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1 Introduction

In situ treatment (remediation), as discussed in this document, is the delivery and dosing of amendments to enhance the abiotic and biotic processes in the subsurface to treat contaminants in the geologic matrix and groundwater. In situ treatment strategies, tactics, and technologies can be applied to create economically and environmentally sound solutions for remediating subsurface settings impacted by a wide range of organic and inorganic compounds, radionuclides, and other compounds. More than 30 years of experience with in situ treatment has greatly improved the state of the science and engineering, resulting in successful mitigation of contaminants in the subsurface at many sites worldwide. In situ technologies can provide cost-effective methods of treating contaminants with minimal impact to the immediate region and ecosystem (ESTCP 2016).

The general categories of in situ treatments to consider include physical treatment (for example, soil flushing), and/or chemical treatment (for example, chemical oxidation or reduction, surfactant flushing), and biological treatment (for example, enhanced bioremediation, anaerobic dechlorination, bioventing).

Chemical and biological treatment technologies are effective when the amendment is successfully injected in contact with the contaminant mass. Failure to adequately characterize the site and accounting for contaminant mass storage (ITRC 2015, 2018) in low permeability zones are the leading causes of ineffectiveness of these remedy technologies. The spatial distribution of contaminant mass must be fully characterized to the extent needed to design an effective in situ remedy. Although numerous technologies can be applied in situ to treat subsurface contamination, the focus of this document is on technologies where biological and/or chemical amendments are distributed in the subsurface to treat targeted contaminant mass and in some cases modify the geochemical conditions to support such in situ treatment. Contaminant mass includes aqueous or solid forms of contaminants in porous media, fractured rock, or stored in low permeability strata. Storage areas contribute contaminants through back-diffusion from areas with low permeability, porous flow, and fracture flow.

Any in situ technology that involves injection into the subsurface has implementation issues (Appendix B). Treatment ineffectiveness can be avoided through effective up-front characterization and design, and in-progress enhancements to both delivery technologies and amendments can improve performance. Each in situ remedial action requires collection, analysis, and evaluation of the treatment technology, site-specific subsurface characteristics, and groundwater chemical properties, to develop an adequate remedial design-level conceptual site model (Remedial Design Characterization or RDC). This is the first step toward site-specific optimization of the selection of amendments, delivery technologies, and dosing requirements.

In addition to the technical considerations discussed, an initial evaluation of the regulatory requirements must be conducted early in the process. Before spending significant time conducting remedial design investigations, designing injection strategies, or planning a monitoring program, determine the levels of regulatory flexibility and community and tribal support. The design team must ensure that field changes during implementation will be acceptable to the regulators.

1.1 The Problem and the Need for Optimization

Optimization is a foundational part of in situ remediation. Although in situ remedies can be effective, challenges with their implementation can lead to technologies failing to achieve performance or remedial objectives (Alleman 2018). There are many types of in situ remediation amendments and injection technologies, and each site provides unique challenges that can limit the effectiveness of the in situ remedy. This guidance identifies challenges that may impede or limit remedy effectiveness and discusses the potential optimization strategies and specific actions that can be pursued to improve the performance of in situ remediation. The best use for this guidance is not to decide whether a particular remedy is the best remedial approach for a

> A survey by the ITRC team showed that practitioners and regulators see about the same number of in situ proposals; the regulators were approximately 40% more likely to deem the first submittal incomplete. Incompleteness included inadequate information, inadequate CSM, inadequate amendment placement according to the CSM, and a proposed remedy not fully supported by

particular site. Rather it provides a pathway and instructions to assist the user in identifying either how to design an optimal but not yet implemented in situ remedy, or optimize an ongoing underperforming in situ remedy. This guidance focuses on amendments listed in Table 3-2 and delivery technologies included in the Injection Screening Matrix. The importance of proactive planning, including using processes such as site characterization analysis, Environmental Sequence Stratigraphy (USEPA 2017a), bench- and field-testing and/or design optimization testing and performance evaluation, cannot be overemphasized.

the CSM. For more survey information go to Section 5.2.2.2.

Many challenges encountered during in situ remediation can be overcome with a thorough understanding of the contaminant phase and distribution, site hydrogeology and biogeochemistry, and the amendment's physical and chemical characteristics. Issues commonly encountered with underperforming remedies are summarized in Appendix B. These issues or common problems are based on field experiences and lessons learned by members of the authoring ITRC team (Appendix H). This Appendix may be used in the planning stage to help identify potential risks, as a guide for managing expectations, or as a resource for optimizing in situ remediation projects. All technologies have limitations, and limitations can be addressed, sometimes through combining or sequencing two or more treatment technologies, potentially including alternative or supplemental remedies, or monitored natural attenuation. E.11, Eastern Surplus Company Superfund Site, Southern Plume Case Study.

Throughout the text links are included to helpful case studies from team members and other resources

Why do initial attempts at implementing in situ remediation often fail or indicate performance below expectations? We can improve the predictability of a positive outcome by:

- understanding common reasons for failures, lessons learned, and best practices Appendix B
- understanding the sequence stratigraphy and depositional environments to adequately map the subsurface in three dimensions
- setting realistic expectations for performance objectives, accounting for uncertainty in CSM and technology limitations (ITRC 2011c; NJDEP 2017)
- considering the long-term value of investigation in regard to life cycle costs (see Section 2.1)
- ensuring the CSM is sufficiently robust for appropriate remedy selection (see Section 2.2)
- selecting appropriate delivery technology to ensure focused delivery of the injectates to have the maximum intended results in reaching the areas of contamination to provide adequate contact, time, and effectiveness
- completing RDC to provide sufficient level of detail for design and implementation (see Section 2.3)
- using adaptive management tools and contingency plans to account for uncertainty (see Superfund Task Force Recommendation #3: Broaden the Use of Adaptive Management, July 3, 2018)
- identifying key decision points and circular feedback loops when performance is not achieving objectives (see Section 3.1)
- managing risk and uncertainty through better characterization (see Section 2.2, & 4.4)
- ensuring that bench and pilot studies are done to verify the efficacy of the proposed remedial alternative during development of the Remedial Investigation/Feasibility Study (RI/FS. see Section 3.3.2)
- interpreting performance monitoring data in a timely manner (see Section 4.4.2)
- optimizing an underperforming in situ remedy (see Section 4.5)
- identifying and understanding potential preferential pathways of injection material

1.2 Intended Audience

This document is designed to provide guidance to those who may not have a comprehensive understanding of the investigation and testing processes involved in optimization of an in situ treatment technique, though many practitioners with limited experience with such technologies will benefit from the overall approach/process to select, implement, and optimize in situ methods. However, the user is assumed to have basic foundational experience with in situ remediation, environmental remediation processes, and natural sciences. This guidance document provides the state of the practice based on firsthand knowledge and experiences for a broad audience, including a variety of government and industry personnel.

Environmental Consultants

▼*Read more*

Consultants have a responsibility to provide options and recommendations for remedial approaches that meet the regulatory requirements and the responsible parties' needs. The technical background of the consultant may not include extensive experience with in situ remedial treatment technologies. This document provides an overview of the currently available technologies and emphasizes the importance of the CSM in the decision and design process.

Responsible Parties

▼*Read more*

Responsible parties may not be familiar with the techniques and current practices for in situ remediation. They may have concerns regarding the costs for detailed, but necessary, site characterization and pilot testing. This document provides information to support in situ remedies while stressing that considering optimization measures in the investigation phase could reduce the schedule and costs over the project's life cycle, when compared to limited characterization that results in partial remediation that ultimately requires additional sampling and analysis, remedial design, and implementation.

Federal and State Regulators

▼*Read more*

Regulators are obligated to verify that the performance of in situ remedial and operational processes are protective. Some of the issues identified are included in Section 5, Regulatory Perspectives. Check with applicable regulatory agencies for any restrictions applicable to injection of materials into the vadose zone that may adversely impact groundwater quality.

Community and Tribal Stakeholders

▼*Read more*

It is very important to perform community outreach early and to inform community and tribal stakeholders of the process and the progress at sites. The local community should be provided opportunities to give input and to understand the planned optimization approach and its potential impact on the surrounding environment and/or cultural values.

1.3 Approaches to Optimizing an In Situ Remedy

The optimization process begins with a refined CSM that conveys a detailed understanding of site conditions and physical limitations necessary to design and install an in situ remedy. Once the geology, hydrology, aqueous geochemistry, groundwater biogeochemistry, and spatial distribution of contaminant mass are understood, amendment screening and selection, dosing, delivery technologies, and performance metrics can be developed.

This document provides guidance for optimizing in situ remediation by:

- refining and evaluating remedial design site characterization data
- selecting the correct amendment
- choosing delivery methods for site-specific conditions
- creating design specifications
- conducting performance evaluations
- optimizing underperforming in situ remedies

As pointed out in the executive summary page iii of an earlier ITRC project (ITRC 2007) *Improving Environmental Site Remediation Through Performance-based Environmental Management*, "As the various environmental cleanup statutes and their implementing regulations evolved, the initial assumption was that these programs could follow a basic *study, design, build* linear paradigm. However, years of experience have led to the realization that the significant uncertainty inherent in environmental cleanup requires more flexible, iterative approaches that manage uncertainty. Uncertainty, as demonstrated by frequently missed target dates, has forced the development of mechanisms that allow for both the systematic reevaluation of initial objectives and the continuous improvement and optimization of remediation technologies and techniques" (ITRC 2007).

This guidance does *not re-create* an entire characterization and remediation process, but relies on the framework described in an earlier ITRC document, titled *Integrated DNAPL Site Strategy* (IDSS) (ITRC 2011c). The IDSS framework is depicted in the left half of Figure 1-1 below. The right half of the figure illustrates the optimization process used in this guidance. Although the decision process has traditionally been viewed as linear, the design of an in situ remedy, in practice, is iterative and cyclical (Superfund Task Force Recommendation #3: Broaden the Use of Adaptive Management, July 3, 2018) with many feedback loops.

Figure 1-1 illustrates that the optimization process for in situ treatment begins with the reevaluation of existing site data to support the selection and design of an in situ remedy. Each of the steps depicted is separately discussed in Sections 2, 3, and 4 of this document. The red icon links to Section 2: Remedial Design Characterization (RDC), which discusses data required to refine the CSM, remedial design, and implementation plan. The data collected and evaluated during RDC activities determine the type of amendment, the amendment dose, and the delivery method represented by the circular green icon. As indicated by the two-way arrow, determination of amendment, delivery, and dose discussed in Section 3 typically occurs as an iterative process, which can include additional site characterization, together with laboratory and/or field pilot testing prior to full-scale implementation. Section 4: Implementation and Feedback (MONITORING) Optimization the blue icon, includes assessment of remedial performance, refinement of the design, and implementation. Optimization as discussed in each of the sections of this document can occur at any of these steps.

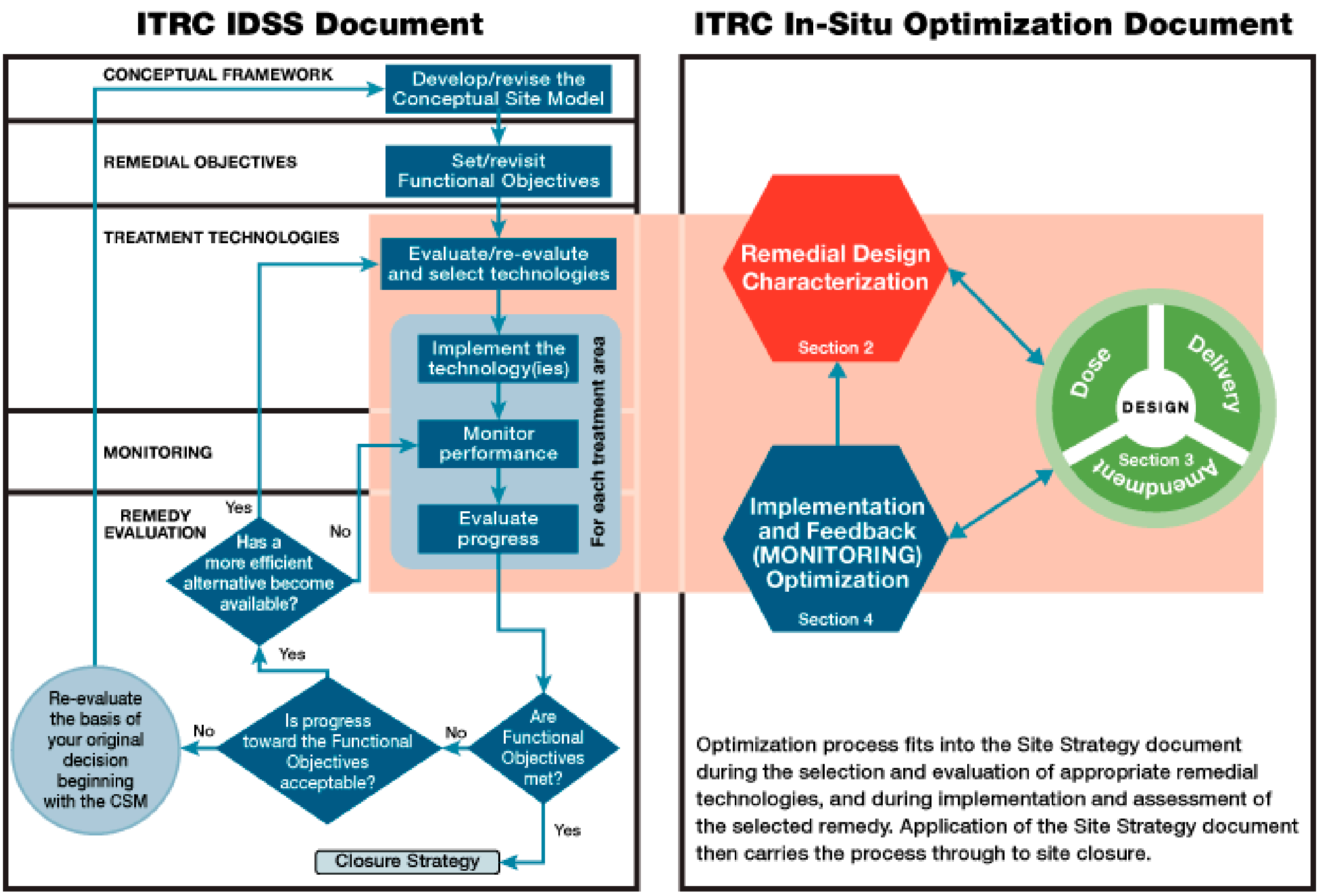

Figure 1-1. The in situ remediation optimization process.

The optimization process fits into the IDSS process during the selection and evaluation of appropriate remedial technologies, and during implementation and assessment of the selected remedy. Application of the IDSS Framework then carries the process through to site closure.

1.4 Document Organization

As described earlier, this document provides guidance to help a remediation professional evaluate site characteristics with in situ treatment in mind. The early investment in detailed data collection, specific to optimize the design of an in situ remedy, reduces the uncertainty of the remedial outcome by promoting an original design that is more effective and improving the chances of successful optimization. Iterative testing and refinement of the amendment composition, dosing, and distribution, even during full-scale implementation, will help ensure that the treatment expectations are met. The following briefly introduces the sections of this guidance.

1.4.1 Section 2 Remedial Design Characterization

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The RDC section defines additional site characterization data that should be collected, above and beyond what is typically gathered as part of general site characterization studies.

1.4.2 Section 3 Amendment, Dose, and Delivery Design

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This section provides information on the selection of amendments, delivery methods, and amendment dose. The remedial design process is commonly visualized as a linear sequence that begins with the CSM. However, in practice, the overall process is iterative and cyclical, with many feedback loops at any step connecting to both earlier and later steps.

1.4.3 Section 4 Implementation and Feedback (Monitoring) Optimization

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Remedy implementation is an iterative process that unites consideration of site characteristics, amendments, and delivery method. This section addresses site-specific logistical and permitting issues that should be considered before mobilizing to the site, as well as during implementation of the remedy, to include changes to dose, amendment, and delivery. The remedy may be optimized at any stage based on the evaluation of monitoring data.

1.4.4 Section 5 Regulatory Perspectives

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The objective of this section is to identify both statutory and procedural challenges that may impede successful implementation of in situ remedies.

1.4.5 Section 6 Community and Tribal Stakeholder Considerations

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

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