5.4 Decision Logic for Adaptive Site Management

Decision-making criteria to implement adaptive site management strategies are incorporated into the long-term management plan. These criteria are used as a guide for adapting the remedy if needed, based on the results of the periodic evaluations. Open, transparent discussions among all the interested parties on contingency actions and remedy transitions and corresponding decision-making criteria are planned in case the remedial approach fails to meet interim or site objectives. Public participation is always recommended and is typically required when a significant change to the remedial approach and an updated decision document is warranted. Transition assessments can apply to any remedy transition decision when a determination has been made that continued implementation of the current remedy components will not meet interim or site objectives.

5.4.1 Potential Outcomes of Periodic Evaluations

Potential decision outcomes of periodic evaluations include the following (see Figure 5):

- Performance is found protective and adequately progressing towards interim and site objectives, so the remedy will continue to operate as is.
- Interim objectives have been met that allow for transition to a less aggressive remedy component (for example, MNA).
- Remedy optimization is needed to improve operation of engineered remedy components or revise the remedial approach. In this case, the CSM would be revised to reflect the latest knowledge of site conditions. Remedy revision may be needed due to one the following identified conditions:
    - Operating conditions are outside the expected design range or specifications.
    - Contaminant concentrations are not decreasing as anticipated.
    - Plumes are expanding or migrating unexpectedly.
    - Treatment efficiencies are not being met (for example, extraction/injection rates are not being met, or discharge limitations have been exceeded).

Two circumstances can warrant reevaluation of an ongoing remedy component or the overall remedial approach. First, recalcitrant contaminants and complex subsurface conditions can cause asymptotic contaminant levels above the interim or site objectives. In this situation, meaningful additional progress toward site objectives is not technically feasible. At a minimum, the long-term management plan lays out a procedure to follow when the remedy is determined to no longer be protective of human health or the environment, or if progress towards interim and site objectives is not satisfactory. Contingency actions or possible modifications to the remedial approach are identified in the long-term management plan to address reasonably anticipated scenarios. Site objectives and the overall remedial approach may need to be reevaluated to determine an appropriate revised long-term management strategy.

In a second situation, interim objectives have been met, but site objectives have not been achieved. The long-term management plan includes provisions for the transition to either a less aggressive remedy component such as MNA, or an alternative “treatment train” polishing technology, based on reaching a practical

Reaching Technology Limits

At a chlorinated solvent site, interim objectives were achieved even though site objectives were not. The proposed remedy was enhanced in situ bioremediation to promote reductive dechlorination. The primary contaminants were TCE and N-nitrosodimethylamine (NDMA). These were present at 125 feet below ground surface in complex geology (bedrock) that prevented contaminant extraction and effective substrate addition. Enhanced in situ bioremediation was not effective against NDMA, but it achieved substantial dechlorination of TCE, reaching asymptotic conditions above action levels. Pilot studies design limitation for the current remedy component. Provisions for remedy component transition and corresponding interim objectives and corresponding performance metrics are included in long-term management plans that allow for discontinuing more aggressive engineered remedy components that are found to no longer appreciably contribute to progress toward site objectives, such as reaching an asymptotic condition.

For each of the above scenarios, adaptive site management can help to determine the data, evaluations, and procedures necessary to determine the technical basis for further long-term management approaches. The reevaluation of interim objectives and corresponding performance metrics could logically transition to strategies employing less aggressive remedy components. It may also be necessary to revisit the remediation potential assessment which may now have a different outcome with the availability of a more comprehensive CSM, monitoring history, and actual site-specific remediation data. For example, at the Savannah River Site, a P&T system was replaced by a hybrid funnel-and-gate system to slow the migration of contaminated groundwater and funnel it through in situ treatment zones at the gates. Periodic injections of an alkaline solution at each gate neutralizes groundwater and promotes contaminant sorption and uranium precipitation. More details on this site are provided in the full case study.

A contingency action or remedial approach is identified and implemented (or may have already been identified in the long-term management plan) when the initial remedial technology fails to perform as predicted (interim objectives are not met) and optimization measures do not significantly improve performance. Criteria for deciding to implement a contingency action or remedial approach can be agreed upon and used to measure remedy component performance.

Finally, it is essential to evaluate remedy protectiveness and to summarize any key data gaps for each site or area of the site (for example, source area, or off-site dissolved-phase plume area) with regards to characterization needs, plume behavior, recent advances in technology or other factors. Periodic evaluations can also identify more sophisticated optimization tools and applications for their use. Causal factors, including changes in broader site circumstances (such as source remediation, changes in flow regimes, changes in land use, and drought) can also be considered.

demonstrated that additional, currently available in situ technologies were ineffective for remediating NDMA (red zone per Figure 7). Based on available technologies and site conditions, stakeholders concluded that technologies were at their practicable limit/potential. The remedial approach was modified to implement natural attenuation and an enforceable environmental covenant to maintain protectiveness.

Use of a Treatment Train and Interim Objectives

When progress toward interim objectives became unsatisfactory at an SVE remediation system, the remedy was optimized. At a VOC-contaminated landfill, SVE was used to achieve at least 97% reduction in VOC soil gas concentrations relative to baseline conditions. Initial high VOC removal rates on the order of 10 kg/hour exponentially declined the first year. By the end of the second year of operation, the VOC removal rate had attained asymptotic conditions at 5 kg/hour (yellow zone per Figure 8). Thermal technology was introduced during the third year of SVE system operation to optimize system performance. At the end of the fourth year, the SVE system *operation was terminated after successfully achieving reduction of VOC concentrations in soil gas (0.27 kg/hour) by 97% or more.*

If monitoring data or new information shows changing conditions that were not anticipated, then a reevaluation of the risk assessment, overall remedial approach, and site objectives may be warranted. Other factors (such as changes in land use, the installation of a nearby water supply well, a new exposure pathway receptor such as VI, or the identification of a new source) may prompt a transition to an alternative overall remedial approach. Site objectives for specific contaminants may also change. Emerging contaminants such as 1,4-dioxane may not have been considered for routine analysis based on previous risk assessments. Research and development and other advancements in technology that increase the understanding of site conditions may present opportunities to optimize the remedial approach. The likelihood of these changes and their potential impact on site operations can be accounted for through maintaining a project risk register (ITRC 2011d, 2012).

Criteria for Triggering a Contingency Action

Performance metrics can specify criteria that trigger a contingency action based on insufficient progress towards interim objectives. For example, an interim objective may be defined for a pump-and-treat system as decreasing contaminant concentrations from 300 to 30 micrograms per liter (µg/L) in eight years based on initial remedy timeframe projections. A performance model can be developed to predict remedy progress over time. For this example, contingency actions (such as, further characterization or targeting "hot spots" with in situ amendment injections) may be triggered if contaminant concentrations are not reduced to a shorter-term performance metric of 150 µg/L or less within the first three years. The design basis (such as trend plots, calculations, and modeling results) of the performance model is documented in the long-term management plan.

5.4.2 Remedy Optimization

Another possible outcome of the periodic evaluation may be a recommendation for formal remedy optimization to evaluate improvements, modifications, or other remedial approaches to improve performance and cost effectiveness of current remedy components. Under the NCP, cost effectiveness is one of the criteria to be considered for remedy selection under 40 CFR 300.430(f)(5)(ii)(g)(D), which is addressed by performing periodic remedial performance optimization evaluations (ITRC 2004). The framework for a remedy's long-term management strategy is identified in the decision document or revised decision document based on the remedy selection (or revision) process. The USEPA definition of remediation optimization in the context of its "National Strategy to Expand Superfund Optimization Practices from Site Assessment to Site Completion" is stated on USEPA's CLU-IN website (USEPA 2017b) on optimization as follows:

> *Efforts at any phase of the removal or remedial response to identify and implement specific actions that improve the effectiveness and cost-efficiency of that phase. Such actions may also improve the remedy's protectiveness and long-term implementation which may facilitate progress towards site completion. Remediation optimization uses defined approaches to improve the effectiveness and efficiency with which an environmental remedy reaches its stated goals. Optimization approaches might include site-wide optimization reviews conducted by a team of independent experts, the use of statistical evaluation tools to determine optimal operating parameters or monitoring networks, the consideration of emerging technologies as the basis for remedy modifications or changes, review of operating systems costs, and the identification of methods for cost reduction without the loss of protectiveness.*

Beyond the Superfund program, numerous definitions of remedy optimization are used, which could range from routine informal ongoing evaluation of operating data to adjust treatment component operating and design parameters to more formal optimization reviews similar to the USEPA's Remediation System Evaluation program, which is analogous to the RPO process defined by ITRC. RPO is a dynamic and flexible management strategy that can be applied at any stage of the remediation life cycle. An RPO evaluation during the remedial action phase can offer many opportunities for improving effectiveness of the remedy and reducing cost without adversely impacting protectiveness.

An RPO assessment evaluates the progress toward meeting developed interim and site objectives and other technology-specific treatment performance objectives. This evaluation is highly recommended at sites that are not adequately progressing towards interim objectives and other performance indicators. This assessment also includes evaluating whether a particular remedy component is meeting its respective design expectations. RPOs may be performed for each of the remedial technologies and other remedy components. The elements of periodic evaluations also apply in general to RPOs, except for the greater level of detail that may be evaluated for each technology and remedy component as part of an RPO. An RPO typically includes comparative cost analyses to evaluate alternative equipment or operating procedures.

Recommendations from RPOs may include any combination of the following:

- transition to a less aggressive remedy component or remedial approach if interim objectives are met, or asymptotic conditions that cannot be improved by further optimization efforts identified
- further refining the CSM
- consideration of a “treatment train” approach using multiple technologies or other proven or emerging technologies to expedite remedial progress
- modifying the existing remedy components or operating parameters (such as adding treatment wells, increasing pumping rates or amendment injection volumes)
- optimizing the monitoring program

An example of a recommendation from an RPO might be redevelopment of groundwater extraction and monitoring wells. When wells become fouled, they often provide less accurate contamination levels. Wells are typically periodically redeveloped to remove fine-grained sediments, minerals, and biogrowth to maintain extraction performance and water quality. Redevelopment can reduce the energy cost, as well as provide better remedy performance, especially if the pumping wells have reduced capture influence due to declining pumping rates. The same is true for monitoring well chemistry results.

Numerous additional resources available on optimization and periodic evaluations for remedial systems (USEPA 2015d, ITRC 2004, 2007a, USEPA 2013e, b, USACE 1999, NAVFAC 2012, 2010a, Air Force Center for Environmental Excellence and Defense Logistics Agency 2001, USEPA and USACE 2007, FRTR 2016).

5.4.3 Community Awareness and Engagement during Remedy Adaptation

Community involvement begins early in site remediation and continues throughout long-term management. Because of the long time frames anticipated at complex sites, it is important to monitor community awareness and continue to engage the community according to the long-term management plan. Engaged communities are already knowledgeable about the site history and key issues. These community members tend to benefit the site because they offer a stable repository for site-specific knowledge. Those most affected by site activities have the largest stake in its outcome. Information handed down through the community safeguards knowledge about the site and its potential hazards.