Executive Summary

At some sites, complex site-specific conditions make it difficult to fully remediate environmental contamination using proven remediation approaches. This guidance presents a recommended process for remediation management at complex sites, termed "adaptive site management." The adaptive site management process is presented in a flow chart and each step is described in detail. Numerous case studies describe real-world applications of remediation and remediation management at complex sites. Stakeholder perspectives at complex sites are also summarized. This guidance incorporates and refers to best management practices, tools, and technologies described in previous publications by the U.S. Environmental Protection Agency (USEPA), ITRC, Department of Defense (DOD), and others.

Complex Sites

The term "complex site" refers to sites where remediation progress is uncertain and remediation is not anticipated to achieve closure or even long-term management within a reasonable time frame.

Site Challenges

Both technical and nontechnical challenges can impede remediation and may prevent a site from achieving federal- and state-mandated regulatory cleanup goals within a reasonable time frame. Examples of technical challenges include geologic, hydrogeologic, geochemical, and contaminant-related conditions as well as large-scale or surface conditions. Examples of nontechnical challenges include managing changes that occur over long time frames, overlapping regulatory and financial responsibilities between agencies, setting achievable site objectives, maintaining effective institutional controls, redevelopment and changes in land use, and funding considerations. Nontechnical challenges may be exacerbated by technical challenges, long remediation time frames, and higher costs.

This guidance offers tools and references for investigating complexities and improving the conceptual site model (CSM) at complex sites. Integrated site characterization (ITRC 2015b) can improve the CSM and maximize remedial effectiveness. This approach iteratively identifies key uncertainties or data gaps in the CSM and establishes objectives prior to data collection and interpretation (ITRC 2015b).

Site Objectives

Site objectives are long-term remedial goals and objectives that are typically established based on federal and state environmental regulations. Examples include meeting applicable or relevant and appropriate requirements (ARARs), achieving target risk levels or contaminant concentrations, restoring impacted media to beneficial use, or protecting human health and the environment.

Remediation Potential Assessment

If substantial complexities are identified, a site-specific remediation potential assessment may be appropriate. The remediation potential assessment evaluates the likelihood of meeting site objectives within a reasonable time frame. Two different series of questions (pre- or postremedy implementation) are provided as examples. Site owners, regulators, and stakeholders can revise the questions and determine the relative importance or weighting of some questions to reflect site-

specific concerns and address contaminated media other than groundwater. Many of the questions relate to effectiveness, feasibility, and cost. Each area of the site can be assessed separately (for example, source and plume, hydrogeologic unit, or operable unit).

The remediation potential assessment has three possible outcomes: a high, moderate, or low likelihood of achieving site objectives. If remediation potential is high, the site area is not considered complex. If remediation potential is moderate, the assessment can be reevaluated (such as criteria used, questions that may dominate the assessment, and the weight of evidence balancing the categories). If remediation potential is low, the site will not likely achieve site objectives in a reasonable time frame and adaptive site management should be considered.

Adaptive Site Management

Adaptive site management is a comprehensive, flexible, and iterative process of remediation management that is well-suited for complex sites, where there is significant uncertainty in remedy performance predictions. Adaptive site management includes periodically evaluating and adjusting the remedial approach, which may involve multiple technologies at any one time and changes in technologies over time. The CSM is refined using information gained from remedy performance. Note that complex sites may require more iterations of the adaptive site management process compared to simpler sites.

Regulatory agencies specify the criteria for evaluating and selecting a remedy—for example, Comprehensive Environmental Response Compensation and Liability Act (CERCLA) nine criteria per 40 Code of Federal Regulations (CFR) 300.430, Resource Conservation Recovery Act (RCRA) corrective measures criteria per 40 CFR 258.57, or analogous criteria under other state-led programs. At complex sites using adaptive site management, this evaluation may incorporate additional considerations. For example, is there flexibility to adjust or optimize the remedial approach based on performance data? Is the remedial approach synergistic with other technologies?

Site remediation managers adapt or adjust the selected remedy over time in response to remedy performance. These adjustments keep the remedy on track to meet interim objectives. Interim objectives and associated performance metrics may reflect a variety of goals such as removal rates/treatment efficiency or reduction in mass, mass flux, concentration, plume footprint, or volume of contaminated soil. Site managers develop time-bound interim objectives and performance metrics in parallel with remedial alternatives and document them in the decision document.

If a site area is not sufficiently progressing towards interim objectives, despite remedy optimization and modifications, site objectives may be revisited. Applicable or relevant and appropriate requirements (ARAR) waivers may be considered at CERCLA sites. RCRA and other state cleanup programs have similar options – a state survey highlights approaches to consider under state cleanup programs.

Interim Objectives

Interim objectives are designed as steps or milestones to achieving the overall site objectives. Interim objectives can be specific to a technology or an area of the site (such as reducing mass flux from the source area, or containing an off-site plume). Achieving interim objectives leads to the next phase of remediation.

Long-Term Management

Adaptive site management continues during the long-term management phase of remediation. Recommended elements include the following:

1. Preparing a long-term management plan with a performance model and metrics. Project risks and uncertainties are also identified, mitigated and tracked.
2. Conducting periodic evaluations to compare actual progress with expected performance.
3. Following predefined decision logic to evaluate, adjust, optimize, modify or transition the remedial strategy if needed to stay on track to achieve interim objectives.

Comprehensive planning and scheduled periodic evaluations of remedy performance help decision makers track remedy progress and improve the timeliness of remedy optimization, reevaluations, or transition to other technologies/contingency actions. Note that optimization is not typically the focus of adaptive site management, but is often appropriate as part of the process.

Sites typically use institutional controls (ICs) and land use controls (such as deed restrictions and fencing) to prevent exposure over the long term. In *Long-Term Contaminant Management Using Institutional Controls*, ITRC (2016b) identified critical elements of effective IC management programs based on successes from established state and federal regulatory programs. These controls, however, are rarely used as stand-alone remediation strategies and are not drivers for changing site objectives or a substitute for remediation.

Case Studies

Detailed case studies are included in this guidance. Each case study describes site conditions and complexities, the technical basis for remedial action, key decisions, remedial approach, monitoring and optimization activities, and regulatory and stakeholder involvement. Case studies describe any adaptive site management processes that were used for site evaluation and decision making.

Stakeholder Perspectives

Stakeholders are members of environmental organizations, community advocacy groups, or other citizens' groups that address environmental issues. Stakeholders can actively participate in the decision-making process at complex sites. Unique circumstances that apply to tribal stakeholders are also discussed. This guidance also presents best practices for including stakeholders in the management of complex sites and communicating with stakeholders through a site-specific stakeholder communication plan or (at CERCLA sites) through the five-year review process.