MEASURING EFFECTIVENESS OF REMEDIAL ACTIONS AGAINST REMEDIAL ACTION OBJECTIVES AT CONTAMINATED SEDIMENT SITES

Sediment Management Work Group

EXECUTIVE SUMMARY

A critical element of a site-specific sediment management strategy is that it be results-focused. That is, the degree of success achieved by implementation of the selected remedial approach should be measurable. Measurement forces the definition of targets or RAOs. As suggested in a number of the papers, but particularly in "Effective Decision-Making Models for Evaluating Sediment Management Options," the initial step in defining an effective management strategy is developing a plausible site conceptual model addressing, for example, the following questions:

- What are the potential COCs?
- What are the specific exposure pathways that give rise to unacceptable risk?
- Are there any ongoing sources releasing COCs to sediments?

Once the model has been developed and validated, it is important to consider it during the development of RAOs which, once achieved, will result in reduction of risk to acceptable levels.

Measuring the success of remediation efforts for contaminated sediments can be accomplished through the following routes, which are discussed in further detail in the sections below:

- Strict comparison of postremedial conditions with conditions existing prior to the contamination event
- Comparison of postremedial conditions with preremedial conditions (i.e., definition of incremental improvement, potentially quantified by degree of long-term risk reduction achieved by remediation, but without a specific risk reduction target)
- Comparison of postremedial conditions with a target concentration in sediments or biota based on a site-specific risk assessment
- Comparison of postremedial conditions with what may often be a relatively conservative regulatory standard, derived with little site-specific analysis
- Achievement of remediation goals defined in terms of removal of a prescribed quantity of contamination from the system or destruction of that contamination without necessarily having an understanding of the role that such removal has in reducing risk
- Accomplishment of specified remedial actions without confirmatory analysis to define any risk reduction achieved

Comparison to Uncontaminated Conditions

It may be extremely difficult to define conditions extant prior to the contamination event. Frequently, contamination may be attributable to a series of overlapping, historical events. To compound the difficulty, the degree of impact to the natural system is often evaluated on the basis of environmental condition factors (e.g., benthic diversity, species abundance, overall condition of the biota).

Degree of Incremental Improvement

While the degree of improvement in specific indicators of environmental quality and in actual sediment and biota COC concentrations may be quantified, incremental improvement alone may be

insufficient to define a threshold that returns the impacted area to productive use or addresses the risk posed by the presence of the contamination.

RAOs Based on Site-Specific Risk Assessment

The risk assessment approach may provide an objective basis for definition of RAOs, assuming the following:

- The conceptual model is robust enough to define the linkage between sediment contamination and that in biota.
- Food chain relationships can be adequately defined.
- Dose-response relationships for the COCs are defined sufficiently to establish cleanup thresholds.

Even if some uncertainty exists, a site-specific risk assessment aids in prioritizing the areas of a site to be included in remedial action. For example, if sediment contamination is relatively widespread yet the conceptual model indicates that uptake is occurring in select areas of the site, an RAO can be developed to prioritize efforts on such areas.

The role of risk assessment and a sound scientific foundation is to

- Avoid remedial actions that may actually exacerbate the problem.
- Avoid actions that offer relatively little benefit when compared with the associated costs.
- Enable definition of the most appropriate action or, more commonly, a range of viable response actions, in the fewest possible number of iterations.

RAOs Based on Regulatory Standards

Basing RAOs on a regulatory standard that does not recognize site-specific conditions often leads to overly conservative remediation targets. It may be appropriate to utilize such regulatory standards as conservative screening level criteria, especially where the standards are based on protection of receptors from unacceptable risk. If remedial action is not triggered by these standards, then the site may be judged a candidate for no further action. If these screening standards are exceeded, then a site-specific risk assessment is generally undertaken to determine appropriate RAOs. Only in very few instances should regulatory standards be used to define RAOs without a supporting site-specific risk assessment.

RAO Based on Performance Standards Not Derived from Risk Assessment

Removing contaminated sediments may be an appropriate RAO if all or a significant quantity of the sediment contamination has a high degree of vulnerability to physical disturbance (e.g., severe wave action, storm events, disturbance via boat props, ice scour). In reality, the prediction of the consequences of severe events to bodies of contaminated sediments is often a complex problem with little ability to generalize results even across similar environmental settings.

In general, mass removal of contaminated sediment cannot be justified as an RAO without further characterization of the system and an understanding of the risks posed, not only by permitting the status quo to be maintained, but also of the implementation risks associated with the removal itself, the potential that removal will be insufficient to meet RAOs or may even exacerbate surface sediment contamination levels, and the net effect of events that may give rise to widespread distribution of the contaminated sediments.

RAO Based on Implementation of Specific Practice Not Based on Risk Assessment

Similar to the performance standard-based approach without reliance on risk, determining that a specific remedial technique (e.g., dredging, capping) should be employed without an understanding of the system or risks posed generally does not lead to a technically satisfactory resolution of the problem. In the current regulatory environment, the risk of the liability being reopened generally reduces the likelihood that this approach will lead to final closure of the liability.

Summary and Suggested Approach

RAOs should be developed based on an effective conceptual model and a site-specific risk assessment. The RAOs should provide a realistic opportunity for the responsible party to reach closure on future liability. Postremediation monitoring likely will be required to demonstrate compliance with the targets and document that risks are either at or trending toward acceptable levels.

A general approach to measuring the success of remedial action based on a specific target RAO in sediment or biota should include documentation of baseline (i.e., preremediation) conditions; monitoring and evaluation of potential external releases to the system and development of norms as a basis for comparison so that any unusual conditions can be readily identified during remedial implementation; and an ongoing evaluation of the success of the remedial action in achieving RAOs so that any appropriate modifications to the approach can be implemented.

INTRODUCTION AND BACKGROUND

A critical element of a site-specific sediment management strategy is that it should be results-focused. That is, the degree of success achieved by implementation of the selected remedial approach should be measurable. In the event that the desired results are not achieved, the following possibilities are suggested:

- The mode of measurement may be called into question and may need to be refined or modified entirely.
- Assuming the measurement is validated, alternative remedies may be suggested or the time frame over which results were anticipated via the selected remedy may have to be extended to provide a fair trial.

Regardless of the outcome of the measurement, there is little argument that measurement must be attempted. Measurement forces the definition of targets or remedial action objectives (RAOs), which provide the focus needed to effectively translate understanding the problem into a recommended resolution. Without RAOs, there is little other than cost or implementability to differentiate among remedial alternatives. Without the ability to measure compliance with RAOs, there is little possibility of actually reaching closure on the liability, an issue which is of significance to all stakeholders, whether they be members of the regulatory or regulated communities or of the public in general.

As suggested in "Effective Decision-Making Models for Evaluating Sediment Management Options" (see Appendix B), the initial step in defining an effective management strategy is to develop a plausible site conceptual model that addresses, for example, the following questions:

- What are the human and environmental receptors of concern?
- Are the food chain relationships of the water column or benthic type?
- What are the potential chemicals of concern (COCs)?
- What are the specific exposure pathways that give rise to unacceptable risk?
- Are there any ongoing sources releasing contaminants to sediments?
- What is the role of the sediments, themselves, as a source of contaminants of concern to the system?

Once the model has been developed and validated, it is important to consider it in RAO development, which, once achieved, will result in reduction of risk to acceptable levels.

Measuring the success of remediation efforts for contaminated sediments can be accomplished through the following routes, which are discussed in more detail in the sections below:

- Strict comparison of postremedial conditions with conditions existing prior to the contamination event
- Comparison of postremedial conditions with preremedial conditions (i.e., definition of incremental improvement, potentially quantified by degree of long-term risk reduction achieved by remediation, but without a specific risk reduction target)
- Comparison of postremedial conditions with a target concentration in sediments or biota based on a site-specific risk assessment
- Comparison of postremedial conditions with what may often be a relatively conservative regulatory standard, derived with little site-specific analysis
- Achievement of remediation goals defined in terms of removing a prescribed quantity of contamination from the system or destruction of that contamination without necessarily having an understanding of the role that such removal has in reducing risk

- Accomplishment of specified remedial actions without confirmatory analysis to define the risk reduction achieved

Comparison to Uncontaminated Conditions

It may be extremely difficult to define conditions existing prior to the contamination event. By definition, the area to be remediated has experienced degradation sometimes from a series of historical events over many years. To compound the difficulty, the degree of impact to the natural system is often evaluated on the basis of environmental condition factors (benthic diversity, species abundance, overall condition of the biota). Many of these condition factors are as much or more influenced by environmental quality (e.g., riffle, pool ratios, dissolved oxygen levels, nutrient loading, water temperature, inter- and intraspecific competition for critical nesting/foraging habitat) than by the occurrence of chemical constituents that are not naturally present in the system. Further, it is often difficult to define suitable background areas that have not experienced some level of disturbance, if not actual impact from contamination, and which are otherwise sufficiently similar in overall environmental condition so as to be truly comparable to the areas to be remediated.

Degree of Incremental Improvement

While the degree of improvement in specific indicators of environmental quality and in actual sediment and biota concentrations of COCs may be quantified, incremental improvement alone may be insufficient to define a threshold that returns the impacted area to productive use or addresses the risk posed by the presence of the contamination.

The degree of incremental improvement may have some application as an indication of the limit of technical practicability. Similar to the presumptive remedy approach used in groundwater contamination scenarios, as sediment contaminant concentrations or biological indicators approach some asymptotic level over time, a case may be made that the point of technical practicability has been reached and that further remedial action may produce limited additional benefit.

The degree of incremental improvement, unless specifically tied to risk reduction, may serve as an indicator, but cannot be viewed as a true RAO against which to measure the overall effectiveness of the remedial response.

RAOs Based on Site-Specific Risk Assessment

The risk assessment approach may provide an objective basis for defining RAOs, assuming the following:

- The conceptual model is robust enough to define the linkage between sediment contamination and that in biota.
- Food chain relationships can be adequately defined.
- Other exposure pathways (e.g., dermal contact, incidental ingestion) are sufficiently understood.
- Dose-response relationships for the COCs are defined sufficiently to establish cleanup thresholds.

The difficulty inherent in this approach is the sensitivity of the conclusion based on the uncertainty associated with one or more of these assumptions. This difficulty is less problematic for human receptors, where consumption surveys can aid in characterizing the uptake of affected biota and where institutional controls can be relied on to moderate or eliminate certain exposure pathways. Dose-response relationships still are not well understood for a number of key bioaccumulative

constituents, and there may be a need for site-specific reference dose development to ensure that conservative default assumptions do not drive overly stringent RAOs. Relative to ecological risk, the difficulty in establishing effective endpoints (e.g., reproductive success, stress indicators, avoidance, mortality) to measure true impact, and the level at which this impact is felt (i.e., individual or population levels) complicates the analysis. These issues are discussed in greater detail in "Risk-Based Management Principles for Evaluating Sediment Management Options" in Appendix B.

Nevertheless, where adequate information is available to characterize the system and objective risk endpoints can be agreed on, the risk assessment approach offers significant benefit in that it enables definition of site-specific, objective RAOs. Even if some uncertainty exists, a site-specific risk assessment aids in prioritizing areas of a site to be included in remedial action. For example, if sediment contamination is relatively widespread yet the conceptual model indicates that uptake is occurring in select areas of the site, an RAO can be developed to prioritize efforts on such areas. Subsequent monitoring can be used to examine the hypotheses used as a basis for the risk assessment. It is important to recognize that full and complete knowledge of the extent of contamination and the mechanisms of contaminant uptake by biota is seldom achieved prior to remedial action selection. To some degree, more so at some sites than at others, iteration should be understood as an effective problem-solving technique. The role of risk assessment and a sound scientific foundation is to

- Avoid remedial actions that may actually exacerbate the problem.
- Avoid actions that offer relatively little benefit compared with the associated costs.
- Enable definition of the most appropriate action or, more commonly, a range of viable response actions, in the fewest possible number of iterations.

RAOs Based on Regulatory Standards

Basing RAOs on a regulatory standard that does not recognize site-specific conditions often leads to overly conservative remediation targets. Often, however, such standards are incorporated into cleanup level selection at Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) or Superfund sites via the applicable or relevant and appropriate requirements (ARARs). Alternatively, cleanup targets may be defined from guidance or other documents viewed as to be considered (TBC) in evaluating remedial alternatives.

Application of chemical-specific compliance-based standards (e.g., a current proposal to use sediment quality criteria based on an equilibrium partitioning approach as a basis for establishing appropriate limits on effluent to surface waters) to existing sediment contamination ignores the fact that the pollution event that these standards are designed to prevent has already occurred. It may be appropriate to use such regulatory standards as conservative screening level criteria, especially where the standards are based on protection of receptors from unacceptable risk. If remedial action is not triggered by these standards, then the site may be judged a candidate for no further action. If these screening standards are exceeded, then a site-specific risk assessment is generally undertaken to determine appropriate RAOs. Only in very few instances should regulatory standards be used to define RAOs without a supporting site-specific risk assessment.

RAO Based on Performance Standards not Derived from Risk Assessment

At some sites, the RAO is based on a subjective assessment of actions needed to resolve the contamination. These assessments are rarely based on an understanding of the conceptual model of contaminant movement and uptake and are not founded on the principle of risk reduction or achievement of acceptable risk targets. More often than not, the performance standards assume

that some degree of contaminant removal or destruction is necessary, without an understanding of the benefit that will accrue from the action, if any.

Removing contaminated sediments may be an appropriate RAO if all or a significant quantity of the sediment contamination has a high degree of vulnerability to physical disturbance (e.g., severe wave action, storm events, disturbance via boat props, ice scour). If the potential for wide-scale redisturbance exists, the impact of redistribution of the contamination and ancillary effects associated with the precipitating event must also be considered prior to making a decision to remove the contaminated sediments. It is possible, for example, that severe climatic events (e.g., hurricanes, flooding) may not only dilute the COC concentrations actually available to receptors, but also import significant quantities of uncontaminated sediments into the system, resulting in burial of the contaminated sediments and effective interruption of exposure pathways. Such actions would serve to reduce overall risk, although the mass of COCs in the system would remain essentially unchanged.

In a perfect world, probabilities could be assigned to the occurrence of severe events and the impact of such events on contaminated sediments could be understood fairly precisely. In reality, the prediction of the consequences of severe events to bodies of contaminated sediments is often a complex problem with little ability to generalize results even across similar environmental settings. The level of effort expended to develop a credible hydrodynamic model needs to be weighed against the potential consequences of a range of adverse outcomes. Two examples (Lavaca and Matagorda Bays, Texas; and Upper Hudson River, New York) are discussed in "Effective Decision-Making Models for Evaluating Sediment Management Options" in Appendix B.

In general, mass removal of contaminated sediment cannot be justified as an RAO without further characterization of the system and an understanding of the risks posed, not only by permitting the status quo to be maintained, but also of the implementation risks associated with the removal itself, the potential that removal may be insufficient to meet RAOs or may even exacerbate surface sediment contaminant levels, and the net effect of events that may give rise to widespread distribution of the contaminated sediments.

RAO Based on Implementation of Specific Practice Not Based on Risk Assessment

Similar to the performance standard-based approach without reliance on risk assessment, determining that a specific remedial technique (e.g., dredging, capping) should be employed without an understanding of the system or risks posed generally does not lead to a technically satisfactory resolution of the problem. Obviously, there have been instances where responsible parties have agreed to undertake specific actions with the understanding that such actions would lead to regulatory closure. Such actions generally do not require confirmatory sampling as the action itself and not the residual contamination in sediments constitutes sufficient justification for closure on future responsibility. In the current regulatory environment, the risk of the liability being reopened generally reduces the likelihood that this approach will lead to final closure of the liability.

SUMMARY AND SUGGESTED APPROACH

The methodology used to define RAOs should consider the following:

- RAOs should be developed based on an effective conceptual model and risk assessment. The RAOs should provide a realistic opportunity for the responsible party to reach closure on future liability. Postremediation monitoring will likely be required to demonstrate compliance with the targets and to document that risks are either at or trending toward acceptable levels.
- The incremental improvement strategy will generally not lead to closure as it is based neither on achievement of a specific risk target nor on meeting a performance or practice-based target. In certain situations, it may be appropriate to use the lack of demonstrated incremental improvement as a basis for removing certain technologies from consideration in remedy selection. Ideally, the data for such determinations can be obtained through a review of performance available in the literature. In some unique situations, however, it may be necessary to pilot specific technologies at a site and obtain empirical evidence of the degree of incremental improvement attained as input to remedy selection.

A site-specific decision will need to be made if the opportunity to achieve closure is provided by a regulatory agency based on remediation to some standard of performance or other regulatory standard. Similarly, the responsible party will need to review opportunities to achieve closure through implementation of a specific remedial technique, such as dredging a specific area within a water body.

The steps below are offered as a general approach to measuring the success of remedial action based on a specific target RAO in sediment or biota, whether the target is based on risk assessment or is established in an arbitrary manner. Obviously, RAOs based on risk assessment are strongly recommended.

1. Document preremedial conditions in the media for which RAOs are established (e.g., sediment and biota).
2. Understand whether there are any extraneous inputs to the system (e.g., continuing sources) that might preclude achievement of the RAOs.
3. Gain an understanding of the time frame over which the target RAOs are likely to be achieved.
4. Develop an effective monitoring program during the sediment remediation effort that documents any unexpected conditions that might adversely affect achievement of RAOs (e.g., encountering free-phase constituents, significant contamination at depth that might be brought to the surface or otherwise mobilized by the remedial action).
5. Develop an effective postremediation monitoring program in consideration of No. 2.
6. Revisit the selected remedy during the design stage and monitor during and subsequent to implementation to ensure that it is appropriate for the site conditions encountered, especially if they are found to deviate from those upon which the remedy selection was based.
7. Continue to monitor during and following remedy implementation to ensure, to the extent practicable, that the remedy is effectively implemented and that the RAOs will be achieved; make whatever modifications are necessary to maintain alignment with the RAOs.

Other papers in this document providing detail as to the role of risk assessment in development of an effective remediation strategy and the range of monitoring techniques that may be employed to characterize sediments and biota are referenced below.

- "Effective Decision-Making Models for Evaluating Sediment Management Options" (see Appendix B)
- "Risk-Based Management Principles for Evaluating Sediment Management Options" (see Appendix B)

- "Decision Tree for Sediment Management" (see Appendix A)
- "Using Natural Processes to Define Exposure from Sediments" (see Appendix C)
- "Advantages and Disadvantages of Remediation Technologies for Contaminated Sediments" (see Appendix D)
- "State of Current Contaminated Sediment Management Practices" (see Appendix D)
- "Sediment Stability at Contaminated Sediment Sites" (see Appendix C)