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Standard Guide for Contaminated Sediment Site Risk-Based Corrective Action – Baseline, Remedy Implementation and Post-Remedy Monitoring Programs[1]

This standard is issued under the fixed designation E3164; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

1. Scope

1.1 This guide pertains to corrective action monitoring before (baseline monitoring), during (remedy implementation monitoring) and after (post-remedy monitoring) sediment remedial activities. It does not address monitoring performed during remedial investigations, pre-remedial risk assessments, and pre-design investigations.

1.2 Sediment monitoring programs (baseline, remedy implementation and post-remedy) are typically used in contaminated sediment corrective actions performed under various regulatory programs, including the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA). Although many of the references cited in this guide are CERCLA-oriented, the guide is applicable to corrective actions performed under local, state, tribal, federal, and international corrective action programs. However, this guide does not provide a detailed description of the monitoring program requirements or existing guidance for each jurisdiction. This guide is intended to inform, complement, and support but not supersede the guidelines established by local, state, tribal, federal, or international agencies.

1.3 This guide provides a framework, which includes widely accepted considerations and best practices for monitoring sediment remedy efficacy.

1.4 This guide is related to several other guides. Guide E3240 provides an overview of the sediment risk-based corrective action (RBCA) process, including the role of risk assessment and representative background. Guide E3163 discusses appropriate laboratory methodologies to use for the chemical analysis of potential contaminants of concern (PCOCs) in various media (such as, sediment, porewater, surface water and biota tissue) taken during sediment monitoring programs; it also discusses biological testing and community assessment. Guide E3382 describes the overall framework to determine representative background concentrations (including Conceptual Site Model [CSM] considerations) for a contaminated sediment site; Guides E3344 (methodologies for selecting representative background reference areas) and E3242 (statistical and chemical methodologies used in developing representative background concentrations for a sediment site) complement Guide E3382.

1.5 *Units*—The values stated in SI or CGS units are to be regarded as the standard. No other units of measurement are included in this standard.

1.6 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety, health, and environmental practices and determine the applicability of regulatory limitations prior to use.*

1.7 *This international standard was developed in accordance with internationally recognized principles on standardization established in the Decision on Principles for the Development of International Standards, Guides and Recommendations issued by the World Trade Organization Technical Barriers to Trade (TBT) Committee.*

2. Referenced Documents

2.1 *ASTM Standards:*[2]

D75 Practice for Sampling Aggregates

D4823 Guide for Core Sampling Submerged, Unconsolidated Sediments

D7363 Test Method for Determination of Parent and Alkyl Polycyclic Aromatics in Sediment Pore Water Using Solid-Phase Microextraction and Gas Chromatography/Mass Spectrometry in Selected Ion Monitoring Mode

E1391 Guide for Collection, Storage, Characterization, and Manipulation of Sediments for Toxicological Testing and for Selection of Samplers Used to Collect Benthic Invertebrates

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[2] For referenced ASTM standards, visit the ASTM website, www.astm.org, or contact ASTM Customer Service at service@astm.org. For *Annual Book of ASTM Standards* volume information, refer to the standard's Document Summary page on the ASTM website.

E3163 Guide for Selection and Application of Analytical Methods and Procedures Used during Sediment Corrective Action

E3240 Guide for Risk-Based Corrective Action for Contaminated Sediment Sites

E3242 Guide for Determination of Representative Sediment Background Concentrations

E3344 Guide for Selection of Background Reference Areas for Determination of Representative Sediment Background Concentrations

E3382 Guide for Developing Representative Background Concentrations at Sediment Sites — Framework Overview, Including Conceptual Site Model Considerations

3. Terminology

3.1 *Definitions:*

3.1.1 *adaptive management, n*—a structured, iterative process of robust decision making in the face of uncertainty, with the goal of ensuring effectiveness during remedial action. **E3240**

3.1.2 *anthropogenic background, n*—human-made substances present in the environment due to human activities, not specifically related to current or historical site-related releases or activities. **E3344**

3.1.3 *background (aka "reference"), n*—substances, conditions, or locations that are not influenced by releases from a sediment site; these are usually a combination of naturally occurring (consistently present in the environment but not influenced by human activity) and anthropogenic (influenced by human activity but not related to specific current or historical activities or releases at the sediment site) components. **E3382**

3.1.4 *bioavailability, n*—the degree to which a contaminant is free to be taken up by an organism. **E3240**

3.1.5 *cleanup level, n*—the prescribed average or point sediment concentration of a chemical that shall not be exceeded at the remediated site. **E3242**

3.1.6 *conceptual site model, n*—the integrated representation of the physical and environmental context, the complete and potentially complete exposure pathways, and the potential fate and transport of potential contaminants of concern at a site. **E3242**

3.1.6.1 *Discussion*—The CSM should include both the current understanding of the site and an understanding of the potential future conditions and uses for the site. It provides a method to conduct the exposure pathway evaluation; inventory the exposure pathways evaluated; and determine the status of the exposure pathways as incomplete, potentially complete, or complete.

3.1.7 *contaminant of concern (COC), n*—substances identified as posing a risk based on a tiered risk assessment and that warrant corrective action. **E3382**

3.1.7.1 *Discussion*—Typically, all PCOCs identified for a sediment site are evaluated in the risk assessment process. PCOCs that have sediment concentrations greater than risk-based thresholds identified in the risk assessment process are defined as COCs. Thus, the COCs identified for a sediment site are a subset of the PCOCs identified for that site.

3.1.8 *corrective action, n*—the sequence of actions that may include site assessment and investigation, risk assessment, evaluations of potential remedial action alternatives, interim remedial action, remedial action, operation and maintenance of the remedy, monitoring of progress, making "No Further Action" determinations, and completion of the remedial action. **E3240**

3.1.9 *data quality objectives (DQOs), n*—the systematic process to develop performance and acceptability criteria by defining study objectives and the type, quality, and quantity of data needed for site decisions. **E3240**

3.1.10 *natural background, n*—naturally occurring substances present in the environment in forms (and at concentrations) that have not been influenced by human activity. **E3344**

3.1.11 *potential contaminant of concern (PCOC), n*—a contaminant whose sediment concentrations at the site may exceed applicable screening levels; this includes chemicals of potential environmental concern (COPECs) and chemicals of potential concern (COPCs). **E3242**

3.1.12 *remedial action, n*—activities conducted to reduce or eliminate current or potential future exposures to receptors or relevant ecological receptors and habitats. **E3240**

3.1.12.1 *Discussion*—These activities include monitoring, implementing activity and use limitations and designing and operating cleanup equipment. Remedial action includes activities that are conducted to reduce sources of exposure to meet RAOs, or sever exposure pathways to meet RAOs.

3.1.13 *remedial action objectives (RAO), n*—stated objectives that describe what the remedial action for a site is expected to accomplish, based on the CSM and the exposure pathways that may pose an unacceptable risk as determined in a risk assessment; RAOs are specific and achievable goals for reducing risk to human health and the environment. **E3240**

3.1.14 *representative background concentrations, n*—chemical concentrations that are inclusive of naturally occurring sources and anthropogenic sources similar to those present at a sediment site but not related to current or historical site releases or activities. **E3382**

3.1.15 *sediment(s), n*—a matrix of porewater and particles including gravel, sand, silt, clay, and other natural and anthropogenic substances that have settled at the bottom of a tidal or nontidal body of water. **E3163**

3.1.16 *sediment site, n*—the area(s) defined by the likely physical distribution of COC(s) from a source area and the adjacent areas required to implement the corrective action. A site could be an entire water body or a defined portion of a water body. **E3240**

3.2 *Definitions of Terms Specific to This Standard:*

3.2.1 *backfill, n*—clean materials placed directly on the post-dredge surface to provide cover or bring the post-dredging surface to a targeted elevation, or both (also see, *cover material*).

3.2.2 *baseline monitoring, n*—monitoring to establish physical characteristics of the sediment site (such as, sediment mudline elevations), chemical characteristics (such as, COC concentrations in various media) and biological characteristics (such as, sediment toxicity to select organisms) prior to the commencement of remedy implementation.

3.2.3 *benthic community, n*—assemblage of aquatic invertebrates that reside in the sediments.

3.2.4 *biologically active zone (BAZ), n*—the zone of greatest organism-sediment interaction.

3.2.4.1 *Discussion*—Typically, at a sediment site the BAZ is the top 10–15 centimeters (cm) of surficial sediment below the sediment – surface water interface. The BAZ is site-specific and in some cases can be deeper than 15 cm.

3.2.5 *biota, n*—the flora and fauna living in a habitat (**1**).[3]

3.2.6 *capping, n*—the process of placing a material over contaminated sediments to mitigate risk posed by those sediments.

3.2.7 *cover material, n*—alternative term for "*backfill*".

3.2.8 *effectiveness monitoring, n*—component of a post-remedy monitoring program to confirm the RAOs are being met or are trending towards being met in an acceptable time frame.

3.2.9 *environmental dredging, n*—the removal of contaminated sediment at a sediment site; typically during the remedy implementation stage of the corrective action.

3.2.10 *enhanced monitored natural recovery (EMNR), n*—a remediation practice that applies clean material to the sediment surface to accelerate natural recovery processes.

3.2.11 *fish community, n*—an assemblage or association of populations of two or more fish species occupying the same geographical area (such as, stream reach) during a particular time frame.

3.2.12 *in situ treatment, n*—application of amendment materials to the sediment, so they may be mixed (either naturally or mechanically) into the sediments and reduce the bioavailable fraction of contaminants in porewater.

3.2.13 *in situ solidification, n*—a remediation approach that mixes solidification agents (such as Portland cement) into impacted sediments; the intended result is to reduce sediment permeability and the mobility of contaminants within the bulk sediment.

3.2.14 *monitoring, n*—the collection and analysis of repeated observations or measurements to evaluate changes in condition and progress towards meeting documented program objectives.

3.2.14.1 *Discussion*—Monitoring is the collection of data (that is physical, chemical, biological) over a sufficient period of time and frequency, so that data analysis can determine trends in one or more environmental parameters or characteristics and compare their status to remedy objectives.

3.2.15 *monitored natural recovery (MNR), n*—a remediation practice that relies on natural processes (such as, sequestration and biodegradation) to protect the environment and receptors from unacceptable exposures to contaminants.

3.2.16 *performance monitoring, n*—component of a post-remedy monitoring program conducted to determine if the remedy is performing as designed.

3.2.17 *post-remedy monitoring, n*—programs that typically include performance monitoring (to demonstrate the remedy is performing as designed) and effectiveness monitoring (to determine whether COC concentrations in affected media met RAOs, or are expected to meet RAOs in an acceptable time frame).

3.2.17.1 *Discussion*—A post-remedy monitoring program may have both short-term and long-term performance and effectiveness monitoring goals (such as, meeting RAOs).

3.2.18 *porewater, n*—water located in the interstitial voids (between solid-phase particles) of bulk sediments.

3.2.19 *remedial investigation, n*—the contaminated site investigation performed prior to remedial alternative selection to determine if the nature and extent of contamination is at unacceptable levels and warrants any potential remedial action.

3.2.20 *remedy implementation monitoring, n*—monitoring of conditions during remedy execution to determine if design criteria have been achieved and if regulatory requirements have been met.

3.2.20.1 *Discussion*—If an active remedy has been chosen, this is often referred to as "construction monitoring". In many cases, there will be permit requirements during the implementation of the remedy and monitoring may be required to ensure compliance with these requirements.

3.2.21 *residuals, n*—untreated contamination that remains in the surface sediment after the completion of sediment dredging operations.

4. Significance and Use

4.1 *Intended Users:*

4.1.1 This guide may be used by various parties involved in sediment corrective action programs, including regulatory agencies, project sponsors, environmental consultants, toxicologists, risk assessors, site remediation professionals, environmental contractors, and other stakeholders.

4.2 *Reference Material:*

4.2.1 This guide should be used in conjunction with other ASTM guides listed in 2.1 (especially Guides E3163, E3240, E3242, E3344 and E3382), as well as the material in the References section.

4.3 *Flexible Site-Specific Implementation:*

4.3.1 This guide provides a systematic but flexible framework to accommodate variations in approaches by regulatory agencies and by the user based on project objectives, site complexity, unique site features, regulatory requirements, newly developed guidance, newly published scientific research, changes in regulatory criteria, advances in scientific knowledge and technical capability, and unforeseen circumstances.

4.3.1.1 This guide provides a monitoring plan development, execution and analysis framework based on over-arching

[3] The boldface numbers in parentheses refer to the list of references at the end of this standard.

features and elements that should be customized by the user based on site-specific conditions, regulatory context, and sediment corrective action objectives.

4.3.1.2 Implementation of the guide is site-specific. The user may choose to customize the implementation of the guide for a particular site, especially smaller, less complex sites.

4.3.1.3 This guide should not be used alone as a prescriptive checklist.

4.3.2 The users of this guide are encouraged to update and refine (when needed) the conceptual site model, Project Work Plans and Project Reports used to describe the physical properties, chemical composition and occurrence, biologic features, and environmental conditions of the sediment corrective action project.

4.4 *Regulatory Frameworks:*

4.4.1 This guide is intended to be applicable to a broad range of local, state, tribal, federal, or international jurisdictions, each with its own unique regulatory framework. As such, this guide does not provide a detailed discussion of the requirements or guidance associated with any of these regulatory frameworks, nor is it intended to supersede applicable regulations and guidance. The user of this guide will need to be aware of (and comply with) the regulatory requirements and guidance in the jurisdiction where the work is being performed.

4.5 *Systematic Project Planning and Scoping Process:*

4.5.1 When applying this guide, the user should undertake a systematic project planning and scoping process to collect information to assist in making site-specific, user-defined decisions for a particular project, including assembling an experienced team of project professionals. These practitioners should have the appropriate expertise to scope, plan, and execute a sediment monitoring program. This team may include, but is not limited to, project sponsors, environmental consultants, toxicologists, site remediation professionals, analytical chemists, geochemists, and statisticians.

4.6 *Stakeholder Engagement:*

4.6.1 The users of this guide are encouraged to engage key stakeholders early and often in the project planning and scoping process, especially regulators, project sponsors, and service providers. A concerted ongoing effort should be made by the user to continuously engage stakeholders as the project progresses in order to gain insight, technical support and input for resolving technical issues and challenges that may arise during project implementation.

4.7 *Other Considerations:*

4.7.1 The over-arching process for risk-based corrective action a sediment sites is not covered in detail in this guide. Guide E3240 contains extensive information concerning that process.

4.7.2 Sediment sampling and laboratory analyses is not covered in detail. Guide E3163 contain extensive information concerning sediment sampling and laboratory analysis methodologies.

4.7.3 Developing representative background concentrations for the sediment site is not covered in detail in this guide. Guides E3242, E3344 and E3382 contain extensive information concerning that topic.

4.7.4 In this guide, "sediment" (3.1.15) is defined as a matrix being found at the bottom of a water body. Upland soils of sedimentary origin are excluded from consideration as sediment in this guide.

4.7.5 In this guide, only COC concentrations are considered. Residual background radioactivity is out of scope.

4.8 *Structure and Components of This Guide:*

4.8.1 The user of this guide should review the overall structure and components of this guide before proceeding with use, including:

Section 1	Scope
Section 2	Referenced Documents
Section 3	Terminology
Section 4	Significance and Use
Section 5	Components of a Generic Monitoring Program
Section 6	Generic Considerations for Sediment Site Monitoring Programs
Section 7	Types of Sediment Remedial Action Monitoring Programs
Section 8	Baseline Monitoring Programs: General Considerations
Section 9	Remedy Implementation Monitoring Programs: General Considerations
Section 10	Post-Remedy Monitoring Programs: General Considerations and Program Planning Examples
Section 11	Keywords
Appendix X1	Discussion of Monitoring Program Development, Data Quality Objective Development and Statistical Analysis of Data Processes
Appendix X2	Case Study: Monitoring of Sediment Remediation Activities
References	

5. Components of a Generic Monitoring Program

5.1 *Framework Overview:*

5.1.1 This section presents the six key steps recommended in U.S. Environmental Protection Agency (USEPA) guidance for developing various types of monitoring plans (**2**); this process (as applied to sediment sites) is used in sediment-specific guidance prepared by USEPA (**3**). The steps in this process are:

5.1.1.1 *Step 1*—Identify Monitoring Plan Objectives

5.1.1.2 *Step 2*—Develop the Monitoring Plan Hypothesis

5.1.1.3 *Step 3*—Formulate Decision Making Rules

5.1.1.4 *Step 4*—Design the Monitoring Plan

5.1.1.5 *Step 5*—Conduct Monitoring, Analysis and Characterize Results

5.1.1.6 *Step 6*—Establish the Management Decision

5.1.2 In the absence of any regulatory requirements or guidance regarding monitoring program development in a jurisdiction, it is recommended that this USEPA process be used to develop various monitoring programs at sediment sites.

5.1.3 The six-step USEPA monitoring program development process relies heavily upon the USEPAs seven-step data quality objective (DQO) process (**4**). The DQO process defines the type, quality and quantity of data necessary to make rational monitoring decisions. Application of the DQO process leads to an optimized data collection plan for a monitoring program.

5.1.4 A detailed discussion of the six-step USEPA monitoring program development process is provided in X1.1. The relationship between the six-step USEPA monitoring program development process and the seven-step USEPA DQO process is also discussed X1.1.

6. Generic Considerations for Sediment Site Monitoring Programs

6.1 *Scope:*

6.1.1 At contaminated sediment sites, monitoring is conducted to accomplish various goals. These may include (**3**):

(1) Assess compliance with remedy design and performance standards (that is, remedy implementation monitoring and post-remedy performance monitoring).

(2) Assess short-term remedy performance and effectiveness in meeting sediment cleanup levels (that is, post-remedy performance and effectiveness monitoring).

(3) Evaluate long-term remedy effectiveness in achieving Remedial Action Objectives (RAOs) and reducing risk to human health and the environment (that is, a combination of baseline and post-remedy effectiveness monitoring).

6.1.2 The considerations discussed in this section can be applied to all types of monitoring programs typically associated with sediment remedial actions.

6.2 *DQO Development:*

6.2.1 DQOs describe the performance and acceptance criteria for the data collected. DQOs are established for each type of monitoring conducted. USEPA has a systematic process for developing DQOs (**4**).

6.2.2 The relationship between DQOs and the six-step monitoring program development process are discussed in more detail in X1.1.1.

6.2.3 Interstate Technology & Regulatory Council (**5**) and USEPA (**3, 6**) discuss applying the USEPA DQO process to sediment monitoring programs.

6.3 *Decision Rules:*

6.3.1 A decision rule describes how the data will be evaluated and how decisions will be made. A decision rule describes what action will be taken for a given monitoring result. Decision rules are often expressed as "if/then" statements.

6.3.2 Decision rules form the basis for decisions to continue, modify, or stop the monitoring, or recommend taking additional corrective action.

6.3.3 Decision rules are discussed in detail in X1.1.4.

6.4 *Types of Sediment Monitoring Measurements:*

6.4.1 Sediment monitoring typically includes three types of measurements:

6.4.1.1 Physical measurements (that is, physical properties of sediment and surface water).

6.4.1.2 Chemical measurements (that is, chemical properties of sediment, porewater, surface water, and biota).

6.4.1.3 Biological measurements (that is, biological characteristics of organisms and communities of organisms).

6.4.2 Methods for collecting physical, chemical, and biological measurements are described in Battelle (**7**), EPRI (**8**), ITRC (**5**), National Research Council (**9**), Space and Naval Warfare (SPAWAR) Systems Center (**10**), USACE (**11, 12, 13**), and USEPA (**3, 14, 15**). Table 1 presents common monitoring methods and provides references to guidance documents on how to perform various physical, chemical, and biological measurements.

6.4.3 All data collection efforts need to adhere to the DQOs, quality assurance plans, field sampling and analysis plans (FSAPs), and standard operating procedures (SOPs). Data analysis, including appropriate statistical procedures, is used to evaluate various aspects (such as achieving RAOs, trend analysis of data) of remedial activities (**4, 53**).

6.5 *Periodic Review of the Monitoring Plan:*

6.5.1 Periodic review of the monitoring program is an important aspect of the program. For example, at CERCLA sites USEPA performs formal reviews every 5 years. Periodic review facilitates a scheduled interaction with the regulator, so decision making can be coordinated. Modifications to the monitoring plan (such as, reduced frequency of monitoring) may be appropriate to optimize the monitoring plan, based on the periodic review of the data collected.

TABLE 1 Measurement Method Summary and References

Type of Measurement	References
Physical Measurements	
Bathymetric Survey	(**16**)
Sediment Geophysical Characterization	(**11**, **13**)
Current Velocity	(**17**, **18**, **19**, **20**, **21**)
Hydrodynamic Characteristics	(**19**, **22**, **23**)
Sediment Settlement Plate	(**11**)
Sediment Trap	(**19**, **22**, **24**, **25**)
Sediments Profile Photography	(**11**, **12**, **19**)
Sediment Shear Stress	(**22**)
Sediment Erosion	(**22**, **26**, **27**)
Suspended Sediment Monitoring	(**22**, **27**)
Chemical Measurements	
Surface Water Samples	(**12**, **13**, **19**, **28**, **29**, **30**, **31**, **32**, **33**, **34**)
Subsurface Sediment Samples	Guide D4823, (**6**)
Surface Sediment Samples	Guide E1391, (**6**, **35**)
Rapid Sediment Characterization Tools	(**15**, **30**)
Seepage Meter/Flux Sampler	(**19**, **23**, **36**, **37**, **38**, **39**)
Porewater Sampling	Test Method D7363, (**6**, **31**, **40**, **41**, **42**, **43**, **44**, **45**, **46**, **47**)
Air Sampling	(**12**)
Biological Measurements	
Benthic Surveys & Community Analysis	Guide E1391, (**19**, **48**)
Caged Organisms	(**19**)
Aquatic Invertebrate Samples	(**19**)
Fish Community or Terrestrial Wildlife Census	(**13**, **19**)
Vegetation Survey	(**13**, **19**)
Tissue Sampling	(**19**, **49**)
Toxicity Testing	Guide E1391, (**19**, **48**, **50**, **51**, **52**)

7. Types of Sediment Remedial Action Monitoring Programs

7.1 *Stages of Monitoring:*

7.1.1 Monitoring associated with sediment remediation is divided into three stages: baseline, remedy implementation, and post-remedy (Fig. 1).

7.2 *Baseline Monitoring:*

7.2.1 Baseline monitoring is performed prior to implementation of an active remedy, or prior to the commencement of a compliance monitoring program, for the purpose of obtaining initial data before future data acquisition efforts. Baseline monitoring determines existing conditions that can be used as reference data for comparative purposes during remedy implementation and post-remedy monitoring.

7.2.2 Data collected during remedial investigation, risk assessment, and pre-design investigation may have different DQOs than baseline monitoring and may not be adequate for characterizing baseline conditions. Alternatively, the DQOs for these historical investigative activities may be the same as for baseline monitoring, but insufficient data are available to characterize the baseline conditions. Finally, these historical data may have been collected a long time ago and may not represent current site conditions. Therefore, monitoring may be warranted to define baseline conditions, prior to remedy implementation.

7.2.3 Baseline monitoring may include evaluating representative background concentrations, which is discussed in 8.4.

7.2.3.1 Remedy implementation monitoring data are compared to baseline data to evaluate if construction is modifying baseline conditions to an unacceptable level.

7.2.3.2 The post-remedy effectiveness monitoring results are compared to the baseline conditions to evaluate if the completed remedy is meeting the RAOs (or is trending towards meeting the RAOs within a reasonable time frame).

7.2.4 Baseline monitoring is discussed in more detail in Section 8.

7.3 *Remedy Implementation Monitoring:*

7.3.1 Remedy implementation monitoring takes place during field execution of the remedy. For more active remedies, this is sometimes referred to as "construction monitoring".

7.3.2 Remedy implementation monitoring is performed to determine if design criteria (as defined in the drawings and specifications) and the permit requirements (or substantive permit requirements) were achieved during the remedy execution.

7.3.3 Remedy implementation monitoring is discussed in more detail in Section 9.

7.4 *Post-Remedy Monitoring:*

7.4.1 Post-remedy monitoring takes place after remedy implementation is completed. The post-remedy monitoring period begins as soon as the remedy implementation phase has been completed. Post-remedy monitoring includes both performance monitoring and effectiveness monitoring.

7.4.1.1 Note that performance and effectiveness monitoring programs can have both short-term and long-term components.

7.4.2 Performance monitoring is conducted to determine if the remedy is performing as designed. It evaluates the performance of the remedial technology (such as, chemical isolation for capping or natural recovery for MNR).

7.4.3 Effectiveness monitoring is conducted to confirm the RAOs are met or that conditions are trending in the right direction for RAOs to be met within an acceptable time frame.

7.4.4 Post-remedy monitoring is described in more detail in Section 10. Examples of the application of the six-step monitoring program development process for post-remedy performance monitoring for various sediment remedial technologies and post-remedy effectiveness monitoring in various environmental media are presented in Section 10.

8. Baseline Monitoring Programs: General Considerations

8.1 *Purpose of Baseline Sampling Programs:*

8.1.1 Baseline sampling is an essential component of a monitoring program that evaluates the long-term success of a

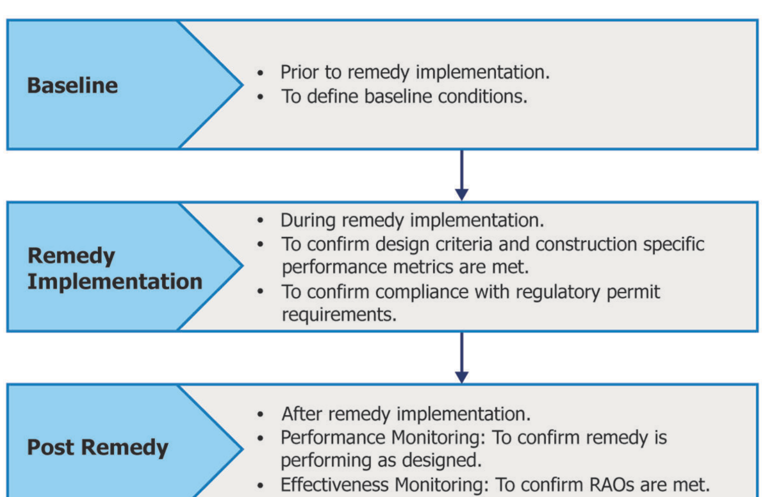

FIG. 1 Monitoring Program Stages During Sediment Site Remedy

sediment remediation project. Sometimes, the baseline sampling is conducted during the site characterization or remedial investigation phase of a project. In other situations (such as, under the conditions described in 7.2.2) the baseline monitoring program is conducted just before remedy implementation.

8.1.2 Once the RAOs for the site are defined, a baseline sampling program may be developed to ensure appropriate data are collected to meet long-term monitoring objectives. Appendix X2 provides a simplistic case study example demonstrating how a baseline monitoring program can be designed and executed.

8.2 *Importance of Baseline Data:*

8.2.1 The data collected during the baseline sampling program need to be sufficient (in quality and quantity) to allow comparison to post-remedy monitoring data to determine if the remedy was a success, whether the RAOs will be met within an acceptable timeframe and if additional adaptive management actions are warranted. To facilitate this comparison, baseline data need to reflect the variability, uncertainty, and complexity of the system being remediated. The baseline data should be consistent with the conceptual site model (CSM examples are provided in Guide E3240) and risk assessment findings, including documentation of media concentrations (such as, sediment, surface water, porewater and biota) and other measures of environmental quality (such as, ecotoxicity, habitat structure and function) that will be affected by the site remedy. Insufficient baseline sampling data may limit the ability of decision makers to determine if post-remedy issues (such as, no decline in biota tissue COC concentrations) are due to the failure of the remedy or have been caused by other factors.

8.3 *When to Collect Baseline Data:*

8.3.1 Baseline data are collected prior to implementing the remedial action. The baseline data collection parameters represent the information needed to determine the effectiveness of the remedy to meet RAOs. The following items should be considered when collecting a baseline data set:

8.3.1.1 The baseline sampling program should be site-specific and augment recently collected data.

8.3.1.2 Sufficient data need to be collected to document spatial variations in conditions, or temporal trends, or both.

8.3.1.3 Baseline sampling programs need to be statistically designed and sufficiently rigorous.

8.3.1.4 Data need to be developed to support the evaluation of the remedial endpoints that risk managers establish.

8.3.2 Data should be related to the human health (such as, safe consumption levels of fish and crab) and ecological risk assessments (such as, biota tissue concentrations, ecotoxicity, measures of community structure and function), where risk drivers are the basis for a proposed remedy, as described in the risk-based corrective action approach.

8.3.3 Data collected during the remedial investigation, feasibility and pre-design phases of the sediment site corrective action may be sufficient to establish the baseline (subject to the conditions outlined in 7.2.2). Otherwise, additional baseline data should be collected following the selection of the remedy (but before remedy implementation) to focus on establishing a data set sufficient to document conditions both before and after remedy implementation, as well as data trends after remedy implementation.

8.3.4 The baseline sampling effort should reflect the size, complexity, and overall scope of the sediment remediation project.

8.3.5 Samples should be collected from all relevant media, for all relevant contaminants. This will vary by site. The sampled media should be consistent with the conceptual site model and the findings from the risk assessments (both human health and ecological).

8.3.5.1 The baseline sampling program need not (and usually does not) monitor all parameters that data was collected for in the site investigation phase of the sediment site corrective action program.

8.4 *Determination of Representative Sediment Background Concentrations for the Sediment Site:*

8.4.1 Establishing representative background concentrations in sediments by sampling a background reference area (or areas) provides a local or regional baseline against which to compare data from a contaminated sediment site (Guide E3382). Typically, the background reference area(s) is identified during the remedial investigation phase. The background reference area(s) selected for developing background concentrations should be as similar as possible in the physical, chemical, geological, biological, and land use characteristics as the site being investigated, but not affected by current or historical site-related activities or releases (Guide E3344, **53**). Further guidance on the selection of background references areas is provided in Guide E3344.

8.4.2 Once data has been collected from the background references areas, the process outlined in Guide E3242 can be used to develop representative background concentrations for sediment site COCs.

8.4.3 Once established, representative background concentrations may be applied as cleanup levels at sites where these concentrations are greater than risk-based cleanup levels, thereby setting the scope and scale of the sediment site corrective actions. "The reasons for this approach include cost-effectiveness, technical practicability, and the potential for recontamination of remediated areas by surrounding areas with elevated background concentrations" (**53**).

8.5 *Selection of Sampling Media:*

8.5.1 The baseline sampling program should include all relevant environmental media and measures of environmental quality that will be affected by the remedy and are related to the risks that are being mitigated by the remedial actions. The specific media that are sampled are selected on a site-specific basis.

8.5.1.1 The media included in the baseline sampling program may change as the remedial, feasibility and pre-design investigation progress. These changes should focus on limiting the baseline sampling program to the scope that is necessary to support relevant risk management decisions and not include monitoring components that are superfluous to making those decisions.

8.5.1.2 Specific environmental media that should be considered for sampling include surface sediment, subsurface sediment, native material, porewater, surface water, groundwater and biota tissue concentrations.

8.5.1.3 Data may include information on physical factors (such as, net sedimentation rates, sediment stability, and grain size) that support assessing the validity of model predictions, as well as trends toward RAOs for monitored natural recovery (MNR) and other remedial alternatives. Baseline data to support the evaluation that RAOs have been achieved may include bioavailability (via porewater COC concentrations), sediment COC concentrations, surface water COC concentrations, benthic community structure, benthic toxicity, fish community assessment, and fish tissue COC concentrations. In cases where the remedy will impact sensitive habitats, measures of community structure, diversity and function should generally be obtained during baseline sampling as a basis of comparison for post-remedy evaluation of restored habitats.

8.6 *Chemical Sampling and Analysis:*

8.6.1 Where COC concentrations in one medium are linked to one or more other media, it is usually important to include all relevant media in the baseline sampling program plan. For example, where crab tissue COC concentrations are identified as the primary exposure pathway in the risk assessments, it may be important to continue to monitor surface sediment and surface water concentrations, to evaluate if these media are sources of the COCs that are having a significant effect on tissue concentrations.

8.6.1.1 In cases where biota tissue COC concentrations exceed risk-based criteria (as identified in the human health and ecological risk assessments) and the organism spends a large portion of its lifetime in contaminated areas outside the sediment site boundaries, it is unlikely that the remedial action taking place at the sediment site will result in tissue COC concentrations being reduced to the point where they meet the risk-based criteria.

8.7 *Sampling Frequency:*

8.7.1 Frequency of sampling should consider daily, seasonal, and long-term (that is, multi-year) variability that are related to site conditions (such as, tidal flow and seasonal flow regimes). For certain parameters, both wet weather and dry weather conditions may need to be evaluated. For some biota (such as certain fish species), natural spatial (such as, the range of the organism) and temporal (such as, migration patterns of the organism) variability may need to be established and separated from trends associated with implementation of the remedy when analyzing the data.

8.8 *Selection of Sampling Locations:*

8.8.1 Sampling locations for the collection of baseline data should be developed on a site-specific basis. In addition, sampling locations should consider the conceptual site model, exposure pathways, system dynamics, and the proposed remedy. Sampling procedures, such as compositing samples, may be considered to better represent exposure concentrations.

8.8.2 The number of sampling locations is often determined using statistical tools such as power analysis (**3**, **54**, **55**). Often data collected at a point in time after remedy implementation is compared to the baseline monitoring data set using statistical tests or trend analysis. Thus, enough data points must be obtained that the data sets provide the statistical power to identify meaningful differences in the two data sets. Alternatively, analysis might be performed to confirm a trend in the post-remedy data (such as, that COC concentrations in surface sediments are decreasing in a MNR program and are predicted to meet the RAOs in a reasonable time frame).

9. Remedy Implementation Monitoring Programs: General Considerations

9.1 *Purpose of Remedy Implementation Monitoring Programs:*

9.1.1 Remedy implementation monitoring (also commonly referred to as construction monitoring for active remedies) takes place during remedy execution and immediately following remedy completion, to determine if the established short-term remedy design objectives have been adequately achieved. In remedy implementation monitoring programs the measures of success can be identified in terms of both remedy performance (are design criteria being met) and compliance (are regulatory criteria met during the remedy implementation phase of the corrective action).

9.1.1.1 Depending upon the scope of the project and the remediation technology utilized, remedy implementation monitoring activities can take many different forms and typically will include multiple matrices. A well-developed sampling plan is vital to obtaining the best remedy implementation monitoring data possible; data that will ultimately be used to make critical decisions during the remedy implementation phase.

9.1.1.2 Data interpretation and decision making needs to be documented in the development of the monitoring plan. Appendix X2 provides a simplistic case study example demonstrating how a remedy implementation monitoring program can be designed and executed.

9.2 *Design of Remedy Implementation Monitoring Programs:*

9.2.1 The scope of the remedy implementation monitoring program should be identified and described in the associated remedy design documents. These documents should also clearly articulate the goals of any such monitoring, along with related implementation methods. Sections 5, 6 and X1.1 provide further guidance regarding the pertinent planning and implementation for such sampling/monitoring operations.

9.2.2 Remedy implementation monitoring activities typically take place at multiple points in time during project execution, which should be specified in the related work plans. Since remedy implementation monitoring will be conducted during performance of the remedy (or immediately following this), it is important to understand how remedy-related activities could impact sampling (and vice versa) when planning the monitoring program. This is important, not only from a data quality standpoint, but also to ensure the field work can be completed safely.

9.2.2.1 Sampling plans should build in the proper flexibility, so that field adjustments can be made as needed during remedy implementation activities. This could include sampling frequency and locations, as well as the various parameters monitored. Because remedy execution is inherently unpredictable, flexibility and contingency planning in terms of sampling is a key consideration in any remedy implementation monitoring plan.

9.2.3 Flexibility may also be needed in terms of scope. For example, the exceedance of permit criteria could force additional sampling for that media. Likewise, it may also be possible to reduce sampling frequency or the number of sampling locations, when monitoring results consistently meet decision rules. These "if/then" decision rules need to be described in the remedy implementation monitoring plans before the field work begins.

9.2.4 The nature of remedy implementation monitoring depends primarily upon the type of remedy that will be applied. Broadly speaking, typical sediment remedial approaches include the following:

9.2.4.1 Dredging (including backfilling dredged areas with clean materials).

9.2.4.2 Engineered Capping.

9.2.4.3 Enhanced Monitored Natural Attenuation (EMNR).

9.2.4.4 Monitored Natural Recovery (MNR).

9.2.4.5 *In situ* Treatment.

9.2.4.6 *In situ* Solidification.

9.2.5 As described in the sections below, each type of remedial approach has a typical set of remedy implementation monitoring activities associated with it, along with other activities that are more dependent upon the characteristics of the site. Not all approaches described below for a given remedial technology may be necessary in every case, but they should at least be considered.

9.2.5.1 Since MNR is passive in nature (that is, no construction is required), implementation monitoring is not applicable to this remedial technology, so it will not be discussed in this section. Given its relatively limited field application to this date at sediment sites, *in situ* solidification is another remedial technology that will not be addressed in this section.

9.2.6 Table 1 provides a more comprehensive listing of those monitoring techniques that could be used during remedy implementation monitoring. While not all are described in further detail below, it should be recognized that they are available for use.

9.3 *Specific Monitoring Considerations—Dredging:*

9.3.1 In most dredging operations, the objective is to remove sediments to a pre-determined elevation or until a pre-determined surficial sediment concentration is met. Many different forms of dredging (such as hydraulic or mechanical) can be implemented, and under different environments (such as, beneath the water or "in the dry").

9.3.2 Because dredging is an inherently intrusive operation, sediments (along with associated contaminants) can be resuspended into the water column during removal activities. While some suspended sediments may migrate away from the area being dredged, some will settle back into the area that they were dredged from, creating what is known as a "residuals" layer (**3, 5, 56**). Residuals can also represent contaminated sediments that were simply missed during dredging (or were never targeted in the first place). In any case, and as discussed further, this residual layer can play an important part in determining whether dredging operations can be considered complete.

9.3.3 Once deemed acceptable per the specifications, the dredged area is often covered with clean backfill, including aggregate or armoring materials. These materials can serve to not only bring the final surface to a desired elevation and act as an isolation layer for dredging residuals, but they can also provide erosion protection. In some cases, the installation of engineered caps have been used as a backfilling technique following dredging, as further described in 9.4.

9.3.4 Regardless of how the dredging operation proceeds, remedy implementation monitoring will likely be required to assess performance (and regulatory compliance) during project execution. The need for sediment, surface water, air and quality of life (QoL) monitoring during remedy implementation should be considered during project planning.

9.3.5 *Dredging—Physical Measurements on Sediment:*

9.3.5.1 As part of any contaminated sediment dredging project, the remedy design should adequately specify the physical bounds (based on previously collected information/data) of the area targeted for dredging. With this design, the contractor will be expected to remove sediment (sometimes incrementally) to a vertical "cut line," or elevation, within an established dredge area. Various factors can contribute to the contractor's ability to control accuracy, including (but not limited to) the type of dredge and positioning equipment used, the presence of debris, the nature of the underlying material and the skill level of the dredge operator (**12**).

9.3.5.2 Dredging accuracy will typically need to be monitored during execution. The development of electronic positioning programs has enabled better monitoring of the physical effectiveness of dredging operations. Should conditions be appropriate, such equipment can produce operating accuracies within 10–15 cm, both horizontally and vertically (**12**). However, site-specific field conditions could significantly limit this accuracy. In cases where clean backfill, cover materials or an engineered cap are placed following dredging, it may be necessary to verify the thickness and spatial coverage of the newly placed materials. Techniques for evaluation of the physical placement of clean backfill, cover materials or an engineered cap following dredging are similar to those used in capping (see 9.4).

9.3.5.3 Hydrographic bathymetric surveys are also useful, although they do not normally produce real-time information. However, they can be helpful in determining the volume of material removed as part of dredging operations and the amount of clean backfill or cover materials placed after the completion of dredging. Comparison to pre-dredging conditions/surveys would be necessary in this case. Side scan sonar or sediment profile imaging (SPI) can also be implemented to understand the physical nature of the residual layer, should that be considered important. See Table 1 for further information regarding these technologies/techniques.

9.3.6 *Dredging—Chemical Measurements on Sediment:*

9.3.6.1 In addition to physical measurements, chemical data can also be used to evaluate dredging performance. Remedial Action Levels (RALs) are sometimes established as COC target concentrations for sediment remediation. In the case of dredging, existing data (in conjunction with established RALs) would likely be used to determine the depth to which dredging should proceed. Once the contractor has excavated to this pre-determined depth, "confirmation" sediment samples could then be collected at this depth to verify that the RALs have been met.

9.3.6.2 Sediment samples (see Table 1) should be obtained either as a grab sample (typically used for surface sediment samples) or core sample (typically used for subsurface sediment samples) depending upon the criteria that are established in the workplan. Additionally, samples may be obtained to represent a "point" concentration, or combined in some way (either physically via sample compositing or mathematically) to represent a larger area. Regardless, if RALs are not met, additional steps may need to be taken, including further dredging or installation of an engineered cap.

9.3.7 *Dredging—Chemical Measurements on Surface Water:*

9.3.7.1 To assess how much contaminated material is resuspended and migrates away from the dredging operation, a surface water column monitoring program should be implemented. In many cases, regulatory requirements mandate that surface water be monitored to ensure it does not become appreciably impacted during dredging. Such monitoring may include water quality measurements such as turbidity, temperature, dissolved oxygen, and pH, but it may also include chemical measurements as well. Baseline conditions should be measured and understood before dredging occurs, to effectively evaluate the impact (if any) of sediment removal operations. In cases where risk-based cleanup levels may be below representative background concentrations, these background concentrations should be established before remedy implementation (Guides E3242, E3344 and E3382).

9.3.7.2 Surface water monitoring could occur at near-field (in the immediate vicinity of the dredge operations) or far-field (further upstream or downstream of the dredge operations) locations, or both. If utilized, near-field monitoring locations should be selected to be relatively close to the dredging operations (but outside of turbidity controls, such as silt curtains) to understand how much of the resuspended material the dredging operations are producing is escaping to the environment. Such data can also be used as an early detection system for receptors further downstream. The far-field locations may be used to represent chronic exposure and also be used for regulatory compliance purposes. Sensitive points, such as locations upstream of a water intake, or upstream of a confluence with another water body, should also be considered when selecting appropriate near- and far-field sampling locations.

9.3.7.3 Depending upon the project's sampling goals, and the nature of the site itself, collecting samples from a single depth in the water column may be acceptable, while other times a combined (or homogenized) sample representing multiple depths is more appropriate. Additionally, the timing and frequency of such sampling depends on a number of factors, not the least of which is tidal influences.

9.3.7.4 In the case of surface water quality, it may be possible to utilize field measurements that are real-time and more cost-effective as compared to standard laboratory testing. To develop such a "proxy", an adequate amount of data would need to be evaluated to determine whether a reliable relationship exists between the results produced by the field and laboratory methods. For example, regulatory permits often require that total suspended solids (TSS) concentrations be measured and compared to background conditions. TSS measurements require laboratory analyses which can take hours, or even days. Should the results indicate an exceedance of regulatory criteria, the condition causing the problem may no longer exist. Thus, having a real-time measurement has much more practical value from a project execution perspective. In this case, turbidity could serve as the proxy measurement for TSS, assuming an acceptable relationship to TSS data exists at the sediment site. Turbidity data are easier, faster and cheaper to collect than TSS data. Better yet, the data can be collected real-time in the field, and can be very beneficial to the dredge operator in better controlling solids releases to the surface water column. This is just one of several different proxy relationships that could be sought and implemented. It is important that these types of relationships be developed (should they exist) using site-specific data.

9.3.8 *Dredging—Chemical Measurements on Air Quality:*

9.3.8.1 Air quality may be evaluated by establishing a perimeter air monitoring plan as part of a broader community action plan. Samples obtained usually represent air quality over a period of time (that is, hours or days), and are typically sent to a laboratory for testing. Monitoring criteria may be developed based on ambient air standards or reports of nuisance odors from the public. For example, should odors from the operation be noted by the community, this may prompt the need for more immediate readings from local air monitoring stations or potential curtailment of dredging operations, or both.

9.3.8.2 Typically, air monitoring stations are established at fixed locations considering predominant wind directions, although variable locations can also be established. The latter would be dependent upon such factors as dredge location, changing wind directions and other site-specific conditions. In all cases, it will be important to understand regional air quality background conditions to better interpret any site-specific data collected.

9.3.8.3 Typically, air quality is measured upwind and downwind from dredging operations; the results are compared to determine the net effect of dredging operations on air quality.

9.4 *Specific Monitoring Considerations—Engineered Capping:*

9.4.1 The goal of an engineered cap (or cap) is to stabilize and isolate contaminated sediments, and to prevent (or minimize) their release, resuspension and transport. In addition to physical isolation, an engineered cap can act as a chemical isolation layer to minimize the migration of COCs from underlying contaminated sediments to the biologically active zone (BAZ) and the surface water column.

9.4.2 The layer(s) of material placed in the cap should minimize the risk of interaction (both physical and chemical) between the underlying contaminated sediments and the recovering BAZ. Capping can be completed as a standalone remedial technology, or after sediments have been dredged. An engineered cap may include one or more layers of the following materials:

9.4.2.1 Natural materials (such as, clean sand or sediment).

9.4.2.2 Amendments (such as, activated carbon).

9.4.2.3 Geotextiles (such as, to separate cap layers or for purposes of geotechnical stability).

9.4.2.4 Armoring material (such as aggregate) to minimize cap erosion.

9.4.3 The monitoring considerations presented in 9.4.4 through 9.4.6 would apply to the placement of the materials listed in 9.4.2, regardless of the ultimate cap design. Monitoring is needed during and immediately after material placement, to ensure that the cap has been constructed to meet the design specifications. Similar to dredging, any permitting/regulatory restrictions for the cap installation will also require the need for remedy implementation monitoring to ensure compliance to these regulatory criteria.

9.4.4 *Engineered Capping— Physical Measurements of Cap Materials:*

9.4.4.1 Prior to placement (and even before purchase), cap materials should be tested to ensure that they meet the physical and chemical specifications required by the cap design. Typically, samples are collected from the material source before every delivery to the sediment site and tested to ensure specifications are met before acceptance of the material. As with other matrices, samples should be collected as grabs or composites using appropriate standards (such as Practice D75), depending upon the project specifications.

9.4.4.2 Once approved for use, the cap material must be properly placed to meet the desired design objectives. During placement, spatial accuracy should be monitored using electronic positioning programs, such as those discussed in 9.3.5.2. The use of electronic positioning programs allows for the position of capping activity to be tracked in real time and documented throughout cap construction.

9.4.4.3 The thickness of the cap should also be monitored during and after material placement (that is, once placement is completed). Bathymetric surveys can be used by comparing pre- and post-capping elevation data. It is important to note that cap placement will likely result in compression and consolidation of underlying sediments, which will need to be accounted for when comparing post-placement bathymetric survey results to evaluate cap thickness conformance with the design specifications. Pre-installed inspection rods may also be used to monitor cap thickness, although a diver is needed to obtain measurements. In cases where a very thin layer of a sediment amendment (such as, on the order of several inches in EMNR programs) is being placed (see 9.5), monitoring may include the installation of collection plates in the application zone that can be used for real time assessment of the thickness of the placed material.

9.4.4.4 After the placement of the engineered cap material, the overall composition of the cap should also be evaluated to determine if the as-placed material meets design criteria. The physical composition (such as, organic carbon content) and thickness of each cap layer can be measured from the collection of sediment cores. In the event that amendment materials are being utilized, it is also important to verify the uniformity of distribution of these reactive materials within the cap layer. It should be recognized that sediment cores provide single point measurements, so the number of cores collected should be sufficient to assess potential spatial variability. Sediment profile imaging (SPI) may also be useful to visually verify the distribution of amendment materials within the engineered cap.

9.4.4.5 Measurement of the composition and thickness of the cap may be evaluated statistically, as measurements may vary from one location to the next. Minimum criteria and an acceptable range for variations should be established as part of the remedial design. For bathymetric survey data, the resolution of these measurements needs to be understood to confirm the collected data can meet the accuracy required by the established design criteria.

9.4.5 *Engineered Capping—Chemical Measurements of Cap Materials:*

9.4.5.1 During cap placement, existing contaminated sediments may become mixed with the cleaner cap material. It is typical to expect that a certain amount of mixing will take place at the cap-sediment interface. Amongst other things, this phenomenon will vary based on the physical characteristics of both the sediments and the capping material. In situations where the underlying sediments are considered soft, the weight of the cap may consolidate the sediments, causing upward movement of contaminated pore water into the clean cap layer(s). Typically, both mixing and consolidation would be accounted for in the cap design process.

9.4.5.2 To assess the extent of such mixing, sediment cores can be collected to evaluate the chemical profile of the various cap layers. However, it is typically not necessary to perform these chemical measurements if sediment physical characteristics have been adequately evaluated and the mixing layer is included in the design. In that case, this objective could be met with the same cores by visual inspection. Alternatively, sediment profile imaging (SPI) may also be used to evaluate the extent of mixing of contaminated sediment within cap materials during construction.

9.4.5.3 It may be worthwhile to conduct some coring midway through cap placement to ensure even placement and limited mixing with the underlying impacted sediments to allow for adaptive management of placement techniques, if warranted. Some monitoring may also be warranted to ensure that cap placement does not result in laterally displacing contaminated sediments at the cap boundary (that is, mudwaving), which could result in a halo of uncapped contaminated sediment located along the cap boundary.

9.4.6 *Engineered Capping—Surface Water Measurements (Physical and Chemical):*

9.4.6.1 Similar to dredging, the potential exists for sediment to be released, resuspended and transported during cap placement. Cap material itself may become suspended during placement and create turbidity, which can impact water quality. A water column monitoring program should be implemented (and will likely be required by permits) during remedy implementation activities. The factors considered as part of a dredging operation (9.3.7) should be evaluated in this case.

9.5 *Enhanced Monitored Natural Recovery (EMNR):*

9.5.1 In the case of EMNR, a relatively thin (that is, on the order of several cenimeters) layer of clean material (that is, sand or clean sediments) is applied to the existing sediment surface to accelerate and support natural recovery processes. While not designed as a traditional engineered cap, the general purpose is the same–to minimize the movement of contaminants from sediments to the overlying water column. With EMNR, the applied material is intended to naturally mix with the existing sediments, and enhance any on-going recovery processes (such as, the sequestration of COCs). The purpose of this approach is not to physically isolate or protect the sediments, as would be accomplished with a traditional engineered cap.

9.5.2 *EMNR—Physical Measurements on Sediments:*

9.5.2.1 Given the objectives above, physical measurements may be obtained to verify adequate coverage and thickness of the applied material. During placement, spatial accuracy should be monitored using electronic positioning programs, such as those discussed in 9.3.5.2. The use of electronic positioning programs allows for the position of placement activity to be tracked in real time and documented throughout remedy implementation. The thickness of the material should also be monitored during and after placement. Due to the relatively thin layers applied, and typical bathymetric resolution, bathymetric surveys are generally not useful for EMNR. Instead, monitoring typically would include placement of collection plates for real time assessment of the thickness of the placed material. Sediment cores or SPI can also be used to evaluate clean layer thickness after placement completion.

9.5.2.2 Minimum criteria and an acceptable range for physical variations in the thin layer cap should be established as part of the EMNR remedial design.

9.5.3 *EMNR—Surface Water Measurements (Physical):*

9.5.3.1 Similar to engineered capping and dredging operations, it is typically necessary to monitor turbidity during cap placement activities. Refer to 9.3.7 for further information.

9.6 *In Situ Treatment:*

9.6.1 *In situ* treatment involves the placement of a thin-layer of an amendment (such as, activated carbon) onto the sediment surface. The goal is to reduce exposure and uptake of the bioavailable fraction of contaminants by benthic organisms by reducing the bioavailable pore water concentration of contaminants in surface sediments. Amendments can be mixed into the biologically active zone (BAZ) by natural processes such as bioturbation, or by using mechanical processes. The effectiveness of *in situ* treatment is influenced by the physical (such as, particle size, bulk density) and chemical (such as, partition coefficients) properties of the amendment materials utilized. It is important to obtain uniform distribution of amendments and maximize the degree of contact between the contaminants contained in the sediments and amendment(s), based on the horizontal and vertical mixing within the amended area.

9.6.2 *In Situ Treatment—Amendment Physical and Chemical Measurements:*

9.6.2.1 Prior to placement, *in situ* treatment materials should be tested to ensure that they meet the physical and adsorption specifications required by the design. This will typically require obtaining manufacturing quality control data and samples of manufactured materials for verification of partition coefficient or other pertinent performance parameters. It is a best practice to obtain this type of information prior to purchase of the materials and delivery to the sediment site.

9.6.2.2 Collection plates can be used to collect data on the amount (that is, thickness) of amendments added to the sediments.

9.6.3 *In Situ Treatment—Amended Sediment Physical and Chemical Measurements:*

9.6.3.1 Immediately following placement, the composition of the *in situ* treatment material should also be evaluated to determine if the design criteria are met. This can be performed using the material recovered on collection plates during the evaluation of the amended sediment thickness. The material must be evaluated to confirm that the quantity of reactive amendment material specified in the design was successfully placed. This evaluation is typically done through an appropriate chemical evaluation of the as-placed material. In addition, it may be advisable to evaluate whether the as-placed material meets the design performance criteria (such, partition coefficients).

9.6.4 *In Situ Treatment—Surface Water Measurements:*

9.6.4.1 Similar to engineered capping and dredging operations, it is typically necessary to monitor turbidity during *in situ* treatment activities. Refer to 9.3.7 for further information.

9.7 *Quality of Life Monitoring During Remedy Implementation:*

9.7.1 For most sediment remediation programs, it is important to consider what impacts (if any) the field execution of the remedy could have on the surrounding community. In some cases, it is necessary to implement a quality of life (QoL) monitoring program that takes into account the everyday activities and expectations of the neighboring communities. Some of the more common QoL considerations are described in this section.

9.7.2 *Odor:*

9.7.2.1 As discussed in 9.3.8, a perimeter air monitoring program could be implemented to protect the surrounding area (including workers and the community) from airborne contaminant exposure. Odors, however, pose a slightly different issue, one that is typically more a nuisance than a health risk.

9.7.2.2 Sediment remediation projects can produce strong odors, primarily through the dredging and handling of decaying organic matter found within the sediments. Monitoring can be difficult, as the detection of odors is typically subjective (that is, what is unpleasant to one person may not be to another).

9.7.2.3 To minimize possible odor complaints, the most prudent course of action is to cover any removed material to the extent possible, whether via tarps, foams (these should be PFAS-free) or some other rigid form of enclosure (such as,