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GUIDANCE FOR OPTIMIZING REMEDIAL ACTION OPERATION (RA-O)

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14. ABSTRACT

Optimization of RA-O programs is an important process which helps to ensure maximum remedial effectiveness, minimum negative environmental and societal impacts, and improved cost efficiency of a remedy. Optimization is an ongoing responsibility of Navy/Marine Corps RPMs and their contractors who operate, maintain, and monitor remediation systems. The goal of optimization is to achieve RC and ultimately site closeout in the shortest amount of time and with the least possible remedy footprint and expenditure.

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ACRONYMS AND ABBREVIATIONS

ACL	alternate concentration limit
AFCEC	Air Force Civil Engineer Center
ARAR	applicable or relevant and appropriate requirement
AS	air sparging
ASTM	American Society for Testing and Materials
AVGAS	aviation gasoline
AWA	area weighted average
BMP	best management practice
BRAC	Base Realignment and Closure
BTEX	benzene, toluene, ethylbenzene and xylene
CCL	calculated concentration limit
CERCLA	Comprehensive Environmental Response, Compensation, and Liability Act
CNO	Chief of Naval Operations
COC	contaminant(s) of concern
CSM	Conceptual Site Model
CSMoS	Center for Subsurface Modeling Support
CTC	cost to complete
DENIX	Defense Environmental Network and Information eXchange
DNAPL	dense non-aqueous phase liquid
DoD	Department of Defense
DON	Department of the Navy
ER	Environmental Restoration
ERB	Environmental Restoration and BRAC
ERT2	Environmental Restoration Technology Transfer
ESD	Explanation of Significant Difference
EVO	emulsified vegetable oil
EVS	Environmental Visualization System
EXWC	Engineering and Expeditionary Warfare Center
FEC	Facilities Engineering Command
FY	fiscal year
GIS	Geographical Information System
GSR	green and sustainable remediation
GTS	Geostatistical Temporal/Spatial
GWQS	Groundwater Quality Standards

HTRW CX	Hazardous, Toxic, and Radioactive Waste Center of Expertise
HQ	Headquarters
IRP	Installation Restoration Program
ISCO	in-situ chemical oxidation
ISCR	in-situ chemical reduction
ITRC	Interstate Technology and Regulatory Council
LNAPL	Light Non-Aqueous Phase Liquid
LTM	Long Term Monitoring
LTMgt	Long Term Management
LUC	Land Use Control
MAROS	Monitoring and Remediation Optimization System
MCAS	Marine Corps Air Station
MCB	Marine Corps Base
MCL	Maximum Contaminant Level
MGO	Modular Groundwater Optimizer
MMA	Monitoring and Management Approach
MNA	Monitored Natural Attenuation
MPE	Multi-Phase Extraction
NAPL	non-aqueous phase liquid
NAS	Natural Attenuation Software
NAVFAC	Naval Facilities Engineering Command
NERP	Department of the Navy Environmental Restoration Program
NIRIS	Naval Installation Restoration Information Solution
NPL	National Priorities List
NPV	Net Present Value
NORM	Navy "Normalization of Data" database
NO_x	oxides of nitrogen
O&M	Operation and Maintenance
PCE	perchloroethene
PDF	Portable Document Format
PRB	permeable reactive barrier
RA	Remedial Action
RA-O	Remedial Action Operation
RACER	Remedial Action Cost Engineering and Requirements System
RBC	Risk-Based Concentration
RBCA	Risk-Based Corrective Action
RC	Response Complete

RCRA	Resource Conservation and Recovery Act
RIP	remedy in place
ROD	Record of Decision
RPM	Remedial Project Manager
RSE	Remediation System Evaluation
SOMOS	Simulation/Optimization Modeling System
SO_x	sulfur oxides
SVE	soil vapor extraction
TCE	trichloroethene
TI	technical impracticability
USACE	U.S. Army Corps of Engineers
U.S. EPA	U.S. Environmental Protection Agency
UST	Underground Storage Tank
UV	Ultraviolet
VOC	volatile organic compound
ZVI	zero valent iron

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1.0 INTRODUCTION

The goal of the Department of Navy (DON) Environmental Restoration (ER) Program is to "achieve environmentally protective site closeout at least cost." Figure 1-1 illustrates the phases of the ER process. In the past, ER programs have focused primarily on site identification and investigation. However, the new Response Complete (RC) goals for the Defense Environmental Restoration Program state that 90% of all sites shall be RC by the end of 2018 and 95% by the end of 2021. If funding remains stable, the DON is projecting to meet these goals. These new goals do not change the current goal of reaching Remedy in Place (RIP)/RC for Installation Restoration Program (IRP) sites by the end of fiscal year (FY) 2014. The majority of sites are projected to reach a minimum goal of RIP by the end of FY 2014, and many sites will require continued remedial action operation (RA-O) for a number of years before RC is achieved. Therefore, the environmental restoration program needs to start transitioning its focus from "assess, design and remediate" to "monitor, adjust, and return to service". The DON is committed to optimizing the program through careful evaluation of project goals, remediation system effectiveness, life cycle design and costs, as well as data management and report streamlining. Optimization is a necessary process to allow the remedial project manager (RPM) to manage remediation programs within budgetary constraints.

Naval Facilities Engineering Command (NAVFAC) formed an Optimization Workgroup to provide guidance to the DON activities regarding optimization during various phases of the cleanup process at Navy installations. This Workgroup, led by the NAVFAC Engineering and Expeditionary Warfare Center (EXWC), is made up of engineers and scientists representing the various components of NAVFAC including NAVFAC Headquarters (HQ), NAVFAC EXWC, and the Echelon III and IV Commands.

NAVFAC policies and associated guidance documents are available for various stages/phases of the ER process (see the NAVFAC ER and Base Realignment and Closure [BRAC] Web Site [Documents tab] and the Optimization Workgroup Page to view and download guidance and policy). NAVFAC HQ established the *Policy for Optimizing Remedial and Removal Actions at All DON Environmental Restoration Program Sites* [1]. This policy is applicable to various phases of the cleanup process:

- remedy evaluation (e.g., feasibility study);
- remedy selection (e.g., record of decision [ROD]);
- remedial design;
- remedial action (RA) construction;
- RA-O; and
- long-term management (LTMgt).

The Navy/Marine Corps optimization policy requires that all remedies are continually optimized at each cleanup phase. The policy requires that RA-O performance be evaluated at least annually to measure progress toward the RA objective, and further states that documentation within the Navy's Normalization of Environmental Data Systems (NORM) database is required of all optimization efforts. This policy requirement regarding RA-O applies to sites that have achieved the remedy in place milestone and will require an extended period of operation and monitoring (O&M) before reaching RC. During this active RA-O period, remediation system performance should be evaluated annually, and optimization reviews should be conducted periodically based on the results of the performance evaluations.

The Management and Monitoring Approach (MMA) [2] may be used to develop well-written annual monitoring reports; this approach is particularly applicable for annual monitoring reports where significant amounts of data may be included. The MMA builds upon the NAVFAC Monitoring Report Template [3] which was developed to provide a consistent format for RPMs to document the long-term management process. This type of documentation will facilitate future optimization efforts and Five-Year Reviews. A more rigorous optimization review shall be conducted if the annual evaluation reveals poor or erratic remedial performance, excessive operating costs, frequent equipment breakdowns, or high monitoring costs.

Periodic third-party independent optimization reviews are highly effective and recommended by the NAVFAC Optimization Workgroup. The following four options (or combination thereof) are available to RPMs for the optimization review and are specified as choices within NORM:

- NAVFAC EXWC Tiger Team. A third-party independent optimization review coordinated through NAVFAC EXWC drawing upon expertise from industry, academia, other government agencies, and DON. Depending upon site-specific requirements, this could be mostly a contracted effort.
- Internal Tiger Team (i.e., a team from the Facilities Engineering Command [FEC] technical group). A third-party independent optimization review primarily by an internal DON team with senior technical staff from DON organizations, e.g., NAVFAC Atlantic, NAVFAC Pacific, other FECs, NAVFAC EXWC, and BRAC Program Management Office. Relatively minor contract support may be acquired to support this effort.
- Contracted Optimization Review. A third-party independent optimization review conducted by contractors other than the current O&M, design, or remediation contractor for the system being evaluated. Contract support from NAVFAC EXWC is available for these reviews.
- Project Team. Optimization review performed by the project team that is comprised of senior technical staff from within the FEC or other Navy resources working with the RPM and current contractors.

1.1 What Is Optimization and Why Is It Important?

Optimization of RA-O programs is an important process which helps to ensure maximum remedial effectiveness, minimum negative environmental and societal impacts, and improved cost efficiency of a remedy. Optimization is an ongoing responsibility of Navy/Marine Corps RPMs and their contractors who operate, maintain, and monitor remediation systems. The goal of optimization is to achieve RC and ultimately site closeout in the shortest amount of time and with the least possible remedy footprint and expenditure. Within the Navy ER Program, the term *remedy footprint* is meant to include adverse impacts on environmental media and society that are a direct or indirect consequence of performing the RA.

The benefits of RA-O optimization include:

- Ensuring that the RA remains protective of human health and the environment
- Enhancing the effectiveness of RA toward achieving remedial objectives
- Reducing the remedy footprint
- Reducing O&M costs
- Accelerating the schedules for RC milestone and site closeout.

1.2 How Can This Manual Help?

This guidance document focuses on the most significant ways to design and optimize RA-O in order to maximize cost efficiency and minimize the remedy footprint while maintaining effectiveness. This guidance manual contains:

- Detailed explanations of the RA-O optimization process
- References to tools that the RPMs can use in the RA-O optimization process
- Technology-specific optimization recommendations for common remedial system operational problems
- Summaries of RA-O optimization case studies conducted at Navy/Marine Corps installations
- Examples of RA-O optimization technical points and concepts based on "lessons learned" from the case studies
- Discussion of how green and sustainable remediation (GSR) should be considered during remedy optimization.

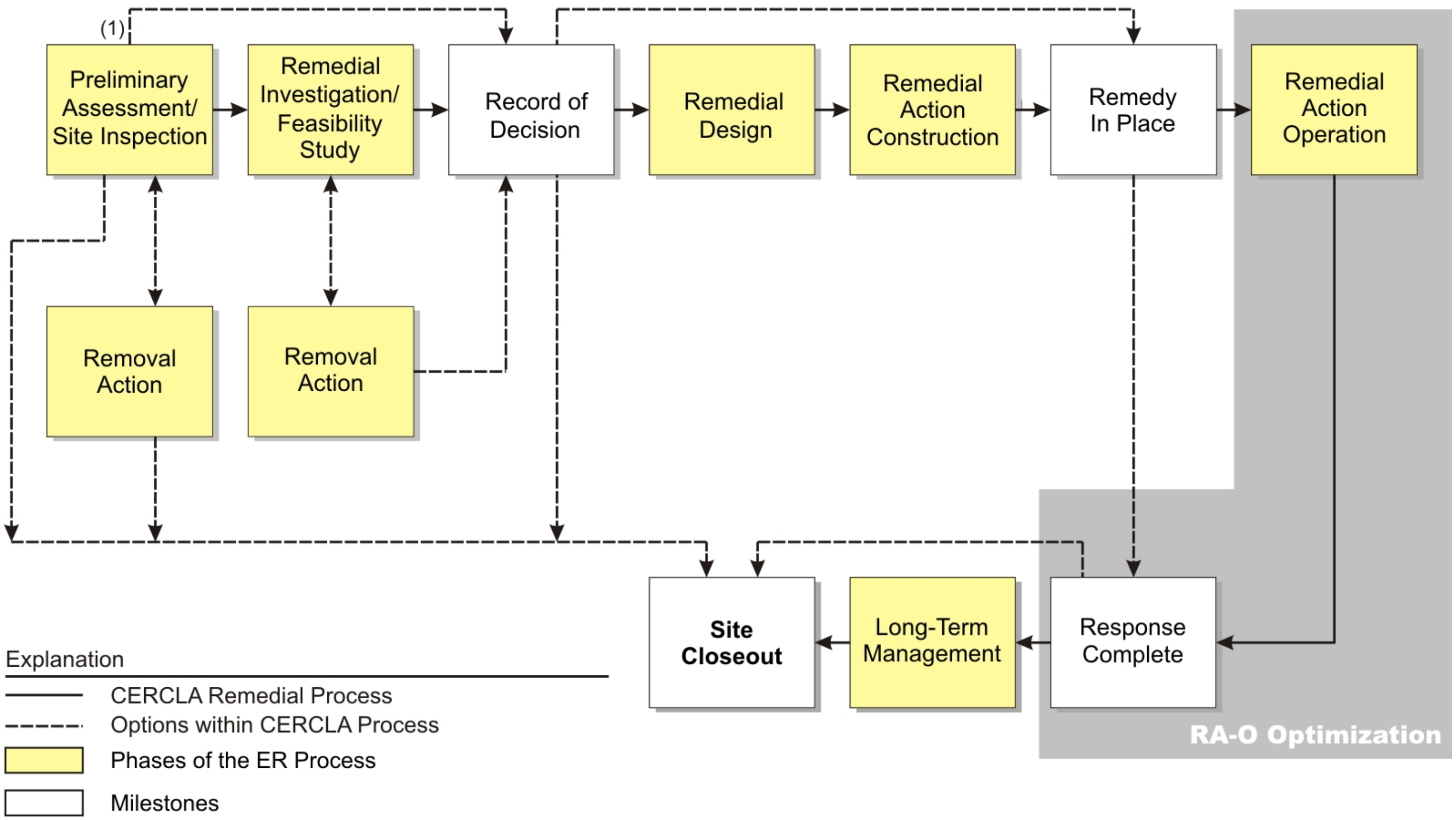
This document presents a step-wise process for optimizing RA-O as developed by the NAVFAC Optimization Workgroup. The guidance and the optimization process were based largely on the findings from RA-O optimization case studies conducted at several Navy and Marine Corps installations. Examples from the case studies are provided throughout this document to highlight technical points and concepts. Relevant information from other Government and private sources, such as guidance documents, engineering manuals, and performance evaluation checklists, was also used in developing this document. Technology-specific optimization recommendations for common remedial system operational problems are provided in Appendix A. The following steps for optimization during RA-O are discussed in this guidance:

1. Review and Evaluate RA Objectives
2. Evaluate Remediation Effectiveness
3. Evaluate the Cost Effectiveness and Sustainability
4. Identify Potential Remedy Improvements or Alternatives
5. Develop and Prioritize Optimization Recommendations and Footprint Reduction Methods
6. Prepare an Optimization Report and Implement the Optimization Recommendations.

This document is a revision to the earlier 2001 document *Guidance for Optimizing Remedial Action Operation*. The revised document provides guidance on the optimization of RA-O programs and serves as a companion document to the following DON optimization guidance documents:

- *Guidance for Optimizing Remedy Evaluation, Selection and Design* [4]
- *Guidance for Planning and Optimizing Monitoring Strategies* [5]
- *Department of the Navy Guidance on Green and Sustainable Remediation* [6]
- *Guidance to Documenting Milestones Throughout the Site Closeout Process* [7].

The above guidance documents can be found at the NAVFAC Optimization Workgroup Web Portal.



Note: (1)The pathway from the PA/SI directly to the ROD may be followed by including the site in a ROD for the relevant Operable Unit or in another ROD at the same installation in order to provide an additional level of concurrence and documentation beyond agency concurrence letters.

Figure 1-1. Department of Navy Environmental Restoration Process for CERCLA Sites

2.0 WHAT IS THE REMEDIAL ACTION OPERATION OPTIMIZATION PROCESS?

The RA-O optimization process is designed to evaluate the site remedial strategy, remedial system design, remedy effectiveness, and cost efficiency. Based on this evaluation, recommendations are developed to improve existing remediation systems, utilize scientific advances in remediation technologies, and/or incorporate changes in regulatory requirements. Optimization is an ongoing process. Therefore, RA-O performance should be evaluated annually, and optimization reviews should be conducted periodically based on the results of the performance evaluation and progress of the RA-O in achieving its objectives.

In general, "lessons learned" from RA-O optimization case studies performed at several Navy/Marine Corps installations were used to develop the RA-O optimization process. These case studies cover a wide range of remediation technologies, including pump and treat, air sparging/soil vapor extraction (SVE), bioslurping, enhanced bioremediation, and in-situ chemical oxidation (ISCO) and reduction (ISCR). Examples from these case studies are provided throughout this guidance document to highlight technical points and concepts.

Other Department of Defense (DoD) documents were referred for additional ideas on optimizing RA-O programs. Specifically, the Air Force, Air Combat Command *Environmental Restoration Program Site Closure Guidance Manual* [8], the Air Force Center for Environmental Excellence (now referred to as Air Force Civil Engineer Center [AFCEC]) *Remedial Process Optimization Handbook* [9] and an updated version of the AFCEC guidance *Environmental Restoration Program Optimization (ERP-O) Guidance* [10]. In addition, the optimization process presented in the Interstate Technology and Regulatory Council (ITRC) document *Remediation Process Optimization: Identifying Opportunities for Enhanced and More Efficient Site Remediation* [11] is similar to the process discussed within this DON guidance.

The RA-O optimization process, as illustrated in Figure 2-1, consists of seven steps:

Step 1. Review and Evaluate Remedial Action Objectives – Prior to any optimization activities, the RPM and optimization review team should review the decision-making framework for a remedial site to ensure that the RA objectives remain appropriate.

Step 2. Evaluate Remediation Effectiveness – Based on an assessment of remedial and system performance, the RPM and optimization review team should determine whether the existing remediation system is capable of achieving the RA objectives within a reasonable timeframe.

Step 3. Evaluate Cost Efficiency and Sustainability – After verifying that the remediation system can achieve RA objectives, the RPM and optimization review team should determine the cost efficiency and GSR metrics of the approach. By relating cost and performance data, the approach can be evaluated to determine its cost efficiency. A comparison of GSR metrics with performance data can be used to determine if the benefits of continued operation outweigh the associated environmental costs.

Step 4. Identify Potential Remedy Improvements or Alternatives – Based on the evaluations of remediation effectiveness, cost efficiency, and sustainability, the RPM and optimization review team should identify alternatives for optimizing the remedial approach. Improvements that may be considered include modifications to the existing remediation system, selection of alternative remedial approaches, and the use of an alternative endpoint. Changes of this nature may require regulatory approval; RPMs should consult with their ER Manager to determine documentation needs for post-ROD remedy changes.

Step 5. Develop and Prioritize Optimization Recommendations and Footprint Reduction Methods – The RPM and optimization review team should formulate optimization recommendations from the potential remedy improvements and prioritize these recommendations based on a relative cost-benefit analysis of life cycle costs and sustainability.

Step 6. Prepare Optimization Report – The RPM and optimization review team should document the findings of the remediation system evaluation and the preferred optimization recommendations in an optimization report. The outcome of the optimization review and projected implementation costs and changes in cost-to-complete (CTC) should be documented in the NORM optimization module.

Step 7. Implement Optimization Recommendations – The preferred optimization recommendations should be implemented following the implementation plan developed by the RPM, and the actual costs and impact on CTC should be updated in the NORM optimization module.

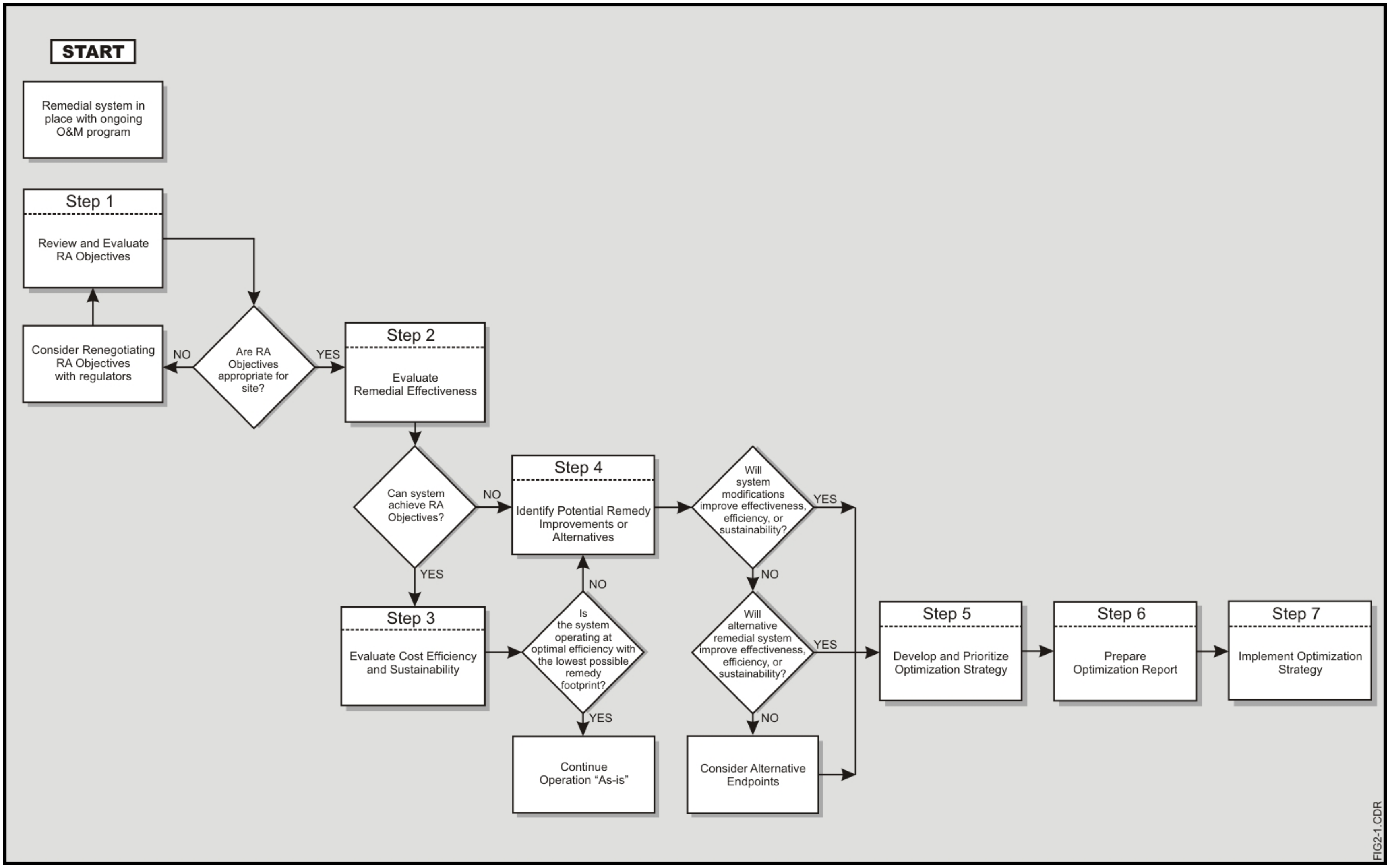


Figure 2-1. Remedial Action Operation Optimization Process

3.0 REVIEW AND EVALUATE REMEDIAL ACTION OBJECTIVES

***Content**: The first step of the RA-O optimization process is to review and evaluate RA objectives. This section describes the process for reviewing the decision-making framework for the remedial site, including verifying the conceptual site model (CSM) and the RA objectives. This evaluation, which includes a review of exposure routes and receptors, the cleanup goals and the life cycle design, allows the RPM to determine whether RA objectives remain appropriate for the remedial site.*

3.1 Verifying Remedial Action Objectives

The RA objectives identified in the decision document for active remedies are criteria that determine when site conditions are protective of human health and the environment under both current and future conditions and when further remedial system operation is unnecessary. The RA objectives provide a clear and concise description of what the RA should accomplish at a given site based on the CSM, which includes:

- Contaminants of concern (COCs)
- Impacted media
- Fate and transport of COCs
- Exposure routes and receptors.

To verify RA objectives, the CSM should be reviewed and updated to ensure that it remains reflective of current site conditions. Any changes to the CSM should be further evaluated to determine if the RA objectives continue to be protective of human health and the environment, or if modifications to the RA objectives are required to ensure this. For example, changes to the site land use may introduce new exposure routes and receptors not previously addressed by the RA objectives, or new information regarding the COCs (e.g., an emerging contaminant) present at the site may necessitate revising the RA objectives to address the identified COC and associated risks.

Any changes to the RA objectives should also be reflected in the cleanup goals. Cleanup goals are quantitative goals representing the point at which the RA objectives have been achieved. Examples include: maximum contaminant levels (MCLs) in groundwater to achieve a RA objective addressing COCs in groundwater designated as a drinking water source, or risk-based soil vapor concentrations to achieve a RA objective addressing COCs in soil vapor resulting in an unacceptable risk to receptors through vapor intrusion. Table 3-1 presents examples of RA objectives and cleanup goals. Further discussion of the CSM and cleanup goals, as they relate to evaluating the RA objectives, is provided in the following subsections.

3.2 Verifying the Conceptual Site Model

A CSM is a representation of the nature, extent, and fate of contamination, as well as potential exposure routes and receptors, which is used to evaluate remedial options to reduce the identified risks. The CSM is a useful engineering management tool and helps to successfully manage a site through the ER process. It is the basis for defining the RA objectives, determining the restoration potential of the site, and evaluating the effectiveness of the existing remediation system, and determining when the RA objectives have been met. The verification and revision, if necessary, of the CSM ensures that changes in the site and the surrounding area, such as revised exposure routes based on current contaminant distribution and development or other land use changes, are incorporated into the decision-making framework. Particular attention should be given to those assumptions that influenced the initial remedial design to ensure that the RA objectives remain appropriate for the site.

Table 3-1. Example RA Objectives and Cleanup Goals

Description	Contaminated Media	Contaminants of Concern	Remedial Action Objectives	Cleanup Goals
Long Beach Naval Shipyard, Site 12	Groundwater	Arsenic	Prevent groundwater from migrating to surface waters at concentrations exceeding water quality objectives in the State Water Resources Control Board's Ocean Plan	Calculated concentration limits based on distance from the monitoring well to the site boundary and the attenuation in concentrations that occurs over that distance
Alameda Point, OU 2C	Soil	Volatile organic compounds (VOCs; perchloroethene [PCE], TCE)	Prevent future office workers from potentially unacceptable risks associated with COCs in soil through vapor intrusion	PCE: 0.36 µg/L TCE: 0.54 µg/L
	Deep Groundwater	Chlorinated VOCs	Prevent human exposure associated with downgradient migration of contamination in deep groundwater and potentially unacceptable risks to downgradient human receptors	Total VOCs: 1,000 µg/L

During the RA-O phase, the CSM is verified and revised as necessary by incorporating the most recent operating and monitoring data. The operating and monitoring data provide current information concerning:

- Hydrogeology
- Types of contaminants removed
- Lateral and vertical distribution of contamination
- Estimated volume and/or mass of contamination
- Fate and transport of COCs.

In addition, the current land use should be considered to determine if other factors could affect decisions at the remediation site and associated monitoring locations, such as mission-related needs, site development and other land use changes. As site conditions change over time, the contaminant exposure routes and receptors specified in the RA objectives should be reviewed to confirm that they remain appropriate for the site. Aspects of the CSM representing the current conditions at the site serve as the basis for this review. This review of the exposure routes and receptors should consider:

- Identifying any changes related to current or proposed future land uses
- Modifying the list of COCs based on the past year of monitoring
- Revising the exposure routes (i.e., groundwater, soil, surface water, soil gas, or sediment) based on current contaminant distribution and concentrations
- Revising exposures based on changes in site features or conditions
- Identifying any new receptors that may be affected by the contamination.

The CSM should continue to be updated as performance data are collected, and analyzed to refocus the remedy(ies) as necessary based on an "observational approach". The CSM should be considered a living tool that needs to be updated after every event and kept up to date throughout every stage of the process. In some cases, additional field investigations may also be necessary to obtain information to update the CSM. Optimizing the remedy and updating the CSM during RA-O activities will help to accomplish the following:

- Evaluate the effectiveness of RAs in reducing the exposure of environmental receptors to contaminants
- Facilitate evaluation and optimization of remediation system performance.

The type of data to be collected will be site-specific to the remedy, but could include tracking total mass removal over time (in situ or ex situ), monitoring residual contaminant concentrations over time, and evaluating the O&M cost and cost per pound of contaminant removed to support exit strategies. In some cases, a targeted CSM may be useful where a more precise depiction is needed in a particular area to address a specific question or to support additional investigative sampling at the site. For example, a targeted CSM could include a fate and transport model for groundwater discharge to surface water near the site boundary to support transitioning from an active remedy to MNA.

The preferred method of maintaining the CSM is through electronic data management systems. This allows the CSM to be updated in the most efficient manner and allows a greater number of people to have access to the CSM. The Naval Installation Restoration Information Solution (NIRIS) is a central Web-based electronic data management system developed by the Navy that is used to store both analytical and spatial data for ER projects at Navy and Marine Corps sites. NIRIS offers tools to access, query, visualize, analyze, and extract data, and should therefore be used by Navy RPMs and their contractors to support development and continued maintenance of the CSM.

A detailed description of CSMs can be found in Section 2.2.2 of the *DON Guidance for Planning and Optimizing Monitoring Strategies* [5] and Section 2.1 of the *Guidance for Optimizing Remedy Evaluation, Selection, and Design* [4]. An example of a CSM diagram for a site in the RA-O phase is presented in Figures 3-1 and 3-2. Figure 3-1 shows a time-series plot illustrating the changes in VOC concentrations and percent VOC reduction in performance wells over time. Figure 3-2 shows a map presenting the nature and extent of contaminants in groundwater based on updated site monitoring data. Additional information regarding the objectives and development of CSMs can be found in the CSM Tool on the ER Risk Assessment Web site.

Example: *At Naval Air Station Corpus Christi, SWMU 1, updating the CSM with accurate hydrology information resulted in optimization of the remedial system by eliminating operation of two of the three groundwater collection trenches. The pumping rate of the remaining collection trench was also reduced over time while continuing to maintain the necessary hydraulic control. Eventually, the site will transition completely to monitored natural attenuation (MNA), eliminating the need for any groundwater collection and treatment.*

3.3 Cleanup Goals

Typically, response actions for environmental cleanup are guided by the processes defined under the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) or the Resource Conservation and Recovery Act (RCRA). Depending on the environmental law (i.e., CERCLA or RCRA), the United States Environmental Protection Agency (U.S. EPA) expects groundwater to be returned to its beneficial uses wherever practicable and requires that RAs attain numeric cleanup levels that comply with Federal and more stringent state standards, which are legally applicable or relevant and appropriate requirements (ARARs), or reflect available or site-specific, risk-based cleanup levels. Cleanup goals should be reviewed to confirm that they remain protective and appropriate for the remedial site given the RA objectives identified. Additional guidance concerning appropriate cleanup goals at a site can be found in Section 8.3.1.3 of the *Department of the Navy Environmental Restoration Program (NERP) Manual* [12].

For groundwater, MCLs are commonly established as the cleanup goals under regulatory programs, such as RCRA, CERCLA, and state underground storage tank (UST) programs. These MCLs, however, are not always appropriate for a remedial site. For example, if the groundwater is not a potential drinking water source, clean up to MCLs may be overly conservative. In this case, risk-based concentrations (RBCs) that consider only complete groundwater exposure pathways may be derived and used as cleanup goals. Cleanup goals should not be established for compounds that are within the concentration range naturally occurring in the aquifer or that are unrelated to the contaminant release. Background concentrations should have been evaluated for naturally-occurring constituents in groundwater before establishing cleanup goals based on regulatory standards or RBCs. However, if there is concern that background concentrations were not adequately considered when developing RA objectives, or if new information has recently changed the RBC or regulatory standard for the cleanup goals, then it may be necessary to reconsider the impact of background constituents on remedy effectiveness and the appropriateness of RA objectives. Guidance for establishing background groundwater concentrations for a site can be found in *NAVFAC Guidance for Environmental Background Analysis Volume III: Groundwater* [13].

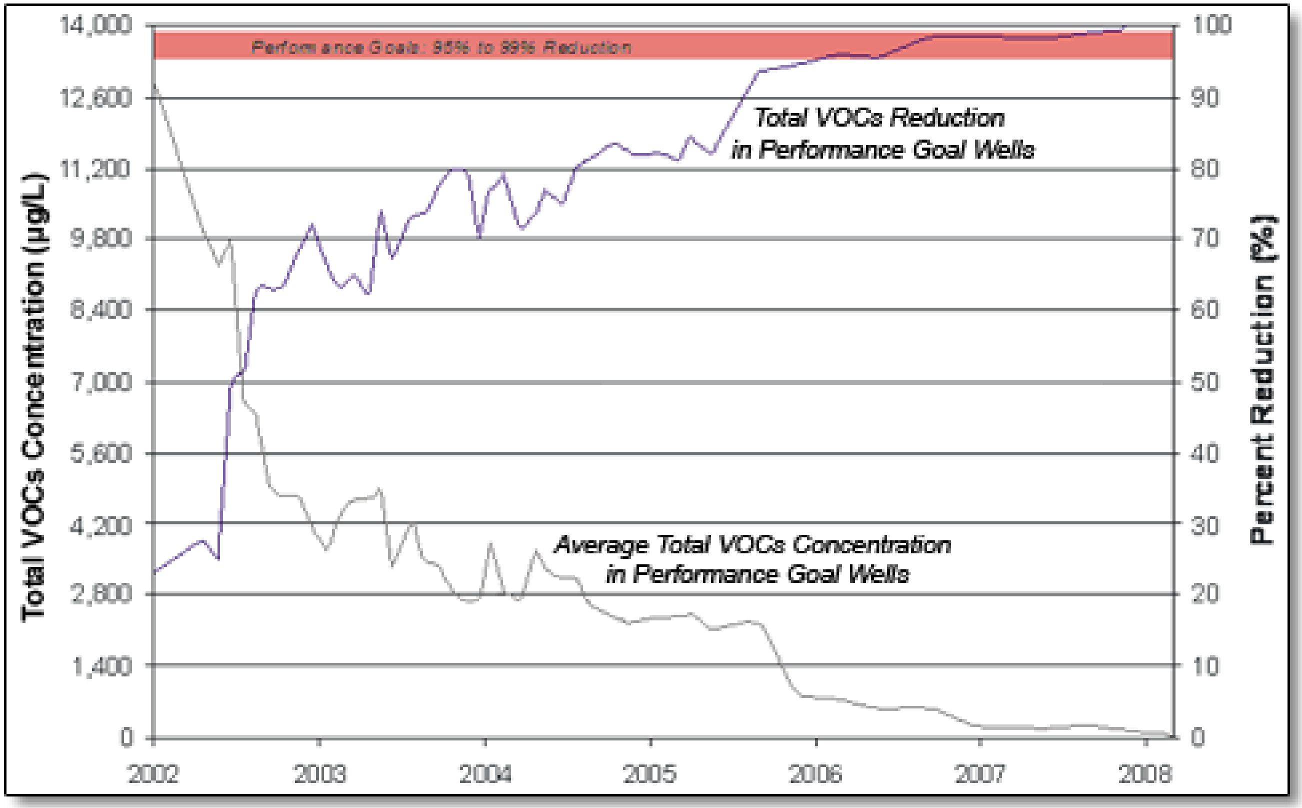


Figure 3-1. Example Conceptual Site Model, Time-Series Plot

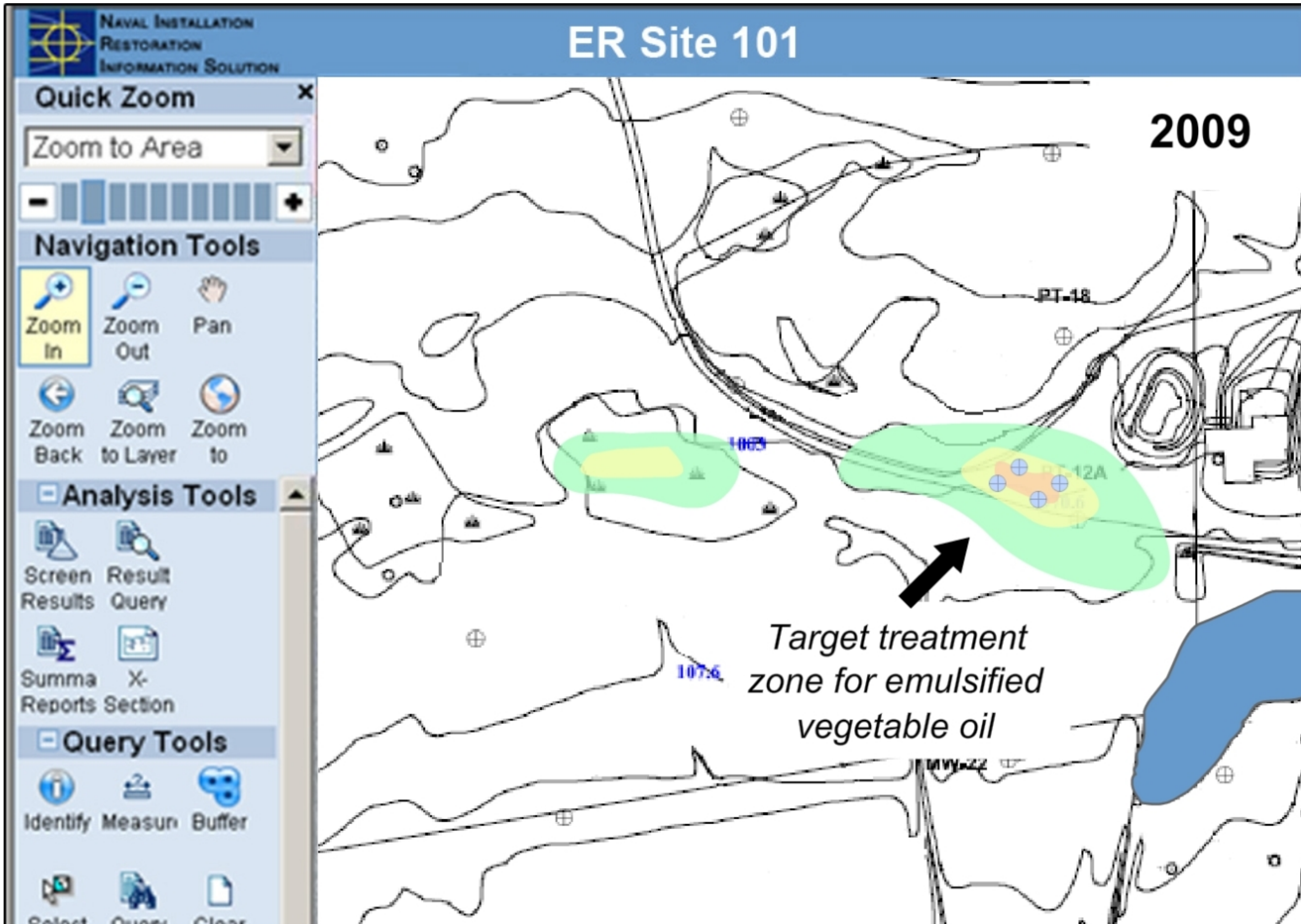


Figure 3-2. Example Conceptual Site Model, Case Study ER Site 101

***Example**: At Marine Corps Base Camp Lejeune OU1 South, the COCs included petroleum contaminants (i.e., benzene, toluene, ethylbenzene, and xylene [BTEX]), chlorinated solvents, and metals in groundwater. Results of routine groundwater monitoring indicated that concentrations of metals in groundwater were uniformly distributed across the site. Subsequent completion of a background study for metals detected in groundwater indicated that the concentrations of metals detected at the site are similar to background concentrations. As a result of the evaluation, metals were removed from cleanup goals for the remedial site.*

With the exception of surface water, regulatory standards have not been promulgated by the Federal government for other environmental media (e.g., soil, sediment, soil gas). For these media, RBCs are used as cleanup goals unless state regulations relevant to these media have been accepted as ARARs. RBCs may be calculated based on site-specific information or selected from generic RBCs derived by U.S. EPA (i.e., regional screening levels) or state-specific programs. In some states, state remediation standards may be enforceable. The applicability of any generic RBC or state-specific standard should be evaluated on a case by case basis for each site to ensure site circumstances match the underlying assumptions, conditions, and models used to derive that RBC or state standard.

Nearly every state UST program has adopted risk-based cleanup criteria to streamline the site closure process for petroleum contaminated sites. Where risk-based corrective action (RBCA) programs have been adopted, the use of risk-based goals for all environmental media should be considered for a site. These risk-based goals are typically more appropriate cleanup goals as they are based on site-specific risk to human health, safety, and the environment. RBCA programs are currently in place in a majority of states and are under development in many more.

Again, background concentrations should have been evaluated for naturally-occurring constituents in the environment before establishing cleanup standards based on regulatory standards or RBC cleanup goals. However, if there is concern that background concentrations were not adequately considered when developing RA objectives, or if new information has recently changed the RBC or regulatory standard for the cleanup goals, then it may be necessary to reconsider the impact of background constituents on remedy effectiveness and the appropriateness of RA objectives. Guidance for establishing background soil and sediment concentrations for a site can be found in *NAVFAC Guidance for Environmental Background Analysis Volume I: Soil* [14], and *NAVFAC Guidance for Environmental Background Analysis Volume II: Sediment* [15].

***Example**: At Naval Air Station Corpus Christi, SWMU 1, a review of regulatory action limits discovered regulatory criteria were being inappropriately applied to this site. Negotiations with state regulators resulted in a more lenient (but still protective) groundwater regulatory standard based on site-specific risk considerations.*

4.0 EVALUATE REMEDIATION EFFECTIVENESS

***Content**: The second step of the RA-O optimization process is to evaluate the effectiveness of the remediation system. This section describes the process to evaluate the effectiveness of the existing remediation system using O&M and monitoring data. This evaluation, which considers the remedial progress toward cleanup goals, and the operating efficiency and suitability of the system, allows the RPM to determine whether the remediation system is capable of achieving RA objectives within a reasonable timeframe.*

4.1 Remedial Performance

The effectiveness of a remediation system is measured by its remedial performance. Remedial performance refers to the system's progress toward meeting cleanup goals. The remedial performance should be evaluated to determine whether the remediation system is capable of achieving cleanup goals.

To evaluate remedial performance, performance data are compared with the cleanup criteria established in the RA objectives. O&M and monitoring data typically found in remediation system O&M reports are used to evaluate remedial performance. Common O&M and monitoring data used for this evaluation include:

- Groundwater/soil/soil gas/sediment/surface water contaminant concentrations
- Groundwater level monitoring, including free product levels
- System influent and effluent contaminant concentrations
- System operating parameters such as flow rates and pressures
- Geochemical parameters, such as dissolved oxygen levels, alkalinity and oxidation-reduction potential.

Table 4-1 lists parameters that are common to various remediation systems and which should be evaluated to determine the progress towards achieving cleanup goals.

These parameters can be evaluated by applying geographic information system (GIS) tools to prepare plots of remedial performance data for each monitoring point and data type. For a groundwater site, maps and cross-sections illustrating groundwater potential and contaminant distribution can be prepared to analyze capture zones and dynamics of the contaminant plume, respectively. For a vapor intrusion site, soil vapor concentrations can be plotted to show contaminant trends over time and sub-slab vacuum measurements can be mapped to demonstrate effectiveness of the mitigation system. For a landfill site, indicator parameters in sentinel wells can be plotted over time to demonstrate effectiveness of the liner system and/or leachate collection system. From these performance plots, maps and cross-sections, trends can be identified over time and distance to determine if the remediation system is capable of achieving cleanup goals.

Contaminant concentrations versus time. These plots should be used to estimate the timeframe to achieve cleanup goals. This timeframe should be compared to the timeframe initially predicted during system design and any significant differences noted. Whether the estimated timeframe to achieve cleanup goals is reasonable is dependent on a site-specific evaluation and considers multiple factors, including the location of receptors, current and future property use, and remedial costs. GIS tools can be used for time-series analysis to visualize contaminant trends for performance evaluation. Figure 4-1 presents an example of a contaminant concentration vs. time plot which was used to predict the time needed to achieve the final remedial goals for polychlorinated biphenyls in sediment through monitored natural recovery.

Table 4-1. Remedial Performance Evaluation Parameters

Evaluation Parameter	Remedial Performance Indicators	
	Positive Indicators	**Negative Indicators**
Change in contaminant concentrations	Continual decline in contaminant concentrations in groundwater, soil, soil gas, sediment, organism tissue, and/or system influent.	No decline in contaminant concentrations and/or steady low contaminant concentrations (asymptotic conditions).
Rate of mass removal	High rates of mass removal from extraction wells, in-situ treatment, and/or aboveground treatment.	Declining rates of mass removal and/or steady low mass removal rate (asymptotic conditions).
Development of capture zones	Inward hydraulic or pressure gradients are established and maintained.	Inability to establish and/or maintain inward hydraulic or pressure gradients.
Changes in plume size and shape	Shrinking or stable contaminant plume.	Expanding and/or migrating contaminant plume.
Evidence of natural attenuation processes	Trends in contaminant concentrations and geochemical parameters consistent with natural attenuation.	No presence of contaminant degradation products and/or geochemical conditions that do not support natural attenuation.
Contaminant flux from the treatment area	Reduction in contaminant flux (e.g., through a groundwater transect or from sediment into surface water).	No change or increase in contaminant flux.
Bathymetry	Bathymetric measurements consistent with those recorded following construction of a sediment cap.	Changed bathymetric measurements that indicate the constructed sediment cap thickness is no longer protective.
Containment integrity	No visual signs of landfill cap settling or erosion and healthy cap vegetation.	Loss of vegetation over significant portions of the cover, visible animal burrows, or increased exposure of erosion control monuments.
Sub-slab vacuum	Negative sub-slab pressures achieved throughout vapor intrusion area.	Inability to achieve negative sub-slab pressures.

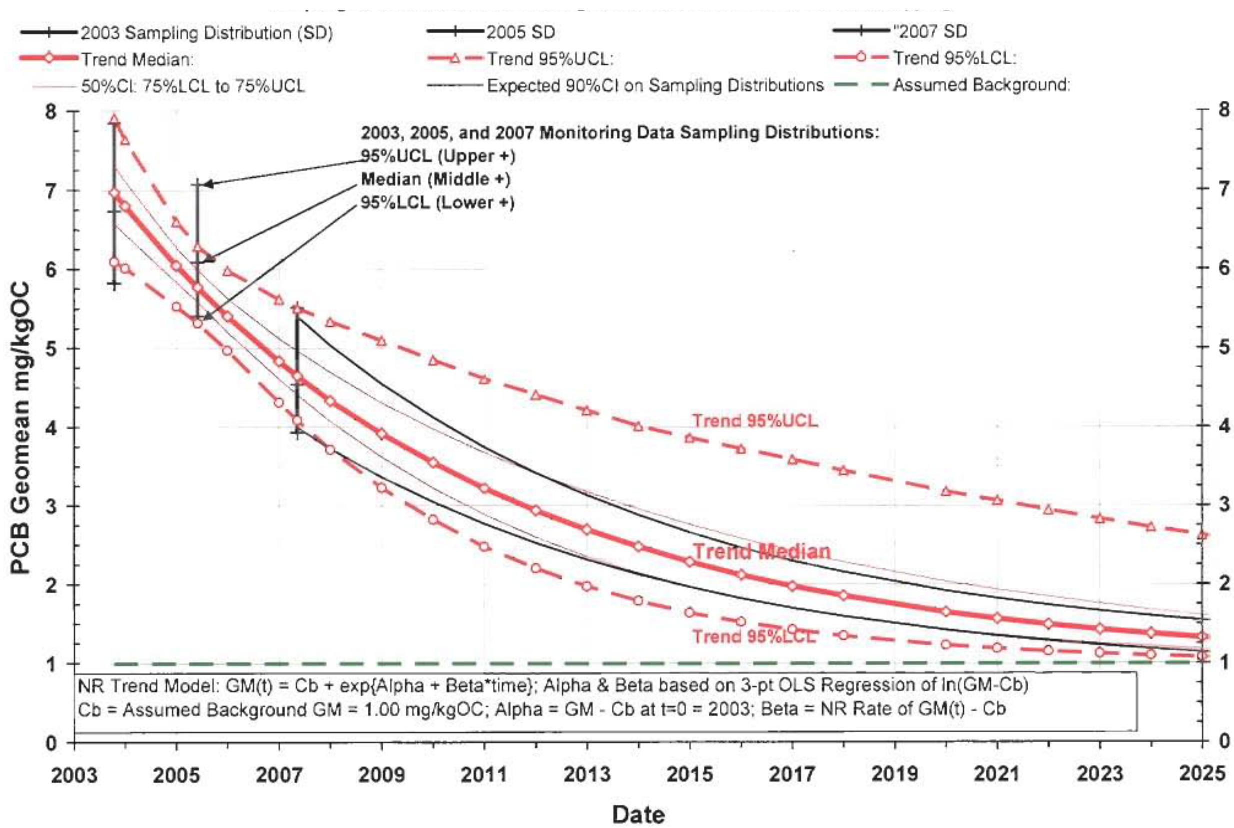


Figure 4-1. Statistical Evaluation of Contaminant Concentrations Versus Time

Example: *Dredging and capping combined with monitored natural recovery were selected as components of the remedy for contaminated sediment at OUB Marine, Bremerton Naval Complex. A primary cleanup goal was established for sediment in the remediation area by determining the level of contamination expected to remain after implementing the remedy and modeling the subsequent attainment of an acceptable area weighted average (AWA) concentration within 10 years through natural recovery processes. Following the remedy, statistical evaluation of the long-term sediment monitoring data using the arithmetic mean to represent the AWA showed an increasing concentration trend over time, which was based on the presence of just a few data outliners in the monitoring dataset. Utilizing a more appropriate statistical method, the geometric mean demonstrated that contaminant concentrations were decreasing over time at a rate that would lead to compliance with the primary cleanup goal within the acceptable 10-year timeframe. The geometric mean is often recommended in statistics as a better measure of central tendency when the data are highly skewed, as they are with the lognormal distribution that typifies environmental sampling data. In addition, the geomean is a multiplicative statistical tool based on an exponential function that dampens the influence of data outliers. The arithmetic mean is highly sensitive to the presence of anomalous values because it is a simple measure of central tendency that equally weighs all contributing data values.*

Contaminant influent concentrations or mass recovery rate versus time. Time-series performance plots of contaminant influent concentrations or mass recovery rates are useful in evaluating the effectiveness of a remediation system in removing contaminants. The plot is applicable to all systems that extract contaminants in water or vapor. A time-series plot of contaminant concentrations or mass recovery rates can be prepared for each individual extraction point, as well as the total system influent, to evaluate the remedial effectiveness of each extraction point and the overall remedial system.

Cumulative mass removed versus time. A plot of cumulative mass removed versus time relates the contaminant influent concentration with the extraction rate to illustrate the effectiveness of a remediation system in removing contaminant mass. For in-situ remediation processes, mass removal can be determined by applying geostat or other GIS tools and using the contaminant distribution obtained from monitoring wells or soil borings. For in-situ aerobic biodegradation processes, mass removal estimates may also be obtained by in-situ respirometry tests. The plot of a system that is operating effectively exhibits an upward slope. A plot that exhibits asymptotic conditions for mass removed suggests that performance has reached the system limits and that a new strategy should be implemented for closeout.

***Example**: An air sparging (AS)/SVE system was installed to address chlorinated VOCs at Site 26, Naval Weapons Station Earl, New Jersey. The ROD indicated that the Site 26 AS/SVE system should operate (at least intermittently) until extracted VOCs reach asymptotic levels with no significant rebound effects and groundwater concentrations are below New Jersey Groundwater Quality Standards (GWQS). The ROD also stated that if concentrations in groundwater are above GWQS when asymptotic levels were achieved, and it is no longer cost-effective to operate the AS/SVE system, fate and transport modeling should be conducted to evaluate the potential for the remainder of the contaminant plume to naturally attenuate before reaching any downgradient receptors. After eight quarters of operation, an optimization study determined that asymptotic mass removal had been achieved and continued operation of the system was no longer cost effective. It was recommended that the AS/SVE system be shut down and that LTM be continued for the MNA remedy. A time-series plot of contaminant mass removed shows the decline in instantaneous mass recovery as well as the cumulative mass recovery asymptote reached for the AS/SVE system (Figure 4-2).*

Change in free product thickness versus time. Product measurement plots are used primarily to evaluate the performance of a product recovery system. A plot of product and water level measurements provides a visual description of the product thickness over time. In addition to product thickness, other trends may be identified, such as water level and seasonal effects on product thickness. A continual reduction in product thickness over time indicates that the remedial system is recovering free product. Conversely, no change or increase in product thickness indicates that the remedial system is either not recovering free product or there is a new or previously undiscovered source.

***Example**: A multiphase extraction (MPE) system to recover weathered jet fuel was installed and operated at the Fueling Pier located at the Marine Corps Air Station Beaufort. Nearly 50,000 lb of petroleum hydrocarbons was recovered during approximately 4 years of operation at this site. Free product thicknesses were measured in site wells before, during and after operation to assess the performance of the system (Figure 4-3). The product thickness in site wells had decreased to zero in most of the wells during operation of the system. After discontinuing*

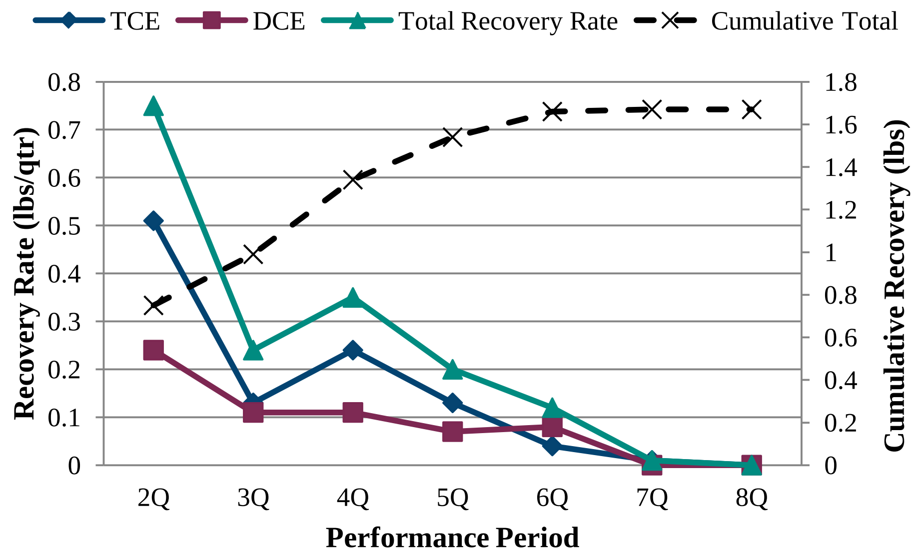


Figure 4-2. Instantaneous and Cumulative Mass Recovered Versus Time Site 26, NWS Earl

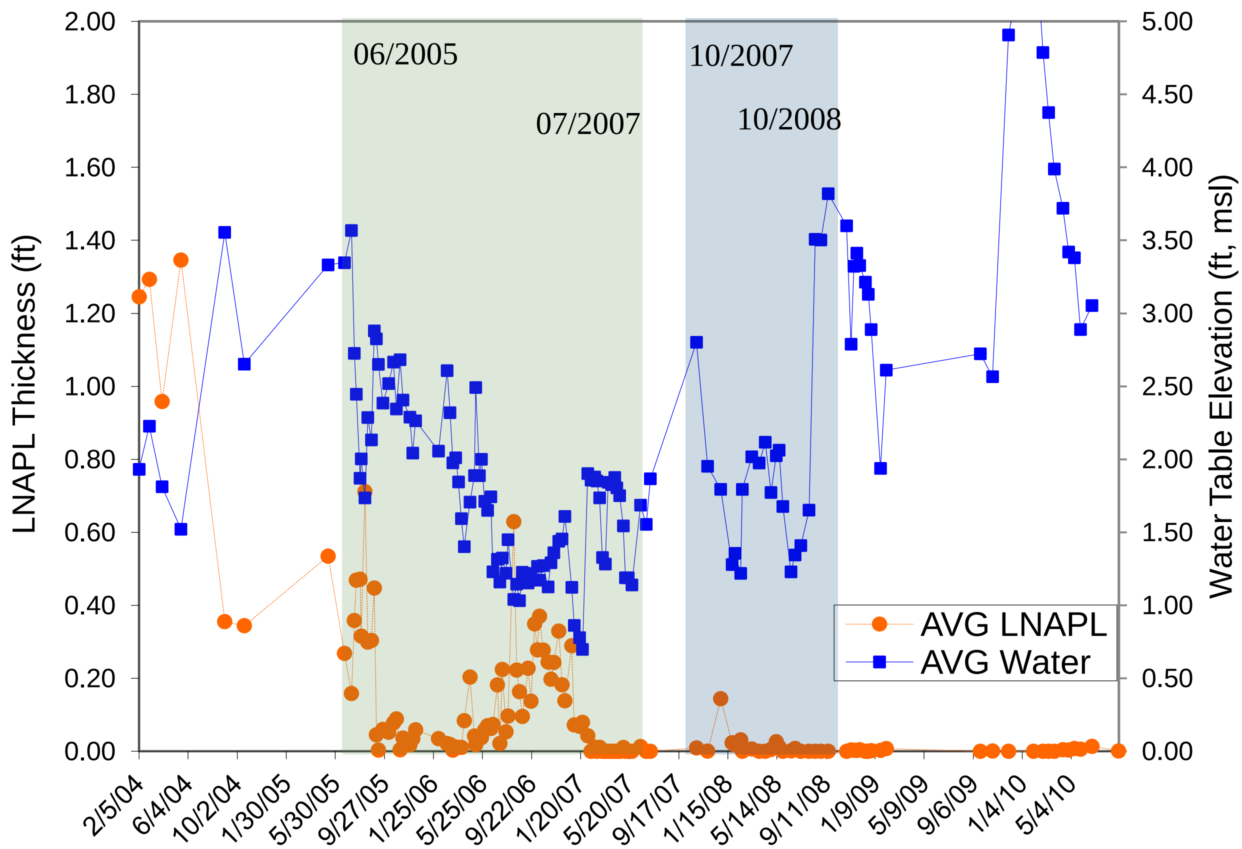


Figure 4-3. Product Measurement Plot MCAS Beaufort

operation of the system, product thickness was monitored for two years and very little rebound was observed. This evaluation of free product thickness over time demonstrated to the Department of Health and Environmental Control that the recovery system had recovered free product to the maximum extent practicable and could be removed from the site.

Change in geochemistry and contaminant concentrations over distance. Spatial data analysis of geochemical parameters and contaminant concentrations are useful for evaluating the occurrence of natural attenuation processes.

Example*: The effectiveness of replacing pump and treat with source area treatment and natural attenuation of chlorinated ethenes in the groundwater system was assessed as part of an optimization study of the RA-O phase at Naval Air Station Pensacola, Florida, Former Sludge Drying Bed and Surge Pond site. Based on trend analyses of monitoring data along a flowpath (Figure 4-4), it was determined that redox conditions were favorable for natural attenuation of chlorinated ethenes. Highly reducing methanogenic conditions were observed in the source beneath the former sludge drying beds and iron-reducing conditions were observed downgradient of the source area. TCE and its biodegradation products were completely destroyed within 250 feet downgradient of the source area. As a result of this assessment, MNA was formally included as a component of the final remedy for the site. The RCRA Corrective Action Permit for the site was modified to replace the pump and treat system with a treatment train including source zone treatment (combination of chemical oxidation and enhanced bioremediation) followed by natural attenuation.*

Change in mass flux over time. Most decisions regarding the cleanup of contaminated environmental media are based on contaminant concentrations. These decisions can be improved by also considering contaminant mass flux over time. For example, the cleanup of a site with a non-aqueous phase liquid (NAPL) source zone can be challenging because the NAPL acts as a continuing source of dissolved contamination to groundwater over a very long time period. Changes in mass flux before and after remediation could be used as one more tool to assess the effectiveness of a remedy by better understanding the impact of partial NAPL source removal and assessing the benefits versus costs of active source zone remediation efforts. The U.S. EPA Scientific Advisory Board has stated that: "measurements of mass flux of the contaminants and footprint parameters - not just concentrations - are necessary to document cause-and-effect and to assess long-term sustainability/permanence. Site-characterization and monitoring plans should be proactively designed to accommodate mass-flux estimates" [16].

Mass flux combines chemical data and groundwater flow velocity into a single measurement. Mass flux is a calculation of the mass of dissolved contaminants that passes through a cross-sectional area over time, and is expressed in the units of mass per time per area (e.g., $lb/hr\text{-}ft^2$). Mass flux calculations can provide an estimate of NAPL source strength and the rate of mass loading to the dissolved phase.

Figure 4-5 depicts a conceptual mass flux model. Note that there are areas where high concentrations correspond with high mass flux and low concentrations correspond with low mass flux. However, there are also areas where high concentrations do not correspond to high mass flux. These zones imply that the high concentrations are located in low velocity soils such as

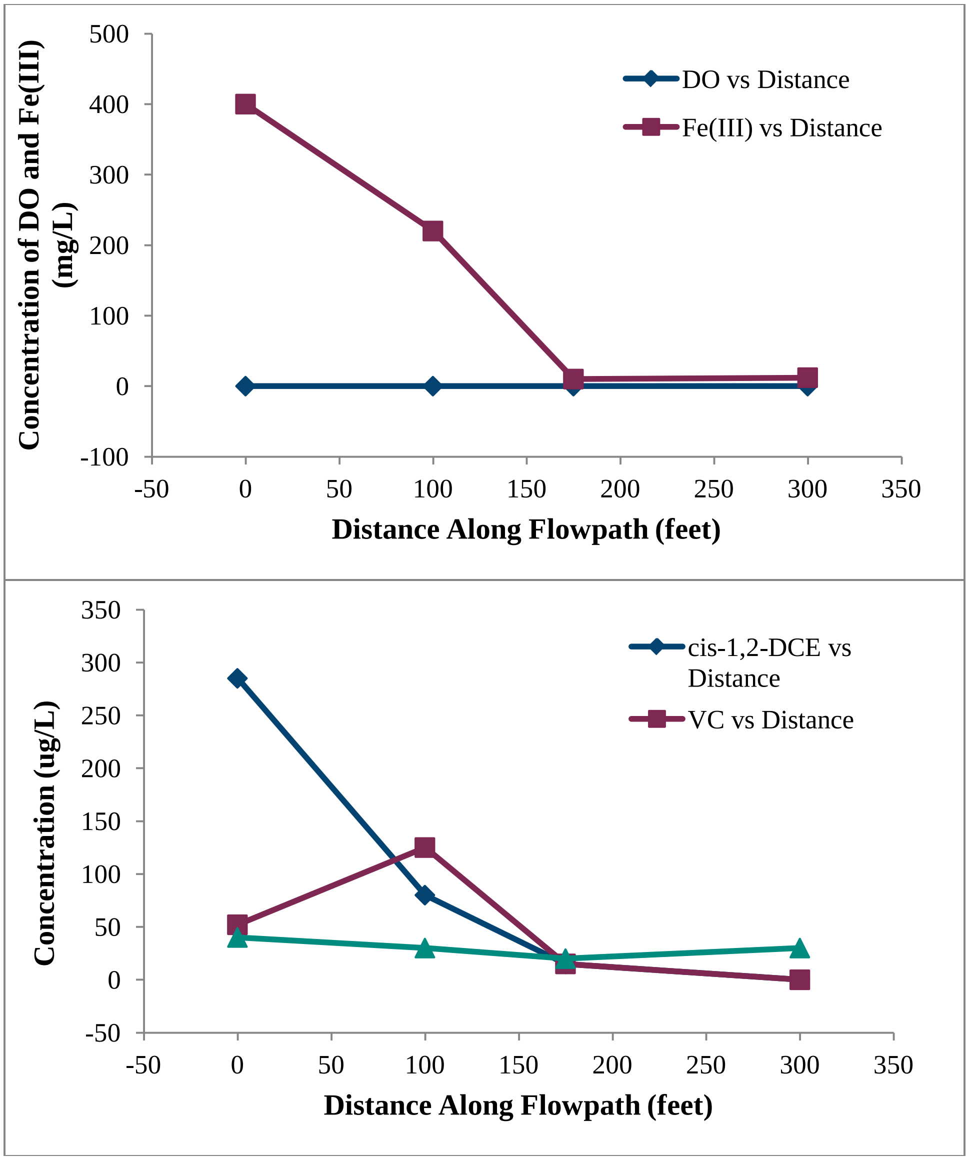


Figure 4-4. Natural Attenuation Trend Analysis NAS Pensacola, Former Sludge Drying Bed and Surge Pond Site

silts and clays. Furthermore, several moderate concentration zones exhibit high mass flux, which implies that they are in high velocity soils.

This variation in mass flux is important to understand and points to an approach where remediation could be targeted to zones with high mass flux to improve effectiveness.

RPMs planning to use reduction of mass flux as a remedial or performance objective should implement a rigorous data quality objective evaluation process to specify precisely how mass flux data will be utilized to make management decisions [17].

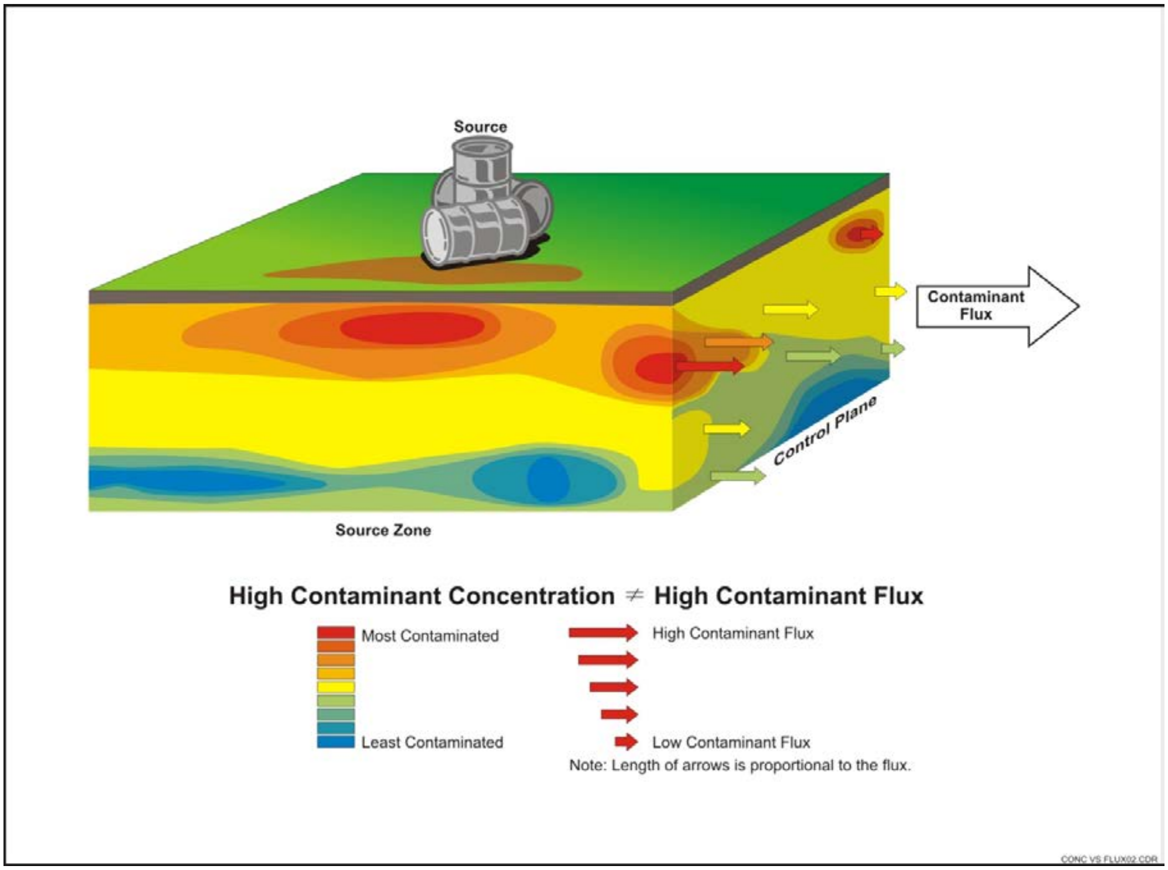


Figure 4-5. Mass Flux Model [18]

While mass flux measurements are not meant as a replacement for concentration-based cleanup values, the mass flux estimates can serve as a tool to characterize site conditions, assess RA performance and determine the optimum time to discontinue O&M intensive source zone treatment in favor of a less aggressive technology such as MNA. Researchers have proposed the following ways to evaluate changes in mass flux before and after remediation of a NAPL source zone:

- Mass flux must be reduced enough to modify the dissolved plume behavior.
- Mass flux must be reduced to a level less than or equal to the attenuation capacity within the plume.
- Mass flux should be small enough so that flux-averaged concentrations at a down-gradient water supply well are below the regulatory limits [19].

For many sites, meeting the above criteria can be used to demonstrate that source zone treatment has been successful in achieving a condition where MNA along with land use controls (LUCs) is protective. Additional information regarding the use of mass flux for evaluating remedial performance can be found in the *DNAPL Management Overview* document [17], and in *Use and Measurement of Mass Flux and Mass Discharge* [20].

Example: *An Environmental Security Technology Certification Program project was implemented at Naval Base Ventura County to demonstrate the use of an innovative direct push system for hydraulic assessments of contaminated aquifers. The system included a high-resolution piezocone and a GeoVIS video microscope sensor to determine the direction and rate of groundwater flow in three dimensions. Mass flux was then calculated using the groundwater flow rate data and contaminant concentration data. The collected data indicated that the flux distributions covered much smaller volumes than the concentration distributions. This could be because low velocity soils bound the plume, thereby resulting in lower calculated flux values. Several conclusions can be drawn from these data. For example, high concentration does not always indicate high mass flux, and perhaps most importantly, a good remediation strategy could include defining high flux zones, followed by surgical removal or hydraulic isolation.*

4.2 System Performance

System performance is a measure of remedial system reliability (i.e., system runtime) and how well a remedial system meets its design objectives. The system performance should be evaluated to determine if the remediation system is operating as designed.

To evaluate system performance, O&M and monitoring data are compared with the specifications from the original design and installation of the remedial system. Common O&M and monitoring data used to evaluate systems that utilize extraction and treatment processes for remediation include:

- Extraction/injection rates and pressures
- Treatment system operational parameters, such as influent flow rates, operating temperatures, and feed valve settings
- Influent/effluent contaminant concentrations for each component of the treatment system
- Run time and maintenance frequency
- Usage of consumables.

System performance data for in-situ treatment varies depending on the remediation technology. Injection rates and volumes are used to evaluate the system performance for many in-situ remediation technologies, including for bioremediation (rate of nutrients/amendments injection), chemical oxidation (volume of chemical injection), and thermal treatment (rate of steam/hot water injection). For thermal conductive heating, system performance data include monitoring subsurface temperatures within the treatment zone.

System performance data for vapor mitigation systems (in particular sub-slab depressurization which is the most common) includes sub-slab vacuum measurements, riser pipe airflow and total system airflow. To ensure maximum distribution of sub-slab vacuum, the rise pipe airflow should be balanced. System performance data must meet design specifications for an effective remediation system. For example, a soil vapor extraction system that does not meet the design specification for vapor extraction rate will not achieve the area of influence necessary to remediate the extent of contamination.

Example*: Fuel Farm 216 located at Naval Air Station Corpus Christi contains soil and groundwater contaminated with aviation gasoline (AVGAS). A MPE system was installed to recover the free-phase AVGAS. However, during the last few years of operation, little AVGAS was recovered, and thicknesses of several feet were measured in monitoring and recovery wells. To assess system performance, the current extent of the AVGAS plume was first evaluated by installing and monitoring additional wells and performing an electrical resistance tomography. Small-scale free-phase recovery, bioventing, and radius of influence tests were performed to further evaluate the recoverability of the remaining contaminants of concern. Extraction flow rates and pressure measurements taken at the recovery system, in wells and in the process manifold, clearly indicated that the subsurface lines were leaking and not properly conducting fluids. The results of these activities clearly indicated that the existing system was ineffective to treat the COCs at the site and was discontinued in favor of an alternative technology.*

4.3 System Suitability

If the effectiveness evaluation indicates that the remediation system is operating as designed, but is not capable of achieving cleanup goals, the system suitability should be evaluated. This evaluation of system suitability may explain why the remediation system is not capable of achieving RA objectives. This evaluation compares the design and operation of the remediation system with the existing site conditions defined by the CSM. The following conditions should be evaluated to determine the system suitability:

- **Adequacy of injection and/or extraction well network** – The injection and/or extraction well network must have adequate radius of influence to cover or capture the extent of contamination to achieve cleanup goals (see Figure 4-6).

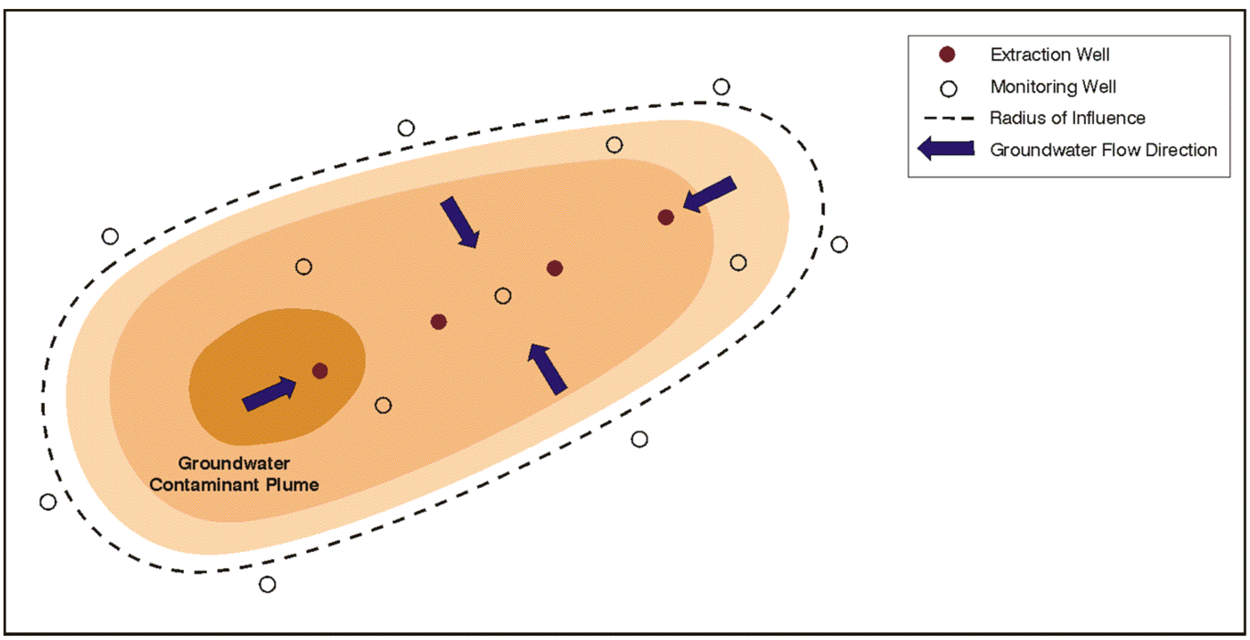


Figure 4-6. Radius of Influence Developed around Plume by Extraction Wells

- **Evidence of technical limitations** – Low permeability, heterogeneous soils and the presence of dense non-aqueous phase liquids (DNAPL) are examples of technical limitations for remediation systems.
- **Life cycle design limitations** – Remedial progress for systems designed for mass removal will be limited by sites in the diffusion-limited phase of the life cycle design. Life cycle design is discussed further in the following subsection.

***Example**: At Naval Air Station Meridian, a remediation system consisting of two dual groundwater/SVE wells and two groundwater extraction wells was installed in 1994 to address light non-aqueous phase liquid (LNAPL) and BTEX in groundwater at a UST site. The dual phase extraction remediation system operated until 2006, and several months of enhanced fluid recovery activities were then completed through mid-2007. While a significant amount of contaminant mass was removed during these previous remediation efforts, free product continued to be observed during times of low water table elevations and final cleanup goals had not been achieved at the site. An optimization study was conducted to evaluate methods to optimize remedial activities in order to achieve the RA objectives while reducing the life cycle cost of the remedy. O&M data reviewed as part of the optimization study concluded that the dual phase extraction system was no longer effectively removing free product or dissolved-phase BTEX due to the low extraction rates of the system and placement of extraction wells compared to the dissolved phase plume. The design of the system was no longer suitable based on the current CSM, and biosparge was identified as the best remedial alternative given the current site conditions.*

4.3.1 Life Cycle Design

Because the behavior of contaminants changes over the life of a remediation project, the life cycle design of the remedy should be considered when evaluating the suitability of remedy in achieving the RA objectives. As the remediation system continues to operate, contaminant concentrations often decrease over time until asymptotic conditions are reached (Figure 4-7). This asymptotic condition becomes a problem when:

- Concentrations are not low enough to declare the site clean and/or to shut off the remediation system, or
- O&M costs and/or sustainability metrics are not decreasing, despite the decrease in mass removal rate.

For sites requiring active remediation, a single remedial technology is rarely the most cost-effective approach throughout the life cycle of a cleanup project because all technologies have limitations. Awareness of technology limitations and the appropriate point to discontinue a technology are keys to optimization during the RA-O phase.

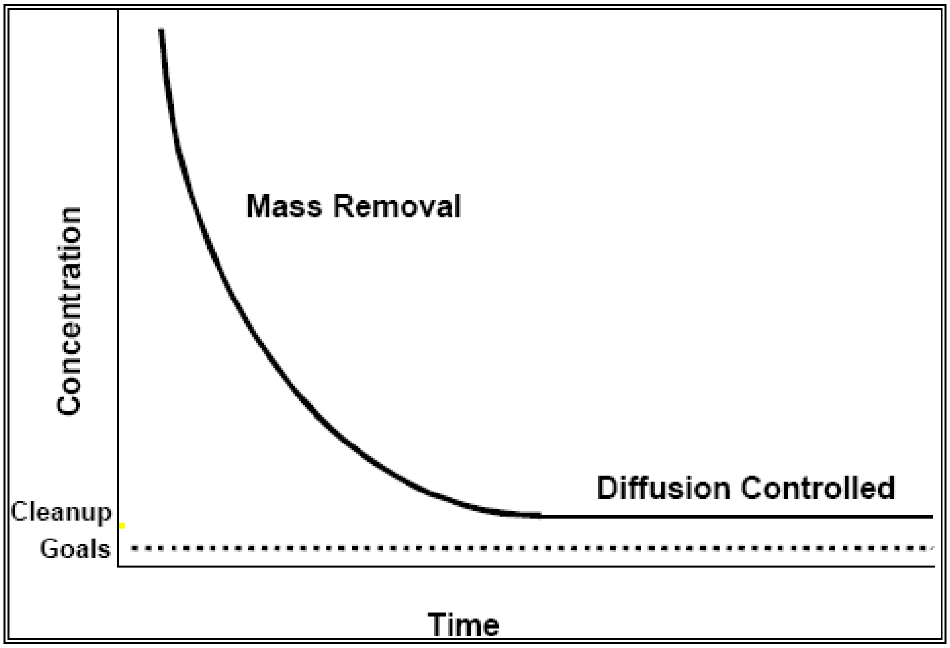


Figure 4-7. Reaching Asymptotic Conditions before Achieving Cleanup Goals

Remedial performance objectives are criteria that measure the operational efficiency and suitability of a particular remedial technology. They trigger a response to:

- Modify or optimize the current system,
- Transition to an alternate (less active and more cost effective) technology, or
- Discontinue a unit process or remediation altogether (an exit strategy).

Performance objectives help to define what the expected effective operational range of a given remedial approach may be and can allow for flexibility within the remedial decision process to discontinue use of a specific technology once it is no longer operating within its pre-determined, cost-effective range. The optimal RA at a given site often requires the use of multiple technologies. A group of technologies working together is referred to as a "treatment train." These technologies may be used either sequentially or concurrently. The treatment train concept emphasizes that multiple remedial technologies often are needed to achieve cost-effective remediation at a given site.

Sequential technology implementation over time allows specific technologies to be used for particular phases of the cleanup that cannot technically or cost-effectively meet RA objectives. Performance objectives trigger the transition to the next phase of the treatment train and can be used to make that transition occur at the optimum time to prevent a technology from operating beyond the point of diminishing returns.

Simultaneous technology implementation of multiple unit processes in a single treatment system allows specific technologies to be used for particular COCs that would otherwise not be appropriate or cost-effective for all contaminants. As site conditions change, it may not be necessary or cost-effective to continue using all unit processes of the treatment train. Performance objectives can be used to trigger the modification of the treatment train at the optimal time to prevent a unit process from being used beyond the point that it is necessary or cost-effective.

Example: *A treatment train with defined performance objectives was used to sequentially transition from more- to less-active treatment technologies at a petroleum-contaminated site. The established treatment train included:*

Phase I: MPE
Phase II: Pulsed IAS/SVE
Phase III: Biosparge with no SVE
Phase IV: MNA

To prevent any technologies from operating beyond the point of diminishing returns and to establish clear transitions to the next technology, performance objectives were established as follows:

- *Operate MPE until the product recovery rate is reduced to a specified level and the VOC concentration in the off-gas can no longer sustain the oxidizer without supplemental fuel. This triggered a transition to IAS/SVE, which increased the concentration in the off-gas, therefore increasing mass removal and decreasing supplemental fuel for the oxidizer.*
- *Operate IAS/SVE until the VOC concentration in the off-gas can no longer sustain the oxidizer without supplemental fuel and the benzene concentrations in the off-gas and shallow soil no longer present a health risk. This triggered a transition to biosparging, which eliminated the need to operate the SVE system and the oxidizer and therefore reduced operating cost and resource consumption.*
- *Operate in the biosparging mode until the concentrations in soil meet risk-based criteria that are protective of human health based on groundwater solute transport modeling. This triggered a transition to MNA, therefore reducing operating cost and resource consumption.*

Developing a treatment train with defined performance objectives allowed the use of the optimal technology for each phase of the remediation.

An exit or transition in technologies should be considered decreasing concentrations are experienced, declining effectiveness/removal rate, or if the current technology is less cost-effective than an alternate (less active) technology. To further evaluate transition and exit strategy options, operational factors such as the remedy footprint can also be evaluated. The negative impacts of an RA (e.g., emissions of criteria air pollutants, greenhouse gas emissions, water and energy consumption, land and ecosystem changes, resource consumption, community impacts and risk to worker safety) should be evaluated against the additional reduction in contaminant concentration that may be gained by continued operation of the RA. As shown in Figure 4-8, the use of performance objectives and exit strategies not only reduces the cost of implementation but also the duration of activities that result in sustainability impacts, thereby minimizing the overall impact. Similarly, for LTMgt, optimization of the monitoring plan should be done on an on-going basis following the DON *Guidance for Planning and Optimizing Monitoring Strategies* [5]. Further discussion regarding the evaluation of GSR metrics can be found in the *DON Guidance on Green and Sustainable Remediation* [6].

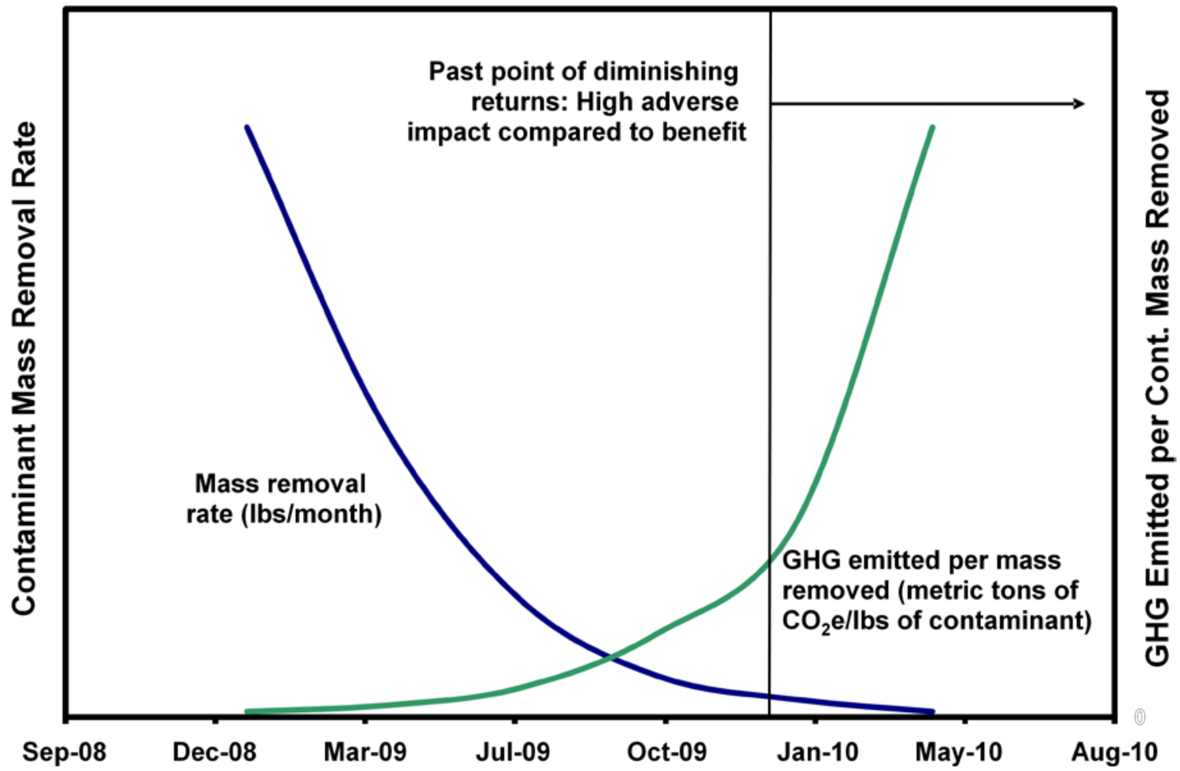


Figure 4-8. Exit Strategies Minimize the Remedy Footprint

5.0 EVALUATE COST EFFICIENCY AND SUSTAINABILITY

***Content**: The third step of the RA-O optimization process is to evaluate the cost efficiency and sustainability of the remediation system. This section describes the process to evaluate the cost efficiency and sustainability of the existing remediation system using a combination of cost and performance data. This evaluation allows the RPM to determine if the remediation system is operating efficiently.*

5.1 Cost Evaluation

After verifying the effectiveness of a remediation system, the cost efficiency of the system must be evaluated. Cost efficiency compares the costs associated with operating and maintaining a remediation system against its performance. The cost efficiency evaluation determines whether the existing remediation system is operating efficiently or whether opportunities to improve the cost efficiency should be investigated and implemented.

5.1.1 Cost and Performance Data

Cost and performance data, which can be found in remediation system O&M reports, are used to evaluate cost efficiency. Common cost and performance data used in this evaluation include:

- O&M costs
- Capital costs of system modifications and upgrades
- Mass of contaminant removed.

All O&M costs are included for the cost efficiency evaluation. However, only capital costs associated with system upgrades and modifications are included in this evaluation. If incurred, these capital costs should not be amortized. The O&M costs should be reported on a monthly basis, while capital costs of modifications and upgrades should be reported when incurred.

The O&M costs should be tracked by the RPM/contractors and grouped into the following categories:

- Labor, including not only O&M labor, but also labor supervision and payroll expenses
- Materials, such as consumable supplies, bulk chemicals, and raw materials
- Utilities and fuel, such as gasoline, electricity, and natural gas
- Equipment, such as equipment rental
- Performance testing and analysis, such as monitoring, sampling and analysis.

Capital costs associated with system upgrades and modifications are needed to quantify increases in remedial performance. Examples of these costs include construction of additional extraction locations, modifications to the aboveground treatment system, and upgrades of pumps, blowers, or other equipment.

5.1.2 Cost Efficiency Plots

Plots of cost and performance data are tools used to assess cost efficiency. These plots should be used to track remediation system operation costs, mass of contaminant removed/destroyed, and cost per pound of contaminants removed/destroyed. The cost efficiency plots should be evaluated to identify trends in cost and performance data. General conclusions that can be drawn from these plots include:

- Efficient system operation demonstrated by cost effective mass removal
- Decreasing system efficiency demonstrated by decreasing cost effectiveness over time, resulting from increasing O&M costs or decreasing mass removal
- Poor system efficiency demonstrated by asymptotic conditions in the cost efficiency plots.

Figures 5-1 and 5-2 show two examples of cost efficiency performance plots. Evaluations of these plots are also provided.

Cumulative costs incurred versus cumulative mass removed. A plot of cumulative costs versus cumulative mass removed illustrates the operating efficiency of a remedial system. The slope of the plot illustrates the degree of cost effectiveness. Near vertical segments represent periods of poor system efficiency due to high cost and/or low mass removal.

Example: *Figure 5-1 is a plot of cumulative costs versus cumulative mass recovered for the AS/SVE system at Site 26, Naval Weapons Station Earl, New Jersey. The plot clearly illustrates, by its nearly vertical slope, the cost ineffectiveness of operating a remediation system that has reached asymptotic levels of mass removal. In this example, the cost per pound of VOC mass extracted increased by over a factor of 80 between the second quarter and eighth quarter of operation (from approximately $45,000/lb in the second quarter to approximately $200,000/lb in the seventh quarter; mass recovery was not measurable in the eighth quarter).*

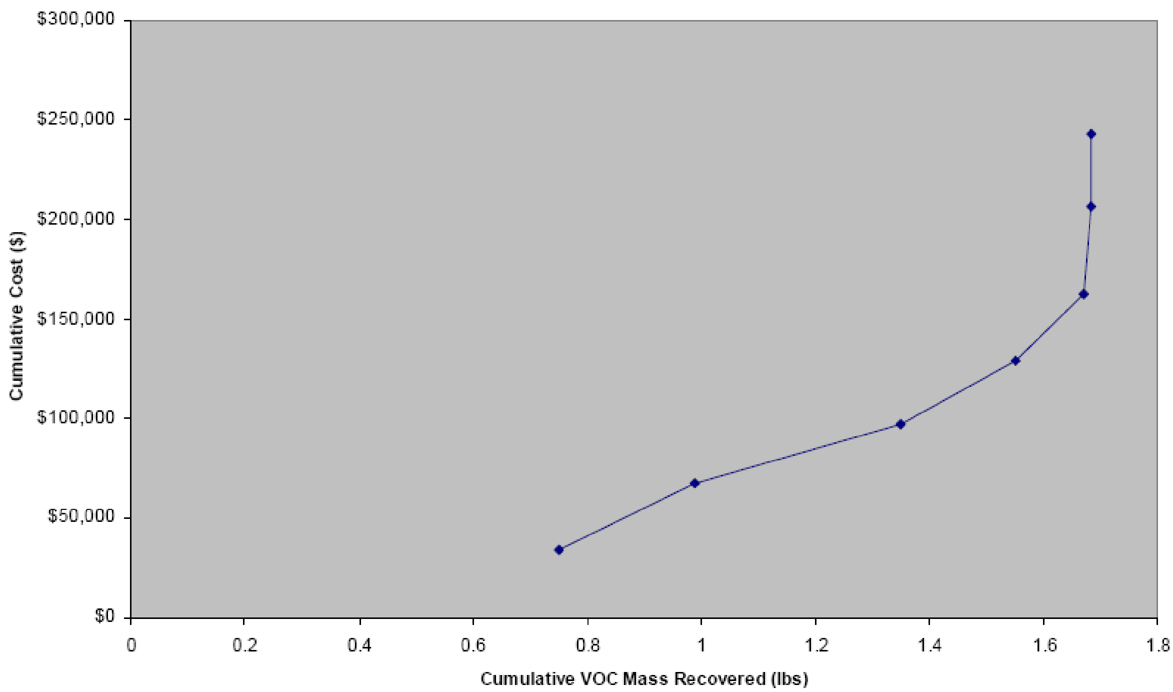


Figure 5-1. Cumulative Costs Versus Cumulative Mass Recovered Site 26, NWS Earl

Cost per unit mass removed versus time. A plot of cost per unit mass versus time is another measure of system efficiency. The overall trend of the plot is generally downward for a system that is operating efficiently.

Example: *Figure 5-2 is a plot of the average cost per pound of contaminant removed by the pump and treat system at Eastern Plume, Naval Air Station Brunswick, Maine. As seen in the figure, the average cost of mass removal decreased from approximately $5,000 in September 1996 to approximately $3,200 in October 1997 when an upward trend began. This upward trend in cost was reversed with the installation of a new well in June 1998 at an estimated cost of $115,000. The improvement of the performance of the remediation system increased the amount of mass recovered, which lowered the cost of mass removal.*

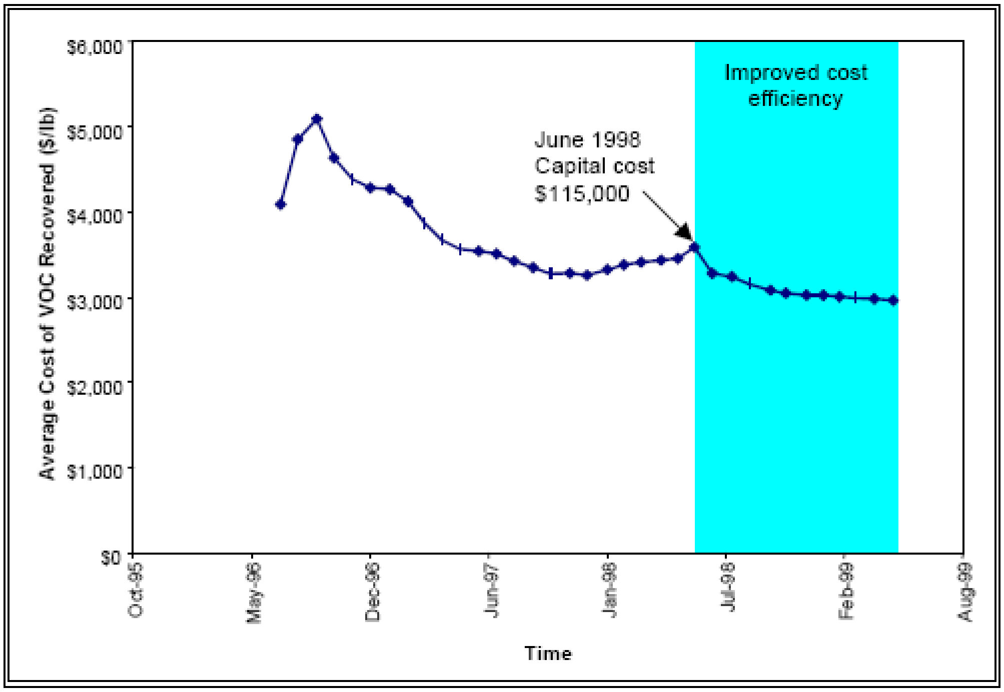


Figure 5-2. Cost per Unit Mass Removed Versus Time NAS Brunswick, Eastern Plume

5.2 Sustainability Evaluation

Evaluation of GSR metrics should be completed during each periodic optimization review performed during RA-O. The Navy issued a fact sheet [21] on GSR followed by the more detailed document *DON Guidance on Green and Sustainable Remediation* [6] that provide guidelines for RPMs on which metrics to consider under GSR, when to consider GSR, and how to ensure that GSR is incorporated into each phase of the remedial process.

5.2.1 Selection of Sustainability Metrics

The Navy uses eight types of metrics to evaluate the remedy footprint, but all eight metrics need not be used in every GSR evaluation. Selection of metrics to conduct a GSR assessment is site specific and should incorporate stakeholder input to focus on the most relevant metrics. Site-specific issues that influence metric selection and prioritization can include site location, site history and use, surrounding environment and communities, and site end use and development. For example, a site located in a residential area would result in a greater concern with community impacts (e.g., odor, noise, remediation traffic, etc.). Conversely, remediation of a site located near a forest that is home to endangered bird species would result in ecological impacts being of great importance. When evaluating metrics, it should also be noted that some are global in nature, such as energy use and GHG emissions, whereas others are important as local or regional impacts such as SO_x or NO_x emissions and for certain sites, depending upon the site location and stakeholders, the local and regional impacts may play a more important role.

The metrics identified and discussed in the Navy's GSR guidance document [6] include the following:

- Energy consumption
- GHG emissions
- Criteria pollutant emissions
- Water impacts
- Ecological impacts
- Resource consumption/waste generation
- Worker safety/accident risk
- Community impacts.

5.2.2 Baseline Sustainability Assessment

Once the relevant sustainability metrics have been selected for a site, a baseline sustainability assessment can be completed. The baseline assessment incorporates current remedial system operating information to quantitatively and qualitatively measure the remedy footprint for the on-going RA activities. Many of the Navy's metrics, such as air emissions and energy use, can be assessed quantitatively. Several tools/models are available for quantifying GSR metrics, including SiteWise™ and SRT™ (see Section 9.5). Prior to conducting a sustainability analysis, inputs regarding energy, water, fuel, materials, and chemical use at the site should be gathered.

A qualitative or semi-quantitative assessment is appropriate for certain metrics such as community impacts or ecological impacts. Qualitative metrics can be assessed based on professional judgment, experience and stakeholder input and simply assigned high, medium or low values. For ecological impacts, an alternative quantitative method such as Net Environmental Benefit Analysis can be used.

Results of the baseline assessment will determine which elements of a given remedy have the greatest footprint. These results can be used to focus footprint reduction methods in areas where the highest footprints are identified (see Section 6.1.3).

Example: At former Naval Air Warfare Center Warminster, a sustainability assessment was performed using SiteWise™ for an operating pump and treat system. Figure 5-3 shows a portion of the output from the tool which summarizes the sustainability impacts from operation and LTM associated with the pump and treat remedy. The relative contribution from various activities is shown during each phase. As an example, the figure shows that during the RA-O phase of the project, the largest contributor to GHG emissions is equipment use (i.e., pumps and blowers), followed by consumables (i.e., activated carbon and ion exchange resin), and finally personnel transportation. This evaluation can help guide the optimization recommendations to focus on the largest relative contributors from the on-going remedial activities to the overall remedy footprint. Often those activities contributing the greatest to the remedy footprint also contribute largely to O&M costs and should be targeted in the optimization recommendations.

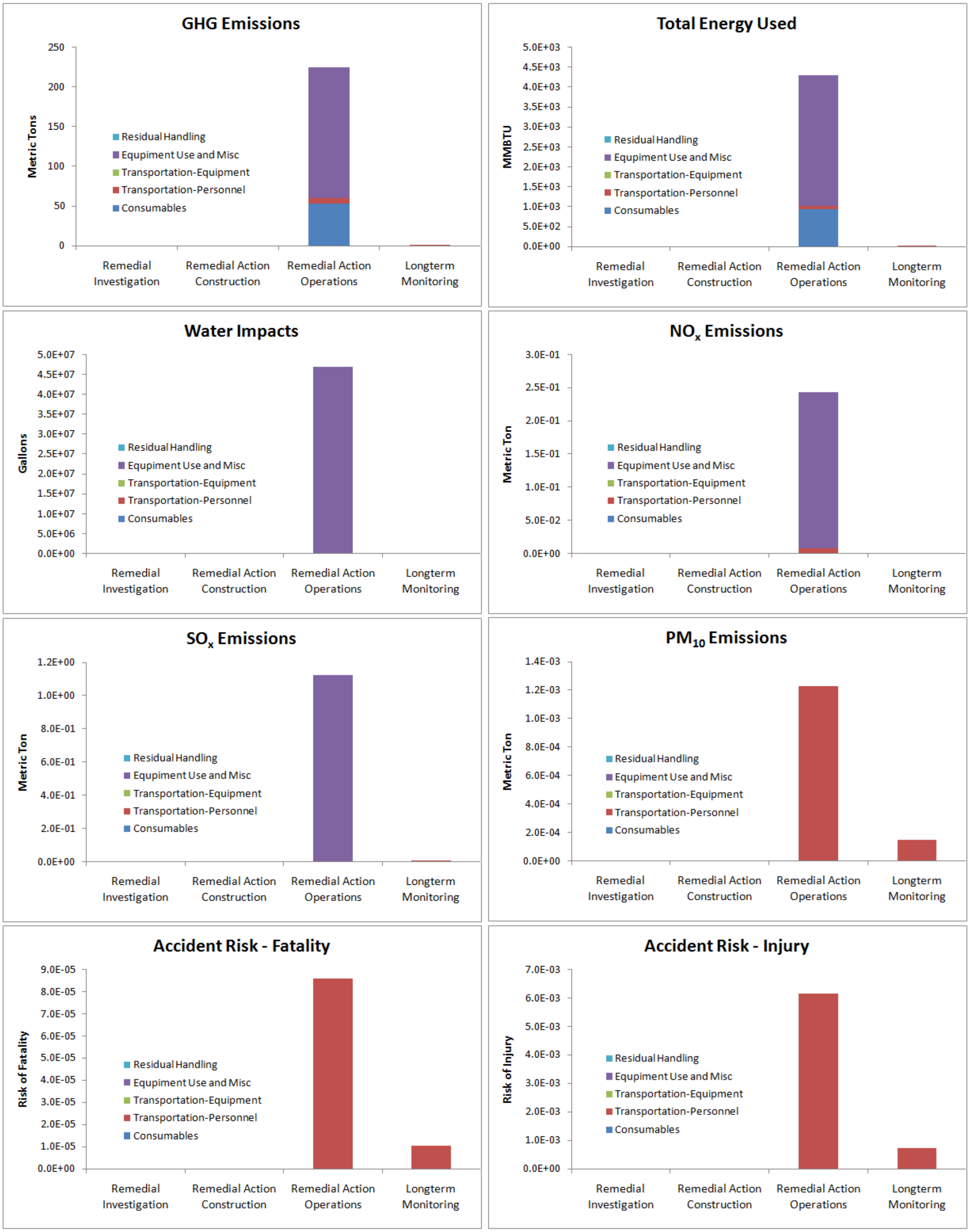


Figure 5-3. Results of a Sustainability Assessment

6.0 IDENTIFY POTENTIAL REMEDY IMPROVEMENTS OR ALTERNATIVES

***Content**: The fourth step of the RA-O optimization process is to identify potential remedy improvements or alternatives to the existing remediation system to improve its effectiveness, cost efficiency, and/or sustainability. This section describes the process to identify potential improvements and select alternatives based on the evaluation of RA objectives, remediation effectiveness and cost efficiency. The remediation alternatives discussed in this section include optimizing the existing remediation system, selecting an alternative remediation technology, and considering alternative endpoints.*

6.1 Improvements to the Existing Remedial System

If the remedial effectiveness, cost efficiency, and sustainability evaluations determine that remedial progress is limited and that the remediation system is not operating at optimal efficiency, the RPM should first consider optimizing the existing remediation system. Methods to improve the remedial effectiveness, cost efficiency, and/or sustainability of a remediation system include enhancing performance and/or reducing O&M costs and the remedy footprint. Modifications, however, are only appropriate for remediation systems that are suitable for the existing site conditions (e.g., no evidence of technical limitations or life cycle design limitations) and capable of achieving RA objectives.

6.1.1 <u>Enhancing Remedial Performance</u>

Existing remediation systems may be modified to improve remedial effectiveness and cost efficiency. Where possible, improvements to system performance and system suitability should enhance the remedial performance of the existing system. Evidence from the remedial effectiveness evaluation that demonstrate a need to improve remedial performance include asymptotic conditions in performance plots, expanding or migrating contaminant plumes, and rebounding of contaminant concentrations.

Opportunities should be identified to address the operational problems that limit remedial performance. In general, these opportunities to optimize RA-O include:

- Modifying system operations to match current site conditions, such as adjusting flow rates, vacuum pressures or injection volumes.
- Upgrading system automation to minimize system shutdown occurrences and duration.
- Operating system intermittently to improve cost efficiency of some technologies under diffusion limited conditions.
- Modifying and/or replacing existing components of the remediation system, such as recovery pumps or treatment system components.
- Adding components to the existing remediation system to improve remedial performance, such as new extraction or injection wells.
- Modifying the amount or type treatment material (e.g., for bio-remediation, modify the bio-enhancement use and/or adding bioaugmentation; for ISCO, consider alternate oxidizing agents, for ISCR, consider micro, nano, or emulsified zero valent iron [ZVI] material).

- Optimizing the injection method to improve distribution of treatment chemicals (e.g., more closely spaced direct pressure injections, fracturing, recirculation).

Technology-specific optimization recommendations for common operational problems are presented in Appendix A.

Ideally, optimization recommendations should not only improve remedial effectiveness but also cost efficiency and sustainability. Optimization recommendations to improve remedial performance may require additional capital expenditure and/or increase monthly O&M costs. However, any additional costs may be offset by an overall decrease in life cycle costs or a proportional increase in the amount of mass removed/destroyed, such that the average cost per pound of contaminant removed/destroyed decreases.

Example*: ISCO was performed to treat a chlorinated solvent plume located at Installation Restoration Site 26, Alameda Point, California. Oxidant was injected into temporary piezometer clusters. High pressures at the injection points and surfacing of groundwater and reagent were noted during the application. Furthermore, low concentrations of oxidant were noted in a well upgradient of the treatment area. As a result, there was concern that the application could push the chlorinated solvent away from the treatment area, possibly underneath buildings or into utility corridors located in close proximity to the site. Hence, the application was modified to use a recirculation approach. Capture modeling was performed and several additional piezometers were installed. Groundwater was extracted from dedicated piezometers, amended with oxidant, and reinjected. Process monitoring performed during recirculation confirmed that the risk of pushing the COCs from the treatment area had been mitigated.*

6.1.2 Reducing O&M Costs

Reducing total O&M costs without compromising remedial progress or data quality should be a routine practice for all remediation systems. Tracking overall O&M costs as well as individual cost items, such as labor, materials, utilities and chemical analysis, provide valuable information regarding areas where cost reductions should be pursued. The elimination of remediation system components that do not contribute to remedial progress can also reduce O&M costs.

Optimization recommendations to reduce the costs associated with O&M functions can result in improvements in the cost efficiency of the remediation system. Minimizing the costs associated with these functions can result in substantial savings, regardless of the remedial technology used. Table 6-1 presents strategies RPMs can use to minimize remedial system O&M costs. These strategies are general and the applicability of these strategies is site specific.

In addition to cost minimization strategies, eliminating existing components of the remediation system that do not contribute to remedial progress can also reduce O&M costs. The evaluation of remedial performance, system performance and system suitability should identify if any existing components can be removed, switched to intermittent operation, or bypassed without affecting remedial progress. This evaluation should consider which, if any, components may be a required part of the remedy (e.g., wells required as part of a landfill monitoring network). Eliminating such components may require additional documentation such as a permit or ROD amendment. Examples of this strategy include:

- Discontinuing operation of extraction/injection wells in areas where cleanup goals have been achieved
- Removal of components of the aboveground treatment system where the vapor/liquid streams have achieved discharge concentrations.

Table 6-1. O&M Cost Minimization Strategies

Cost Category	Cost Minimization Strategy	Remarks
Labor	• Use base personnel for the O&M of the remedial system • Implement remote data acquisition/analysis • Use autodialing systems to notify operator of unplanned system shutdowns • Minimize sampling frequencies • Use a streamlined data reporting system • Develop detailed standard operating procedures for O&M tasks • Contract O&M of similar systems in large packages to obtain economy of scale and minimize administrative burden	• When using contractors, on-site labor rates can result in significant cost reduction. This usually requires issuing adequate work to a particular contractor to allow dedication of one or more full-time staff to operate and maintain one or more remedial systems. • Administrative burden for RPMs can be reduced by minimizing the number of contracts that must be managed to implement a RA-O program.
Analytical	• Reduce analytical methods and collection frequencies to only those data needed to measure system/remedial performance and justify site closure • Use of on-site analyses can significantly reduce analytical costs if analyses are performed frequently • Frequently obtain competitive laboratory cost quotes • Coordinate sampling events to obtain bulk analysis discounts • Negotiate permit flexibility to minimize sample collection frequencies if compliance is consistently demonstrated	• If the remedial system is subject to discharge requirements, analytical flexibility should be negotiated.
Power/Utilities	• Use appropriately sized equipment • Use treatment equipment appropriate for system influent concentrations and contaminant profile • Minimize system downtime to avoid multiple startup costs • Operate using system pulsing to minimize unit cost of contaminants removed • Use utility suppliers that have the lowest rates • Consider using treated water for alternative uses at the installation	• Operating in-situ remedial systems in a "pulse" mode can reduce unit mass extraction costs. • Alternative uses for treated water include irrigation, heating water, cooling water, and fire fighting supply water. Significant cost savings can be realized by using treated water for purposes where supply water would normally be purchased.
Repairs	• Prepare standardized system designs • Purchase and stock replacement parts in bulk that are common to numerous systems • Practice preventative maintenance in accordance with component manufacturer recommendations • Periodically update O&M manual to address recurring problems	• Maintaining accurate documentation regarding component failure may allow RPMs/contractors to pursue vendor warranties, which would reduce repair costs.

Example*: Data evaluation conducted during an optimization study at NAWC Warminster determined that the concentrations of metals in the extracted groundwater no longer required treatment to meet the permitted discharge criteria. Recommendations were provided to modify the operation of the aboveground treatment train to bypass the metals removal equipment, including the flash mix and flocculator tanks with inclined plate separator, the sand filter, the neutralization tank, the sludge thickener tank, and the filter press. The sand filter was the flow limiting factor in the treatment system and required a high degree of operator labor associated with balancing the system flow rates and backwashing the unit. Bag filters were added in place of the sand filter to provide filtering of the influent prior to the air stripper and granular activated carbon. The cost to bypass the equipment, clean out and dispose of the sand filter media, and install new bag filters was approximately $48,500. The estimated O&M savings was $10,900 per year, which equates to a payback period of less than 5 years.*

6.1.3 Reducing the Remedy Footprint

System modifications implemented to improve cost efficiency often reduce the remedy footprint, but in addition to these changes, activities identified during the baseline sustainability assessment as having the greatest contribution to the remedy footprint should be targeted for optimization. Several footprint reduction approaches can be implemented during the RA-O phase of the RA. Table 6-2 lists various remedial activities that tend to have a high remedy footprint and summarizes potential footprint reduction methods.

Table 6-2. Examples of Footprint Reduction Techniques for Selected Activities

Activity	Impact(s)	Footprint Reduction Technique(s)
Regrading or landfill cap maintenance	• Soil erosion • Consumption of energy • Transport of air-borne contaminants • Ecosystem disturbance	• Optimize planning to determine best options for excavated material (e.g., treat material and keep on site or remove and use local material for back-fill, find nearby facility to accept waste or one allowing for rail transport) • Establish decision points that could lead to in situ treatment instead of excavation for part or all the material
Sediment dredging, dewatering, and disposal	• Emissions of greenhouse gases and criteria pollutants • Consumption of energy • Ecosystem disturbance	• Consider passive dewatering instead of physical/mechanical methods • If available, consider hydraulic dredging directly to disposal facility instead of mechanical dredging, dewatering, and traditional transportation disposal
Transportation of materials and waste	• Emissions of greenhouse gases and criteria pollutants • Consumption of energy • Accident risk • Traffic	• Evaluate rail versus road transportation • Locate closer disposal facility • Consider in situ or on-site treatment • Use greener fuels • Implement after-treatment emission controls

Table 6-2. Examples of Footprint Reduction Techniques for Selected Activities (Continued)

Activity	Impact(s)	Footprint Reduction Technique(s)
Transportation of personnel during RA-O and long-term management	• Worker safety • Traffic • Emissions of criteria pollutants and greenhouse gases • Consumption of energy	• Increase automation and remote data acquisition in operating systems to reduce operator trips • Optimize long term monitoring plans to reduce frequency of trips • Take holistic approach to base LTMgt activities to reduce number of trips to base • Establish performance objectives linked with exit strategies to prevent systems from operating beyond point of diminishing returns
Operate mechanical equipment with motors, such as pumps, blowers and compressors	• Emissions of greenhouse gases and criteria pollutants • Consumption of energy	• Use high or premium efficiency motors and variable frequency drives where appropriate • Ensure equipment is optimally sized considering current and expected future operating conditions • Apply system pulsing where appropriate (e.g., for AS systems) • Consider renewable energy sources • Optimize operating conditions to reduce waste generation • Reuse/recycle (e.g., recovered free product) • Establish performance objectives linked with exit strategies for each system component as well as the overall system to prevent equipment and system from operating beyond point of diminishing returns
Drilling/Well installation	• Emissions of greenhouse gases and criteria pollutants • Consumption of energy • Accident risk	• Optimize selection of well casing material and diameter to minimize material use and well installation time • Consider direct push to decrease drilling time and reduce waste from drill cuttings
Consumption of chemicals or other materials for treatment	• Emissions of greenhouse gases and criteria pollutants • Consumption of energy	• Use updated CSM to target treatment area • Perform additional design work or treatability testing to optimize injection strategy and make more efficient use of treatment materials

In some cases, several footprint reduction methods may be identified as a means for reducing the overall footprint of a RA. Before any footprint reduction method is selected, a prioritization analysis should be completed. The prioritization analysis should evaluate the cost for implementing the footprint reduction method against the footprint reduction to be gained. The footprint reduction methods chosen will depend on the estimated costs for implementation, the potential cost-savings (if any) to be realized, and the anticipated footprint reduction after implementation. More details regarding completion of a prioritization analysis for selecting footprint reduction methods can be found in the *DON Guidance on Green and Sustainable Remediation* [6].

***Example**: Construction of a renewable energy system for operation of a remediation system is often not cost effective. However, at a remote site such as the former Adak Naval Complex,* *Alaska, where a power source is not always available, the cost of bringing in power lines can offset the cost of a renewable energy system. At the former Adak Naval Complex, mobile wind turbines were designed and constructed to generate power for the free product recovery systems. The mobile wind turbines power a 1,000-watt generator that can produce 12 volts of electricity, enough to power the free product recovery pumps. In addition to eliminating electrical infrastructure costs, wind power is a clean source of energy.*

6.2 Identify Alternative Remedial Technologies

If the evaluation of remedial effectiveness and cost efficiency indicates that the system cannot be improved to achieve RA objectives, the optimization effort should then identify alternative remedial technologies and the administrative process necessary to change the remedy or RA objectives. The alternative remedial technologies must be capable of attaining RA objectives in a shorter timeframe and/or at lower costs and with a smaller remedy footprint. Also, the alternative remedial technologies must address those conditions, such as evidence of technical limitations and life cycle design limitations, which limited the remedial progress of the existing remediation system.

Considerations for life cycle design are discussed in Section 4.3.1 and potential remediation technologies that may be used as an alternative remedial strategy are discussed in Appendix A. The RPM should conduct a detailed screening and selection process to identify an appropriate alternative remedial strategy. This may require preparing a feasibility study, engineering evaluation and cost assessment, or similar documentation relevant to the particular regulatory program for the site. Selection of an alternative remedy may need to be agreed upon by the regulatory agencies in a ROD Amendment, Explanation of Significant Differences, RCRA Permit Modification, or other Decision Document Addendum depending on the regulatory program. More information regarding remedial alternative evaluation and documentation can be found in the *Guidance for Optimizing Remedy Evaluation, Selection and Design* [4].

6.3 Alternative Endpoints for Site Remediation

If an alternative remedial strategy cannot improve the remedial effectiveness and cost efficiency, the RPM should consider the use of alternative endpoints for remediation to manage risk associated with concentrations of chemicals remaining at a site. Alternative endpoints are based on an evaluation of the contaminated media, exposure pathways, and impact to current and future receptors. For example, traditional endpoints for groundwater remediation are numerical criteria established by regulations and include ARARs and RBCs, whereas alternative endpoints for groundwater waive or substitute for the traditional endpoint (e.g., ARAR, RBC) and allow concentrations above cleanup standards to remain in groundwater. Under CERCLA, instituting alternative endpoints during the RA-O phase will require acceptance of the alternative endpoints by the regulatory agencies and documentation of the change in a ROD amendment. An in-depth discussion of this approach is provided in the *Groundwater Risk Management Handbook* [22] and additional information regarding the use of alternative endpoints and alternative remedial strategies is available in a recently published document by the ITRC entitled *Assessing Alternative Endpoints and Remedial Approaches to Address Groundwater Cleanup Challenges: Remediation Risk Management* [23]. An overview of these strategies is provided below.

- Groundwater Reclassification – A regulatory process whereby the groundwater is no longer classified as drinking water and therefore drinking water standards no longer apply. Reclassification may not need to be a formal process. In some cases documentation of regulatory concurrence may be sufficient to redefine RA objectives based on most likely exposures. This approach is appropriate for sites where groundwater quality or site characteristics make it unsuitable as a potential drinking water source. For more information refer to *Evaluation of Site-Specific Criteria for Determining Potability and Cleanup Goals for Impacted Groundwater* [24].

> **Resources for Risk Management Strategies and Alternative Endpoints**
>
> - Alternative Endpoints and Approaches Selected for the Remediation of Contaminated Groundwater [25].
> - Technical Impracticability Assessments: Guidelines for Site Applicability and Implementation, Phase II Report [26].
> - Assessing Alternative Endpoints and Remedial Approaches to Address Groundwater Cleanup Challenges: Remediation Risk Management [23].
> - Groundwater Risk Management Handbook [22].
> - Guidance for Optimizing Remedy Evaluation, Selection, and Design [4].
> - Guidance for Evaluating the Technical Impracticability of Ground-Water Restoration [29].
> - Use of Alternate Concentration Limits in Superfund Cleanups [27].
> - Summary of Key Existing EPA CERCLA Policies for Groundwater Restoration [28].
> - Updated EPA fact sheets describing CERCLA sites that have received TI waivers in the past (EPA HQ, in press).

- Alternate Concentration Limits (ACLs) - ACLs provide alternative numeric cleanup goals often developed using groundwater fate and transport models and mixing zone analyses for sites where the primary exposure pathway is discharge to surface water. For example, calculated concentration limits (CCLs) were developed for metals in groundwater which discharged to surface water at Naval Shipyard Long Beach. The established CCLs account for the downgradient distance from each well to the site boundary and the attenuation in concentrations that occurs as contaminants migrate across that distance.

- ARAR Waivers - Under certain circumstances, ARARs can be waived in favor of another protective remedy. The ARAR waiver that could potentially be implemented during the RA-O phase is a technical impracticability (TI) waiver. A TI waiver can be invoked during a RA if restoration of groundwater to numeric cleanup levels is technically impracticable from an engineering standpoint, based on the feasibility, reliability, and cost of the engineering methods required. Specific information required to support the need for a TI waiver will vary by site, but generally include a well defined and current CSM, an evaluation of the restoration potential of the site based on remedy performance data, predictive analyses of the timeframes to attain the required cleanup levels, and a demonstration that no other remedial technologies could reliably, logically, or feasibly attain the cleanup levels at the site within a reasonable timeframe [29]. TI waivers generally will be applicable only for ARARs used to establish cleanup performance standards or levels, such as chemical-specific MCLs or state groundwater quality criteria.

- Groundwater Management Areas – Used to define areas that exceed water quality standards and manage contaminants in place. Terminology and meaning varies from state to state (e.g., plume management zone, containment zone) and between state- and federal-sponsored cleanup programs (e.g., waste management area).

6.3.1 Challenges Associated with Alternative Endpoints

Although the above alternative endpoints are a viable option as part of a remedy, it is important to consider the long-term, life cycle costs of revising remedial goals and possibly introducing the need for LTMgt. The implementation of most alternative endpoints results in continuing liability of an indefinite duration for DON. Therefore, the long-term costs of maintaining these alternatives must be weighed against the time and costs of continued remediation. Other challenges also may arise during the development and implementation of a risk management approach as provided below:

- **Regulatory acceptance**. Regulatory acceptance of alternative endpoints that may be perceived to be less stringent, and thus less protective, may require developing several lines of evidence to justify the need for an alternative endpoint. Extensive data collection and evaluation during the RA-O phase may be needed to develop this justification, including an effectiveness evaluation of the remedy, demonstration that optimization of the remedy cannot significantly improve effectiveness, and projections indicating that a significant amount of time is required to achieve the current RA objectives.
- **State regulations and guidelines.** Each state has its own risk-based methodology and may have specific criteria for some of the alternative endpoints discussed above. Before proposing revisions to the remedial strategy or remedial goals, review current state regulations for evolving risk management provisions.
- **TI waiver approval.** The NCP preamble states that TI determinations should be based on "engineering feasibility and reliability, with cost generally not a major factor unless compliance would be inordinately costly." U.S. EPA believes that, in many cases, TI decisions should be made only after interim or full-scale aquifer remediation systems are implemented because often it is difficult to predict the effectiveness of remedies based on limited site characterization data alone. Data needs to support a TI waiver include an evaluation of the restoration potential of the site, including an analysis of the performance of the ongoing or completed remedial actions, predictive analyses of the timeframe to attain required cleanup levels using available technologies, and a demonstration that no other remedial technologies could reliably, logically, or feasibly attain the cleanup levels at the site within a reasonable timeframe. An evaluation of the existing system that demonstrates the existing system cannot be enhanced or augmented to improve its ability to attain ARARs should also be completed before concluding that a TI waiver is applicable for a site.
- **Planned use of the property**. Land use could change, potentially resulting in changing exposure risks. Where contamination remains on site, it is important to anticipate long-term legal and financial factors related to the presence of contamination and how changing land use or site alteration may affect exposure risks. However, when evaluating future land use scenarios, only reasonably anticipated future land use should be considered.
- **LUC Maintenance**. The willingness and ability of the appropriate entity to implement, maintain, and monitor the LUCs (institutional controls or engineering controls) is another factor of importance. In some cases, a third party is responsible for LUC maintenance, although the Navy retains the overall responsibility for the site. Even where the Navy

remains in control of the site, LUCs may need to remain in place for many years spanning multiple personnel responsible for LUC maintenance. Thus, it is crucial that the RPM has access to the historical documents related to the LUCs and has the ability to effectively and efficiently monitor the LUCs to ensure that protectiveness is maintained. To assist the RPM in maintaining LUCs, the Navy has developed LUC Tracker, which is a Web-based management tool that has been deployed as part of NIRIS. This tool can be used to store LUC information (e.g., maps, reports, inspection forms etc.), query LUC data (e.g., inspection results, violation and corrective action) and automatically send e-mail reminders for inspections and reporting requirements. Additional guidance for LUCs can be obtained from the Environmental Restoration Technology Transfer (ERT2) Web page at: https://portal.navfac.navy.mil/portal/page/portal/NAVFAC/NAVFAC_WW_PP/NAVFAC_NFESC_PP/ENVIRONMENTAL/ERB/ERT2.

- **LTMgt Challenges.** The need for additional monitoring or other requirements should be considered when evaluating alternative endpoints. In particular, the use of groundwater management areas is not recommended where pumping would be required to maintain hydraulic control. In addition, if ACLs are not developed or groundwater is not reclassified, then additional monitoring could be required to demonstrate compliance with the existing ARARs within the groundwater management area.
- **Community acceptance**. Community acceptance of the proposed revisions to the remedy and the use of alternative endpoints should be evaluated. For information regarding risk communication, the Risk Communication Navy Health, Operational and Environmental Web site developed by the Navy Environmental Health Center can be consulted at http://www.nmcphc.med.navy.mil.

7.0 DEVELOP AND PRIORITIZE OPTIMIZATION RECOMMENDATIONS AND FOOTPRINT REDUCTION METHODS

***Content**: The fifth step of the RA-O optimization process is to develop and prioritize optimization recommendations and footprint reduction methods. This section describes the process to develop optimization recommendations based on applicable remediation alternatives and to prioritize the recommendations based on cost benefit analyses. This step allows the RPM to develop and select the appropriate optimization recommendations to implement at a remedial site.*

7.1 Developing Optimization Recommendations

The optimization recommendations are developed to address the findings from the RA-O program evaluation, including any limitations that may prevent the existing remedial system from achieving cleanup goals. Optimization recommendations must demonstrate benefits to the ER program goal of cleaning up contaminated sites in an effective and efficient manner, including:

- Improving remedial performance, operational costs, and the sustainability of the existing remedial system
- Improving or at least maintaining progress towards achieving cleanup goals
- Improving or maintaining the remedy's protectiveness of human health and the environment.

An optimization strategy can consist of one or more recommendations to either improve the operation of the existing system or implement more effective technologies or revise remedial goals to be better suited to site conditions. These recommendations can be implemented simultaneously or in succession. Suggestions regarding how to improve the performance of existing remediation systems can be found in Appendix A and in the *DON Guidance on Green and Sustainable Remediation* [6]. Guidance concerning how to select more appropriate remedial technologies can be found in *Guidance for Optimizing Remedy Evaluation, Selection, and Design* [4]. Under CERCLA, a change in the remedy may require an Explanation of Significant Difference (ESD) or ROD amendment. An ESD is required to document a significant, but not fundamental, change from the selected remedy, whereas a ROD amendment is required if a fundamental difference from the selected remedy or use of alternative endpoints is recommended.

Cost-benefit and sustainability assessments should be completed for potential optimization recommendations for comparison to the current remedial system. Completing the GSR assessment will illustrate which recommendations will result in the greatest reduction in the remedy footprint compared to the baseline value. Reductions in the remedy footprint should be considered along with a cost-benefit analysis when evaluating the potential optimization recommendations. However, some recommended optimization strategies may not warrant a detailed cost-benefit analysis and sustainability assessment. For example, implementation of best management practices (BMPs) such as reducing the monitoring frequency or number of samples collected.

In addition to developing optimization recommendations for the remedy, optimization of the monitoring program should also be evaluated throughout the RA-O phase. It is important that the monitoring program reflect any changes in exposure routes and receptors, as identified during evaluation of the CSM. In addition, the purpose of each monitoring location should be reevaluated and redefined based on the current CSM as necessary (e.g., background, source area, point-of-compliance, etc.). Finally, the timeframe required for each of these monitoring locations to demonstrate risk reduction, such as meeting cleanup goals for four consecutive quarters of monitoring, should be updated to reflect any changes in monitoring frequency and duration. Detailed descriptions of optimizing a monitoring network and monitoring frequency can be found in the *DON Guidance for Planning and Optimizing Monitoring Strategies* [5].

***Example**: Source areas of chlorinated solvents in groundwater have been effectively remediated using ISCO at the Naval Submarine Base Kings Bay Landfill site and the Naval Air Station Pensacola Sludge Drying Bed/Surge Pond site. The efficiency of natural attenuation was assessed at each site with quarterly sampling for approximately 2 years. Results indicated that effective source reduction would ensure natural attenuation processes would be protective of downgradient receptors. ISCO using the Fenton's reagent was selected as the technology for source reduction. The optimization strategy combined ISCO for source control with MNA as the selected approach to replace the ineffective pump-and-treat system and resulting in significant life-cycle cost savings.*

7.2 Prioritizing Optimization Recommendations

Since more than one optimization recommendation may be available for a remedial site, the various optimization recommendations should be prioritized to determine the most appropriate recommendations to implement. Prioritization of optimization recommendations is based on a relative cost-benefit analysis and sustainability evaluation over the life cycle of a remediation alternative. This analysis will allow the most effective and efficient optimization recommendations to be implemented at the remedial site.

7.2.1 Cost Analysis

The cost analysis compares the current costs of system operation with the costs of the proposed alternatives after optimization. This cost analysis should compare the O&M costs of the existing system with administrative, capital and O&M costs of the remediation alternative. Administrative costs can include activities such as completing a feasibility study or engineering evaluation/cost assessment to evaluate potential remedial alternatives, or preparing an ESD or ROD amendment to document a significant or fundamental change in the remedy or cleanup goals for the site. These costs are additional costs that would be incurred with a significant or fundamental change to the remedy during the RA-O phase, and should be accounted for in the cost analysis. Table 7-1 summarizes the cost components that should be considered when evaluating options for optimization of the existing remedy, implementation of an alternative remedy, or selection of alternative endpoints. The cost comparison should also consider life cycle costs based on the expected timeframe of each remediation strategy.

Table 7-1. Components to be Considered in the Cost Analysis

Cost Component	Existing Remedy	Optimization of Existing Remedy	Alternative Endpoints for Existing Remedy	Implementation of Alternative Remedy
Capital Costs		X		X
O&M Costs	X	X	X	X
FS or EE/CA Cost				X
ESD or ROD Amendment Cost			X	X

Net present value (NPV) calculations are used to determine the investment value of remedial costs. The NPV allows a more direct comparison of optimization recommendations with different capital and O&M costs and over different timeframes of operation. The equation for calculating the NPV of O&M costs is provided below:

$$P = F * \frac{1}{(1+i)^n}$$

where P is the present value
F is the future value
i is the interest rate per interest period
n is the number of compounding periods.

Interest rates are typically considered to vary from 2% to 4%. The Office of Management and Budget provides guidance on the selection of an appropriate interest rate for projects funded by the Federal government. Capital costs of remediation alternatives should be added to the NPV of its O&M costs to calculate overall NPV costs. NPV calculations of O&M costs should be performed for any alternative requiring costs to be incurred in future years and is especially important for alternatives requiring more than just a few years of operation. This will ensure that the time value of money is properly evaluated in the cost analysis.

Since project budgets are based on expenditures not investment, a cost analysis based on actual cost over the project life cycle may be more appropriate for budgeting remedial costs. Rather than calculating the investment value of remedial costs for the NPV calculation, this approach evaluates costs as they are incurred over the life of the remediation strategy. The approach also allows the RPM to recognize high capital and/or annual costs that may be difficult to budget. The cost benefit analysis can then be used to determine the payback ratio or projected savings associated with each optimization strategy.

Example*: A pump and treat system is in place for removal of chlorinated solvents (primarily TCE) from the source zone in Area A at the former NAWC Warminster. In addition, a TI waiver is in place waiving MCLs within the source area where it was determined that DNAPL is potentially present in fractured bedrock. The pump and treat system has been operational since 1999 in Area A, and concentrations of TCE in the source zone are currently in the range of 4.1 to 9.5 mg/L. An optimization study was conducted to evaluate potential alternative technologies for supplemental source area treatment in Area A. Concentration trend analyses predicted that without source treatment, operation of the pump and treat system will need to continue for 30 or more years to reduce TCE concentrations below the MCL in the source area. The evaluation* *also concluded that if source area treatment is applied, the pump and treat system would need to continue to operate for approximately 15 additional years after treatment to reduce TCE concentrations below the MCL. Three options for source treatment were evaluated, including ISCO, ZVI, and thermal conductive heating, and a cost analysis was performed (Figure 7-1). Based on results of the cost evaluation, it was determined that source area treatment should be pursued rather than continuing with pump and treat. Additional sampling and bench testing is planned to further evaluate source treatment in Area A and, based on site-specific conditions regarding implementation, ISCO was selected for bench-scale testing.*

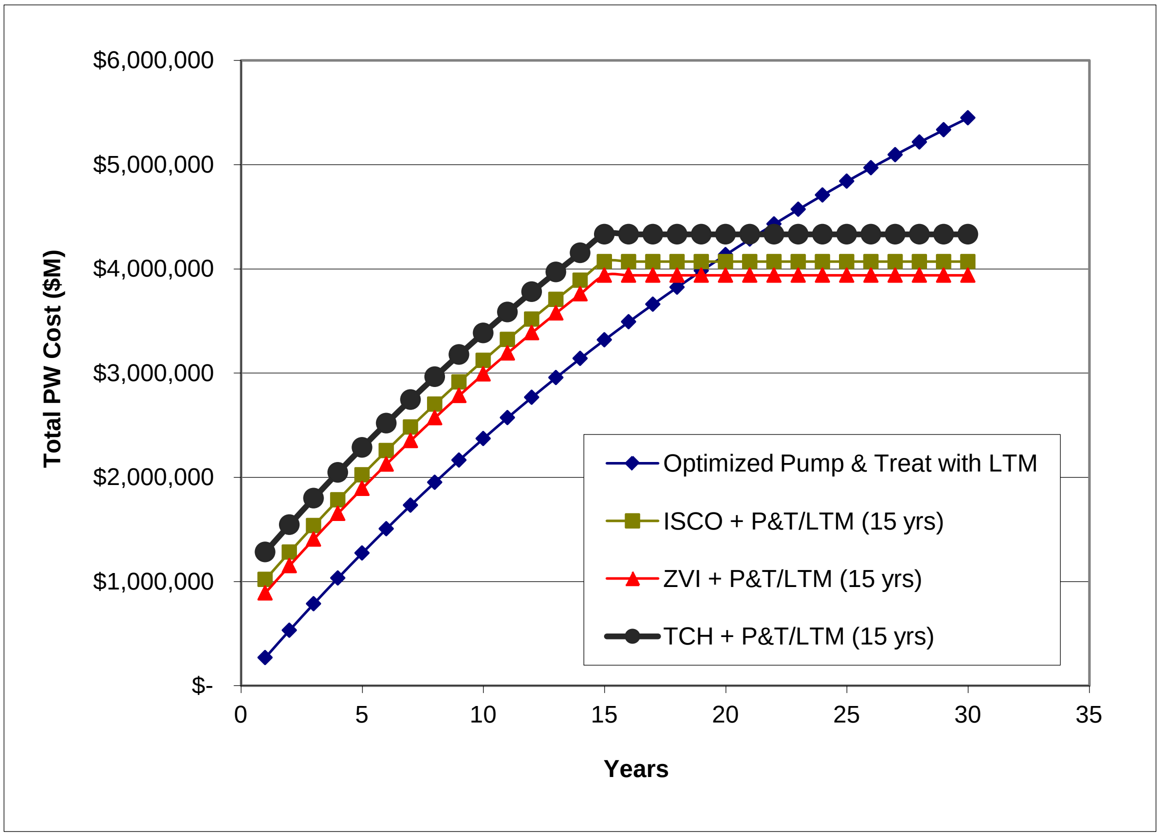
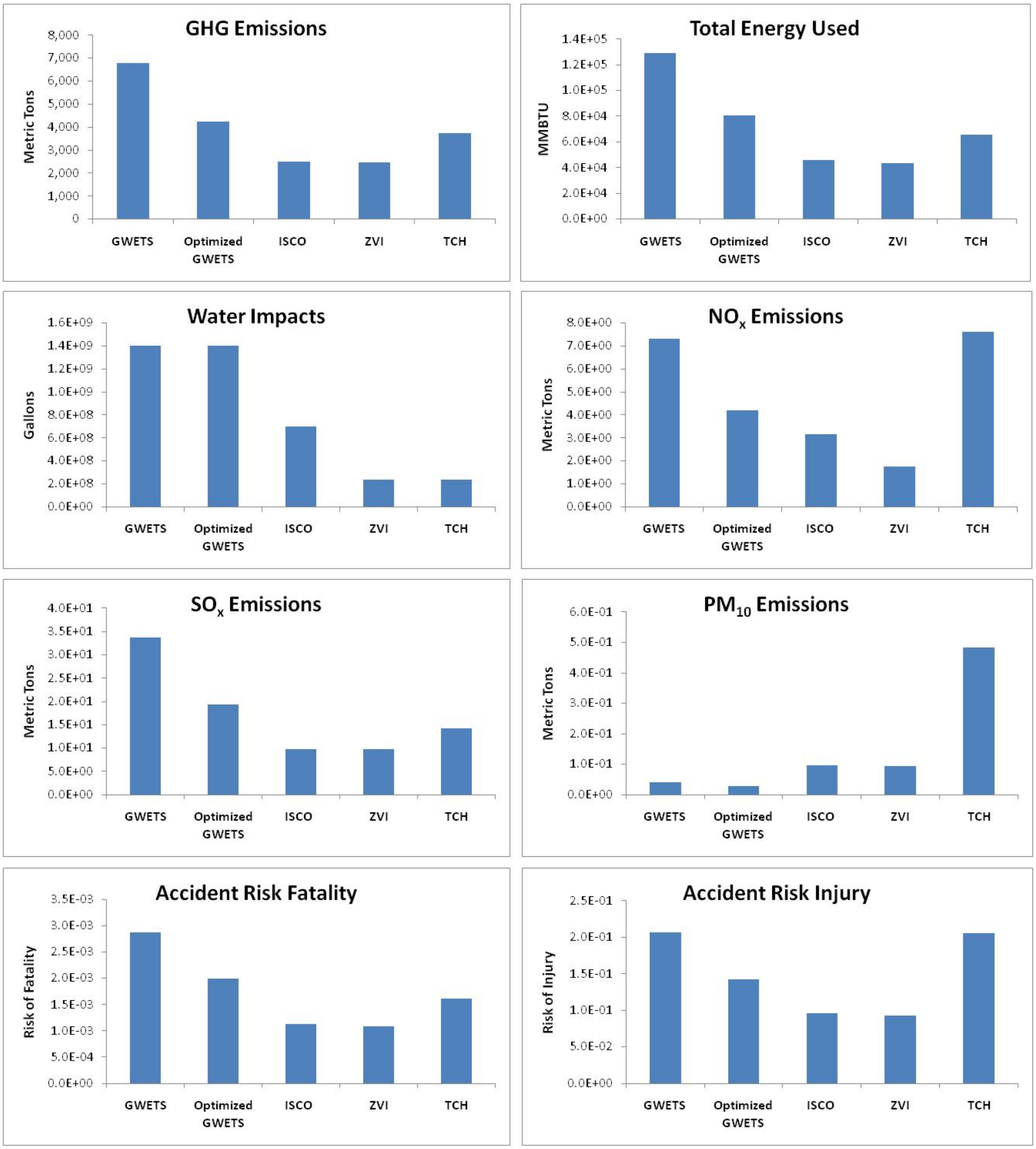


Figure 7-1. Cost-Benefit Analysis of Treatment Alternatives

7.2.2 Sustainability Analysis

Sustainability metrics can also be evaluated for each proposed alternative, in a similar manner to the baseline evaluation. The SiteWise™ tool allows for data to be input for up to 12 remedial alternatives and the resulting sustainability metrics are automatically compared. Figure 7-2 shows an example of a comparative analysis completed for the former NAWC Warminster. Several remedial technologies were evaluated to supplement the existing pump and treat system and achieve source area treatment of chlorinated solvents and potential DNAPL in Area A, including ISCO, ZVI, and thermal conductive heating. Based on the sustainability analysis, ISCO and ZVI have the lowest remedy footprint and ISCO was selected for further consideration and testing based on these results as well as the cost evaluation and site-specific considerations regarding implementation of each alternative within Area A. Because the sustainability evaluation focuses on the efficient use of energy, materials, time, and resources, the most cost-effective strategies will often result in a reduction of the remedy footprint as well.



GWETS = groundwater extraction and treatment system

Figure 7-2. Comparative Analysis of Sustainability Metrics

8.0 PREPARE OPTIMIZATION REPORT AND IMPLEMENT OPTIMIZATION RECOMMENDATIONS

Content*: The final steps in the RA-O optimization process are to prepare the optimization report, implement the optimization recommendations, and track progress of the optimization efforts. The optimization report details the evaluation of RA-O at the site, presents conclusions on the remedial effectiveness, cost efficiency, and sustainability of the remedial system and provides recommendations to optimize the approach. The conclusions and recommendations from the optimization report should be incorporated into project documents submitted for regulatory review prior to implementing the optimization recommendations.*

8.1 Report Format and Content

The evaluation of RA-O should be properly documented in an optimization report. The RA-O optimization report contains site-specific information concerning the remedial site, remedial system, remedial performance and cost, and recommendations to improve RA-O to achieve site closeout effectively and efficiently. The content of the optimization report should follow the steps of the RA-O optimization process. A sample outline for a RA-O optimization report is shown in Figure 8-1. For some of the more simple sites, the optimization results can be documented in a streamlined technical memorandum but the basic components shown in Figure 8-1 should still be addressed.

RA-O Optimization Report

1. Background
    - 1.1. Purpose and Scope
    - 1.2. Site Description and History
    - 1.3. Remedial System and Monitoring Activity Status
2. Remedial Action Objectives Review
    - 2.1. Current Conceptual Site Model
    - 2.2. Regulatory Framework Evaluation
3. Remediation and LTMgt Plan Effectiveness Evaluation
    - 3.1. Remedial Performance Baseline
    - 3.2. System Performance
    - 3.3. System Suitability
4. Cost Efficiency and Sustainability Evaluation
5. Remediation Modifications and Alternatives
    - 5.1. Modifications to the Existing System
    - 5.2. Alternative Remediation Systems
    - 5.3. Alternative Regulatory Mechanisms
6. Optimization Recommendations
    - 6.1. Optimization Strategy
        - 6.1.1 RA-O Recommendations
        - 6.1.2 LTMgt Recommendations
    - 6.2. Cost-benefit Analysis
    - 6.3 Remedy Footprint Reduction Analysis
7. Implementation Plan
    - 7.1. Annual regulatory review
    - 7.2. Regulatory documentation
    - 7.3. Schedule for Implementation

Figure 8-1. Example RA-O Optimization Report Outline

8.2 Reporting Frequency

The Optimization Workgroup recommends that RPMs and the project team review remedy performance and protectiveness at least once per year and use third-party reviews periodically to conduct optimization reviews. The findings from these annual reviews should be incorporated into project documents subject to regulatory review. The opportunities to present the recommendations to optimize the RA-O program include annual program reviews, CERCLA five-year reviews, and RCRA permit modifications. However, it should be noted that the five-year reviews or the RCRA permit modifications are not substitutes for RA-O optimization reports. The findings from RA-O optimization reports should be included in these documents.

8.2.1 Optimization Reviews

The RA-O evaluation should be incorporated into the program reviews to identify opportunities to optimize the remedial system. The Optimization Workgroup recommends that RPMs review the performance of the remedy during the RA-O phase at least annually. If this review indicates that a more detailed optimization evaluation of the remedy is needed, then a detailed optimization evaluation and an optimization report should be developed. The regulators should be involved with optimization efforts. The routine involvement of the regulators in site evaluation will result in consensus conclusions and recommendations for changes and improvements in RA-O.

8.2.2 CERCLA Five-Year Reviews

Remedial sites subject to CERCLA requirements must be evaluated every 5 years. This process, generally known as the Five-Year Review, requires evaluating RA objectives as detailed in the ROD, evaluating whether the response action remains protective, and proposing changes to improve remedial progress. The Navy RPMs are responsible for completing the Five-Year Review reports for their sites. The RA-O optimization evaluation should provide data and conclusions to directly support these Five-Year Reviews.

U.S. EPA guidance on the five-year reviews is provided in the *Comprehensive Five-Year Review Guidance* [30]. For National Priorities List (NPL) sites, U.S. EPA's role is to review the report and issue a finding of concurrence or non-concurrence. For non-NPL sites, U.S. EPA does not have any explicit role to review the Five-Year Review report. Five-year reviews are conducted at sites where contaminants will be left on site after completion of the RA(s). The trigger date for start of the five-year review period is the beginning of RA construction, which is equivalent to the on-site mobilization date. More details on the applicability and requirements for five-year reviews can be found in Navy policy [31].

8.3 Implementing the Optimization Recommendations

The RPM should prepare a plan to implement the optimization recommendations. The implementation of the optimization recommendations may require additional regulatory documentation. For CERCLA sites, an ESD or ROD amendment may be required. An ESD documents a significant modification in cleanup goals or approach to those detailed in the original ROD, without a change in the overall remedy. A ROD amendment documents a complete change in cleanup goals and/or approach to those detailed in the original ROD, including a change in the selected remedy. Where an ESD is used, the lead agency (Navy) should publish a summary of the ESD in a local newspaper, and makes the ESD and supporting information available to the public in the Administrative Record and in the site's information repository. Public involvement for ROD amendments is carried out in the same manner as for a ROD, including requirements for public comment, response to comments, and update of the Administrative Record.

Remedial sites subject to RCRA requirements must operate within the framework of the RCRA permit. The implementation of optimization recommendations may require a modification of the RCRA permit. The requirements to modify the permit are dependent on the extent of change. Minor changes to system operation may only require a letter to the regulatory agency (Class I modification). More significant changes to system operation may require additional background and supporting documentation (Class II modification), or a complete permit reapplication (Class III modification). The three classes of RCRA permit modifications are described in further detail in 40 CFR 270.42.

The optimization recommendations must gain acceptance from the regulatory agency prior to implementation. The optimization recommendations may also require public review, and thus, would need to gain community acceptance as well. Finally, the RPM must ensure that the optimization recommendations are implemented once acceptance is received from all stakeholders.

8.4 Track Progress of the Implemented Optimization Recommendations

There is currently an optimization module within NORM that tracks optimization reviews, recommendations, and implementation in all phases of a site cleanup, including remedial and removal action screening, evaluating, selecting, designing, implementing, RA-O and long-term managing. RPMs and their project teams should track optimization reviews and document progress of implemented optimization recommendations in the NORM Optimization module. This module and the associated tutorial have been revised to include GSR metrics, and tracking of the GSR metrics throughout the stages of site cleanup. The module requires that the RPM identify the metrics relevant for their site, provide an estimated percent reduction for the following metrics: GHG emissions, energy usage, air pollutants, waste generation, and water impacts/use, and briefly describe actions taken to reduce environmental footprint of the remedy. Reporting the outcome of optimization efforts in NORM is required.

9.0 WHAT TOOLS CAN I USE TO OPTIMIZE MY REMEDIAL ACTION OPERATION PROGRAM?

Content: *RA-O optimization involves a broad range of activities. This section describes a number of tools that can be used to assist the RPM in evaluating RA-O and developing optimization recommendations.*

9.1 Remedial System Optimization Checklists (Corps of Engineers)

The U.S. Army Corps of Engineers (USACE) Hazardous, Toxic, and Radioactive Waste Center of Expertise (HTRW CX) has prepared a series of 22 remediation system evaluation (RSE) checklists. The checklists are designed to evaluate the effectiveness of long-term remediation systems and include a general checklist that is applicable to every site, an environmental monitoring checklist, and individual checklists for various remediation technologies. The checklists are available in portable document format (PDF) at the following Web site: http://www.environmental.usace.army.mil/rse_checklist.htm

9.2 Geographical Information System and Naval Installation Restoration Information Solution

In 2005, NAVFAC developed a centralized database to facilitate the management and use of ER data through GIS and Web-based applications in a consistent and cost-effective manner over the life of the Navy ER program. NIRIS can be used by DON RPMs, DON contractors, and other team members who are granted access to manage and access many types of data associated with RA-O and remedy performance evaluation, as well as site documents and records. NIRIS minimizes duplication of effort, facilitates data sharing, reduces the learning curve for users, facilitates easy access to ER information, and provides standardized data management, collaboration, document management, analysis and visualization tools. NIRIS stores various types of ER data including:

- Environmental sample data;
- Munitions response/unexploded ordnance data;
- Administrative record/site file documents;
- GIS mapping data;
- ER site boundary information; and
- LUC data.

GIS facilitates data evaluation and interpretation through its visualization, analysis, and querying capabilities. GIS is useful for visualization of changes in the CSM as it is updated with data from RA-O, and it also allows the user to illustrate the data in real time presentation. NIRIS uses Web- and desktop-based GIS and related tools to effectively analyze the spatial distribution and correlate large volumes of data. During RA-O optimization, NIRIS can be used to generate figures similar to those shown in Section 4 to be used to evaluate the effectiveness of the remedy towards meeting the RA objectives and determine if continued operation is expected to achieve these goals in a reasonable timeframe.

NIRIS is not only a centralized data repository, it is also a tool for data evaluation and visualization. NIRIS is linked to GIS packages which can help display data spatially and can also be used to construct and track plume or other types of concentration-over-area maps. By linking GIS directly to the NIRIS database, data handling is streamlined and errors associated with redundancy between multiple sources of data storage are reduced. Standard GIS functions include the ability to pan, zoom in, zoom out, and other standard navigation tools. All of these features can be used for an effective presentation because of the ability to provide real-time responses to any data requests the audience may have. Presentations to regulators and the community can be greatly enhanced by using such a system. Regulator agreement may be obtained during a data visualization meeting, rather than awaiting comments on bulky documents.

Additional details regarding NIRIS and GIS can be found in the *DON Guidance for Planning and Optimizing Monitoring Strategies* [5].

9.3 Statistical Data Evaluation Methods

Statistical methods are recommended in all phases of the remedial program as a means for evaluating data. During the RA-O phase, these methods may be useful in evaluating progress toward achieving RA objectives, assessing overall performance of the remediation system, or evaluating the suitability of the current remediation system at the site. These methods provide an objective methodology for making specific decisions based on the data. Because statistical tests can be used to quantify uncertainty in data, they provide answers to what the data mean and how certain the conclusions are. A wide range of statistical tools can be applied to monitoring, depending on the specific objectives of the program. In terms of project objectives, questions that these tools can address include:

- **How can I test for a contaminant trend at a monitoring point or group of points?** Statistical tools that can identify trends include the Mann-Kendall test or regression analysis.
- **How can I evaluate hydrogeological or contaminant data spatially and what do I gain from such an analysis?** Geostatistical tools that can evaluate data spatially (i.e., ways to identify spatial trends) include semivariogram plots and kriging methods.
- **How can I identify monitoring point concentrations that exceed regulatory standards?** Statistical tools that can address such an objective are individual comparisons (such as an upper tolerance limit) and one-sample means comparisons (such as a one-sample t-test).
- **How can I identify outliers or extreme concentrations?** Statistical tools that can identify outliers are box plots and a U.S. EPA outlier test.
- **How can I identify differences in concentrations between downgradient and upgradient monitoring points or differences in concentrations between current baseline data?** Statistical tools that can identify differences between two sets of data are two-sample means comparisons (such as the two-sample t-test), individual comparisons (such as an upper tolerance limit), and the quantile test.
- **How can I identify differences in chemical concentrations among monitoring points or identify differences in concentrations among multiple chemicals?** Statistical tools

that can identify differences among multiple sets of data are analysis of variance procedures, multiple comparison tests, and contrasts.

- **How can I determine the level of statistical certainty achieved by a statistical method?** The statistical methods themselves provide a means of identifying the power achieved by the statistical test.

A more detailed discussion of the tests described above is provided in the *DON Guidance for Planning and Optimizing Monitoring Strategies* [5]. In addition, the following references have useful summary tables and demonstrations of how to set up and use appropriate statistical tools and methods.

- Gilbert, R.O. 1987. *Statistical Methods for Environmental Pollution Monitoring*. Von Nostrand Reinhold, New York, NY.
- U.S. EPA. 2002. *Guidance on Choosing a Sampling Design for Environmental Data Collection*. EPA/240R-02/005. Office of Environmental Information, Washington DC.
- U.S. EPA. 2000. *Guidance for Data Quality Assessment*. EPA/600/R-96/084. Office of Environmental Information, Washington DC.
- U.S. EPA. 1992. *Preparation of Soil Sampling Protocols: Sampling Techniques and Strategies*. EPA/600/R-92/128. Office of Research and Development, Washington DC.
- U.S. EPA. 1989. *Methods for Evaluating the Attainment of Cleanup Standards*, Volume 1: Soils and Solid Medi*a*. EPA 230/02-89-042. Office of Policy, Planning, and Evaluation, Washington DC.
- U.S. EPA. 1992. *Methods for Evaluating the Attainment of Cleanup Standards*, Volume 2: Ground Water, EPA 230-R-92-14, Office of Policy, Planning, and Evaluation, Washington DC.
- U.S. EPA. 1992. *Statistical Methods for Evaluating the Attainment of Cleanup Standards*, Volume 3: Reference-Based Standards for Soil and Solid Media, EPA 230-R-94-004, Office of Policy, Planning, and Evaluation, Washington DC.
- U.S. EPA Web Site for the Technical Support Center for Monitoring and Site Characterization: Includes links to papers and fact sheets related to monitoring and site characterization as well as the statistical software package *ProUCL 4.0 for Environmental Applications for Data Sets with and without Nondetect Observations*.

9.4 Sustainability Evaluation Tools — SiteWise™ and Sustainable Remediation Tool (SRT™)

SiteWise™ and SRT™ are two DoD tools developed specifically to assess the secondary environmental effects of site remediation. SiteWise™ is a stand-alone tool developed jointly by the Navy, USACE, and Battelle that assesses the remedial footprint of a remedial alternative/technology in terms of a consistent set of metrics, including: (1) greenhouse gas emissions; (2) energy use; (3) air emissions of criteria pollutants such as oxides of nitrogen (NO_x), sulfur oxides (SO_x), and particulate matter, (4) water impacts; and (5) worker safety. The assessment is carried out using a building block approach where every remedial alternative is first broken down into modules which calculate the remedy footprint for each remedial phase individually, including remedial investigation, RA construction, RA-O, and LTMgt. The footprint for each phase can then be combined to estimate the overall footprint of the remedial alternative. SiteWise™ also identifies impacts from individual activities (e.g., the material production of consumables used during RA-O) that contribute the most to the overall footprint. This information is especially useful during RA-O because it allows the RPM to focus on footprint reduction methods that can have the most significant effect on reducing the overall remedy footprint. The results of the analysis can also be used to calculate each metric on a per month basis or other units such as mass of contaminant removed. This can be helpful in demonstrating that a technology has operated beyond the point of diminishing returns as discussed in Section 4. SiteWise™ and the SiteWise™ User's Manual can be downloaded from the NAVFAC Green and Sustainable Remediation Web page. In addition, the *Department of Navy Guidance on Green and Sustainable Remediation* [6] provides additional information regarding the use of SiteWise™ during the remedial process and includes case studies where SiteWise™ was used.

SRT™ is a stand-alone tool developed by AFCEC that calculates carbon dioxide emissions, emissions of criteria air pollutant emissions, total energy consumed, change in resource services, technology cost, and safety/accident risk for a remedial technology based on remedial parameters input by the user. The technologies currently enabled in the tool are excavation, SVE, pump and treat, enhanced in-situ biodegradation, thermal treatment, ISCO, permeable reactive barrier (PRB), and MNA. The tool is structured into tiers that allow the user to choose the level of effort and detail appropriate for the study objectives. Tier 1 (simplest tier) calculations are based on inputs that are widely used in the environmental remediation industry. Tier 2 calculations are more detailed and incorporate site-specific factors. SRT™ also includes several features to help interpret the results. Users have the option to consider various scenarios for future costs of carbon dioxide offsets and for energy. These costs consider NPV over the lifetime of the project. Also available to users is a Stakeholder Roundtable in which various parties involved can choose to weigh the importance of each metric. The group's weights are then compiled into a consensus set of metrics, which represents an equal compromise of metric weights for the group. These features allow users more flexibility and aid in the decision-making process. SRT™ is distributed through the AFCEC Web site at:
http://www.afcec.af.mil/

Additional details regarding SiteWise™ and SRT™, as well as other tools available for conducing sustainability related evaluations can be found in the *DON Guidance on Green and Sustainable Remediation* [6].

9.5 General Groundwater Plume Assessment Tools and Management Strategies

As large dilute groundwater plumes continue to be expensive and difficult to remediate, the Groundwater Risk Management Handbook was developed by NAVFAC EXWC to provide RPMs with practical approaches and management options [22]. Approaches presented in this handbook may be considered as an optimization strategy during evaluation of RA-O at these sites. After the release of the handbook, a Dilute Groundwater Plume Management Remediation Innovative Technology Seminar (Spring 2008) was developed to showcase the new approaches to large dilute plume management highlighted in the handbook. The RITS focused on the unique problems associated with dilute groundwater plumes in terms of residual sources (e.g., matrix diffusion effects), risk-based approaches such as risk-based corrective-action and alternative clean-up goals, novel assessment methods (e.g., mass flux monitoring), and sustainability issues related to managing these plumes.

A Frequently Asked Questions document was compiled by ESTCP to address the current understanding of chlorinated solvent plumes and provide best management approaches for these sites [32].

The new technique discussed in the Groundwater Risk Management Handbook as well as the Frequently Asked Questions document is mass flux. Mass flux or mass discharge depending on context provides a means of understanding the strength of the contaminant source. The ITRC has produced a technology guidance document (Use and Measurement of Mass Flux and Mass Discharge) to promote the proper use and application of mass flux and mass discharge [20]. A Mass Flux Tool Kit is also available to help learn about different approaches to mass flux and to calculate mass flux.

An essential part of managing the remediation of a groundwater plume is monitoring and assessing site conditions over a long period of time. To ensure adequate data analysis and interpretation, NAVFAC developed the Management and Monitoring Approach (MMA) [2]. As discussed in Section 1.0, the MMA can be used to develop well-written annual monitoring reports and is particularly applicable for annual monitoring reports where significant amounts of data are included. Appropriate elements of the MMA can be used as a resource for improving the public transparency and understanding of the site conditions, actions taken and site closeout requirements.

9.6 DNAPL Source Zone Treatment

Additional evaluation of source zone treatment may be necessary if RA-O data indicate that the RA objectives cannot be achieved within a reasonable timeframe, or if the current remediation system is found to not be suitable for treating the remaining source zone at the site. The ESCTP source zone program area Web page (http://www.serdp.org/Featured-Initiatives/Cleanup-Initiatives/DNAPL-Source-Zones/(list)/1/#TT) lists current and past projects that focused their efforts in restoration of DNAPL source zones. There are links to each project which provide project documentation such as fact sheets, interim reports, and final reports (for past projects). Several of the projects developed tools and training as products of their research. Links to these tools and training material are provided at the following Web site (http://www.serdp.org/Tools-and-Training/Environmental-Restoration/DNAPL-Source-Zones).

Technologies capable of source zone remediation have been presented as part of the Navy's Technology Transfer program. The RITS which have addressed potential source zone technologies include DNAPL Management Challenges (Spring 2006), Electrical Resistive Heating Design and Performance Criteria (Spring 2007), and Emulsified ZVI Treatment of Chlorinated Solvents (Spring 2009). Following the DNAPL Management Challenges RITS, NAVFAC EXWC developed the DNAPL Management Overview guidance [17]. This short and informative product highlights the challenges associated with DNAPL sites and summarizes technology performance at DNAPL sites. Finally, more information is also provided in the

DNAPL Technology Evaluation Screening Tool located on the ER Technology Transfer Resources Web page.

The ITRC also formed several teams to address DNAPLs and how best to address these sites. The Integrated DNAPL Site Strategy ITRC Team developed a guidance document entitled *Integrated DNAPL Site Strategy* [33] that encourages a holistic approach to addressing DNAPL sites through an integrated strategy. In 2008, the DNAPL team released *In Situ Bioremediation of Chlorinated Ethene: DNAPL Source Zones* [34] which discussed the use of bioremediation to enhance DNAPL degradation within source zones. Additional publications from the BioDNAPL team include BIODNAPL-1 [35] and BIODNAPL-2 [36].

9.7 MNA Tools

Evaluation of MNA during the RA-O phase can help determine when transition from active remediation to MNA is appropriate given the current CSM and progress by the remediation system toward achieving the RA objectives. Discontinuing active remediation systems in favor of more passive remediation approaches will increase sustainability of the remedy while lower the life-cycle cost to achieve the RA objectives. A number of tools are available to assist in evaluating the potential of a site to support natural attenuation.

DON Technical Guidelines for Evaluating Monitored Natural Attenuation at Naval and Marine Corps Facilities [37]. This document provides an overview of natural attenuation, how the efficiency of natural attenuation can be assessed for petroleum hydrocarbons and chlorinated solvents, identifies the hydrogeologic and geochemical data needed to make these assessments, and summarizes the monitoring requirements needed to verify the effectiveness of natural attenuation.

U.S. EPA OSWER Directive EPA/540/R-99/009: Use of Monitored Natural Attenuation at Superfund, RCRA Corrective Action, and Underground Storage Tank Sites [38]. Available at the U.S. EPA MNA for Ground Water Cleanups Web site (http://www.epa.gov/superfund/health/conmedia/gwdocs/monit.htm) along with other reports with information on MNA for various contaminants in groundwater.

U.S. EPA's Center for Subsurface Modeling Support (CSMoS). Two models available from CSMoS for evaluating MNA are *BIOCHLOR* and *BIOSCREEN*. *BIOCHLOR* is a screening model that simulates the natural attenuation of chlorinated compounds. It includes a scoring system to help determine the potential for reductive dechlorination from site-specific data. BIOSCREEN is a similar screening model for evaluating the natural attenuation of dissolved petroleum constituents. The CSMoS can be accessed through U.S. EPA's Web page at www.epa.gov.

AFCEC Technical Protocol for Implementing Intrinsic Remediation (Natural Attenuation) with Long-Term Monitoring Option for Dissolved-Phase Fuel Contamination in Groundwater [9].

The Natural Attenuation Software (NAS) offers users the ability to predict the timeframes for remediation at a site based on MNA and/or removal of source material. The tool includes options for determining stabilization distances or times based on site-specific concentrations at compliance locations. In addition, the tool provides a time range when evaluating the impact of source reduction on plume-wide site remediation. Two RITS presentations discussed the use of NAS (Estimating MNA Remedial Timeframes with Natural Attenuation Software [Spring 2008] and Estimating Times of Remediation Associated with Natural Attenuation [Spring 2003]).

9.8 Biological Treatment/Enhanced In-Situ Bioremediation Tools

Similar to MNA, evaluation of biological treatment during the RA-O phase can help determine when transition from active remediation to a more passive remedial technology is appropriate given the current CSM and progress by the remediation system toward achieving the RA objectives. Discontinuing active remediation systems in favor of more passive remediation approaches will increase sustainability of the remedy while lower the life-cycle cost to achieve the RA objectives.

Enhanced in situ bioremediation refers to an engineered or designed approach to improve the biodegradation of contaminants at site. A variety of guidance documents and tools are available to aid in implementing and optimizing enhanced in situ bioremediation.

The ITRC's Enhanced Attenuation: Chlorinated Organics Team developed a guidance document (EACO-1 [39]) that outlines how best to bridge active source zone treatment (via thermal, ISCO, etc.) with MNA. This bridge refers to the enhanced portion of the remedy where the environment is provided with additional substrate, micro-organisms, and/or nutrients to promote and sustain biodegradation. In addition to the team's guidance document, an electronic resource guide Web page was developed (www.itrcweb.org/teamresources_50.asp). This page provides general resources such as an enhanced attenuation fact sheet and information sheets written for difference audiences (i.e., general public and state manager).

The use of emulsified vegetable oil (EVO) as a means to enhance or stimulate bioremediation has increased as more EVO products have come to the market and regulatory acceptance has increased for this technology. To aid in design, a guidance document was written as part of an ESTCP project (Protocol for Enhanced In Situ Treatment of Bioremediation Using Emulsified Vegetable Oil [40]). This protocol explains the fundamentals behind EVO usage and provides general design criteria when considering the application of EVO at a site. As a follow on to the protocol, an emulsion design tool kit was developed (http://www.serdp.org/Tools-and-Training/Environmental-Restoration/Groundwater-Plume-Treatment/Emulsion-Design-Tool-Kit). The tool kit is an excel-based spreadsheet which allows the user to determine design specifics such as substrate quantities using site-specific data and injection costs.

Another aspect of enhanced bioremediation is the addition of micro-organisms to the contaminated environment and is called bioaugmentation. The use of bioaugmentation has increased with improvements in microbiological tools such as quantitative polymerase chain reaction that provide quantitative information on microbial presence at a site. Bioaugmentation research is still ongoing, and several ESTCP projects (ER-200515; ER-2005513) worked on elucidating best practices for adding microbial cultures. For guidance on microbiological tool sampling, a RITS seminar *Applications of Molecular Biological Tools for Site Remediation* was presented in Spring 2009. Strategic Environmental Research and Development Program projects will be releasing Standard Operating Procedures for microbiological tool sampling soon.

9.9 Land Use Control Tracker

LUCs may be necessary to maintain protectiveness at a site during RA-O until the final RA objectives are achieved. NAVFAC has developed the LUC tracking tool (LUC Tracker), which is a Web-based tool that operates as part of NIRIS. LUC Tracker can be used to ensure that sufficient monitoring is occurring to maintain protectiveness and to document that LUCs are functioning as intended. LUC Tracker assists in actively managing interim LUCs placed on parcels transferred under the early transfer process and also long-term LUCs associated with RAs. The application tracks LUCs and provides automatic reminders to the Navy RPM, BRAC Environmental Coordinator, or Base Closure Manager of inspection, reporting and certification requirements, as well as the means to both facilitate and document implementation of these requirements through the generation of standard and custom forms and reports. In the event of a LUC violation, it can notify the appropriate parties and track the status of corrective action efforts.

Additional detail regarding the LUC Tracker and other LUC management tools can be found in the *DON Guidance for Planning and Optimizing Monitoring Strategies* [5] and at the ER Long Term Management Web site.

9.10 Data Visualization Software

GIS provides a powerful tool for interpreting site data by helping to display data spatially and by constructing and tracking plume or other types of concentration-over-area maps. The ability to continuously track a plume's size and shape through GIS allows for RA-O and monitoring program optimization by deciding which monitoring points to sample or when to shut down active remediation systems.

Depending on the complexity of the site to be modeled, more sophisticated software packages to aid in analysis and visualization of geological, geohydrological, and contaminant sampling data can be considered. A recent class of new visualization software includes true three-dimensional programs capable of generating high-quality, three-dimensional renderings and animations. Most of these programs provide a suite of geological modeling capabilities and spatial analysis tools. Examples of this type of visualization software include the following products:

- ESRI ArcView® with ESRI 3-D Analyst extension
- Environmental Visualization System (EVS) from C-Tech
- EVS for ArcView from C-Tech
- Visual Groundwater from Scientific Software Group
- Groundwater Modeling System 6.5
- Spatial Analysis and Decision Analysis

9.11 Optimization Software Packages

Various optimization software packages can be used to assist with optimization of hydraulic containment at pump and treat systems, as well as optimization of LTM activities which are often associated with RA-O. The goal of optimizing the LTM is to increase sustainability of the remedy and decrease life-cycle costs for the remedial action, while continuing to collected sufficient data to support evaluation of RA-O and progress toward the RA objectives.

SOMOS (Simulation/Optimization Modeling System) is a family of simulation/optimization modules developed by the Utah State University Research Foundation to aid in optimally managing water resources. This Windows-based software tool provides simulation capabilities and optimization algorithms that assist in the development of mathematical and physical water management strategies. A $SOMOS_{WEB}$ version is now available to download and includes the following executables:

- SOMOS_SOMO3(vs2.2e) for running SOMO3 - for contaminant plume management problems such as optimizing pump and treat design
- SOMOS_SOMO1(vs1.6c) for running SOMO1 - for hydraulic optimization problems such as water supply, conjunctive use and plume containment problems

Modular Groundwater Optimizer (MGO) is another software package for optimization of groundwater pump-and-treat systems developed by Chunmiao Zheng and P. Patrick Wang at the University of Alabama in cooperation with Groundwater Systems Research Ltd. The MGO software and installation details can be downloaded at www.frtr.gov/estcp/source_codes.htm.

The *Monitoring and Remediation Optimization System (MAROS)* software has been developed for AFCEC by Groundwater Services Inc. and the University of Houston. The software provides site managers with a strategy for formulating appropriate long-term groundwater monitoring programs that can be implemented at lower costs. MAROS is a decision support tool based on statistical methods applied to site-specific data that accounts for relevant current and historical site data as well as hydrogeologic factors (e.g., seepage velocity) and the location of potential receptors (e.g., wells, discharge points, or property boundaries). Based on this site-specific information the software suggests an optimization plan for the current monitoring system in order to efficiently achieve the termination of the monitoring program. Additional information is available and a link to the software can be found at http://www.frtr.gov/decisionsupport/DST_Tools/maros.htm.

Summit Monitoring Tools, developed by Summit Envirosolutions, Inc., is a set of desktop software tools that support comprehensive evaluation of LTM data relative to remedial targets. The software is designed to assist engineers, geologists, chemists, and others in reviewing site data. Three components comprise the Summit Monitoring Tools. The first, Model Builder, creates geostatistical or statistical models of spatial and temporal data. The second, Sampling Optimizer, identifies redundant sampling locations and frequencies in historical data, along with highlighting areas of 7-18 significant data uncertainty that may benefit from additional sampling. The third, Data Tracker, enables users to create time-dependent, site-wide remediation targets (e.g., expected reductions in mass) or well specific targets (e.g., expected concentration trends) and evaluate new data relative to those targets, providing automated alerts of unexpected deviations. The Summit Monitoring Tools are available at no cost for use at government sites (visit the ESTCP Web site for further information).

The Geostatistical Temporal/Spatial (GTS) algorithm is a decision logic-based strategy for optimizing long-term groundwater monitoring networks using geostatistical methods. The algorithm uses kriging to optimize sampling frequency and to define the network of essential sampling locations. The GTS software incorporates a decision pathway analysis that is separated into both spatial and temporal (i.e., location and frequency) components that integrate the optimization process and assist project managers in cost-effectively managing resources for monitoring both passive sampling networks and those that monitor the performance and/or effectiveness of remedial systems. The algorithm is used to identify spatial and temporal redundancies in existing monitoring networks and resolve them by recommending reductions in the frequency and number of monitored wells.

9.12 Example Statement of Work for Optimizing Remedial Action Operation

As mentioned in Section 1, several options are available for an RPM to implement an optimization study, including a NAVFAC EXWC and/or NAVFAC Atlantic Tiger Team, Internal FEC Tiger Team, Project Team Review, and Contracted Optimization Review. The following is an example Statement of Work that the RPM may use in cases where retaining an independent contractor to assess a RA-O and provide optimization recommendations is preferred. The Statement of Work specifies general requirements and four specific tasks that should be included in any optimization evaluation.

General Requirements: The contractor will employ a multi-disciplinary team and approach to assess and evaluate the efficiency and appropriateness of the RA-O strategy, adequacy of the LTMgt plan, and sustainability of the RA (***insert appropriate installation, operable units and/or sites***). This evaluation will be done in accordance with the DON *Guidance for Optimizing Remedial Action Operation (RA-O)* [41], the DON *Guidance for Planning and Optimizing Monitoring Strategies* [5], the *DON Guidance on Green and Sustainable Remediation* [6], and other applicable site-specific guidance documents and regulations. The primary purposes of the optimization assessment are to: (1) assess the relevance of the existing RA objectives and the adequacy of the existing system for achieving those goals; (2) evaluate whether the current RA-O is making progress toward attaining site RA objectives; (3) assess the sustainability of the current RAs; and (4) provide optimization recommendations to increase the effectiveness of RA-O while reducing the overall cost and remedy footprint. These objectives must be accomplished without loss of data and information quality.

In accomplishing this evaluation, it is anticipated that the contractor will require the following experience and expertise (edit list as appropriate). Individual project tasks are detailed in subsequent paragraphs.

- *Project Manager* with demonstrated optimization experience
- *Mid-level to senior-level geologist or hydrogeologist* with specific experience in the geologic formations at (***insert installation/region***)
- *Project chemist*
- *Statistician* with specific experience evaluating monitoring data
- *Toxicologist or risk assessment specialist*

- *CADD/GIS specialist*
- *Groundwater modeler*
- *Mid-level to senior-level engineer(s)* with passive (e.g., MNA) and active (e.g., pump and treat and in-situ treatment technology) remediation experience, and experience with GSR evaluations
- *Regulatory analysis specialist* with experience specific to (***insert State and U.S. EPA Region***) and (***insert governing program [e.g., RCRA or CERCLA]***)
- *Life cycle cost engineer/specialist* to evaluate cost savings, avoidance, and payback periods for appropriate recommendations and alternatives.

Task 1: Project Work Plan. Contractor will provide a work plan in draft and final versions. At a minimum, the work plan will include:

- Project description and objectives
- Project organization including roles, responsibilities, and contact information for team members
- Description and procedures for primary technical tasks
- List of project deliverables
- Schedule of primary project milestones.

Task 2: Site Visit and Data Gathering. The contractor will perform a site visit to collect the necessary data (***specified in Table 9-1***) and interview appropriate personnel to perform a comprehensive evaluation and assessment of the RA-O program at (***insert installation***). In order to assist installation personnel in preparing for the site visit, a letter request for site-specific data, along with a data needs checklist, will be submitted 3 to 4 weeks prior to the visit.

In addition, a pre-visit conference call will be conducted to review project goals and objectives, and coordinate on-site logistics and data gathering needs. The call will include the contractor project team, the responsible RPM from the supporting FEC, and representatives from (***insert installation***). During the site visit, a formal project in-brief and outbrief will be required.

Task 3: Remedial Action Operation Optimization Report. The contractor will produce a report detailing the overall approach, findings, conclusions, and optimization recommendations for (***insert installation***). The report will be delivered in working draft, draft, and final versions, and at a minimum will include an assessment of the elements listed below. In addition, all recommendations will have a suggested priority for implementation; and as appropriate, lifecycle cost savings and/or avoidance will be calculated and presented.

- Overview and goals of the RA-O, including regulatory framework, RA objectives, and site closeout strategy
- Adequacy of the CSM

- System description including extraction/injection wells or trenches, aboveground treatment train, and components of monitoring network
- Design basis including specifications and design parameters, system upgrades and modifications, and total capital costs
- Baseline of system performance, cost, and sustainability including all system components and O&M activities (e.g., extraction/injection well network, monitoring well network, and aboveground treatment train)
- Energy and consumables use
- Summary of system maintenance activities since last review
- Best technical and management practices already in place at the installation
- Frequency and approach for data evaluation, trend analysis, presentation, and reporting.

Table 9-1. Site Visit Data Collection Requirements

Data Requirement Categories	Specific Data Requirement
Understand Site Background and Conceptual Model	• Types of contaminants being removed and maps illustrating the lateral and vertical distribution of contamination • Estimated volume of contaminated medium or mass of contaminants in the medium • Any factors that could affect decisions at the remediation site/monitoring locations (e.g., mission-related needs, land use changes, site development, or attitudes and concerns of the public)
Verify Remedial Action Objectives and Cleanup Criteria	• Basis for cleanup objectives (e.g. risk based concentrations, ARARs, etc.) • The indicator(s) to be used to determine when monitoring can be stopped • State regulations or guidance used to set the sampling or measurement frequencies, analytes, or total time of monitoring • Ecological considerations and factors
Extraction and Treatment System Design Specifications	• As-built (if completed) drawings and descriptions of equipment and/or wells • As-built descriptions of sampling or measuring points, (depth, length, devices used) • Corrective measures study, feasibility study, and/or pilot test reports related to the existing remedial systems • Design analysis report • Groundwater modeling reports • Extraction well pumping test reports • Radius of influence reports for injection wells • Current or planned operations and maintenance manuals • Current or planned inspection/maintenance schedule • Annual log of material and energy usage for the RA and monitoring activities (e.g., chemical usage for in-situ treatment injection, GAC replacement, other residual disposal)
Ongoing Operation Costs (O&M)	• Equipment replacement costs • Current sampling costs: labor cost per location and cost of measurement or analysis • Annual power consumption and costs • Annual operating costs (labor, parts, chemicals, etc.) and/or budget • Handling, repackaging, transportation, or disposal costs

Task 4: Presentation of Optimization Report Conclusions and Recommendations. The contractor shall prepare for and attend a meeting to present the conclusions and recommendations contained within the report to applicable installation and regulatory agency personnel. A draft version of the presentation will be reviewed and approved by Navy personnel prior to the formal presentation to the regulatory agencies.

9.13 Acquisition Strategies for Remedial Action O&M

The approach to the management of program costs is defined by the contracting mechanism, approach and strategy. Contracting options are available which can be used to align O&M contractor's financial incentives with the goals of the remediation program.

9.13.1 Defining Program Cost Approaches

The appropriate use of contract mechanisms and performance measures is a necessary element to ensure optimal site closure. Contractor performance should be evaluated based on demonstrated cost-effective progress toward site closure. The use of appropriate contract mechanisms provides incentives to contractors while simultaneously protecting the interests of the Government.

For example, it is common for a contractor's performance evaluation to be based, in part, on the up-time for a remedial system. While percentage up-time can be an important performance measure, it is not always correlated with optimal progress toward site closure. This example becomes further confounded when the O&M contract vehicle is of the cost reimbursable type, where the majority of the performance risk lies with the Government. Table 9-2 provides guidance in forming and implementing an appropriate contract strategy.

9.13.2 Cost Reimbursable versus Fixed Price

Contract types fall into two major categories, fixed-price and cost-reimbursable, and are most notably distinguished from one another on the basis of the amount of risk associated with the costs of performance assumed by or allocated to the parties. Contractors assume the greatest amount of risk under fixed-price contracts because they are responsible for the costs of performance. Under cost reimbursement contracts, the Government assumes the risk for the cost of performance. Cost reimbursable contracts may be appropriate during initial startup of RAs. After the initial startup, fixed-price contracts are preferable during RAs.

The use of fixed-price, performance-based contract mechanisms is recommended where appropriate. Fixed-price contracts are a preferred mechanism when the project scope is well define and unlikely to be modified. This contract strategy provides an incentive to the contractor to conduct operations effectively and efficiently and manage costs. The disadvantages of this contract strategy include:

- The need to establish targets up front
- Potentially higher costs to offset the higher risk to the contractor
- Loss of cost savings if the actual costs are less than the fixed-price amount.

If fixed-price mechanisms are not available, cost-reimbursable, performance-based (cost-plus incentive fee or cost-plus award fee) contracts can be considered. The more a remedial system is subject to modifications, the more favorable a cost or cost plus award fee a contract becomes. This contract strategy still provides an incentive to the contractor to perform the work efficiently and control costs; however, the risks associated with the costs of performance are not assumed by the contractor.

Table 9-2. Contracting Guidance

Contract Strategy	Benefits	Remarks
Use fixed-price, performance-based contract mechanisms where feasible	• Provides operating flexibility and appropriate incentives for the contractor to focus on achieving site closure in the most optimal manner possible • Promotes financial risk sharing between the contractor and the Government	• Cost reimbursable contracts are appropriate during the first few months of operation (e.g., startup, shakedown, and optimization of new remedial systems). • If fixed-price mechanisms are not available, a cost plus incentive fee or a cost-plus award fee contract can be considered.
Establish a set of performance measures directly tied to the site closure strategy	• Ensures the contractor is operating and monitoring the system toward the ultimate goal of site closure	Example performance measures include the following: • Achievement of cleanup or closure-criteria by a specified time • Mass of contaminants removed • Percent reduction of contaminant mass or concentration • Reduction in total operating or monitoring costs
Establish a set of performance measures directly tied to the site closure strategy (continued)		• Zero permit violations • Maintaining a predetermined removal efficiency • Maintaining plume capture Note: Contractor's scope must provide authority to implement changes to achieve goals.
Issue work in bulk packages	• Reduced contract administrative burden • Reduced analytical and labor rates • Increased data quality	• Labor is reduced for the Government through minimizing the number of contracts requiring administration. • Labor and analytical rates are reduced by allowing on-site labor rates (no G&A surcharge) and bulk analysis discounts. • Data quality can be improved by coordinating sampling events and instructing laboratories to analyze all routine and quality control analyses in the same analysis batch.
Specify reporting, administrative, and analytical requirements in statements of work	• Provides program flexibility by allowing significant project parameters to be adjusted while not revising existing manuals or sampling plans	• Significant parameters include monitoring, reporting, sampling frequencies, and analytical methods-these parameters can be easily be modified to account for changing site conditions during remediation. • Often referred to as a “plug-in” Statement of Work.

9.13.3 Contractor Performance Incentives

Contractor performance incentives can be used to motivate the contractor to reduce costs, improve product/services, and reduce the delivery time. The performance metrics should be directly linked to the site closeout endpoint. Example performance measures include:

- Achievement of cleanup or closure criteria by a specified time
- Mass of contaminants removed
- Percent reduction of contaminated mass or concentration
- Reduction in total operating or monitoring costs
- Zero permit violations
- Maintaining a predetermined removal efficiency
- Maintaining plume capture.

Establishing these performance measures and basing performance incentives on them ensures that the contractor is operating and monitoring the system toward the ultimate goal of site closure. The contractor's scope must include the authority to implement changes to achieve site goals. Careful contract administration may be required with cost-reimbursable projects to ensure that excessive reimbursable costs are not incurred to achieve contract incentives.

10.0 WHERE ELSE CAN I GO FOR HELP?

***Content**: This section provides a listing of resources related to RA-O optimization. State and local regulators should be contacted for state-specific and local regulatory requirements. Section 15 of the DON Guidance for Planning and Optimizing Monitoring Strategies [5] provides links to all 50 state environmental agencies.*

10.1 Useful Web Sites

NAVFAC Environmental Restoration and BRAC (ERB). The NAVFAC ERB Web site provides innovative environmental cleanup technologies and approaches for the Navy and Marine Corps. The site covers information on environmental cleanup of Navy property contaminated with hazardous substances and provides details on the Navy's cleanup program, technologies, regulations and policies, outreach efforts, support services, and output from technical work groups.
https://portal.navfac.navy.mil/go/erb

Environmental Restoration Technology Transfer (ERT2) Multimedia Training Tools. Web-streaming multimedia tools are available at the ERT2 Web site and provide enhanced opportunity for NAVFAC to exchange information regarding environmental treatment technologies using animated graphic art, video, audio, electronic pictures, as well as text and hypertext Web links.
https://portal.navfac.navy.mil/portal/page/portal/navfac/navfac_ww_pp/navfac_nfesc_pp/environmental/erb/ert2/t2tools

NAVFAC Technology Transfer Optimization Web Site: This Web site provides direct links to Navy optimization policy and guidance documents, an optimization Web tool, case studies and other optimization related links.
https://portal.navfac.navy.mil/portal/page/portal/NAVFAC/NAVFAC_WW_PP/NAVFAC_NFESC_PP/ENVIRONMENTAL/ERB/OPT

Hazardous Waste Cleanup Information (Clu-In). The site is managed by the U.S. EPA, Technology Innovation Office. Clu-In provides information about innovative treatment technologies to the hazardous waste remediation community. The Technology Focus links provides information on sources for AS, bioremediation of chlorinated solvents, fracturing, ground-water circulating wells, in-situ flushing, in-situ oxidation, multi-phase extraction, natural attenuation, permeable reactive barriers, phytoremediation, soil vapor extraction, and thermal desorption. http://clu-in.org

Interstate Technology and Regulatory Council (ITRC). The ITRC is a coalition of state environmental regulators working with federal partners, industry and stakeholders to advance innovative environmental decision making. A remediation process optimization group was developed within ITRC and several guidance documents are available regarding optimization from the website. In addition, several technology specific groups have developed technology specific guidance documents (e.g., ISCO, in-situ bioremediation, DNAPL, LNAPL, unexploded ordinance, vapor intrusion). These guidance documents and other useful information can be found at the ITRC Web site. http://www.itrcweb.org/

Federal Remediation Technologies Roundtable. Includes links and chapters to RA-O technologies, work groups, publications, cost and performance information, case studies on full- and demonstration-scale remedial technologies, optimization and evaluation technology, remediation screening matrix, and sampling and analysis matrices. Of particular interest is the document, "Remediation Technologies Screening Matrix and Reference Guide." http://www.frtr.gov

United States Army Corps of Engineers (USACE). Web site provides multiple manuals and publications on remediation technology and services for the public and military. Useful programs include the Environmental Division and BRAC. The Military Programs Environmental Division provides management, design, and execution of a full range of cleanup and protection activities. There is also information on BRAC for multiple installations. http://www.usace.army.mil

The Air Force Civil Engineer Center. AFCEC provides a range of environmental, architectural and landscape design, and planning and construction management services and products. AFCEC provides research findings, fact sheets, documents, and manuals on remediation technology easily accessed through their search engine. http://www.afcec.af.mil/
Defense Environmental Network and Information eXchange (DENIX). DENIX provides DoD personnel with access to environmental legislative, compliance, restoration, cleanup, and DoD guidance information. It serves as a central electronic junction where information can be exchanged worldwide among environmental professionals. DENIX was developed and is maintained and operated by the USACE Construction Engineering Research Laboratories. http://www.denix.osd.mil

United States Environmental Protection Agency. The U.S. EPA Web site provides information on environmental laws and regulations, programs by media and topic, scientific and research-related programs, hotlines, publications, and a search engine. Links of interest include: (1) Enviroene, which provides pollution prevention, compliance assurance, enforcement information, and data bases, and (2) EPA REACH IT (Remediation and Characterization Innovative Technologies), a new system designed to search, view, download, and print information about innovative remediation and characterization technologies. The site provides links to technologies for treatment, characterization, or monitoring of a particular contaminated medium, information about service providers, and sites at which a particular type of technology has been implemented. http://www.epa.gov

10.2 Useful Documents

10.2.1 General Optimization

U.S. Army Corps of Engineers (USACE). 2003. "Engineering and Design - Safety and Health Aspects of HTRW Remediation Technologies." EM 1110-1-4007. August 15. This engineering manual identifies and analyzes generic safety and health hazards for 25 remediation technologies used in cleanup operations at HTRW sites.

Air Force Center for Engineering and the Environment (AFCEE). 2009. *Environmental Restoration Program – Optimization*. Revision 9.0. August.

Interstate Technology and Regulatory Council (ITRC). 2004. *Remediation ProcessOptimization: Identifying Opportunities for Enhanced and More efficient Site Remediation*. RPO-1. September.

Interstate Technology and Regulatory Council (ITRC). 2006. *Exit Strategy – Seeing the Forest Beyond the Trees*. RPO-3. March.

Interstate Technology and Regulatory Council (ITRC). 2006. *Performance-Based Management*. RPO-6. March.

Interstate Technology and Regulatory Council (ITRC). 2007. *Improving Environmental Site Remediation Through Performance-Based Environmental Management*. RPO-7. November.

U.S. EPA. *How to Evaluate Alternative Cleanup Technologies for Underground Storage Tank Sites: A Guide for Corrective Action Plan Reviewers*. EPA 510-B-94-003; EPA 510-B-95-007; and EPA 510-R-04-002).

10.2.2 Pertinent Guidance and Policy

Naval Facilities Engineering Command (NAVFAC) Headquarters (HQ). 2012. "Policy for Optimizing Performance and Sustainability of Remedial and Removal Actions at All Department of Navy (DON) Environmental Restoration Program Sites," April 2.

Department of Navy. 1998. "Technical Guidelines for Evaluating Monitored Natural Attenuation at Naval and Marine Corps Facilities," March.

U.S. EPA. 1998. EPA Technical Protocol for Evaluating Natural Attenuation of Chlorinated Solvents in Groundwater, September.

U.S. EPA. 1997. EPA OSWER Directive 9200.4-17: Use of Monitored Natural Attenuation at Superfund, RCRA Corrective Action, and Underground Storage Tank Sites (Interim Final December).

Department of Defense. 2001. *Guidance on Land Use Control Agreements with Environmental Regulatory Agencies*. March.

Department of Defense. 2001. Policy on *Land Use Controls Associated with Environmental Restoration Activities*. January 17.

Department of Defense. 2003. *Principles and Procedures for Specifying, Monitoring and Enforcement of Land use Controls and Other Post-ROD Actions*. October 20.

Department of Navy. 1999. *Land Use Controls, Interim Final (Policy Memorandum 99-02).* May 25.

Naval Facilities Engineering Command (NAVFAC). 2006. *Department of the Navy Guidance to Documenting Milestones throughout the Site Closeout Process* (UG-2072-ENV). March.

Naval Facilities Engineering Command (NAVFAC). 2007. *DNAPL Management Overview*. April.

Naval Facilities Engineering Command (NAVFAC). 2008. *Groundwater Risk Management Handbook.* January.

Naval Facilities Engineering Command (NAVFAC). 2010. *Guidance for Optimizing Remedy Evaluation, Selections, and Design* (UG-2087-ENV). March.

Naval Facilities Engineering Command (NAVFAC). 2010. *Department of the Navy Guidance for Planning and Optimizing Monitoring Strategies* (UG-2081-ENV Rev.1). November.

U.S. Department of Energy. 1997. "Uncertainty Management: Expediting Cleanup through Contingency Planning." DOE/EH/(CERCLA)-002.

U.S. Department of Energy. 1999. "Use of Alternate Concentration Limits (ACLs) to Determine Cleanup or Regulatory Levels Under RCRA and CERCLA." DOE/EM-413-9912.

U.S. EPA. 1988. "Guidance for Conducting Remedial Investigations and Feasibility Studies under CERCLA." Washington, DC. OSWER- 9355.3-01. (EPA). EPA publication order number: PB89-184626.

U.S. EPA, Office of Underground Storage Tanks. 1995. "How to Evaluate Alternative Cleanup Technologies for Underground Storage Tank Sites: A Guide for Corrective Action Plan Reviewers." EPA 510-B-95-007. (EPA). EPA publication order number: EPA 510-B-95-007 – This document is designed to determine whether appropriate cleanup technologies have been proposed and provides information on alternative cleanup technologies. The document provides detailed descriptions of ten alternative technologies: soil vapor extraction, bioventing, biopiles, landfarming, low-temperature thermal desorption, AS, biosparging, natural attenuation, in-situ groundwater bioremediation, dual-phase extraction.

10.2.3 Cost Information

Remedial Action Cost Engineering and Requirements (RACER) System is an electronic cost system that resides on a Microsoft® Access platform. The cost models are based on the parametric method of cost estimating and are validated using historical cost data. The cost engineering system is used primarily to price and program for the environmental cleanup requirements from current execution year through site close-out. The execution year projects use RACER as their baseline and are modified based on historical costs and RPM experience.

Cost and Performance Reports. The Navy has helped prepare cost and performance reports for multiple technologies, providing an in-depth evaluation of innovative technology. These reports are available on the NAVFAC ER Web site (https://portal.navfac.navy.mil/portal/page/portal/navfac/navfac_ww_pp/navfac_nfesc_pp/environmental/erb/documents-c). The Navy is now adding "sustainability" as an evaluation criterion in addition to cost and performance, as exemplified in the pending *Sustainable Cost and Performance Report for Permeable Reactive Barriers* to be released in early 2011.

Federal Remediation Technologies Roundtable. 1998. "Guide to Documenting and Managing Cost and Performance Information for Remediation Projects." EPA 542-B-98-007. 77 pp. (Clu-In) (U.S. EPA) – This document outlines the types of data that should be compiled to document the performance and cost of future cleanups for 13 technologies. The document also presents a standard set of parameters to be used for documenting completed remediation projects.

Yager, Kathleen and Robert Greenwald. 1999. "Pump and Treat Optimization Technology Brings Significant Cost Savings." *Ground Water Currents*. Issue No. 34. (EPA) – The U.S. EPA Technology Innovation Office and Office of Research and Development along with HSI GeoTrans, assessed the effectiveness of an optimization technology for pump and treat systems. Study results indicated that savings in O&M costs are possible. Primary objectives of the study included: (1) to evaluate a technology that could improve the efficiency of pump and treat systems along with reducing O&M costs, (2) to emphasize the importance of evaluating system performance on a regular basis, and (3) to develop guidance on when detailed optimization analysis is beneficial. The report includes the use of case studies.

10.2.4 Life Cycle Design

Interstate Technology and Regulatory Council (ITRC). 2006. *Life Cycle Cost Analysis*. RPO-2. March.

Nyer, E.K. 1996. "In-Situ Treatment Technology." CRC Press LLC.

10.3 Remedial Technologies

Pump and Treat

BMP sustainability EPA – Clu-in (referenced in GSR guide.)

U.S. EPA. 2008. *A Systematic Approach for Evaluation of Capture Zones at Pump and treat Systems*. EPA 600-R-08-003. January.

U.S. EPA. 2007. A *Cost Comparison Framework for Use in Optimizing Ground Water Pump and Treat Systems*. EPA 542-R-07-005. May.

U.S. EPA. 2002. *Elements for Effective Management of Operation Pump and Treat Systems*. EPA 542-R-02-009. December.

Air Sparging/Soil Vapor Extraction

Naval Facilities Engineering Service Center (NAVFAC). 2005. *Cost and Performance Report Multi-Site In Situ Air Sparging*. TR-2260-ENV. April.

ESTCP. 2002. *Air Sparging Design Paradigm*. - Design guidance that recognizes inherent complexities involved in operating an air sparging system. Core of paradigm is the approach recommended for air sparging pilot studies, full-scale design, and diagnostic testing.

Miller, Ralinda. 1996. "Air Sparging." Ground-Water Remediation Technologies Analysis Center." Pittsburgh, PA. (GWRTAC) – This technology summary report provides an overview of air sparging, including an introduction to its general principles, reported applicability and utilization, and advantages/disadvantages. A comparison to bioventing is also provided.

U.S. Army Corps of Engineers. 1997. "In-Situ Air Sparging." Engineering and Design. Washington, DC. EM 1110-1-4005. 154 pp. (USACE) – This engineering and design manual provides guidance for the evaluation of the feasibility of in-situ air sparging for remediation of contaminated groundwater and soil sites and to describe design and operational measures for in-situ air sparging systems.

U.S. Army Corps of Engineers. 1995. "Soil Vapor Extraction and Bioventing." Washington, DC. EM 1110-1-4001. 247 pp. (USACE) – This engineering and design manual provides guidance for the design and operation of soil vapor extraction and bioventing systems and provides a description of current best practices for soil vapor extraction and bioventing technologies and operations.

U.S. EPA. 1995. "Soil Vapor Extraction (SVE) Enhancement Technology Resource Guide: Air Sparging, Bioventing, Fracturing, Thermal Enhancements." (EPA) – This guide contains abstracts of SVE technology guidance documents, overview/program documents, studies and demonstrations, and other resource guides. Each technology is also summarized. For each technology, a matrix is provided to screen the abstracted references. Many of the documents listed within this guide are available from U.S. EPA.

WASTECH. 1998. "Vacuum Extraction and Air Sparging." Innovative Site Remediation Technology: Design & Application, Volume 7. American Academy of Environmental Engineers, Annapolis, MD. – This report is available from the American Academy of Environmental Engineering at (410) 266-3390. This report is a cooperative project managed by the American Academy of Environmental Engineers with grant assistance from the U.S. EPA, DOD, and DOE. This is one report of many publications that provide precise engineering information on, in this case, vacuum extraction and air sparging.

Soil Vapor Extraction

U.S. EPA. July 20, 1999. HyperVentilate (free computer software). (EPA) - HyperVentilate is a user friendly software that aids in the use of vapor extraction (soil venting) technology. The software helps the user identify and characterize site-specific data, decide if soil venting is the appropriate technology, evaluate air permeability test results, calculate the number of extraction wells needed, and compares your site results to an ideal situation.

Bioventing

Air Force Center for Environmental Excellence. 1994. "Bioventing Performance and Cost Summary, Draft." Brooks AFB, TX. (AFCEE)

Department of Energy. 1993. "Methanotrophic In-Situ Bioremediation Using Methane/Air and Gaseous Nutrient Injection Via Horizontal Wells, Technology Information Profile Rev. 2." DOE ProTech Database. TTP Reference No.: SR-1211-06.

U.S. Air Force Environics, Air Force Center for Environmental Excellence, and U.S. EPA Office of Research and Development. September 1995. "Principles and Practices of Bioventing, Volume I: Bioventing Principles." EPA 540-R-95-534a. USAF AL/EQ-TR-1995-0037. (EPA).

EPA Publication Order Number: EPA 540-R-95-534a. This manual was prepared by Battelle Memorial Institute for the U.S. Air Force and U.S. EPA. The manual contains information on bioventing principles, site characterization, field treatability studies, system design, installation, and operation, process monitoring, site closure, and other technologies.

U.S. Air Force Environics, Air Force Center for Environmental Excellence, and U.S. EPA Office of Research and Development. September 1995. "Principles and Practices of Bioventing, Volume II: Bioventing Design." EPA 625-xxx-001. USAF AL/EQ-TR-1995-0037. (EPA) EPA Publication Order Number: EPA 625-xxx-001. This manual was prepared by Battelle Memorial Institute for U.S. Air Force and U.S. EPA. The second volume of "Principles and Practices of Bioventing" focuses on bioventing design and process monitoring.

Wisconsin Department of Natural Resources. July 1993. "Guidance for Design, Installation and Operation of Soil Venting Systems." Madison, WI: Emergency and Remedial Response Section. PUBL- SW185-93. This document is intended to guide professionals in designing soil venting systems for soil contaminated with volatile organic compounds. This document discusses the basics of soil venting system design, technical considerations, site characterization, treatability or pilot testing, design and installation, operation, and references.

Multi-Phase Extraction

Miller, Ralinda. 1996. "Bioslurping." Ground-Water Remediation Technologies Analysis Center. Pittsburgh, PA. (GWRTAC). This is a technology overview report of bioslurping, providing an introduction to its general principles, reported applicability and utilization, and cited advantages and disadvantages.

U.S. Air Force. 1995. "Draft: Test Plan and Technical Protocol for Bioslurping." Air Force Center for Environmental Excellence, Brooks AFB, TX. A324068.

U.S. EPA Office of Solid Waste and Emergency Response. 1997. "Analysis of Selected Enhancements for Soil Vapor Extraction." EPA/542/R-97/007. 246 pp. (EPA). EPA publication order number: EPA/542/R-97/007. This report evaluates five SVE enhancement technologies, including: air sparging, dual-phase extraction, directional drilling, pneumatic and hydraulic fracturing, and thermal enhancement. For each technology, the report provides background and applicability information, an engineering evaluation, an evaluation of performance and costs, a list of vendors, a discussion on its strengths and limitations, recommendations for future use and applicability, and references.

Wickramanayake, G.B., et al. 1996. "Best Practices Manual for Bioslurping." Technical Memorandum. Naval Facilities Engineering Service Center, TM-2192-ENV. (NAVFAC ESC). This document was prepared by Battelle. This document provides information on the use of bioslurping, bioslurper feasibility testing, installation, implementation, data reduction and results interpretation, system operation and performance monitoring, cost-estimating guide, and references.

Enhancement of In-situ Bioremediation for Fuel and Chlorinated Contaminated Sites

Bioremediation of Chlorinated Solvents Consortium of the Remediation Technologies Development Forum (RTDF). May 1997. "Natural Attenuation of Chlorinated Solvents in Groundwater: Principles and Practices." Version 3.0. (EPA). This manual is formatted as a quick reference, question and answer document, discussing the science and practice of natural attenuation of chlorinated solvents. The manual includes an introduction, background information on the technical challenges at chlorinated solvent contaminated sites and types of chlorinated solvent attenuation processes, evaluation of natural attenuation, and methodology used to evaluate and implement natural attenuation.

ESTCP and DoD. 2004. *Principles and Practices of Enhanced Anaerobic Bioremediation of Chlorinated Solvents*.

U.S. EPA. 2007. *The Use of Soil Amendments for Remediation, Revitalization, and Reuse*.

U.S. EPA. 2000. *Engineered Approaches to In Situ Bioremediation of Chlorinated Solvents: Fundamentals and Field Applications*.

ITRC. 2005. Characterization, Design, Construction, and Monitoring of Mitigation Wetlands. WTLND-2. February.

ITRC. 2007. *In Situ Bioremediation of Chlorinated Ethene DNAPL Source Zones: Case Studies*. BIODNAPL-2. April.

ITRC. 2008. *In Situ Bioremediation of Chlorinated Ethene: DNAPL Source Zones*. BIODNAPL-3. June.

ITRC. 2008. *Enhanced Attenuation: Chlorinated Organics*. EACO-1. April.

Grindstaff, Megan. 1998. "Bioremediation of Chlorinated Solvent Contaminated Groundwater." U.S. EPA Technology Innovation Office. (Clu-In). The purpose of this document is to present information regarding field applications of enhanced in-situ bioremediation for treating groundwater contaminated with chlorinated solvent. It also includes a discussion on bioremediation technologies and cost and performance for nine applications.

U.S. EPA. "Methodologies for Evaluating In-Situ Bioremediation of Chlorinated Solvents." EPA Bioremediation Publications. NTIS PB92-146943. (EPA)

In -Situ Chemical Oxidation

ITRC. 2005. *Technical and Regulatory Guidance for In Situ Chemical Oxidation of Contaminated Soil and Groundwater – Second Edition*.

U.S. EPA. 1998. "Field Applications of In-Situ Remediation Technologies: Chemical Oxidation." EPA 542-R-98-008. 37 pp. (EPA). EPA document order number: EPA 542-R-98-008. This report documents pilot demonstrations and full-scale applications of soil and groundwater treated either in place or through an increase in the solubility and mobility of contaminants to improve their removal by other remediation technologies.

In-Situ Thermal Treatment

U.S. EPA. 2004. *In Situ Thermal Treatment of Chlorinated Solvents: Fundamentals and Field Applications*.

USACE. 2009. *Engineering and Design Manual, Design: In Situ Thermal Remediation*.

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