstances, and establishing institutional controls that can be readily addressed in the monitoring plan and by the entities responsible for enforcing them.

Section VI Recommendations and Conclusions

A properly designed and executed long-term monitoring plan will benefit the sediment remedial project manager by providing measurable outcomes that support the efficacy and permanence of the selected cleanup strategy. The following recommendations and conclusions should be considered when developing a long-term monitoring plan for sediments:

- A long-term monitoring plan should provide measurable outcomes to gauge whether a contaminated sediment site's remedial goals and objectives are achieved. The monitoring plan's goals and objectives should be consistent with the remedial decision document

- The design and implementation of a long-term monitoring plan should be considered during the FS, when various alternatives (e.g., active or passive sediment remediation strategies) are being selected. Remedial goals and objectives selected following the FS will form the basis for a long-term monitoring plan's goals and objectives.

- Essential components of a long-term monitoring plan include: a summary of the baseline physical, chemical, and biological conditions before remediation, the goals and objectives of the monitoring plan, a site conceptual model, all data collection and evaluation methods, and any other relevant decision-related criteria.

- Changes in physical, chemical, or biological site conditions over the monitoring period may require adaptability in a plan, therefore, contingency plans for anticipated or unanticipated outcomes should be included.

- Decision rules within a long-term monitoring plan should establish specific criteria for continuing, prolonging, or stopping data collection activities. In some cases, sediment and biota monitoring may justify further response or remedial action consistent with the regulatory framework.

- A large array of physical, chemical, and biological monitoring techniques is available to sediment remedial project managers; these should not be mutually exclusive. Monitoring plans that include concurrent measurements of physical, chemical, and biological conditions, both pre- and post-remediation, will provide multiple lines-of-evidence useful for determining and communicating whether a remedial action has been effective.

- The ultimate goal of a monitoring plan is to ensure protection of human health and the environment.

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Appendix: Case Studies

The following section presents 6 case studies that are intended to illustrate the importance of an effective monitoring plan through discussion of actual site successes and lessons learned. The case studies present a variety of impacted sediment sites in both inland and coastal locales, and reflect sites with both human health and ecological pathway concerns. Contaminants of concern include metals, polychlorinated biphenyls, polychlorinated terphenyls, and polycyclic aromatic hydrocarbons.

In developing a monitoring plan, the case studies highlight the importance of establishing numerical or measurable goals that have clear endpoints, data compatibility to avoid apples/oranges comparisons over time, baseline (pre-remedy) sampling, source monitoring, selecting a key indicator species as sensitive measure of ecological recovery, designing a plan that has contingencies that can address unforeseen circumstances, and establishing institutional controls that can be readily addressed by the monitoring plan and the entities responsible for enforcing the institutional controls.

Site Name: Ciba Corporation Floodplains (Operable Unit 3), McIntosh, Alabama

Site Location: Ciba Corporation is approximately 50 miles north of the city of Mobile. The facility encompasses approximately 1,500 acres of which 1,130 acres comprise the actual plant facility operations, and the remaining 370 acres are undeveloped floodplains of the Tombigbee River.

Contaminants: DDTr (DDT metabolites)

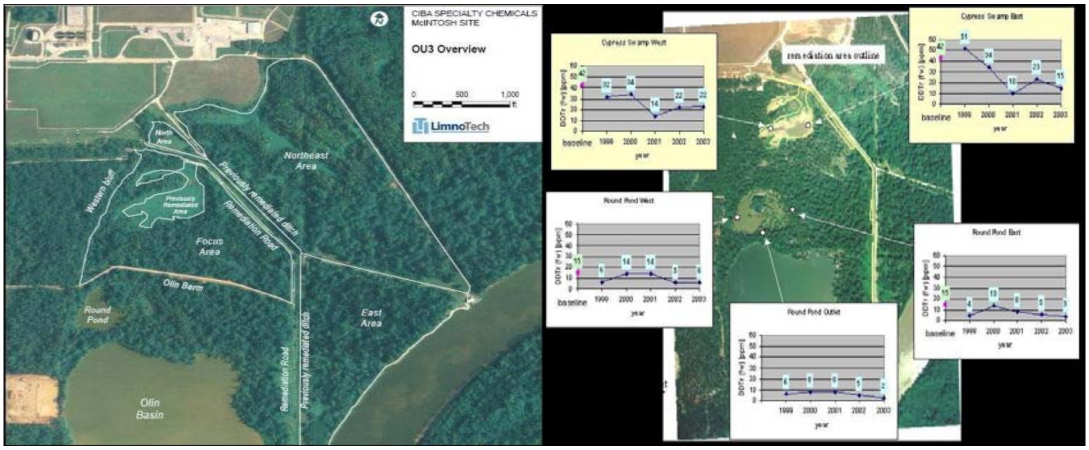
Size/Area of site: A 300-acre wetland/floodplain area

Volume of contaminated sediments: Unknown

Removed: 23,000 Cubic Yards (cypress swap and effluent ditches)

Levels of Contaminants: 83 mg/kg (surface weighted area concentration)

Remedial Goal: Average sediment concentrations of 15 mg/kg over the entire OU-3, and a reduction in *Gambusia* body burdens to a range of 0.3 to 1.5 mg/kg DDTr.



Types of Ecological Systems Impacted: All aquatic and wetland ecosystems were impacted by the contaminated sediments.

Animals: Terrestrial and amphibious wildlife, red-cockaded woodpecker, wood stork, gopher tortoise, gulf sturgeon, inflated heelsplitter mussel, Louisiana quillwort, and black pine snake, Bald Eagles, deer, frecklebelly madtom, Alabama shad, seal salamander, eastern coachwhip, black-knobbed sawback, Alabama map turtle, and the alligator snapping turtle.

Plants: Aquatic, riparian (willows, sedges, rushes, grasses), sycamore, bald cypress, cherrybark oak, water hickory, hop hornbeam, water oak, blackgum, sweetgum, overcup oak, American elm, and sugarberry trees and other wetland vegetation.

Human Health Risk(s): Risks assessments concluded there was no risk to human health. This area is private property; therefore it will not be utilized for recreation.

Remedy: The Record of Decision required the removal of 12 acres of contaminated sediments located in the area known as the cypress swamp. The remaining areas were considered highly sensitive areas and would remain undisturbed to protect the habitat. The remedial goal was to obtain an average sediment concentration of 15 mg/kg DDTr over the entire site.

The remedial action for the area included removal of one foot of contaminated sediments from the open areas (i.e. Cypress swamp and effluent ditch). Then the area was backfilled with clean sediment from the nearby Tombigbee River.

Summary of (Original) Monitoring Plan: The operation and monitoring (OAM) plan included long term monitoring of *Gambusia* and *Lumbriculus* species. Sediment samples would be collected at six locations throughout the remediation area. A portion of the sample locations were located in the removal area and the remaining locations were placed in non-removal areas. In conjunction, *Gambusia* were collected in the same locations to correlate the fish body burden to sediment concentrations. These fish were to be collected once the floodwaters had receded and the three water bodies had completely separated for approximately 30 days. The sediment samples were also used to conduct laboratory *Lumbriculus* testing to provide bioavailability data.

Summary of New Monitoring Plan: The “new” monitoring plan will be designed to collect the necessary data to evaluate the effectiveness of the amended remedial action. Monitoring will include *Gambusia* collection and analysis, caged and free range fish tissue analysis, sediment sampling and analysis, sediment traps, sediment plates, sediment mats, and sediment cores.

Discoveries: Sediment data indicated that the levels of DDT were increasing in some areas, including the removal areas. Sediment samples were not collected in the appropriate locations. Samples collection techniques were determined to be inappropriate for evaluating remedy effectiveness. The DDT levels in fish were decreasing but had not met the 0.3 -1.5 mg/kg remedial goal. Sedimentation in the undisturbed areas was not occurring effectively. Sedimentation across the entire site was not fully understood or considered in the original plan.

Lessons Learned

- Baseline data is essential to the development of an effective long-term monitoring plan. After five years of operation and maintenance monitoring, the remedial goals established in the ROD appeared to have not been met. Results showed that the removal areas were increasing in contamination concentrations. The decline in fish concentrations was apparent but not significant.

- The development of data quality objectives is imperative. In this case, the list of unknown factors increased with each monitoring cycle. As a result, U.S. EPA's 2006 five-year review evaluation of the OU-3 project indicated additional remedial action would be required to achieve the remedial goals.

- Additional assessment work prior to remedy implementation may save time and resources. Ciba conducted several activities including sedimentation studies, habitat research, and sediment coring. The sedimentation studies determined the actual movement of sediment in the floodplain.

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Site Name: Streamside Tailings Operable Unit (SSTOU)

Site Location: Silver Bow Creek and the associated floodplain west of Butte to the Warm Springs Ponds, located just above the confluence of the Clark Fork River.

Site Description: Butte was the leading copper producer in the world at the turn of the last century. Environmental concerns were virtually nonexistent. Mining that occurred near Silver Bow Creek often sluiced the tailings directly into the creek. In 1908 a rain on snow event led to a 100-year flood which washed mine tailings stockpiled throughout the town of Butte into Silver Bow Creek. The upper 10 miles of the creek holds the deepest deposits of tailings and impacted soils since the flood's force ripped out or churned up the floodplain. The next 3-5 miles of the creek is in a fairly narrow canyon, further constricted by three rail lines. The velocity of the flood picked up through the canyon area, which led to less deposition. The last 8-10 miles of the creek is a broad, flat alluvial floodplain in which the 1908 flood dispersed its energy and laid down a generally thin layer of contamination over hundreds of acres.

Contaminants: Copper, lead, mercury, zinc, arsenic, and cadmium.

Size/Area of site: 23 miles of Silver Bow Creek, one operable unit in the largest Superfund site in the world, which runs from Butte, Montana to Milltown, Montana (112 miles), including the towns on Butte and Anaconda, all of Silver Bow Creek, and the Clark Fork River to Milltown Dam.

Volume of contaminated sediments: Approximately 4.5 million cubic yards.

Removed: 3 million yards to date

Levels of Contaminants: Highly variable. Worst case 10,000 mg/kg copper and zinc.

Remaining: 1.5 million cubic yards, slated for removal over the next 3 years.

Levels of Contaminants: Highly variable, some not known yet.

Ecological Systems Impacted: Aquatic, wetland, upland, semi-arid upland plains. All ecosystems were impacted by the flood of sediments which killed virtually all aquatic species and most of the vegetation in the floodplain.

Animals: Fish (cutthroat trout, brook trout, long-nosed suckers, sculpin, etc.), macroinvertebrates (various species), birds (various duck species, Canadian geese, various shore birds, upland game birds, song birds, etc.), fox, coyote, deer antelope, and moose. All of these species have been seen on Silver Bow Creek in the remediated areas. Prior to remediation, species were either absent or passing through. Since remediation, deer and antelope have given birth and raised their young in the floodplain. Bird species and number have increased dramatically. In 2007 for the first time, brook trout have been documented in a remediated section of Silver Bow Creek.

Plants: Includes aquatic, riparian (willows, sedges, rushes, grasses), and upland (trees-limited aspen stands in floodplain, shrubs, grasses) species. After the flood, most vegetation was restricted to metals-tolerant species and large willows that survived the initial flood. The willows were unable to reproduce either vegetatively or by seed because of the high metals content in the surface soils.

Human Health Risk(s): Prior to cleanup, risk assessments concluded that there was no risk to humans using the area for recreation.

Summary of Monitoring Plan: Instream sediment monitoring began after remediation had progressed approximately five miles downstream. Monitoring stations are located along both remediated and unremediated portions of the stream. Sediments, vegetation, water quality, macroinvertebrates, periphyton, and fish are monitored. Sediment and surface water quality is monitored quarterly. Groundwater is monitored during low water. Vegetation is monitored at the peak of the season and follows a 3, 6, and 10 year interval. Macroinvertebrates, periphyton, and fish are generally sampled in the fall. Results thus far showed significant improvement immediately following remediation. However, monitoring seems to indicate an inflow of contaminated sediment into Silver Bow Creek. The most likely causes are upstream inputs from storm water events and the Butte wastewater treatment plant. Further monitoring is needed to determine whether these sediments pose a threat to Silver Bow Creek, or if they will pass through the system without significantly affecting recovery.

The monitoring plan is evaluated during the reporting period, generally January through March. During that time the consultants prepare a formal report which documents the previous year's data, and compares the data and trends to the success criteria. The monitoring plan includes a section which outlines how monitoring is expected to change as the goals are attained, so the monitoring plan can be modified as needed. The monitoring plan is also evaluated during the reporting period to determine whether the monitoring activities are adequate to judge the success or limits of the remediation.

Lessons Learned

- The impact of one contaminant may be masked by another. This, and the appearance of other previously unknown sources of contamination, may be difficult to plan for in the development of the monitoring program. In Silver Bow Creek, the impact from the metals contamination was so severe that until the contaminated sediments were removed from the floodplain, the impact from high nutrients (and lesser amounts of metals) discharged from the Butte wastewater treatment plant were unknown. Also, the amount of contaminated sediments coming from upstream sources was indeterminable prior to cleanup.

Point of Contact: Shellie Haaland, Montana DEQ. shaaland@mt.gov

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Site Name: Cumberland Bay Sludge Bed B Wilcox Dock

Site Location: Northwestern portion of Cumberland Bay, Lake Champlain, Plattsburgh, New York

Site Description: The site included underwater and shoreline wetland areas within and along the northwestern portion of Cumberland Bay in Lake Champlain that contained accumulations of contaminated sludge. The sludge bed was composed of wood pulp, wood chip debris, fine organic matter, and other processing wastes that were discharged from local wood product industries (sawmills, wood chip producing industries, and paper manufacturing and processing industries). Records show that the wastes either settled or were directly discharged in this area for several decades. The untreated waste disposal ended in 1973.

Environmental sampling determined that the sludge was impacted with polychlorinated biphenyls (PCBs) and other types of contamination. The PCB levels were the highest (up to 13,000 mg/kg) in the layers or beds that contain cellulose wood pulp or fine wood debris. Contaminated wood chip debris was readily suspended by wave action or boats and typically washed up along the shoreline. Sampling and analysis detected PCB concentrations as high as 210 mg/kg in the wood chip debris washing up on shore and nearby bathing beaches. PCBs have generally been measured as total aroclors.

The Record of Decision was signed in 1997 for the removal of the sludge bed. The Remedial Action began in April 1999 and dredging was completed in October 2000.

NYSDEC annually cleans PCB-contaminated wood chips from the public and private beaches north of the site as well as the beaches on the south side of Breaker Peninsula. The removal of PCB- contaminated wood chips from Cumberland Bay beaches was performed during the 1995 B 2006 tourist seasons. The beaches were inspected on a weekly basis in 2007, but no cleanups were performed. The weekly inspections will continue in 2008.

Contaminants: PCBs with sediment concentrations up to 13,000 mg/kg (prior to remediation).
Other contaminants (within the sludge bed materials) included phthalates, polynuclear aromatic hydrocarbon (PAH) compounds, polychlorinated dibenzodioxins and polychlorinated dibenzofurans (present at levels found in paper sludge). These other contaminants were present at concentrations below current action levels.

Size/Area of Site: Sludge Bed covered 52 acres

Volume of Contaminated Sediments:

Removed: Estimated that 20,000 pounds of PCB mass was removed from the Sludge Bed. The actual removal included 195,000 cubic yards sediments dredged, and 37,000 cubic yards removed in the dry (wetlands and near shore area). The pre-remedial estimated sludge bed volume was 130,000 cubic yards and the wetlands volume was 15,000 cubic yards.

Remaining:

Levels of Contaminants: Sediment sampling performed post remediation estimates the average PCB concentrations were 1.5 mg/kg (assuming cores with only sand as non detect) in areas that were dredged.

Ecologic System(s) Impacted: There is small deciduous forested wetland and a shallow/deep emergent wetland complex located within the site boundaries. Sediment consists primarily of sand with varying amounts of silt, clay and gravel.

Animals: Mammals, amphibians, reptiles, fish and bird species are found in and around the surrounding area. Lake Champlain and the Saranac River represent a significant landlocked salmon fishery. Fish include yellow perch (*Perca flavescens*) and rock bass (*Ambolplites rupestris*). Ospreys, a threatened species in New York State, have been observed nesting in a wetland within half a mile. Great blue herons have been observed feeding at the site.

Contaminants of Concern: PCBs

Plants:
Contaminants of Concern: NA for contaminants. The habitat was restored naturally and it has recovered.

Human Health Risk(s):
Direct contact with contaminated sediments: 7.7×10^{-5}
Consumption of contaminated fish: 3.4×10^{-3}

Contaminants of Concern: PCBs

Summary of Monitoring Plan: Baseline monitoring was performed in April 1999 prior to commencement of remediation. The post remediation monitoring plan assessed PCB concentrations in fish tissue, surface water and zebra mussels following remediation. Five years of annual monitoring have been completed.

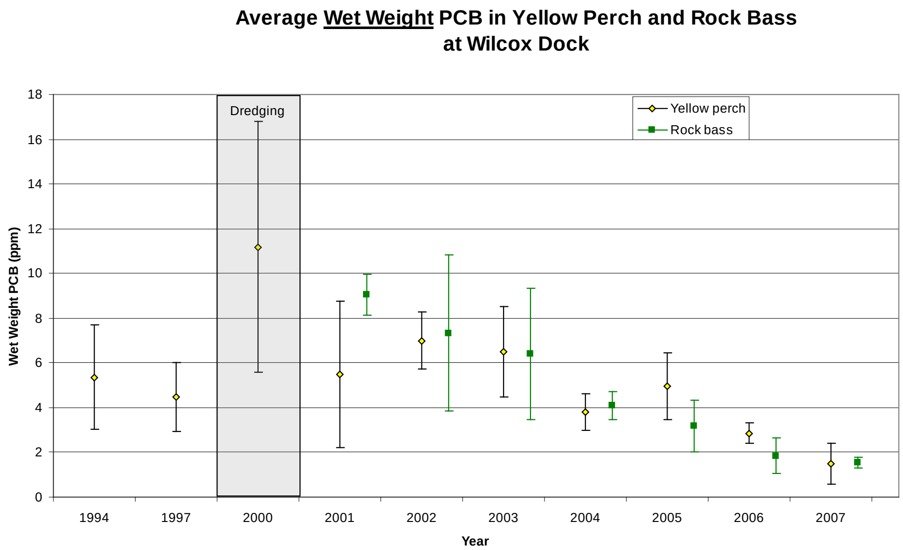
Lessons Learned

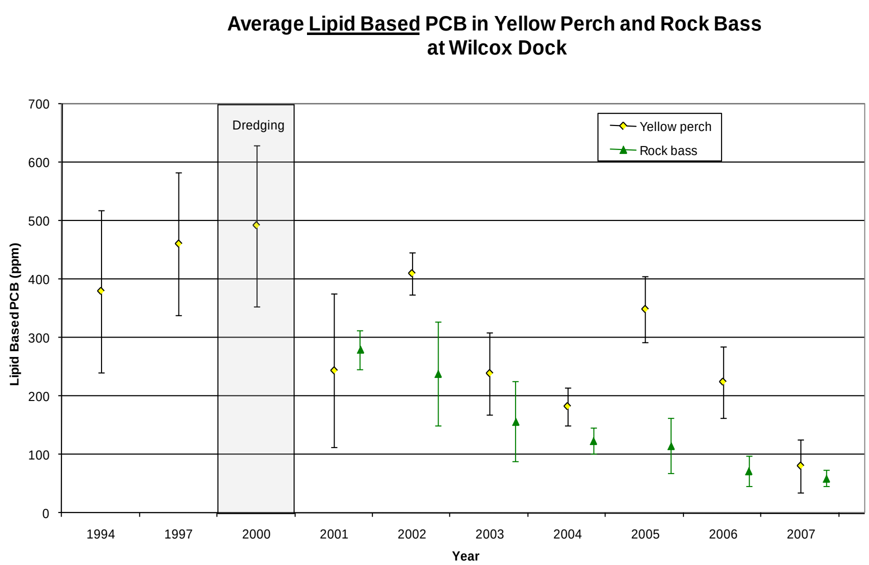
- Confirmatory sediment samples were collected immediately after the dredging. Only sediment samples with wood sludge were analyzed for PCBs because samples that contained only sand were assumed to be clean. This is a data gap. Better confirmatory sampling for PCB concentrations in sediment should have been performed to determine post-remedy sediment concentrations and to allow comparison to pre-remedial sediment concentrations.

- PCB fish tissue sampling and analysis provided an important endpoint to evaluate PCB concentrations following remediation. Tissue monitoring of multiple fish species is an important tool for evaluating long-term trends and variations.

- No specific numerical goals were established for fish or sediment PCB concentrations in the Record of Decision. The goal was to remove the sludge waste bed materials.

- Wetlands restoration was performed as a part of the remedy, but no specific remedial goals were established.





Point of Contact: Robert Edwards, NYSDEC Project Manager. 518-402-9676

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Site Name: Black River, Ohio

Site Location: Ohio, Lorain County.

Contaminants: Polycyclic Aromatic Hydrocarbons (PAHs) and heavy metals

Size/Area of Site: 5.5 km reach of the river, from where the Black River empties into Lake Erie to the site of a former coking plant discharge area.

Volume of Contaminated Sediments:

Removed: ~150,000 cubic yards

Levels of Contaminants: Pre-remedial surveys in the early 1980s showed concentrations of hundreds of mg/kg for various PAHs. A consent decree obtained by the US EPA against US Steel in the early 1980s required dredging of the most contaminated stretch of river above and below the location of the coke plant outfall. Dredging was accomplished between 1989 and 1990.

Remaining:

Levels of Contaminants: As of 1997, total PAHs in sediment were generally less than 15 mg/kg.

Ecologic System(s) Impacted

Animals: Benthic Invertebrates, Fish

Contaminants of Concern: PAHs

Plants: Not evaluated.

Human Health Risk(s): Contact with Black River sediments or water prohibited as of 1983 because of potential carcinogenicity. In 2004, following natural and active remediation, contact prohibition order was rescinded.

Contaminants of Concern: PAHs

Summary of Monitoring Plan: Biological monitoring occurred before and following natural and active remedial actions. Before remediation, researchers with the National Biological Survey (NBS) found fish (brown bullheads) populations during the early 1980's that had a liver cancer prevalence of over 30% for mature fish (age 3 and older), and a total liver neoplasm frequency of 60%. In 1983 the coking complex was closed, eliminating the major source of PAHs. Natural attenuation of PAHs in surface sediments, following closing of the coking complex, was demonstrated by a dramatic reduction of skin and liver tumors in brown bullhead in the late 1980's (by over 50%). Fish tumor monitoring also demonstrated that dredging activities during 1989 and 1990 resulted in a transient increase in tumor frequency. However, in 1998, incidence of fish liver tumors dropped to less than 7%.

Contaminated Brown Bullhead photo credit: USGS Great Lakes Science Center

Lessons Learned

- Long-term biological monitoring can be used as sensitive measure of the recovery of aquatic biota following a selected remedial action and should be considered as an important metric in monitoring the efficacy of either natural attenuation or active remedial actions.

- The Black River sediment monitoring plan, by including both chemical and fish health measures, provided strong evidence for the reduction of PAHs in sediments to a health-protective level, for the efficacy of the selected remedial action, and for demonstrating to the public that the selected remedial action was successful.

- Monitoring of fish health should be considered when developing long-term sediment monitoring objectives. A bottom-dwelling species, with close association with sediments and high site fidelity, should be selected. In the case of the Black River, a bottom-dwelling fish species with a strong association to sediment was selected as the key indicator species. Likewise, in marine environments, a bottom-dwelling fish such as flatfish may be suitable indicator species for assessing long-term changes in fish health (Myers et al., 2008).

- Following selection of an indicator species, baseline information should be collected before the remedial action and subsequently collected on a yearly basis thereafter throughout the duration of the plan.

Attachments:
Site Map(s). See: http://www.epa.gov/glnpo/aoc/blackrv/
Black_Final_State_Approved.pdf

References

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Site Name: Tabbs Creek, NASA Langley Research Center (LaRC)

Site Location: Hampton, Virginia

Site Description: NASA LaRC is a research and development facility for aircraft and spacecraft. Areas of research include instrumentation, materials fatigue acoustics, aerodynamics, and guidance control. NASA LaRC was listed on the National Priorities List in 1994. Tabbs Creek is one of several sites at NASA LaRC being investigated and remediated under CERCLA. PCBs and PCTs were inadvertently released into storm sewers and migrated into Tabbs Creek.

Contaminants: Polychlorinated biphenyls (PCBs)/Polychlorinated terphenyls (PCTs)

Size/Area of Site: 60 acres

Volume of Contaminated Sediments

Removed: 1.4 acres up to 4 feet (4,300 cubic yards)

Levels of Contaminants: Up to 760 mg/kg of PCBs and PCTs

Remaining:

Levels of Contaminants: 5 mg/kg cleanup level

Ecologic System(s) Impacted

The site is a meandering creek (about 400 to 2,000 yards wide) and marsh. The creek is tidal and generally brackish with thick brush and trees along the perimeter. Creek sediments are fine-grained silts and clays mixed with organic matter.

Animals:
Mollusks: oysters (*Crassostrea virginica*), hard clams (*Mercenaria mercenaria*), and ribbed mussels (*Geukensia desmissa*).

Polychaetes: *Nereis sp*., *Arenicola sp*., *Clycera sp*. and *Cirratulus sp*.

Crustaceans: Blue claw crab (*Callinectes sapidus*, wharf crab (*Sesarma reticulatum*, fiddler crabs (*Uca sp*), and grass shrimp (*Palaemonetes pugio*).

Fish: Banded Killifish (*Fundulus diaphianus*), mummichog (*Fundulus heteroclitus*), Striped killifish (*Fundulus majalis*), sheepshead minnow (*Cyprinodon vaiegatus*), Atlantic croaker (*Micropogonias undulatus*), Spot (*Leiostomus xanthurus*), Atlantic Menhaden (*Brevortia tyrannus*), Northern Tonguefish (*Strongylura marina*), Bay Anchovy (*Ancoa mitchilli*), Atlantic Needlefish (*Symphurus pusillus*), Inland Silverside (*Menidia beryllina*), Atlantic Silverside (*Menidia menidia*), Hogchoker (*Trinectes maculatus*), Darter (*Etheostoma sp*.), and Mullet (*Mugil sp*).

Mammals: White-tailed deer (*Odocoileus virginianus*), raccoon (*Procyon lotor*), Virginia opossum (*Didelphis virginiana*), eastern cottontail (*Sylvilagus floridanus*), muskrat (*Ondatra zibethicus*), and marsh rice rat (*Oryzomys palustris*).

Birds: Osprey (*Pandion haliaetus*), Great Blue Heron (*Ardea herodias*), Green Heron (*Burorides striatus*), Great Egret (*Casmerodius albus*), Herring Gull (*Larus argentatus*), Caspian Tern (*Sterna caspia*), White Ibis (*Eudocimus albus*), Virginia Rail (*Rallus limicola*), Plover (*Charadrius sp*), Killdeer (*Charadrius vociferous*), Sandpiper (*Calidris sp*), Red-Winged Blackbird (*Agelaius phoeniceus*), and Gray Catbird (*Dumetella carolinensis*).

Contaminants of Concern: PCBs and PCTs

Plants:
Saltmarsh cordgrass (*Spartina alternaflora*), spike grass (*Distichlis spicata*), salt hay grass (*Spartina patens*), black needlerush (*Juncus roemerianus*), salt reed grass (*Spartina cynosuroides*), common reed (*Phragmites australis*), marsh elder (*Iva frutenscens*), and groundsel tree (*Baccharis halimifolia*).

Contaminants of Concern: PCBs and PCTs

Human Health Risk(s):
Direct contact with contaminated sediments: $> 10^{-4}$
Consumption of contaminated fish: $> 10^{-4}$

Consumption of contaminated blue crabs: > 10^{-3}

Contaminants of Concern: PCBs and PCTs

Summary of Monitoring Plan: The Record of Decision included a post remediation monitoring plan to assess four components of ecosystem recovery: 1) wetland restoration vegetation monitoring; 2) wetland restoration wildlife usage monitoring; 3) benthic community monitoring studies; and 4) live caged bivalve studies and indigenous fish body burden monitoring studies. Five years of monitoring have been completed. Monitoring was conducted annually with one exception. Each of these components is summarized below.

Wetland Restoration Vegetation Monitoring

Objective: To monitor the recovery of wetland vegetation after remediation.

The monitoring consisted of qualitative surveys of plant species composition and cover at eight locations with the center of each location surveyed and staked. The success criteria was a vegetation composition composed of desirable wetland species similar to that of pre-remedial activities, and total vegetation cover at least 85 % of original.

Wetland Restoration Wildlife Usage Monitoring

Objective: To monitor wildlife usage in the remediated wetland.

The monitoring consisted of visual observation and identification of avian species specifically. Other wildlife was noted if observed.

Benthic Community Monitoring Studies

Objective: To monitor the recolonization of the remediated areas and assess the overall health of the benthic community based on taxa richness and density.

Benthic sample collection includes collection of 15 benthic samples (3 replicates per station) using a petite ponar. Samples are (0.023 m^2 per grab)collected, sieved (500 um sieve), preserved in 70% isopropyl alcohol, identified to lowest practical taxon, and enumerated. Water quality and substrate measurements include water temperature, conductivity, turbidity, dissolved oxygen, salinity and pH at each station. Percent dissolved oxygen is estimated from water temperature and dissolved oxygen concentration using a dissolved oxygen saturation nomogram. The substrate is described using visual, olfactory, and tactile observations.

Live Caged Bivalve Studies and Indigenous Fish Body Burden Monitoring Studies

Objectives: To assess trends in PCB/PCT body burdens in transplanted bivalves and indigenous fish.

Live Box Studies

Purchased bivalves were deployed to 5 locations (4 sites, one reference). During Years 1, 2, and 3 the studies used both hard clams and American oysters. The evaluation was limited to oysters only during years 4 and 5 since they had been shown to be the more sensitive species. The bivalves were deployed for 8 weeks and sampled on days 0, 28 and 56. The sampling period coincides with accumulation of adipose tissue for winter stores. Tissue samples were analyzed for PCBs and PCTs. Length, weight, and lipid content were also measured.

Figure 4-1
NASA LANGLEY RESEARCH FACILITY
TABBS CREEK YEAR 2 BIOTA SURVEY/BIOMONITORING ASSESSMENT
Photograph of Shellfish Biomonitoring Rack Used In Tabbs Creek.

Mummichog Sampling

Three replicates were collected from each of the 5 stations using killipots baited with squid. Length and weight were measured. The fish were examined for external abnormalities and analyzed for PCBs, PCTs and percent lipids.

Lessons Learned

- The ROD required restrictions on biota harvesting for 5 years but there was no provision to monitor the restrictions. Biota harvesting restrictions are not controlled by the agencies that were party to the ROD. Therefore it is not clear whether this ROD requirement is being met.

- The objectives of some of the monitoring components were open-ended so it is not clear when the monitoring will be complete. The wetland vegetation monitoring had a measurable endpoint (85% vegetation coverage). However, the endpoint for the wildlife usage monitoring was not specified. There was also no stated endpoint (tissue concentration) for the caged bivalve studies or the mummichog tissue analyses.

- Sediment sampling and analysis was not included in the monitoring plan. Therefore, there is no way to confirm that the sediments are not being recontaminated.

References

Final Year 5 Post Remedial Biomonitoring Report for Tabbs Creek , NASA LaRC, Department of the Navy, Navy Facility Engineering Command Mid-Atlantic, August 9, 2007.

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Final Year 2 Post Remedial Biomonitoring Report for Tabbs Creek , NASA LaRC, Department of the Navy, Engineering Field Activity, Northeast, Naval Facilities Engineering Command, February 4, 2004.

Final Remedial Work Plan for the Tabbs Creek Site, NASA LaRC, Northern Division, Naval Facilities Engineering Command, October 1999.

Point of Contact: Paul Herman, Virginia DEQ. peherman@deq.virginia.gov

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Site Name: Puget Sound Naval Shipyard, (EPA ID: WA2170023418)

Site Location: Bremerton, Washington

Site Description: Puget Sound Naval Shipyard (PSNS) is located in Bremerton, Washington, on Sinclair Inlet in Puget Sound where it has been owned and operated by the Navy since 1891. It covers 350 acres upland and 340 acres of tideland along 11,000 feet of shoreline. Industrial activities include construction, repair, overhaul, maintenance, mooring, berthing, and dry docking of naval ships.

In 1990, the Navy found elevated levels of semi volatile organics, pesticides, PCBs, and heavy metals in soils, groundwater, and sediments. PSNS was put on EPA's National Priority List in 1994. EPA and the State of Washington have joint lead on this site. However, the EPA only recognizes parts of the State's regulations as applicable and relevant for setting cleanup levels. The naval complex is divided into six operable units (OU). This case study concerns the marine operable unit, "OU B," which extends from the shoreline to include submerged sediments in Sinclair Inlet.

Contaminants: Those listed above, with PCBs and mercury driving cleanup.

Size/Area of Site: OU B lies primarily within the subtidal zone of Sinclair Inlet and extends up to 1,500 feet offshore from the terrestrial portions of the naval complex. It contains approximately 230 acres of subtidal land with depths to 40 feet.

Puget Sound Naval Shipyard, Bremerton, Washington

Volume of Contaminated Sediments: Of 368,000 cubic yards of sediment to be dredged from vessel berthing areas and turning basins, approximately 217, 000 cubic yards of contaminated sediment were designated for removal.

Removed: The June 2000 Record of Decision stipulated the chosen remedy to be dredging contaminated sediments and placing them in a confined aquatic disposal (CAD) pit to be capped. The 600 ft x 615 ft CAD was excavated to a depth of 30 ft, and the removed clean material was stockpiled next to it. Through March 2001, 225,000 cubic yards of contaminated sediments were dredged and deposited in the CAD pit which was then capped with 17,000 cubic yards of sand (about 1.4 feet thick) and left to consolidate. In August 2001, 69,000 cubic yards of clean native sediment were placed as a final cap to a thickness of 4.5 feet.

Levels of Contaminants (Pre-remedial Levels): To determine the concentration of PCBs, the entire OU B was divided into a number of grids from which random sediment samples were taken. The pre-remedial concentration of PCBs is stated in the ROD to be 7.8 mg/kgOC (concentration normalized to organic carbon) based on the area-weighted average (AWA) from the grid system. Based on the levels established by pre-remedial monitoring, a cleanup level for PCBs in sediment was set at 3 mg/kgOC to protect human health. Areas above 12 mg/kgOC would be removed and the 3 mg/kgOC cleanup level was predicted to be attained over 10 years via natural attenuation. Co-located sediments with mercury above 3 mg/kg would also be removed. **These target cleanup level**

concentrations for both PCBs and mercury are significantly lower than levels measured after remediation.

Remaining: No additional volume planned for removal.

Levels of Contaminants (Post-remedial Levels): In 2005 the grid AWA was 10.17 mg/kgOC PCBs with the AWA of individual grids ranging from 4.4 to 23.0 mg/kgOC. Concentrations in discrete samples were as high as 125.5 mg/kgOC PCBs, and 18.8 mg/kg mercury.

Ecologic System(s) Impacted
Marine (saltwater) inlet, inner-tidal and sub-tidal environments

Animals:
Benthic invertebrates, fish including English Sole.

Contaminants of Concern: PCBs and mercury

Human Health Risk(s):
Seafood consumption for tribal subsistence.

Contaminants of Concern: PCBs and mercury

Summary of Monitoring Plan

Pre-remedial monitoring
Pre-remedial monitoring was limited primarily to shoreline and apron sediments and not conducted beyond hot spot areas or within the larger inlet. In the CAD pit area, surface samples were analyzed from only 10 stations 20 feet out from the planned perimeter to establish baseline levels. Sample depth for this single baseline round was 10 cm. Core samples were clean.

Post-remedial monitoring
Post-remedial monitoring around the perimeter of the CAD pit revealed that PCB and mercury concentrations were elevated above pre-remediation levels. It became necessary to amend the post-remedial monitoring plan and develop a new and more rigorous one containing contingencies.

Amended monitoring plan
New monitoring plans were developed in a manner to gather adequate data at regular intervals in order to understand true conditions at the site. Plan changes included adding sample collection at 2 cm in addition to the 10 cm samples and providing flexibility for contingent actions to address a range of data results.

Under amended plans, additional rounds of sequential sampling were conducted starting with stations at 20 feet, then 50, 95, 100, 125, 155, 200 and finally 300 feet from the perimeter as the results from each round triggered the next. From this effort, a pattern of contaminant concentration rings was determined radiating out from the CAD pit where mercury and PCB concentrations peaked at 125 feet and then dropped off. At 300 feet concentrations remained elevated.

During post construction sampling, a number of samples 2 cm deep were also collected. Previous conditions at the 2 cm depth were unknown as samples had not been collected at that depth during baseline monitoring. Upon comparison to the 10 cm sample data from the same round, a significant difference was found. Sediment chemistry concentrations at the 2 cm depth were much lower at 1/2 to 1/3 the concentrations measured in the 10 cm samples. There was no pattern of concentration increase and then decrease radiating out from the perimeter that the deeper samples indicated.

Long term monitoring plan and results
The long term sediment monitoring plan for OU B, the CAD pit area, and larger Sinclair Inlet was drafted in March 2007. This sets forth a substantial monitoring effort which will continue over the next 15 years. Goals include confirming the predicted natural recovery of OU B marine sediments and evaluating the success of the remedy in reducing concentrations of PCBs and mercury in fish tissue.

Chemical analysis conducted in 2007 for the first five year review showed a decline in contaminant concentrations across the board. Sediment vertical profile imaging additionally confirmed benthic recolonization of the remediated area. This has been attributed to the contingency action taken to immediately address the unexpected recontamination of the CAD pit area and enhance natural recovery.

Dredging at PSNS with Environmental Bucket

Lessons Learned

- Baseline and post-remedy monitoring should be carried out using similar techniques to avoid incompatible data. At this site, top surface conditions were not characterized until after remediation, and all response actions were based on samples collected at 10 cm. Subsequent characterization of the top 2 cm sediments revealed a significant difference between top surface conditions and those at the 10 cm depth. Response actions may have been somewhat different had surficial sediments been characterized before response actions were taken.

- Rigorous, complete pre-remedial monitoring to establish thorough site conditions prior to remedy selection and action is a cost effective investment. For this site, the post-remedial monitoring showed that baseline conditions were not thoroughly established. Cleanup goals were based on inadequate pre-remedial baseline monitoring data which set an unrealistic timeframe for compliance. It is still unclear exactly what impact the remedy actually had on sediment quality at the site because pre-remedy baseline was inadequate.

- Ideally, the response goal in the ROD should be compatible with the state's stated policy/rule for assessing compliance with a standard. In this case the cleanup goal was based on area-weighted average, which was lower than the actual concentrations and not consistent with the State's regulation that requires point-by-point (discrete samples) compliance with criteria. This affects the State's ability to meet its cleanup goal.

- As contaminated materials are placed into an underwater pit in the seabed, they must first travel through the water column. This is not precise and may be problematic. Thorough planning and rigorous monitoring increase the chances for success.

- Having a solid post-remedial monitoring plan in place to address contingencies instead of reacting to problems as they arise allows for agreement to be reached by involved parties on the general principles that will be followed prior to emergent situations.

- A comprehensive long term monitoring plan should support necessary contingencies and is crucial to understanding trends and analyzing remedy effectiveness over time.

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