Systems-Based Framework for Remediation Endpoints – 14355

Hope Lee[1], Michael Truex[1], Dawn Wellman[1], Mark Freshley[1], Danny Katzman[2], Velimir Vesselinov[2], Miles Denham[3], Amoret Bunn[1], Carol Eddy-Dilek[3], John Morse[4], Michael Thompson[4], Eric Pierce[5], Skip Chamberlain[6], Kurt Gerdes[6]
[1] Pacific Northwest National Laboratory
[2] Los Alamos National Laboratory
[3] Savannah River National Laboratory
[4] US DOE Environmental Management, Richland Operations Office
[5] Oak Ridge National Laboratory
[6] US DOE Environmental Management, Office of Soil and Groundwater Remediation

ABSTRACT

A framework has been developed for evaluating soil and groundwater remediation at complex sites. This framework provides a structured, systems-based technical approach that can be applied to remediation processes established under the Comprehensive Environmental Response, Compensation, and Liability Act and the Resource Conservation and Recovery Act. The approach is intended to facilitate remedy decisions and implementation for complex sites where restoration may be uncertain, require long time frames, or involve use of progressive and adaptive management approaches. The framework is based on defining appropriate remediation endpoints, which are risk-informed remediation goals or scenarios permitted by statutes and regulations that protect human health and the environment, and facilitate management of the remedy process at complex sites. This document also identifies challenges and opportunities associated with refining and applying the framework.

INTRODUCTION

Remediation of subsurface contamination remains a significant challenge facing the nation (EPA 2004a). Despite progress over nearly 40 years of remediation efforts in the United States and other industrialized countries, restoration of groundwater to a condition allowing for unlimited use/unrestricted exposure remains a significant challenge. Substantial portions of the remaining challenge are owned by the Department of Defense (DoD) and the Department of Energy (DOE) Office of Environmental Management (EM), representing two of the largest soil and groundwater cleanup programs in the world. In 2013, the U.S. Army Environmental Command supported a National Research Council (NRC) study that addressed technical and management issues arising from barriers to restoration of contaminated groundwater [1]. The NRC study concluded that many of the remaining sites to be cleaned up have residual contamination at levels preventing them from reaching closure and can be described as complex, meaning restoration is unlikely to be achieved in the next 50 to 100 years due to technological limitations. The report stated that about 1,260 sites across the U.S. have complex groundwater contamination issues.

Technical issues that render a site complex include difficult subsurface access, deep and/or thick zones of contamination, large areal extent, and subsurface heterogeneities that limit the effectiveness of remediation strategies and approaches. Complexity also exists because of significant uncertainty with respect to understanding source distribution and contaminant behavior as well as response of the subsurface system to a remedial action. Sites where long time frames will be needed to remediate contamination (e.g. because of long-term sources or large extent) present technical and fiscal challenges.

The National Contingency Plan, the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA), and the Resource Conservation and Recovery Act (RCRA) statutes defined in the Code of Federal Regulations provide the legal context for setting cleanup goals. These statutes provide the basic steps to remediate subsurface contamination. However, remedy implementation also must consider site-specific conditions and complexity. For a complex contaminated site, a sequence of remediation steps may be appropriate. The steps in the process can be adaptive to account for changing conditions and improved understanding as additional data about the site are obtained through remedy implementation and monitoring. With the adaptive approach, initial decisions do not necessarily need to result in selection of a remedy that will fully meet restoration goals. Rather, an iterative approach can be used that maintains protectiveness (e.g. institutional controls, targeted actions for exposure pathways), reduces future risk, and provides information to evaluate each subsequent remediation decision.

A framework has been developed for evaluating soil and groundwater remediation at complex sites. The framework provides a structured, systems-based technical approach that can be applied to remediation processes established under CERCLA and RCRA. The approach is intended to facilitate remedy decisions and implementation at complex sites where complete restoration may be uncertain, require long time frames, or involve use of progressive and adaptive management approaches. A foundation of the approach is a “systems-based” conceptual model of a site describing the associated “system” of features, events, and processes that collectively describe contaminant behavior, remedy performance, and control of exposure pathways. The framework is based on defining appropriate remediation endpoints, which are risk-informed remediation goals or scenarios that facilitate management of a progressive remedy path that is protective of human health and the environment, are acceptable under current regulations and guidelines, and most importantly agreed upon or negotiated with stakeholders and regulatory agencies. The framework identifies use of appropriate metrics that support evaluation of performance with respect to the remediation endpoints. Evaluation criteria are also used to guide evaluation of data with respect to the ability to reach restoration goals or consideration of alternative goals and associated compliance points (e.g., as described by [2]).

Existing guidance from U.S. Environmental Protection Agency, Interstate Technology Regulatory Council, state regulatory agencies, and other technical institutions has clarified elements of the CERCLA and RCRA processes, including establishing options for cleanup goals. The systems-based framework is intended to provide a technical basis for reaching and achieving remediation goals by providing an adaptive approach for gathering appropriate information, analyzing to provide a decision basis, and defining implementation approaches to ensure progress toward remediation of complex sites. The framework enables remedy decisions that maintain protectiveness, but can be implemented in an adaptive approach for complex sites where cleanup is uncertain. Incremental remediation is allowable under CERCLA and RCRA, however a technical approach for achieving success at complex sites is lacking. This framework is intended to facilitate negotiation and effective decisions for the nation’s complex remaining subsurface contamination challenges.

SYSTEMS-BASED FRAMEWORK

The framework is intended to provide a structured approach for technical experts, site owners, federal and state regulators, and stakeholders to negotiate progressive and adaptive remedy approaches for complex sites (Figure 1). The approach is based on developing and iteratively refining a systems-based site conceptual model in conjunction with defining a path for remediation. Successful implementation of the framework includes addressing the risks to human health and the environment and re-evaluating comprehensive system behavior over the course of remedy implementation to ensure the most appropriate actions have been taken. The systems-based framework progresses through data collection, remedy selection, and remedy implementation phases to be consistent with the process described by CERCLA and RCRA, and is based on compliance with applicable or relevant and appropriate requirements (ARARs). As shown in Fig. 1, there are four main elements of the framework, each with multiple components, as described in more detail below.

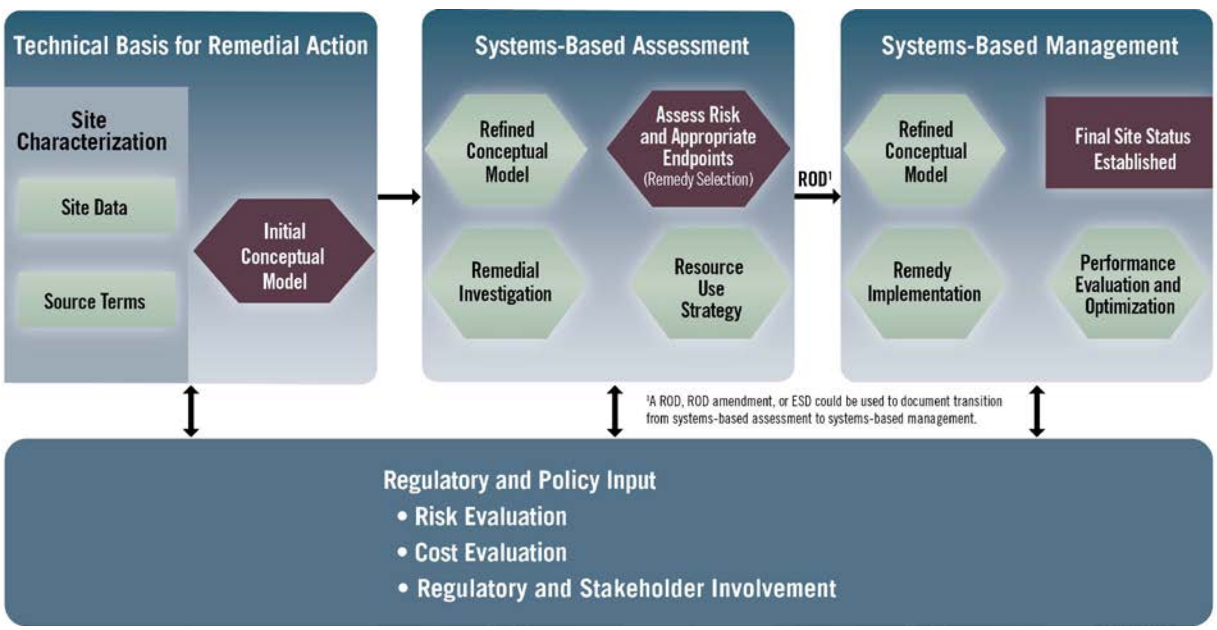

Fig. 1. Systems-based framework for remediation endpoints

Technical Basis for Remedial Action

Site characterization data sufficient to define potential contamination issues and conduct the baseline risk assessment is an essential starting point for the remediation process. This portion of the framework includes the CERCLA steps of the preliminary assessment and initial site characterization. The site characterization data are used to develop an initial site conceptual model depicting information about contaminant source terms, the distribution of contaminants in the environment, the hydrologic properties of the site, and the physical setting with respect to potential impacts to human health and the environment (as described by [3]). The conceptual model describes the overall contaminant fate and transport setting, the factors that affect contaminant behavior, and the exposure pathways and associated potential risks. The conceptual model is used to create an analytical or numerical model that is used in a subsequent systems-based assessment to determine an appropriate remediation approach as described in the next element. The conceptual model provides the technical basis for subsequent remedial actions (Fig. 2).

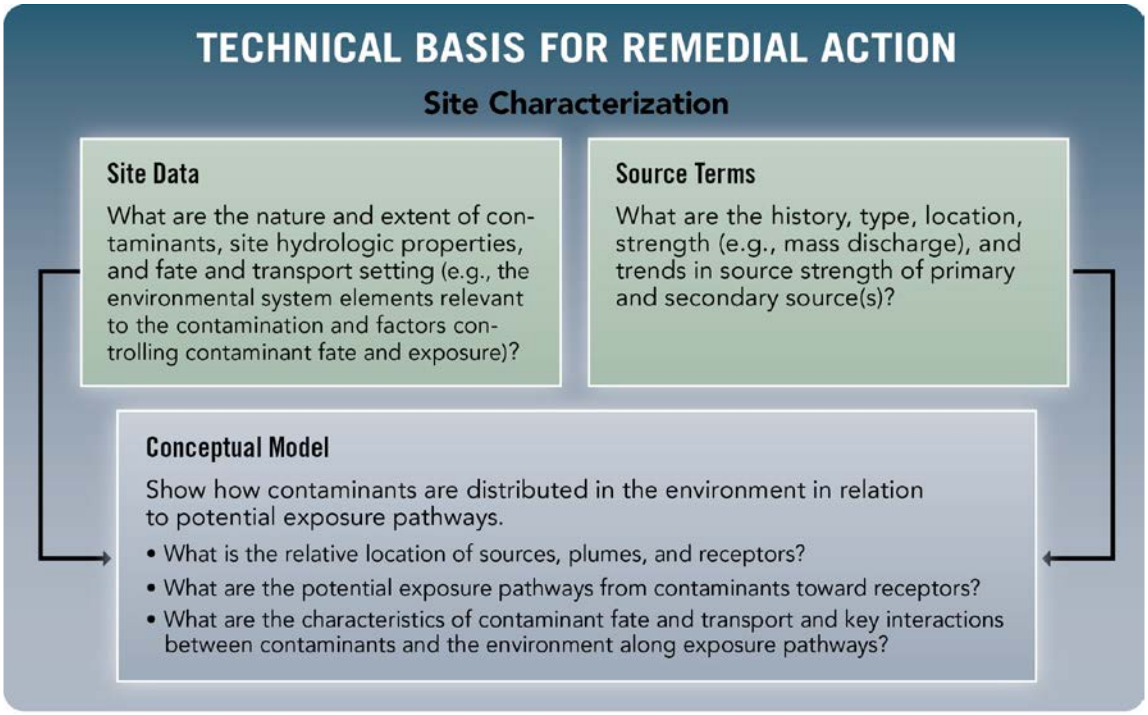

Fig. 2. Technical basis for remedial action including characterization of the site and source terms and generating the initial site conceptual model.

Systems-Based Assessment

The process of selecting an appropriate remediation approach and reaching a Record of Decision (ROD) needs to account for the site setting, potential exposure pathways, nature and extent of the contaminants, and expected fate and transport. This portion of the framework aligns with the CERCLA remedial investigation/feasibility study process leading to a ROD. In CERCLA, this includes steps of developing and screening alternatives, treatability investigations, and detailed analyses of potential remedies. As shown in Fig. 3, components of a systems-based assessment to determine the remediation approach include 1) the resource use strategy, 2) refining the conceptual model, 3) remedial investigation, and 4) assessing risk for contaminants and site conditions, selecting a remediation approach, and defining appropriate endpoints to facilitate implementation of the remediation process. A key element of the systems-based assessment is to consider current exposure and exposure pathways and remediation approaches in conjunction with resource use, institutional controls [4, 5, 6], or other measures that can be implemented to manage exposure during the remedy period. The ability to manage exposure during the remedy period using institutional controls provides a basis for setting the remediation timeframe and determining an appropriate strategy and associated endpoints to meet restoration goals. For sites where effective institutional controls or other measures can be implemented to manage exposure, longer remediation timeframes may be negotiated with regulators and stakeholders to maintain protectiveness and mitigate risk during the remedy period. Consideration of exposure management during the remedy process is important with respect to selecting progressive and adaptive remediation approaches that are iteratively applied with interpretation of monitoring data to guide subsequent steps toward the restoration goals established for the site.

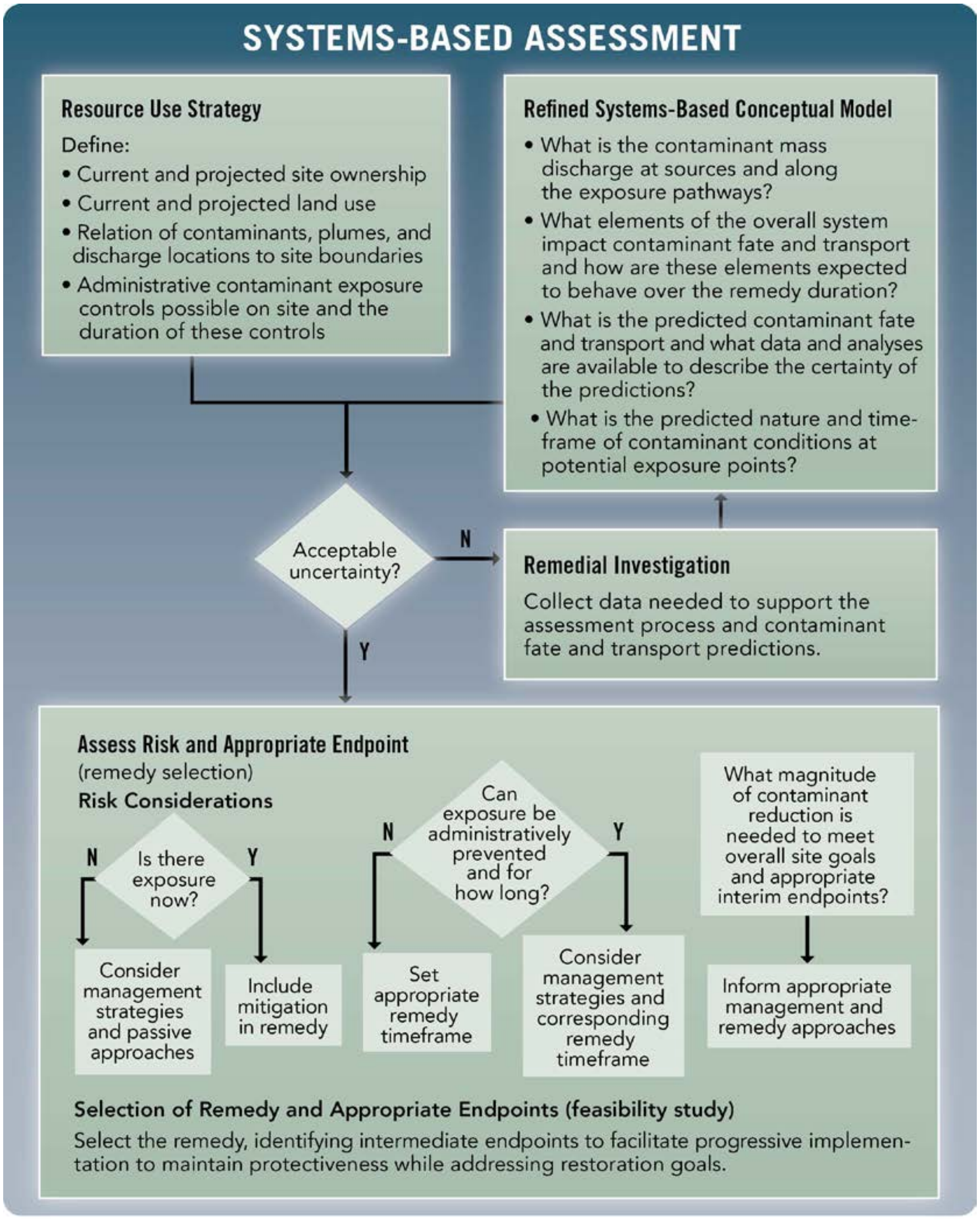

Fig.3. Systems-based assessment, including definition of the resource use strategy, refining the CSM, performing the remedial investigation, and assessing risk and appropriate endpoints.

Systems-Based Management

The Systems-Based Management portion of the framework (Fig. 4) includes remedy design, implementation, monitoring, and adaptation leading to final long-term management or closure decisions associated with restoration goals for the site. This element aligns with the CERCLA RD/RA and closure processes. Remedy actions include appropriate measures to verify performance in terms of maintaining protectiveness, making progress toward reducing future risk, and providing information to evaluate subsequent remedy actions or in support of assessing the ability to reach restoration goals. Thus, important components of the remedy actions include 1) selecting an appropriate design for the remedy implementation that enables adaptation and progression with respect to the identified endpoints, 2) defining the means of performance evaluation and remedy optimization, and 3) establishing metrics to support intermediate endpoint transition decisions and final long-term management and closure decisions associated with final restoration goals. The systems-based management and monitoring approach should adapt to the progression of remedy implementation stages and provide suitable information to interpret performance and maintain compliance [7]. The systems- based approach also links with the conceptual model to identify appropriate lines of evidence (monitored parameters) that can be used to verify that contaminant behavior over time is within expected limits and will meet restoration goals.

The framework is intended to enable selection of a progressive implementation approach at the onset of remediation, recognizing that a comprehensive remedy for a complex site and the ability to meet restoration goals may not be known at the time of the ROD. A sequence of remediation endpoints will enable an iterative and progressive remedy informed by data gained through implementation and associated monitoring. Criteria need to be established, collaboratively with regulators and stakeholders,for the identified intermediate endpoints and to guide evaluation of data with respect to the ability to achieve restoration goals or to define alternative remediation goals.

CONCLUSIONS

Throughout the remediation process, performance and environmental risk and remediation costs need to be jointly considered by the site and regulators with stakeholder input. The systems-based framework provides a context for negotiating and implementing adaptive and progressive remediation at complex sites. The intent is to facilitate site, regulator, and stakeholder interactions during this process by using a site conceptual model as the technical foundation for decisions and through identification of endpoints that define a path of remediation along with appropriate metrics that support decisions during the process. The framework emphasizes use of a remediation approach that maintains protectiveness and provides information over time to improve the basis for restoration decisions. Thus, the framework is intended to provide a technical foundation that supplements existing guidance by providing a suitable mechanism for the site, regulators, and stakeholders to manage remediation at complex sites where adaptive and progressive remedies are needed. The framework would be implemented within CERCLA or RCRA statutes and consistent with the National Contingency Plan.

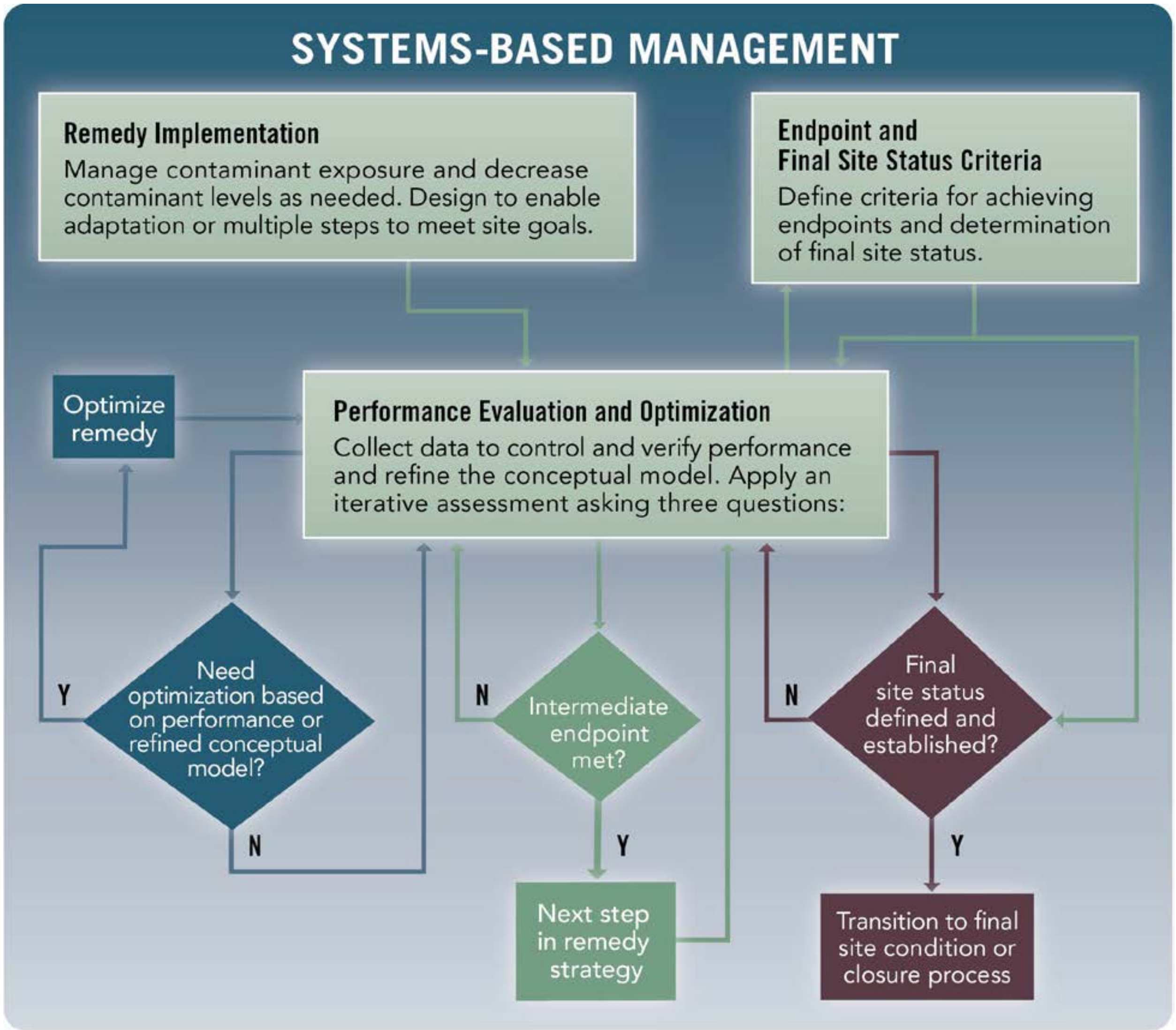

Figure 4. Systems-based management to evaluate remedy implementation and determine when endpoint criteria are met.

REFERENCES

1. NRC. 2012. Alternatives for Managing the Nation's Complex Contaminated Groundwater Sites. Pre-publication, National Academy of Sciences, Washington, D.C.

2. Deeb R, E Hawley, L Kell, and R O'Laskey. 2011. Final Report - Assessing Alternative Endpoints for Groundwater Remediation at Contaminated Sites. ESTCP Project ER-200832, Environmental Security Technology Certification Program. Available at http://www.serdp-estcp.org/content/download/10619/130969/file/ER-200832-FR.pdf.

3. EPA. 1988. Guidance for Conducting Remedial Investigations and Feasibility Studies Under CERCLA. EPA/540/G-89/004.

4. EPA. 1997. Rules of Thumb for Superfund Remedy Selection. EPA 540-R-97-013, OSWER 9355.0-69, Office of Solid Waste and Emergency Response, U.S. Environmental Protection Agency, Washington, D.C.

5. EPA. 2009. Summary of Key Existing EPA CERCLA Policies for Groundwater Restoration, Memorandum. OSWER Directive 9283.1-33, Office of Solid Waste and Emergency Response, U.S. Environmental Protection Agency, Washington, D.C.

6. EPA. 2010. Institutional Controls: A Guide to Planning, Implementing, Maintaining, and Enforcing Institutional Controls at Contaminated Sites. EPA-540-R-09-001, Interim Final, OSWER 9355.0-89, Office of Solid Waste and Emergency Response, U.S. Environmental Protection Agency, Washington, D.C.

7. Bunn AL, DM Wellman, RA Deeb, EL Hawley, MJ Truex, M Peterson, MD Freshley, EM Pierce, J McCord, MH Young, TJ Gilmore, R Miller, AL Miracle, D Kaback, C Eddy- Dilek, J Rossabi, MH Lee, RP Bush, P Beam , GM Chamberlain, J Marble, L Whitehurst, KD Gerdes, and Y Collazo. 2012. Scientific Opportunities for I at Environmental Remediation Sites (SOMERS): Integrated Systems-Based Approaches to Monitoring. PNNL-21379, Pacific Northwest National Laboratory, Richland, Washington.