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Sediment Assessment and Monitoring Sheet (SAMS)

Adaptive Site Management – A Framework for Implementing Adaptive Management at Contaminated Sediment Superfund Sites

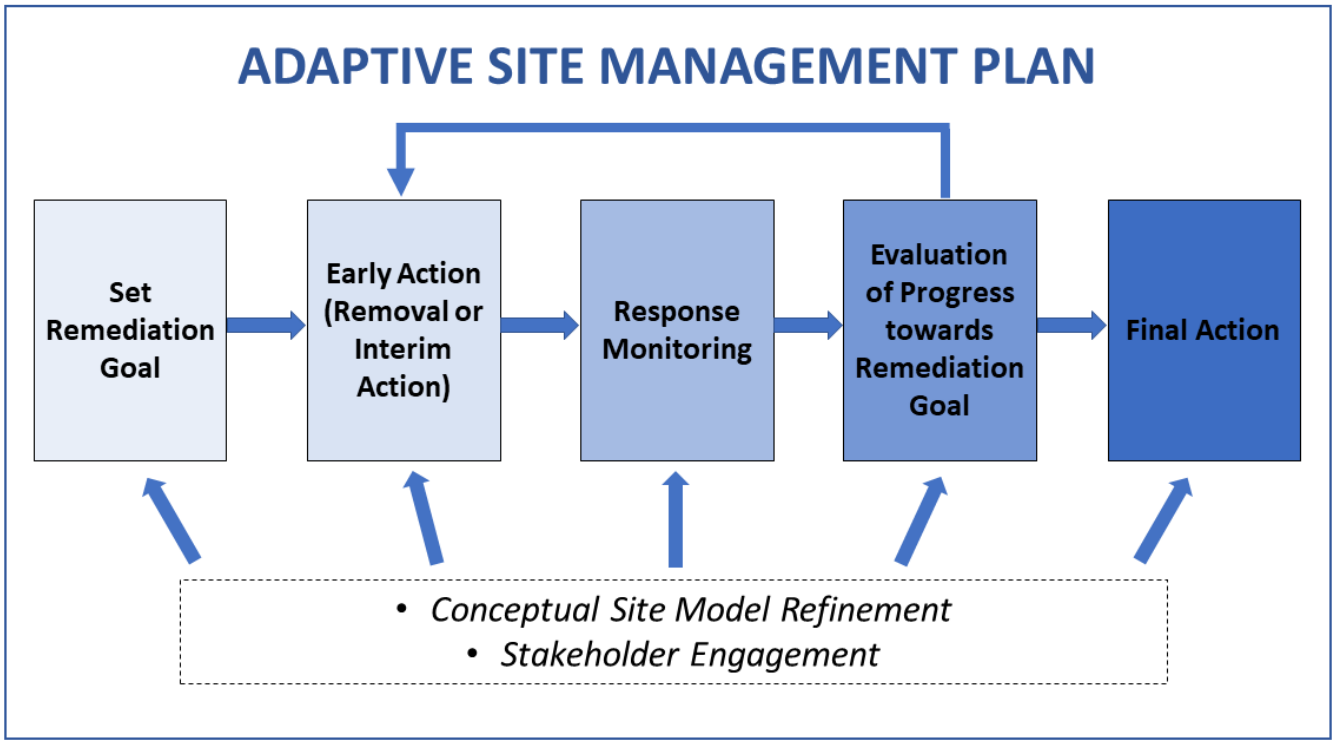

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Table of Contents

Figures

PREFACE

This fact sheet was prepared by the U.S. Environmental Protection Agency (EPA), Office of Superfund Remediation and Technology Innovation (OSRTI) as part of the Sediment Assessment and Monitoring Sheet (SAMS) series. The SAMS series of documents provide greater detail and discussion on topics of interest in contaminated sediment management. This fact sheet presents a framework for implementing adaptive site management within Superfund by performing early or interim actions followed by a final action, guided by an adaptive site management plan. This fact sheet supplements but does supersede or replace current guidance, and it does not impose legally binding requirements on EPA, states, or the regulated community.

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STATEMENT OF PURPOSE

This Sediment Assessment and Monitoring Sheet (SAMS), prepared by the U.S. Environmental Protection agency (EPA), describes how adaptive site management can be applied to large, complex contaminated sediment sites in a manner consistent with the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) and the National Oil and Hazardous Substances Pollution Contingency Plan (NCP).

Adaptive site management is one option for planning remediation at large, complex Superfund sediment sites with long remediation times and high levels of uncertainty regarding the remedial actions necessary to achieve final, protective remediation goals. Adaptive site management relies on a plan developed in consultation with stakeholders to describe how Superfund processes will be assembled and utilized. The plan includes the adaptive site management elements of site-specific goals, actions, monitoring, evaluation, and remedy adaptation and presents them within the Superfund context. Planning early in the remedial process ensures that these elements are agreed upon and available to guide decision making over the course of site cleanup.

INTRODUCTION TO ADAPTIVE SITE MANAGEMENT AT SUPERFUND SEDIMENT SITES

Large and complex contaminated sediment sites often have long remediation timeframes; multiple, widespread, and inter-connected sources of contamination; wide-ranging human and ecological receptors; and uncertainty in the timing and magnitude of effect between sediment remediation and reduction in risk to receptors. Sediment bed characterization is challenging because of heterogeneous conditions and ongoing transport processes. Remediation is difficult to conduct in underwater environments and may be prone to recontamination. At large, complex sediment sites, these issues make it challenging to develop and select a final, protective remedy in a Record of Decision (ROD) prior to conducting any remediation.

Adaptive site management combines iterations of remediation and monitoring to determine progress towards remedial action objectives (RAOs) and remediation goals, inform uncertainties, and make decisions about whether and when additional remediation is necessary to achieve RAOs. This approach can facilitate progress at Superfund sites through:

- agreement between stakeholders on what is known and what is unknown about the site;
- early management of high-risk areas and source areas; and
- a structured decision-making process that accommodates the uncertainty inherent to large, complex cleanups while maintaining focus on achieving the site's final remediation goals.

Adaptive site management relies on monitoring to continually improve site understanding and track progress towards goals. This allows decision makers to:

- better establish the contaminant relationship between soils/sediments, water, and biota;
- identify unknown contaminant sources or exposure drivers;
- assess the effectiveness of remedial approaches; and
- determine the degree of remediation necessary to achieve a final, protective remedy.

At a practical level, the value of adaptive site management at sediment sites is the potential for expediting significant progress toward final remediation goals, while monitoring the system response and gauging what, if any, additional steps are needed to achieve those goals. Remediation under adaptive site management acts on what is known while acknowledging what is not fully understood. It includes plans to collect the necessary information to reduce uncertainties and achieve a final, protective remedy for the site. This approach allows work to proceed in areas with high contaminant exposure and transport while additional data collection and testing of responses is conducted to determine the appropriate level of remediation in remaining areas. (See Box 1 for additional background and terminology.)

Box 1. Background and Adaptive Management Terminology

Adaptive management at Superfund sites has been extensively discussed and reviewed for decades. EPA recommends an iterative approach to decision making that will include "*testing of hypotheses and conclusions and foster re-evaluation of site assumptions as new information is gathered.*" (EPA 2002a, Principle 6). The National Research Council (NRC) has published extensively on the use of adaptive management in water resources and at contaminated sediment sites (NRC 2003, 2004, 2005, 2007). Reviews have been published in academic and law journals (e.g., Apitz 2008, Cannon 2005). Federal agencies and the Interstate Technology and Regulatory Council (ITRC) have produced adaptive site management guidelines (Fischenich 2019, ITRC 2017, Williams et al. 2009). Adaptive management for sediment sites is described in several EPA documents and its use is recommended at complex sites (EPA 2005, 2017a, 2017b).

So why is additional discussion needed? Adaptive management is not a single approach. In contaminated sediment management, the term has been applied to decisions and processes from large to small where outcomes may be uncertain. At sediment sites, examples have ranged from modifying sampling strategies during characterization, to conducting pilot studies, to modifying approaches during remediation to improve their performance. The applications have generally entailed collecting information during operations to modify decisions, reflecting the "learning while doing" aspect of adaptive management. However, the over-use of the term "adaptive management" at the small scale has diluted the meaning of adaptive management as a long-term site management strategy. At large, complex Superfund sites, the fundamental uncertainty to be adaptively managed is the degree of remediation that will be necessary to achieve a final, protective remediation goal. The adaptive management process of remediation, monitoring, and evaluating progress towards final remediation goals is well-suited to address this uncertainty.

In 2018, EPA addressed the wide range of purposes and definitions in adaptive management, describing "site level" and "project level" adaptive management, with "site level" corresponding to broader strategies to achieve site cleanup (EPA 2018a).[1] This site level application of adaptive management to achieve site remediation goals is consistent with the purposes of adaptive management in contaminated site cleanup outlined in previous efforts (NRC 2003, 2005, 2007) and EPA's contaminated sediment guidance (EPA 2017a).

The term "adaptive site management" is used in this document, consistent with previous applications (NRC 2003 and ITRC 2017), to establish that adaptive management is being used as a long-term site management strategy, and to differentiate it from other uses of the term adaptive management. Herein, adaptive site management is described as a formalized process to manage risks from contaminated sediment sites where iterations of remediation, monitoring, and progress evaluations are guided by a formalized adaptive management plan that establishes the goals of the project, sets expectations, uses monitoring data to evaluate progress towards those expectations, and adapts the remedy as necessary based on those evaluations.

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[1] Superfund Taskforce #3 (EPA 2018a) developed a broad working definition that encompassed the "site level" and "project level" application of adaptive management: "*Adaptive management is a formal and systematic site or project management approach centered on rigorous site planning and a firm understanding of site conditions and uncertainties. This technique, rooted in the sound use of science and technology, encourages continuous re-evaluation and management prioritization of site activities to account for new information and changing site conditions. A structured and continuous planning, implementation and assessment process allows EPA, states, other federal agencies, or responsible parties to target management and resource decisions with the goal of incrementally reducing site uncertainties while supporting continued site progress.*"

Adaptive site management may not be necessary or well-suited for all sites. For sites where final, protective alternatives can be developed and evaluated using the standard Superfund process, and a preferred alternative selected, there is likely no need for adaptive site management. At these sites, contaminant(s) of concern (COC), sources, and exposure areas are defined, and a link between remediation and RAO attainment is reasonably anticipated. If necessary, remedy refinement or maintenance can occur through operations and maintenance protocols, remedy optimization, incorporating flexibilities into RODs, contingency remedies, or formal remedy changes, such as an Explanation of Significant Difference (ESD) or ROD amendment. Remedy effectiveness will be verified and tracked through long-term monitoring as part of the five-year review. At other sites, it may be appropriate to use removal or interim actions to quickly manage high risk areas or source areas without accompanying adaptive site management, recognizing that remaining unacceptable risks will be addressed by a final ROD.

ADAPTIVE SITE MANAGEMENT FRAMEWORK

Several adaptive site management frameworks have been developed over the years. These have generally contained similar elements (e.g., NRC 2004, 2005, EPA 2017a, ITRC 2017):

1) Identification of a remediation goal,
2) Action(s) to make significant progress toward that goal,
3) Monitoring of progress toward the remediation goal, and
4) Use of monitoring information to guide decisions regarding additional actions to achieve the remediation goal.

These elements are typically preceded and supported throughout adaptive site management by development and refinement of the conceptual site model (CSM) and stakeholder engagement.

The adaptive site management framework presented in this document is based on these elements and is intended to be applied as part of existing Superfund guidance.

> *"[w]hen applying [adaptive management] at CERCLA sites, activities and response decisions must be done in accordance with CERCLA regulations, policy, and guidance. Moreover, the application of [adaptive management], to the extent practicable, strives to establish site or project strategies that employ existing CERCLA process flexibilities such as the use or application of early and/or interim actions to address immediate risks, to mitigate source migration, and/or to return portions of sites to beneficial use pending more detailed evaluations at other parts of sites"* (EPA 2020).

One way to implement adaptive site management within the Superfund context is to execute early actions followed by a final action[2], guided by an adaptive site management plan focused on evaluating progress toward and attainment of remediation goals (see Box 2). That example process is described below.

Box 2. Terms: Actions and Goals

Early and final actions. In this document, the term early action refers to actions taken early in the process, prior to the final action and may include removals or interim actions (see section 8.2.2 in EPA,1999). The final action is the final remedy selected in the final ROD that is intended to be protective of human health and the environment.

Remediation goals. The remediation goal is the contaminant concentration in the media (e.g., sediments and/or fish) that is the goal of the early or final action. Final remediation goals are, as indicated in the NCP, intended to be protective of human health and the environment (see footnote 3). Early action remediation goals are associated with the early actions and reflect the limited scope of the action (for example, *"[t]he interim action should protect human health and the environment from the exposure pathway or threat it is addressing, and the waste material being managed at least in the short term (until a final ROD is implemented))*" (EPA 1999, highlight 8-7).

The specific usage of terms associated with "remediation goals" varies during the Superfund process as information is collected and needs change. For example, "*PRGs [preliminary remediation goals] are refined into final remediation goals throughout the process leading up to remedy selection… The ROD itself, however, should include a statement of final clean-up levels based on these goals…*" (EPA 1991, section 1.5). Regions should use the terms appropriate for the site, remedial action, and timing, consistent with guidance.

DEVELOPING AN ADAPTIVE SITE MANAGEMENT PLAN

The adaptive site management plan is a site strategy document that guides the iterative remedial actions that will ultimately result in a final, protective remedy. The plan is developed and implemented with the stakeholder group (e.g., potentially responsible parties, States, trustees, Tribal nations, and affected communities) and should include meaningful community involvement "early and often" (EPA 2002a, Recommendation 2). The adaptive site management plan does not replace the need for a decision document (a ROD or, in the case of a removal action, an action memorandum) for any response action under CERCLA.

The plan describes the relationship among operable units (especially those that constitute source control for the sediment action) and the site's use of early and final actions to achieve final RAOs and

[2] EPA 2017b: "*Under an Adaptive Management strategy, Regions are encouraged to consider greater use of early and/or interim actions including use of removal authority or interim remedies, to address immediate risks, prevent source migration, and to return portions of sites to use pending more detailed evaluations on other parts of sites."*

remediation goals. The plan relies on the CSM and includes the goals, expectations, and timeframes for the actions, as well as the timepoints when monitoring data will be evaluated and decisions will be made regarding the need for additional remediation. The adaptive site management plan should be reviewed periodically and updated based on new site information, if warranted.

An adaptive site management plan using this process includes the following steps.

1. Establish the remediation goal(s). The site's RAOs "…*provide a general description of what the cleanup will accomplish…" (EPA 1999)* while the remediation goals are the contaminant exposure levels associated with the RAO.[3] As such, the remediation goal is the quantitative indicator that the RAO has been achieved. The adaptive site management plan relies on the remediation goal as the benchmark for quantitatively understanding progress and establishing when the remediation has been completed. Optimally, the remediation goal will be the protective remediation goal associated with a final remedy and attainment of acceptable risk at the site, consistent with the NCP.[4] This final goal represents the desired condition of the system post-remediation and allows for an understanding of the degree to which early actions make progress toward that final goal.

This final remediation goal will be site-specific, derived consistent with the NCP and EPA guidance, and will consider applicable or relevant and appropriate requirements (ARARs), acceptable risk (10^{-4} to 10^{-6} excess upper bound lifetime cancer risk and/or a non-cancer hazard quotient of 1 or below), technical limitations (including background)[5], uncertainty, and other pertinent information (NCP: 40 CFR 300.430(e)(2)(i)). The final RAOs and remediation goals are distinct from remediation goals associated with the early action(s). Early actions have separate remediation goals specific to those actions that are intended to make significant progress toward final remediation goals. For example, the RAO of an early action may be to significantly reduce sediment COC exposure concentrations and may specify a threshold sediment concentration as the early action remediation goal. The final remedy will establish a final remediation goal that represents acceptable exposure levels protective of human health and the environment (for the COCs, media [e.g., sediments and/or fish] and exposure pathways defined in the

[3] 40 CFR 300.430(e)(2)(i) of the NCP states that site managers, "*Establish remedial action objectives specifying contaminants and media of concern, potential exposure pathways, and remediation goals... Remediation goals shall establish acceptable exposure levels that are protective of human health and the environment and shall be developed...*"

[4] Ibid

[5] "*The contribution of background concentrations to risk associated with CERCLA releases may be important for refining specific cleanup levels for COCs that warrant remedial action. For example, in cases where a risk-based cleanup goal for a COC is below background concentrations, the cleanup level may be established based on background*" (EPA 2002b).

final RAOs). Final and early action remediation goals should be measurable and specific in terms of COCs, media, areas over which they will be measured, and how data will be analyzed to ascertain goal attainment (see EPA 2017a, Recommendation 5 and additional discussion below).

Early in the process, it is possible that the risk assessment is not yet finalized, or information is not sufficient to establish a final remediation goal. In such cases, a preliminary remediation goal (PRG)[6] can be used, and an early action that makes substantive progress toward that goal (or that significantly decreases current COC exposures) could be implemented. A final remediation goal is normally not required for an early or interim action; however, in adaptive site management, having the final action remediation goal as early as possible is important to understand and communicate the degree to which the early action is consistent with and makes progress towards the final remediation goal. The adaptive site management plan is intended to be revisited and updated, allowing information on the final remediation goal to be included when it is available. It is also recognized that, consistent with five-year review procedures (EPA 2001), exposure assumptions, cleanup levels[7], and RAOs will be periodically re-evaluated to determine if they are still valid (and the outcomes included in updates to the adaptive site management plan).

2. Determine the action. At this step, the site's CSM should provide a "*representation of the environmental system and the physical, chemical, and biological processes that determine the transport of contaminants from sources to receptors*" (EPA 2005). Site data should be able to depict current areas of COC exposure and transport to allow the identification and remediation of the primary COC contributors. An early action would be designed to achieve early action RAOs and remediation goals and make significant progress toward final remediation goals. The actions would target areas of highest

[6] *"Initially, preliminary remediation goals are developed based on readily available information, such as chemical-specific ARARs or other reliable information. Preliminary remediation goals should be modified, as necessary, as more information becomes available during the RI/FS"* (NCP, 40 CFR 300.430(e)(2)(i)).
[7] When the ROD is issued, cleanup levels and final remediation goals are synonymous: *"In the ROD, it is preferable to use the term "remediation level" or "cleanup level" rather than "remediation goal" in order to make clear that the Selected Remedy establishes binding requirements."* (EPA 1999).

risk, exposure, and COC transport to biota, downstream, or adjacent areas (see Box 3). Remediation in targeted areas may be anticipated to expedite recovery of remaining, lesser contaminated areas. Some sites and watersheds may be so large and contamination so widespread that multiple early actions may be necessary. In those cases, early actions make significant progress by targeting the most significant sitewide sources of COC exposure and transport but may only achieve early action goals on a localized scale. When combined, those localized actions make significant progress toward sitewide final RAOs and remediation goals.

Box 3. What constitutes a significant area/action?

Early actions that target a greater portion of COC exposure and transport make greater progress to final, protective remediation goals. The most relevant examples of adaptive site management principles applied at sediment sites, such as the Diamond Alkali, Passaic River, Operable Unit 4 (EPA 2021) and Ventron/Velsicol, Berry's Creek, Operable Unit 2 (EPA 2018b), sought 93-95% decreases in exposure to the primary COCs, respectively, and targeted the most upstream and highly contaminated areas. Actions that reduce contaminant exposures and transport create immediate risk reduction but can also foster conditions where natural recovery is able to address lesser contaminated areas (assuming natural recovery processes exist). Actions at that magnitude may obviate the need for subsequent actions or monitoring after the early action may help identify remaining areas driving unacceptable risk. The Bunker Hill Superfund Site in Idaho and Washington is another site using adaptive site management principles. This site covers a vast area, much larger than the preceding examples, and the first iterations of actions targeted high-priority areas based on their potential to serve as a source, exposure, or recontamination in the most upstream and heavily contaminated segments of the site (EPA 2012).

3. State the expectations. In this adaptive site management framework, early actions are intended to achieve the early action's remediation goals while making significant progress towards the site's final, protective remediation goals. The adaptive site management plan should state the goals of the early action(s) and the expectations and timeframes for attainment of final remediation goals following the early action. The stated goals and timeframes provide the basis for evaluating remedy performance (Step 5, below).

The 2017 Contaminated Sediments Directive (EPA 2017a) advised that an adaptive management plan:

"*a. Specifies key indicators (i.e., monitored parameters that are tied to the remedial action objectives),*

b. Selects specific trigger criteria (i.e., concentrations and timeframes) of those key indicators that might trigger a change in the remedy, and

c. Specifies the specific actions based on attainment or non-attainment of trigger criteria."

These elements encompass several aspects of planning, monitoring, evaluation, and adaptation. They are critical to communicate expectations, including how the remediation will be monitored and evaluated, and how decisions will be made based on those evaluations. The concentration and timeframe "trigger criteria" are particularly important as they reflect expected progress toward the final remediation goal.[8] For example, the concentration and timeframe that might trigger a change in the remedy are whether the final remediation goal (in the stated media and area) was achieved 15 years following the early action.[9] Because of the importance of the trigger criteria, they should be unambiguous and specific in terms of COCs, media, area, and associated level of contaminant exposure. The plan also needs to be clear on when data will be evaluated and decisions will be made (See Box 4).

Box 4: Timepoints for Data Review and Decisions

The adaptive site management plan should be clear on the timing for data evaluation and management decisions. These are critical timepoints for stakeholder involvement. Establishing the evaluation and decision timepoints provides certainty that performance will be evaluated and that additional actions will be conducted, if necessary, based on progress towards objectives.

In the simple example where a trigger criterion is set at 15 years from the early action, the adaptive site management plan would include data evaluation timepoints every five years (consistent with five-year review requirements) and a decision timepoint at year 15. The evaluation and decision timepoints also provide the opportunity to update the CSM and adaptive site management plan.

Terms:

Evaluation timepoints: Timepoints when collected data will be evaluated and compared to expectations. While data may be collected and compiled more frequently, these evaluation timepoints are an opportunity for stakeholders to evaluate whether the stated expectations are being met.

Decision timepoints: Timepoints when collected data are compared to the trigger criteria to inform a management decision.

The confidence in future predictions and the ability to establish triggers and decision timepoints will vary depending on the site (see discussion in Box 5). For example, at large, watershed-wide mining sites, the timeframe to attain final remediation goals may be highly uncertain as multiple iterations of priority area remediation are planned and the identification of additional source areas may be anticipated. The adaptive site management plan should state this expectation and that routine monitoring and data evaluations will be used to identify priority areas and chart progress toward final remediation goals and RAOs. As information is gathered, timeframes will be revised and decision timepoints established as the adaptive site management plan is

[8] Again, the final remediation goal is distinct from the early action remediation goal.
[9] In this example, the trigger criterion is the same as the final remediation goal. This may not always be the case; in some cases, a trigger criterion may represent progress toward, but not attainment of, the final remediation goal.

updated. At other sites, expectations for the degree and timing of remediation are more certain. For example, an early action may be intended to make significant progress by remediating high concentration areas and attaining final remediation goals over time by the iterative remediation or natural recovery of lower concentration areas. At set decision timepoints, the stated expectations and trigger criteria will be evaluated.

An important aspect to be addressed by stakeholders is the potential need to revise the decision timepoints, trigger criteria, and remediation goals based on new information. These adaptive site management elements are directly used to determine whether to conduct additional remediation, so their revision will be significant. Evaluating new information and adapting to this information is central to adaptive site management. However, since remediation goals and acceptable risk reduction timeframes are primarily a risk management function subject to Superfund's requirements for protective and cost-effective remedies, they are less likely to be modified by factors such as site uncertainties, unexpected rates of concentration declines, or model discrepancies. However, as described in Step 1, new information can be relevant to their basis.

Box 5. Predictions, Modeling, and Monitoring in Adaptive Site Management

Adaptive site management relies on the site's CSM to make predictions about effects from remediation. The CSM will include a baseline data set that is sufficiently robust to support predictions and permit an understanding of the magnitude of change during future monitoring events. A wide variety of approaches are used at sites to depict those future conditions. Sites have used empirical approaches such as applying observed rates of COC reduction to predicted post-remediation concentrations, simple modeling approaches such as sediment deposition and mixing models based on measured deposition rates, and the more complex and time-consuming linked hydrodynamic, sediment transport, and contaminant transport model complexes.

In the adaptive site management paradigm, it is recognized that future predictions are fundamentally uncertain, and that monitoring will be used to refine predictions, inform progress, and support future decisions (see also Principle 6 in EPA 2002a and Recommendation 7 in EPA 2017a). One advantage is that this approach lessens the need for the unattainable goal of model "accuracy" in large, complex, and uncertain environments and making final decisions based on incomplete understanding of the site. Instead, adaptive site management prioritizes monitoring to define trends, update predictions, verify success, or identify unforeseen problems and the areas or processes driving those problems. Intrinsic to the monitoring and learning process are regular reviews of the CSM and the opportunity to update it based on new information.

4. Monitor progress. A strong monitoring program is critical in adaptive site management. Baseline sampling is needed to support a CSM, adequately depict current conditions, and allow site managers "t*o evaluate, predict, and communicate environmental improvements from implemented remedial actions*" (see EPA 2017a, Recommendation 9). Monitoring during and after remediation provides the basis for understanding conditions and comparing them to the stated expectations. It is also key to understanding why those expectations were or were not achieved. The results are used to refine the CSM, reduce uncertainty, and inform next steps.

Monitoring key indicators of RAOs and remediation goals is central to evaluating remedy performance. EPA highlights the need for specificity in these stated expectations (EPA 2017a):

"A remedy's risk reduction expectations should answer several fundamental questions:

- *What condition (e.g., contaminant concentration or level of toxicity) is expected to be achieved?*
- *In what media (e.g., sediment, fish tissue, surface water, porewater)?*
- *In what area?"*

These stated expectations communicate anticipated performance in terms of COCs, media, receptors, and the associated area. The adaptive site management plan should include a description of the monitoring program that is designed to evaluate stated expectations and remedy performance.

Considering the nature of sites that are good candidates for adaptive site management, the program will likely include multiple iterations of data collection prior to reaching the decision timepoint when trigger criteria are evaluated. This repeat sampling would permit a greater understanding of the rate, variability, and distribution of site responses and may provide information to modify the CSM or monitoring program.

Monitoring program design is beyond the scope of this document, but EPA recommends *"[t]he monitoring endpoints used to measure progress towards or achievement of RAOs…are site-specific, and should directly indicate the RAO and be linked to the remediation...*" (EPA 2017a). Clarity and specificity in the expectations and how criteria will be evaluated are essential to providing an unambiguous basis for reviewing and modifying the remedy. The trigger criteria should be specific to the media; establish whether remediation goal comparisons are to individual samples, composites, or areal averages; specify the area over which samples will be aggregated; and describe how data will be analyzed and compared to the goals.[10] Spatial and temporal density of sampling should be sufficient to reliably indicate progress towards or attainment of goals over the relevant exposure area and to identify problematic areas. Methods for developing monitoring programs to assess cleanup level attainment are discussed in EPA guidance (EPA 1989, 2004).

[10] For example, a monitoring plan could establish that yellow perch and largemouth bass will be sampled every two years after the completion of the early action. Sampling design will include chemical and lipid analysis of whole-body individual (largemouth) and composites (yellow perch) with adequate replication such that the average fish tissue concentration in each 1-mile section is expected to have a relative standard deviation no greater than 50%. The expectation (and in this case the trigger criteria) is to achieve an average fish tissue concentration of 0.5 ppm in each 1-mile section of river from river mile 0 to 5 within 10 years of the early action. The 95% upper confidence limit of each 1-mile average for each species will be compared to the trigger criteria at the decision timepoint (year 10).

Monitoring also helps diagnose why goals were or were not achieved by providing results with sufficient spatial and temporal resolution to indicate the areas or sources slowing or driving the non-attainment of remediation goals. However, such monitoring may not provide adequate context to understand *why* a remedy did or did not perform as anticipated. This "diagnostic" monitoring helps to diagnose the drivers of the observations and is particularly important where site uncertainties drive the need for adaptive site management approaches. As such, a monitoring plan should also include monitoring of processes to inform CSM uncertainties and help identify why trigger criteria have not been achieved. For example, supporting information such as sediment bed stability analyses (e.g., through repeated bathymetric surveys) and upland or lateral loading data can help ascertain drivers of anomalous results (e.g., whether high COC concentrations are related to un-remediated site sediments or off-site COC sources). Such information can be used to support decisions in the next stage. To provide a direct, contemporaneous link to the primary indicators, this diagnostic monitoring can occur during routine synoptic sampling of the primary indicators. Separate efforts may also be needed to address specific needs (e.g., high-resolution sampling in specific areas to determine processes responsible for patterns seen in fish, water, or sediment COC concentrations).

5. Evaluate and adapt. The trigger criteria for adapting the remedy should be evaluated at the decision timepoints stated in the adaptive site management plan by comparing data from the monitoring program to the stated expectations. At the decision timepoint, the anticipated progress toward or attainment of the final remediation goals is assessed. If the anticipated progress is not achieved, a range of outcomes are possible based on the process described in the site's adaptive site management plan. For example, outcomes could include performing additional sampling and analyses to evaluate the drivers of unanticipated results, conducting additional remediation to address unacceptable exposures, or continuing the monitoring program and delaying the decision until the next evaluation timepoint. These actions will be site-specific and should be clearly described in the adaptive site management plan along with determining factors for the selection. The iterative nature of the process also recognizes that the CSM and the adaptive site management plan (including remediation goals or timeframes) may be updated, if necessary, as warranted by new information or site data.

Decisions at this point may indicate success, additional remediation, or that revisions to expectations or monitoring programs are needed. In some cases, decision points may be explicitly intended to establish the next iteration of priority areas for remediation. Actions resulting from the data review at the decision timepoint may require additional Superfund decision documents (e.g., ESD, ROD amendment, interim ROD, final ROD, etc.) depending on the type and magnitude of changes and the proposed action, consistent with existing policies (EPA 1999, 2001).

IMPLEMENTING AN ADAPTIVE SITE MANAGEMENT PLAN

The NCP and EPA's Superfund guidance already have processes that correspond with the framework for implementing adaptive site management (see Figure 1). For example, the NCP preamble describes that the program has a bias for action, and that actions should be taken despite uncertainty.[11] RAOs and remediation goals are required by the NCP[12], and when contaminants are left in place, the action's objectives, remediation goals, and remedy should be evaluated every five years and revised if they are no longer valid to ensure continued protectiveness of human health and the environment (EPA 2001). There are many options to implement early actions in Superfund that can be used to make significant progress toward final protective remediation goals, including removal actions, interim actions, or contingent actions.[13] Long-term monitoring to assess progress toward and attainment of remediation goals, as well as the drivers of those results, is strongly emphasized in EPA guidance related to contaminated sediment management (EPA 2002a, 2005, 2017a). There are several options for modifying remedial decisions, depending on the degree of change compared to existing decisions (EPA 1999). At PRP-lead sites, the intent to use adaptive site management as a long-term site strategy should be recognized in the enforcement agreement and statement of work.

Overall, it is anticipated that existing procedures and regulations can be used in conjunction with an adaptive site management framework at large, complex contaminated sediment sites to achieve a final, protective remedy. Regions should consider whether these adaptive site management approaches are appropriate for use at their sites to address immediate risks, prevent source migration, and to inform, select, and achieve a final remedy.

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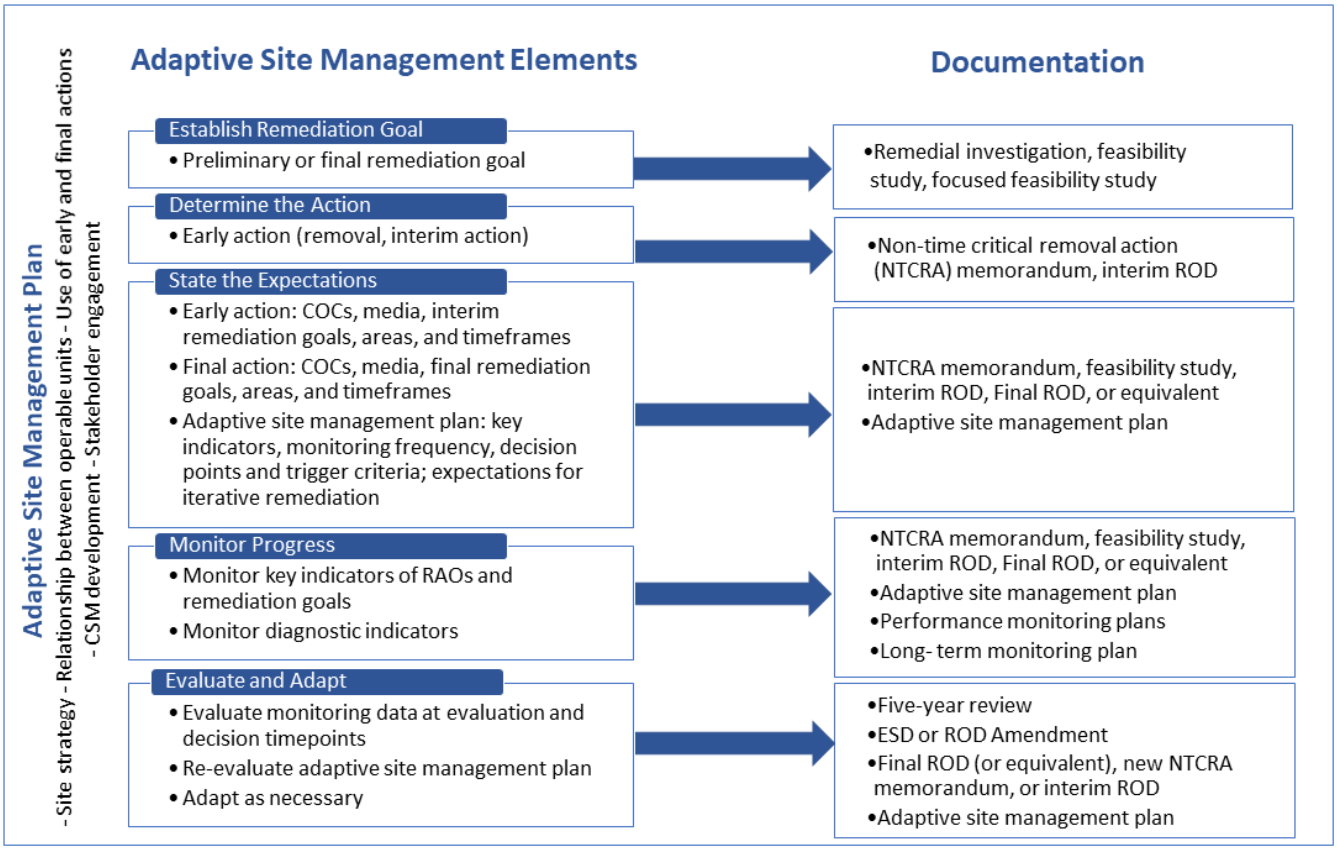
[11] *"In deciding whether to initiate early actions, EPA must balance the desire to definitively characterize site risks and analyze alternative remedial approaches for addressing those threats in great detail with the desire to implement protective measures quickly. Consistent with today's management principles, EPA intends to perform this balancing with a bias for initiating response actions necessary or appropriate to eliminate, reduce, or control hazards posed by a site as early as possible."* (55 Fed. Reg. at page 8704, March 8, 1990).

[12] 40 CFR 300.430(e)(2)(i) of the NCP states that site managers, "*Establish remedial action objectives specifying contaminants and media of concern, potential exposure pathways, and remediation goals… Remediation goals shall establish acceptable exposure levels that are protective of human health and the environment and shall be developed…*"

[13] EPA 1997: *"A "phased approach" to site investigation and cleanup generally will accelerate risk reduction and provide additional technical site information on which to base long-term risk management decisions. Phased cleanup approaches should be employed wherever practicable (40 CFR 300.430(a)(1)(ii)(A)). For more information about the use of early actions to expedite site cleanup, see SACM Guidance and the Ground-Water Presumptive Strategy."*

Figure 1. Framework for Adaptive Site Management Plan



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