DECISION TREE FOR SEDIMENT MANAGEMENT

G. Peterson, J. Wolfe, J. DePinto, Limno-Tech, Inc.
and the Sediment Management Work Group

EXECUTIVE SUMMARY

Developing an effective strategy for managing contaminated sediment sites requires the integration of a variety of factors, including, but not necessarily limited to, the following:

- An understanding of physical, chemical, and biotic components of the environmental setting
- The occurrence and dynamics of the chemicals of concern (COCs)
- The viability of potential exposure pathways
- The occurrence of potential human and ecological receptors of concern
- An understanding of the range of management technologies available
- The remedial action goals and objectives

Figure A-1 outlines a decision tree for integrating these factors in a manner that results in a coherent sediment management strategy. The decision tree provides for early actions, where appropriate, to address more imminent adverse effects or to undertake actions that can be readily conceived and implemented without significant site evaluation. It also provides for early recognition and/or elimination of important ongoing external sources of contamination that could negatively impact the effectiveness and successful outcome of any future actions.

Below is a brief description of the main processes in the decision tree. It is important to note, however, that the decision tree should be used in an iterative manner to arrive at a long-term sediment management strategy. In some cases, it is more effective to undertake remedial actions within specific portions of a site and evaluate their impact on the system rather than to defer action until the completion of a full-scale feasibility study. Such iterations are usually accompanied by a period of monitoring, which serves to calibrate the temporal conceptual model and enhance its reliability as a predictive tool.

Regardless of how the decision tree is used, discussions with regulatory representatives should occur throughout the process. Obtaining regulatory perspectives at the beginning of the sediment management process allows a more focused strategy to be developed and leads to a more efficient and effective achievement of remedial action objectives and project goals.

- *Initial Evaluation and Early Decision*
  This step is designed to address "new" sites and determine whether immediate action is appropriate, no action is appropriate, or no early decision can be made. Available information regarding physical characteristics, sources, pathways, receptors, basic data on chemicals of concern, and potential risks are gathered and evaluated. Immediate response actions to mitigate exposure are identified and evaluated, if necessary. Site information is compared with qualitative or generic quantitative criteria to make appropriate risk-based decisions.
- *Source Control*
  Source control actions may be desirable if on-going external sources significantly contribute contaminants of concern to sediments or the water column. It is prudent to identify and prioritize opportunities to control external sources in the context of overall site evaluation and sediment management decision making because contaminated areas are likely to receive continuing impacts unless upstream sources are controlled. External sources are defined as loadings that are external to site sediments, including point sources or nonpoint source loads from outside of the specific study area.
- *Site Evaluation and Risk Assessment*

The site evaluation is an iterative process with the following three primary objectives:

— Determine the existing risks to human health and the environment by developing a baseline conceptual model.
— Determine the future risks to human health and the environment by developing a temporal conceptual model, if necessary.
— Prioritize the areas and issues of concern based on the developed models.

When developing the baseline conceptual model and temporal conceptual model, data are collected, and evaluations are conducted, to define site characteristics, sources, extent and distribution of chemicals of concern, fate and transport processes, exposure pathways and uptake, and baseline human health and ecological risk. If necessary, data and models are developed to evaluate future conditions at the site, with consideration of natural processes. It is at this point in the process that the potential adequacy of natural recovery as a remedial choice is preliminarily addressed. The result is a site conceptual model that describes the nature, magnitude, and extent of the contamination and characterizes the risks of and uses impaired by the contamination. As such, the site conceptual model serves as the basis for determining whether remedial actions or improvements are necessary or beneficial and, if so, where these actions should be focused.

- *Feasibility Study/Remedy Selection*
  A feasibility study is conducted if the site evaluation reveals that baseline risks and future risks warrant remediation and that feasible alternatives are available. The feasibility study process involves developing remedial objectives; identifying, screening, and developing technologies and alternatives; and conducting detailed analyses of alternatives and comparative analyses of alternatives. The approach of a sediment feasibility study follows the typical feasibility study process and relies on the nine National Contingency Program (NCP) criteria as the primary basis for decision making. However, because of the complex nature of sediment sites, emphasis is placed on comparatively evaluating alternatives in the areas of absolute and relative reductions in "real" risk over time, implementation risks, permanence, and cost. The natural recovery alternative serves as the baseline by which the effectiveness, implementability, and cost of "active" alternatives are compared and evaluated.

  To select the most appropriate remedy, a tiered approach is applied that moves from qualitative evaluations and comparisons to detailed quantitative and predictive approaches. As necessary, quantitative models developed in the site evaluation are applied to simulate the effects of different remedial alternatives and to serve as a quantitative means of comparison. Similar to the site evaluation, the feasibility study should be focused on the areas of highest priority (areas of highest exposure or source areas), as determined in the site evaluation process. The primary criteria for comparison are as follows:

  — Overall protection of human health and the environment
  — Compliance with applicable or relevant and appropriate requirements (ARARs)
  — Long-term effectiveness and permanence
  — Toxicity, mobility, or volume reduction through treatment
  — Short-term effectiveness
  — Implementability
  — Cost
  — State agency acceptance
  — Community acceptance

  Upon completion of the feasibility study and given that sufficient information is generated, a remedy is selected and proposed based on balancing the evaluation criteria.

- *Implement and Monitor*
  After agreement is reached among stakeholders, implementation of the remedial action can

proceed. Following implementation, it may be necessary to conduct an effective monitoring program to

- Ensure that remedial action objectives (RAOs) are met.
- Reestablish RAOs based on the practical limitations of selected technologies.
- Revisit the remedy selection in the event that the selected technologies prove to be ineffective.

INTRODUCTION

Developing an effective strategy for managing contaminated sediment sites requires the integration of a variety of factors, including, but not necessarily limited to, the following:

- An understanding of physical, chemical, and biotic components of the environmental setting
- The occurrence and dynamics of or dynamic processes affecting the chemicals of concern (COCs)
- The viability of potential exposure pathways
- The occurrence of potential human and ecological receptors of concern
- An understanding of the range of management technologies available

Figure A-1 outlines a decision tree for integrating these factors in a manner that results in a coherent sediment management strategy. The decision tree provides for early actions, where appropriate, to address more imminent adverse effects or to undertake actions that can be readily conceived and implemented without significant site evaluation. It also provides for early recognition and/or elimination of important ongoing external sources of contamination.

The decision tree ultimately rests on the synthesis of a prospective conceptual model of the contaminated sediment site. This model allows an examination of historic data trends, a prediction of future changes, and an understanding of existing and potential risks to human health and relevant environmental receptors. Site-specific remedial action objectives (RAOs) are developed based on the temporal conceptual model. Because potential remedial technologies are evaluated in accordance with the RAOs to examine effectiveness and screen for implementability and order-of-magnitude costs, RAOs are the building blocks of a site-specific management strategy.

It is important to note that the decision tree should be used in an iterative manner to arrive at a long-term sediment management strategy. In many cases, it is more effective to undertake remedial actions within specific portions of a site and evaluate their impact on the system rather than to defer action until the completion of a full-scale feasibility study. Such iterations are usually accompanied by a period of monitoring, which serves to calibrate the temporal conceptual model and enhance its reliability as a predictive tool.

Regardless of how the decision tree is used, discussions with regulators should occur throughout the process. Once it is established that existing risks will require remedial action, other stakeholders should be included in the decision process. Obtaining regulatory perspectives at the beginning of the sediment management process allows a more focused strategy to be developed and leads to a more efficient and effective achievement of remedial action objectives and project goals.

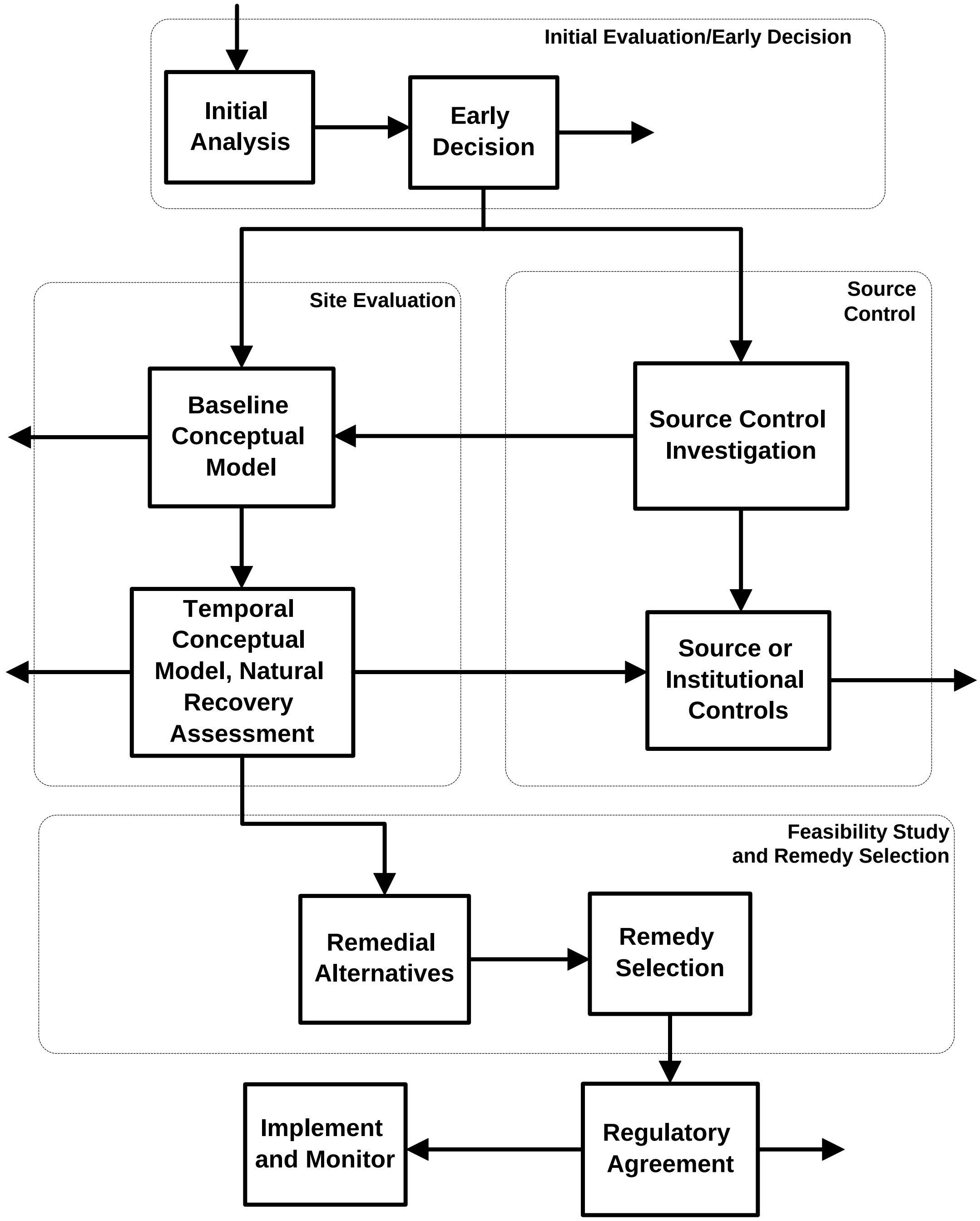

Figure A-1. Sediment management decision framework.

INITIAL EVALUATION AND EARLY DECISION

This step is designed to answer the following question: Are there simple actions that can quickly reduce the apparent problem? This step addresses "new" sites where new information or a change in current conditions or regulatory status triggers a site concern (see Figure A-2). Examples of such trigger events are as follows:

- Field observations (e.g., surface water sheen, stressed vegetation)
- Potential release of COCs from a responsible party site at levels of potential concern
- Public concern
- Recently collected or reviewed data
- New regulatory programs
- Redevelopment

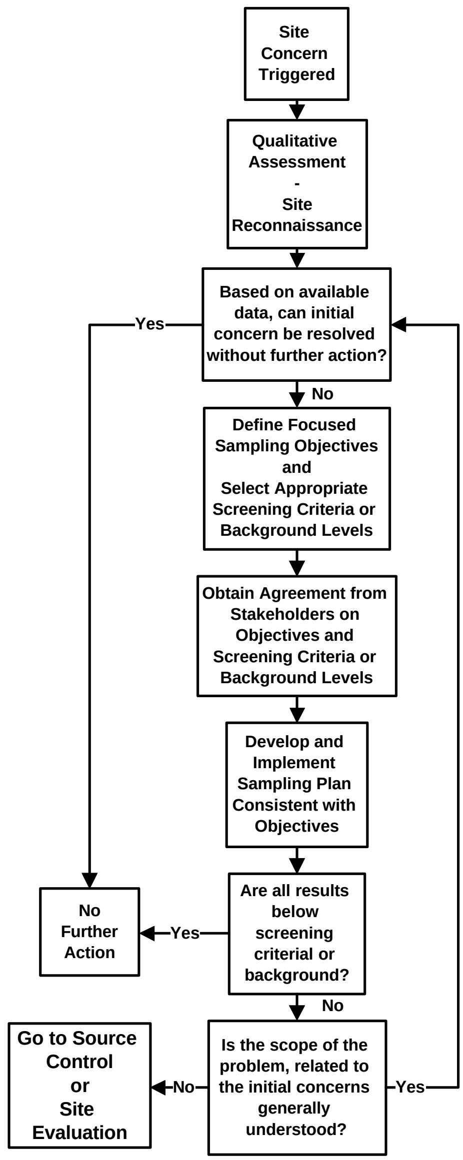

Figure A-2. Initial evaluation and early decision.

Once a trigger occurs, the initial evaluation and early decision steps provide an initial understanding of the surface water and sediment system processes and allow the determination of whether an early action can be implemented to address concerns. The logic behind the initial evaluation and early decision component of the decision tree is an iterative process in which decisions are made based on the following three options:

- No further action is appropriate.
- Immediate remedial action is appropriate.
- More data are needed.

Site Reconnaissance

The first task in the initial analysis and early decision step is to perform a site reconnaissance, including a paper review of site-specific and publicly available information and a site visit. A cursory, qualitative assessment of this kind frames the nature of the potential problem and, in some cases, is sufficient to allow an easily implemented early action that addresses the problem. An early action generally involves remediation of an obvious problem, such as the repair of a faulty tidal gate. A relatively high level of confidence must exist, and personnel must demonstrate that the system as a whole will improve as a result of the early action.

During a paper review, available information regarding physical characteristics, sources, pathways, receptors, basic data on COCs, and potential risks are gathered and evaluated. The depth of the review is dictated by the specific site conditions and the information level needed to make an informed qualitative assessment. Some sources of information concerning stream flow, velocity, bathymetry and water/sediment quality, and potential sources and COCs are as follows:

- United States Geological Survey (USGS) regional data bases, such as the National Water Information System (NWIS), which can be found at http://www.epa.gov/owowwtr1/watershed/proceed/briggs.html
- Federal Emergency Management Act (FEMA)
- The United States Environmental Protection Agency's (USEPA's) Office of Water storage and retrieval system (STORET)
- Contaminated sediment data bases
- U.S. Army Corps of Engineers studies and data bases
- Natural Resource Conservation Service (NRCS) studies
- Regional studies by federal, state, or municipal agencies
- Historical and current aerial photographs
- Local business directories
- USEPA Resource Conservation and Recovery Act (RCRA) data base (RCRIS) and Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) information system data base (CERCLIS)
- National Pollutant Discharge Elimination System (NPDES) permits
- Polk Directory
- USEPA watershed data base, which can be found at http://www.epa.gov/surf/
- USEPA sediment report to Congress, which can be found at http://www.epa.gov/ost/cs/congress.html
- Land use maps (e.g., the USEPA's Office of Water environmental analysis system BASINS found at http://www.epa.gov/year2000/basins.html, USGS maps)
- National Oceanic and Atmospheric Administration (NOAA) bathymetric charts
- University of Iowa maps

A site visit often is helpful to inspect the site conditions that may have triggered the initial concern and to qualitatively assess hydrologic, hydrodynamic, and sediment transport conditions. Review of a quadrangle/topographic map of the area before the site visit allows identification of potential areas of interest (e.g., areas of erosion or deposition). Site visits can encompass the following types of activities, as appropriate:

- Observe the site conditions after a significant rain event.
- Consider the current use of the waterway and upland areas (e.g., major shipping lanes, heavy industrial use) and current activities such as land development in the area.
- Note the physical characteristics of the water body (e.g., depth and width, erosional and depositional areas, floodplain dimensions, elevation).
- Obtain tide levels, if applicable, and observe the site through a tidal cycle period.
- Identify the locations and note the size of tributaries and distributaries.
- Identify those items that control surface water level and flow velocity or cause abrupt changes in surface water elevations (e.g., dams, weirs).
- Estimate the energy of the system by noting sediment size range over different reaches (e.g., cobbles, sand, mud).
- Note potential area of concern characteristics and their relation to potential upstream sources.
- Identify potential sources that can be eliminated from consideration and others that should be considered.
- Identify potential ongoing sources (see "Source Control").
- Initially identify potential sampling locations in case sampling is deemed necessary. Focus on areas of finer-grained material, including potential areas of concern, upstream and downstream areas, and background locations.

If the initial concern can be resolved without further action based on available data, obtaining an assessment of "no further action" is considered. If the initial concern can be addressed without additional data collection, immediate response actions to mitigate exposure are identified and evaluated. In addition, site information is compared with qualitative or generic quantitative criteria to make appropriate risk-based decisions.

Sampling Plan and Screening Guidelines

Depending on the event or condition that triggered the concern, a focused sampling plan may help to define the problem and allow resolution. The initial sampling event is not intended to be comprehensive, but is designed to confirm previous data or address other specific objectives. Sampling plan objectives are developed to ensure that sampling addresses concerns raised by the triggering event. Typical preliminary sampling plan objectives include the following:

- Compare sediment quality in the area of potential discharge from potential sources (i.e., worse case conditions) with background area.
- Compare sediment quality in a specific depositional area with background area.
- Compare overall sediment quality in a specific area with background area.
- Verify or confirm results of previous sampling and/or conclusions.

Based on these comparisons, appropriate screening guidelines or background levels are identified. A number of procedures based on chemical and/or biological analyses may serve as the basis for developing no observable effects level (NOEL) sediment quality screening values, including the following:

- Background concentration approach
- Correlative approaches
  - — Apparent effects threshold (AET)
  - — Screening level concentration (SLC)
  - — Effects range
  - — Threshold effects level (TEL) and probable effects level (PEL)
- Equilibrium partitioning (EP) approach

More detail is provided in Box A-1 and in the following reference: U.S. Army Corps of Engineers (Waterways Experiment Station) document "Use of Sediment Quality Guidelines in Dredged Material Management," *Dredging Research Technical Note*, EEDP-04-29 (May 1998).

Because of their inherent uncertainty and limited scientific basis, an important caveat in dealing with sediment screening guidelines is that their use often is prone to misinterpretation and misapplication by those who are not familiar with these limitations. In particular, it is important to understand that all screening guidelines are surrogate predictors of sediment toxicity, and are therefore less reliable than direct measurements of the actual toxicity. Results of screening studies should not take precedence over actual measurements, and they should not be interpreted as action levels. As explained below, screening guidelines are normally conservative, and if measured levels in sediment are less than the screening guidelines, the COC in question is very likely not present at toxic levels and, therefore, may be used to estimate NOELs. If measured levels are greater than screening guidelines, the COC in question may or may not be present at toxic levels. In this case, better, more direct measurements of effects and exposure leading to risk-based assessments may be warranted.

Box A-1
Sediment Quality Screening Guideline Approaches

Background Concentration Approach
The concentration of a substance in sediment is compared to the background concentration of that substance in a sediment believed to be unaffected by that substance but representative of regional sediment quality (e.g., no substantive anthropogenic inputs or biological effects). However, it is frequently difficult to determine appropriate background concentrations, and the approach has no basis in either COC bioavailability or biological effects.

Correlative Approaches
Correlative methods assume, but are not based on, causal relationships between concentrations of individual COCs and observed effects on biota. These approaches are all biased by the simultaneous exposure of organisms to multiple stressors. Because physical stressors, effects of local substrate matrix on animal survival, and COC synergism are not considered and organisms could be responding to unmeasured COCs, correlative approaches always result in overly conservative sediment quality screening values.

- Apparent Effects Threshold (AET)
  The AET approach determines the concentration of a particular COC above which a significant effect is expected. The AET screening values are determined empirically from an examination of synoptic observations of sediment chemistry and biological effects on a defined species and endpoint at a specified level of statistical significance. The AET value is the chemical concentration above which some lower level of biological response (e.g., 20% mortality) occurs in all samples in the data set.
- Screening Level Concentration (SLC) Approach
  The SLC approach compares the distribution of benthic invertebrates with synoptic measurements of the concentrations of COCs in the same sediment samples. To obtain a good estimate of the threshold concentration of each COC for each species, the SLC approach assumes that the data set includes locations containing the full range of concentrations of each COC to which each species may be exposed. SLC values estimate the greatest concentration of a particular COC tolerated by 95% of the benthic invertebrate species included in the data set.
- Effects Range
  The effects range approach ranks the COC concentrations from the samples with observed biological effects in

ascending order. The 10th percentile value of the COC concentration ranking is referred to as the effects range-low value (ER-L) and is considered to represent a lower threshold value above which adverse effects on sensitive life stages or species are likely to occur. Similarly, the 50th percentile value is referred to as the effects range-median (ER-M) and is considered to represent a threshold above which adverse effects on most species will frequently occur.

- Threshold Effects Level (TEL) and Probable Effects Level (PEL)
  This approach is almost identical to the effects range approach except that it ranks COC concentrations from both "no effect data" and "effect data" in an ascending manner. The TEL is calculated as the COC concentration value corresponding to the geometric mean of the 15th percentile of the "effect data" and the 50th percentile of the "no effect data". The PEL is calculated as the COC concentration corresponding to the geometric mean of the 50h percentile of the "effect data" and the 85th percentile of the "no effect data."

Equilibrium Partitioning (EP) Approach
The intent of the EP approach is to correct for the bioavailability of COCs in sediments and organisms so that better predictions of biological effects can be made from chemical analyses of solid-phase sediments or tissue residues of organisms. As such, the EP approach relies on fundamental chemical theory and assumes COCs will reach equilibrium between the interstitial (pore) water, the solid phase sediment, and associated organisms. This approach was developed primarily for nonionic organic compounds based on the normalization of solid-phase COC concentrations in sediments using the sediment concentration of total organic carbon. The utility of the approach is also investigated for other COCs, such as metals (with normalizations based on both acid volatile sulfide and organic carbon concentrations in sediments).

Once sampling plan objectives and screening guidelines or background levels are identified, agreement is obtained from appropriate stakeholders and regulatory representatives. Then, a sampling analysis plan (SAP) consistent with the objectives is developed and implemented. The purpose of the SAP is to ensure that sampling data collection activities are comparable to and compatible with previous data collection activities performed at the site and to document the details of all field activities and laboratory analyses prior to the work being conducted. The SAP also provides a mechanism to obtain the regulatory agency's approval of the proposed activities and to communicate to the regulatory agency the (1) sampling rationale and objectives of the sampling, (2) details of the sample locations and collection procedures, and (3) details associated with analytical procedures and data reporting data.

Many state regulatory agencies as well as the USEPA have specific guidance on preparing SAPs, including requirements on sediment sampling activities. Typically, SAPs consist of a field sampling plan and a quality assurance project plan (QAPP). Details of these components are provided in Box A-2.

When developing the SAP, a tiered or phased sampling approach is recommended to focus the data collection effort. Within the initial evaluation and early decision portion of the decision tree, the initial sampling is equivalent to a first tier sampling event. The first tier typically has fewer samples collected and is primarily analyzed for the COCs, total organic carbon (TOC), and sediment grain-size distribution. The rationale and objectives of the SAP dictate sampling locations and the analytical parameters; however, background or upstream sediment sampling locations may be needed to evaluate whether the COC levels downstream represent natural background levels or are the result of other anthropogenic sources.

Regulatory agencies prefer that samples be collected in depositional areas where COCs are likely to be present (i.e., adsorbed onto the finer-grained sediments). Subsequent sampling tiers, if needed, are developed based on the findings of the first tier. Subsequent tier sampling can include additional sampling for COC delineation, benthic organism evaluation, or toxicity. In consideration of efficiencies associated with mobilization of field crews and processing analytical samples and data, the scope of initial sampling may be expanded to collect additional data to resolve or clarify other issues.

Box A-2
SAP Components

Field Sampling Plan
The field sampling plan provides guidance for all field work by defining in detail the sampling and data gathering methods to be used. The generic outline of the field sampling plan should include consideration of the following potential data needs:

- Site background
- Sampling objectives
- Sample location and frequency
- Sampling equipment and procedures
- Sampling handling and analyses

The QAPP describes the laboratory's policy, organization, functional activities, and quality assurance and quality control protocols necessary to achieve the data quality objectives dictated by the intended use of the data. The QAPP should include consideration of the following potential data needs:

- Project description
- Project organization and responsibilities
- Quality assurance objectives for measurement
- Sampling procedures
- Sample custody information
- Calibration procedures
- Analytical procedures
- Data reduction, validation, and reporting information
- Internal quality control information
- Performance and systems audits
- Preventative maintenance information
- Data assessment procedures
- Corrective action information
- Quality assurance reports

After sampling and analysis are complete, results are compared to screening criteria or background levels. If results are at or below these guidelines, obtaining a "no further action" is considered. If results exceed screening criteria or background levels and the scope of the contamination is not generally understood, then an early decision is not appropriate, and a site evaluation must be conducted. If, after reviewing the results, more data are required to identify the scope of the problem, then an early decision is inappropriate and a site evaluation or an evaluation of source control alternatives is necessary.

SOURCE CONTROL

This step is designed to answer the following question: Are ongoing, external sources significant? If ongoing external sources (as identified in the site visit) significantly contribute COCs to sediments or the water column, source control actions may be desirable before conducting a detailed site evaluation. The source control framework is detailed in Figure A-3. External sources are defined as loadings that are external to site sediments, including both point sources or nonpoint loadings from outside of the specific study area. External sources can be located beyond upstream or shoreline boundaries or along tributaries of a river system, or they can involve atmospheric or groundwater transport.

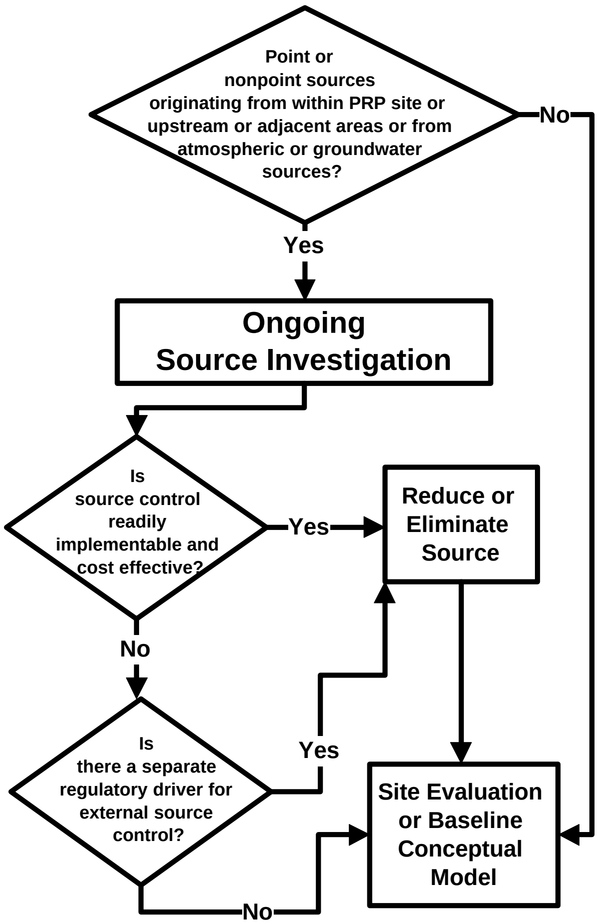

Figure A-3. Source control logic diagram.

Because contaminated areas are likely to receive continuing impacts unless ongoing sources are controlled, it is prudent to identify and control external sources in the context of overall site evaluation and sediment management decision making. *EPA's Contaminated Sediment Management Strategy* explicitly recognizes pollution prevention and source controls as methods of limiting further contamination and as potentially appropriate means of allowing natural processes to diminish risks to within acceptable levels.

Information developed during the source control evaluation or after implementing source control measures is fully integrated into the site evaluation. In particular, the reduction or elimination of sources is accounted for when evaluating future risks for remedial alternatives.

Initial Determination

For each COC, an initial determination is made whether a condition is present that could indicate potential impact from an external source. Examples of such sources are as follows:

- Site-related point sources such as stormwater outfalls and permitted process discharges
- Site-related nonpoint sources such as sheet flow and groundwater discharge to surface water
- Upstream or adjacent point sources, such as permitted and unauthorized outfalls, publicly owned treatment works (POTWs) with both sanitary and stormwater discharges, and improperly closed or abandoned gas wells or underground mines
- Upstream or adjacent nonpoint sources such as operations involving logging, construction, mining, agricultural activities (e.g., cultivation, feed lots) and scrap yard and urban and commercial development areas

Applicable data (e.g., historical aerial photographs, business directories, and investigations), topographic maps, and state Clean Water Act (CWA) and NPDES files are reviewed; site reconnaissance is performed to identify key conditions (e.g., outfalls, deposition areas, erosion areas, tributaries); and data base searches are conducted. (There are companies that specialize in performing regulatory data base searches.) During this process, the following considerations are addressed to a level of detail commensurate with the nature of the problem and the cost and time allocated to the project.

- Determine if the COC is uniquely identifiable with a particular neighbor and if the neighbor is the sole discharger of the COC.
- Consider past or abandoned industrial operations as sources of ongoing contamination of water bodies
- Recognize that significant amounts of materials are legally discharged to water bodies under publicly recorded permits, the details of which are becoming increasingly available via the Internet (e.g., http://www.epa.gov/surf/). These information sources can be easily surveyed for permitted discharges of COCs.
- Recognize that water bodies are often the recipients of a variety of upland discharges during storm periods. Municipal sewage treatment systems can be overwhelmed, resulting in combined sewer overflows, where untreated sewage enters the water body in an uncontrolled manner. Municipalities may discharge significant amounts of oil and grease from individual, illegal dumping of crankcase oil, solvents, and pesticides into storm sewer systems. Major storms are generally periods of significant sedimentary deposits which may contain varieties of pollutants from nonpoint sources.
- Consider the contribution of agricultural nonpoint sources. If the COCs include nitrates and phosphates, consider farm animal waste products, particularly from large farms.
- Search data bases for groundwater and other subsurface sources of ongoing sediment contamination.
- Recognize that the area of concern may be a natural deposition area, gathering contamination from a variety of external sources distributed over many miles. If a flowing water body bends in the vicinity of the area of concern, recognize that bending flow results in unequal erosion/deposition from bank to bank.

If no condition is present that indicates a potential impact from an external source, then the evaluation of source control is complete, and a site evaluation commences. If a condition is present, then an investigation of potential external sources for the particular COC is performed.

There may be multiple evaluations for multiple COCs if site conditions considered at an earlier stage indicated potential impacts for each of those contaminants.

Bypassing this step and proceeding with remedial action without addressing ongoing sources can have serious consequences. Natural processes play an important role in the ultimate success of any remedial action and must not be overshadowed by ongoing sources.

Ongoing Source Investigation

If significant sources are identified, the next step is to decide whether source control offers a potential net benefit given the available information. The decision ultimately depends on estimated cost, implementability, and anticipated effectiveness and relies heavily on the environmental setting and the suspected transport pathway(s) of COCs. With regard to effectiveness, an evaluation of external sources must address recontamination potential in sediment areas for which remediation is being considered.

As an initial step, an approximate mass balance is developed to prioritize among various potential external sources. This approach enables the investigator to

- Understand the relative contribution of sources such as groundwater discharge, process releases (both airborne and aqueous), erosion from areas of contaminated soils or sediments.
- Place site-related sources in context relative to regional background sources.
- Identify areas where the material balance does not close properly, which may suggest unknown sources requiring further investigation.

Once a relative prioritization of the significance of external sources has been developed, informed decisions are made as to the value of further characterization and/or the need for interim measures. Throughout this process, priorities for source control are iteratively revised as new information becomes available during the investigation.

Guided by the information gathered during the initial determination, the potential significance of ongoing sources is investigated by comparing and evaluating upstream, downstream, tributary, and point source data. Some considerations involved in this process are as follows:

- Recognize important forensic tools and techniques. Organics and inorganics often carry a unique fingerprint capable of source identification.
- Consider groundwater and other subsurface sources of ongoing sediment contamination, including light nonaqueous phase liquids (LNAPLs) and oils from ongoing or abandoned industrial operations. Groundwater often enters a water body beneath the sediment surface, particularly if the surrounding land is several feet or more higher than the water body surface.
- Recognize that solids suspended in water can be a strong sorbent for a variety of contamination and can travel for many miles before settling out and becoming sediments. (Contamination can be concentrated many-fold by this process, and the process can continue for many years.)

If, after reviewing existing data, additional data are needed to determine if source control is necessary, sampling is performed. Please note that regulatory approval and other necessary permissions may be necessary prior to some off-site sampling. Additional items to consider during sampling include the following:

- If a water body is a flowing river or stream, consider a screening survey of shallow sediments upstream of the area of concern to determine if primary COCs are present in significant concentrations. Investigate further where significant concentrations are identified, and report necessary COCs under all applicable regulations [e.g., Toxic Substances Control Act (TSCA)].

- If a water body is tidal, and significant tidal currents are present periodically, consider screening in all directions from which tidal currents may originate.
- Devote extra attention and sampling in areas adjacent to known historic operations and discharge locations, particularly if the COCs are potentially associated with the historic site.
- Obtain screening samples upstream, midstream, and downstream of any operations in question to identify step increases in local background levels and in surface water concentrations.

Implementability

On the basis of the information obtained in the investigation, a decision is made whether source control is expected to be practical, implementable, and cost-effective. Source control is cost effective if it prevents recontamination at reasonable cost. If source control is expected to meet all of the criteria listed below, then actions to reduce or eliminate external source(s) are undertaken (see "Source Reduction or Elimination"), and a site evaluation commences. The criteria to determine practicability and implementability are as follows:

- Quickly achievable
- Readily implementable
- Reasonable cost while effective in preventing recontamination of sediments
- Consistent with potential final remedy
- Self-initiated and under own control
- Little or no agency approval required

If source control is expected to be impractical, not implementable, or not cost-effective, then regulatory requirements are considered. If external source control is required by regulation (e.g., TSCA, RCRA, CWA total maximum daily loads (TMDL) assessment, state sediment quality standards, state landfill regulations), then source control is undertaken to the extent possible, after which site evaluation commences. If there is no regulatory requirement for external source control, then the source control component of decision making is complete, and the site evaluation commences. If ongoing sources are large enough to overwhelm a remedial action yet impractical to eliminate, regulatory relief should be sought prior to further investigation and/or remedial action.

Source Reduction or Elimination

As stated previously, if source control is expected to meet all of the practicability and implementability criteria listed above, then the following actions to reduce or eliminate external source(s) are undertaken:

- *Interim Remedial Actions*

  The initial analysis may suggest immediate priorities for source reduction/elimination (i.e., interim actions) prior to the performance of the site evaluation and development of site conceptual models. Interim remedial actions most often are those which are readily implementable at low to moderate cost, such as modifying a process waste stream, cleaning discharge lines known to harbor historic contamination, providing detention storage and settling for stormwater discharges, or even undertaking groundwater interception for localized groundwater plumes. In the event that interim remedial actions are suggested, the following questions are helpful in focusing the effort:

  — Will the interim remedial action effectively reduce or eliminate a significant external source?

  — Is the interim remedial action readily implemented at a reasonable cost?

  — Is the interim remedial action likely to be consistent with longer-term remedial actions?

  — What, if any, will be the likely effect of taking the action on the ability to effectively characterize other sources and sinks of contamination at the site?

- *Longer-Term Remedial Actions*
  As the site evaluation proceeds, external sources become better defined. The approximate mass balance, assigning loads to various internal and external sources, will be refined. At some point, reduction or elimination of external sources is considered in the context of longer-term RAOs. External sources are either point or nonpoint and are either within or beyond the direct control of the PRP. Those external sources that are under PRP control may be process-related or associated with historic contaminant sources. Managing active process sources should be closely coordinated with ongoing operations. It may be possible that relatively minor modifications in existing process controls can achieve significant benefits.

  As a cardinal rule, RAOs for longer-term remedial action should be based on a temporal site conceptual model, which includes an understanding of the relative contribution of individual external sources to the contaminated sediment site and the significance of these sources in maintaining unacceptable contaminant levels in sediments, the water column, and receptors.

SITE EVALUATION AND RISK ASSESSMENT

This step is designed to address the following three questions:

- What are the real risks—is there truly a problem?
- When will risks become acceptable via natural recovery?
- Will rare events (e.g., storms) significantly disrupt conditions?

The site evaluation is an iterative process with the following three primary objectives:

- Determine the potential for existing risks to human health and the environment by developing a baseline conceptual model.
- Determine the potential for future risks to human health and the environment by developing a temporal conceptual model (i.e., assess how the situation is changing).
- Prioritize the areas and issues of concern based on the developed models.

The activities involved in the site evaluation are detailed in Figure A-4.

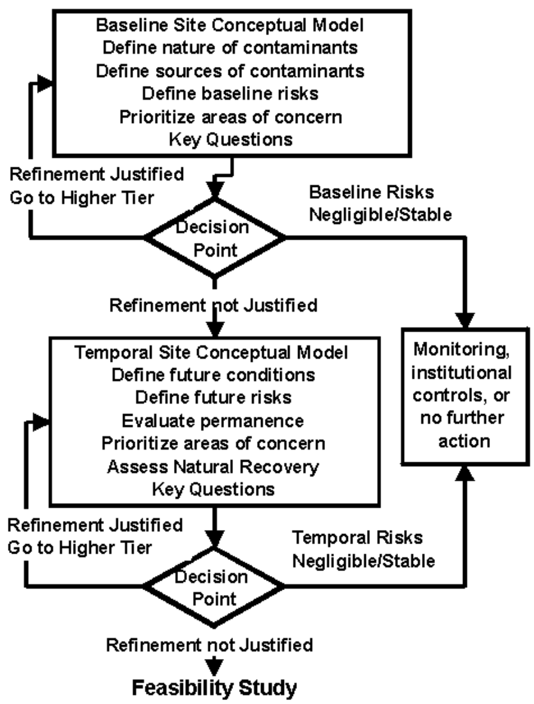

Figure A-4. Site evaluation.

When developing the baseline conceptual model, data are collected and evaluations are conducted to define site characteristics, sources, COC extent and distribution, fate and transport processes, exposure pathways and uptake, and baseline human health and ecological risk. Using this information, areas of concern are prioritized. If necessary, a temporal conceptual model is developed to consider natural processes and future conditions at the site. It is at this point in the process that the potential adequacy of natural recovery as a remedial choice is preliminarily addressed. Both the baseline and temporal conceptual models are described in more detail in the subsections below.

Throughout this evaluation, a tiered approach is applied, beginning with general, qualitative, and conservative approaches and moving to detailed, quantitative assessments. The baseline conceptual model begins as a qualitative general model. As needed to better characterize exposures and risks and as justified by the costs and benefits of doing so, the conceptual model moves to a qualitative site-specific model, quantitative empirical models, quantitative predictive models for specific important issues; and ends as a quantitative, comprehensive, predictive model. There is an important decision point within each subprocess. Appendix B provides detailed papers about risk assessment and model development.

Baseline Conceptual Model

The purpose of a baseline conceptual model is to define the present nature of contamination, potential sources, and baseline risks and to prioritize areas of concern. As such, the baseline conceptual model serves as the basis for determining whether remedial actions or improvements may be necessary or beneficial and, if so, where these actions should be focused.

Contamination, potential sources, and baseline risk are defined while integrating the site environmental setting throughout the process. Potential sources and sinks are characterized by using background and regional information, assessing boundary conditions, and identifying potential external/internal sources and sinks. The COC extent and distribution is obtained by characterizing sediment and pore water. Other media (e.g., surface water, groundwater, flood plain, air) can also aid in this characterization. Data needs and evaluations for conceptual model development are provided in Figure A-5. Using these data, a baseline risk characterization is performed that identifies exposure pathways and receptors.

Box A-3 lists the key questions to be considered when developing a baseline conceptual model. Answers to the questions should be developed in a tiered, iterative manner, working from qualitative to quantitative and general to specific as necessary and justified by the project scope, with the goal of reducing uncertainty of the most important answers. With each iteration, the process should allow the prioritization and identification of critical issues and factors while filtering out the unimportant issues. As new information is developed, the model should be reevaluated to determine whether it remains valid. Because each iteration incurs a time and resource commitment, characterization may reach a point where initiation of remedial actions based on uncertain and, thus, conservative risk estimates are justified over further characterization efforts.

If, after the baseline model is developed, baseline risks are negligible and very likely stable, future efforts focus on monitoring, institutional controls, or no further action. If it is uncertain that the risks are negligible, the model and data are refined, if cost effective. If the baseline risks are not negligible and perhaps not stable, a temporal conceptual model is developed.

Data Needs

Sources and Sinks	*Extent and Distribution*	*Risk Characterization*	
Media: Upstream and tributary sediment, water column, biota; regional sediment, point source discharges; sediment deposits Literature estimates Historical data Snapshot data Intensive survey data Multiple intensive surveys	Media: Sediment Historical data Grab surface Grab sediment cores Statistical 3-D sampling Media: Water, Soils, Air Literature estimates Snapshot data Intensive surveys	Exposure Pathways Extent and distribution data Generic partition coefficients Bioavailability indicators Site-specific food web data	Receptor Risks Screening criteria Literature values for uptake and effects for similar and same species Site-specific values for uptake and effects

Natural Processes			
Data Sources	Parameters to be Characterized		
Historical data Literature data, estimates Site-specific estimates, data (phased), process research	Geometry Flow Hydraulics Hydrology Dispersion Sorption Bioavailability	Sediment physical properties Sediment burial rates Sediment mixing rates Sediment resuspension rates Solids settling rates Hydraulic export	Watershed solids loads Internal solids production rates Chemical properties Chemical transformation rates Air/water exchange rates Historical trends

Evaluations

Statistical data analyses Empirical process analyses Empirical trend analyses Process component analyses Simple and complex deterministic mass balance models Probabilistic mass balance models	Simple ratio Regression models Food web model	Comparisons with criteria Screening assessment Risk assessment Probabilistic assessment

Note: Arrows indicate a tiered process.

Figure A-5. Data needs and evaluations for conceptual model development.

Box A-3
Key Questions for Baseline Conceptual Model Development

Receptor, Exposure, and Risk Analysis
This analysis attempts to answer the following question: What are the priority areas, receptors, exposure pathways, COCs, and potential human health and ecological risks?

- Human Health
  What exposure pathways and routes are potentially complete?
  What are the COCs and their critical forms?
  What is the probability, duration, and frequency of potential exposure?
  For each potentially complete exposure route, what is the exposure concentration?
  What are the potential risks of the COCs at exposure concentrations?
  What are the properties or natural processes that may affect exposure or toxicological effects?
  What is the acceptable level of risk?
  What are the critical assumptions, uncertainties, and information needs?
- Ecological Health
  What relevant receptors are potentially exposed to sediment or media affected by sediment?
  What exposure pathways and routes are potentially complete?
  What are the COCs and their critical forms?
  What is the probability, duration, and frequency of potential exposure?
  For each potentially complete exposure route, what is the exposure concentration?
  What are the potential risks of the COCs at exposure concentrations?
  What are the properties or natural processes that may affect exposure or toxicological effects?
  What populations or receptors are to be protected, and what is the acceptable level of risk?
  What are the critical assumptions, uncertainties, and information needs?

Extent and Distribution
This evaluation focuses on the COCs, critical receptors, exposure pathways, and priority areas from above to answer the following question: Where are the critical sediment areas, and what is the distribution of the COCs in the sediment areas and in other media?

- Sediment
  What is the areal and vertical distribution of COCs in sediment?
  Where and how much of the COCs in the system sediments are bioavailable?
  What are the chemical and physical properties of the COCs that may affect extent, distribution, and exposure?
  What are the natural processes in the system that may affect extent, distribution, and exposure?
  What are the critical assumptions, uncertainties, and information needs?
- Other Media
  What other media are affected by sediment and are important to exposure or transport of the COCs?
  What other media are affecting sediments (e.g., siltation, erosion)?

Sources and Sinks
This evaluation focuses on the COCs, critical receptors, exposure pathways, and priority areas from above to answer the following question: Are existing sources or background/regional conditions significant to exposure?

- What are the sources of the sediment bed (e.g., upstream, tributary, historical solids)?
- What are the sources and sinks of the COCs in sediment?
- Where and when were COCs introduced?
- Are COCs naturally occurring and, if so, at what levels?
- What is the distribution of COCs upstream and regionally?
- What are the critical assumptions, uncertainties, and information needs?

Temporal Conceptual Model

The purpose of the temporal conceptual model is to define how conditions are changing with time, define future conditions and future risks, evaluate the permanence of the COCs, and prioritize the areas of concern. The temporal conceptual model builds upon the baseline conceptual model. Box A-4 lists the key questions to be considered when developing a temporal conceptual model.

Answers to the questions define how the baseline conceptual model changes over time due to natural processes. The model may also be used to evaluate short- and longer term risks associated with various remedial options. Similar to the baseline conceptual model, the temporal conceptual model is developed in a tiered manner, working from simple to complex. The focus remains on the COCs, critical areas, and critical receptors, with the goal of reducing the uncertainty of the most important answers.

Box A-4
Key Questions for Temporal Conceptual Model Development

Receptor, Exposure, and Risk Analysis
This analysis attempts to answer the following question: What are the priority areas, receptors, exposure pathways, COCs, and human health and ecological risks, and how will they change over time due to natural processes and habitat changes?

- Human Health
  How will potentially complete exposure pathways change over time?
  Will the COCs and critical forms of the COCs change over time?
  What is the future probability, duration, and frequency of exposure?
  For each COC and potential exposure route, what are the future exposure concentrations of COCs over time?
  What are the toxicological effects and resulting risks of the COCs at future exposure concentrations?
- Ecological Health
  Will relevant receptors potentially exposed to sediment or media affected by sediment change over time (e.g., via natural processes, habitat changes)?
  Will the COCs and critical forms of the COCs change over time?
  How will potentially complete exposure pathways change over time?
  What is the future probability, duration, and frequency of exposure?
  For each COC and potential exposure route, what are the future exposure concentrations over time?
  What are the toxicological effects and resulting risks of the COCs to populations and communities or relevant receptors at future exposure concentrations?

Extent and Distribution
This evaluation focuses on the COCs, critical receptors, exposure pathways, and priority areas from above to answer the following question: How will the concentration distribution of the COC in critical sediment areas and other media change over time due to natural processes?

- Sediment
  How will the sediment bed change over time due to deposition and scour?
  How will the areal and vertical distribution of COCs in sediment change over time due to natural processes?
  Where and how much of the COCs in the system sediments are bioavailable and how will this change over time due to natural processes?
- Other Media
  What other media are affected by sediment and are important to future exposure or transport of the COCs?

Sources and Sinks
This evaluation focuses on the COCs, critical receptors, exposure pathways, and priority areas from above to answer the following question: Are ongoing sources or background/regional conditions significant to future exposure?

- What are the sources of "clean" solids and how will they change the sediment bed over time?
- How will the sources of COCs in sediment change over time?

Future potential sources and sinks are characterized by using background and regional information, assessing boundary conditions, and identifying potential external/internal sources and sinks. The attenuation or reduction of sources is considered during this process. The future COC extent and distribution is obtained by studying the natural processes of sediment and pore water, as well as other media (e.g., surface water, groundwater, flood plain, air). These processes include, but are not limited to, the flowing properties of the water body that determine burial or scour, biological and geochemical reactions that affect contaminant migration, and sequestration. Based on these natural processes, a preliminary natural recovery assessment is performed (see Figure A-6).

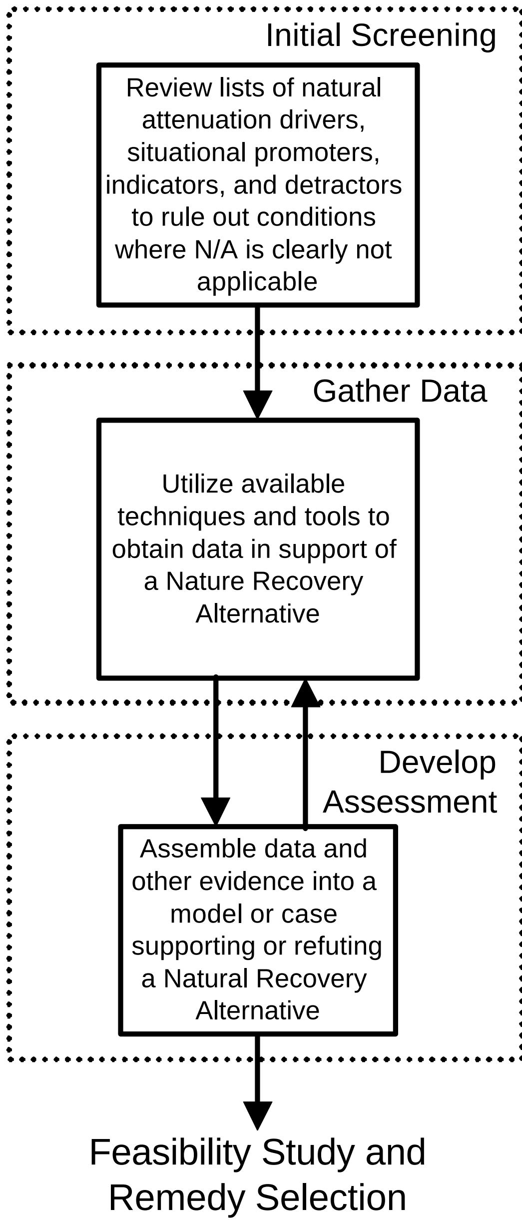

Figure A-6. Assessment of natural recovery.

Natural Recovery Assessment

The natural recovery assessment process is designed to answer the following two questions: (1) Is natural recovery already complete and adequate? and (2) Will natural recovery become adequate within an appropriate time period? To answer these questions, the basic drivers or detractors and indicators of natural recovery are assessed. Figure A-6 provides a decision tree outlining the assessment, with various responses and corresponding next steps highlighted. In-depth information about natural processes and sediment stability is provided in Appendix C. The basic drivers and detractors as well as the basic indicators determining the adequacy of natural recovery are highlighted in Box A-5. Please note that there are combinations of indicators that cannot coexist. Concurrent observation of these indicators suggests an assessment error. For instance, highly bioavailable COCs cannot persist against years of flushing unless fed by an ongoing source.

Box A-5
Natural Recovery Drivers, Detractors, and Indicators

Basic Drivers of Natural Recovery
The physical processes are as follows:
- Mixing with cleaner sediments via suspension and redeposition
- Other dispersion
- In-place burial (covering) by deposition of progressively cleaner sediments
- Physical sequestration
- Diffusion

The chemical and geochemical processes are as follows:
- Sorption (often related to organic carbon content)
- Oxidation and reduction (redox)

The biological processes are as follows:
- Bioturbation, promoting dispersion, oxidation
- Degradation of near-surface COCs by aerobic microorganisms
- Degradation of buried COCs by anaerobic microorganisms
- Complexing of metals by sulfate-reducing bacteria [sufficient acid volatile sulfides (AVS)]

Basic Detractors of Natural Recovery
The basic detractors of natural recovery are as follows:
- Ongoing contamination sources, including high concentrations of mobile COCs, are present within the system.
- Highly energetic sediment transport environment is present and often overturns or moves sediments.
- There is a lack of clean sediment deposition.
- There is a lack of sufficient organic carbon or sulfide to bind COCs.
- Highly soluble contaminants are present.
- COCs are resistant to degradation.
- Deep benthic mixing organisms are present relative to sedimentation rate (bioturbation).
- Sources of colonizing organisms are restricted due to changes in factors such as upstream/downstream water quality, flow regimes, and migration capabilities.

Basic Indicators of Adequate Natural Recovery
The basic indicators of natural recovery are as follows:
- Known discharge sources are several years old and not ongoing.
- COC concentrations are low or nondetect in the upper 10 centimeters (i.e., living zone) of sediments.
- COCs are present only at greater depth in the sediment column.
- Species population gains since COC releases have terminated.
- Sustained decreases of COC concentrations have occurred in fish, shallow sediment, and water column.
- Half-times for COC concentrations are short compared to the project duration and effectiveness of other alternatives.
- Recent known discharge sources are halted or removed.
- Shallow sediments pass laboratory toxicity testing with appropriate organisms.
- Valid, calibrated math models accurately reflect past progress and performance and predict adequate protectiveness in the future based on natural deposition rates and COC mobility.
- Dating of finely sectioned sediment cores confirms steady, reliable burial by cleaner sediments.
- Diverse and healthy biota are present in the shallow sediments, comparable to background areas.
- COCs are present only in nonbioavailable (total) forms that are extractable only by extreme laboratory procedures, not reflective of natural biological processes.

For natural recovery to occur, at least one of the basic drivers listed in Box A-5 must be true or present. (Usually more than one basic driver is necessary for natural recovery to be adequate.) Other situational promoters of natural recovery include organic COCs that are either nontoxic to biota or very hydrophobic, with a low concentration in pore water; sufficient total organic carbon content in sediment; primarily depositional area of concern in terms of sediment transport; and sufficient time elapse since most recent COC release. One or more detractors present may not be sufficient to rule out natural recovery as an alternative. After the drivers are assessed, the basic indicators of natural recovery are examined for adequacy. Figure A-6 provides a logic tree for decision making based on this examination.

Every site situation is unique. The following techniques and tools can help in gathering necessary data during a natural recovery assessment:

- Chronological bathymetric survey data
- Sediment traps
- Groundwater seepage meters
- Measurements of surface water, fish tissue, and sediment COC levels with time
- Measurements of pore water COC levels with depth and time (i.e., peeper results)
- Half-time plots showing exponential decays
- Toxicity testing
- Finely sectioned sediment core analysis (e.g., chemical analysis, dating by ^{137}Cs and or ^{210}Pb, contrasting and comparing COC concentrations with layer dating)
- Analysis of products and substrates for biological degradation (e.g., large experimental microbiological literature)
- Well calibrated mathematical models (simple and complex)
- External sources (well understood and/or eliminated/controlled)
- Sedimentation (well understood)

These techniques and tools can be used to demonstrate natural recovery. Every site situation is unique, but below are possible items that may need to be demonstrated if natural recovery is selected. In addition, these items may help in establishing an appropriate site investigation and sampling plan.

- Assemble available historic data on COC levels to show exponential decays in shallow sediments, fish, plants, and/or surface water.
- Use substrate and daughter product analysis to demonstrate that microbiological degradation has taken (or is taking) place. Use analogous techniques to demonstrate chemical and geochemical destruction.
- Assemble available historic bathymetry data to show a steady deposition rate.
- Use sediment traps to quantify current deposition rates. Analyze the contents to demonstrate that new sediments are now clean.
- Use finely segmented sediment cores to show that historic contaminants have been buried beneath a significant thickness of new, cleaner sediments.
- Use dating techniques to verify a steady depositional rate and identify time periods in which contamination took place.
- Use pore water analysis to demonstrate that contaminants are tightly bound and not bioavailable.
- Use laboratory batch and column studies to show that contaminants are tightly bound to sediments and immobile.
- Halt an ongoing source of contamination, and demonstrate an exponential recovery in contaminant levels in shallow sediments, fish, plants, and/or surface water.
- Use benthic assays to demonstrate a healthy, diverse population. Use laboratory toxicity testing to demonstrate low toxicity in shallow sediments.

- Use seepage meters and/or benthic flux chambers to demonstrate no contaminant flux from the sediment surface to the water column.
- Use shaker tests and flume tests to demonstrate that sediments are resistant to resuspension.
- Use moderate to heavy storm events to demonstrate moderate resuspension depths. Build a data base of bathymetric and other data over extended time periods. (Note: Intuition tends to overpredict (overestimate) the effects of major storms in terms of resuspension depth. Real data can correct this tendency.)
- Build a moderate to complex mathematical model of the area of concern. Calibrate the model with available data (see items above) to accurately reflect historic data and show that the model predicts low environmental impact and continued natural recovery. (Note: The model can be used to explain present adequacy of natural recovery forces and increase confidence in what has been observed; the model might also predict growing or continuing protectiveness in the future.)
- Use analogous case studies both as a guide and as supporting evidence.

Data needs and evaluations for temporal model development are also provided in Figure A-5. Using these data, a temporal risk characterization is performed that identifies prospective changes in exposure pathways and relevant receptors and assesses habitat, use, and food web changes. If, after the temporal model is developed, future risks are negligible and stable, efforts then focus on monitoring, institutional controls, or no further action. If it is uncertain that future risks are negligible, the model and data are refined, if cost effective. If, after assessing risk to the level of detail and certainty commensurate with the scope of the issue and resources/time committed for study and the baseline and future risks are not both negligible, a feasibility study is conducted.

FEASIBILITY STUDY AND REMEDY SELECTION

This step is designed to address the following questions:

- Can active remediation significantly accelerate the achievement of acceptable risk?
- What impacts will active remediation have on risks?

A feasibility study is conducted if the site evaluation reveals that baseline risks and future risks may be significant and that feasible alternatives are available. (Detailed information about assessing risk is provided in "Risk-Based Management Principles for Evaluating Sediment Management Options" in Appendix B.) As discussed in detail in Appendix D, the feasibility study process involves developing remedial objectives; identifying, screening, and developing technologies and alternatives; and conducting detailed and comparative analyses of alternatives (see Figure A-7). The approach of a sediment feasibility study follows the typical feasibility study process and relies on the nine NCP criteria as the primary basis for decision making. The natural attenuation alternative serves as the baseline by which the effectiveness, implementability, and cost of "active" alternatives are compared and evaluated.

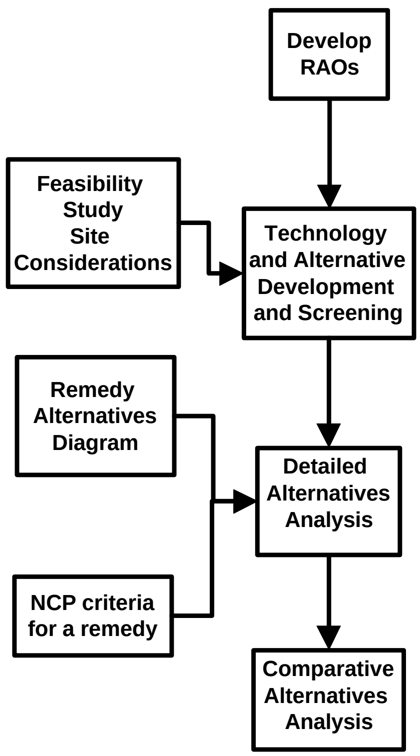

Figure A-7. Feasibility study and remedy selection.

To select the most appropriate remedy, a tiered approach is applied that moves from qualitative evaluations and comparisons to detailed quantitative and predictive approaches. As necessary, quantitative models developed for the site evaluation are used to simulate the effects of different remedial alternatives and serve as a quantitative means of comparison. As with the site evaluation, the feasibility study should be focused on the areas of highest priority (i.e., areas of highest exposure or source areas), as determined in the site evaluation process.

RAO Development

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. Measurement forces the definition of targets or remedial action objectives (RAOs).

RAOs should be developed based on an effective conceptual model and risk assessment and 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.

A general approach to measuring 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 the ability to provide an ongoing evaluation of the success of the remedial action versus RAOs so that any appropriate modifications in the approach can be implemented.

There are six approaches commonly applied to establish RAOs for contaminated sediment projects, and not all are equal in scientific basis and correctness:

- 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 a priori risk reduction target)
- *Comparison of postremedial conditions with a target concentration in sediments or biota based on 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 the risk reduction achieved

In all nontrivial situations, the risk-based approach (in italics above) is preferred. Even if some uncertainty exists, a site-specific risk assessment aids in prioritizing those areas of a site to be included in remedial action. For example, if low-level 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 1) avoid remedial actions that may actually exacerbate the problem; 2) avoid actions that offer little added benefit, but may engender significant cost [e.g., dredging where such action is so severely limited by technical practicability that it has little hope of reducing risk despite removal of contaminant mass from the system]; and 3) enable definition of the most appropriate action or, more commonly, a range of viable response actions, in the fewest possible number of iterations.

Technology and Alternative Development and Screening

Technologies and alternatives are developed and subjected to a rapid prescreening using the basic site information in Box A-6. The available alternatives outlined in “Advantages and Disadvantages of Remediation Technologies for Contaminated Sediments” in Appendix D have associated advantages based on site-specific conditions and characteristics. Situations favoring the selected technologies and comparable favorable benefits are listed in Table A-1. At the conclusion of the technology and alternative development and screening, a short list of alternatives is developed to undergo detailed analysis.

Table A-1
Favorable Situations and Benefits of Select Technologies

Remedial Technology	Situation Favoring Technology as Remedy	Situation Hindering Technology as Remedy	Potential Advantages	Potential Disadvantages
Natural Recovery	Low ecological risk present and living zone healthy Large area and/or volume Historic, buried contamination Low COC mobility and bioavailability Sources identified and halted Sediments stable Limitations in treating/disposing of dredge spoils	Absence of identifiable natural recovery mechanisms (e.g., bioattenuation, sequestration, sedimentation) Sediments unstable Immediate and significant harm to human health and the environment Active remedies achieve RAOs much more rapidly	Minimum secondary impact on habitat Risk of resuspension minimized No spoils produced Cost efficient	COCs remain in place
Hydraulic Modification	Clean, unobstructed pathway for rechanneling Sufficient water depth and other conditions to favor creation of dams and/or depositional areas. Limitations in treating/disposing of dredge spoils	Sediments scheduled for removal in near future for purposes unrelated to environmental risk Engineering factors prevent rechannelization, damming, and sedimentation basin creation	Contaminated sediment separated from new channel Bioavailability reduction COC water column and biota reductions Navigability potentially enhanced Smaller areal extent containing COC sediments COC migration control Sediment deposition promoted	COCs remain in place Alteration/modification of existing benthic community/habitat, fish Flooding/hydraulic effects Sediment accumulation Sediment resuspension High relative cost Limits fish movement
Particle Broadcasting	Low energy environment Low COC mobility Well defined treatment area Natural recovery nearly sufficient, but augmented sedimentation would benefit Limitations in treating/disposing of dredge spoils	Sediments scheduled for removal in near future for purposes unrelated to environmental risk High COC mobility/diffusion/advection Area subject to destructive disturbances (e.g., tides, waves, prop wash) Sediments unstable Marginal depth of water body for ongoing boat traffic	Retards diffusive flux of COCs Translocates bioturbation zone up and out of COCs Limited effect on benthic community Less resuspension than dredging or other capping methods No spoils produced Cost efficient	COCs remain in place Limited precedents for use Cap erosion Ensuring appropriate thickness and accurate cap placement Resuspension during installation
Engineered Capping	Low energy environment Low COC mobility Small, well defined treatment area Limitations in treating/disposing of dredge spoils	Sediments scheduled for removal in near future for purposes unrelated to environmental risk High COC mobility and diffusion Area subject to destructive disturbances (e.g., tides, waves, prop wash) Marginal depth of water body for ongoing boat traffic Recreational and commercial in-river and near-shore activities	Reduces chemical bioavailability, water column concentrations, and downstream migration Raises living zone above any contamination Less resuspension than dredging No spoils produced Promotes natural degradation	COCs remain in place Hydraulic effects Resuspension and/or mixing of COC sediments during placement Benthic community alteration Long-term erosion Cap surface recontamination

Remedial Technology	Situation Favoring Technology as Remedy	Situation Hindering Technology as Remedy	Potential Advantages	Potential Disadvantages
Dredging	Navigational or other nonrisk-based need to remove material Low energy environment Small site or small, clearly defined hot spot Highly mobile COCs* Material easily accessible Safe, efficient means of spoils disposal available	Very large area Potential risk from treatment or spoils disposal equals or exceeds that posed by leaving COCs in place One-time destruction of habitat exceeds long-term risk of alternative remedies Risk of suspended COCs in water column greater than current COC risks in sediment Risk to worker safety approaches or exceeds added risk of alternative remedies Presence of boulders/debris Need to achieve low COC cleanup levels	Significant COC removal, although not complete Faster regulatory approval in some instances USACE knowledge base and support available	Sediment resuspension/downstream migration Elevated COC levels in residual sediments Long- or short-term increases in COC mobility Alteration/destruction of benthic community Inability to achieve low cleanup levels Areas missed by dredge High relative cost
Dry Excavation	Small site Easy shoreline accessibility Shallow water and sediments Water easily and safely removed/diverted Bedrock accessible for use as "clean floor" Safe, efficient means of spoils disposal available	Very large area Potential risk from treatment or spoils disposal equals or exceeds that posed by leaving COCs in place No practical engineering approach to dewatering/inability to maintain dry conditions No reasonable shoreline access One-time destruction of habitat exceeds long-term risk of alternative remedies	Visual contact during removal Faster regulatory approval in some instances Near complete removal in some instances	Inability to achieve low cleanup levels Elevated COC levels in residual sediment Long- or short-term increase in COC mobility Suspension/downstream transport of sediment Alteration/destruction of benthic community High relative cost

* Mobility also increases risk of water column impacts from dredging.
Note: A complementary table of advantages and disadvantages is provided in Appendix D in "Advantages and Disadvantages of Remediation Technologies for Contaminated Sediments."

Box A-6
Feasibility Study Site Considerations

Contamination Boundaries

- Areal Extent—Defines the area to be addressed, the ownership of the area, and the type of terrain. The areal extent directly impacts total volume to be addressed, which is an important factor in selecting an alternative. For very small areas, removal can sometimes be accomplished from shore using common excavation equipment.
- Sediment Thickness—Along with areal extent, defines the volume of material to be addressed and impacts remedial option feasibility and selection.
- Total Volume—Serves as an important determining factor in remedial alternative selection. In general, small volumes favor removal options while large volumes justify the extra effort needed to demonstrate adequate protectiveness of less intrusive options.

Waterway Features

- Water Depths—Serves as an important determining factor in remedial selection in that water depths help determine if the contaminated area is accessible by boat and how large a boat is appropriate. Removal options require water deep enough to accommodate a dredge, small enough to be reachable from shore, or shallow enough to be dammed and dewatered for dry excavation. For very deep water, variable options may be limited.
- Bathymetry—See above comments for water depth. For significantly variable water depths, different remedial options are selected for different areas.
- Current Velocity—Determines appropriateness of some remedial options. In general, strong current make any water operation more difficult, hazardous, and expensive. Specifically, strong currents can eliminate natural recovery and capping options due to sediment stability impacts. Strong currents also make it difficult to maintain dewatering for dry excavation.
- Tidal Patterns—Affects remedy selection by impacting water depth (tidal swings) and sediment stability (currents). The effect of tidal swings on water depth can result in difficulty accessing equipment, and extreme tidal swings can cause large intertidal areas to be alternately dry and under water (especially in far northern areas), forcing intermittent operations.
- Wave Energy—Imposes the same limitations as tidal patterns, particularly with regard to sediment stability in the area of breaking waves. Please note, however, that wave energy dies out quickly with depth, greatly affecting only the area where waves are breaking.
- Erosion/Deposition Potential—Varies with position. For instance, if the impacted sediments are in a depositional area, natural recovery is enhanced.
- Severe Weather History—Imposes the same limitations as current velocity, and wave energy and ice flows can exaggerate these effects. Assessing the effects of severe storms often drives cleanup goals; therefore, expert advice is recommended to avoid an overassumption of effects on sediment stability. (Scouring depths from severe weather conditions are often surprisingly small.)

Waterway Uses

- Navigation—Affects removal option and applicability of natural recovery and related options. If navigation dredging is required in the impacted area, all nonremoval options become far less applicable. If navigation dredging is not required but the sediments are subject to wake or propeller wash, sediment stability can be impacted, which reduces the applicability of natural recovery and related options.
- Recreation—Increases risks related to human exposure. All applicable exposure pathways must be carefully considered based on recreational uses (e.g., boating, swimming, wading, clamming)
- Defense Facilities—Adds issues regarding unexploded ordnance and/or unusual toxics.
- Water Supply—Virtually assures that removal operations will cause at least a temporary increase in contaminant levels in the water body, regardless of the care exercised in removal planning and execution. Therefore, when the overlying water column feeds a water supply, careful remedy selection is of great importance.
- Wastewater Discharge—Potentially contributes to ongoing sources of contamination that will need to be eliminated.
- Utility Crossing Identification—Ensures safe operations and provides valuable forensic clues in the investigation phase.
- Fishing/Harvest Areas—Affects cost-benefit analysis. Impacts on recreational and commercial fishing and shellfish operations must be carefully factored into any cost-benefit analysis. Seasonal cycles, such as spawning,

and the direct and indirect impacts on these processes should be evaluated. Plans should note that mollusks are especially sensitive to particulate disturbances during spawning periods.

- Seasonal Use Restrictions—Applies to remedial operations that may suspend particulates unnaturally, as in the case of dredging. Northern water bodies often become frozen solid in winter, greatly restricting remedial operations. Equipment (e.g., water lines) becomes frozen sooner than the water bodies themselves, restricting the operating season for screening and washing operations. In addition, boat-based operations become much more hazardous in icy weather.

Geotechnical Characteristics

- Sediment Stratification—Impacts remedy selection. If the sediments to be addressed vary greatly from layer to layer, different approaches can be chosen for different layers. For example, during removal, hydraulic removal might be optimally combined with mechanical removal of boulders.
- Groundwater Flow—Impact remedy selection and complicates capping, both mechanically and chemically, if flow is to a water body. For a dry excavation, groundwater incursion is pumped constantly and, in some cases, treated. Groundwater flow must be ruled out as a source of ongoing contamination before a remedy can be selected
- Bottom Conditions—Affects remedy selection. For removal operations, hydraulic dredging is problematic; clamshell/bucket approaches are preferable. Removing heavy boulders and other armoring features unstabilizes sediments and geographic features in energetic fresh water and marine environments. Caution should be taken to replace these bottom conditions or leave them undisturbed.
- Depth to Bedrock—Allows both advantageous and disadvantageous conditions depending on the remedy selected. When dredging, no overdredging is possible so it is nearly impossible to achieve high fraction removal with excavation equipment. When performing dry excavations, depth to bedrock provides a convenient bottom and visual verification of sediment removal.

Aquatic Life Characteristics

- Benthic Community—Affects remedy selection. Removal options (e.g., dredging, dry excavation) and capping destroy the present benthic community. Heavy operations (e.g., dredging, capping) result in plumes of fine particulates in the water column that can settle at great distances downstream. Many shellfish, mollusks in particular, are very sensitive to fine particle deposition during the annual spawning season; therefore, season must be carefully considered when choosing and planning heavy operations. Particle broadcasting permits application of a cap in a gradual manner, preserving benthic communities. Natural recovery imposes the least negative impact.
- Water Column Life—Affects remedy selection. Fish feed on benthics; therefore, the destruction of the benthic community by removal or heavy capping will cause fish to seek new feeding grounds.
- Avian Use—Affects remedy selection. Birds feed on both benthic and water column inhabitants. Destroying the benthic community, with the associated disappearance of fish, will require that birds find other feeding grounds. Natural recovery, enhanced natural recovery, and particle broadcasting provide the least disruption to birds.
- Submerged Aquatic Vegetation— Affects remedy selection and mirrors benthic community impacts from remedial efforts. Similarly, the natural recovery and enhanced natural recovery remedial options afford the greatest protection to otherwise healthy plants.

Detailed Alternative Analysis

The detailed alternative analysis portion of a feasibility study applies a tiered approach that moves from qualitative to quantitative and predictive analyses as needed to resolve remedial alternative selection. Figure A-8 provides a step-by-step flow chart. Although the approach is designed to increase the detail of the evaluation process, it may be necessary to collect technology-specific, alternative-specific, or site-specific engineering information to better characterize costs, implementability, and effectiveness (see Appendix D). The level of detail required to obtain this information may proceed from generic engineering information to similar site experience to treatability studies to pilot studies. It is also important to note that some technologies have a variety of subsequent operations that must be considered (see Figure A-9).

Quantitative comparisons of alternative effectiveness are based on reasonable assumptions regarding remedy implementation and performance. The primary criteria for comparison are the nine National Contingency Program (NCP) criteria, as follows:

- Overall protection of human health and the environment

- Compliance with applicable or relevant and appropriate requirements (ARARs)
- Long-term effectiveness and permanence

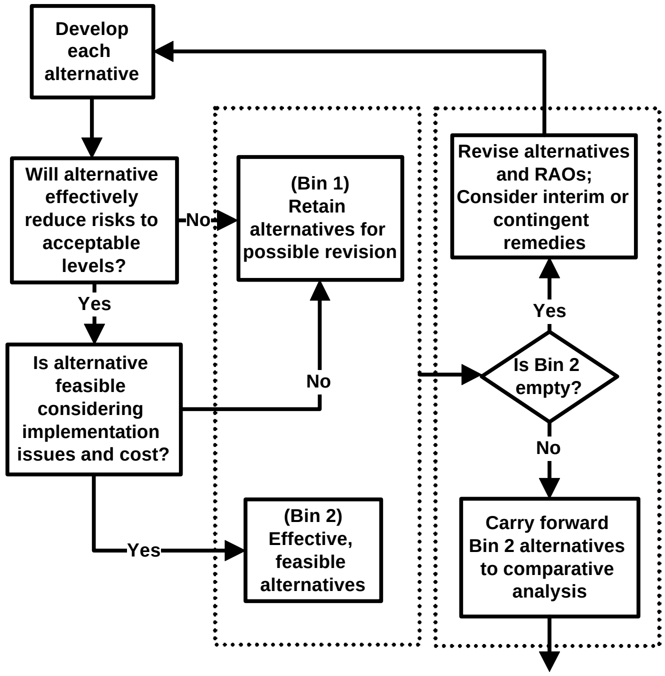

Figure A-8. Detailed analysis of alternatives.

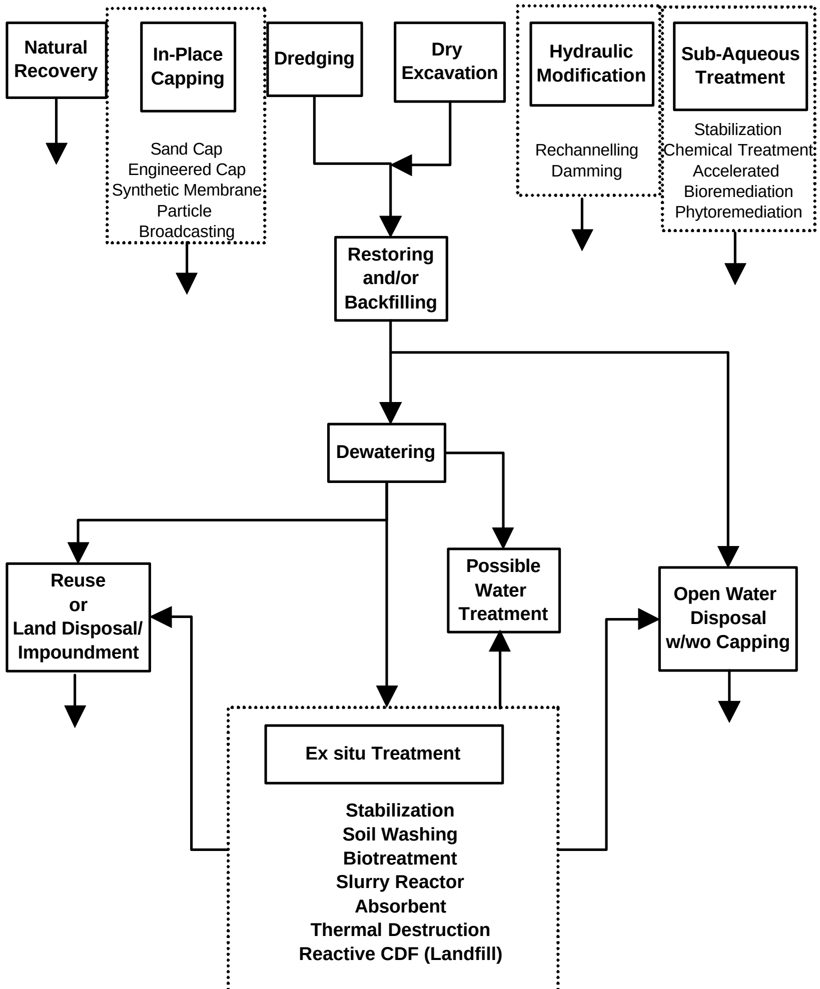

Figure A-9. Remedial alternatives diagram.

- Toxicity, mobility, or volume reduction through treatment
- Short-term effectiveness
- Implementability
- Cost
- State agency acceptance
- Community acceptance

Incorporating realistic estimates of the time to implement (including time necessary for administration, design, permits, siting, and construction), releases during implementation, and surficial sediment concentrations upon completion is critical when comparing technologies. Unrealistic assumptions such as assuming that removal actions are instantaneous, do not cause releases, and will result in all mass being removed lead to flawed and unscientific comparative analyses (see Appendix D for actual site performance).

Comparative Alternative Analysis

The purpose of the comparative alternative analysis is to characterize and weigh benefits versus costs of each alternative, identify the greatest benefit for the least cost, and conduct refined analyses to prioritize and target sediment areas that need to be addressed. All comparisons are weighted against meeting risk-based RAOs. To conduct the analysis, the rate of risk reduction is evaluated by considering the following factors:

- Implementation risks (e.g., exposure and releases during implementation, habitat destruction)
- Realistic duration of implementation
- Realistic exposure concentrations upon implementation completion
- Potential for recontamination of remediated or uncontaminated areas
- Background or regional conditions

The costs and time necessary to address the engineering and administrative issues are also evaluated by considering the ability to construct, achieve objectives, ensure permanence, manage spoils, and control releases during implementation; obtain permits, regulatory approvals, and community acceptance; ensure site access, availability of materials and services, and consistency with potential future remedial actions; and achieve ARAR compliance.

Upon completion of the feasibility study and generation of sufficient information, a remedy with a time frame to meet RAOs is selected and proposed.

IMPLEMENT AND MONITOR

After agreement is reached with the regulator(s), implementation of the remedial action can proceed. Following implementation, it may be necessary to conduct an effective monitoring program to ensure that RAOs are met, reestablish RAOs based on the practical limitations of selected technologies, and revisit the remedy selection in the event that the selected technologies prove to be ineffective.

CONCLUSIONS

Managing a contaminated sediment program can be challenging due to the various factors involved. The decision trees provided in this paper serve as useful tools to integrate these factors into the decision-making process, resulting in a comprehensive, logical sediment management program. Figure A-10 provides a more detailed logic diagram of the process outlined in this paper.

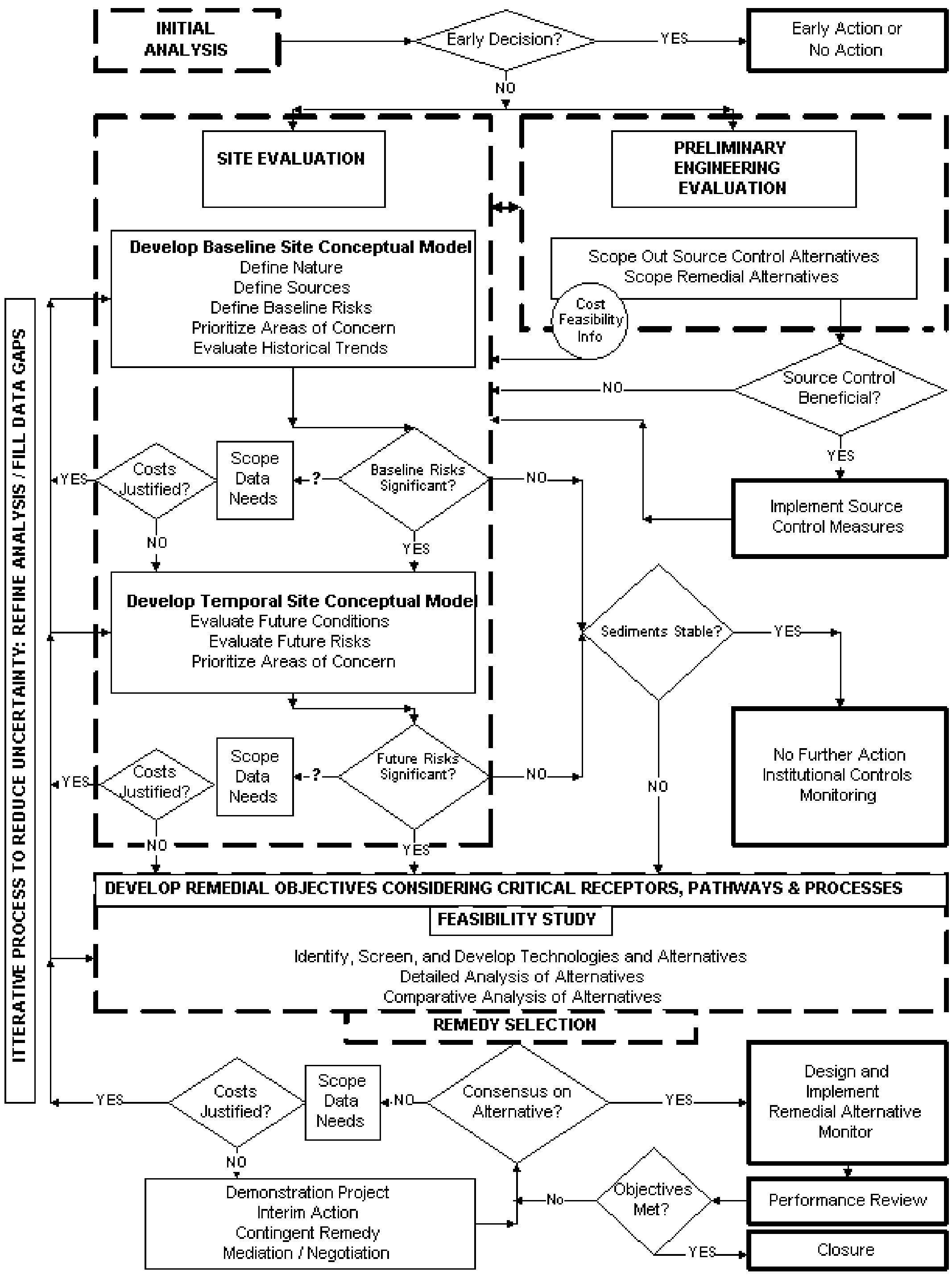

Figure A-10. Contaminated sediment remedial action decision framework.