Technical/Regulatory Guidance

Project Risk Management for Site Remediation

March 2011

Prepared by
The Interstate Technology & Regulatory Council
Remediation Risk Management Team

ABOUT ITRC

Established in 1995, the Interstate Technology & Regulatory Council (ITRC) is a state-led, national coalition of personnel from the environmental regulatory agencies of all 50 states and the District of Columbia, three federal agencies, tribes, and public and industry stakeholders. The organization is devoted to reducing barriers to, and speeding interstate deployment of, better, more cost-effective, innovative environmental techniques. ITRC operates as a co mmittee of the Environmental Research Institute of the States (ERIS), a Section 501(c)(3) public charity that supports the Environmental Council of the States (ECOS) through its educational and research activities aimed at improving the environment in the United States and providing a forum for state environmental policy makers. More information about ITRC and its available products and services can be found on the Internet at www.itrcweb.org.

RRM-1

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ITRC (Interstate Technology & Regulatory Council). 2011. *Project Risk Management for Site Remediation*. RRM-1. Washington, D.C.: Interstate Technology & Regulatory Council, Remediation Risk Management Team. www.itrcweb.org.

ACKNOWLEDGEMENTS

The members of the Interstate Technology & Regulatory Council (ITRC) Remediation Risk Management (RRM) Team wish to acknowledge the individuals, organizations, and agencies that contributed to this guidance document on remediation risk management.

As part of the broader ITRC effort, the RRM Team is funded primarily by the U.S. Department of Energy. Additional funding and support have been provided by the U.S. Department of Defense and the U.S. Environmental Protection Agency. ITRC operates as a committee of the Environmental Research Institute of the States (ERIS), a Section 501(c)(3) public charity that supports the Environmental Council of the States (ECOS) through its educational and research activities aimed at improving the environment in the United States and providing a forum for state environmental policy makers.

The RRM Team would particularly like to thank the Air Force Center for Engineering and the Environment (AFCEE) for its support. AFCEE provided in-kind funding support for the team Program Advisors (PAs) and document editing. Sriram Madabhushi of Booz Allen Hamilton (current PA and former Team Co-Leader while with South Carolina Department of Health and Environmental Control), Paul Jurena of AFCEE (interim PA), and Patty Reyes of Noblis (former PA) have kept the project focused and well supported and have fostered the development of RRM as a valid and viable concept.

The team recognizes the following states for their support of team leadership and guidance preparation:

- California Department of Toxic Substances Control—Ning-Wu Chang, Team Co-Leader
- New Jersey Department of Environmental Protection—Tom O'Neill, former Team Co-Leader
- Massachusetts Department of Environmental Protection—Dorothy Allen
- South Dakota Petroleum Release Compensation Fund—John McVey
- South Carolina Department of Health and Environmental Control—Keisha Long
- Virginia Department of Environmental Quality—Thomas Modena
- Florida Department of Environmental Protection—Tara Kulkarni and Art Torvela
- Missouri Department of Natural Resources—Sudarshan Kurwadkar
- Iowa Department of Natural Resources—Mary Skopec

The team would also like to recognize the excellent participation from various federal agencies and other public institutions:

- U.S. Air Force—Javier Santillan, Samuel Brock, Erica Becvar, Dave Bell, and Edward Brown
- U.S. Army Corps of Engineers—Dave Becker
- U.S. Navy—Karla Hare and Tanwir Chaudhry
- U.S. Department of Energy—Beth Moore, Blaine Rowley, Paul Beam, and Ming Zhu

- U.S. Environmental Protection Agency—Pamela Baxter, Richard (Kirby) Biggs, and Teri Richardson
- Strategic Environmental Research and Development Program/Environmental Security Technology Certification Program—Marvin Unger

Stakeholder and academic perspectives are critical to the success of any ITRC document. The team would like to thank Jimmy Mackey and Geoffrey Cullison for their efforts as stakeholders.

Finally, the team would also like to recognize the efforts and contribution of the following consultants and industry representatives:

- S. S. Papadopulos & Associates—Michael Rafferty
- Battelle Corporation—Russell Sirabian
- Risk Strategies, LLC—Gordon Ballentine
- Brown and Caldwell—Robert Ferry
- Noblis—M. R. “Peaches” Callier and James Gibbs (formerly with Brown and Caldwell)
- ARCADIS (formerly Malcolm Pirnie, Inc.)—Rula Deeb, Elisabeth Hawley, and Frederick Stanin
- ENVIRON—Mark Nielsen

All parties who contributed to this document, whether named or unnamed, be they team member, independent reviewer, or ITRC staff, are thanked by the RRM Team for their efforts. Though some made major contributions to the project while others made minor contributions, all are appreciated for their time and effort.

EXECUTIVE SUMMARY

What is remediation risk management, and why is it important?

This document addresses project risk management for site remediation projects. It applies generally accepted risk management industry approaches to project risks encountered during site remediation and uses the term "remediation risk management" (RRM) to describe this approach. Site project managers are the primary audience for this document, prepared by the Interstate Technical & Regulatory Council (ITRC) RRM Team, but other environmental practitioners will be interested as well, including state and federal regulators, consultants, and responsible parties—any stakeholders in remediation project risks.

RRM addresses project risks or constraints to achieving ultimate goal of remediation: protection of human health and the environment. Investigation and remediation activities have their own set of risks, apart from the risks associated with chemical contamination. This document focuses on the management of project risks associated with investigation and remedial activities. Examples include inadequate remedy performance, risks to ecological habitats resulting from remediation activities, health and safety concerns, greenhouse gas (GHG) emissions caused by remediation, consumption of energy and other resources needed to perform remediation, the risks of traffic accidents, and other unintended adverse impacts.

The purpose of RRM is to significantly improve the quality of remedial decision making throughout a project life cycle regardless of the site size and complexity, type of cleanup program, or stage in the cleanup process. RRM prompts careful consideration of a variety of potential project risks and helps project managers identify and address the most significant risks to their project. RRM uses a broad perspective and provides general tools to allow project managers to execute risk mitigation plans to improve the likelihood of achieving project objectives to remove contamination, restore resources, and close sites.

What is RRM not?

RRM is not a way to rationalize doing less work on environmental cleanup projects or compromising the quality of restoration efforts. All remedies must be protective of human health and the environment and must meet regulatory requirements. Through RRM, site managers consider and appropriately act on project risks that are site specific; therefore, the outcome is also site specific. For example, RRM may favor an active remedy at a site where cleanup timeframe overruns would pose a significant project risk. RRM might favor a passive remedy at a site with sensitive ecological habitats or similar long-term timeframes/outcomes for both passive and active remedies.

RRM is not more "red tape" for project managers or additional paperwork requirements with no change in site activities. The objective of RRM is to benefit the project through optimization. RRM is a thought process to improve the quality of environmental decision making to benefit the project. The approach is scalable for site circumstances to avoid being a cumbersome, time-consuming process that could delay project implementation. It is not a regulatory requirement and therefore does not require any additional reviews.

What resources are available to better understand RRM?

This document is the primary resource for understanding RRM. Detailed information, references to useful tools, case studies, and points of contact are provided in the appendices. Similar documents have been published on risk management for specific cleanup programs, including the following:

- "Restoration Performance Risk Management—RPRM" (AFCEE 2010a)
- *Risk Management Guide* (DOE 2008)
- *Groundwater Risk Management Handbook* (NAVFAC 2008)
- *Improving Environmental Site Remediation Through Performance-Based Environmental Management* (ITRC 2007)
- *A Guide to the Project Management Body of Knowledge* (PMI 2008)

This document is different from other guidance in that it is not specific to a particular regulatory framework or cleanup program. It builds on previous ITRC publications (e.g., ITRC 2004, 2007) and customizes general project management principles on risk management for application to remediation projects.

When is RRM most applicable in the site remediation process?

RRM can be used in support of environmental decision making during any stage of the cleanup process (e.g., investigation, remedy selection, implementation, operation and maintenance, optimization, and site closeout). Major decisions that can benefit substantially from RRM include the selection of a remedy and remedy implementation.

What does RRM entail?

When considering project risks, RRM elements fit into a sequence of planning, execution, and verification. Project risk management elements include project risk identification, evaluation, mitigation, monitoring, and reporting. Appendix D illustrates the application of RRM at a site. As shown in Figure ES-1, RRM consists of the following five elements to address project risks.

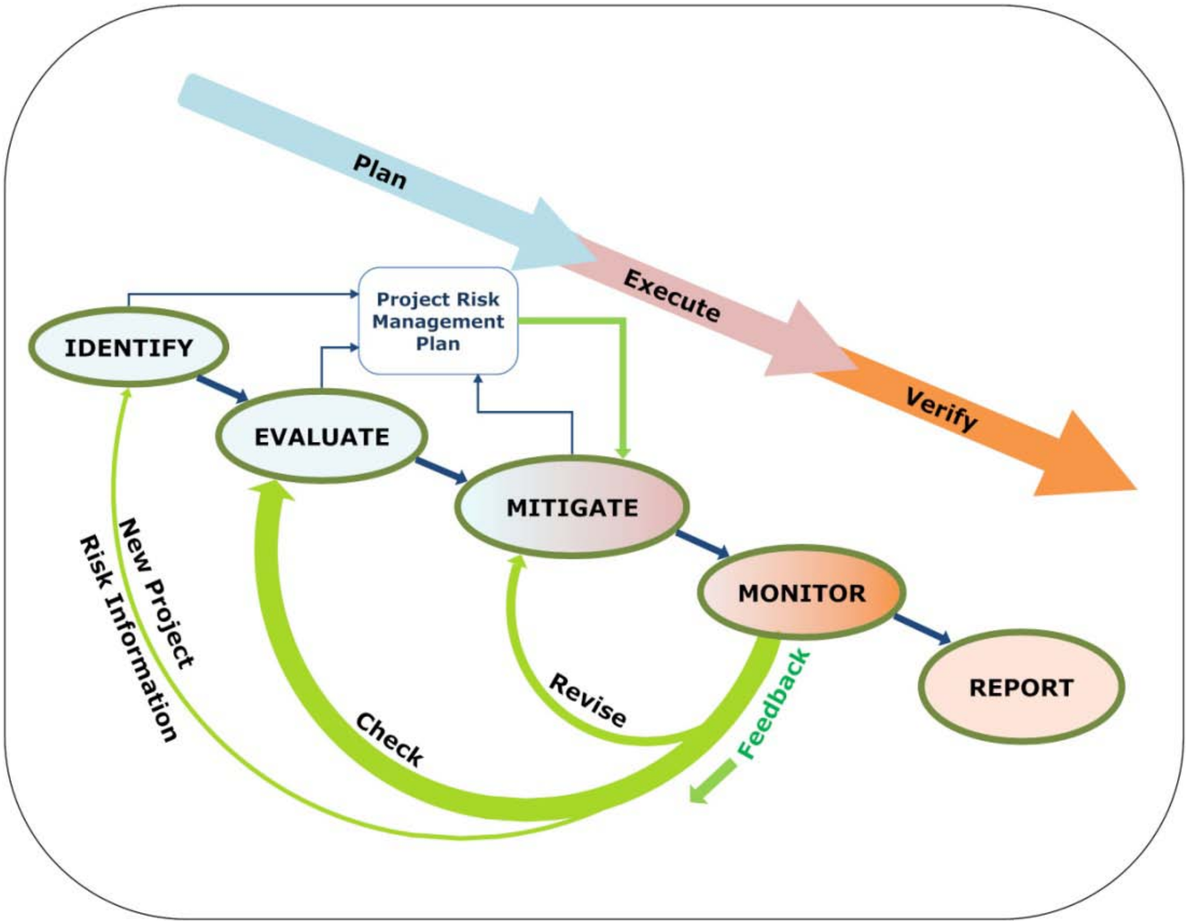

Figure ES-1. Elements of remediation risk management.

1. Project Risk Identification

During this step, which is part of the planning stage of RRM, identify a variety of potential project risks. Consider the categories of project risks shown in Table ES-1.

Table ES-1. Categories and examples of project risks

Category of project risks	Examples of project risks
Remedy performance	• Selection of inappropriate remedy • Technology feasibility • Inappropriate objectives • System failure
Human health	• Changes to human health risk assessment • Accidents (travel, transportation)
Environmental/ecological	• Greenhouse gas emissions • Energy consumption • Risk to ecosystems, endangered species
Regulatory	• Changing regulations • Emerging contaminants

Category of project risks	Examples of project risks
Economic	• Value of land use after remediation • Economic consequences of delayed site closure • Cost of delayed redevelopment
Project schedule, staffing, financials	• Schedule • Scope management • Cost • Quality • Communications • Contracting
Legal	• Litigation • Natural resource damage claims
Political, geographic, and social	• Preservation of historic landmarks • Long-term land-use plans • Community perceptions

Figure ES-2 shows project risks in graphical form.

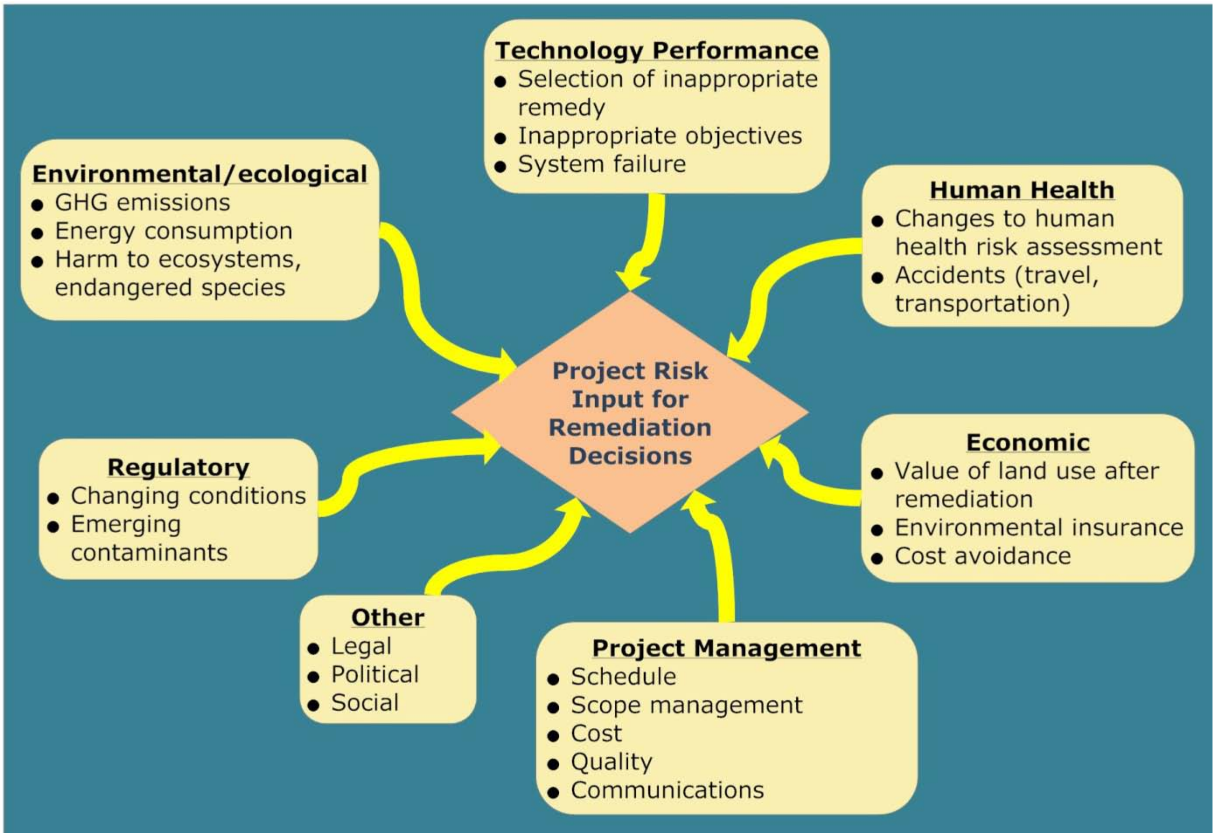

Figure ES-2. Risks associated with RRM.

2. Project Risk Evaluation

Project risk evaluation addresses both the probability that each project risk event may occur and the magnitude of adverse impacts or consequences that could result. Qualitative and quantitative tools can be used to evaluate project risks, including risk registers, computer modeling, consultation with knowledgeable or expert professionals, and project team discussion. The evaluation process classifies project risks ranging from low to very high risk.

3. Project Risk Mitigation

Strategies to mitigate high-risk potential risk events are developed and implemented during this stage of RRM. Mitigation methods might include eliminating, reducing, transferring liability for, or accepting the potential project risk. For example, one mitigation approach to addressing a project risk of remedy failure might be to develop and position a contingency remedy and decision logic for implementing the contingency approach.

4. Project Risk Monitoring

This step specifies the way in which a project will be tracked over time to make sure that the project risk mitigation strategies have been effectively and successfully implemented. Project risk monitoring also seeks new information that may change the nature, likelihood, or severity of potential project risks.

5. Project Risk Reporting

In this final step, key findings from project risk monitoring are summarized and communicated to other stakeholders for use in decision making. For example, project risks from different sites might be compiled and assessed at the program level to decide how to better manage similar sites or identify priority topics for research and development efforts. On a site-specific level, project risks might be discussed at a stakeholder meeting or communicated to the site owner.

Which sites will benefit from using RRM?

All sites benefit from using RRM to identify, consider, and appropriately address project risks. RRM is applicable to sites in all types of programs and is not targeted at sites in a particular regulatory framework. The principles apply at Comprehensive Environmental Response, Compensation and Liability Act; Resource Conservation and Recovery Act; underground storage tank; voluntary cleanup; and brownfields program projects. In a survey of state cleanup programs conducted by ITRC, no states reported any regulatory barriers to implementing RRM concepts at state-lead sites. The thought process reflected by RRM (identify, evaluate, mitigate, monitor, and report) is general enough to be used as the basis for state cleanup programs or other agencies to develop a process to address remediation project risks.

RRM can be used at relatively simple or small sites as well as at large, complex sites. Some project managers are already conducting much of the RRM analyses. For example, the potential impact of construction activities on workers and nearby residents is routinely addressed as part of remedial action plans. It is important to apply RRM in ways that support the project. Therefore, the level of efforts associated with RRM should be scaled appropriately (e.g., using simple qualitative assessments and simple documentation at sites where the project risks are relatively low). Extensive RRM assessments are called for at sites where project risks are relatively high.

What are the costs and benefits of RRM?

The benefits of RRM include improved likelihood of project success, reduction of adverse secondary impacts on the environment (such as the depletion of natural resources or ecological habitat), and, in some cases, reduced time and cost to achieve site closure and post-closure goals. The cost and effort associated with RRM is scalable—a basic RRM project risk analysis could be completed in one or two days; more complex analyses might take hundreds of hours (e.g., stakeholder meetings, modeling under different scenarios, optimization efforts). However, the costs of RRM are relatively low, even at complex sites, because many mitigation activities would be occurring anyway, such as the preparation of health and safety plans or groundwater modeling in support of remedy selection or remedy evaluation. RRM produces better planning that can be communicated to stakeholders to emphasize high-priority issues and concerns at the site (e.g., sustainability, long-term liability, accelerated schedule). This process reassures stakeholders that their concerns are being taken seriously and that steps are being taken to mitigate the potential effects of these project risks.

How is RRM used in practice?

This document provides project managers and others who are interested in RRM with a roadmap for systematically thinking about and addressing project risks. Reading this document is the first step toward putting RRM concepts into practice. Other risk management documents that are applicable to the site regulatory program should also be reviewed. Detailed examples are provided in this document to illustrate how project risks can be addressed through RRM. Because of the site-specific nature of project risks, not all types of project risks are identified in this document. Each project team should identify site-specific project risks and use the tools described in this document to qualitatively/quantitatively evaluate each project risk. Project managers can then plan mitigation strategies for significant high-risk events, implement these strategies, and monitor the outcomes. Monitoring results are used to help make quality decisions regarding environmental remediation optimization, identify new potential high-risk events, and help keep stakeholders up to date on remediation progress.

Summary

RRM is a course of action to holistically address a broad set of remediation project risks related to site investigation, remedy selection, implementation, and site closure. RRM encourages project managers to proactively address project risks through project risk identification, evaluation, mitigation, monitoring, and reporting, thus making decisions that balance various project considerations to better meet all project objectives to remove contamination, restore resources, and close sites.

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1. INTRODUCTION

1.1 Purpose

This document is intended to help environmental remediation practitioners to assess and manage project risks associated with site remediation. Project risks include any uncertain events or conditions that have the potential to adversely affect a project's objectives, scope, time, cost, or targeted primary outcomes or to result in unintentional adverse outcomes. Project risk management is the systematic process of identifying, analyzing, and responding to project risks.

The primary objective of site remediation is protection of human health and the environment; however, the focus of this document is on project risks. Risks to human health and the environment are addressed here only to the extent that they may be impacted by project risks. Regulations require environmental remedial strategies to be protective of human health and environment; therefore, all remediation projects will need to meet these absolute objectives. Project risk management is instead focused on secondary objectives of remediation projects that contribute to overall project success.

> This document focuses on the management of project risks. It does not address human health and environmental risk assessment.

This document presents tools and processes to help remediation practitioners anticipate, plan for, and mitigate project risks (i.e., minimize the probability of occurrence or the magnitude of adverse consequences). These tools and processes can be used at sites in a variety of different cleanup programs and are scalable to meet site-specific needs.

1.2 Background

Over the past 30 years of environmental remediation efforts, industry professionals have documented lessons learned regarding project risks (see, for example, EPA 2010a). Some project risks potentially hinder the success of environmental restoration projects (e.g., achieving cleanup goals) and/or produce unintended consequences (e.g., secondary water quality impacts). Figure 1-1 shows the conceptualization of the overall remediation risk management (RRM) process as applicable to site restoration and rehabilitation activities. This figure uses the specific language and phases related to Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) process as an example; however, it is to be noted that that RRM process can be applicable to all program areas, including Resource Conservation and Recovery Act (RCRA), underground storage tank (UST), voluntary cleanup, dry-cleaning, and brownfields programs. As can be seen, the top portion of this flowchart separates the site-specific human health and ecological risk evaluation from project management risks, while connecting these two risks as envisioned by the Interstate Technology & Regulatory Council (ITRC) RRM Team. For the traditional human health and ecological represents how a site should meet the "threshold criteria" for a remediation decision can be appropriately made. The RRM process, on the other hand, considers input from a variety of risks that are associated with the actual implementation of project. This figure also relates the RRM process to the performance-based environmental management (PBEM) process (ITRC 2007), as it relates to overall remediation life cycle.

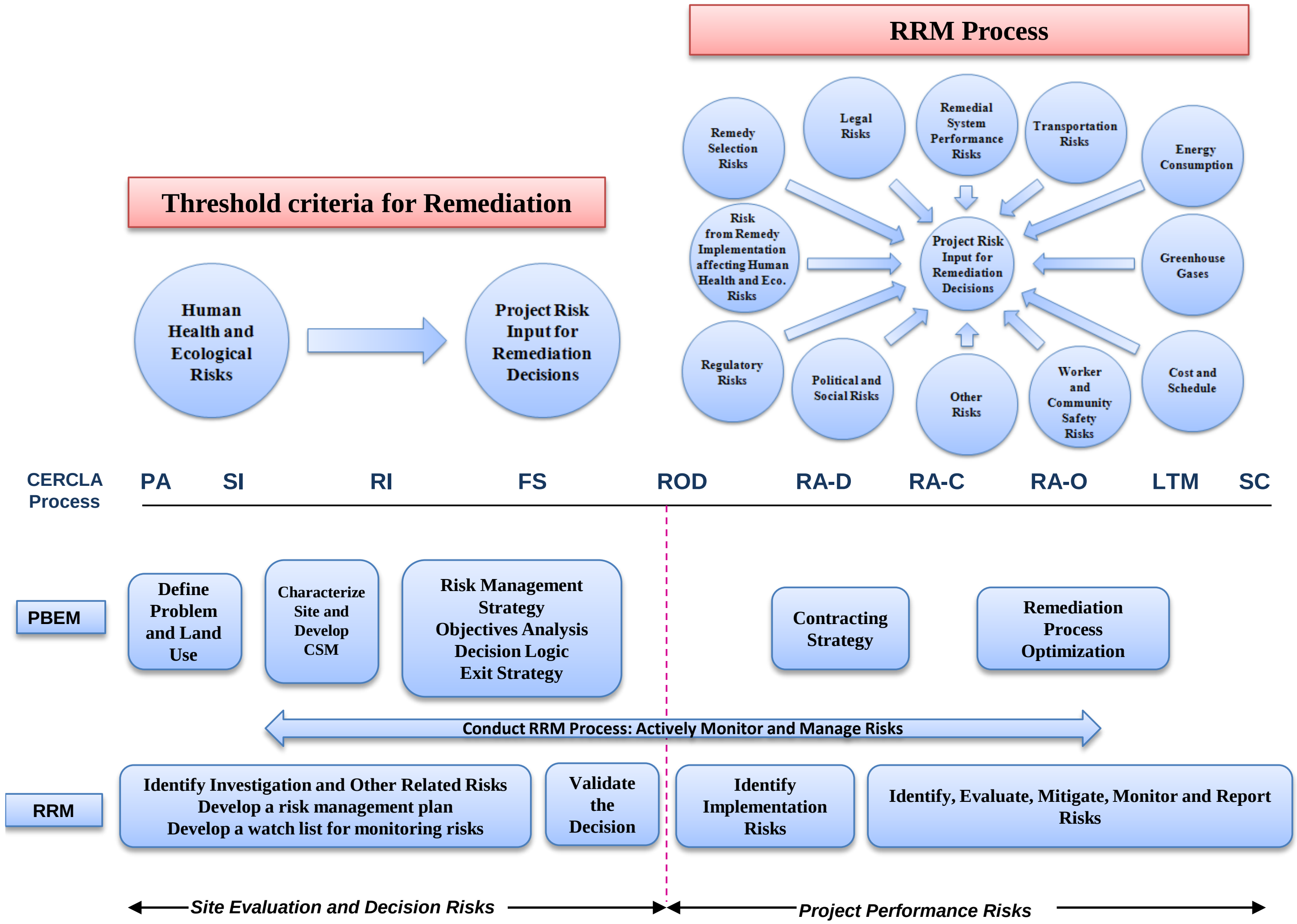


Figure 1-1. Relationship between traditional human health and ecological risk evaluation and project management risks throughout the remediation life cycle, using the CERCLA process as an example. Note: Though the CERCLA process is used as an example, the project management risks can be applicable to all remediation programs. PA = Preliminary Assessment; SI = Site Investigation; RI = Remedial Investigation; FS = Feasibility Study; ROD = Record of Decision; RA-D, RA-C, and RA-O = Remedial Action Design, Construction, and Operations, respectively; LTM = Long-Term Monitoring; SC = Site Closure.

ITRC, U.S. Army, U.S. Air Force, and other agencies have published the results of several related initiatives to better manage and optimize remediation efforts. ITRC's Remediation Process Optimization (RPO) Team produced a guidance document titled *Remediation Process Optimization: Identifying Opportunities for Enhanced and More Efficient Site Remediation* (ITRC 2004) by synthesizing various methods from diverse agencies and institutions into a coherent optimization process. The RPO document expanded work from long-term monitoring (LTM) optimization programs such as the Air Force Center for Engineering and the Environment (AFCEE) Monitoring and Remediation Optimization System (MAROS) (AFCEE 2007) and remedial action operations optimization in the U.S. Army Corps of Engineers (USACE) Remediation System Evaluation (RSE) guidance. In 2007, the ITRC RPO team published a technical and regulatory guidance document (ITRC 2007) on PBEM, a project management methodology that can be used throughout the life cycle of a project. These documents describe a variety of tools and methods to help remediation practitioners identify, quantify, and manage project risk.

This document takes a logical next step by drawing on general project risk management concepts and knowledge that have been published for general projects and applying/customizing these concepts to the environmental remediation industry. Developed by ITRC's Remediation Risk Management Team, this document collects a series of tools for evaluating project risks and establishes a framework for the use of those tools.

1.3 Concepts and Definitions

1.3.1 Project Risks

The Project Management Institute's (PMI) *A Guide to the Project Management Body of Knowledge* (PMI 2008) states the following regarding project risk:

> Project risk is an uncertain event or condition that, if it occurs, has a positive or a negative effect on at least one project objective

Likewise, the U.S. Department of Energy (DOE) defines "risk" as follows:

> A factor, element, constraint, or course of action that introduces an uncertainty of outcome, either positively or negatively, that could impact project objectives (DOE 2008).

Although ITRC recognizes the utility of defining a risk in terms of both positive and negative consequences, this document focuses on ways to minimize the probability and consequences of project risks that, if they occur, will have negative effects on at least one project objective. This document presents concepts that are similar to those discussed in PMI's *A Guide to the Project Management Body of Knowledge*, with a focus on project risks specific to remediation.

Project risks that can be considered during a remediation project include, but are not limited to, the following:

- remediation technology feasibility
- remedy selection

- remedy construction, operation, and monitoring
- remedy performance and operations
- environmental impacts of remedial systems to land, water, climate, etc. during system operation
- worker safety, human health, and ecological impacts due to remedy operation
- cost and schedule changes that will affect funding and contracting issues
- energy budget and management for remedy systems
- emerging sustainable restoration approaches

Any event or condition that threatens project objectives at any level can be addressed by project risk management.

1.3.2 Project Objectives

> **Remediation risk management** involves carefully considering project risks and uncertainties and making decisions that balance various project considerations to better meet project objectives.

The overall (or absolute) objectives of a remediation project typically focus on pr otection of human health and the environment. Other project-specific objectives (termed "functional objectives" by the National Research Council [NRC 2005]) are established as a means to achieve the overall objective or as secondary goals regarding how to achieve the overall objective. Examples of functional objectives include remedy performance objectives (e.g., hydraulic containment, reduction in mass flux), sustainability aspects (e.g., reduced greenhouse gas [GHG] emissions, reduced energy footprint, conservation of local resources), project management objectives (i.e., cost, schedule, and quality goals), or a variety of other project-specific goals.

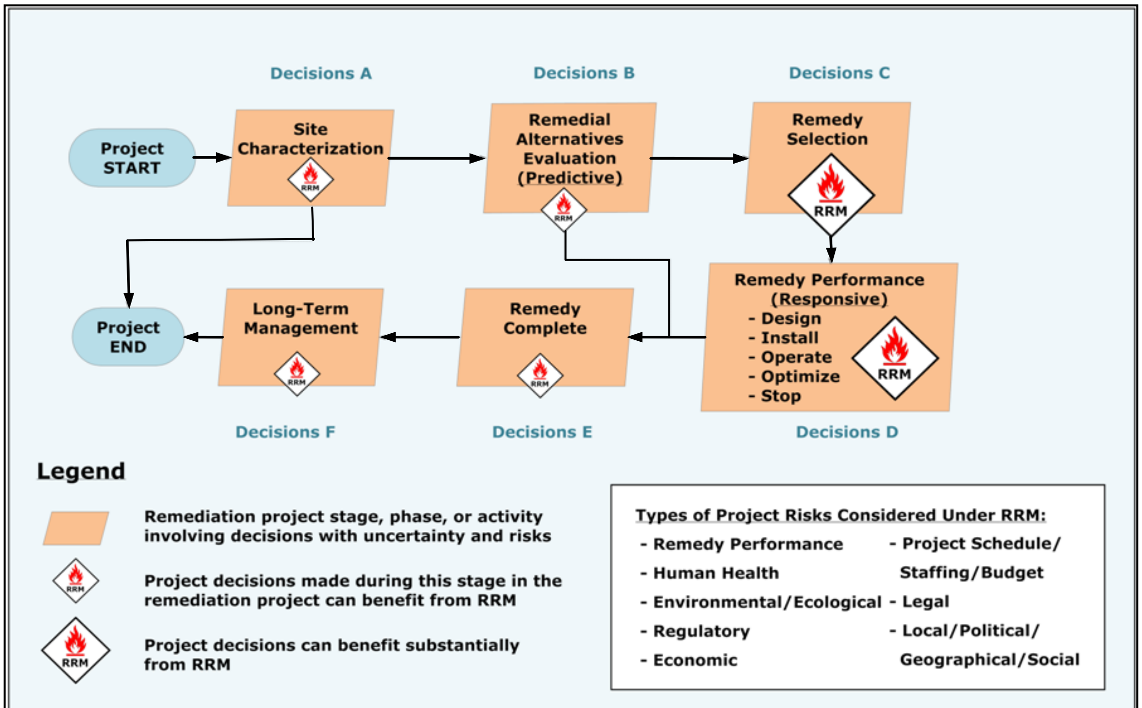
Project managers must often make sure that actions taken to meet a functional project objective do not undermine the ability to achieve absolute objectives. For example, a cleanup method with a high risk of worker injury or exposure to contamination may be contrary to protecting human health and the environment. Through a holistic approach to addressing project risks, RRM can help project managers make decisions that best achieve overall project objectives.

A project risk may have one or more causes and one or more potential impacts. Decisions that involve a variety of competing input factors comprise a field of study in decision theory called "multi-objective optimization." RRM similarly helps project managers carefully consider project risks and uncertainties and make decisions that balance various project considerations to better meet functional or supporting project objectives while still protecting human health and environment.

1.3.3 Remediation Risk Management

"Remediation risk management" is defined in this document as the application of risk management concepts to project risks associated with site remediation. A principal goal of RRM is to achieve significant improvement in the quality of remediation decisions throughout the project life cycle. Risk management planning is the process of deciding how to select, approach, and prepare for project activities to minimize project risks. Proper planning ensures that the level, type, and visibility of management efforts are commensurate with the potential impact of project risks. This process is essentially equivalent to a due diligence approach to project risk management.

RRM is a course of action through which a broad set of project risks related to site investigation, remedy selection and implementation, and site closure are holistically addressed. The elements of RRM are to identify potential project risks, evaluate these project risks, implement actions to mitigate the occurrence and impact of these risks, and monitor and track mitigation measures to make sure that the risks have been successfully managed. Any significant new or residual risks that are identified during remediation should also be managed. RRM elements should be incorporated into a written project risk management plan that describes how the project team will identify and quantify risk, develop and implement risk mitigation strategies, and monitor and record risk events and corrective actions taken during the life of the project. Figure 1-2 explains several aspects of how RRM can be implemented to guide decisions at different stages of environmental remediation.



Stage	Site Characterization	Remedial Alternatives Evaluation	Remedy Selection	Remedy Performance	Remedy Complete	Long-Term Management
CERCLA	Remedial Investigation	Feasibility Study or EE/CA	ROD	Remedial Action	Response Complete	LTM/LTMgt/LTMO
RCRA	RCRA Facility Investigation	Corrective Measures Study	RCRA permit	Corrective Measures Implementation	Certification of Remedy Completion or Construction Complete	Post Closure Care
UST/LUST/BUSTER	Varies by Regulatory Authority					
State	Varies by State					

Figure 1-2. Roadmap illustrating when RRM is most applicable in the site remediation process.

Figure 1-2 emphasizes the most critical stages in a remediation project life cycle (represented here as a process flow diagram) at which RRM concepts can be incorporated to provide the most benefit. All white diamond shapes represent management decisions that can benefit from RRM considerations. They are distributed throughout the diagram to acknowledge that project risks always needs to be managed. The third step in the process flow (Decisions B) represents the determination as to whether any remedial response is warranted given the site conditions. This document was prepared for projects at which site conditions are found to warrant some response and therefore is most applicable to the project stages following that decision. RRM concepts can also reduce project risk during site characterization prior to the response decision.

Because of the frequent confusion between project management risk and risk to human health and the environment, explicit definitions are warranted. This document uses the term "project risk" to clarify that the topic is focused on events or issues that could potentially hinder the project from achieving all of its objectives with maximum efficiency and to distinguish the subject from risk to human health and the environment. Project risks described here do not identify all risks but are intended to illustrate issues that managers may need to address or incorporate into their planning such that the likelihood of project success is maximized.

The large white diamonds in Figure 1-2 represent the most critical stages that offer the greatest opportunity for benefits from RRM considerations. The first large white diamond (Decisions C) is the critical decision taken to select the best response given site conditions and project constraints. Decisions informed by RRM can result in timely and efficient project risk mitigation. Poor or uninformed decisions taken here can waste time and money and, in some cases, even increase project risk and human health risks. RRM considerations incorporated at this stage are necessarily forward-looking and predictive. RRM guides planning approaches because the response activity has not yet been implemented. The second large white diamond (Decisions D) represents the diverse range of surprises, uncertainties, and decisions that emerge during the execution or implementation stage of a project. Even with good planning, changing conditions and project requirements require that a project manager continually find appropriate responses to fend off risks to achieving project objectives. Incorporation of RRM at these stages is mostly responsive in nature. Of course, new insights and lessons learned also can inform managers of previously unconsidered risks for which additional planning is needed.

Figure 1-3 presents an overview of RRM elements and how they fit into a sequence of planning, execution, and verification of the management of project risks. RRM elements can be conducted at various phases of site remediation in support of key decisions (white diamonds), as shown previously in Figure 1-2.

Plan

Figure 1-3 illustrates how RRM elements are rationally sequenced, starting with the identification of project risks. Once identified, project risks are then evaluated to understand their nature, probability of occurrence, and potential effects on the project. Risks include both probability and consequences, and both of these features should be explored during evaluation. Once the risks are evaluated, remediation project managers can begin to include ways to mitigate or minimize the probability and the consequences of the significant project risks in their project planning responses. Identification, evaluation, and response preparations can all be considered part of planning. These preparations are most useful when they are documented in an easily updatable, flexible, or "living" plan to provide continuity among the various mitigation measures for project risk management.

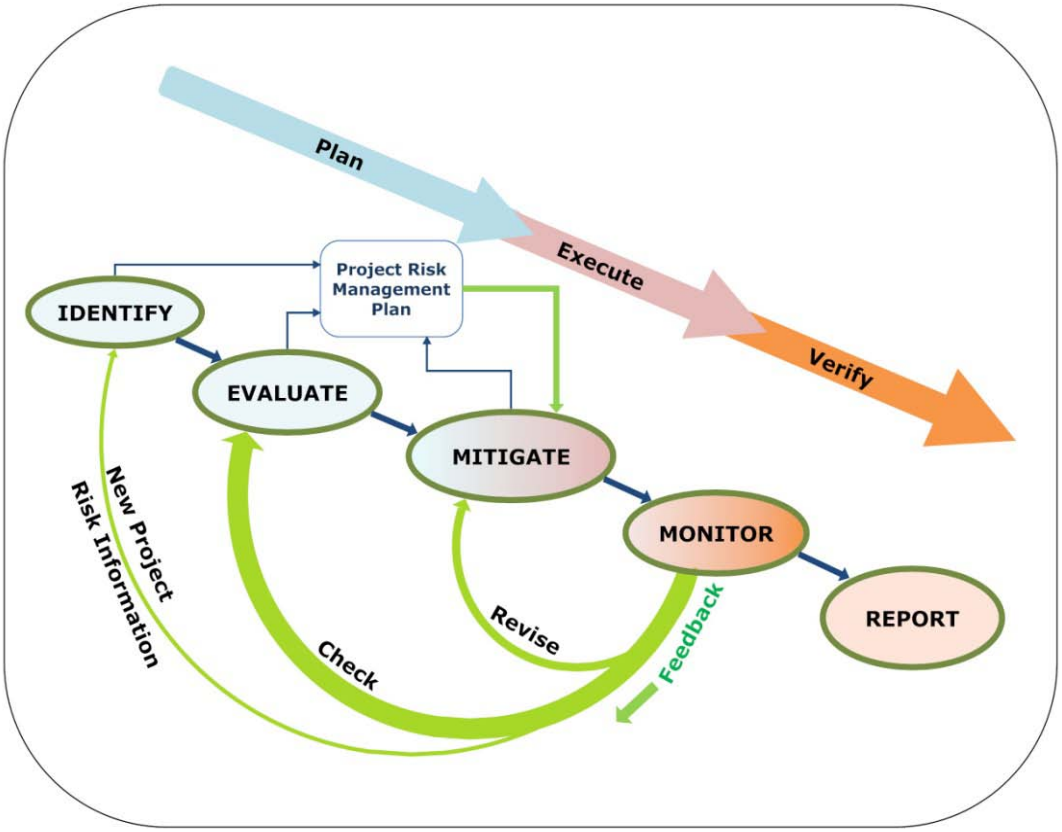


Figure 1-3. A systematic incorporation of RRM elements into project management.

Execute

Once responses are planned, they must be implemented to counter project risks. Implementation can range from disseminating information to establishing contingencies, adding physical or financial protective measures, or altering the methods used to accomplish project objectives. Standard protective practices may be incorporated into projects in response to some project risks. Extra quality assurance review of all data and communications materials is an example of a response to contentious stakeholder involvement, as it can improve the quality of communications and therefore boost confidence in the program. For accountability, and to ensure a positive outcome, the project status must be monitored to determine whether project risks have actually been reduced and remediation performance improved by the planned and executed responses. Project risk monitoring provides information that can be used to improve previous actions in the RRM approach. Project risk monitoring can reveal other previously unidentified or emergent project risks. Lessons learned from project risk monitoring can improve evaluation practices and can also help to devise more effective responses to mitigate project risks. Transitioning planned project risk management responses into actions and monitoring those actions to test their effectiveness can be considered executing aspects of remediation project risk management.

Verify

Assessing the project risk monitoring information and comparing it to the intended results from planning and execution of the project risk management response provide a logical test and an opportunity to modify the response. Summarizing and documenting the project risk monitoring methods that were used, their results, modifications that were seen to be warranted, and lessons learned from all previous project-specific project risk management efforts can help inform other project managers, support future RRM efforts, communicate with stakeholders, and provide a record of diligent project risk management. Such institutional knowledge can be invaluable in the future in case unintended consequences (beneficial or detrimental) trigger a project review.

1.4 Benefits of RRM

Some of the benefits of RRM include the following:

- identification and consideration of key risks and uncertainties that may impact a project
- implementation of measures to address risk, reduce uncertainties, and improve project outcomes
- improved remedial success at contaminated sites by selecting appropriate remedies, using alternative approaches to meet cleanup goals, and reducing the risks associated with remedy implementation
- reduced time and cost to achieve site closure and post-closure goals

1.5 Regulatory Frameworks

> Many state and federal agencies have developed best practices, processes, and tools that use RRM.

RRM can be used by project managers for all types of remediation projects and is not specific to a particular regulatory framework. RRM is equally applicable to many cleanup programs, including CERCLA, RCRA, USTs, voluntary cleanup programs, and brownfield programs. RRM concepts and principles are scalable to the size and complexity of different projects and can be applied at types of sites ranging from simple to complex cleanups.

1.5.1 State Regulatory Perspectives

In the ITRC survey of state interest and knowledge of the topic of RRM (see Appendix A), states did not report any regulatory barriers to implementing RRM practices or tools. However, states reported that they generally have little involvement in the day-to-day management of projects except when states are designated as the lead agency for site remediation. At state-lead sites, states recognized several benefits of using RRM tools and practices, including more timely and efficient cleanups.

1.5.2 Federal Agency Perspectives

Many federal agencies have developed processes and programs that use RRM tools and practices, as described in the following sections. More details on existing RRM tools and practices are summarized in Appendix B.

Department of the Navy

The U.S. Department of the Navy (DON) environmental restoration (ER) program has applied several approaches to manage risk in environmental remedial actions at different stages of the cleanup process:

- **Remedy selection:** An important element of project risk reduction is selecting the most appropriate technologies for remediation. DON conducts third-party reviews of remedy selection decisions, beginning before the draft remedy selection document/feasibility study (FS) has been prepared and continuing until the document is finalized. DON considers this review process vital for reducing risk of remedy failure later in the project (NAVFAC 2008).

- **Optimization:** At sites where remedies are in place, DON has developed optimization guidance outlining a stepwise process for evaluating site and process data and developing optimization recommendations if the remedy is not making adequate progress towards achieving cleanup goals. Data evaluation provides early warning of potential remedy failure and thus enables timely implementation of corrective or contingency measures. DON also has a policy requiring optimization evaluations at all phases of the restoration process for all sites. The DON optimization workgroup has developed guidance for Navy remedial project managers (RPMs) to optimize remedy selection, remedial action operations, monitoring, and proper documentation of site closeout (NAVFAC 2008).

- **Site closure:** Irrespective of site size, complexity, and type of contaminants, DON has adopted a systematic approach for addressing site closeout at all sites. The goal of the ER program is to achieve site closeout cost-effectively while achieving protection of human health and the environment.

DON has also developed guidance that is applicable at several stages of the cleanup process:

- **Conceptual site model:** An accurate conceptual site model (CSM) is one of the basic elements for assessing project risks at different stages of remediation. DON recently provided its RPMs with new guidance and a tool for developing and updating the CSM (NAVFAC 2010).

- **Financial risks:** To minimize financial risks inherent in budget estimates of remediation projects, the Navy uses accredited cost models for estimating cost-to-complete within the Navy's Normalization of Environmental Data Systems (NORM). RPMs update project cost estimates in NORM at least twice per year.

- **Sustainability:** DON is currently developing guidance for RPMs to enhance the sustainable selection of remedies. The guidance will address some of the same project risks and unintended consequences as this ITRC document, including GHG emissions, energy consumption, worker safety, and community impacts.

Department of the Army

Both the U.S. Army and USACE consider RRM principles in a variety of ways, including assessment of risk in developing cost estimates for cleanup, determining the likelihood of critical failure of various engineering systems, considering attendant environmental impacts of cleanup efforts, and promoting the likelihood of success in achieving remediation goals. The degree of effort to incorporate these principles at a site depends on the site characteristics and familiarity of the project team with RRM principles. There is no comprehensive Army policy or mandate to consider aspects of RRM in cleanup projects. USACE has developed several tools in support of RRM principles, including COSTRISK, a cost-estimating risk analysis software (USACE 2008).

Department of the Air Force

To more effectively manage remediation risks and ensure that site remediation is conducted in a responsible, efficient, and cost-effective manner, the U.S. Air Force has developed the Restoration Performance Risk Management (RPRM) process. The RPRM process is a systematic approach for evaluating significant risks and uncertainties associated with site remediation, thus effectively protecting human health and the environment while minimizing the probability of remedy failure. RPRM evaluations consider and measure diverse issues, evaluating them as potential risks. RPRM considerations include programmatic and regulatory issues, technical attributes, human health and ecological impacts, and remedial action performance. Potential risks are comprehensively evaluated and ranked. A risk management plan is then developed to document appropriate risk statements and contingency actions to address events that may affect reaching cleanup goals (AFCEE 2010a). Recently, the Air Force has been addressing certain risks and unintended adverse consequences through the framework of sustainable remediation assessments, using the Sustainable Remediation Tool (SRT) (AFCEE 2010b).

Department of Energy

DOE Order 413.3A (DOE 2006) states that risk management is an essential element of every project and lists monitoring and reporting requirements for managing project risks at DOE sites. DOE defines "risk" as a factor, element, constraint, or course of action that introduces an uncertainty of outcome that could impact project objectives.

Risk management is emphasized through the DOE project management process. Although not specific to remediation, principles for effective risk management are described in the DOE *Risk Management Guide* (DOE 2008), which forms the basis for a framework to identify key technical, schedule, and cost risks, per the requirements of the DOE Order. The framework is forward-looking and structured. Communication of the risks and actions are captured in a risk management plan prior to implementation. For example, Lawrence Livermore National Laboratory (LLNL) has developed a risk management process that identifies and develops a risk management plan and implementation procedures to monitor and mitigate risks as needed.

U.S. Environmental Protection Agency

Although the U.S. Environmental Protection Agency (EPA) has not institutionalized policy or guidance that formally considers all aspects of RRM, it has incorporated many principles and practices to address project risks. For example, at CERCLA sites, project risks associated with remedy selection, technology feasibility, remedy performance, unintended environmental impacts of various technologies, and other factors may be assessed under the nine remedy selection criteria. These criteria, used to select a preferred cleanup alternative that will reduce or eliminate site risks and return the site to productive use, include the two threshold criteria of protecting human health and the environment and complying with applicable or relevant and appropriate requirements (ARARs). EPA also considers five balancing criteria—long-term effectiveness and permanence; reduction of toxicity, mobility, or volume through treatment; short-term effectiveness; implementability; and cost—as well as two modifying criteria: state and community acceptance.

As remediation technologies and processes have evolved over time, EPA has increasingly used optimization principles to improve older remediation systems, methods, and design assumptions. Like RRM, these optimization processes are all targeted toward reducing uncertainties in the remediation decision-making process and minimizing time and cost to cleanup. Examples include the following:

- use of the Triad Approach for characterization at any stage of the process
- independent design reviews at the design stage
- remedial system evaluation at the remedial action stage
- long-term monitoring optimization (LTMO) of pump-and-treat sites

EPA performs a "value engineering" screening of all site cleanups as well as more intensive value engineering studies at sites with projected costs greater than $25 million. These studies reassess a project's direction and approach to reduce potential errors during remedy implementation and significantly reduce the cost of cleanups while still remaining protective of human health and the environment.

Recently, EPA has been incorporating green remediation principles and practices into site cleanups to promote environmentally friendly restoration and land reuse practices. Green remediation seeks to evaluate and weigh the impacts of a cleanup project on six core elements: air, water, energy, materials and waste management, land and ecosystems, and stewardship. Similar to RRM, green remediation attempts to examine site cleanup holistically and conduct a project in a way that minimizes adverse secondary impacts on the environment.

2. RRM ELEMENTS

This section provides an overview of each of the elements of RRM, as depicted in Figure 1-3, including project risk identification, evaluation, mitigation, monitoring, and reporting. Examples of types of project risks are provided in this section, as well as methods for identifying, evaluating, mitigating, and monitoring project risks. As shown in Table 2-1, the following sections of this document provide more detail on each element of the RRM process.

Table 2-1. Document organization following the RRM process

Document section	Content
3. Project Risk Identification	Discussion of typical project risk identified during remediation
4. Project Risk Evaluation	Illustration of qualitative and quantitative analyses for typical remediation project risk
5. Project Risk Mitigation	Risk mitigation strategy, response planning and execution for typical remediation project risk
6. Project Risk Monitoring	Monitoring and tracking the effectiveness of risk mitigation and control
7. Project Risk Reporting	Documenting and reporting the RRM activities

2.1 Project Risk Identification

Project risks can be identified at any time during the life of a project. Ideally, they are first considered during the planning stages concurrently with the development of project objectives. Additional project risks may be identified as the path forward takes shape.

Potential project risks can be identified through brainstorming sessions or facilitated project team[1] meetings. Checklists of common risk factors may be used, such as those provided as an example in Section 3. However, key risk factors are often unique to a project, particularly for environmental remediation projects where every site is different, and there can be a high level of uncertainty in key design parameters (Wendel 1995). A combination of site-specific experience and professional considerations from similar projects is desirable. A list of potential project risks can be generated through a structured review and discussion of project assumptions, work plans, and documents. Key sources of project risks can be discussed.

Potential project risks can be identified through brainstorming sessions or facilitated team meetings. Additional project risks may be identified as the path forward takes shape.

2.2 Project Risk Evaluation

The purpose of this element of RRM is to evaluate the potential significance of project risks. Two factors influence the potential significance of a risk: likelihood of occurrence and adverse impacts of occurrence. Project risks can be evaluated as soon as they have been identified. The initial project risk evaluation can be revisited if additional data become available that narrow initial uncertainty in project characteristics and the nature of potential project risks.

Likelihood of occurrence and adverse impacts can be gauged qualitatively, semiquantitatively, or quantitatively, depending on the type of project risk. For example, a qualitative assessment of likelihood of occurrence might be defined subjectively, ranging from very unlikely to very likely, as shown in Table 2-2. Quantitative and semiquantitative ways of evaluating risk would be based on measured probability values.

[1] For the purposes of risk identification, the project team may be more broadly defined to include a wide variety of subject matter experts and functional areas, including project management, organizational management, subject matter experts, construction managers, procurement specialists, stakeholders, and/or regulators.

Table 2-2. Likelihood of occurrence guidelines

Likelihood of occurrence category	Guideline for qualitative assessment
Very unlikely	You would be surprised if this happened.
Unlikely	Less likely to happen than not.
Likely	More likely to happen than not.
Very likely	You would be surprised if this did not happen.

Similarly, the adverse consequences of each project risk should be evaluated. Some project risks may have negligible consequences, while others may have significant consequences or even a crisis level of potential adverse impacts.

Once both components of a project risk have been evaluated, the most significant risks can be identified. The most significant risks are those with a high probability of occurrence and high consequence of occurrence. Table 2-3 shows an example of a qualitative evaluation of project risk. An evaluation like this could be made for each type of project risk to identify the most significant.

Table 2-3. Example qualitative evaluation of a project risk

Likelihood of occurrence	Impact or consequence of occurrence				
	Negligible	Marginal	Significant	Critical	Crisis
Very unlikely	Low risk	Low risk	Low risk	Low risk	High risk
Unlikely	Low risk	Low risk	Moderate risk	Moderate risk	High risk
Likely	Low risk	Moderate risk	High risk	High risk	High risk
Very likely	Low risk	Moderate risk	High risk	High risk	High risk

To use the table, first rate the likelihood of occurrence and the impact or consequence of occurrence for each project risk. The risk level is at the intersection of this row and column in the table. After each project risk has been given a risk level using the table, the most significant (high) risks to the project can be identified. Alternatively, all project risks that exceed some site-specific threshold[2] of acceptable risk can be identified. Quantitative and semiquantitative methods for evaluating risk levels are presented in Section 4.

Note that all evaluations of risk level are based on some combination of historical information, analysis of underlying systems and processes, and professional opinions. For project risks where there are significant unknowns, professional opinions may be the predominant method (Claycamp 2006). Numerous techniques for integrating diverse professional opinions have been developed for the fields of risk and decision analysis and can be applied to RRM as described in Section 4. Specific project risks may be revisited with a more rigorous risk evaluation, particularly if the initial evaluation has a high level of uncertainty, and a more careful evaluation has the potential to reduce the perceived level of risk or change the remediation approach to manage the risk (see Section 6 for more details).

[2] The strategy and threshold for accepting a project risk are made on a site-specific basis. Ideally, all project risks that are evaluated as high-level risks would be mitigated.

2.3 Project Risk Mitigation

Project risk mitigation involves planning and executing a response or mitigation strategy to address project risks. Mitigation efforts reduce the impact of a project risk or decrease its likelihood of occurrence. When possible, early action should be taken. Some project risks may be unavoidable; others may not warrant mitigation if they are low-level risks. Mitigation strategies are specific to the nature of the project risk and site-specific circumstances. Some examples include the following:

- employing redundant systems or processes
- considering alternative technologies
- conducting treatability studies to better assess technology and remedy performance
- setting interim performance goals to identify conditions indicating that the final remedy objectives may not be met as planned
- adopting a simpler process
- adding or reallocating resources
- negotiating project scope or compliance requirements with regulatory agencies
- adjusting schedules; implementing early starts to activities
- performing aggressive cost control

Mitigation efforts reduce the impact of a project risk or decrease its likelihood of occurrence.

Initially, cause-and-effect analyses are performed to determine the conditions under which a specific risk may occur. If the conditions or causes of a project risk are known, mitigation strategies might focus on managing the causes. Section 5 provides more detail on project risk mitigation.

2.4 Project Risk Monitoring

Project risk monitoring is the systematic tracking and checking of risk mitigation actions. It is part of the project management function and should not generally become a separate discipline. Risk monitoring compares predicted results of planned actions with the results actually achieved to determine the status and need for any change in risk mitigation actions. Risk monitoring and reporting are ongoing processes throughout the life of the project. The project implements risk monitoring and reporting primarily by performing risk reviews. These reviews may lead to reevaluation of the technical performance of a project, additional or modified risk mitigation measures, scope change requests, reallocation of resources, or revised likelihood of occurrence/ impact estimates. In some cases, persons not involved in the project may perform audits. In addition, prior to the start of significant new activities within a project, a focused risk evaluation may be performed so that appropriate risk mitigation measures can be included in the planning process, if needed.

After the appropriate risk mitigation measures have been implemented, residual risk may remain. The risk mitigation strategy for each risk event may also include measures to address this residual risk. A list of project risks is generated for each risk event selected for inclusion in the risk

Risk monitoring compares actual and predicted results to gauge the need for any additional project risk management efforts.

management program. These worksheets contain specific information, such as the staff responsible for managing the risk, risk category, urgency, likelihood of occurrence/ impact estimates, risk mitigation strategy, and status. Section 6 provides more details.

2.5 Project Risk Reporting

Project risk reporting generally includes a repository for all current and historical information related to project risk (e.g., risk register) and a system to allow retrieval, reporting, and communication of project risk-related data. Using consistent methods for project risk reporting is often important for ensuring the credibility, relevance, and understandability of project risk information for decision makers.

2.6 Project Risk Management Plan

The site-specific application of RRM as a risk management process should be described in a written risk management plan. That way, the project management team and other stakeholders can document their process for identifying and evaluating project risks, plans to mitigate project risk, and strategy for monitoring and reporting the outcome. Table 2-4 summarizes the project risk management process; Appendix C presents an example project management plan.

Project risk management can be an iterative process. Although the project management team prepares an initial project risk management plan, several changes can be made to the project risk management strategy over time. These changes should be made to refine the management plan based on pr oject risk monitoring information and site decision making or in response to the identification of new project risks. A risk management plan can be part of other plans to minimize the number of submittals. For example, several states and other organizations use a Quality Assurance Project Plan (QAPP) following the EPA's Unified Federal Policy QAPP document, as an important planning tool to reduce uncertainties and mitigate certain project risks associated with data quality in the remediation decision-making process (see, for example, Intergovernmental Data Quality Task Force 2005, ITRC 2008a). Ideally, the project management team reviews and evaluates project risk periodically as part of regularly scheduled project meetings. This approach leads to a thorough, comprehensive, and dynamic project risk management program.

Table 2-4. Example of the project risk management process

Process step	Summary
Identify roles and responsibilities	• Responsibilities are linked to the project organizational structure. • The project manager is responsible for confirming that all project risk management activities are performed in a manner consistent with the project risk management plan, including maintaining the risk database, identifying new project risk events, facilitating periodic reviews, and ensuring that all required project risk mitigation is being conducted.
Determine project risk management activities	• Project meetings are held to review past project risk events, identify new events, and revise project risk mitigation strategies. • Prior to the start of significant new projects, identify potential project risks so that appropriate risk mitigation measures can be included in the project planning process, if needed.

Process step	Summary
Project risk identification	• A comprehensive list of potential project risk events is generated by reviewing project assumptions, documents, and work plans. • The list is discussed with project management and staff to collect all available information. • The list of potential project risk events is qualitatively screened using a checklist, yielding a set of events that are evaluated quantitatively.
Project risk evaluation	• A likelihood/impact matrix is used to determine a risk level for each event. • The overall risk position of the project is identified. • A list of project risk events requiring additional analysis is created. • A risk category is assigned to each event (technical, logistical, or funding). • Urgent risks requiring immediate attention are identified.
Project risk mitigation	• A risk mitigation strategy is developed for each event to ensure that the appropriate risk control or mitigation measures are implemented.
Project risk monitoring	• A worksheet containing all relevant data is generated for each risk event. • The worksheets are maintained and updated as needed. A project risk monitoring strategy is developed for each significant event to ensure that mitigation measures continue to effectively manage project risk until disposition of the event.
Project risk reporting	• Project risk monitoring is primarily accomplished using project risk reviews. • A risk register is maintained that documents the status of each project risk event, including total and expected value impact.

3. PROJECT RISK IDENTIFICATION

Many types of project risks can be encountered along the road to successful site remediation and closure. Examples include the following categories of project risk considerations:

- remedy performance
- human health
- environmental/ecological
- regulatory
- economic
- project schedule/staffing/financials
- legal
- political/public perception

Each type of project risk is described in this section, along with examples of project risks under each category. The identification of project risks is site-specific; however, the examples provided in this section may help project managers think of other site-specific project risks that can be evaluated and addressed through RRM. RRM is illustrated at an example site in Appendix D. Appendix E provides several case studies illustrating different aspects of project risk management.

3.1 Remedy Performance

Remedy performance project risks are associated with the performance of a technology or combination of technologies used for environmental remediation. The common element of these project risks is that the remedial technology or technologies may not function as intended and may not achieve remedy performance goals. Examples of these project risks are described in the following two subsections: those that are being evaluated prior to remedy selection using predictive tools and analyses and those that are being evaluated after remedy selection based on actual performance data.

3.1.1 Prior to Remedy Selection (Predictive)

Uncertainty in site characteristics/CSM

As experienced environmental practitioners are aware, there are common and significant uncertainties in site conditions, including contaminant sources and distribution, hydrogeology, geochemistry, fate and transport pathways, future site use, and many more. Investigation efforts cannot completely define the nature and extent of subsurface contamination; therefore, there is some residual project risk that the selected remedial approach will not be capable of achieving cleanup goals. This project risk should be anticipated during the investigation stage of a remediation project. It is the role of the investigating professionals and remediation design engineers to understand, anticipate, and mitigate any project risks associated with incomplete or insufficient investigation that may lead to remediation system failure.

The CSM is a dynamic tool that is meant to be modified as site characterization information is received. The CSM is used to assess and guide almost all technical and management decisions, including remedial system design, extent of the area to be addressed by remediation, the type(s) of technologies that may be effective, predicted timeframe to achieve remedial goals and objectives, and the approximate cost of the remediation technology (ITRC 2007). Some states evaluate CSM data gaps on an ongoing basis and assess their significance with regard to remedial design (for example, see Connecticut guidance [CDEP 2007]). Uncertainty in site characteristics and key factors affecting remedy performance translates into uncertainty in the CSM and, therefore, uncertainty in remedy performance/project risk of remedy failure.

Inappropriate cleanup goals/drivers

Cleanup criteria are established for contaminants at the site prior to remedy selection. These compound-specific remediation goals and objectives are typically derived from applicable regulatory requirements and/or site-specific human health and ecological risk assessments. A thorough identification of project risks requires careful evaluation of cleanup goals, regulatory and risk drivers, and the appropriateness of cleanup goals. If cleanup goals and objectives are too stringent, they may not be achievable within a reasonable timeframe. Underestimated remedial technology limitations and incorrect assumptions about overall remedy performance produce project risks. Cleanup standards that are unnecessarily low may also result in cleanup efforts that are overdesigned in size, scale, durability, and complexity. Conversely, if cleanup goals and objectives are not strict enough, they may not be protective of human health and the environment—the primary objective of cleanup efforts. For example, vapor intrusion was historically sometimes overlooked as a potential exposure pathway, requiring additional technology applications at some sites to protect human health and environment. Inputs to and estimation methods used in ecological risk assessments are typically even more complex than those used for human health risk assessments and potentially more susceptible to errors from incorrect assumptions.

Selection of an inappropriate remedial technology

Remediation technologies are typically evaluated based on the CSM and site-specific remediation goals and project objectives. Remediation can ultimately fail to achieve project objectives because of errors in identifying appropriate technologies for actual site conditions and fate and transport mechanisms. Failures can be the result of an inaccurate or outdated CSM or decision errors in the technology selection and remedial system design processes.

Complex sites

Subsurface heterogeneity and other site complexities are major reasons for remedial action performance project risks. Pump-and-treat technologies target dissolved-phase contamination in areas accessible to flow zones. Extraction technologies may not, however, be sufficiently aggressive to remove all contamination from the subsurface, particularly in fractured rock settings or sites with layered stratigraphy (NRC 1994, MacDonald and Kavanaugh 1994). Dense, nonaqueous-phase liquid (DNAPL) contaminants may become entrapped as small globules in fine-particle, thin silt or clay lenses surrounded by larger sand grains in the subsurface. Contaminants can diffuse into inaccessible regions of the subsurface (nonmobile pore spaces) after being released and slowly diffuse back out after remediation, extending the timeframe for remediation.

Use/evaluation of emerging technologies

The consideration or selection of emerging technologies to achieve remediation goals presents project risks due to the lack of a track record for predicting technology effectiveness over time. This has been a challenge for the environmental remediation industry for years (see, for example, NRC 1994), with emerging technologies only slowly becoming more widely accepted. The familiarity of the regulatory and consulting community with conventional technologies and the hesitancy of contractors and owners to accept and manage the risk of implementing an innovative technology have slowed innovation in the environmental remediation industry. These barriers have resulted in the application of outdated technologies chosen years before site cleanup begins that are now recognized to be inefficient and effective for achieving only selected project objectives.

3.1.2 Post-Remedy Selection (Responsive)

Once selected and implemented, remedial technologies may fall short of initial predictions and fail to achieve performance objectives. To identify and mitigate project risks at these sites, the practitioner is encouraged to include the following considerations.

Improperly designed remedy

Insufficient or improper analysis, design, or adaptation of a remedial technology can sometimes be revealed only in the actual evaluation of system performance. Subsurface heterogeneity and other site complexities, accelerated schedules, or cost concerns can increase the risk of implementing an improperly designed remedy and may be realized only in hindsight because of inherent site and mechanistic uncertainties. The technology may not be appropriate based on actual site conditions that aren't known or understood until after remediation commences. In some cases, the operation of an improperly designed remedy may be worse than no action. For example, extraction and monitoring wells installed with improper placement, screened interval, or casing can and have spread contamination to previously uncontaminated aquifer intervals. Similarly, pumping from a lower aquifer not adequately protected by an aquitard may draw contamination downward.

Remediation is too slow

If remediation technologies are inadequate to achieve targeted rates of contaminant treatment or removal, then project performance objectives, regulatory schedule milestones, funding, property transfer, and other issues can all be affected. Depending on the magnitude of their consequences, these project risks may warrant revising schedule milestones, conducting remedial optimization, or even changing the remedial approach. These activities and transitions themselves pose significant project risk by consuming project resources. Significant system optimization or modifications may be required to refine the remedy performance and enhance removal rates. At complex sites where no technologies can meet cleanup goals and objectives within a reasonable timeframe, alternative approaches may be appropriate as part of the revised final remedy.

Identification of new sources

Due to the significant expense of site characterization, a combination of historic disposal information and limited subsurface investigation data is often used. In some cases, limited characterization data are sufficient to design a successful remediation strategy; however, limited data can result in the later discovery of other unknown sources of contamination that would have had a higher chance of being detected with a more comprehensive sampling approach. This situation exemplifies one of the most common tradeoffs cleanup teams must negotiate: How is project risk best minimized? Is project risk minimized by investing in very thorough site characterization efforts and techniques? Or is it minimized by performing a more limited investigation and saving resources for the possible contingency that another source or project obstacle is discovered (and must be mitigated) later in the project? One of these options is vulnerable to error by looking for something that does not exist, and the other is vulnerable to error by not identifying something that does exist. This is one decision that entails project risk that should be identified, evaluated, mitigated, and monitored.

Although any monitoring program should consider the potential for unidentified sources, some sites are more likely to have multiple sources. At other sites, the implications of unidentified sources may be greater. Once remediation is under way, new contaminant sources (or inadvertent mobilizations) could be discovered. Often new sources are discovered during soil excavation, building demolition, or high-resolution profiling or through monitoring groundwater over time and seeing unexpected contaminant trends. The discovery of new sources can lead to additional site characterization, risk assessment, and technology evaluations. Newly discovered sources may warrant significant changes to the remedial strategy, use of supplemental technologies, and/or expansion of the existing treatment systems. These additional resource requirements should be considered as potential project risks when the decision is made to accept site characterization as adequate.

3.2 Human Health

Examples of project risks related to human health include the following:

- underestimation of risk to human health that results in remediation end points that are not protective
- overestimation of risk to human health that results in unnecessary expenditures of resources
- unintended consequences (or necessary tradeoffs) from project activities that result in an increased hazard or risk to humans.

Sources of these project risks can include the following:

- assumptions, parameters, methodology, and uncertainty in the human health risk assessment process (See regulatory guidance documents for more information, e.g., ITRC 2008b, EPA 2010a.)
- underlying uncertainty in human health toxicological data, including reference doses (RfDs) and reference concentrations (RfCs)
- increased risk of accidents from truck traffic, drill rig operation, and other site investigation and remedial construction activities
- health and safety concerns associated with remedial activities (For example, partially treated or untreated contaminants may be released to the atmosphere either unintentionally or intentionally as a result of remedial efforts.)

Section 4 provides discussion on how to evaluate these risks.

3.3 Environmental/Ecological

A variety of different factors can create project risks associated with ecological effects or adverse environmental impacts. Examples include the following:

- use of inappropriate or highly uncertain ecological risk assessment parameters, assumptions, and methodology (Typically, less species-specific information is available for ecological risk assessments, requiring the extrapolation of results from indicator or surrogate species for which dose/response data does exist.)
- impact of project activities on wetlands (which are managed and protected under Section 404 of the Clean Water Act)
- impact of project activities on threatened or endangered species and their habitats (protected under the Endangered Species Act)

- secondary water quality impacts, such as the mobilization of arsenic or other previously immobile contaminants due to remediation-induced changes in geochemistry
- impact of project activities on the local and global environment through the use of mechanical and electrical equipment, generation of GHGs and other emissions, energy usage, generation of wastes, consumption of water resources, and other impacts (Executive Order 13423)[3]
- natural resource damages (discussed in more detail in Section 3.4)

3.4 Regulatory

Federal, state, and local laws must be evaluated as part of setting remedial goals and objectives, including the interpretation of the law as applied to cleanup actions at similar sites; however, policies and regulations are slowly changing. New policies for groundwater and soil cleanup can affect remedial goals and objectives and may influence the applicability of remediation technology options.

There may be substantial variability among states, EPA regions, and individual case managers in numerical groundwater cleanup goals. For example, UST site cleanup target levels range 1–10 µg/L benzene in Florida (depending on aquifer water quality) and 18,000–382,000 µg/L benzene, toluene, ethylbenzene, and xylenes (BTEX) in Mississippi (assuming no indoor air pathway or potable water supply is present) (Kavanaugh 2010).

An example of changing regulations is illustrated through "emerging contaminants," also referred to as "trace organic compounds," "microconstituents," and similar terms. Examples include methyl *tertiary*-butyl ether, perchlorate, pharmaceuticals, firefighting agents, plasticizers, hormones, and personal care products. Emerging contaminants are not currently regulated but have been identified as potential future candidates for regulation based on available information and/or public concern, such as widespread presence in the environment, persistence, bioaccumulation, or toxicity.

Several states have developed monitoring requirements and advisory levels for select emerging contaminants. The U.S. Department of Defense (DOD) has established a watch list and action list for several emerging contaminants as a proactive programmatic response to evaluate compounds of potential concern for site remediation at DOD facilities. The state of Connecticut requires that a release be characterized for all chemicals expected to be present based on knowledge of historical site activities and processes. State regulations permit the development of cleanup criteria for nontargeted chemicals if they are detected. The presence of chemicals that may be regulated in the near future can pose a project risk. How such specific chemicals will be regulated, their actual distribution in the environment, their susceptibility to available characterization and remediation technologies, and the magnitude of the harm they represent are all factors that contribute to project risk posed by emerging contaminants.

An example of newly promulgated regulations is climate change legislation. Individual states or groups of states have combined their efforts to pass new legislation and policy initiatives that require the reduction of GHG emissions and/or place limits on CO_2 emissions from power

[3] See also: ITRC. In review. *Green and Sustainable Remediation: State of the Science and Practice*. Forthcoming overview document by the Green and Sustainable Remediation Team.

generators. Federal initiatives for GHG reductions have already commenced via Executive Order 13514. These new regulations may affect decisions related to remedy selection, operation and maintenance, or remedy completion through application of ARARs, to-be-considered standards, and cleanup precedents. ITRC is currently developing a technical and regulatory guidance document on green and sustainable remediation (GSR) practices which may contribute to broader changes in environmental practices.

3.5 Economic

Economic project risks extend beyond the cost of completing the project. For example, delays in site remediation can jeopardize planned property transactions and decrease property value relative to buyer expectations. State initiatives on climate change may create financial incentives to use renewable energy and improve energy efficiency. These new incentives, together with the federal subsidies, offer opportunities to minimize GHG emissions at remedial sites (EPA 2010b). The concern over climate change by the general public and business sector has already created voluntary carbon markets. Financial incentives offered by current and future carbon offset markets present opportunities for innovation in site remediation and other regulatory programs that achieve significant and verifiable reductions in GHG emissions.

Other site-specific economic impacts ought to be considered and identified as part of RRM. Opportunity costs might be considered in this category (i.e., the value of a lost opportunity after a decision has been made). For example, if deed restrictions or long-term remedial strategies are selected instead of active remediation over a short timeframe, there are associated opportunity costs relative to the lost resources the property could provide.

3.6 Project Schedule/Staffing/Financials

Several factors can create project management risks, potentially extending the project schedule or cost to complete or creating temporary staffing requirements. Examples include equipment malfunction, property access issues, subcontract negotiations, labor productivity, cash flow constraints, and others. Project managers are, therefore, most aware of these types of project risks on a day-to-day basis and are more likely to have already identified them and implemented mitigation strategies.

3.7 Legal

Legal issues may present a number of different project risks, ranging from the impact of access agreements on project schedule to liabilities associated with site cleanup. Natural resource damage (NRD) claims, one type of legal risk, are damages incurred by the public from injury to or destruction or loss of natural resources due to a hazardous substance release or response action. Under CERCLA, the measure of damages is the cost of restoring injured resources to their baseline condition, compensating for the interim loss of injured resources pending recovery, and the reasonable cost of a damage assessment. Successful NRD claims often result in the responsible party making significant payments to the trustees, which are used for restoration or replacement of the injured natural resource or for acquisition of an equivalent resource. The estimation and evaluation of NRDs contribute to the uncertainty associated with the overall remediation process.

3.8 Political, Geographical, and Social

Political, geographical, and social factors can significantly impact the implementability or efficacy of a remediation project and, therefore, should be considered as potential project risks. Issues related to local, state, or federal laws regarding land use or resource protection can delay a remediation project or prevent its implementation. For example, if a site is likely to contain archeological remains, archeological studies need to be considered during the investigation phase to comply with the Archeological and Historic Preservation Act, particularly if intrusive remedial activities are being considered that might disturb the area. Similarly, to comply with the National Historic Preservation Act and other local ordinances, site remediation impacts to historic properties must be considered.

Additional issues to consider include, but are not limited to, the following:

- local community awareness, involvement, and perceptions of the project
- local zoning or long-term land use plans
- airport restrictions on nearby land use (Federal Aviation Administration regulations)
- effect of base closure and realignment on base master plans and future land use

Section 4 describes evaluation of each of these types of project risk.

4. PROJECT RISK EVALUATION

4.1 Overview

RRM evaluation of project risk involves assessing the probability of occurrence of each project risk event and the resulting adverse impacts or consequences of such an event. A higher probability of occurrence or a greater impact will result in a greater project risk. Both the likelihood of occurrence and potential impacts are site specific and depend on the specific nature of the project risk.

Section 4.2 describes a variety of different tools and techniques can be used to evaluate the significance of project risks (probability and impact). Sections 4.3–4.10 present examples of considerations when applying these evaluation methods to different types of project risks. RRM is illustrated at a hypothetical site in Appendix D. Appendix E provides several case studies illustrating different aspects of project risk management.

4.2 Tools and Methods

4.2.1 Risk Register (A Qualitative Method)

A risk register is a tool used to summarize and communicate the results of project risk identification and evaluation. In its most basic form, a risk register is a table that describes each project risk, summarizes project team concerns, and evaluates each risk in terms of its likelihood and potential impacts. Risk registers can be expanded to include additional RRM information, such as risk mitigation strategies, roles and responsibilities for managing project risks, etc. A typical RRM risk register contains the following elements:

- title of the project risk event
- brief description of the project risk
- summary of the project team's consideration of the project risk
- likelihood of occurrence, impact on project objectives (in terms of likelihood, impact, and weighted risk level)
- factors affecting project objectives (in terms of likelihood, impact, and weighted risk level)

Table 4-1 provides an example of a risk register entry, showing impacts on cost and schedule. Impacts on other project outcomes could also easily be added to the risk register to reflect impacts on remedy performance, human health, environmental impacts, legal implications, community impacts, and other impacts of project risks described in this document.

Table 4-2 shows an example of a completed risk register, providing a record of each identified risk and the severity of impacts on project objectives. High-level risks can then be identified, including project risk events that could result in high-level risks to several categories (e.g., high risk of impacting cost and schedule).

Table 4-1. Example entry in a risk register (one project risk)

Element	Risk event information
Risk ID #	5
Risk event title	In situ chemical oxidation (ISCO) effectiveness
Risk event description	Incomplete contact may result in contaminant concentrations in the source area not being reduced uniformly to target levels, requiring additional mobilizations to the site by the ISCO contractor or remedy changes
Date prepared	July 25, 2008
Date last revised	January 17, 2009
Risk event owner	Jane Doe, Project Manager
Urgent response required?	No
Likelihood[a]	Likely
Impact on schedule[a]	Critical
Risk level for schedule[a]	High
Impact on cost[a]	Critical
Risk level for cost[a]	High
Risk handling strategy	Ensure site characterization data are adequate to allow optimal oxidizing reagent injection design and implementation. Conduct treatability studies to refine remedial design. Drill test borings during and after injection to evaluate and verify penetration and coverage of reagent into the contaminated media. Develop realistic performance criteria for contaminant mass and concentration reduction.

Element	Risk event information
Risk monitoring and reporting strategy	Collect and analyze sufficient subsurface samples to allow evaluation of remedy performance.
Risk status	Active

[a] See Section 2.2 for more information about evaluating project risk likelihood and adverse impacts.

Table 4-2. Example of a completed risk registry

Risk ID #	Risk title	Risk event description	Likelihood*	Project objective #1 (e.g., cost)		Project objective #2 (e.g., schedule)	
				Impact[a]	Risk level[a]	Impact[a]	Risk level[a]
1	Availability of key personnel	Unanticipated delays in obtaining approvals or reaching key decisions could occur. The project involves meetings, decision making, and work product reviews by multiple personnel from the project team, ISCO and excavation contractors, stakeholders, and regulatory/redevelopment agencies. The state's orphan site program has been struggling under recent staffing and funding limitations. Significant schedule delays may occur if critical path activities are impacted.	Likely	Marginal	Moderate	Significant	High
2	Accelerated procurement of contractors	Procurement of contractors is being accelerated to meet critical redevelopment schedule deadlines. The scope of work is not yet well defined. The scope of work is based on the current CSM and may be inadequate due to limited characterization data. Bidders may include high levels of contingency in their bids due to the accelerated schedule and limited characterization data. The current procurement strategy includes selection of multiple, independent contractors.	Very Likely	Significant	High	Marginal	Moderate
3	Excavation uncertainty	The volume of contaminated soil that will be excavated is uncertain. Unanticipated drums or other debris may be encountered. Changes in current assumptions about excavation soil volumes or unanticipated materials will affect project cost and schedule. Due to safety concerns, excavation may be halted if drums are encountered, resulting in project delays.	Likely	Significant	High	Marginal	Moderate

Risk ID #	Risk title	Risk event description	Likelihood*	Project objective #1 (e.g., cost)		Project objective #2 (e.g., schedule)	
				Impact[a]	Risk level[a]	Impact[a]	Risk level[a]
4	Release of contaminants above allowable levels	Vapor-phase carbon breakthrough occurs with release of contaminants above allowable levels. Regulatory agency fines could be assessed and could be tens of thousands of dollars. The credibility of remediation with nearby residents might then be diminished, resulting in project delays or increased community outreach costs.	Likely	Marginal	Moderate	Negligible	Low
5	In situ chemical oxidation effectiveness	Incomplete contact may not reduce contaminant concentrations in the source area to target levels uniformly. Additional mobilizations to the site by the ISCO contractor or remedy changes might be needed.	Likely	Critical	High	Critical	High
6	Presence of utilities	Numerous existing utilities are present at the site and adjacent light industrial parcels. Impacts to utilities at and near the site will need to be addressed and may require relocation. Unknown utilities may be encountered during remediation, causing schedule delays.	Unlikely	Significant	Moderate	Marginal	Low

[a] Section 2.2 for more information about evaluating project risk likelihood and adverse impacts.

4.2.2 Computer Modeling and Other Quantitative Evaluation Methods

Quantitative risk evaluation methods provide project teams with a way of evaluating variability in point estimates for project costs, schedule duration, accident risks, and other quantifiable aspects of a project that can be affected by project risks. For example, probabilistic modeling of risk factors can be conducted so that confidence levels are associated with each outcome. This process can help decision makers understand the level of confidence in achieving predicted performance goals, cost, schedule, etc. in the context of project risks. Quantitative risk evaluation methods are more commonly used for projects outside of the environmental industry. For example, USACE requires all civil works projects exceeding a total project cost of $40 million to conduct a formal risk evaluation for cost and schedule (Waters 2007).

Computer models and other quantitative risk evaluation methods have been used to support decision making at hazardous and radioactive waste sites (although model results are not used as a substitute for actual compliance demonstration). Models are typically used to augment expert opinions and facilitate expert review of historical data. As early as 1992, a study that was jointly funded by EPA, DOE, and NRC identified 127 computer models that have been used to support remedial decision making (Moskowitz et al. 1992). Engineering and remedy performance models can be used to predict the impact of project risks on outcomes such as contaminant concentrations and remedial timeframes. As a caveat to any modeling exercise, there are inherent uncertainties in modeling and input parameters. Modeling output is only as accurate as the underlying data and the logic used by the model's algorithm, yet may convey a false sense of precision regarding the results. With risk modeling, as with any other type of modeling, it is important to evaluate sensitivity and the relative probability of different outcomes. Appendix F presents further discussion on the use of models to evaluate project risks.

4.3 Remedy Performance

Several factors can lead to remedy performance project risks, as identified in the examples listed in Section 3. During the project risk evaluation process, assessments should be made of the likelihood and severity of consequences of these project risks. Ideally, the evaluation is performed prior to remedy selection but also needs to be revisited after remedy selection, as described in the following sections.

4.3.1 Prior to Remedy Selection (Predictive Analysis)

The likelihood and potential impact of not meeting remedy performance goals and objectives should be evaluated. The evaluation may be qualitative or semiquantitative.

When evaluating the likelihood that remedy performance goals and objectives will be met, among other site-specific questions, the following should be considered:

- Not all remedial options have equal probabilities of attaining site goals and objectives. Remedial technologies can be classified as conventional, innovative, or emerging to reflect technology maturity and the uncertainty associated with the likely success or failure of that technology by the general remediation industry. Some options may have a higher likelihood of achieving cleanup goals at a higher cost. Decision makers ought to consider the relative cost and performance of various remedial alternatives during remedy selection.

- Remediation is more likely to be difficult at complex sites. Depending on the long-term cleanup goals and objectives, it may not be feasible to meet long-term site cleanup goals using any currently available technology. Long-term site remedial approaches may be needed to achieve ultimate cleanup goals, though interim goals may be set as well. CERCLA and several state cleanup programs have formally acknowledged this difficulty with the term "technical impracticability" and similar concepts. Multiple lines of evidence can be used to evaluate technical impracticability at complex sites, with the following factors contributing to cleanup difficulties:
    - Contaminant-related factors, especially the presence of DNAPL, mass, recalcitrance to degradation, and contaminant distribution (extent and, especially, depth of subsurface contamination).
    - Complex hydrogeologic conditions, such as a wide range of local variations in porosity, hydraulic conductivity, and other parameters. Examples include fractured bedrock aquifers and those with interbedded, low-permeability layers or high heterogeneity.

- Other lines of evidence indicating that cleanup goals and objectives will not likely be met within a reasonable timeframe. Examples include physical access issues due to on-site wetlands, structures, or upgradient (off-site) sources of contamination.
- Cost is generally not a primary justification for site complexity; however, a remedy may be deemed unlikely to succeed if the cost of attaining cleanup objectives is "inordinately high" (EPA 1993).

When evaluating the impacts of not meeting remedy performance goals and objectives, the following site-specific questions should be considered:

- Will failing to meet project goals and secondary or supporting objectives adversely affect the remedy's protectiveness of human health and the environment?
- What impacts on project cost and schedule would result if remedy performance goals and objectives were not met? Would a new technology or remedy need to be selected? Is a contingency remedy (or plan) in place?
- Would there be any economic impacts associated with failing to meet project goals and objectives (e.g., delay of a property transaction, construction of new development)? Would economic impacts affect the surrounding community?
- What are the regulatory impacts of failing to meet remedy performance objectives? Would the project be out of compliance with regulations? Are there potential fines or legal ramifications?

By carefully considering the most important issues, the RRM evaluation process can lead to a better understanding of site data gaps and information needed to reduce uncertainty and better refine the project risk evaluation. For example, a project risk evaluation may reveal data gaps, leading to more detailed site characterization or field testing of promising technologies to reduce project risk.

4.3.2 Post-Remedy Selection (Responsive Analysis)

An accurate evaluation of remedy performance project risks is more certain at sites where the technology has already been implemented, adjusted, or optimized in an attempt to improve performance; however, there is a greater impact of a technology not as effective as expected at these sites because significant resources have already been invested.

When evaluating the likelihood that long-term performance goals and objectives will not be met by an operating system, the following questions, as well as other site-specific issues, should be considered:

- How has the remedy or specific technology performed in the past under similar site conditions? Extrapolating past performance of the remedy or specific technology at this site into the future, how likely is it that cleanup goals and objectives will be achieved within a reasonable timeframe?

- Is it possible that remedy or specific technology failure is a result of engineering factors such as equipment malfunction, operator error, improper design, or application of a technology not suitable for existing site conditions? Have optimization efforts been tried, and have they been successful?

These questions shed some light on the root cause of remedy performance failure and help project managers assess how likely it is that performance will lag in the future, as well as to devise project risk mitigation measures. For example, failure to properly follow the operation and maintenance procedures can lead to equipment malfunctions. Although there may be a way to quantitatively estimate specific mechanical failures or component lifespan, estimates of remedy performance are usually qualitative, based on the team's experience or the interpretation of published studies.

Technology-specific design and equipment failures may occur often enough to be predictable. For example, the likelihood that biofouling or mineral precipitation will reduce extraction well yields is relatively high, as indicated by its frequency of occurrence at other sites. Appendix G presents common types of cleanup technology failures, causes, and their likelihood.

When evaluating the impacts of not meeting remedy performance goals and objectives, consider the consequences of not meeting remedy performance expectations on protectiveness of human health and the environment, regulatory requirements, economic factors, changes to project cost and schedule, and other issues.

4.4 Human Health

Project risks to human health must also be evaluated to gauge the likelihood of their occurrence and potential impact. Examples include the discovery of exposure to emerging contaminants, exposure pathways that were not considered in the human health risk assessment, and the increased risk of accidents affecting community members and site workers. When evaluating the likelihood that a project risk will impact human health, among other site-specific questions, the following should be considered:

- Existing risk assessment paradigms and guidance can be used to evaluate the likelihood of human exposure to contaminants not considered in the original risk assessment. For example, both the EPA and states have published screening levels and guidance documents to evaluate the site-specific importance of vapor intrusion.

- Regarding accidents associated with site transportation, travel,[4] and construction and disposal activities, a significant set of data and statistics on incident and fatality rates is published by the U.S. Bureau of Labor Statistics (BLS),[5] the U.S. Department of Labor, the Centers for Disease Control and Prevention, National Institutes of Health, and other organizations. For

[4] It should be noted that travel risks are normalized by the entire population, rather than those incurring the travel risk. In contrast, increased incremental cancer risk for site contaminants pertain only to individuals that meet the exposure scenario. Thus, the risk of accidents during remediation cannot be directly compared to the risk posed by the chemicals of concern at the site.

[5] For construction occupations (carpenters, construction laborers, equipment operators, electricians, painters, construction and maintenance workers, pipe layers, plumbers, pipefitters, steamfitters, roofers, structural iron and steel workers, etc.), see the BLS table entitled "Fatal occupational injuries, employment, and rates of fatal occupational injuries by selected worker characteristics, occupations, and industries, 2007" (BLS, 2007).

example, the fatality rate associated with transportation is 1.4 fatalities per million miles (U.S. Department of Transportation 2007). In 2007, there were 12.1 construction-related worker fatalities per 100,000 employees (BLS 2007). These values have relatively low uncertainty and therefore do not have any applied safety factors. They are typically reported as incident rates or annual events. Use of these data assumes that future accident rates will be similar to past rates (i.e., that remediation activities will be performed in a similar manner as those under which the tabulated events occurred).

When evaluating the impacts of a project risk on human health, among other site-specific questions, the following should be considered:

- the number of people who will potentially be affected by the project risk
- the severity of the impacts to human health (injury, increased risk of mortality, etc.)

In general, with all else equal, the remedies that involve large amounts of construction and transportation incur higher human health risks. Consideration of in situ remedies that reduce transportation and heavy equipment use might reduce overall project risk.

4.5 Environmental/Ecological

Project risks to the environment and to ecological species must also be evaluated to gauge their likelihood and potential impact. Examples include the possibility of causing greater risk to ecological habitats during remedial activities, energy and resource use, release of GHG emissions, and other sustainability considerations. When evaluating the likelihood and adverse impacts of a project risk on environment/ecology, among other site-specific questions, the following should be considered:

- Negative ecological impacts can be associated with remedial efforts or specific technologies. For example, short-term habitat destruction may be caused by excavation, capping, or dredging. Long-term changes in the functional values of habitats may occur if impermeable features (such as a soil cap or alteration of a stream channel) are used to reduce exposure. Guidance specifies the need to evaluate whether a proposed remedy will cause more ecological harm relative to baseline (existing) conditions (EPA 1999) and provides lists of factors to consider as part of the assessment of short-term and long-term impacts, rates of recovery for biological communities, and designated uses during recovery (U.S. Department of the Navy 2006).

- Depletion of environmental resources through remedial efforts, including energy, water, topsoil, landfill space, and other resources. Under CERCLA, these considerations are secondary and do not factor into the decision of the appropriate cleanup goals or whether site remediation is warranted. However, EPA and many states consider these issues as part of the balancing criteria for selecting the most appropriate remedy. Energy consumption can be assessed by considering on-site consumption of fuel and electricity; transportation of materials, equipment, and staff to and from the site; off-site management of waste; and in some cases, energy requirements to manufacture consumables used for remediation. Tools to estimate energy requirements and use of other resources are being developed and used. For example, AFCEE has developed an Excel-based model called the Sustainable Remediation Tool, while the Navy and Army have jointly developed a model called SiteWise.

- GHG emissions that adversely affect global climate. One goal of Executive Order (EO) 13423 is for federal agencies (e.g., EPA, DOD, DOE) to reduce GHG emissions by 3% annually through the end of fiscal year 2015 (a net reduction of 30% relative to fiscal year 2003). EO 13514 has subsequently required agencies to establish GHG reduction targets through 2020. Some state agencies have established similar GHG reduction programs.[6] GHG emissions currently are not typically evaluated or even estimated during the remedial process. A full discussion of methods to perform this evaluation is beyond the scope of this document; however, more details are provided in the forthcoming ITRC GSR Team overview document. Similar to energy estimation, estimates of on-site GHG emissions are more easily obtained and have more certainty than those for off-site activities. GHG emission factors are available for on-site fuel consumption, electricity usage, transportation, and (to a certain extent) for emissions associated with manufacturing reagents and other consumables. Projects where large amounts of chemical reagents are used or large amounts of waste materials are transported off site for treatment may leave a significant GHG footprint.[7] Active remedies that require the continual use of mechanical or electrical equipment are also more likely to have a greater GHG emissions impact relative to more passive remedies, such as permeable reactive barriers (PRBs) and/or monitored natural attenuation (MNA).

- Other damage to the environment caused by remediation activities can be measured using ecological risk assessment methods to yield an ecological hazard index. For example, a pump-and-treat system that extracts groundwater and discharges it to a surface body of water (after treatment) could have potentially beneficial or detrimental effects on the receiving waters' ability to provide habitat for the natural biota. One evaluation technique is to perform estimates similar to natural resource damage assessments (NRDAs). NRDAs are intended to determine appropriate monetary compensation for temporary or permanent loss of resources and are therefore described in monetary units. The use of ecosystem service valuation techniques, such as the monetary units used for NRDAs, can help decision makers quantify a range of effects based on the specific remedial approach under consideration.

4.6 Regulatory

Changes in regulations and regulatory case workers assigned to a project can present several project risks. The likelihood of regulatory changes can be evaluated qualitatively by maintaining cognizance of applicable legislation and regulatory deliberations using a due diligent approach. For example, being aware that bills are currently being debated or considered by state or federal legislatures can help a project manager gauge the likelihood of new requirements relevant to the

[6] For example, the California Environmental Quality Act (CEQA) requires that "public agencies refrain from approving projects with significant adverse environmental impacts if there are feasible alternatives or mitigation measures that can substantially reduce or avoid those impacts" (CAPCOA 2008).

[7] The importance of GHG emission reduction from the perspective of the project may be significant. On a global scale, the risks are small. For example, if 10,000 different pump-and-treat systems that each produced an average of ~1,000 metric tons of CO_2 annually were shut down, the global anthropogenic CO_2 footprint of ~8 billion metric tons per year will be reduced by only 0.125%. The effect on climate and resulting reduction in global risk is therefore difficult to quantify.

project. The impact of changed or new regulatory requirements clearly depends on the specific issue. It is recommended that a due diligence approach be adopted for evaluating the impact of changing regulations such that project resources are allocated to the evaluation of potential impacts of those changes only after the likelihood of passage and enforcement exceed some rational threshold.

4.7 Economic

As described in Section 3, economic project risks include those with economic impacts that extend beyond project costs. For example, a change in property value associated with site remediation would have an economic impact. In this case, a project risk event such as a deed restriction would need to be evaluated for economic impacts. For most site scenarios, a qualitative evaluation of the likelihood and impact of economic project risks (using a risk register approach, for example) will be sufficient. Larger projects that are thought to have significant economic project risks may benefit from a quantitative evaluation of the economic impacts of different risk scenarios.

4.8 Project Schedule/Staffing/Financials

Environmental remediation project managers are familiar with evaluating the likelihood and impacts of basic project risks on project schedule, staffing, and costs. Additional considerations for project managers when evaluating the likelihood and impact of these project risks include the following:

- Restrictions on project schedule due to sensitive or protected ecological resources (e.g., nesting season). Slight schedule overruns could significantly delay project activities, resulting in a higher risk.

- Uncertainty in cost estimates due to temporal changes in economic market conditions. For example, the sharp increase in steel prices in 2007 significantly impacted the cost of steel storage tanks and granular activated carbon vessels. Changes in oil prices in the same timeframe impacted the cost for petroleum-related products such as geomembranes. Given the dynamics and volatility of the market, cost estimates prepared for the remedy evaluation and selection may no longer be accurate at the time of remedy implementation. Price changes outside of the normal inflation prediction are especially significant. Economic risks would be higher at times of uncertain market conditions.

4.9 Legal

The evaluation of the likelihood of legal issues and potential project impacts is highly project specific. Potential project impacts can be severe. For example, pending lawsuits or court rulings can halt remedial progress. Legal decisions can also expand the scope of a remediation project or change the direction of a final remedy.

4.10 Political, Geographical, and Social

Political, geographical and social issues can pose project risks. The likelihood and potential impacts of these issues on a project need to be evaluated from a site-specific point of view. Certain political and social aspects, such as community acceptance, are typically considered in the remedy selection process; however, community perspectives may change over time in response to population shifts, or controversial, trust-decreasing (or -increasing) events. Several common elements that should be considered include the following:

- Likelihood that a change in stakeholder group membership, community composition, or newly elected officials will change the direction of the project.
- Ongoing local and regional political issues that relate to the project (e.g., water reuse, development, tensions between stakeholder groups, policy changes).
- Likelihood that the project will result in community stress from noise, odors, traffic and other interferences, etc. Public disturbances associated with remedy implementation should be considered during RRM. In general, more aggressive remedial approaches will create greater short-term disturbances.

5. PROJECT RISK MITIGATION

After project risks have been evaluated using a risk register approach and/or other methods presented in Section 4, mitigation strategies are planned and executed to address high-risk threats to project objectives. Appendix D illustrates project risk mitigation through RRM at a hypothetical site. Appendix E provides several case studies illustrating different aspects of project risk management.

5.1 Overview of Mitigation Approaches

RRM project risk mitigation involves the use of specific, preplanned options, approaches, and actions to reduce a variety of project risks. Developing risk mitigation strategies is a collaborative process that may need to be revisited if additional project risks are identified. Project risk evaluations should be refined in response to changes in the scope of the project, new regulations, technology advancements, or other events. Project risk mitigation strategies should be reviewed periodically and updated to account for these changes (DOE 2008). Early planning and continuous communication are key elements to successful mitigation.

> RRM project risk mitigation involves the use of specific, preplanned actions to reduce a variety of project risks. Mitigation strategies may be revisited if additional project risks are identified.

The following general approaches for mitigating risks are described in this document:

- **Elimination:** Under this strategy, the project team modifies project plans to eliminate or avoid a project risk. For example, conducting on-site soil treatment would eliminate the risks of transporting excavated soil to an off-site landfill. Elimination or avoidance methods for project risks are primarily used during remedy selection or technology reevaluation.

- **Reduction:** This strategy does not eliminate the project risk but reduces the likelihood of occurrence or impact of the project risk to an acceptable level. For example, preference can be given to the selection of equipment or technologies with a lower likelihood of failure, even if they cost more. Independent review of design parameters, approach, and selected equipment by knowledgeable staff can reduce errors and minimize project risks. A system for early warning or contingency measures can be established in advance to reduce the likelihood of a project risk occurring.

- **Transfer:** The impact of a project risk is transferred (wholly or partially) to a third party who accepts or shares ownership of the project risk. For example, a fixed-price remediation contractor shares the risk of cost overruns with the project owner. Purchasing environmental insurance is another example of project risk transfer/sharing.

- **Acceptance:** This strategy is used when the project team is unable to or chooses not to eliminate, mitigate, or transfer/share a project risk. For example, project risks that are deemed to be insignificant or unlikely may be accepted by the project team. Also, project risks for which mitigation methods would only create new, greater, high risks may simply be more tolerable given the available options.

Examples of ways to mitigate different types of project risks are presented in the following sections.

5.2 Remedy Performance

5.2.1 Prior to Remedy Selection (Predictive Analysis)

Remedy performance project risks can be mitigated through planning prior to selecting a remedy. A project team can eliminate project risks associated with a particular remedy by selecting a different remedial approach. Such an analysis must consider other types of project risks so as not to eliminate one type of project risk at the expense of creating several other high risks. As illustrated in Table 5-1, project risks are a function of remedial approach. For example, compared with an air sparge/soil vapor extraction system, using a remedial approach like excavation and off-site disposal will reduce remedy performance project risks but may potentially pose a greater risk of accidents, future liability, ecological impacts, and public disturbance.

Table 5-1. Magnitude of project risks as a function of remedial approach

Risk type	Examples of project risks	Remedial approaches				
		Excavation, transport and disposal	**Pump-and-treat**	**Air sparge, soil vapor extraction, dual-phase extraction**[a]	**In situ chemical or biological treatment**[b]	**Passive methods (MNA, barriers)**[c]
Remedy performance	Remedy failure	Low impact	Often ineffective at restoring resources to beneficial reuse	May reach asymptotic removal after several years	May exhibit substantial rebound or incomplete metabolism of contaminant	Long time needed for beneficial use

Risk type	Examples of project risks	Remedial approaches				
		Excavation, transport and disposal	Pump-and-treat	Air sparge, soil vapor extraction, dual-phase extraction[a]	In situ chemical or biological treatment[b]	Passive methods (MNA, barriers)[c]
Human health	Accident	Highest impact due to on-site excavation and transportation	Moderate impact due to long-term site operation	Moderate impact due to operation of equipment and if high number of injection points are needed	Moderate impact if high number of injection points are needed	Low impact
	Air emissions, fugitive contaminated dusts	Moderate to high impact	Potentially highest impact due to long-term cross-media contamination	Potentially high impact due to cross-media contamination	Low impact	Low impact
Environment/ecology	Ecological impacts	High impact due to site disturbance	Low impact	Moderate impact if high number of points is needed and area needs to be cleared	Moderate impact if high number of points is needed and area needs to be cleared	Low impact
	Climate change	Moderate impact, mostly from transportation	Highest impact due to long-term operation of electrical equipment	High impact due to operation of electrical equipment	Moderate impact due to consumable use and transportation	Low impact
	Gain/loss of resources	Potential for high gain of property use but with a loss of landfill space and topsoil	Potential high loss of energy and water	Potential for high gain of property use but with a potential high loss of energy	Potential for high gain of property use and moderate loss of resources	Low impact for loss of financial resources, medium impact for loss of time resource
Regulatory	Notice of violation	Medium/low impact (improper disposal, invalid permit or license)	Low impact	Medium/low impact (possible air emissions and vapor intrusion issues)	Medium/low impact (injection permit, persistent chemical agent)	Low impact
Economic	Cost expansion	Medium impact (changing costs of energy)	High impact (elusive exit strategies)	Medium/low impact (secondary waste stream treatment)	Medium impact (sensitivity of biological systems to disruption)	Low impact
Project schedule/ staffing/costs	Employee turnover	Low impact	Low impact	Low impact	Medium impact (specific expertise needed)	Medium/high impact (specific expertise needed, and remediation rates variable)

Risk type	Examples of project risks	Remedial approaches				
		Excavation, transport and disposal	Pump-and-treat	Air sparge, soil vapor extraction, dual-phase extraction[a]	In situ chemical or biological treatment[b]	Passive methods (MNA, barriers)[c]
Legal	Lawsuit, NRDA	Moderate due to long-term liability	Low impact	Low impact	Low/medium impact (reagents can be deleterious to secondary water quality)	Low/medium impact (emerging issues may present greater impact)
Local, social, political, geographical	Public disturbances	High impact if site is located near public areas	Moderate impact	Moderate impact	Moderate impact	Low impact

[a] Active in situ remedies include multiphase extraction, in situ air sparging (IAS), and soil vapor extraction (SVE).
[b] Injection methods include ISCO, zero-valent iron (ZVI), and bioremediation.
[c] Passive methods include PRBs, which may include reactive materials such as ZVI or biobarriers, and MNA.

Other suggested considerations for mitigating these risks include the following:

- Clearly distinguish between interim/short-term, technology-specific, and long-term cleanup goals and objectives and set metrics that can be measured to determine progress towards these objectives (see, e.g., EPA 2000). NRC (2005) differentiated between functional and absolute objectives: functional objectives are a m eans to achieve absolute objectives. Example remedy performance objectives (functional objectives) include a t arget value for mass of contaminants removed over time or a reduction in mass flux as measured at a specific transect of monitoring wells. Final cleanup goals (absolute objectives) might be to achieve maximum contaminant levels (MCLs) or other numerical levels throughout the aquifer.

- At complex sites where all technologies may have only partial success, evaluate the potential applicability of alternative cleanup approaches. For example, CERCLA, RCRA, and some state cleanup programs recognize the concept of technical impracticability, where specific cleanup standards may not be met within a defined volume of the aquifer known as a TI zone, groundwater management zone, plume management zone, or other similar terminology.

- Some state and federal cleanup programs use groundwater mixing zones as an alternative approach (SCDHEC 1997, MTDEQ 2000, DOE 1998, EPA 2006). A similar concept applied at CERCLA and RCRA sites is alternate concentration limits (ACLs), risk-based concentrations for groundwater that is diluted by discharging to surface water (40 CFR §264 Subpart F, 40 CFR §300; EPA 1987, 2005). Generally, ACLs are not appropriate unless protectiveness of human health and the environment is maintained, no e xposure to groundwater is anticipated, contaminant concentrations in surface water do not statistically increase significantly downstream of the groundwater discharge, etc. (EPA 2005). Alternative approaches do not constitute an exit strategy that disregards protectiveness standards but provide alternative means of attaining protectiveness.

- Evaluate the potential applicability of alternative remedial strategies that do not alter the long-term cleanup goal but provide interim/short-term or technology-specific cleanup goals and objectives. Potential remedial strategies include accepting that a longer timeframe is reasonable and necessary to meet final cleanup objectives, designating specific points of compliance, using an adaptive site management approach, applying technologies sequentially, etc.

- Discuss and select contingency technologies/actions in case of remedy failure. Contingency language can be documented as part of the description of the final remedy. For example, if MNA is the selected remedy for a groundwater plume that will likely stabilize before impacting downgradient receptors, biostimulation could be selected as a contingency remedy.

- Plan an effective performance monitoring program that can provide early warning of potential remedy failure and prompt the implementation of corrective or contingency measures. Prepare decision flowcharts showing the exit strategy and decision points based on monitoring progress towards cleanup goals.

5.2.2 Post-Remedy Selection (Responsive Analysis)

At some sites, technologies have already been implemented and may not be making adequate progress to meet performance objectives. Suggested considerations to mitigate this project risk include the following:

- Effective performance monitoring to provide early warning of potential remedy failure.

- Technology optimization reviews, system adjustments, and monitoring in an attempt to improve performance.

- Implementation of contingency remedies, if applicable.

- At complex sites where no technologies are expected to meet performance goals and objectives, consider alternative approaches such as TI determinations for CERCLA and RCRA sites and consider analogous state cleanup program designations (e.g., plume management zones, containment zones). Technical impracticability decisions made after long-term testing are referred to as “post-implementation” TI determinations. Care must be taken to ensure that the remedy is still protective of human health and the environment and that groundwater cleanup objectives will still be reached within a reasonable timeframe in all areas beyond the designated TI zone.

- At sites where cleanup goals and objectives are based on background concentrations and remedies are not making sufficient progress towards meeting these requirements, consider state cleanup program designations for low-threat site closure criteria as well as refining the definition of background concentrations based on site-specific analysis. Sites may be eligible for low-threat closure if concentrations are in the same range as background levels and do not pose excess risk to human health and the environment beyond background conditions. Simple statistical methods can be used to determine background concentrations using a set of monitoring data and ProUCL Statistical methods (EPA software) are described in guidance documents (Singh et al. 2007, FDEP 2008, EPA 2002, NAVFAC 1999, Helsel 2005). These methods are incorporated into software packages like ProUCL, which makes it easy to analyze data sets with nondetects or nonparametric data distributions.

5.3 Human Health

Mitigating project risks to human health requires an evaluation of the root causes and sources of high risk. A thorough analysis of all human health–related project risks must be site and project specific. To illustrate the RRM process, below are some considerations for mitigating the risk of accidents associated with implementing environmental remedies (one type of human health project risk):

- Prepare and implement a thorough site health and safety plan and accident prevention plan. More information about the content of such plans is provided in the Code of Federal Regulations and guidance documents (29 CFR §1910.120 and §1926, USACE 2008).

- Reduce transportation, whenever possible, through the use of teleconferencing for project meetings, supervisory control and data acquisition (SCADA) systems and other remote access technology for treatment system operation and maintenance, using local project team staff and vendors when possible, and treating wastes on site or transporting them to local facilities. Rail transport has a lower risk of accidents than automobile traffic. In general, employ good optimization procedures and efforts to ensure that all data necessary to reduce accident-related project risks are collected (ITRC 2004).

- All else equal, use the minimal amount of active remediation needed to achieve cleanup goals and objectives. For example, excavations have a higher accident risk per cubic yard at deeper excavations when compared with surface soils. Consider using a combination of active excavation, land use controls, capping, and other management approaches to reduce the risk of accidents instead of complete excavation.

5.4 Environmental/Ecological

As with other types of project risks, mitigation approaches for environmental/ecological project risks need to be considered on a site-specific basis by the project team after identifying the key causes. Several examples of ways to mitigate environmental/ ecological project risks include the following:

- Consider the species' characteristics and vulnerabilities to mitigate ecological disturbances from environmental construction activities. Scheduling construction activities to avoid mating or nesting seasons may reduce ecological impacts associated with temporary habitat destruction, excessive noise, or vibration.

- Per existing guidance, prepare and implement a site restoration and monitoring plan to restore any habitat that was temporarily destroyed and promote return of habitat and indigenous species and protect against invasive species (see, for example, NAVFAC 2004).

- To reduce project use of environmental resources such as energy and water, use conservation and optimization techniques.

- When active remedies are used, ensure that only necessary remedial action is performed.

- Check that equipment is properly sized; oversized equipment is less efficient than equipment operating near its design capacity.

- Use high-efficiency motors and/or variable-frequency drives.

- Use energy-efficient lighting as appropriate

- Use pulse extraction systems, as appropriate, to increase well efficiency.

- Suspend system operations during periods of low effectiveness (e.g., suspend free-product recovery during periods with high water table).

- Review and optimize the selection of equipment and treatment trains to improve energy and water efficiency.

- Use renewable energy such as photovoltaics or wind turbines to supply energy for remedial systems when viable. If possible, shift peak energy consumption to off-peak times and use a greater percentage of renewable energy. Several references provide more information about renewable energy options and other GSR best practices (e.g., EPA 2008a, 2008c).[8]

- Use biofuels to reduce GHG emissions for construction equipment and transportation vehicles (EPA 2007). Success stories of the use of renewable energy for site remediation are documented in several publications, including the EPA's Green Remediation Primer, fact sheet, and other publications (EPA 2008a, 2008b; Dellens 2007). It has been estimated that the use of B20 biodiesel (20% biodiesel) reduces life-cycle GHG emissions by 10%, and B100 biodiesel (100% biodiesel) reduces life-cycle GHG emissions by more than 50%.

- Minimize losses in groundwater resources associated with pump-and-treat systems. The purpose of groundwater remediation is to restore aquifer resources. Consider minimizing losses during treatment: reinjecting treated groundwater back into the aquifer or finding beneficial uses for treated groundwater, such as potable distribution, irrigation, habitat enhancement, or enhanced groundwater recharge. Note that water losses for one user may be beneficial for another. Water removed from an aquifer and discharged to surface waters or to a wastewater treatment plant practicing reuse may still be usable by others downstream.

[8] See also: ITRC. In review. *Green and Sustainable Remediation: State of the Science and Practice*. Forthcoming overview document by the Green and Sustainable Remediation Team.

- Landfill space is another important resource for which use should be considered as a secondary adverse impact on the environment. The resource cost may not be reflected in landfill disposal fees. Minimize the use of landfill space through on-site treatment of contaminated soils, reduce volume of soils taken off-site for disposal, and consider reuse opportunities for the impacted material, such as the use of petroleum-impacted soil for the manufacturing of asphalt.

5.5 Regulatory

Mitigation of regulatory risks requires keeping up regular communication and acting in ways that strengthen relationships and build trust with site regulators. Taking steps to stay informed about new regulatory requirements and their potential impacts on the project is another way to mitigate regulatory project risks. Participating in public comment periods and regulatory development as part of expert panels and other professional activities can help shape and disseminate information about emerging regulations and help regulators anticipate and address practical concerns associated with the new law. For example, the DOD MERIT program addresses regulatory risks of emerging contaminants by tracking regulatory developments for specific contaminants, conducting research, and taking other actions where appropriate.

5.6 Economic

There are a number of different ways to mitigate economic project risks, including approaches to mitigate the underlying causes of such risks, through innovative funding mechanisms, environmental insurance, and other options. Other approaches include adjusting cost estimates and project decisions to reflect changes in the market outlook, incorporating financial contingencies in cost estimates, and potentially implementing a remedy in a phased approach. It should be recognized that economic impacts to projects are almost always associated with other project risks, both as causes and effects. Economic impacts should always be considered as a dimension incidental to other project risks.

5.7 Project Schedule/Staffing/Financials

Project managers are most familiar with mitigation methods for managing project schedule, staffing, and financials. In addition to standard project management techniques (e.g., creating a flexible and realistic schedule, building redundancy into project staffing), innovative approaches such as performance-based contracting have been successful. Performance-based contracts mitigate project risk by transferring it to the site remediation contractor, who is, ideally, better equipped to manage and mitigate project risk.

5.8 Legal

Many legal issues are addressed and mitigated in standard project work plans and reports through the consideration of a variety of regulatory cleanup requirements and relevant regulations. Still, legal issues can arise that are not adequately incorporated into standard environmental reports and decision making. Liability for residual contamination can be avoided by using technologies that permanently destroy contaminants instead of transferring them to another media (e.g., into air) or another location (e.g., off-site landfill). Maintaining better working practices by addressing stakeholder concerns and potential liabilities (e.g., off-site migration, human exposure pathways) may mitigate legal project risks.

5.9 Political, Geographical, and Social

Mitigation approaches depend on the nature of those site-specific political, geographical, and/or social project risks that are determined to be significant. For example, if environmental construction activities are being conducted in residential communities or other public areas, care should be taken to minimize the project's impacts on residents after soliciting and incorporating suggestions from the community for incorporation into specific plans to address community concerns. For example, if a large number of trucks are transporting construction material to and from the site, it is useful to understand the schedule and routes of local traffic and develop a plan to avoid heavy congestion. Noise and odor control is sometimes an important aspect of a remediation project. A site perimeter monitoring program could be considered to help prevent impacts to the public. Community involvement activities should be implemented not only to keep the public informed about the remediation progress but also to solicit community feedback and suggestions.

With the prevalence of the "not-in-my-backyard" attitude, communicating project risk management plans and accident prevention plans can help to mitigate political pressures instigated by the public or other jurisdictions. These are especially helpful when one community is perceived as being affected by a remediation project being performed in another community (i.e., environmental justice issues). Project risks caused by crossing political or social boundaries with waste (especially hazardous waste) can be mitigated through evaluation of other alternatives, detailed planning, and effective communication.

6. PROJECT RISK MONITORING

Project risk monitoring is used to track the effectiveness of risk mitigation measures, implement changes if needed, and ensure that managers remain aware of the context within which past risk management decisions were made. Project risk monitoring is implemented as soon as mitigation measures for project risks have been planned and implemented.

Appropriate, specific project risk monitoring methods and techniques depend on the nature of the particular project risk being managed. Mitigation measures may be procedural, administrative, engineering, analytical, active controls, or other component modifications. Despite the diversity in monitoring techniques, managers can remain on the alert for indicators that warrant responses, including the following:

> It is essential to track the effectiveness of project risk mitigation measures through monitoring. Feedback from project risk monitoring could be used to inform appropriate risk management activities.

- observations that contradict the salient components of the planning process
- type of risk
- probability of risk
- consequences

- changes in conditions under which the project will be conducted (e.g., changes in end land use, changes in economic incentives for a project)
- emerging or unanticipated project risks (e.g., emerging contaminants)
- changes in project objectives
- scope modifications
- changes in stakeholders, their views, perceptions, or positions

Observing indicators and performance measures during project risk monitoring should produce feedback information that can then be used to inform the appropriate project risk management activity. Newly discovered project risks should be processed in their entirety just as if they were identified in the early planning stages of the project.

Monitoring project risk information can sometimes support decisions that substantially change the course of the project. Project risk monitoring may indicate that project risk mitigation activities are not sufficient and that an alternative management approach is warranted to achieve project objectives. For example, a highly complex site with DNAPL in deep-fractured bedrock may be identified as being at high risk of not satisfying the site characterization and cleanup objectives. Mitigation measures such as alternative end points, alternative remedial technologies, contingency actions, and improved project risk mitigation and monitoring methods may be considered. There may be risks that cannot be adequately mitigated, in which case the risks must be avoided, transferred (to an entity that can tolerate the risk without unacceptable harm), or tolerated. Note that failure of mitigation activities does not necessarily reflect on the effectiveness of the project management team or the project risk management plan.

At some sites, cleanup can be progressing at an expected pace that becomes redefined as unacceptably slow due to changes in project demands or site circumstances. For example, an impending property transaction (with changes to planned future land use) may provide incentive to select an aggressive, short-lived removal strategy instead of a long-term remedial strategy. Substantial schedule delays may present an unacceptable project risk because remedial objectives must be reached within a reasonable timeframe. Therefore, a change in project risk mitigation strategy will be needed.

Changing site conditions, such as observation that the rate of contaminant transport in the subsurface exceeds the rate of natural attenuation mechanisms, can also impact remedy performance and increase project risks. Preventing off-site migration may require more aggressive remedial action through optimization, additional system capacity, or a modified or alternative remedial approach. Even if the planning and execution of project risk mitigation measures are performed effectively, monitoring the effects of these mitigation measures can be informative for future projects and future project managers.

All elements monitored and reported are potential beneficial responses to the feedback provided by the project risk monitoring information. It is essential to track the effectiveness of project risk mitigation efforts by monitoring the project and evaluating how it is responding to mitigation efforts over time.

7. PROJECT RISK REPORTING

> Documentation and reporting of residual project risks should communicate their potential impacts, effectiveness of mitigation strategies, and lessons learned.

Project risk monitoring results must be documented and reported to communicate the residual probabilities and effects of project risks as they are being managed. Similarly, the report should include a discussion of project risks that were expected, risks that were incurred, how risks were mitigated, as well as lessons learned from RRM activities. The risk register is an excellent tool for keeping track of all project risks. The register should be updated to document risks incurred during the project and can be included in periodic and final reporting documents. Some efficiency can be realized if the project team agrees that updating the risk register (taken from the project risk management plan) satisfies project risk reporting requirements.

More project management value can be derived from a more thorough treatment of project risk reporting. Documenting the entire life cycle of RRM elements from identifying to monitoring project risks can reveal mitigation strategies and approaches that worked, can be consolidated, function symbiotically, and were found to be effective and efficient, or alternatively, can illuminate failure mechanisms for strategies that were ineffective and drained project resources providing little value. Both eventualities can provide important lessons learned that can be used to make RRM more productive, successful, effective, and efficient in other future projects.

Additionally, documenting and reporting RRM activities and results can inform project reviewers in the event that a project audit is triggered. This record can demonstrate that due diligence was expended to manage remediation project risks and that responsible project management practices were engaged. The ease or difficulty in achieving project objectives while managing project risks can affect future remediation decisions, including technology optimization and the establishment of achievable remedial action objectives.

8. STAKEHOLDER CONCERNS

For the purpose of this document, the term "stakeholders" includes all individuals or groups that have the potential to be negatively impacted by the project. Examples of stakeholders include community members, business owners, employees, local governments and tribes, local utilities, developers, and realtors.

8.1 Background

> Stakeholders include all individuals or groups that have the potential to be negatively impacted by the project. Stakeholder involvement through RRM builds trust, fosters respect, and improves the quality of decision making.

Coordination with stakeholders and the reasonable opportunity for meaningful involvement in a project are required by various federal government, state, and sovereign tribal nations' environmental statutes, ordinances, and acts.

Given the financial, technical, and regulatory complexities inherent in the remediation process, it is highly recommended that affected stakeholders have input to all phases of project decision making. If stakeholders are given the opportunity to have meaningful and substantial participation in the decision-making process, they are more likely to support difficult policy, budgetary, and technical decisions. In addition, positive interaction through quality community involvement programs fosters respect between community members and project decision makers, one of the foremost factors determining whether communities accept project remedies.

Stakeholders often have valuable information about site characteristics, history, and future site use that can improve significantly the quality of remediation process decisions. Stakeholders generally show great interest in the contamination problem, the restoration process, and in the associated risks to human health and environment. The project benefits from the careful explanation of findings and proposals that may be needed and the extra work needed to resolve site issues raised by stakeholders. Stakeholders also tend to be open-minded about innovative technologies, particularly if they offer an increased chance of success at lower cost, compared with mature technologies. Stakeholders should always have access to information that goes into the remediation decision-making processes and be included in the decision-making process. It is important to provide community members with information in a timely way and address their concerns.

8.2 Methods for Stakeholder Involvement

Where there is significant community interest, environmental decision makers may find it useful to go beyond a one-time or occasional community meeting and create a project-specific community advisory board with representatives from each segment of the community. Such boards have improved community relations at numerous DOE, DOD, and private sites across the country. Community advisory boards and/or restoration advisory boards often provide remedial project decision makers with "one-stop shopping" for community input. Relying on community advisory boards or restoration advisory boards can help work out differences among various community members, avoiding any guessing or assuming which community interest represents the public.

8.3 Common Stakeholder Concerns

Concerns common to all stakeholders typically relate to health issues, economic or monetary issues, inconvenience, and natural resource issues. Issues related to health and risks should be discussed in the stakeholder forum during the remedial investigation phase of the project. Not only do releases of hazardous substances pose public health risks, but frequently the investigative and remedial processes generate noise, dust, and other inconveniences. Community stakeholders are a diverse body and may be concerned about the following:

- health effects
- property values
- utility costs (especially water)
- jobs, tax revenues, profits
- traffic
- noise
- odor

- length of time required for remediation
- natural resource issues

Project stakeholders are usually more willing to seriously consider emerging technologies and approaches when conventional technologies are known to be inefficient. To counteract the project risk of selecting an ineffective remedial technology, stakeholders are sometimes willing to accept and manage the uncertainty associated with the use of emerging technologies with the goal of mitigating a larger project risk by accepting a new technology within their particular management constraints.

The level of stakeholder participation and the appropriate process for the inclusion of stakeholders must be tailored to each site and situation; however, from the formulation of the problem through the exit strategy, stakeholder issues, needs, and concerns must be taken into account. An effective communication mechanism between the expert team and the stakeholders must be in place throughout the remediation process from beginning to end. For example, DOD requires that stakeholders be involved through the Restoration Advisory Board process (32 CFR §202).

9. SUMMARY AND CONCLUSIONS

This guidance document describes a systematic approach to addressing project risks related to environmental site remediation, termed "remediation risk management" by ITRC. RRM elements are customized from general project risk management principles and are specific to site remediation projects. RRM takes into account similar risk management practices previously documented by ITRC, states, and federal agencies. The following summarize key points about RRM:

- Although contaminant-related human health and environmental risks drive environmental remediation projects, other secondary risks associated with remediation activities are also important. RRM focuses on managing these secondary project risks.

- It is valuable to apply RRM to a variety of site remediation projects under different regulatory cleanup programs and at different stages in the cleanup process. RRM can be scaled to appropriately address projects of different size and complexity.

- RRM has several different elements that fit into a sequence of planning, execution, and verification. Project risk management using RRM can be an iterative process. Changes to initial project risk management plans should be made to refine the approach based on monitoring information or in response to the identification of new project risks.

- The five elements of RRM include project risk identification, evaluation, mitigation, monitoring, and reporting. These analyses should be documented in a site-specific project risk management plan (see Appendix C for example).

- The first step in RRM is to identify project risks. A variety of types of project risks are considered under RRM, including those associated with remedy performance; human health;

environment/ecology; regulations; economics; project schedule and staffing; finances; legal; and political, geographical, and social issues. Project risk identification is a site-specific exercise typically conducted by the project team through brainstorming with input from other stakeholders. Examples of common project risks are described in Section 3.

- The second step in RRM is to evaluate project risks to determine their importance, ranging from low to high. Two components to project risk evaluation include (1) an assessment of the likelihood that the potential project risk event will occur and (2) an evaluation of the severity of consequences. High risks are those with a high likelihood of occurrence and/or significant adverse impacts. Qualitative and quantitative methods for evaluating different types of project risks are described in Section 4, along with examples.

- The third step in RRM is to mitigate project risks that are determined to be significant. Mitigation strategies include eliminating, reducing, or transferring project risk. For example, a different technology may be selected to avoid or eliminate a technology-specific project risk. Treatment system operation may be optimized to reduce project risk. Environmental insurance may be purchased to partially transfer project risks. Other project risks may be accepted. Examples of different mitigation strategies for commonly encountered project risks are described in Section 5.

- The fourth step in RRM is to monitor project risks to determine whether project risk mitigation strategies have been successfully implemented and are effective. Project risk monitoring also seeks new information that may change the project team's assessment of the nature, likelihood, or severity of potential project risks, thereby requiring adjustments in plans. More details are provided in Section 6.

- The fifth and last step in RRM is to report the results of monitoring by summarizing and communicating them to decision makers and other stakeholders. Reporting can be facilitated by keeping a repository for all current and historical information related to project risk (e.g., risk register). More details are provided in Section 7.

- Overall, RRM is a process to inform project managers and help them to make decisions that balance various project considerations to better meet secondary project objectives, while still achieving overall project objectives such as protecting human health and environment. The outcome of RRM and subsequent decision making can be improved by involving multiple stakeholders and providing them with reasonable opportunities to have meaningful and substantial participation. In most cleanup programs, public outreach and involvement are already occurring and may be a regulatory requirement. RRM also provides a process for taking the concerns of the public and other stakeholders and assessing them in the framework of project risks.

RRM supports the overall objectives of environmental remediation: removing contamination, restoring resources, and closing sites. This document provides a general, systematic thought process for planning and implementing project risk management strategies for site remediation. The process at a generic site is illustrated in Appendix D. State and federal agencies have adopted a variety of best practices for mitigating and managing project risks. ITRC intends that this document be a guide for project managers throughout the risk management process, as a supplement to existing state or federal guidance. Agencies can use this guide to facilitate project oversight and/or develop their own framework or best management practices for addressing project risks specific to their cleanup program.

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Appendix A

RRM State Survey and Addendum Results

RRM STATE SURVEY AND ADDENDUM RESULTS

A.1 SURVEY OF STATE REMEDIATION RISK MANAGEMENT PRACTICES

A.1.1 Overview

To gain an understanding of states' interest in and knowledge of the topic of remediation risk management (RRM) to aid in discussion with outside parties, the ITRC RRM Team surveyed ITRC member states through the ITRC State Point of Contact (POC) network. This survey was conducted between August 4, 2008 and September 17, 2008 (the survey questionnaire is provided as Attachment A-1). The results of this survey aided the team in the development of the technical and regulatory guidance and overview documents. Although some of the issues raised in this survey may not appear to apply to every specific state program today, topics related to anticipating and managing remedial shortfalls are being raised by the regulated community. The RRM tech/reg guidance document is intended to provide the necessary information and framework to assist state regulators in these discussions with outside groups, and the goal of this survey is to capture the current status of how these remedial issues are being addressed.

This survey focused on identifying the degree to which states implement formal RRM, what priorities they set, and how they perform oversight of the various stages of remediation. Responses gathered included feedback on technical impracticability determinations and current modeling practices. It also asked the respondents to identify preferred types of training and information tools. Thirty-one people representing 19 states responded to the survey. The majority of the respondents worked for state environmental cleanup and hazardous waste management organizations. Also represented were underground storage tank management, water quality, and Superfund programs.

A.1.2 Summary of Survey Results

<u>Use of Formal RRM Processes</u>

For this survey, RRM was defined as "a process through which all risks related to the remediation process—remedy selection, execution, and completion—are comprehensively addressed to manage and minimize uncertainties in the cleanup process, ensuring protection of human health and the environment." Based on this definition, nearly half (48.4%) of the respondents stated that they used formal RRM processes in their cleanup efforts (question #3). A little fewer than a third of the respondents (32.3%) indicated that informal processes were followed, and 19.4% of the respondents indicated that RRM was not really addressed in cleanup efforts. In response to question #4, 26 respondents reported that their state had formally applied RRM techniques in the following program areas: CERCLA, RCRA, voluntary cleanup programs, brownfields, dry cleaning, and USTs.

RRM techniques were most frequently applied in voluntary cleanup programs (69.2%), with CERCLA, RCRA, and brownfields programs a close second, all at 61.5%. Twenty-three percent of the respondents identified USTs and dry cleaning programs. One respondent stated that RRM techniques were applied formally in all program areas that deal with hazardous substance remedial actions. Other program areas identified were state and DOD cleanup programs, a state water quality assurance revolving fund, and CERCLA.

Formally Identified Sources of Remedy Selection Risk

When asked in question #5 to select which sources of project risk associated with remedy selection are formally identified and addressed in their state, 58.3% of the respondents selected the project risks associated with various remedial options/alternatives, while 50% identified the project risks to selected remedy posed by technical constraints (e.g., challenging geology, technology limitations), short-term risks posed to site workers, and risks remedial actions pose to ecological receptors. Other remedy selection risks included the following:

- changes to required criteria/cleanup drivers (e.g., MCLs, ARARs) (41.7%)
- project risks associated with remedial technologies and transport of materials, soil, sediments, and/or waste posed to adjacent communities (37.5%)
- system failures (33.3%)
- liability or financial concerns associated with remedial actions (25%)
- remedy failure because of poor CSM or insufficient consideration of alternatives to active remediation (both 16.7%)
- cost escalation (12.5%)

One-third of the respondents indicated that none of the above sources of project risk associated with remedy selection were formally addressed in their state but that the following were informally addressed as provided in the survey comment section:

- All but the first (risks posed by changes to required criteria/drivers [e.g., MCLs, ARARs] are considered in the work plan review process, although not specifically addressed unless a specific risk is identified).
- Informally addressed by CERCLA and RCRA remedy selection criteria.
- Most of the above are addressed informally (and haphazardly) on a case-by-case basis.
- Program evaluates end-point achievement of target criteria expressed as numeric remedial goals, environmental consultants responsible for remedy selection; implementation, and seeing that verification goals are met.
- Remedy failure due to incomplete/improper evaluation of site conditions.
- Technical constraints, risk of cost escalation, risk posed to adjacent communities, risk posed to ecological receptors, risk of system failures.
- We consider all of these in our process, but not all are formally addressed.

RRM Practices Related to Site Characterization

In response to question #6, 21 of 26 respondents stated that their program allowed interim or stabilization system construction and implementation without completing site characterization. However, only four of these respondents indicated that their program allowed final remedial system construction and implementation without the completion of site characterization (question #7). One state allowed final remedial system construction and implementation in the case of emergencies or because of presumptive remedies (questions #8). Another applied a remedial action plan based on complete site characterization but allowed for a reevaluation of an interim remedy as a validation before a final remedy is implemented.

For question #9, 28% of the 25 respondents indicated that, after a site has been characterized and a remedy has been selected, significant attention was placed on RRM to identify, address, and manage possible failures. Thirty-two percent indicated that moderate or some attention was given, and 8% indicated that little or no attention was given. Eleven respondents gave additional comments:

- A thorough semiannual to annual case review is performed. Higher-priority sites are reviewed more frequently.
- Attention is due to prime programmatic oversight at verification of successful remediation stage; the Department of Environmental Protection is hands off until this point unless permits are required to implement remedy.
- Contractors and responsible parties are mainly responsible to ensure minimal risk from approved remedial system.
- For long-term remedies, periodic reporting and evaluation are required to demonstrate progress toward cleanup goals. For short-term remedies, a final report demonstrating compliance with state cleanup standards is sufficient.
- Periodic review required by regulations (6NYCRR375).
- Permit conditions (RCRA) require effectiveness evaluation and remedy modification if not effective.
- Quarterly monitoring is typically required.
- Review of performance monitoring data and optimization studies are conducted, and these activities are not viewed as a formal RRM process.
- Some staff continue to follow performance monitoring data to be ready or able to require/ request changes and/or modifications to design or operation of operating systems. Our program would benefit from presentations based on real projects demonstrating how to review data, evaluate potential for shortcomings or failures, how to change or improve monitoring to further evaluate potential failure, and how to modify systems to reduce potential for or eliminate failure.
- The periodic reports must document any problems encountered and how they were resolved.

In response to question #10, nearly half (47.8%) of 23 respondents stated that only some attention was focused on RRM to identify, address, and manage possible failures where site characterization is periodic or ongoing. Moderate attention was cited by 30.4%, little or no attention by 13%, and significant attention by 8.7%. Some respondents pointed out that their state's RRM efforts depended on the priority of the site, often based on its sensitive receptors, and project manager workload. Additionally, they stated that monitoring of receptor pathways determines the level of effort required and that periodic reporting and evaluation are used to demonstrate progress toward cleanup goals for long-term remedies. This reporting is often informal.

Remedial Performance Risks

Respondents indicated that, when it is found that the selected remedy does not meet remedial action objectives (RAOs), they most frequently changed the remedy or technology, then looked at adjusting the time to completion objective, followed by considering other alternatives to active remediation such as monitored natural remediation/attenuation (question #11). Less frequently, they changed RAOs or considered TI waivers. Examples of other options employed were institutional controls (ICs) to manage exposures; moving the point of compliance; or implementing a different, or successor, remedy in the treatment train if the consultant or responsible party (RP) could not verify that regulatory numeric remedial goals were being met. One respondent noted that it seemed that failed or poorly performing systems continued to operate with little change or are suspended.

In response to question #12, most respondents (91.7%) stated that they conduct an additional site characterization when new risks are identified at a site. Identifying and characterizing new or recalcitrant chemicals and incorporating new cleanup/risk levels or lower detection limits when applicable were identified by 66.7% of the respondents. A little more than 54% incorporate new ARARs, 50% assess any changing environmental conditions (floods, geomorphologic), 33.3% adapt remedies to protect cultural or archeological resources, and 16.7% indicated that they also responded in other ways. One respondent's state identified and characterized the new risk, identified the cause of new risk, and then changed regulatory goals as appropriate. Another indicated that a response was chosen depending on what risk was evident and its severity.

Some respondents cited the difficulties with fully characterizing sites as a basis for remedy selection. One respondent stated that failure to adequately characterize is prime source of failure since the remedy does not account for all site conditions. Another example given was that, due to the segregation of various technical responsibilities, it can be difficult to review new data; characterize the type and magnitude of new risks; and communicate specific requirements for additional investigation, monitoring, or a change in remedial system design and operation.

Remedy Selection Process

Seven out of 22 r espondents used other criteria in their state's remedy selection process in addition to the nine CERCLA and/or seven RCRA criteria (question 13). Nine respondents gave examples of criteria used in their state:

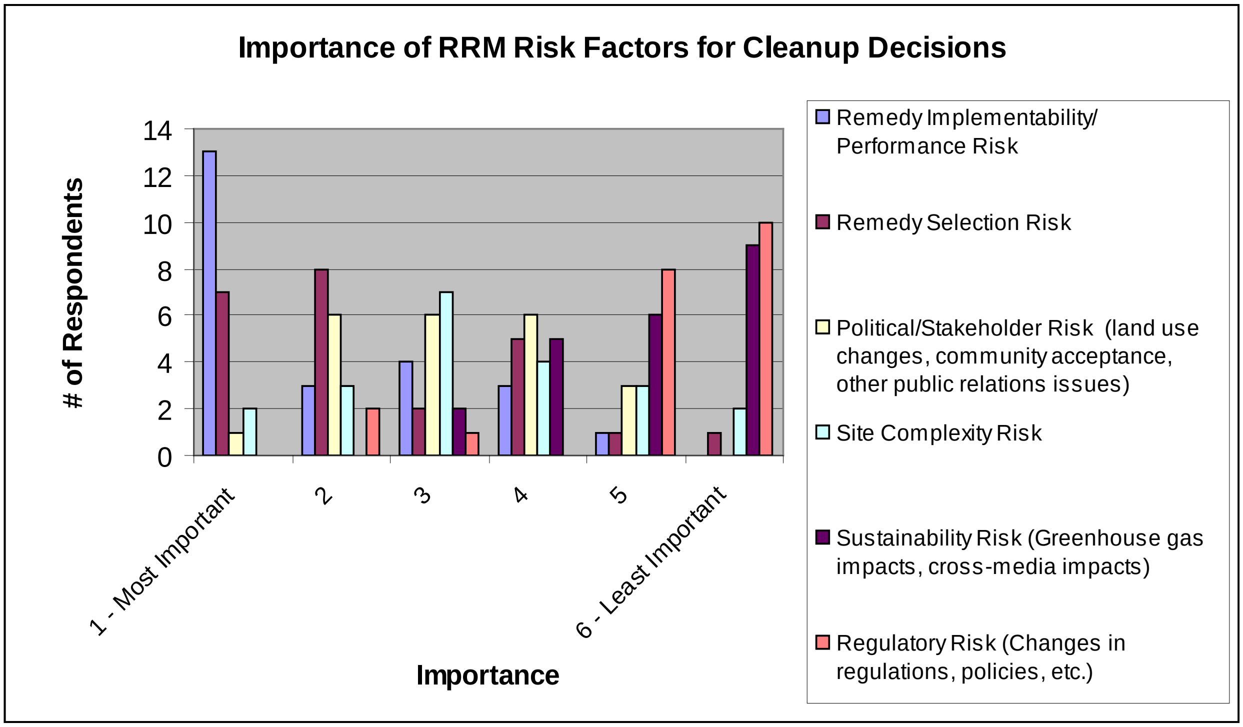
- Solid waste management unit guidance document of the Georgia Environmental Protection Division.
- California Health and Safety Code section 25356.1 statement of reasons, California CEQA, public participation (PP) requirements (information regarding CEQA and PP requirements is available on the Department of Toxic Substances Control Internet site).
- Reasonableness of cost.
- In the Voluntary Remediation Program there are four threshold criteria and seven balancing criteria in statute to which remedies must be evaluated.
- Our state looks for best engineering and best management practices in all of our remediation projects.

- Remedy selection is private party–driven towards numeric goals. Private party decisions often incorporate cost vs. time differently than CERCLA/RCRA approach and do not always evaluate remedy globally but rather from a site perspective (e.g., excavation to elsewhere ranks higher). Remediation regulations are structured to prefer a permanent remedy for site.
- See 6NYCRR375-1.8(f).
- California law (CEQA) requires the lead agency to evaluate the potential for the "project" to have a negative effect on the environment and, if needed, to spell out the mitigation measures to offset negative effects. Process can be very complex and time-consuming, but generally for our project we are able to file a Notice of Exemption, and these decisions still require public comment.
- Our program has five established cleanup standards: two residential (default and site specific), two nonresidential (default and site specific), and one that requires engineering or ICs to control risk in the event the first four cannot be met (referred to as Type 5 cleanup). Our remedy selection process evaluates the effectiveness and timeliness of the remedy to bring the site into compliance with our cleanup standards.

In response to question #14, 21 of 24 respondents stated that less than one third of the cleanup sites in their state/program area have remedies revised or enhanced to address RRM concerns after implementation begins. The remaining three respondents said that remedies are revised or enhanced between one- and two-thirds of the cleanup sites.

RRM Risk Factors

When asked to rank the importance of RRM risk factors for site cleanup decisions in their state/program area, most (13 of 24) respondents identified remedy implementability/performance risk as the most important, and none ranked it as least important (question #15). Figure A-1 depicts the result of their ranking.



Note: The legend is ordered Most Important to Least Important in the importance of RRM risk factors for cleanup decisions.

Figure A-1. Importance of RRM risk factors for cleanup decisions.

<u>Sources Requesting Remedy Revisions</u>

Table A-1 shows how the respondents ranked the frequency with which sources requested remedy revisions for question #16.

Table A-1. Frequency of requests for remedy revisions

Answer options	1: Most frequent	2	3	4	5	6: Least frequent	Response count
Responsible party request	5	12	3	0	2	0	22
Scheduled administrative reviews (e.g., 5-year CERCLA review)	8	5	3	2	1	3	22
Internal staff request	7	1	5	4	2	2	21
Community concern	0	2	5	9	3	2	21
Request from elected or nonagency government official	0	0	2	6	10	3	21
Other sources	3	0	0	0	2	1	6

<u>RRM Alternatives Considered</u>

For question #17, all 24 of the respondents identified MNA as an alternative that is considered in their state/program area. Twenty-three of the 24 identified land-use controls (LUCs), LTM (20), TI waivers (16), additional modeling (15), combination of alternatives depending on s ite characteristics (13), ACLs (11), and mixing zone application (MZA) (5). Figure A-2 depicts the distribution of considered alternatives across the whole.

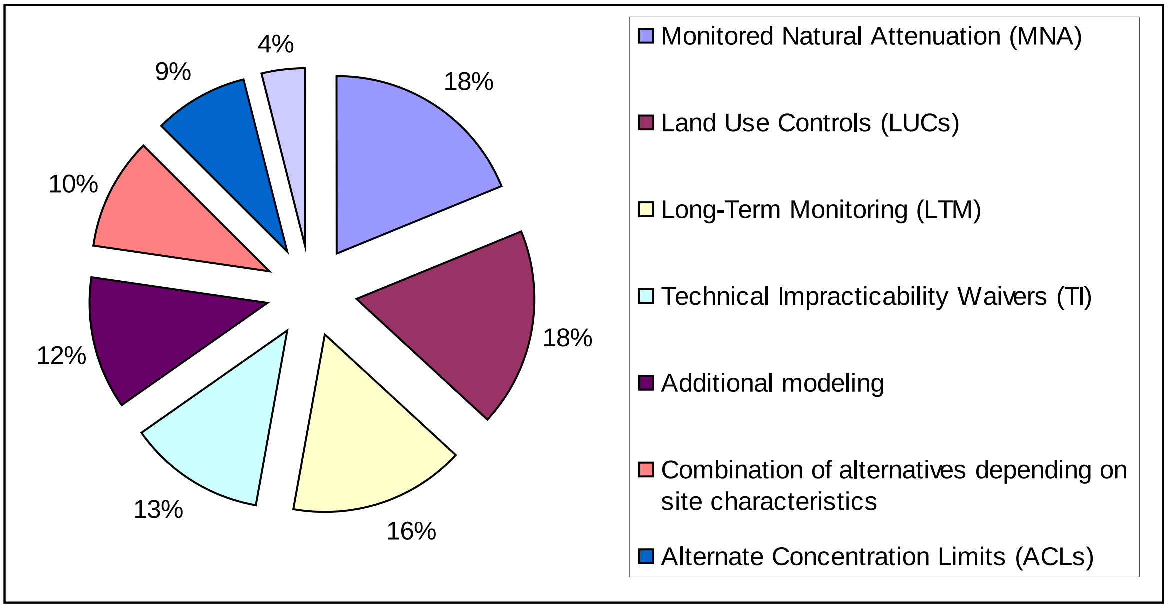


Figure A-2. RRM alternatives considered.

Further explanations of how combinations of these alternatives are considered follow:

- For complex sites where some areas may not have been impacted.
- For example, for cleanup that does not accomplish unrestricted use, LUCs are also included as part of the remedy to restrict the site.
- A combination of technologies and actions may be required to address all exposure pathways.
- More than one of the alternatives might be implemented concurrently. LUCs are generally required with LTM, MNA, and TI, for instance.
- Often remedies selected are active with follow-up MNA.
- Active remediation technologies combined with MNA and LUCs, engineering controls (ECs) combined with MNA and LUCs.
- LUCs are usually be coupled with another factor.
- Flexible regulations preference for permanent remedy drives the remedy choice by the RP. LUC and MNA are permissible under regulations and popular elements in remedies, often after more an aggressive initial remedy is completed but not to final numeric goal (either by design or as a result of “failure”).
- Generally speaking, we do not accept mixing zones. Depending on site conditions, an LUC may be required, and if concentrations of contaminants in groundwater do not warrant active remediation, then the program can also approve MNA. Program would benefit from specific technical examples from real projects how and when LTM is used vs. MNA or how to determine whether MNA is actually viable and what type of MNA monitoring data actually demonstrate natural attenuation (and what kind) is dominant.

- Referring to alternatives "To RAOs" (in our case, established cleanup standards). Only one of our cleanup standards (the ECs and ICs) would allow the use of LUCs, LTM, TI, and additional modeling.

The LUCs alternative was also considered by 61.9% of the respondents' states/program areas when the selected remedies are making progress toward RAOs but are not on track to meet them during initial projected time to completion (question #18). Additionally, LTM was considered by 57.1% of the respondents, MNA (52.4%), ACLs and TI waivers (both at 33.3%), additional modeling (28.6%), and MZA (19%) in this situation. Other alternatives were considered 23.8% of the time. Other alternatives included extending the time of performance, adding an enhanced attenuation step, or evaluating new innovative remedies. One respondent noted that the remedy is usually driven by a property sale, so quicker remedies are often preferred, even if more costly.

<u>TI Waivers</u>

Out of 24 respondents, more than half (14) follow a protocol for considering TI waivers or their equivalents (question #19). Respondents' comments about their protocol for considering TI waivers were as follows:

- We follow EPA guidance.
- A formal TI request has never come in to our division. Generally, if normal remedial alternatives are impractical, the issue is handled in the feasibility stage of assessment/design, and consensus decisions are made there.
- Technological and economic analysis, use of risk assessments, EPA TI waiver, and ACL guidance documents.
- We follow EPA Superfund guidance on TI wavers, but I don't think we have asked for one yet.
- TIs are not allowed or considered in Alabama.
- Few applications to date; given individual review. Review protocols are unwritten since only a few staff have review responsibility. Currently, reviewing staff are reconceptualizing policy and approach.
- A TI could be used to demonstrate a Type 5 cleanup (engineering and institutional controls) as appropriate. These would be evaluated on a case-by-case basis.

Additionally, the survey respondents were asked whether they felt their state/program area would benefit from a guidance sheet or fact sheet on a step-wise evaluation/application of TI waivers (question #26). Of the 25 that responded, nearly 67% indicated that such a guidance sheet or factsheet would be useful.

<u>Modeling and Prediction Practices</u>

In response to question #20, three out of 25 respondents stated that they put significant emphasis on modeling and prediction of chemical fate and transport in determining remedial decisions. Eleven put moderate emphasis, nine indicated they put some emphasis, and two applied little or no emphasis. Some respondents stressed the need for verification sampling. The CSM framework, which incorporates qualitative fate and transport considerations for site characterization, was one example given. For question #21, 8% of the 25 respondents stated that model projections are revised based on verification monitoring once the remedy implementation starts. Sixteen percent revised model projections most of the time, 56% made revisions some of the time, and 20% seldom or never.

Cost and Liability Information Sharing

Sixty percent of the respondents stated that their state/program area tracked and shared cleanup cost and liability information with the public (question #22). However, some respondents stated that the appropriate performance measures still needed to be defined by their program areas before this kind of information could be tracked. They also identified difficulty in getting responsible parties to disclose cleanup costs.

RRM Considerations

In response to question #23, 14 out of 25 respondents (56%) consider the natural resource damages caused by the site remediation process when assessing the impacts of remedial alternatives. Explanations of how NRD is considered are as follows:

- Through ecological risk assessments during characterization and as part of CEQA analysis prior to making a decision on the project.
- In evaluating the short-term risk and long-term risk criteria.
- The capability for the state to consider NRD is available. It has not yet been done at a site.
- No formal recognition. This issue may come to light on a case-to-case basis.
- Have only considered NRD one time during a bankruptcy claim; no formal NRD program.
- Another state agency does this in coordination with our agency.
- Remedial goals established with expectation of eventual ability to achieve goal. Other programs in state allow refocus of groundwater goals under public process.
- This is just now being considered as a tool to use to get response actions in particular situations.
- CEQA requires the lead agency to evaluate the potential for the "project" to have a negative effect on the environment and, if needed, spell out the mitigation measures to negate negative effects. Process can be very complex and time-consuming. Generally for our project we are able to file a Notice of Exemption, but these decisions still require public comment.
- NRDs are not considered in a formal sense; however, if a natural resource is identified and may be impacted by the remedy, the effect would be considered on a case-by-case basis.

When asked if their state/program area routinely capture RRM considerations in decision documents (e.g., records of decision [RODs]) in question #24, 48% of the 25 respondents answered yes. For question #25, 48% percent of the 25 respondents reported that their state/ program area has a specific process or protocol to consider alternatives to active remediation. Ten respondents provided additional clarification as follows:

- Normal reviews through the FS stage or corrective measures evaluation.
- The standard is protectiveness, which can be achieved through active or passive alternatives.
- We follow EPA guidance.

- Built into the risk evaluation process.
- Title 118, Groundwater Quality Standards and Use Classification, Appendix A, Groundwater Remedial Action Protocol using a remedial action classification (pollution ranking scheme) and groundwater classification (groundwater use designation).
- No action is always considered, as are others. Alternatives are not selected very often except for groundwater, where MNA is a frequently selected remedy. However, this often is revisited, and active remediation is needed.
- Land-use restrictions and MNA are routinely considered, as are ECs. All provided under regulatory framework. Also, EPA TI guidance cited by regulation language enabling TI use with approval.
- No, other than the requirement to include the no-action alternative. Both active and passive remedies are considered when proposed.
- Yes, but not as well thought out and developed as it should be.
- Informal, case-by-case, basis.

Modeling Document

In response to question #27, less than a third (29.2%) out of 25 respondents indicated that they have a specific process or protocol to consider the modeling process during remedy selection process. Seventeen of the 25 respondents said that a guidance sheet or fact sheet on the application of modeling (whether for sediments, groundwater, or vapor intrusion) during remedy selection and implementation would be useful provided it had in-depth coverage (question #28). In response to question #29, the respondents also indicated that a guidance sheet or fact sheet that addressed the area of groundwater would be considered most useful, vapor intrusion as somewhat useful, and sediments as least useful. However, some respondents preferred specific detailed training or noted modeling limitations.

One example of modeling limitations given was that, while regulations permit alternative criteria and alternative means for compliance demonstration that could be incorporated into model-based arguments, lack of review protocol and precedents and predictability in outcome limit use of this provision by RPs. Modeling conditions must typically deal with fractured bedrock aquifers, heterogeneous overburden, and small-scale features, limiting model effectiveness and practicality in these scenarios. It should be noted that modeling predictions are not used as a substitute for actual compliance demonstration. State remediation regulations are typically end-point analytical-based comparisons of remediated media to specified criteria.

Training Mechanisms

Half of the respondents stated that their agency preferred a combination of both Internet-based training and classroom training, while 41.7% cited Internet-based training and 8.3% preferred only classroom training. Respondents also reported on how extensive RRM training needs were in their agencies. Twelve percent were very extensive, 52% were moderately extensive, and 36% were not very extensive. The respondents stated the need for training based on real projects, with real examples and handouts that involve the participants to review short data tables to make decisions, demonstrate how to contour data, and how to evaluate cleanup levels taking into consideration cost, time, remedial design, and community acceptance factors. They also said they would benefit from presentations based on real projects on how to determine when an investigation is complete enough, such that additional investigation and/or monitoring would not change significantly, or if a final remedy should be selected and implemented based on the available data, or if the decision for a final remedy should be postponed pending additional focused investigation.

ITRC Document Preference

When given the choice of a tech/reg guidance document or a shorter guidance sheet/fact sheet from the ITRC RRM team, slightly over half of the respondents preferred the former. Comments included the need for this document to be robust and detailed, focusing on practices to manage risk, and giving a lot of examples based on real state projects.

A.2 ADDENDUM TO SURVEY OF STATE INTEREST IN REMEDIATION RISK MANAGEMENT OVERVIEW DOCUMENT ON TECHNICAL IMPRACTICABILITY ASSESSMENT

A.2.1 Overview

To gain further understanding of state interest in and knowledge of the topic of the RRM Team–proposed overview document in TI assessment, the RRM Team surveyed ITRC member states through the ITRC POC network. This survey was conducted between August 6, 2009 and September 17, 2009. This survey was based on the four questions (questions 17, 18, 19, and 26) in the original survey with a slight refocus based on the proposed approach for the overview document. The survey addendum questionnaire is also in Attachment A-1. Twenty-six people representing 25 states responded to the survey addendum. In combining with the original survey to these four questions, a total of 30 out of 46 member states (65%) responded to the survey.

A.2.2 Summary of Survey Addendum Results

Alternatives Considered

For question #17, 24 of the respondents identified MNA as an alternative that is considered in their state/program area. Twenty-four also identified LUCs, LTM (23), TI waivers (19), additional modeling (11), combination of alternatives depending on site characteristics (13), ACLs (13), and MZA (6). Figure A-3 depicts the distribution of considered alternatives.

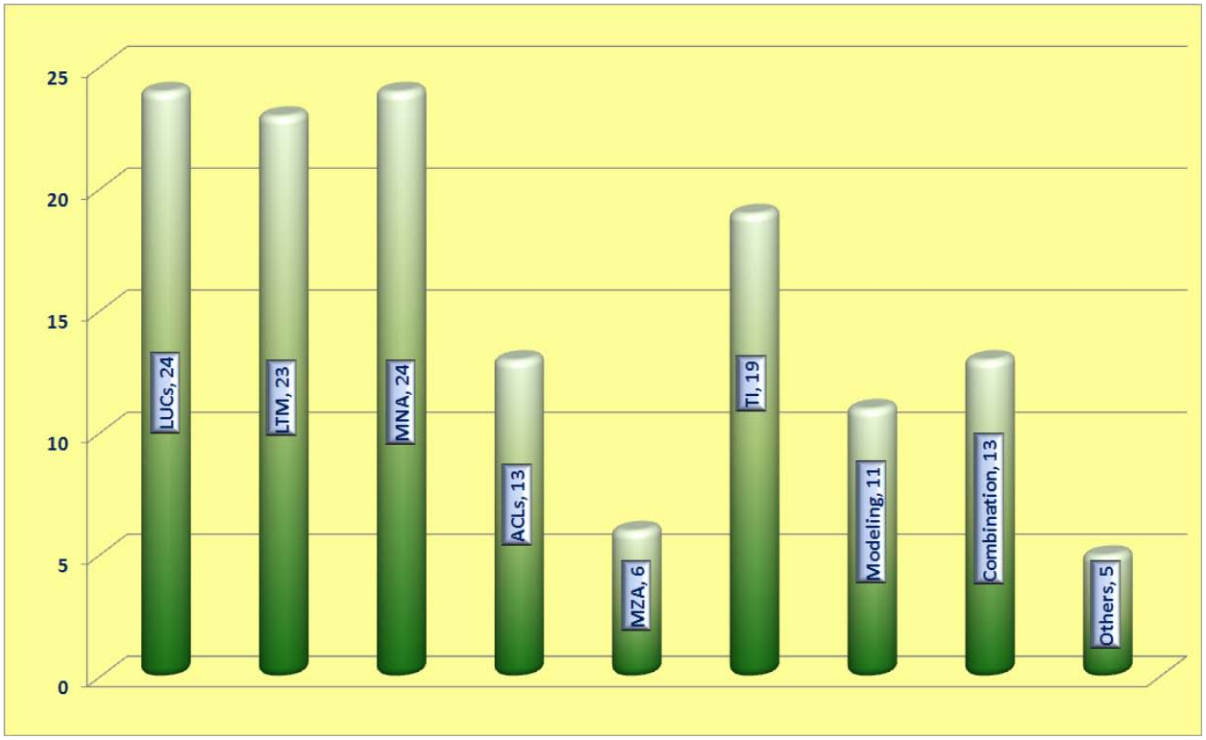


Figure A-3. Distribution of considered alternatives.

Further explanations of how combinations of these alternatives are considered are as follows:

- Plume management zone (PMZ) is a stable/reducing plume which is a combination of MNA and ACLs.
- Assume a mixing zone would be the same as a zone of discharge (ZOD).
- We consider all proposals and evaluate them based on their merits. Plume stability is a common approach not listed.
- The department allows the use of all applicable and effective risk management alternatives, including combining alternatives at a single site.
- We don't use the same terminology (TI), but the outcome may be the same. If treatment has come to the point where it is no longer removing significant mass, the approach might be changed. Treatment may be discontinued, but monitoring or other lower-energy treatment may be initiated. MNA may be applied if the plume is stable or shrinking. Phytoremediation may be implemented if the plume is still migrating.
- Any combination of alternatives that meet the state's land-use risk-based cleanup criteria are allowable. Criteria based on certain assumptions for each applicable pathway has been published, but site-specific criteria are also allowed to be developed. TIs are allowed but are a special case.
- Can approve site-specific alternate criteria if equally protective and site-specific means of demonstrating compliance. RPs decide timeline and may under regulation implement various controls as alternative to permanent remedy. LTM and care may be a requirement for ICs, and MNA is considered a remedial process leading towards goal. Application for TI requires receptors be protected.

- It's possible that ECs could be used in concert with ICs. May use a form of ACL when on occasion have reclassified groundwater, which changes the stringency of the applicable rules and standards. However, this is not a quick process. May first reevaluate whether other cleanup or polishing remedies could apply.
- LUCs are not currently available for all programs.
- Will "consider" any alternative but have not yet implemented TI on any site.

LUCs, LTM, and MNA alternatives were considered mostly (see Figure A-4) by the respondent's state/program area when the selected remedies are making progress toward RAOs but are not on track to meet them during initial projected time to completion (question #18). ACLs, TI waivers, and modeling alternatives were next considered. Others include considering LUCs as a remedy under the current rules, considering alternative cleanup levels if it is proven MCL numbers cannot be met, and classification exception zones as an IC established for groundwater where the standards are not met.

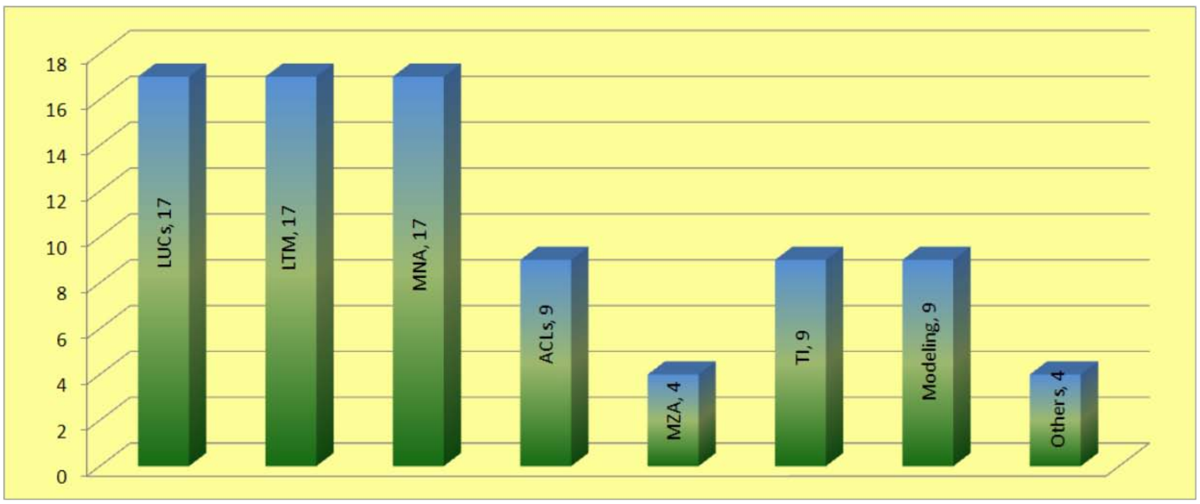


Figure A-4. Alternatives considered.

<u>Technical Assessment</u>

Out of the respondents, more than half (13) (see Figure A-5) follow a protocol for considering alternative remedial objective if the selected remedies are not on track to meet established remedial objectives (question #19).

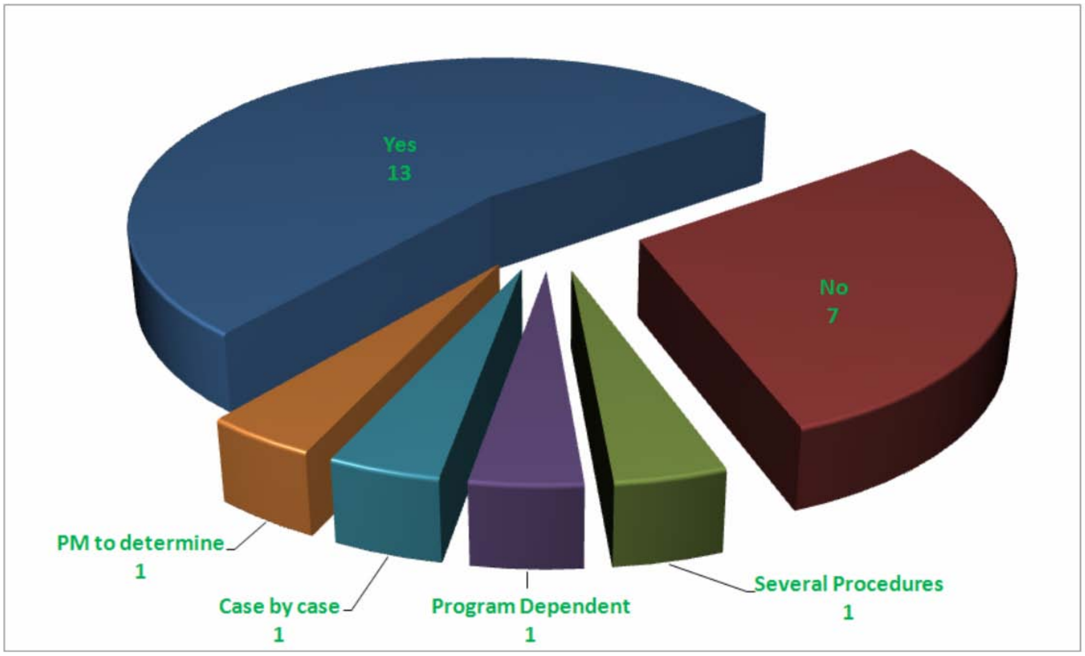


Figure A-5. Procedures for considering alternatives.

Respondents' comments were as follows:

- For RCRA the RP decides on the remedial action system and determines the timeframe for meeting remedial goals. For CERCLA the state decides the remedial objective and selects the remedial alternative which will achieve the remedial objective.
- Few of our remedies include a strict timetable for achievement of objectives. Should this become an issue at a site, we would evaluate the situation on a site-specific basis.
- Ex Groundwater Regulation, if an active remedial action has been implemented and it has been demonstrated that achieving regulatory requirements is not feasible, then the RP can apply for a residual zone for the affected groundwater on the basis of TI. The residual zone must be limited to the extent of the plume, and the RP must have or must gain control of all affected groundwater. Note the RP must first attempt an approved remedial action before applying for a residual zone using a TI waiver.
- We have a promulgated protocol that allows the use of alternative cleanup levels if cleanup to promulgated numerical standards is not technically or economically feasible.
- It is up to project managers how they want remedy agreements to read in case the selected remedy does not reach objectives under the projected timeframe.
- Not a formal protocol, per se. Compliance with the applicable rules is required.
- Regulations allow application for ECs, ICs for approval by commissioner, approval process with public comment could be considered protocol for implementation, but the RP decides to initiate. Sites not on track are usually doing nothing and are subject to enforcement as resources allow.
- No promulgated regulations, etc., but internal procedures are followed.
- There are no protocols for considering alternative remedial objectives, but evaluation alternatives are considered on a case-by-case basis.

- Alternative remedial technologies are evaluated only under the site-specific standard. But there is no requirement that the most effective or lowest-cost remedies be selected. Cannot require a remediator to use any particular methodology. As long as the remediation results in attainment of the selected standard, the final report will be approved.
- Do not have anything like a "technically impractical" assessment or the concept of "alternative remedial objectives." Under the program there is no requirement to remediate groundwater if it is not used or if it can be treated. A pathway elimination or pathway risk management remedy is considered just as acceptable as a complete removal remediation. There is no need for the remediator to conduct anything like a TI assessment to justify use these alternatives. The concept of viewing containment remedies or pathway elimination or risk management remedies as second-tier alternatives to removal remedies that require some kind of assessment of technically impractical justification is what existed prior to the program.

Additionally, the survey respondents were asked if they felt their state/program area would benefit from an overview document on how to do a technical assessment of whether any remedy, based on currently available technology, would meet remedial objectives (question #26). Of the 31 that responded, nearly 90% (28) indicated that such an overview document would be useful (Figure A-6).

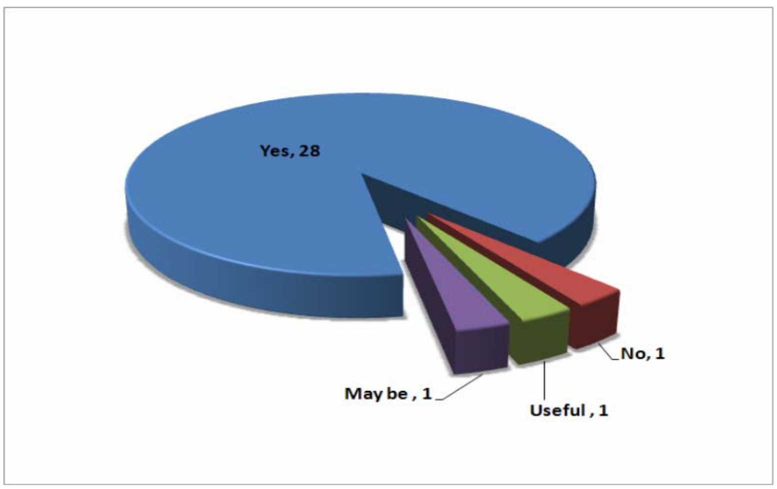


Figure A-6. Usefulness of an overview document.

Additional respondents' comments were as follows:

- It would be helpful if the guidance document included a discussion on mass reduction and factored this into any matrix concerning TI. That is, it may not be possible to achieve regulatory objectives at the end of the remedial action; however, the overall reduction in mass of contaminants may translate into a shorter natural attenuation time. It is recommended that any metric produced in the document consider this factor.
- Some consultants represent only technologies their company sells or downgrade technologies with which they are unfamiliar. Having an independent technical evaluation would be helpful.
- Would have to include assessment of karst terrain, making some remedies less practical.

- We already do such assessments. It is always useful to learn what others are doing. However, it is not sure how much benefit an overview would be because the assessments are simple in principle but very site-specific in application.
- Don't think it would be useful to state, perhaps to RPs making decisions. Usually decisions are based on cost and time to complete. Since state regulations do not themselves consider time to complete, MNA is almost always an available remedy, but RPs are more often trying to avoid the ongoing cost of monitoring and the continuing cloud of "not done yet since goal not yet met." They are doing this by seeking TI determinations and/or groundwater quality goal reclassifications. It is currently revisiting its policy on how to handle TI applications and groundwater quality goal reclassifications since sites are trying to exit remedial programs through these means rather than address goals directly. To the extent that the guidance would enlighten our policy development, it could prove useful. Would not be interested if it encouraged more parties to seek to avoid cleanup because available remedies were, in the RP's opinion, too costly or lengthy. Regulations already provide great flexibility in meeting goals on t he technical merits of getting to clean. Concerned that the guidance could encourage RPs to seek flexibility based solely on perceived business benefits driven by incomplete cost-benefit evaluations. This tactic would involve extensive state resources in areas not currently supported by staffing.
- There would be a potential for using this as the need arises, but currently there is no formal process for doing so, which does not guarantee use of document even when applicable.
- Guidance document must be clean and concise.
- This would be helpful since we do not have guidance for technical assessments or TI.

ATTACHMENT A-1. SURVEY QUESTIONNAIRE

REMEDIATION RISK MANAGEMENT (RRM) TEAM
STATE SURVEY QUESTIONNAIRE (Web-based Survey)

1. Only state identifiers will be used in writing up the results of this survey. Contact information is requested so we may follow up with you should we have further questions about the data.

Name:
State:
ZIP/Postal Code:
E-mail Address:

2. Program or office

For this survey, RRM is defined as "a process through which all risks related to the remediation process—remedy selection, execution and completion—are comprehensively addressed in order to manage and minimize uncertainties in the cleanup process, ensuring protection of human health and the environment."

3. Based on the definition above, how does your state/program area address RRM in its cleanup efforts?

Formal processes
Informal processes
Not really addressed

4. In which program areas are RRM techniques formally applicable in your state? (Please check all that apply.)

Underground Storage Tanks
CERCLA
RCRA
Voluntary Cleanup Program
Brownfields
Dry Cleaning
Other (please specify)

5. Which of the following sources of remedy selection risk are formally identified and addressed in your state/program area? (Please check all that apply.)

Risk posed by changes to required criteria/drivers (e.g. MCLs, ARARs)
Risks associated with various remedial options/alternatives
Risk that remedy may fail because of poor conceptual site modeling

Risks to selected remedy posed by technical constraints (e.g. challenging geology, technology limitations)
Risk of insufficient consideration of alternatives to active remediation
Risk of cost escalation
Risk of system failures
Risks that remedial actions pose liability or financial concerns
Short-term risks posed to site workers
Risks that remedial technologies and transport of materials, soil, sediments, and/or waste pose to adjacent communities
Risks remedial actions pose to ecological receptors
None are formally addressed but the following are informally addressed (please specify)

6. Does your program allow <u>interim</u> or <u>stabilization</u> system construction and implementation without completing site characterization?

Yes
No

7. Does your program allow <u>final</u> remedial system construction and implementation without completing site characterization?

Yes
No

8. If you answered "Yes" to question 7, under what conditions? (Please check all that apply.)

Emergencies
Presumptive remedies
Other (please specify based on site specific or program specific needs.)

9. After a site has been characterized and a remedy has been selected, how much continued attention does your state/program area place on RRM to identify, address, and manage possible failures? (Select one.)

Significant attention
Moderate attention
Some attention
Little or no attention

10. If site characterization is periodic or ongoing, how much attention does your state/ program area put into RRM to identify, address, and manage possible failures? (Select one.)

Significant attention
Moderate attention
Some attention
Little or no attention

11. How does your state/program area handle implementation or remedial performance risks when the remedy selected does not meet remedial action objectives (RAOs)? (Please rank how frequently these options are relied on—one choice per column.)

	1 (Most Frequent)	2	3	4	5	6 (Least Frequent)
Change remedy or technology						
Adjust time to completion objective						
Change RAOs						
Consider Technical Impracticability waivers						
Consider other alternatives to active remediation, (e.g., monitored natural remediation /attenuation)						
Other options (Please provide examples below)						

12. How does your state/program area respond when new risks are identified at a site? (Please check all that apply.)

Conduct additional site characterization
Identify and characterize new or recalcitrant chemicals
Assess any changing environmental conditions (floods, geomorphologic)
Incorporate new cleanup/risk levels or lower detection limits if applicable
Incorporate new ARARs (applicable or relevant and appropriate requirements)
Adapt remedies to protect cultural or archeological resources
Other (Please list in comment box below)

13. Are any other criteria used in your state's remedy selection process in addition to the nine CERCLA and/or seven RCRA criteria?

Yes
No

14. What proportion of cleanup sites in your state/program area have remedies revised or enhanced to address RRM concerns after implementation begins? (Select one.)

At less than one-third of the sites
Between one- and two-thirds of sites
At more than two-thirds of sites

15. For your state/program area, please rank the importance of RRM risk factors for site cleanup decisions (one choice per column).

	1 (Most Important)	2	3	4	5	6 (Least Important)
Remedy selection risk						
Remedy implementability/performance risk						
Regulatory risk (changes in regulations, policies, etc.)						
Sustainability risk (greenhouse gas impacts, cross-media impacts)						

Political/stakeholder risk (land use changes, community acceptance, other public relations issues)
Site complexity risk

16. For your state/program area, please rank the source of requests to revise remedies (one choice per column). If the source is a combination of factors, please explain in the comment box.

1 (Most Frequent) 2 3 4 5 6 (Least Frequent)

Scheduled administrative reviews (e.g., 5-year CERCLA review)
Community concern
Request from elected or non-agency government official
Responsible party request
Internal staff request
Other sources (List below)

17. Which of the following alternatives are considered in your state/program area? (Please check all that apply.)

Land-use controls (LUCs)
Long-term monitoring (LTM)
Monitored natural attenuation (MNA)
Alternate concentration limits (ACLs)
Mixing zone application
Technical impracticability (TI) waivers
Additional modeling
Combination of alternatives depending on site characteristics (Elaborate in Comment box below.)
Others (List in Comment box below.)

18. For the alternatives listed in Question #17, please list the options your state/program area considers when selected remedies make progress toward RAOs but are not on track to meet them during initial projected time to completion? (Please select all that apply.)

Land-use controls (LUCs)
Long-term monitoring (LTM)
Monitored natural attenuation (MNA)
Alternate concentration limits (ACLs)
Mixing zone application
Technical impracticability (TI) waivers
Additional modeling
Other (Please list in comment box.)

19. Does your state/program area follow a protocol for considering technical impracticability waivers or their equivalents?

Yes
No

20. In your state/program area, how much emphasis is put on modeling and prediction of chemical fate and transport in determining remedial decisions?

Significant emphasis
Moderate emphasis
Some emphasis
Little or no emphasis

21. Once the remedy implementation starts, how often are model projections revised based on verification monitoring?

Almost always
Most of the time
Some of the time
Seldom or never

22. Does your state/program area track and share cleanup cost and liability information with the public?

Yes
No

23. Does your state/program consider the natural resource damages (NRD) caused by the site remediation process when assessing the impacts of remedial alternatives?

Yes
No

24. Does your state/program area routinely capture RRM considerations in decision documents (e.g., Records of Decision)?

Yes
No

25. Does your state/program area have a specific process or protocol to consider alternatives to active remediation?

Yes
No

26. Would a guidance sheet or fact sheet on a step-wise evaluation/application of technical impracticability waivers be useful for your state/program area?

Yes
No

27. Does your state/program area have a specific process or protocol to consider the modeling process during remedy selection process?

Yes
No

28. Would a guidance sheet or fact sheet on application of modeling (whether for sediments, groundwater, or vapor intrusion) during remedy selection and implementation be useful for your state/program area?

Yes
No

29. If you answered Yes to question 28, please rank the usefulness for the areas below from 1 to 3. (One choice per column)

	1 (Most Useful)	3 (Least Useful)
Sediments		
Groundwater		
Vapor intrusion		

30. What product would you prefer from the ITRC RRM team?

Technical regulatory document
Shorter guidance sheet or fact sheet

31. How extensive are the RRM training needs in your agency?

Very extensive
Moderately extensive
Not very extensive

32. Which training delivery method does your agency prefer?

Classroom training
Internet-based training
Both

Revised Remediation Risk Management Team State Survey of Interest

Per the ITRC Board's direction, a focused survey with the following questions is being solicited for input from the State Points of Contacts. This survey is an addendum to the original survey that was conducted in September 2008 and is aimed at obtaining responses from a broader audience for the specific questions from the original survey. Please see detailed background for this survey on the attached document.

Please take a few minutes to fill out this survey and return to Ning-Wu Chang (nchang@dtsc.ca.gov) or Sriram Madabhushi (madabhushi_sriram@bah.com) by August 28, 2009.

If you have any questions, please contact Ning-Wu at 714-484-5485 or Sriram at 210-487-2611.

General Information about the Person Participating in the Survey

Name	
Agency	
Division	
Program Area	
Title	
E-mail address	
Phone Number	

Revised Survey Questions:

17. Which of the following alternatives are considered in your state/program area? (Please check all that apply.)

Land-use controls (LUCs)	
Long-term monitoring (LTM)	
Monitored natural attenuation (MNA)	
Alternate concentration limits (ACLs)	
Mixing zone application (MZA)	
Technical impracticability (TI) assessments	
Additional modeling	
Combination of alternatives depending on site characteristics (Elaborate in the Comments section below.)	
Others (List in the Comments section below.)	

Additional Comments:

18. For the alternatives listed in the above question, please list the options your state/program area considers when selected remedies make progress toward remedial objectives but are not on track to meet them during initial projected time to completion. (Please select all that apply.)

Land-use controls (LUCs)	

Long-term monitoring (LTM)	
Monitored natural attenuation (MNA)	
Alternate concentration limits (ACLs)	
Mixing zone application (MZA)	
Technical impracticability (TI) assessments	
Additional modeling	
Others (List in the Comments section below)	

Additional Comments:

19. Does your state/program area follow a protocol for considering alternative remedial objectives, if the selected remedies are not on track to meet established remedial objectives?

Yes
No

Additional Comments:

26. Would an overview document on how to do a technical assessment of whether any remedy, based on currently available technology, would meet remedial objectives be useful for your state/program area?

Yes
No

Additional Comments:

Please share any additional comments you may have about this survey or this topic.

Appendix B

RRM Toolbox

RRM TOOLBOX

The RRM Toolbox is a resource for deeper research into the RRM process. Section B.1 includes links to various websites that have RRM-related information. Section B.2 provides technical resources, including recent examples of processes, technologies, and procedures that may be useful in the remediation process.

B.1 RRM TOOLS

B.1.1 Risk Register

Link: www.afcee.af.mil/shared/media/document/AFD-080731-051.pdf (John Smith's presentation on the Risk Register at the 2008 AFCEE Technology Transfer Workshop)
Sponsor: EPA
Description: EPA has been considering/using risk registers as applicable to contaminated sites for several years. Using a three-level (L, M, H) scale and considering the cost impacts and probability of occurrence, a potential cost impact of risk is calculated, and a strategy to manage the risk is developed. Risk impacts are stated, and the same process is repeated for all risk elements. This spreadsheet captures project management risks associated with funding risks, schedule risks, scope risks, external risks, and contracting risks.

B.1.2 LLNL RMP

Link: https://e-reports-ext.llnl.gov/pdf/363829.pdf (an example RMP)
Sponsor: DOE
Description: LLNL has developed a process that is specific to the environmental remediation that considers the project-related risks and develops a management plan to mitigate and manage risks.

B.1.3 AFCEE RPRM Tool

Link: www.afcee.af.mil/resources/restoration/rprm/index.asp
Sponsor: AFCEE
Description: AFCEE developed a process to identify, prioritize, and manage risks related to restoration performance. In this approach, risk statements are developed to verify the risks associated with systems throughout the restoration process. Once the risks are identified and detailed risk statements are developed, the tool helps in evaluating and prioritizing risks. These risks are captured in a risk management plan and are managed as needed.

B.1.4 Emerging Issues Assessment Tool

Link:
www.afcee.af.mil/resources/technologytransfer/programsandinitiatives/contaminants/index.asp
Sponsor: AFCEE
Description: AFCEE is in the process of developing a tool to track and manage emerging issues which can be used in the RRM process. This is a consensus-based statistical approach that

considers the opinions and inputs of all the relevant stakeholders and helps determine the emerging issues that are to be addressed in a proactive manner.

B.1.5 Uncertainty Analysis Tool

Sponsor: AFCEE—Contact the RPO Outreach Office (www.afcee.af.mil/resources/restoration/rpo/outreach/index.asp) for a copy of the tool.
Description: This tool identifies and measures the uncertainties associated with the remediation processes at individual sites and compares the costs associated with the recommendations of the Environmental Restoration Program–Optimization (ERP-O) analysis based on a series of questions specific to the site and existing approaches. This is compared to the ERP-O team suggested recommendations to improve the cleanup times and performance. The tool then determines the human health and risk, time to completion, and cost benefits.

B.1.6 Performance Tracking Tool

Link: www.afcee.af.mil/resources/restoration/editt/index.asp
Sponsor: AFCEE
Description: To understand and measure the performance of a remediation system or a cleanup technology at a specific site, AFCEE developed a tool that basically correlates the remedy performance to the cost performance and graphically presents the variations over the complete timeframe of the system operations. This tool currently is applicable to the technologies, including pump and treat, SVE, dual-phase extraction, solvent extraction, bioslurping, and MNA.

B.1.7 Sustainable Remediation Tool

Link:
www.afcee.af.mil/resources/technologytransfer/programsandinitiatives/sustainableremediation/srt/index.asp
Sponsor: AFCEE
Description: For future planning, as well as for a means to evaluate existing remediation systems from a sustainability perspective, AFCEE developed the SRT. The current version of the tool includes modules to evaluate the sustainability levels of: excavation, pump and treat, SVE, and enhanced in situ bioremediation. Modules to include other technologies and metrics are expected to be added to the tool in the future versions.

B.1.8 EPA's ETV Program

Link: www.epa.gov/nrmrl/std/etv/center-mmr.html
Sponsor: EPA
Description: EPA's Environmental Technology Verification program's Materials Management and Remediation Center specifically tests and verifies the performance of materials management technologies and, as part of this process, also looks into innovative technologies and methodologies that are applicable in the RRM process.

B.1.9 SiteWise Tool

Link: www.ert2.org/t2gsrportal/SiteWise.aspx
Sponsor: Battelle/USACE/Navy
Description: Battelle Memorial Institute originally developed a series of spreadsheets to calculate impacts of remediation in terms of sustainability metrics, now further developed in a collaborative effort with Navy and USACE. Remedial technologies are broken into activities or modules, and, using the modules, users can build the overall remedy. Environmental footprint is evaluated during the remedy selection with the identification of those elements that will result in greatest impacts or footprint. This will help in the mitigation and management techniques on those activities that cause the greatest impact.

B.2 OTHER REMEDIATION PROCESS OPTIMIZATION TOOLS UPDATED

In the original ITRC remediation process optimization technical regulatory guidance document (ITRC 2004), the RPO toolbox contained several web page links that were current in 2004. In this document, we are trying to update those resources along with additional updates.

B.2.2 Multi-Agency

Link: www.frtr.gov/optimization.htm
Sponsor: Federal Remediation Technologies Roundtable (FRTR)
Description: Provides a wide variety of information and links on the topic of optimization. FRTR has prepared a comprehensive directory of long-term management and optimization case studies.

B.2.3 Air Force

Link: www.afcee.af.mil/resources/restoration/rpo/index.asp
Sponsor: AFCEE
Description: Contains the latest Air Force RPO guidance. Includes the AFCEE RPO Handbook.

B.2.4 Army Corps of Engineers

Link: www.environmental.usace.army.mil/rse_checklist.htm
Sponsor: USACE
Description: Remediation System Evaluation checklists

B.2.5 Department of Energy

Link: www.em.doe.gov/Pages/EMHome.aspx
Sponsor: DOE
Description: DOE's home page for environmental information. Search on "optimization" for various related topics.

B.2.6 EPA

Link: www.clu-in.org/optimization
Sponsor: EPA
Description: Part of the Technology Innovation Program's initiative to promote optimization of site remediation activity, the Clu-In optimization page provides a wealth of information on the topic of optimization.

Link: www.epa.gov/CERCLA/cleanup/postconstruction/optimize.htm
Sponsor: EPA
Description: Located within the CERCLA area of the EPA website, this page contains many of the EPA source documents on optimization, as well as links to other optimization web pages.

Link: www.epa.gov/oswer/iwg/basic.htm
Sponsor: EPA
Description: Provides information about and contact information for the Innovations Work Group. RPO frequently relies on innovative answers to remediation problems. The Innovation Workgroup provides a wide range of expertise in the area of innovative remediation technology.

Link: http://envinfo.com/dec2000/implementation.pdf
Sponsor: EPA
Description: CERCLA Reform Strategy, Implementation Memorandum: Optimization of Fund-Lead Groundwater Pump and Treat (P&T) Systems, December 2000.

Link: www.epa.gov/CERCLA/accomp/5year/index.htm
Sponsor: EPA
Description: A CERCLA resources site for five-year review guidance.

B.2.7 Navy

Link:
https://portal.navfac.navy.mil/portal/page/portal/navfac/navfac_ww_pp/navfac_nfesc_pp/environmental/erb/opt
Sponsor: Navy, Naval Facilities Engineering Service Center (NFESC)
Description: Home page for NFESC's environmental information specific to optimization

Link:
https://portal.navfac.navy.mil/portal/page/portal/navfac/navfac_ww_pp/navfac_nfesc_pp/environmental/erb/wg-opt
Sponsor: Navy and Marine Corps Working Group
Description: Optimizing remedial action operations and long-term monitoring.

Link:
https://portal.navfac.navy.mil/portal/page/portal/navfac/navfac_ww_pp/navfac_nfesc_pp/environmental/erb/documents-s/pres_smart-site.pdf
Sponsor: Navy, Naval Facilities Engineering Service Center

Description: NAVFAC Tech Data Sheet SMART SITE—Cost-Efficiencies in Remedial Action Operations and Long-Term Monitoring.

B.2.8 State Agencies

Link: www.nj.gov/dep/srp/training/sessions/rpo200304
Sponsor: New Jersey Department of Environmental Protection (NJDEP)
Description: Link to NJDEP's presentation on RPO.

B.2.9 Educational and Stakeholder Groups

Link: www.earthdrx.org
Sponsor: Private
Description: Provides environmental information in a format directed at the general public. Unique approaches to groundwater remediation and subsurface gas migration are presented.

Appendix C

Sample Risk Management Plan

SAMPLE RISK MANAGEMENT PLAN

Environmental Restoration Program at Lawrence Livermore National Laboratory Site 300

This case study describes the Risk Management Program in use by the Environmental Restoration (ER) Program at LLNL Site 300. Site 300 is an 11-square-mile DOE experimental test facility located in the eastern Altamont Hills about 40 miles east of San Francisco, California.

C.1 SITE BACKGROUND

Site 300 began operations in 1955 and is primarily a high-explosives test facility supporting the LLNL weapons program. DOE began environmental investigation activities at Site 300 in 1981. These have identified numerous locations at Site 300 where contaminants were released to the environment. Site 300 was placed on the National Priorities List (NPL) in August 1990. Release sites at Site 300 have been assigned to nine operable units (OUs) to more effectively manage the site cleanup. The cleanup budget for Site 300 is typically around $11,000,000 per year.

The primary contaminants at Site 300 include radionuclides (tritium and uranium), trichloroethene (TCE) and other volatile organic compounds (VOCs), high-explosive (HE) compounds, perchlorate, nitrate, polychlorinated biphenyls (PCBs), dioxin and furan compounds, tetrabutyl orthosilicate (TBOS), and metals.

Cleanup activities have resulted in significant reductions in contaminant concentrations throughout the site and mitigated risks to on-site workers in many areas. The remedies include the following:

- groundwater and soil vapor extraction and treatment
- MNA of VOCs and radionuclides in groundwater
- in situ bioremediation
- soil excavation
- ex situ solidification of PCB/dioxin/furan-contaminated soil
- capping and closing numerous landfills, rinse water lagoons, and burn pits
- removing radiologically contaminated firing table gravel
- performing risk and hazard management (human and ecological)
- implementing administrative controls to prevent workers from being exposed to contamination while cleanup proceeds

Cleanup standards for groundwater and surface water are typically federal MCLs unless California state MCLs are more stringent. Cleanup standards for surface soil are EPA preliminary remediation goals (PRGs). The cleanup standards for subsurface soil/rock are based on mitigating risk and hazard to human health and preventing further impacts to groundwater.

C.2 SITE 300 RISK MANAGEMENT PROGRAM

LLNL developed and implemented a comprehensive Risk Management Program in 2006. In compliance with DOE Order 413.1, the Risk Management Plan is part of the overall Baseline Work Plan for Site 300.

LLNL uses the following working definitions of risk and contingency:

- "Risk" refers to potential events that are not included in the Baseline Work Plan and cost estimates. Project risk is a measure of the potential inability to achieve project objectives within defined scope, cost, schedule, and technical constraints. An example would be inability of a groundwater remedy to achieve cleanup standards.

- "Contingency" refers to uncertainties in executing the scope of work defined in the Baseline Work Plan. An example would be fluctuations in the cost per foot to install wells.

The project risk management process for LLNL Site 300 employs a qualitative risk identification and screening process followed by quantitative analysis. Potentially significant project risk events are evaluated based on the potential impact to the ER Program. Following the project risk identification and screening, project risk events are evaluated in terms of probability, consequence, and urgency. For each event, project risk mitigation strategies are identified that include mitigation and monitoring measures.

Project risk management responsibilities are linked to the Site 300 Work Breakdown Structure. The LLNL Program Leader is responsible for confirming that all risk management activities are performed in a manner consistent with the Risk Management Plan, including maintaining the project risk database, identifying new project risk events, facilitating periodic reviews, and ensuring that all required project risk mitigation is being conducted. Project meetings are held to review existing project risk events, identify new events, and revise mitigation strategies. Prior to the start of significant new projects, potential new risks are developed so that appropriate project risk mitigation measures can be included in the project planning process, if needed.

Project risk management is an iterative process. The ER management teams perform the initial project risk analyses and develop project risk mitigation strategies. The entire project team and primary stakeholders make successive iterations. To achieve an unbiased analysis, persons not involved with the ER projects may conduct additional reviews. This process leads to a thorough, comprehensive, and dynamic project risk management program.

C.2.1 Project Risk Identification

A comprehensive list of potential project risk events is generated by reviewing project assumptions, documents, and work plans, facilitated by the Program Leader. The list is discussed with project management and staff to collect all available information.

The list of potential risk events is qualitatively screened using a checklist, yielding a set of events that are evaluated quantitatively. Table C-1 describes a risk event for potential excavation and off-site disposal of radioactive waste from the unlined Pit 7 Landfill at Site 300.

Table C-1. Potential project risk event screening checklist for the Pit 7 Landfill

Trigger question	Response (yes/no)	Comments
If excavation of buried radioactive debris in the Pit 7 Landfill is required, would there be:		
Potential health or safety concerns for on-site workers or the public?	Yes	Excavated radioactive debris would require off-site disposal, potentially exposing the public to contaminants in the case of a transportation accident
Potential threat to the environment or natural resources?	No	
Any laws violated?	No	
Any legally required milestones threatened?	No	
A threat to any commitments made to the regulatory agencies, DOE, or other stakeholders?	No	
Existing resources inadequate to address the risk event?	Yes	Excavation and off-site disposal are not included in the Site 300 ER Program baseline funding profile
Staff reductions or reassignments?	No	
Significant modifications to current strategies, procedures, or operations?	No	
Significant impact to project cost?	Yes	Current estimate for excavation and off-site disposal is approximately $47M
Significant impact to project schedule?	No	
Are there any other considerations not addressed in the above trigger questions?	No	

C.2.2 Project Risk Evaluation

Probability and Consequence Criteria

The probability and consequence criteria used by the ER Program are based on the nature and requirements of the activities performed but are consistently applied to individual projects. A set of general guidelines to define probability and consequence criteria is used:

- probability criteria
  - high: greater than an 80% probability of occurrence
  - medium: 10%–80% probability of occurrence
  - low: less than a 10% probability of occurrence

- consequence criteria
    - high-consequence project risks can include the following:
        - greater than 20% impacts to cost or schedule
        - serious regulatory compliance violations that could lead to fines or work stoppages
        - missing legally required milestones
        - significant or urgent threats to human health, the environment, or worker safety
    - medium-consequence project risks can include the following:
        - 5%–20% impacts to cost or schedule
        - significant regulatory compliance issues
        - moderate and nonurgent threat to human health, the environment, or worker safety
    - low-consequence project risks can include the following:
        - less than 5% impacts to cost or schedule
        - minor regulatory compliance issues
        - minor, nonurgent threats to human health, the environment, or worker safety

Risk Index

The probability and consequence criteria of each project risk are used to assign a numerical risk index as shown in Table C-2. The risk index allows project risks to be compared quantitatively.

Table C-2. Project risk probability/consequence matrix

Probability	Consequence	Risk index
High	High	9
Medium	High	6
Low	High	3
High	Medium	6
Medium	Medium	4
Low	Medium	2
High	Low	3
Medium	Low	2
Low	Low	1

Project Risk Categories

A project risk category is also assigned to each project risk event to provide more information to the decision maker than is contained in the risk index. Risk categories include the following:

- Technical—Project risks related to the ability to execute the scope of work. A technical risk could be the failure to achieve groundwater cleanup standards within a reasonable timeframe.
- Logistical—Project risks due to regulatory, political, and public relations considerations. A logistical risk could be a change in environmental regulations or cleanup standards.
- Funding—Project risks due to variability in financial allocations to the LLNL ER Program from DOE.

C.2.3 Project Risk Mitigation

Project risk mitigation consists of two primary activities: mitigation and monitoring. For each project risk event, the ER Program develops (1) a risk mitigation strategy to ensure that the appropriate risk control measures are implemented and (2) a monitoring strategy to confirm that these mitigation measures continue to effectively manage the project risk until disposition of the event.

Initially, cause-and-effect analyses are performed to determine the conditions under which a specific project risk may occur, and the program attempts to mitigate or reduce the project risk by managing the cause. Subsequently, the ER Program may conduct a more rigorous risk evaluation focusing on reducing the impact of the project risk, should it occur. This may consist of a more detailed examination of the potential impact, including identifying cost and/or schedule impacts under multiple scenarios.

Project risk mitigation strategies are designed to either avoid or minimize the impact of events. When possible, the ER Program takes early action to reduce the probability of a project risk event occurring or to minimize the impact of the event. A mitigation strategy is specific to the nature of an individual project risk event, but the program employs general strategies such as the following:

- adjusting schedules
- adopting a less complex process
- adding or reallocating resources
- negotiating project scope or compliance requirements with the regulatory agencies
- employing redundant systems or processes
- implementing early starts to activities
- performing aggressive cost control
- conducting treatability studies to assess technologies
- considering alternative technologies

In some cases, the project team may elect not to change the project plans to deal with a specific project risk event. Active acceptance of a project risk may involve developing a contingency plan that will be executed should the risk be realized. Alternatively, the team may select a passive strategy and address the risk, should it occur. The strategy and threshold for accepting a project risk is made on a case-by-case basis.

After the appropriate project risk mitigation measures have been implemented, residual project risks may remain. The project risk mitigation strategy for each risk event may also include measures to address this residual risk.

Unanticipated and/or greater than expected project risk impacts are possible. The ER Program addresses these on a case-by-case basis by modifying the risk mitigation measures, creating additional mitigation measures, or accepting the project risk either actively or passively.

C.2.4 Project Risk Monitoring

Project risk monitoring is an ongoing process throughout the life of the ER Program. The objectives of project risk monitoring are as follows:

- evaluate whether the assumptions made in the initial mitigation strategy are still valid
- ensure the project risk mitigation measures have been implemented as planned
- evaluate the effectiveness of the project risk mitigation measures
- identify any previously unanticipated project risks
- detect trends

The project implements risk monitoring primarily by performing project risk reviews facilitated by the Program Leader. These reviews may lead to reevaluation of the technical performance of a project, additional or modified risk mitigation measures, scope change requests, reallocation of resources, or revised probability/consequence and expected value estimates. In some cases, persons not involved in the project may perform audits. In addition, prior to the start of significant new activities, a focused project risk evaluation is performed so that appropriate risk mitigation measures can be included in the planning process, if needed.

Ultimately, all project risk events are realized, successfully mitigated, or determined to no longer be a project risk. The Program Leader is responsible for updating the risk management database to accurately reflect the disposition of each event.

A risk analysis worksheet is generated for each project risk event selected for inclusion in the risk management program. These worksheets contain specific information such as the staff responsible for managing the project risk (the risk event owner), risk index, risk category, urgency, probability/consequence data, expected value, risk mitigation strategy, action items, and ultimate disposition. Members of the ER Program initially prepare the worksheets. The Program Leader is responsible for consistency between worksheets, tracking each worksheet, and confirming the successful disposition of each risk event. Table C-3 presents an example risk analysis worksheet for the Pit 7 Landfill.

C.2.5 Project Risk Reporting

ER projects track each project risk event and provide estimates of potential cost and schedule impacts. The risk tracking databases include information such as risk event owner, risk index, probability, estimated total cost, expected value, schedule impact, and risk event disposition. Table C-4 shows a prioritized list of risk events for Site 300.

Table C-3. LLNL Site 300 project risk analysis worksheet for the Pit 7 Landfill

Element	Risk event information
Risk event tracking code	ER/S300/R2
Risk event title	The selected remedy for the Pit 7 Landfill Complex could involve excavation of the buried radioactive debris.
Risk event description	Remedial options to address contamination at the Pit 3, 5, and 7 Landfills, collectively designated the Pit 7 Landfill Complex, are being evaluated. LLNL assumes the selected final remedy will include monitoring surface and groundwater hydraulic control to prevent further leaching of tritium and uranium from the landfills; MNA of VOCs and tritium in groundwater; and extraction and treatment of uranium-, nitrate-, and perchlorate-contaminated groundwater. It is possible that the regulatory agencies could require excavation of the landfill contents, which differs significantly in scope and/or cost from the remedial action contained in the baseline.
WBS number and element title	1.4.5.4.3.16. Building 850/Pit 7 Complex
Prepared by	Michael Taffet
Date prepared	June 2, 2003
Date last revised	March 5, 2007
Risk event owner	Leslie Ferry
Risk index	3
Risk category	Logistical, funding
Urgent response required?	No
Probability	5%
Cost impact	$47,053,000. The estimated cost impact assumes excavation of the contents of the Pit 3 and 5 landfills with off-site disposal as mixed hazardous and radioactive waste. Costs are derived from estimates presented in the 1999 Site-Wide Feasibility Study.
Schedule impact	Build-out scheduled for FY08 would not be met if additional remediation efforts, including landfill excavation above what is currently planned for in the Site 300 ER baseline, are required.
Expected value	$2,353,000
Risk mitigation strategy	Generate appropriate documentation leading to a nonexcavation remedy selection. Negotiate project scope with regulatory agencies.
Risk monitoring strategy	Maintain interactions with the regulatory agencies to minimize potential remedy impacts, primarily through the monthly meetings with the RPMs.
Action items	None
Disposition	Successfully mitigated. Installation of a drainage diversion system, rather than excavation of the landfill waste, was selected as the source control remedy component in the Final Site-Wide ROD.

Table C-4. Prioritized risk events for the LLNL Site 300 ER Program

Risk event tracking code	Risk event title	Probability	Consequence	Risk event index	Status
ER/S300/R3	The regulatory agencies could impose more stringent groundwater cleanup standards than currently anticipated.	Medium	High	6	Successfully mitigated. Cleanups standard negotiated in ROD.
ER/S300/R11	Scope of the soil excavation and solidification at Building 850 could significantly differ from that defined in the Baseline.	Medium	High	6	Active
ER/S300/R12	Regulatory agencies may require active remedial measures to address perchlorate contamination.	Medium	High	6	Active
ER/S300/R13	Active remediation may be required at Building 812.	Medium-high	High	6	Active
ER/S300/R14	Active remediation may be required at the Pit 2 Landfill.	Medium	High	6	Active
ER/S300/R1	Significant changes to the scope of remediation could be required in the Final Site-Wide ROD.	Medium	Medium	4	Successfully mitigated. Interim remedies accepted in Final ROD.
ER/S300/R4	Active remediation could be required at Building 865.	Medium	Medium	4	Successfully mitigated. No further action required.
ER/S300/R10	Changes to Eastern General Services Area (GSA) discharge permit could be required.	Medium	Medium	4	Realized
ER/S300/R2	The selected remedy for the Pit 7 Landfill Complex could involve excavation of the buried radioactive debris.	Low	High	3	Successfully mitigated. No excavation required in ROD.
ER/S300/R8	DOE funding may not be sufficient for regulatory oversight costs.	High	Low	3	Active
ER/S300/R9	The stakeholders may not accept an MNA remedy for tritium in groundwater at the Pit 7 Landfill Complex.	Low	High	3	Successfully mitigated. Stakeholder acceptance achieved.
ER/S300/R5	A new water-supply well could be required at the Pit 6 Landfill.	Medium	Low	2	Active
ER/S300/R6	Significant changes to the remedial approach could be required at Building 834.	Low	Medium	2	Active
ER/S300/R15	Eastern GSA treatment facility will either have to treat naturally occurring constituents or discontinue the discharge into Corral Hollow Creek.	Medium	Medium	2	Active
ER/S300/R7	Active remediation could be required at the Sandia Test Site.	Low	Low	1	Successfully mitigated. No further action required.

C.3 Contingency

"Contingency" refers to uncertainties in executing the work defined in the Baseline Work Plan resulting from variability in the cost estimates, schedule, and scope. Contingency covers costs that may result from incomplete design, unforeseen and unpredictable conditions, or uncertainties within the defined project scope. Contingency is derived from a structured analysis of project uncertainties.

The Site 300 ER Program identifies contingencies at the activity level. Contingency applies to planned activities and is considered to arise from uncertainty of the unit cost of resources and/or the amount of resources necessary to achieve the objective of the activity. The latter can occur when an activity meets its objective but the quantity of resources required is not estimated accurately or when the objective of the activity is not met.

To calculate contingency, activities whose budgeted costs were estimated to have approximately equal ranges of potential uncertainty were grouped in bins. Five bins (A–E) were defined, in order of increasing uncertainty of unit cost estimates. Table C-5 shows example activities for each bin. A triangular probability distribution function describing the potential error band for each bin was developed, and that function was applied to the cost estimate of each activity in the bin. The triangular distribution model was selected as a reasonable error band for all activity bins as it is characterized by a customizable skewed shape that accounts for a low probability of high excess costs.

Table C-5. Example activity grouping for contingency analyses

Bin	Unit cost uncertainty	Example activities
A	Triangular distribution, with a minimum of 95% of baseline and a maximum of 120%; mode is 100% of baseline value.	Groundwater modeling Water level measurements Water quality sampling and analysis Monthly Remedial Project Manager meetings Institutional space charges Office supplies DOE-ER Program meetings
B	Triangular distribution, with a minimum of 95% of baseline and a maximum of 125%; mode is 100% of baseline value.	Audits and reviews Remedial design reports DOE requests for information Well and sampling equipment maintenance Treatment system operation and maintenance Monitor well construction
C	Triangular distribution, with a minimum of 95% of baseline and a maximum of 130%; mode is 100% of baseline value.	Baseline revisions Design of treatment facility site General treatment facility support

Bin	Unit cost uncertainty	Example activities
D	Triangular distribution, with a minimum of 95% of baseline and a maximum of 140%; mode is 100% of baseline value.	Landfill isolation technology testing Construct site for a treatment system Pipeline construction Design and construction of chromium treatment facilities Major reports (e.g., Remedial Investigation/Feasibility Study)
E	Triangular distribution, with a minimum of 95% of baseline and a maximum of 150%; mode is 100% of baseline value.	Extraction well installation Horizontal well installation

A Monte Carlo analysis of 1,000 realizations was made, and the 85% confidence level that the sum of baseline estimate plus contingency would not be exceeded was calculated. "Contingency" is defined as the difference between the 85% confidence level value and the baseline value. Analyses were made on a year-by-year basis. The ability to estimate cost of activities in outyears is considered to be the same as for the current fiscal year; hence, the probability distribution function ranges are the same.

In all cases, the sum of the contingencies for each project exceeds the lumped contingency values for each project. This occurs because the risk of any one project being characterized by an extreme value for any one realization (hence contributing to a large individual contingency for that one element) is typically offset by less extreme values for the other projects in the same realization. The resulting overall dilution of the risk of extreme values (i.e., costs greatly exceeding the baseline) is thus reduced somewhat for the overall ER Program.

Table C-6 shows an example summary contingency analysis.

Table C-6. Example contingency analysis for the Site 300 ER Program

WBS	Project	Mean ($)	85th percentile ($)	Contingency $	Contingency %
03.02	Site 300 Site Wide	1,495,539	1,617,044	121,505	8
03.07	General Services Area	443,020	478,654	35,634	8
03.11	Building 834	547,390	592,926	45,536	8
03.14	HE Process Area	824,329	890,163	65,834	8
03.16	Building 850	4,749,667	5,715,910	966,243	20
03.18	Building 854	633,713	699,200	65,487	10
03.19	Building 832 Canyon	1,090,611	1,205,598	114,987	11
03.21	Site 300 Program Management	1,207,538	1,312,294	104,755	9
03.22	Building 865 (ATA)	58,105	64,122	6,017	10
03.24	Building 812/STS	182,506	199,187	16,681	9
03.28	Site Wide Documents	219,544	240,468	20,925	10
03.30	Infrastructure Support	3,334,038	3,589,694	255,657	8
Totals:	Site 300 Total	14,786,001	16,404,853	1,618,852	11

Appendix D

Illustration of RRM at a Former Plating Facility

ILLUSTRATION OF RRM AT A FORMER PLATING FACILITY

This case study of a former plating facility (the "site") illustrates how RRM can be applied to improve decision making at different stages of site investigation and remediation.

D.1 SITE SETTING

The two-acre site is located in an urban setting in an area zoned for light industrial activities. Currently, the site is zoned for nonresidential redevelopment. A custom metal-plating facility operated at the site 1962–1983, where activities included plating, degreasing, painting, and other industrial processes. Prior to 1983, operations were conducted under an interim RCRA permit. Since 1989, the site has been used for automobile repair. The solvents TCE and 1,1,1-trichloroethane (TCA) were used at the site, as well as metals (chromium, cadmium, zinc, and silver). Paints containing lead, zinc, and other metals were also used.

Until 1973, liquid wastes were discharged to a small on-site holding pond. This pond was eventually filled in and wastes were minimally pretreated before being discharged to the municipal sewer. Solid wastes, including paint and degreaser sludge, were also disposed of on site in the early years, before off-site disposal began in 1975.

Just east of the site is a residential neighborhood of modest single-family homes. The area is served by city utilities, including water and sewer. Topography is subdued with a slight slope to the east-southeast toward a small stream, Hickory Brook. The overall area is set on a broad terrace of the larger Old River located a mile south of the site. The local geology consists of, from the deepest to shallowest units, weathered shale bedrock overlain by 15–40 feet of fine to coarse alluvial sands with some clay layers, which is overlain in turn by 15–20 feet of overbank deposits of silts, clays, and silty sands. Site stratigraphy is consistent with this description. Bedrock was encountered at depths of 45–50 feet below grade at the site. Groundwater was encountered at 20–25 feet below grade. A 450-gpm municipal production well is located approximately 1.25 miles southeast of the site.

In the 1980s, following initial state inspections, site investigations were conducted. Soil borings at the former pond and sludge disposal area confirmed shallow soil contamination with metals. Groundwater was sampled from two wells on the eastern side of the site, where hexavalent chromium, TCE, and TCA were detected. No groundwater contamination was detected in one well to the west. Based on water levels in the three wells, groundwater flow direction was inferred to be toward the southeast, consistent with regional flow direction.

Additional site investigation was postponed due to bankruptcy of the former plating company and the resulting legal complications. Recent detections of solvents in the municipal well have led to the site's being given a priority designation for remediation under the state's orphan site program.

The remedial action selected for implementation at this site consists of hot-spot treatment using ISCO and excavation of hotspots of metal-contaminated soils. Air stripping and vapor-phase carbon will also be used for production wellhead treatment. This remedy has a predicted present value of $0.63M.

D.2 USE OF RRM FOR MITIGATION OF PROJECT RISK

The use of RRM at the site can be illustrated at many points in the remedial process. The examples that follow describe the use of RRM at two such points to address remedy failure (Section D.2.1) and budget and scheduling (D.2.2). As described in this document, RRM includes the following steps:

- project risk identification
- project risk evaluation
- project risk mitigation
- project risk monitoring
- project risk reporting

D.2.1. Remedy Failure

<u>Project Risk Identification</u>

Examples of potentially significant failure modes for the chosen remedy are as follows:

- Contact is incomplete between chemical oxidant and contaminants.
- During excavation of the metals-contaminated soils, debris or drums are encountered.
- Vapor-phase carbon breakthrough occurs with release of contaminants above allowable levels.

<u>Project Risk Evaluation</u>

As described in this document, project risk evaluation involves assessing (1) the probability of each project risk event and (2) the resulting impacts of such an event. Here, remedy failure is evaluated qualitatively. Use of a risk register to tabulate probabilities and potential impacts may be helpful.

Each potential project risk event may result from one or more of several causes. To evaluate the likelihood of each event, the likelihood of the potential causes must be assessed. Potential causes of the events identified in this example include the following:

- The ISCO design overestimated the distribution of reagents (likely); contractor did not inject the prescribed mass of oxidant/foot due to carelessness or malfunctioning flow meter (unlikely); subsurface heterogeneities were not known or injection footprint not large enough relative to source extent (likely).
- Limited characterization of the former pond (unlikely).

- Variable influent concentrations led to unexpectedly rapid breakthrough (unlikely); malfunctioning photoionization detector (unlikely); inadequately regenerated carbon (very unlikely); inadequate operator testing of influent/effluent concentrations (unlikely); moisture build-up in carbon vessels (unlikely); piping break between lead/lag vessels (very unlikely).

After assigning likelihoods to the potential causes of each project risk event, the events may be assigned likelihoods as follows:

- Contact is incomplete between chemical oxidant and contaminants (likely).
- During excavation of the metals-contaminated soils, debris or drums are encountered (unlikely).
- Vapor-phase carbon breakthrough occurs with release of contaminants above allowable levels (unlikely).

The project risk events identified carry project impacts of differing severity. These impacts include the following:

- Contaminant concentrations in the hot-spot area are not reduced uniformly to target levels, requiring additional mobilizations to the site by the ISCO contractor. This need, in turn, causes schedule and property reuse delays with attendant substantial costs and potential legal liabilities. Costs may be in the hundreds of thousands of dollars.
- Excavation is halted with growing costs for excavation and transport contractor standby time. Schedule and property reuse are delayed with attendant substantial costs and potential legal liabilities. Costs for disposal increase. Overall project cost increase may be in the hundreds of thousands of dollars.
- Regulatory agency fines are assessed. Fines may be in the tens of thousands of dollars. Additionally, the credibility of the remediation with the nearby residents is diminished, leading to attendant increases in project management and consultant time/costs.

Project Risk Mitigation

The potential project risks due to implementation of the remedy can be mitigated through elimination, reduction, transfer, or acceptance. For example:

- Risk of ISCO failure can be reduced (avoidance) through use of a larger safety factor in selecting injection point spacing; closer oversight of the injection contractor, including independent calibration of meters; or further predesign site characterization to determine source extent and subsurface stratigraphy (to an acceptable level of certainty). Failure can be mitigated to some extent by allowing extra time in schedule for additional ISCO injection events and/or through the use of a type of contract that provides incentives for the contractor to meet schedules and specified concentrations (after rebound) or liquidated damages if the schedule or concentration targets are not met (note this approach will raise the cost of the contract, as risk is being shifted to the ISCO contractor).
- Discovery of buried drums can be foreseen (mitigation) through preconstruction surface geophysical surveys looking for metallic objects in the excavation volume. Project schedules, materials handling equipment, and disposal contracts could be developed based on t he

outcome of the surveys. Targeted removals of metallic debris could avoid delays and standby costs.

- Failure can be avoided through use of larger carbon vessels, prescribed frequent sampling of influent and effluent from each vessel with changeout of lead carbon vessel at a lower breakthrough concentration, methods to reduce moisture condensation in the vessels (insulation, heat tracing, preheating influent air), routine independent review of operator logs to ensure readings are being taken and requirements for instrument calibration, use of virgin carbon, and proper design of vapor piping and instrumentation to shut down the system if a piping break occurs.

Project Risk Monitoring and Reporting

The project risk of remedy failure at this site would be monitored through appropriate sampling, including groundwater sampling and the influent, intermediate, and effluent contaminant concentrations at the carbon vessels. The data generated by these actions require timely evaluation of the results and documentation of those evaluations. The reporting may include immediate notification of the appropriate managers if contaminant concentrations indicate failures have occurred or post-construction compilation of a summary of the risk outcomes for use on other projects.

Decision Making Informed by RRM

The assessment of the remedy failures discussed above might lead the project team to implement only some of these measures. In other words, after considering the likelihood and impact of some of the failures and the cost for avoiding or mitigating the risks, some of the project risk may be accepted. For example, for the ISCO application, if the cost for extensive characterization is small compared to the cost for multiple ISCO mobilizations, modest investments in additional characterization may be made instead. Tables D-1 and D-2 are examples of an event screening checklist and a risk analysis worksheet the project manager may use to assess ISCO. For the excavation, the low cost of the geophysical surveys and the magnitude of the impacts may lead the project manager to conduct the surveys before excavation. In the case of unacceptable release of contaminants to the air, the higher cost for virgin vapor-phase carbon and the low likelihood of acquiring inadequately regenerated carbon from a reputable source may lead the project manager to accept the risk and not require the use of virgin carbon.

Table D-1. Example potential risk event screening checklist for use of ISCO at the site

Trigger question	Response (yes/no)	Comments
If ISCO fails to achieve project objectives, could there be:		
Potential health or safety concerns for on-site workers or the public?	No	
Potential threat to the environment or natural resources?	No	
Any laws violated?	No	
Any legally required milestones threatened?	No	
A threat to any commitments made to the regulatory agencies or other stakeholders?	No	

Trigger question	Response (yes/no)	Comments
If ISCO fails to achieve project objectives, could there be:		
Inadequate resources to address the risk event?	Yes	Project budgets do not currently include funding to address potential failure of ISCO.
Staff reductions or reassignments?	No	
Significant modifications to current strategies, procedures, or operations?	Yes	If target concentrations are not achieved using ISCO, additional injections or changes to the remedy may be required.
Significant impact to project cost?	Yes	Performing a second phase of injections would be very costly, as would major modifications to the overall remedial approach.
Significant impact to project schedule?	Yes	Failure of ISCO to achieve project objectives within the anticipated remedial timeframe would necessitate renegotiation of milestones with the regulatory agencies.
Are there any other considerations not addressed in the above trigger questions?	No	

Table D-2. Example risk analysis worksheet for ISCO at the site

Element	Risk event information
Risk event tracking code	UPS-5
Risk event title	In situ chemical oxidation effectiveness
Risk event description	Incomplete contact may result in contaminant concentrations in the hot-spot area not being reduced uniformly to target levels, requiring additional mobilizations to the site by the ISCO contractor or remedy changes.
Date prepared	July 25, 2008
Date last revised	January 17, 2009
Risk event owner	John Doe, Project Manager
Urgent response required?	No
Likelihood of cost impacts	Likely
Cost impact	Critical
Cost risk level	High
Likelihood of schedule impacts	Likely
Schedule impacts	Critical
Schedule risk level	High
Risk-handling strategy	Ensure site characterization data are adequate to allow optimal oxidizing reagent injection design and implementation. Conduct treatability studies to refine remedial design. Drill test borings during and after injection to evaluate and verify penetration and coverage of reagent into the contaminated media. Develop realistic performance criteria for contaminant mass and concentration reduction.

D.2.2 Project Risk to Schedule and Budget

To illustrate how the project risk to schedule and budget would be quantified and addressed by project decision makers, this section discusses the schedule and budget risks associated with the excavation of the former waste pond. This component of the remedy would include excavation of soil above the water table contaminated with metals and organics.

Project Risk Identification

Refer to Risk #3, excavation uncertainty, in the risk register for the site (Table D-3) that has been completed for impacts on schedule and budget. Each project risk in the risk register would be developed by the project team members directing that activity. The site project team members involved in the excavation activities include the project manager, geotechnical engineer, and the geologist. For this project risk, the project team identified the following subrisks:

- Risk 3a: Volumes of soil requiring removal and disposal would increase due to unanticipated extent of the contamination.
- Risk 3b: Drums or other solid debris would be encountered that would require specialized equipment and handling procedures not immediately available.

Table D-3. Risk register for the site

Risk event tracking code	Risk event title	Project team discussions	Cost			Schedule		
			Likelihood	Impact	Risk level	Likelihood	Impact	Risk level
UPS-1	Availability of key personnel	Unanticipated delays in obtaining approvals or reaching key decisions could occur. The project involves meetings, decision making, and work product reviews by multiple personnel from the project team, ISCO and excavation contractors, stakeholders, and regulatory/redevelopment agencies. The state's orphan site program has been struggling under recent staffing and funding limitations. Significant schedule delays may occur if critical path activities are impacted.	Likely	Marginal	Moderate	Likely	Significant	High
UPS-2	Accelerated procurement of contractors	Procurement of contractors is being accelerated to meet critical redevelopment schedule deadlines. The scope of work is not yet well defined. The scope of work is based on the current conceptual model and may be inadequate due to the limited characterization completed. Bidders may include high levels of contingency in their bids due to the accelerated schedule and limited characterization data. The current procurement strategy includes selection of multiple, independent contractors.	Very likely	Significant	High	Very likely	Marginal	Moderate

Risk event tracking code	Risk event title	Project team discussions	Cost			Schedule		
			Likelihood	Impact	Risk level	Likelihood	Impact	Risk level
UPS-3	Excavation uncertainty	The volume of contaminated soil that will be excavated is uncertain. Unanticipated drums or other debris may be encountered. Changes in current assumptions about excavation soil volumes or unanticipated materials will affect project cost and schedule. Excavation may be halted due to safety concerns if drums are encountered resulting in project delays.	Likely	Significant	High	Likely	Marginal	Moderate
UPS-4	Release of contaminants above allowable levels	Vapor-phase carbon breakthrough occurs with release of contaminants above allowable levels. Regulatory agency fines could be assessed, perhaps tens of thousands of dollars. Additionally, the credibility of the remediation with the nearby residents may be diminished and result in project delays or increased community outreach costs.	Likely	Marginal	Moderate	Likely	Negligible	Low
UPS-5	In situ chemical oxidation effectiveness	Incomplete contact may result in contaminant concentrations in the hot-spot area not being reduced uniformly to target levels, requiring additional mobilizations to the site by the ISCO contractor or remedy changes.	Likely	Critical	High	Likely	Critical	High
UPS-6	Presence of utilities	Numerous existing utilities are present at the site and adjacent light industrial parcels. Impacts to utilities present at and near the site will need to be addressed, and some utilities may require relocation. Unknown utilities may be encountered during remediation and cause schedule delays.	Unlikely	Significant	Moderate	Unlikely	Marginal	Low
Risk reporting and monitoring strategy		Collect and analyze sufficient subsurface samples to allow evaluation of remedy performance.						
Risk status		Active						

Project Risk Evaluation

The project team members responsible for the excavation component would assess the available information to determine a percentage likelihood of each risk identified above as well as a specific potential impact to schedule and budget. Based on a review of the site historical practices and the available soil sampling data, the following probabilities of the risks were estimated:

- Risk 3a: 35% likelihood that the excavation volumes would exceed 110% of the design quantities. Maximum reasonable increase would be 400 yd^3.
- Risk 3b: 5% likelihood that drums or large debris exist in the pond. Quantities would be minimal (affecting no more than 10% of the volume, 200 yd^3).

The impacts on schedule and budget of these project risks were assessed by the team members, as well:

- Risk 3a: Cost impact would be 400 $yd^3 \times \$200/yd^3$ = \$80,000. Schedule impact would be approximately one additional week in the duration of the activity.
- Risk 3b: Cost impact would conservatively be estimated as \$15,000 standby time for the excavation crew and an additional \$40,000 for specialized crew and equipment for drum/debris removal. Disposal costs would potentially grow by \$10,000 for a total cost impact of \$65,000. Schedule impacts could be as long as an additional two weeks in the duration of the activity.

Project Risk Mitigation

The project team also determined the costs for actions that would mitigate the project risks:

- Risk 3a: Additional soil sampling activities to reduce the risk of an increase in the excavation volumes to less than 10% would involve an additional \$10,000 for mobilization, sampling, analysis, and reporting. The additional sampling would not increase the time for the excavation activity, as the additional sampling could proceed during the time allocated for final design and procurement.
- The risk of discovering buried drums and debris could be assessed further by a geophysical survey for a cost of \$8,000 with no impact on the scheduled start of excavation.

Decision Making Informed by RRM

The project manager decided the investment in additional sampling to mitigate the project risk of increased excavation volumes was worthwhile as the budget and schedule were tight. In addition, sidewall sampling with rush turnaround for the sample analyses would be conducted while excavation was under way to monitor risks as excavation proceeds.

Based on the low likelihood of finding buried debris, the project manager decided to accept this project risk and not conduct the additional survey; however, she decided to sequence the excavation to allow initial test pitting by the contractor to monitor the risk of buried debris while the rest of the excavation was under way.

Appendix E

Case Studies

CASE STUDIES

E.1 OVERVIEW OF CASE STUDIES

This appendix includes case studies of nine different locations that have conducted RRM-related processes. They include several sites in different EPA regions and illustrate different aspects of RRM.

- E-2. Hardage CERCLA Site (Region VI)
- E-3. McColl CERCLA Site (Region IX)
- E-4. PetroProcessors CERCLA Site (Region VI)
- E-5. Brio Refining CERCLA Site (Region VI)
- E-6. Tyson's Lagoon CERCLA Site (Region III)
- E-7. Lone Pine Landfill CERCLA Site (Region II)
- E-8. American Chemical Service CERCLA Site (Region V)
- E-9. LLNL examples (Region IX)
- E-10. Hill Air Force Base example

Potential remedy implementation project risks have been an important consideration in selecting remedies at numerous CERCLA sites across the country. At the McColl, Tyson's Lagoon, Lone Pine Landfill, Hardage, and American Chemical Service CERCLA sites, intrusive remedies were rejected prior to implementation, in large part due to consideration of potential worker and community project risks. The excavation remedies originally selected and initiated for the PetroProcessors Site in Louisiana and the Brio CERCLA Site in Texas were ultimately abandoned in favor of a nonintrusive remedy due to off-site risks. Details regarding the Hardage, McColl, PetroProcessors, Brio, Tyson's Lagoon, Lone Pine Landfill, and American Chemical Service sites are provided below.

E.2 HARDAGE CERCLA SITE (REGION VI)

According to the ROD issued by the EPA (EPA 1989), the Hardage CERCLA Site in Oklahoma received an estimated 20 million gallons of a wide variety of hazardous wastes 1972–1980. The primary means of disposal included mixing liquids and sludges with clean soil and placing the liquids in unlined impoundments. Most of these residues are concentrated in three areas, collectively referred to as the source areas.

Groundwater underneath the site and off site of the source areas was contaminated with VOCs. Downgradient off-site water supply wells have been closed since 1986, when affected residences were connected to a municipal water system. EPA's selected remedy for the Hardage CERCLA Site was described in the final ROD dated November 27, 1989. T he primary elements of this remedy included the following:

- excavating drums present in the source areas
- removing nonaqueous-phase liquids (NAPLs) for off-site incineration

- replacing soils excavated during drum removal
- removing VOCs by vacuum extraction in the source areas
- installing trenches to intercept groundwater downgradient of the source areas
- pumping and treating intercepted groundwater
- capping the source areas

The potentially responsible parties (PRPs) at the Hardage Site, known collectively as the Hardage Steering Committee (HSC), reviewed EPA's selected remedy and determined that it was inappropriate for a variety of reasons, including the potential project risk posed to workers and the off-site community during remedy implementation. Thus, HSC developed an alternative remedy consisting of the following elements:

- removing pumpable organic liquids from the source areas for off-site treatment
- installing a system of wells and a trench to intercept groundwater downgradient of the source areas
- pumping and treating intercepted groundwater
- capping the source areas

A critical difference between the EPA and HSC remedies is that the HSC remedy is far less intrusive, thus posing lower short-term project risks to workers and the off-site community. To evaluate project risk to the off-site community, HSC evaluated and compared the off-site project health risks associated with implementing the two remedial alternatives. Pathways of direct exposure included in the assessment were inhalation of vapors, inhalation of particulates, and ingestion of particulates. Pathways of indirect exposure included in the assessment were ingestion of milk, beef, fish, and leafy vegetables.

HSC assessed the relative project risk to workers in two ways: semiquantitatively by comparing the number of man-hours required by the two remedies and qualitatively by identifying and examining the particular hazardous activities of the two remedies. Activities unique to the EPA remedy that exposed workers to toxic, flammable, and explosive chemicals included removal and handling of drums from the source areas and excavation of hazardous materials such as asbestos and NAPLs in the source areas. There were also reports of phosgene canisters in the source areas, potentially posing an even greater worker safety hazard.

HSC's evaluation of project risks to the community during remedy implementation indicated that potential cancer risks posed by the EPA remedy were more than 1,000 times higher than for the HSC remedy. Overall, the total lifetime cancer risk for the EPA excavation remedy was estimated to exceed 1×10^{-4} (i.e., one in ten thousand), a level generally regarded as unacceptable by EPA. The assessment also concluded that the EPA remedy posed greater project risk of worker accidents and heat stress than the HSC remedy because of the substantially greater number of total man-hours and man-hours requiring use of Level A or Level B personal protective equipment (PPE).

The U.S. District Court for the Western District of Oklahoma ultimately ruled in favor of the HSC, thereby overturning EPA's ROD for the Hardage Site in favor of a less intrusive remedy. In developing its conclusions, the court considered that excavation-based remedies selected by

EPA at various other sites, including the PetroProcessors CERCLA site, have been delayed or reconsidered because of unacceptable vapor emissions. In addition, the court found the following arguments against the excavation-based remedy persuasive (USDC 1990):

- The dangerous short-term project risk to workers from emissions generated during remediation is not outweighed by the alleged long-term benefits associated with excavation.
- The excavation implementation components, including liquids removal, transportation of wastes to staging area, and maintenance of the soil vapor excavation system, create significant project risks.
- Excavation will present risk of fire, explosion, and physical injury from direct contact with hazardous wastes if incompatible wastes mix during remedial work.
- Excavation to remove drums and drummed wastes will cause off-site releases of exceedingly toxic substances that can contaminate soil and surface water near the site and can persist long after the remedy is constructed.
- Excavation as a remedy will have marginal utility given that extensive soil and groundwater contamination will remain long after the excavation is completed and therefore will require containment systems to be maintained and operated indefinitely.
- EPA failed to evaluate adequately the costs and project risks associated with the handling, testing, storage, transportation, and incineration of drums, liquids, sludge, and other material.
- Because wind gusts are likely during any excavation of the Hardage Site, the proposed use of a plastic covering to control vapor emissions from stored materials is unlikely to succeed.

In addition, the court found that "the HSC's proposed remedy complied fully with the provisions in CERCLA that require that remedies address the 'persistence, toxicity, mobility, and propensity to bioaccumulate of...hazardous substances and their constituents.... The HSC remedy will not release as much dust and vapor into water, soils, and vegetation surrounding the site and therefore is less likely to introduce chemicals into the food chain that may bioaccumulate and cause cancer and other adverse health effects" (USDC 1990). According to Judge Phillips of the U.S. District Court, the HSC remedy was found to be more protective of public health, safety and welfare, and the environment than EPA's excavation-based remedy. This position was supported by the State of Oklahoma; a representative of the Oklahoma Department of Health testified in favor of the HSC remedy and cited the HSC's project risk assessment as a partial basis for the department's position.

E.3 MCCOLL CERCLA SITE (REGION IX)

The McColl CERCLA Site in California is an inactive facility used in the 1940s for the disposal of refinery sludge (EPA 1992). The waste was deposited in a series of sumps across an area of about 8 acres. From 1951 through 1962, fill soil and drilling mud from oil exploration activities near the site were deposited in some of the pits in an effort to make the site suitable for future development.

The principal compounds of concern at the McColl Site include benzene, sulphur dioxide, tetrahydrothiophenes, and arsenic. Waste material is distributed across the site in 12 sumps ranging in depth 17–55 feet. Based on field studies, the volume of contaminated material is approximately 100,000 yd^3. During warm weather, the tar sometimes seeps out onto the surface, releasing an unpleasant odor and creating potential for direct contact with contaminants.

In 1962, a portion of the site was covered with soil and has since remained an open space. A soil cap was placed on the remainder of the site in the early 1980s in an attempt to reduce odors and lower the potential for direct human contact with material seeping from the sumps. In the late 1970s and early 1980s, areas directly adjacent to the McColl Site were subdivided and developed for single-family residences. Recreational park facilities were developed directly adjacent to the site, and a golf course was constructed over a portion of the sump areas.

In 1982, the McColl Site was placed on the NPL. In February 1989, after an evaluation of alternative remedies for the site, EPA proposed an excavation-based remedy as the preferred cleanup alternative. The PRPs for the McColl Site, known collectively as the McColl Site Group (MSG), determined that the originally proposed EPA excavation and thermal treatment option was inappropriate for the site for several reasons, including the short-term implementation project risks posed during excavation activities. As a result, the MSG evaluated the short-term implementation risks posed by the EPA remedy and compared them to those of a less intrusive, in situ solidification option. The MSG concluded that the project risk of an accident which could injure workers and the off-site community were high and were not offset by any risk reduction that might be achieved by an intrusive remedy.

A limited trial excavation of the waste material at the site was conducted under an enclosure during June and July 1990 to assess the technical feasibility and safety hazards posed by the proposed remedy. Equipment used for the trial excavation included conventional track hoe excavators, loader/backhoes, and roll-off bins. A pug mill was used to mix the excavated tar wastes with water, fly ash, and cement to improve handling characteristics. The enclosure system consisted of a rigid-frame polyvinylchloride-covered structure with an exhaust treatment system. Unexpected problems encountered during the trial excavation impeded the ability to excavate within the enclosure; problems included higher than expected vapor emissions which necessitated upgraded levels of worker PPE, temperatures within the enclosure approximately 20°F above outdoor temperatures, and diesel engine emissions which caused decreased visibility inside the enclosure.

After a subsequent reevaluation of the excavation alternative originally proposed for the site, EPA reversed its position and selected a nonintrusive, partial solidification option in its final proposed plan (EPA 1992). EPA's abandonment of the original remedy was based primarily on concerns regarding short-term remedy implementation project risks during excavation. According to the EPA (1992), "while excavation under an enclosure is technically possible, the uncertainties associated with undertaking full-scale excavation at McColl in close proximity to residences are high. The uncertainties could adversely affect the overall cost, the overall time for implementation, and the ability to implement the remedy successfully. It is also possible that the uncertainties could adversely impact the ability to provide protection of the community and workers during implementation (short-term effectiveness)." These project risks involve primarily short-term exposures to sulphur dioxide and tetrahydrothiophene during excavation activities, exposures of workers to high temperatures within the enclosure, and the potential for accidents during excavation activities.

E.4 PETROPROCESSORS CERCLA SITE (REGION VI)

The PetroProcessors CERCLA Site in Louisiana is an inactive hazardous waste disposal site which had been used for the disposal of organic wastes from the production of methylene chloride, waste crude oil, off-spec rubber, and other wastes from nearby petrochemical and chemical plants. The wastes were deposited in several former borrow pits, with the depths of the wastes extending to 40 feet in some areas. The chemicals of concern include chlorinated ethanes, benzene, and hexachlorobutadiene.

EPA first became involved with the PetroProcessors Site in May 1980 when inspections performed by EPA and the State of Louisiana found that open waste pits were in danger of overflowing. Evidence of discharges from the waste pits was also noted. EPA and Louisiana filed a lawsuit in Federal Court in July 1980 to force cessation of the discharges and cleanup of the site. In 1982, interim measures consisting of surface water diversions, dike reinforcement, and site security were implemented by the state's contractor. A settlement agreement was reached in the lawsuit in 1983; the terms of the agreement were set forth in a consent order lodged in December 1983.

A ROD issued by EPA for the PetroProcessors Site in 1984 specified the excavation of contaminated materials, solidification of lagoon sludges, and disposal of the treated waste in an on-site RCRA landfill. In addition, a pump-and-treat system was selected to address ground contamination. The on-site landfill was subsequently constructed, and waste excavation was initiated in 1987.

Excavation, solidification, and stockpiling activities during remediation of the PetroProcessors Site were halted in January 1988 when vapor emissions were found to be consistently unacceptable (NPC 1988). These vapor emissions resulted in exceedances of occupational exposure standards at the site boundary on numerous occasions, threatening the health of the off-site community, and had resulted in earlier temporary stoppages of remedial activities. After two years of reevaluation, an alternative remedy was chosen for the site. This remedy included the construction of a clay cap over the waste disposal area and deed restrictions to restrict future use of the site.

E.5 BRIO REFINING CERCLA SITE (REGION VI)

The Brio Refining CERCLA Site in Houston, Texas is an inactive petrochemical processing facility which had been used for reclamation of petrochemicals from various source materials, such as residues, tank bottoms, and tars from off-site facilities. Most of the feedstock materials were stored in on-site pits extending 14–32 feet in depth.

EPA placed the site on the NPL on March 31, 1989. Numerous investigations and site activities were performed at the site to determine the exact location of the former storage pits and to determine the nature and extent of contamination. Following the site investigations, EPA issued a ROD in 1988 that selected remedial actions consisting of (1) excavation and on-site incineration of pit residuals; (2) removal of surface contamination; (3) channel improvements to

Mud Gully, a flood control ditch and local tributary of Clear Creek located along the western boundary of the Brio Site; (4) demobilization of remaining process equipment and removal of debris on the site; and (5) removal of DNAPL and pump and treat for groundwater in the numerous sand channel zone water bearing unit (EPA 1997). The EPA and the Brio Site Task Force (BSTF) entered into a consent decree in April 1991 to implement the ROD remedy.

A temporary groundwater treatment system was installed in 1994 to address the movement of contaminated groundwater into Mud Gully. Demolition of the majority of the remaining process equipment was also completed. Subsequently, a rotary kiln incinerator and support equipment were mobilized to the site. To contain emissions during excavation, temporary enclosures were erected over the pits to be excavated. Excavation began at one pit for "shakedown" operations and to stockpile material for the trial burn (EPA 1997). Emission problems during excavation led to a "stop work" order until appropriate emission equipment control equipment could be installed. In May 1994, the BSTF submitted a force majeure claim to EPA stating that the short-term air standards set by EPA for the remedial action would result in delays in complying with the milestone schedule established in the consent decree, and in June 1994, the BSTF petitioned EPA to alter the remediation action for the Brio Site (EPA 1997). In August 1994, EPA notified BSTF that its petition, along with community input, provided a basis to reevaluate the incineration remedy. In making this decision, EPA considered that the emissions generated during excavation of pit residuals were higher than expected, resulting in the need for rigorous engineering controls and that the engineering controls necessary to abate these emissions would add significantly to the cost of the remedy (EPA 1997). The BSTF subsequently "demobilized the incineration unit, replaced soils excavated in preparation for the trial burn, and began a reevaluation of the site remedy through a focused feasibility study" (EPA 1997, p. 6).

In 1997, EPA issued an amended ROD for the Brio Site which replaced the excavation and on-site incineration remedy selected in the 1988 ROD with a containment remedy. The amended ROD states the following:

- Both the incineration and the containment alternative provide protection of human health and the environment by eliminating, reducing, or controlling risk through treatment or capping along with access restrictions (EPA 1997, p. 12).
- The service life of caps is uncertain, but a cap with a high-density polyethylene geomembrane may perform satisfactorily for several hundred years (EPA 1997, p. 13).
- The excavation and incineration alternative would involve significantly more intrusive activities in areas likely to contain the highest levels of contamination, thus representing the highest potential for releases (EPA 1997, p. 14).
- ECs and monitoring will reduce the potential for any adverse impacts during implementation of either remedy; however, the likelihood of airborne releases increases with intrusive activities despite the application of ECs (EPA 1997, p. 14). In fact, as observed during the trial excavation, despite the use of stringent ECs, emissions generated during excavation were still detected at the fence line of the site (EPA 1997).

E.6 TYSON'S LAGOON CERCLA SITE (REGION III)

The Tyson's Lagoon CERCLA Site in Pennsylvania is an abandoned waste disposal site used 1960–1970 for the disposal of septic and chemical wastes. The waste disposal area is within a sandstone quarry and consists of a series of unlined lagoons into which liquid wastes were discharged. The key contaminants identified at the site are VOCs (toluene, trichloropropane, and xylene).

In 1973, the Pennsylvania Department of Environmental Resources ordered closure of this facility. Following an investigation in 1983 by EPA (prompted by a citizen complaint about the site), the site was placed on the NPL in 1984. In December 1984, EPA issued a ROD for the on-site area, selecting a remedy that included excavation of lagoon materials followed by off-site disposal. Subsequent to the ROD, one of the PRPs agreed to conduct a remedial investigation (RI)/FS and performed on-site pilot studies for addressing treatment of lagoon materials and contaminated groundwater. As a result of the findings of the innovative vacuum extraction studies performed, EPA issued a revised ROD in March 1988 which replaced the excavation and off-site disposal remedy with a remedy which included soil vacuum extraction. In selecting the alternative remedy, EPA stated that the disadvantages associated with the excavation remedy included "greater potential release of volatile organic vapors to the community" (EPA 1987).

E.7 LONE PINE LANDFILL CERCLA SITE (REGION II)

The Lone Pine Landfill CERCLA Site in Freehold Township, New Jersey is a privately owned 45-acre landfill which operated 1959–1979. During its operation, liquid chemical waste and chemical waste sludges were disposed of in the landfill; wastes were received in drums (at least 17,000 drums were disposed) and by bulk tanker (several million gallons of wastes were disposed). The wastes placed in the landfill consisted primarily of VOCs (including benzene, toluene, xylene, tetrachloroethene, and TCE), heavy metals (including arsenic, chromium, and lead), and pesticides.

From the early 1970s until 1979, the New Jersey Department of Environmental Protection investigated the site and worked to close the facility. In 1981, the site was ranked in the top 20 of EPA's Interim NPL. Following an investigation of the site during 1981–1983, an FS was performed to evaluate remedial alternatives, including no action, containment, and excavation and disposal. While the local community appeared to favor complete excavation and removal, EPA's preferred remedy was the containment alternative. The containment alternative included the construction of a soil cap and a shallow groundwater cut-off wall; in addition, a groundwater extraction system would be used to maintain an inward gradient and remove any water that infiltrated through the cap. In selecting its preferred remedy, EPA noted that the FS indicated that the excavation and removal of drummed wastes (of unknown quantity and composition) and contaminated soils was not cost-effective, had potential safety problems, and had limited practicality. Specific concerns included the following:

- Potential fire and explosion from use of heavy equipment or spontaneous combustion.

- Excavation of the drums could potentially result in the release of volatile organic vapors and odors, which in themselves are potentially hazardous to public health.
- Excavation would subject on-site workers to the potential for direct contact with the hazardous materials and subject workers to dangers from fire and explosion.
- The reliability of excavation was questionable since it was likely that the majority of buried drums had ruptured and it might be difficult to identify all of the contaminated material; even a complete excavation of the drums and adjacent soil and waste material might not necessarily remove the bulk of the contamination.
- Excavation of drums below any encountered water would require extensive dewatering and treatment of highly contaminated water removed by the dewatering process.
- The state-of-the-art technology was such that after excavation there would be some uncertainty that all the drums had been located and removed.
- Assuming the drums could be excavated, the volume of material requiring transport would, despite stringent safety procedures, greatly increase the odds of traffic accidents and the resultant exposure of the public to hazardous substances.

Excavation of any kind was thereby rejected by EPA for this site. The remedy selected in the ROD issued by EPA in 1984 specified the containment alternative, which included the installation of a cap and slurry wall. EPA concluded that “excavation could change the situation from one that does not currently threaten the public to one that could cause releases of hazardous substances, cause chemical fires, and/or explosions. The potential long-term benefits of excavation are dwarfed by the potential short-term threats and impacts.” Furthermore, EPA concluded that “containing the landfill and drawing down the internal hydraulic head may decrease the exposure of water to the contents of the drums, reducing the waste’s mobility” (EPA 1984).

E.8 AMERICAN CHEMICAL SERVICE CERCLA SITE (REGION V)

The American Chemical Service (ACS) CERCLA Site in Griffith, Indiana is an active chemical manufacturing facility. Past solvent-recovery activities by ACS between 1955 and 1990 led to the contamination of this 19-acre site. Large areas of buried contaminants pose potential contact hazards to site workers and are a source of groundwater contamination. Soil contaminants include VOCs, semivolatile organic compounds (SVOCs), PCBs, and heavy metals.

EPA issued a ROD in 1992 with the intent to restore the property for potential future residential use with restriction on groundwater usage. The selected remedial actions in the ROD include the following (EPA 1999):

- excavation of buried wastes, 400 drums, and 135,000 cubic yards of contaminated soil and debris
- off-site disposal of miscellaneous debris
- off-site incineration of the contents of the excavated drums
- on-site treatment of excavated soils using low-temperature thermal desorption
- on-site treatment of in-place soils via SVE
- on-site treatment of groundwater beneath the site via a groundwater extraction and treatment system capable of dewatering the site and containing the off-site groundwater plume

- long-term groundwater monitoring
- evaluation and monitoring of the impacted wetlands with possible cleanup of the wetlands
- installation of a fence around the site
- restriction on property use through deed restrictions

Subsequent to issuance of the ROD, a subsurface barrier wall was installed around the ACS property, a groundwater extraction system was installed inside the barrier wall to dewater the area and prevent movement of groundwater outside the wall, and a groundwater extraction and treatment system was installed to the north of the site to control the movement of highly impacted groundwater in this area (EPA 1999, p. 4).

The EPA performed additional sampling at the site in 1996 and 1997 and also conducted waste handling and treatability studies in 1997. The waste handling study indicated that the 1992 ROD cleanup method would not be cost-effective in comparison to other cleanup or waste management methods. In addition, this study determined that "an extra high level of safety" would be needed for site workers due to the high levels of VOCs that would be encountered when contaminated soils, wastes, and debris were excavated for treatment; "the high levels of VOCs could constitute an explosion hazard as well as an exposure hazard to the workers and plausibly to areas residents" (EPA 1999, p. 4).

In 1999, subsequent to the waste handling study and following a request from the ACS PRP group that EPA reconsider the future-use site assumption in making a cleanup decision, EPA issued a proposed plan to amend the ROD for the site. The proposed plan recommended containment of wastes via a subsurface barrier wall and surface capping, and soil vapor extraction of VOC-laden soil and debris with the excavation and incineration of the contents of buried drums (EPA 1999). Specifically, the proposed plan included the following:

> (1) a revision to the assumed future use of the ACS property from residential use to industrial use; (2) a modification of the site cleanup approach from full treatment of contaminated materials to a combination of containment (using subsurface barrier wall and capping technologies) and partial treatment of mobile contaminants; (3) a modification to the wetlands cleanup method; (4) a modification to the groundwater containment plume cleanup method; and (5) the placement of deed restrictions on the future use of the site (EPA 1999, p. 1).

This proposed plan was driven in part by EPA's concerns regarding the health and safety of site cleanup workers, ACS workers, and the surrounding public should widespread waste excavation occur since the high level of VOCs could create a health hazard (EPA 1999, p. 5).

E.9 LAWRENCE LIVERMORE NATIONAL LABORATORY (REGION IX)

At LLNL, DOE has developed a rigorous process for project risk management. There are two large CERCLA sites at LLNL: Livermore Site and Site 300. RODs are in place at both facilities, and the remedies are generally performing as expected. Contaminants include VOCs, radionuclides, high explosives, metals, nitrate, and perchlorate. Remedial technologies include groundwater and/or soil vapor extraction, radioactive landfill capping, soil excavation (off-site disposal or on-site solidification), in situ bioremediation, and MNA. Projects at this site are managed through Baseline Work Plans that include a Project Risk Management Plan.

At LLNL, risk is defined as uncertainty whether the overall scope or schedule in the Baseline Work Plans is correct. Examples could include remedy failure requiring change from in situ bioremediation to excavation, unacceptable remedy performance, and changes in CSM (e.g., land-use assumptions, exposure pathways, and receptors). A "risk event" is defined as an individual occurrence or situation that could cause scope or schedule impacts to the project. "Contingency" is defined as uncertainty in executing the tasks defined in the Baseline Work Plans. Examples of contingency could include changes in cost per foot for well drilling or the number of groundwater extraction wells and minor adjustments in radioactive waste disposal fees.

Project risk management is performed through a process similar to RRM covered in this document, including identifying, quantifying, handling, and tracking risk events. The process also includes defining who participates, from the top-to-bottom involvement by the DOE project staff, and assigning responsibilities.

Project risk identification involves generation of potential risk events by r eviewing project assumptions, documents, and work plans and discussing this list with project management and staff to ensure completeness and collect additional information. Potential risk events are screened using a checklist, yielding a set of events to evaluate quantitatively. For each risk event, a risk analysis worksheet is generated that is reviewed and updated periodically until final disposition of the risk event (i.e., risk tracking).

Example risk events for LLNL Site 300 include the following:

- Excavation of several radioactive waste landfills could be required.
- At Building 865 active remediation could be required instead of MNA.
- A change to the TCE MCL could result in more stringent groundwater cleanup standards.
- Funding shortfalls could result in missed milestones.
- Suitable treatment and disposal options may not be found for radioactive waste.

Risk quantification is performed for each risk event that includes estimating the probability of the event occurring; quantifying the cost or schedule impacts; calculating the expected value for each event; determining whether immediate action is required; assigning a "risk event owner"; identifying a risk category in terms of technical expertise, logistic support, and project funding; and finally determining a numerical risk event index using a probability/consequence matrix.

"Risk handling" is defined as the addition of risk mitigation and risk monitoring. "Risk mitigation" is defined as the implementation of risk control measures. Examples of mitigation measures include adjusting schedules, adopting a less complex process, adding or reallocating resources, and negotiating project scope or compliance requirements with the regulatory agencies. "Risk monitoring" is defined as an ongoing, iterative process to ensure mitigation measures continue to effectively manage the risk until disposition of the event, more specifically, evaluating whether the assumptions made in the initial mitigation strategy are still valid, ensuring the risk mitigation measures have been implemented as planned, evaluating the effectiveness of the risk mitigation measures, identifying any previously unanticipated risks, and detecting trends.

Risk Summary

- The LLNL risk management process employs a qualitative risk identification and screening process followed by quantitative analysis and development of risk mitigation and monitoring measures.
- Although risk and contingency are estimated, they are not included in the baseline cost estimates.
- Risk analysis is performed by reviewing all scopes of work and assumptions included in the Baseline Work Plans and by consulting project staff.
- Risk management activities are included in the Work Plans. Specific risk-handling actions are defined in the Risk Management Plan.
- Twenty-nine risk events were identified.
- One risk event has been realized.
- Two risk events have been successfully mitigated by implementing the risk-handling strategy presented in the Risk Management Plan.

Contingency

Contingency is calculated on the activity level, such as installing a monitor well, constructing a groundwater treatment facility, or disposing of dioxin-contaminated waste. The contingency approach is as follows:

- Activities whose budgeted costs are estimated to have approximately equal ranges of potential uncertainty are grouped in bins. Five bins are defined in order of increasing uncertainty of unit cost estimates.
- A probability distribution function describing the error band for each bin is developed, and that function is applied to the cost estimate of each activity in the bin. A Monte Carlo analysis of 10,000 realizations is made, and the 85% confidence level that the sum of baseline estimate plus contingency would not be exceeded is calculated.
- Contingency is the difference between the 85% confidence level value and the mean value.
- The typical contingency range for LLNL environmental restoration tasks is 5%–6%.

E.10 HILL AIR FORCE BASE

AFCEE's RPRM process was applied to OU-11 at Hill Air Force Base. Uncertainties such as cost to complete, biofouling, additional assessment/well installation, pilot studies, etc. were considered in the RPRM evaluation. The basic process is outlined in the flow diagram shown in Figure E-1.

Site-specific project risks were checked against a screening checklist for different categories, such as site-characterization (seven events), RAOs (ten events), technology (nine events), sustainability (six events), and cost and schedule (seven events) were considered. Elements of a project risk management plan have been developed, and an analysis using a statistical model was conducted. The model considers input from different stakeholders for technical, political, and regulatory considerations (Figure E-2). A combined score was developed for all different options, and a set of recommendations was made for developing a risk management plan and making the best remedial decision at the OU-11.

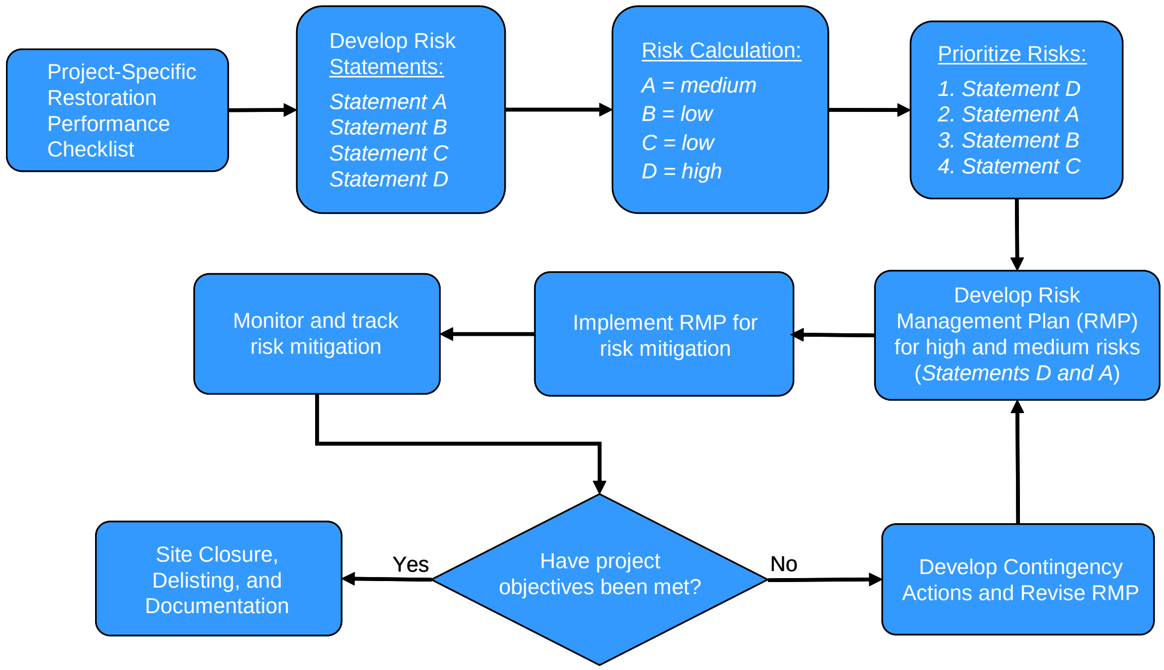


Figure E-1. AFCEE's RPRM process flowchart.

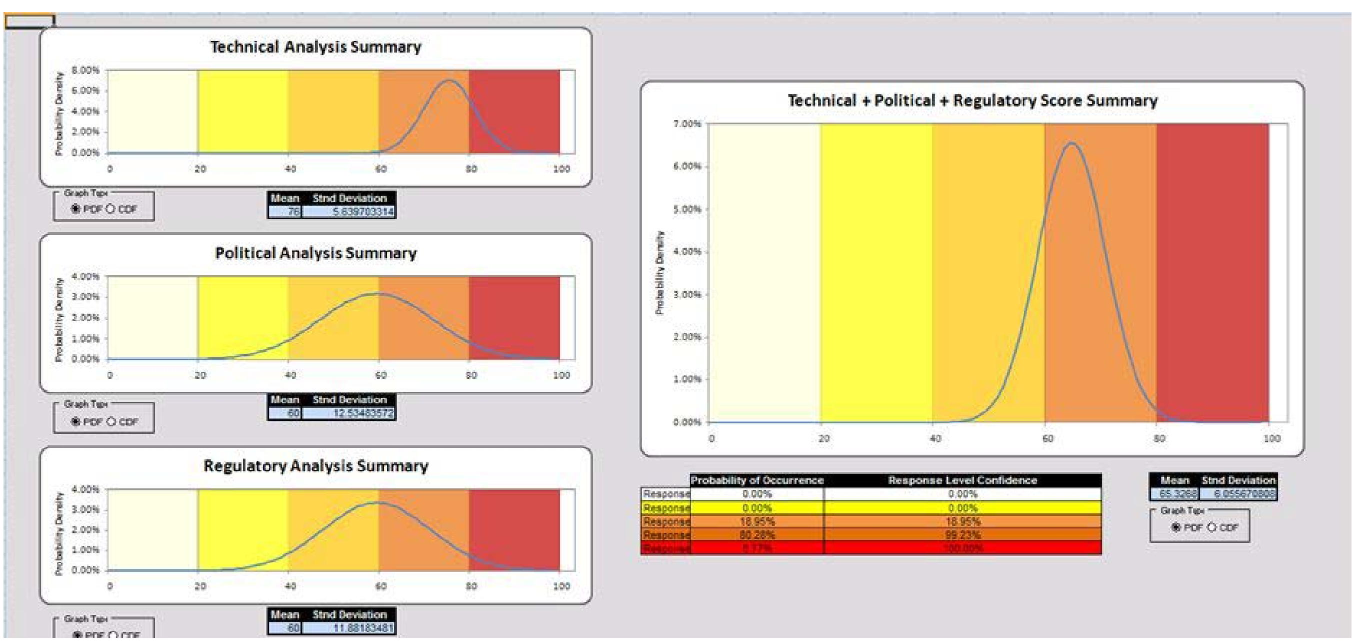


Figure E-2. Example modeling of prioritization and analysis of risks related to project management.

E-11. REFERENCES

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Appendix F

Project Modeling Risks

PROJECT MODELING RISKS

F.1 INTRODUCTION TO PROJECT REMEDIATION RISKS ASSOCIATED WITH GROUNDWATER MODELING

The ITRC RRM team has developed this appendix in response to requests from state and federal partners and other stakeholders to address project risk mitigation through groundwater modeling by following a streamlined approach that is consistent with the overall ITRC RRM process. It does not contain any extensive discussion of specific models, model selection methods, or other technical aspects of modeling processes, which are covered under numerous EPA (EPA 1990) and other guidance documents. This appendix provides an implementation protocol that follows the ITRC PBEM process to help streamline and systematically plan and implement a modeling exercise. Because the modeling process and the uncertainties associated with their acceptance are critical to many remediation projects, this appendix, though part of the overall RRM process, can be used as standalone document in planning any modeling exercise.

Groundwater modeling is a critical process in understanding the nature and behavior of contaminants in the subsurface. It plays an important role in building a conceptual model of current conditions and reasonably predicting future fate and transport of the contaminants. Properly used, this tool helps the project team better understand the groundwater dynamics at specific sites, including subsurface flow, contaminant fate and transport, and efficacy of remedial approaches. This improved understanding can be used to support remedial decisions. Currently, the modeling process is often controversial and can actually hinder remedial decision making. Streamlining this process and developing decision logic will increase the likelihood of an investment in modeling yielding results that benefit the project.

If not properly identified and included in the overall remedy selection and implementation process, project risks inherent in the groundwater modeling processes can contribute to inappropriate remedial decision and ineffective cleanups. When employing modeling, it is important to use PBEM to reduce the uncertainties and project risks introduced by groundwater modeling. PBEM includes understanding the project risks, documenting them, and developing an action plan to clearly address them. Proper documentation allows for efficient information sharing with all stakeholders. In turn, this allows for collective decision making by RPs and regulators and results in a mutually agreeable modeling plan. Involvement of regulatory agencies during the planning stages of modeling increases regulator confidence in and acceptance of the modeling results.

Modeling has been discussed in many guidance and documents. This document builds on and references existing guidance by federal (EPA and Nuclear Regulatory Council) (EPA 1990, 1993a, 1993b, 1994) and state (GEPD n.d., Lovanh et al. 2000) agencies.

F.2 PURPOSE

The purpose of this appendix is to provide a systematic approach to assist state/federal regulators, site owners, and remediation contractors in the evaluation, selection, and deployment of groundwater models that are mutually acceptable and will allow for appropriate remedial decisions. It captures common project risks associated with the modeling process, describes how to identify and mitigate them using the PBEM process, and outlines the development of a groundwater modeling strategy.

F.3 MODEL COMPLEXITY

Various models have different purposes and, consequently, are more appropriate at different stages of the remediation process. An important characteristic of the model is its level of sophistication. Appropriate model complexity varies based on site-specific conditions. For example, a simple situation may warrant use of a simple analytical model, while a complex situation may require use of a sophisticated numerical model. In general, models of moderate sophistication are considered appropriate for remedial decision making.

F.4 MODELING PROCESS IMPLEMENTATION

Implementing the modeling process needs a systematic approach to successfully achieve stakeholder goals. Stakeholders as defined in the ITRC realm include all the concerned parties, including RPs, regulators, consultants, contractors, and the general public who are directly or indirectly affected by the restoration activities at the site. The approach must include stakeholder input and be carried through planning, execution, reporting, and final acceptance.

F.5 BUILDING THE EXPERT TEAMS

To successfully execute a modeling process, it is important to identify team roles and responsibilities. The expert team framework, as depicted in Figure F-1, establishes several teams, including the project, technical, and modeling teams, whose interaction is vital to the success of the project. Establishment of the teams need not be rigid; team members may overlap, and teams may form subteams.

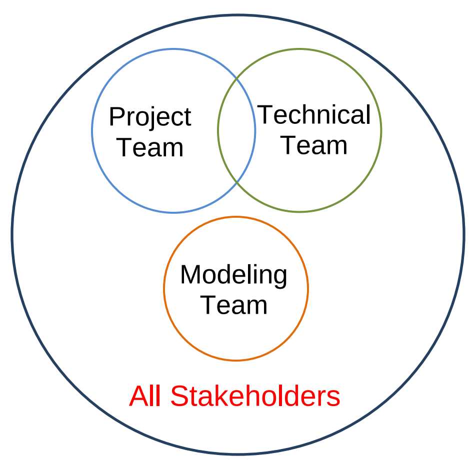

Figure F-1. Expert team dynamics in the modeling process.

- The **project team** consists of the primary stakeholders, including the RPs, main consultants, regulators, and financiers, who have decision-making authority throughout the modeling process.
- The **technical team** consists of experts in different areas of the remediation and may include modeling experts, geologists, hydrologists, chemists, computer programmers, and engineers.
- The **modeling subteam** consists of experts in modeling, including the consultants and regulators, who understand the process and are able to make appropriate decisions based on the models.

Roles and Responsibilities

At the scoping stage, the expert teams should be identified and roles and responsibilities should be clearly identified. Decision makers and information providers should be identified and communication paths documented. If there are specific data and communication needs during a particular stage of the process, these should be identified and documented in the modeling plan. To streamline communication, each organization should designate a single point of contact to internally disseminate information.

F.6 QUALITY ASSURANCE AND QUALITY CONTROL ISSUES

All the quality assurance and quality control issues should be identified and discussed among the modeling team and the project team. These should be documented and approved as part of the planning process.

F.7 CSM/EXIT STRATEGY TO BUILD THE PROBLEM

To successfully conduct a modeling exercise, it is important to clearly understand the purpose and value of the modeling to the remediation process. An understanding of the CSM and exit strategy (ES) allow the modeling to be tailored to overall project needs for decision making. Figure F-2 shows an example CSM.

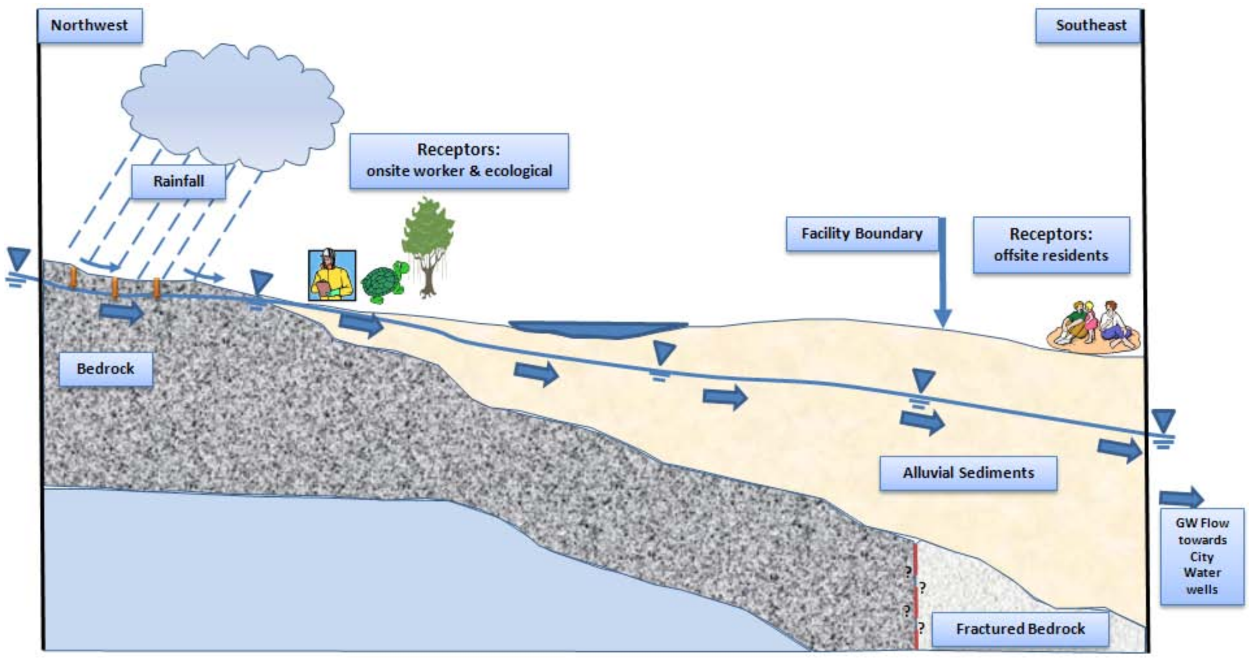

Figure F-2. Example CSM used for modeling.

Geological, hydrological, and chemical conditions, as well as the receptors and current and potential future land use considerations, are all important in determining the final exit strategy and appropriate action needed to accomplish it.

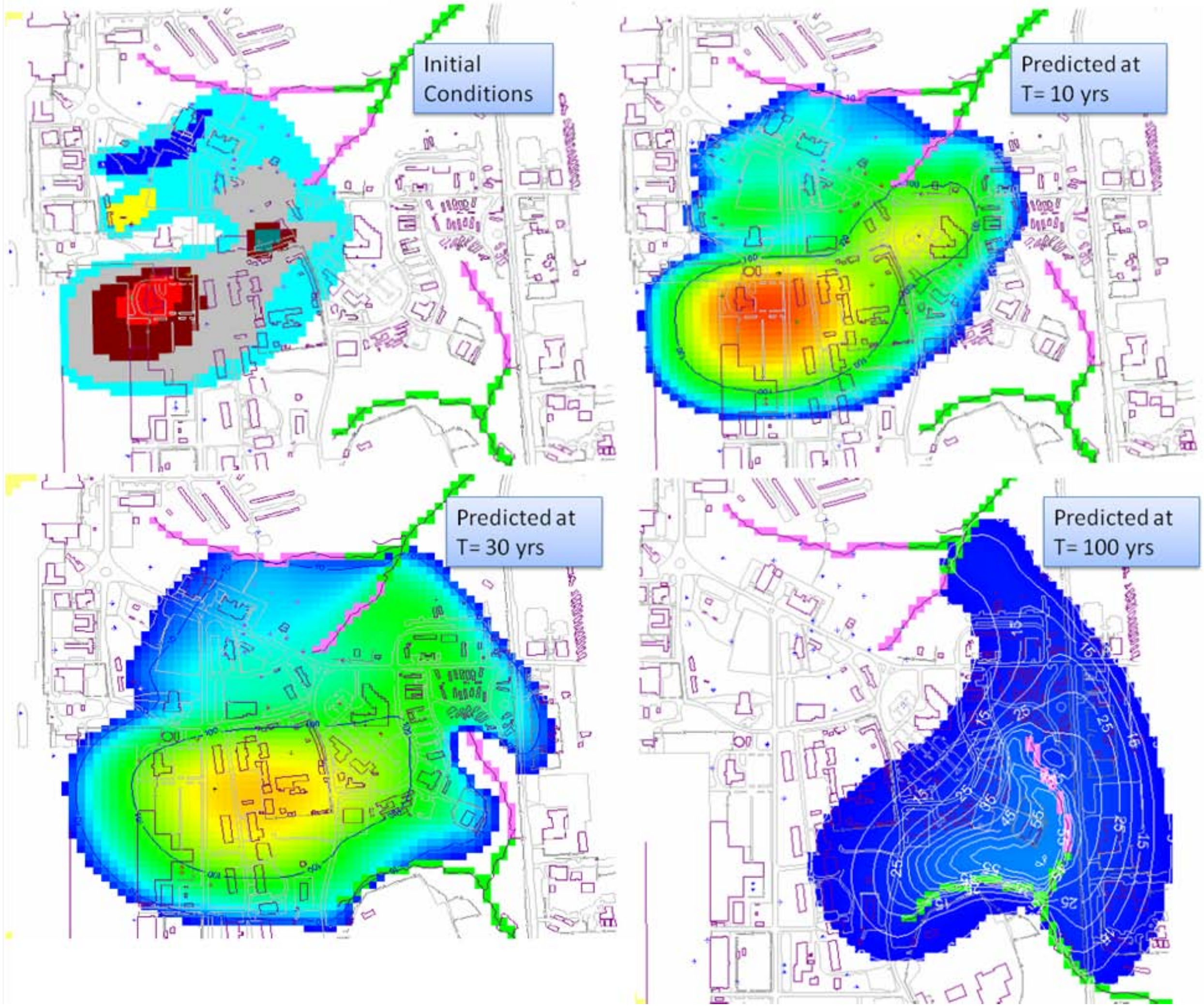

Figure F-3. Example of model-predicted plume maps over a period of time.

Often, there may be additional data requirements before the CSM can be completed. In such cases, the Triad approach for rapid site characterization may be employed to focus efforts on identifying and filling the data gaps. Once all the data are gathered, a concise, current, and complete CSM as described in the ITRC PBEM process (ITRC 2007) should be developed. Along with the CSM, the final goals of the site remediation process should be understood and captured in the ES document. This document is shared with and approved by the regulators. The ITRC ES technology overview document (ITRC 2006) provides details on developing an ES. Both CSM and ES documents are dynamic documents and need periodic updates; it may be necessary to update these following groundwater modeling.

F.8 PRE-MODELING SCOPING MEETING

Once the modeling need is identified, a team scoping meeting needs to be developed. This is an important and frequently ignored step in the modeling process. Prior to the scoping meeting, a summary document drafted by the technical team that describes the data needs should be shared with the project team. This should include any relevant data and documents. At the meeting, the technical team is responsible for clearly communicating the project team's needs and vision to the modeling team. All data needs should be discussed during the scoping meeting. Essentially, this meeting provides the teams with an opportunity to understand each other's needs. This meeting decreases the probability of model failure and project remediation risk and streamlines the rest of the modeling process.

F.9 CONSENSUS MODELING REQUIREMENTS

This stage of the project involves compiling a thorough list of model requirements and parameters. The modeling subteam compiles this list, which includes the following:

- software/programs to be selected
- selecting input parameters and boundary conditions
- model calibration
- uncertainty issues
- sensitivity issues
- detailed schedule for planning
- evaluation of results

Once the list has been compiled, members of the technical and project teams must come to a consensus on each model requirement. It may be necessary, after initial modeling has been performed, to update these requirements and rerun the model; however, consensus should be reached on all unknowns before any modeling begins. Since these model requirements and parameters are often the basis for regulatory rejection of modeling, it is primarily this consensus that provides for mutual acceptance of the model by regulators and RPs.

F.10 DEVELOPING A MODELING PROCESS PLAN

A modeling process plan documents the entire modeling process. All parameters that need to be modeled, the general modeling protocol, and reporting and analysis requirements should be included. Figure F-4 shows a general conceptual chart for the modeling process. Any uncertainties should be clearly captured and addressed. If there are any critical decision points in the process, decision logic and possible actions should be clearly defined. This deliverable document should be submitted for regulatory approval prior to modeling. Allowing for this approval will again reduce future resistance from regulators. Once the plan is approved, periodic progress reports should be documented and communicated as needed, especially following critical decision points.

Decision Logic

Decision logic should be included in the modeling process plan. Decision logic, often presented in the form of a flowchart or table of decisions, guides decision makers through complex decisions. Decision logic should be developed by the modeling subteam and agreed upon by the project team.

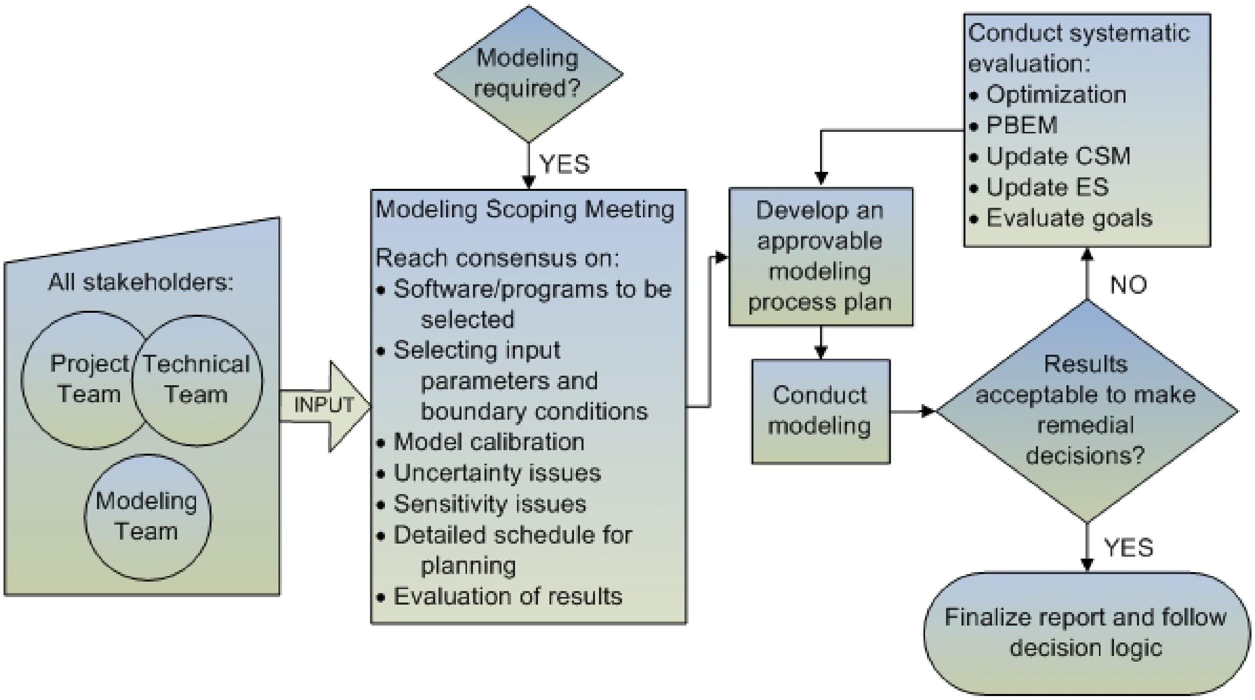

Figure F-4. Conceptual chart for modeling process to reduce modeling-related risks.

F.11 CONDUCTING THE MODELING PROCESS

The modeling process should be conducted as outlined in the modeling plan by the modeling subteam. Appropriate allocation of time for completion of the modeling process is important for successful modeling; failure to allocate sufficient time may result in model failure. Any deviations from the original plan or time schedules must be communicated with the project team and regulatory agencies.

F.12 PRESENTATION OF MODELING RESULTS

Verbal Updates

Throughout the modeling process, verbal updates should be used to communicate progress and deviations from the modeling plan with the project team. This method helps keep regulators informed.

Electronic Updates

Some updates to the project team should be electronic and include results. These communications will vary on a case-by-case basis. For example, this may include electronic visualization, or it may include solicitations for stakeholder input.

Presentations in Meetings

Before the final results are presented to project team in a report, the modeling team should present the highlights of the results to the project team. After receiving the results presentation, the project team will arrive at a consensus for remedial decisions.

Report Preparation and Presentation

Following the initial results presentation, a report should be generated to capture the results and subsequent remedial decisions. This report can be a standalone document or can be part of a required document such an appendix to an FS or CSM. The report should be approved by the regulators and their concerns satisfactorily addressed. This process may sometimes require additional modeling steps or revision of assumptions to ensure that uncertainties are properly addressed and any project modeling risks are clear to the project team.

F.13 VERIFICATION THROUGH FIELD MEASUREMENTS

No modeling process is complete without a thorough field verification of predicted behavior. Although the modeling process is technically considered finalized after the report has been approved, the process actually continues during verification. Field data will confirm whether plume behavior follows model predictions or deviates from them. Figure F-4 shows a comparison between predicted versus actual field measurements that can be used to compare and verify the actual predictions. If plume behavior deviates from predictions, it may be necessary to revise the model.

F.14 SUMMARY AND CONCLUSIONS

In summary, a systematic approach to modeling should be used to minimize project modeling risk. Recent advances in computing power and the availability of a variety of programs often lead to inappropriate remedial decisions based on poorly executed modeling processes. Due to a myriad of variables and unknowns, including variation in geology, variation in hydrogeology, and anisotropy, modeling is an art requiring expertise and input from all teams. Developing a decision-making process and understanding the capabilities and limitations of models are critical in using the PBEM approach to reduce the project risks associated with the modeling process.

F.15 REFERENCES

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Appendix G

Technology-Specific Project Risks

TECHNOLOGY-SPECIFIC PROJECT RISKS

This appendix summarizes the common types of failures, their typical causes, and likelihood of failure associated with commonly applied cleanup technologies. These include groundwater extraction, SVE, IAS, bioremediation, ISCO, MNA, and PRBs.

G.1 GROUNDWATER EXTRACTION AND TREATMENT

Groundwater extraction failures commonly include the following (possible root causes are provided in parentheses):

- reduced pumping rates (biofouling, encrustation on well screens, reduced saturated thickness due to drought or pumping influences, corrosion holes in discharge lines, electrical supply and control damage)
- pump failure (fouling, motor overheating due to operation outside of performance range or inadequate cooling, excessive cycling, corrosion, mechanical failure [production flaw, wear, or inadequate maintenance])
- inadequate plume capture (low pumping rates or inappropriate well depths, shifts in plume axis due to external stresses on aquifer, differing site hydrogeologic or geochemical conditions, inappropriate well pumping rate selection by operator)
- unexpectedly high or low concentrations of contaminants or natural constituents that affect processes (incomplete or inadequate site characterization, plume changes, inappropriate lateral and/or vertical placement of the extraction wells)

Not all of the failures listed are preventable, and some may require mitigation measures or contingency actions.

Groundwater treatment may include a myriad of individual processes such as air stripping, carbon adsorption, ion exchange, biological treatment, metals precipitation, filtration, chemical or ultraviolet oxidation, and others. A comprehensive discussion of failure modes for these "aboveground" processes is beyond the scope of this document. General failures of impact for these processes include process effluent concentration excursions, uncontrolled release of untreated or partially treated water, inadequate treatment capacity, power and control failures, inappropriate chemical dosages, and inadvertent operator contact with hazardous chemicals. Pumps and blowers may mechanically fail due to flaws, wear, or inadequate maintenance.

G.2 SOIL VAPOR EXTRACTION AND IN SITU AIR SPARGING

The typical failures of SVE and IAS systems include the following (possible root causes are provided in parentheses):

- technology not capable of adequately addressing contaminant mass sequestered in low-permeability zones where diffusion limitation/back-diffusion become controlling factors (inadequate site characterization of low-permeability layers, improper well location/screen depth, inadequate flow to individual wells as a result of operator error or subsurface limitations)

- inadequate zone of influence to address all target soils with SVE or all target groundwater with IAS (inadequate site characterization of contaminant extent, improper well location/screen depth, inadequate flow to individual wells as a result of operator error, clogging of wells, or subsurface limitations or stagnation zones)
- recontamination of treated soils (fluctuating and contaminated groundwater table, continuing source of contaminants, spills of recovered product)
- blower failure (electrical supply failure, inadequate maintenance, operation outside of application range, high ambient temperatures, fabrication flaws, wear)
- piping failure (no ultraviolet radiation protection and brittle fracturing, condensate freezing, accidents)
- no flow to/from wells (operator error such as valves inadvertently closed, submerged SVE well screen, short-circuiting along well casings, inadequate blower pressure or vacuum)
- unexpectedly high or low concentrations recovered with SVE that cause problems for the treatment processes (inadequate site characterization, short-circuiting of air along casing or from subsurface utilities or basements, new source of contaminant, recontamination of soil by fluctuation of groundwater)

Note that the simultaneous application of several technologies such as SVE, IAS, and in situ thermal remediation can decrease the likelihood of some of the failures identified above.

Aboveground processes often associated with SVE include air/water separation, carbon adsorption, and thermal oxidation. A detailed description of the potential failure modes of these processes is beyond the scope of this document, but common or important failures include exceedances of discharge criteria, condensate carryover into the blower due to failure to drain the tank or failure of control systems and/or sensors, explosion, operator injury, or exposure to vapors.

G.3 IN SITU REMEDIATION TECHNIQUES

The failures of in situ remedies such as chemical oxidation/reduction and bioremediation are largely due to inadequate understanding of the subsurface hydrogeology and geochemical conditions due to inadequate/incomplete characterization. Since most in situ remedies involve the delivery of amendments, the permeability distribution of the subsurface is of particular importance. Subsurface complexity can inhibit the transport of amendments to targeted contaminant zones and/or lead to the diversion of amendments. Geochemical conditions can affect the quantities of required amendments. The most significant failure of in situ remedies is the inability of the technologies to attain cleanup goals. Other failures include the unintended release of amendments to the surface, utilities, or structures and may even include damage to structural foundations. High injection pressures can result in soil fracturing and such side effects as pavement or foundation damage for nearby structures. In some cases, the high pressures and soil fracturing are intended for further distribution of the amendments but in other cases result from inattention during the operation.

Other failures may include delivery of insufficient amendment mass due to inadequate mixing of reagents in aboveground vessels prior to injection, inability to probe or drill to the desired depths, and inadequate design of injection volumes or injection point spacing.

As discussed here, PRBs involve the placement of materials in the subsurface that create conditions that result in the destruction of the contaminant of concern. The reactive materials may include ZVI or mulch, for example. The primary failure is incomplete treatment of the targeted portion of the plume. The causes for this mode of failure may include the following:

- poor or inconsistent placement of materials in the trench or fracture
- inadequate thickness of the treatment zone or mass of material either by design mistakes or construction errors/mishaps (e.g., trench collapse during excavation)
- incomplete removal of damage to adjacent native materials due to excavation (such as smearing of clays, infiltration of mud/residual guar etc., and causing diversion of groundwater flow)
- inadequate design of the depth and location of the barrier relative to the plume and high permeability pathways as a result of poor characterization
- changes in the lateral or vertical location of the plume over time due to hydrologic changes (external pumping, climatic events)
- reduced reactivity of the reactive materials over time due to exhaustion of material mass, coating of material by mineral precipitates, or other causes

G.4 MNA

Failure of MNA remedies typically involves the expansion of the contaminant plume or a slower than expected reduction in plume mass or size. Since there is generally no activity other than monitoring (assuming source treatment/removal/containment is conducted separately), the failure is usually caused by an inaccurate conceptualization of the subsurface hydrogeology and geochemical conditions as a result of incomplete or erroneous site characterization. The inappropriate design and implementation of the monitoring program may contribute to the failure through having inadequate information to assess true plume conditions. MNA may also fail due to incomplete source control or removal or the failure of other active remediation components.

G.5 LUCs

The failure of LUCs typically results from lack of monitoring and maintenance of ECs or ICs. ECs are the remedies implemented at a site to contain the contaminants and/or to achieve cleanup goals. ICs are administrative and/or legal controls to prevent human exposure to contaminants present at a site and protect the integrity of ECs at the site. Examples of ECs include the commonly applied cleanup technologies discussed earlier in this section. Examples of ICs include deed restrictions such as easements and covenants, zoning ordinances, consent decrees, and notices filed in the land records (EPA 2000). Local government agencies typically have the legal authority to enforce some of these ICs, and a lack of adequate long-term mechanisms at the local government level could lead to IC failure. For federal facilities, real property–related ICs (e.g., deed restrictions) are not available for on-site contamination. A lack of alternative mechanisms such as updated base master plans could result in inadequate implementation and monitoring of controls (e.g., no soil excavation without authorization) at a contaminated site. For groundwater plumes that have migrated beyond the boundary of a federal facility, real property–related ICs are applicable, and a lack of close cooperation between the federal facility, regulators, and local government could lead to IC failure.

G.6 GENERAL REMEDIATION PROJECT RISKS

This section is intended to address the unintended consequences of remediation activities. There are tradeoffs that must be made and due diligence invested to minimize the risk presented by performing site remediation. Typically, these issues have not been addressed holistically as part of site remediation. Specific risks may be addressed as part of the permitting process for a remedial activity. Unintended damage and risk of adverse impacts caused by the implementation of the remedy include the following:

- accidents resulting in injury and/or death to workers or the public (i.e., accident risk)
- impacts to human health from air emissions or fugitive contaminated dusts
- ecological impacts
- loss of resources (e.g., energy, water, top soil, landfill space)
- contribution to global warming (and its associated impacts) due to emission of GHGs
- stress from public disturbances (e.g., noise, odor, dust, traffic, infrastructure interferences)

G.7 REFERENCE

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Appendix H

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Appendix I

Glossary

GLOSSARY

anisotropy. The property of being directionally dependent, as opposed to "isotropy," which means variation of properties being the same in all directions.

bioaugmentation. The addition of beneficial microorganisms into groundwater to increase the rate and extent of anaerobic reductive dechlorination to ethene.

bioremediation. Use of microorganisms to biodegrade contaminants in soil and groundwater.

biostimulation. The addition of an organic substrate or nutrients into groundwater to stimulate anaerobic reductive dechlorination.

chlorinated solvent. Organic compounds with chlorine substituents that commonly are used for industrial degreasing and cleaning, dry cleaning, and other processes.

compliance monitoring. The collection of data which, when analyzed, can allow for the evaluation of the contaminated media against standards such as soil and or water quality regulatory standards, risk-based standards, or remedial action objectives.

conceptual site model (CSM). A hypothesis about how contaminant releases occurred, the current state of the source zone, and current plume characteristics, potential receptors and pathways that connect the sources to the receptors, how the contaminants are expected to behave, etc.

contaminant risk assessment. An important step in the risk management process that determines the quantitative value of risk related to contaminant and determines the hazard related to the nature and extent of a specific chemical under given site circumstances.

contingency. Anticipating unforeseen and planning for some things that may not go as expected. It is preparing for fall-back actions and making sure that leeway for time, alternative remedial actions, and resources exists to rectify or replace the original proposed remediation actions.

dense, nonaqueous-phase liquid (DNAPL). A water-immiscible organic liquid that is denser than water (e.g., tetrachloroethene).

diffusion. The process of net transport of solute molecules from a region of high concentration to a region of low concentration caused by their molecular motion in the absence of turbulent mixing.

dilution. A reduction in solute concentration caused by mixing with water at a lower solute concentration.

dispersion. The spreading of a solute from the expected groundwater flow path as a result of mixing of groundwater.

ecological risk analysis. An analysis of any potential adverse effects that human activities have on the living organisms that make up ecosystems.

emerging chemicals. The chemicals identified by chemists and toxicologists as they bring to the light the toxicological effects of these chemicals pose on human health mainly based on the improved detection and chemicals in environment and biological media.

emerging issues. A variety of concerns that encompass the spectrum of contaminants, their behavior, and techniques to manage them, including regulatory limitations.

emerging technologies. Innovative technologies used in site remediation to achieve remediation goals, especially at complex sites that need specific approaches for site cleanup.

flux. Rate of flow of fluid, particles, or energy through a given surface.

human health risk analysis. Analysis for determining the effects of chemical contamination on human health to understand whether current or future chemical exposures will pose a health risks to a broad population such as a city or community.

hydraulic conductivity. The capability of a geologic medium to transmit water. A medium has a hydraulic conductivity of unit length per unit time if it will transmit in unit time a unit volume of groundwater at the prevailing viscosity through a cross section of unit area, measured at right angles to the direction of flow, under a hydraulic gradient of unit change in head through unit length of flow.

hydraulic gradient. The change in hydraulic head (per unit distance) in a given direction, typically in the principal flow direction.

impact of occurrence. Along with *likelihood of occurrence*, dictates the overall influence of an event and how effective it will be on the success of a project. The product of likelihood and impact of occurrence is estimated as the overall risk. The higher the product, the higher the need for addressing it.

inorganic compound. A compound that is not based on covalent carbon bonds, including most minerals, nitrate, phosphate, sulfate, and carbon dioxide.

in situ bioremediation. For purposes of this document, the use of biostimulation and bioaugmentation to create anaerobic conditions in groundwater and promote contaminant biodegradation for the purposes of minimizing contaminant migration and/or accelerating contaminant mass removal.

integrated contaminant mass flux. The total quantity of a migrating substance that moves through a planar transect within the system of interest and oriented perpendicular to the direction of *x* movement. If the transect is at the entry point to the system, the integrated mass flux is the loading. If the transect is at the exit point from the system, the integrated mass flux is the discharge. Note that these terms have units of mass per time (kg/year, g/day, or the like) and represent an extension of the traditional engineering definition of flux (e.g., kg per year per m^2) in which the transect area is accounted for to allow mass balance calculation of plume- or system-scale behavior.

likelihood of occurrence. Along with *impact of occurrence,* dictates the overall influence of an event and how effective it will be on the success of a project. The product of likelihood and impact of occurrence is estimated as the overall risk. The higher the product, the higher the need for addressing it.

mass balance. Quantitative estimation of the mass loading to the dissolved plume from various sources, as well as the mass attenuation capacity for the dissolved plume.

mass discharge. Contaminant load past a transect (mass per time) (also called "cumulative mass flux" and "mass discharge," or confusingly, "mass flux" by some groups). Represented as M_d (mg/d).

mass flux. Contaminant load (per unit area per time) (a general term where mass flux and/or mass discharge type calculations are performed). Represented as J ($mg/day/m^2$).

mass loading. Contaminant released to the environment (in this case the aquifer or unsaturated zone) from the source material.

mass transfer. The irreversible transport of solute mass from the nonaqueous phase (i.e., DNAPL) into the aqueous phase, the rate of which is proportional to the difference in concentration.

monitored natural attenuation (MNA). The term “natural attenuation” refers to naturally occurring processes in soil and groundwater environments that act without human intervention to reduce the mass, toxicity, mobility, volume, or concentration of contaminants in those media. These in situ processes include biodegradation, dispersion, dilution, adsorption, volatilization, and chemical or biological stabilization or destruction of contaminants. When scientists monitor or test these conditions to make sure natural attenuation is working, it is called “monitored natural attenuation.”

natural attenuation. Naturally occurring processes in soil and groundwater environments that act without human intervention to reduce the mass, toxicity, mobility, volume, or concentration of contaminants in those media.

performance monitoring. The collection of information which, when analyzed, allows for the evaluation of the performance of a system on environmental contamination.

plume. A zone of dissolved contaminants. A plume usually originates from a source and extends in the direction of groundwater flow.

process monitoring. The collection of information documenting the operation of a system’s engineered components.

project life cycle. The whole process of a project from the planning to closure. In terms of RRM, the whole process of identifying, evaluating, mitigation, monitoring and reporting of a event as captured in the risk management plan.

project risk evaluation. Addresses both the probability that each project risk may occur and the magnitude of adverse impacts or consequences that could result.

project risk identification. The step normally first considered during the planning stages of a project, though risks can be identified throughout the life of a project. These can be identified by brainstorming, project specific experience, or through expertise of projects from past knowledge.

project risk management. The systematic process of identifying, analyzing, and responding to project risks.

project risk mitigation. A process of implementing strategies to address high-risk potential risk events identified and captured in the risk management plan. Mitigation methods might include eliminating, reducing, transferring liability for, or accepting the potential project risk.

project risk monitoring. Refers to the way in which a project is tracked over time to ensure that the project risk mitigation strategies have been effectively and successfully implemented.

project risk prioritization. Helps in classifying and monitoring risks per their severity and the relative effect they have on overall success of a project.

project risk reporting. Summarizes the key findings from a project risk monitoring and communicates them to all stakeholders for appropriate decision making.

project risk tracking. A process through which the risk management is conducted throughout the project execution till the final disposition of the risk event.

regulatory framework. Laws and regulations that outline the legal requirements to be met in a particular program such as CERCLA, RCRA, USTs, brownfields, voluntary cleanup programs, etc.

risk analysis. The process of defining and analyzing the dangers to human health and ecology as well as other risks associated with a remediation project. Once they are quantified, it is easy to compare with existing action levels, and appropriate actions can be conducted to manage the risk.

risk register. A tool used to summarize and communicate the results of project risk identification and evaluation. In its most basic form, a risk register is a table that describes each project risk, summarizes project team concerns, and evaluates each risk in terms of its likelihood and potential impacts.

saturated zone. Subsurface environments in which the pore spaces are filled with water.

source zone. The subsurface zone containing a contaminant reservoir sustaining a plume in groundwater. The subsurface zone is or was in contact with contamination. Source zone mass can include sorbed and aqueous-phase contaminant mass as w ell as contamination in free phase.

specific discharge. An apparent velocity calculated from Darcy's law, represents the flow rate at which water could flow in an aquifer if the aquifer were an open conduit.

substrate. A molecule that can transfer an electron to another molecule and/or provide carbon to the microorganism. Organic compounds, such as lactate, ethanol, or glucose, are commonly used as substrates for bioremediation of chlorinated ethenes.

volatilization. The transfer of a chemical from its liquid phase to the gas phase.

Appendix J

Acronyms

ACRONYMS

ACL	alternate concentration limit
ACS	American Chemical Service
AFCEE	Air Force Center for Engineering and the Environment
ARAR	applicable or relevant and appropriate requirement
BLS	U.S. Bureau of Labor Statistics
BSTF	Brio Site Task Force
BTEX	benzene, toluene, ethylbenzene, and xylenes
CAPCOA	California Air Pollution Control Officers Association
CEQA	California Environmental Quality Act
CERCLA	Comprehensive Environmental Response, Compensation, and Liability Act
CFR	Code of Federal Regulations
CSM	conceptual site model
DNAPL	dense, nonaqueous-phase liquid
DOD	U.S. Department of Defense
DOE	U.S. Department of Energy
DON	U.S. Department of Navy
EC	engineering control
ECOS	Environmental Council of the States
EE/CA	engineering evaluation/cost analysis
EFA	engineering field activity
EO	executive order
EPA	U.S. Environmental Protection Agency
ER	environmental restoration
ERIS	Environmental Research Institute of the States
ES	exit strategy
ESTCP	Environmental Security Technology Certification Program
FDEP	Florida Department of Environmental Protection
FS	feasibility study
GHG	greenhouse gas
GSR	green and sustainable remediation
HE	high explosive
HSC	Harding Steering Committee
IAS	in situ air sparging
IC	institutional control
IRIS	Integrated Risk Information System
ISCO	in situ chemical oxidation
ITRC	Interstate Technology & Regulatory Council
LLNL	Lawrence Livermore National Laboratory
LTM	long-term monitoring
LTMO	long-term monitoring optimization
LUC	land-use control
LUST	leaking underground storage tank
MAROS	Monitoring and Remediation Optimization System

MCL	maximum contaminant level
MNA	monitored natural attenuation
MSG	McColl Site Group
MTDEQ	Montana Department of Environmental Quality
MZA	mixing zone application
NAPL	nonaqueous-phase liquid
NAVFAC	Naval Facilities Engineering Command
NORM	Normalized Management Information System
NPL	National Priorities List
NRC	National Research Council
NRD	natural resources damage
NRDA	natural resources damage assessment
OSWER	Office of Solid Waste and Emergency Response
OU	operable unit
PBEM	performance-based environmental management
PCB	polychlorinated biphenyl
PMI	Project Management Institute
PMZ	plume management zone
POC	point of contact
PP	public participation
PPE	personal protection equipment
PRB	permeable reactive barrier
PRG	preliminary remediation goal
PRP	potentially responsible party
QAPP	Quality Assurance Project Plan
RAO	remedial action objective
RCRA	Resource Conservation and Recovery Act
RI	remedial investigation
ROD	record of decision
RP	responsible party
RPM	remedial project manager
RPO	remediation process optimization
RPRM	Restoration Performance Risk Management
RRM	remediation risk management
RSE	Remediation System Evaluation
SCADA	supervisory control and data acquisition
SCDHEC	South Carolina Department of Health and Environmental Control
SRT	Sustainable Remediation Tool
SVE	soil vapor extraction
SVOC	semivolatile organic compound
TBOS	tetrabutyl orthosilicate
TCA	1,1,1-trichloroethane
TCE	trichloroethene
TI	technical impracticability
USACE	U.S. Army Corps of Engineers
UST	underground storage tank

VOC	volatile organic compound
ZOD	zone of discharge
ZVI	zero-valent iron