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Guidance for Optimizing Remedial Action Operation (RAO)

Interim-Final

April 2001

Prepared for
Department of the Navy RAO/LTM Optimization Working Group

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INTERIM FINAL

**Guidance for Optimizing
Remedial Action Operation (RAO)**

Prepared for:
Naval Facilities Engineering Service Center
Port Hueneme, California

Prepared by:
Radian International
P.O. Box 13000
Research Triangle Park, North Carolina 27709

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Preface

The goal of “optimization” is to achieve site closeout in the shortest amount of time and to minimize the cost of environmental restoration (ER) projects without sacrificing data quality and the ability to make environmentally protective decisions. As the Department of the Navy (DON) ER Program matures, more projects are entering the post-remedy selection phase where millions of dollars can be spent operating, monitoring, and maintaining remediation systems. The DON is committed to optimizing the program through careful evaluation of project goals, remediation system effectiveness, life cycle design and cost analyses, and data management and reporting. This *Guidance for Optimizing Remedial Action Operation (RAO)* presents a step-wise process for optimizing RAO projects as developed by the Navy RAO/Long Term Monitoring (LTM) Optimization Working Group. The objective of this guidance document is to provide information to remedial project managers (RPMs) and their contractors so they can readily implement to reduce operating costs while maintaining program effectiveness. As we understand more about remediation projects and how they can be optimized, we can also apply that knowledge to the remedial design. This guidance presents the concept of life cycle design for optimizing existing RAO projects. This concept should also be applied to the remedial design phase.

The *Guidance* and the optimization process were based largely on the findings from RAO optimization case studies conducted by the Working Group at several Navy and Marine Corps installations. The remediation technologies included in the case studies were pump and treat, air sparging/soil vapor extraction, bioslurping, and in-situ chemical oxidation. For two DON in-house case studies, the Engineering Field Division/Activities (EFD/A) optimized the RAO programs and provided information to prepare brief case study reports. For seven other case studies, contractors provided recommendations for optimizing RAO programs and/or developed strategies for site closeout. Examples from the case studies are provided throughout this document to highlight technical points and concepts. Summaries of the case study reports are provided in Appendix B of this document. In house Navy case studies where EFD/As undertook actions to optimize their own RAO optimization programs are provided in Appendix C. 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.

This document is written in general language to apply to a variety of site conditions, but at the same time provides guidance for RAO optimization of specific technologies. Technology-specific optimization strategies for common remedial system operational problems are provided in Appendix A. The *Guidance* is intended to provide RPMs with the information they need to understand the main points of RAO optimization so that they can apply the process to their programs. The optimization steps described in the document generally follow the approach implemented in completing the case studies.

The *Guidance* focuses on a step-wise process to maximize cost-effectiveness without compromising program and data quality. These steps are:

1. Review and Evaluate Remedial Action (RA) Objectives
2. Evaluate Remediation Effectiveness
3. Evaluate the Cost Effectiveness
4. Consider Remediation Alternatives
5. Develop and Prioritize Optimization Strategies
6. Prepare an Optimization Report and Implement the Optimization Strategy

Optimization should be an iterative and systematic process. Ideally, RAO projects should be evaluated and optimization recommendations should be generated annually. Optimization reports should be prepared in time to allow RPMs to include any changes in their annual budget requests. Regular evaluations and organization of monitoring data will also streamline the 5-year review process.

The Navy *Guide to Optimal Groundwater Monitoring* is a companion document to this guidance that discusses monitoring optimization; therefore this RAO optimization guidance defers monitoring issues to that document. Other Department of Defense (DOD) documents were also referenced for additional ideas on optimizing RAO programs at military installations.

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LIST OF ACRONYMS

ACL(s)	Alternate Concentration Limit(s)
AFCEE	Air Force Center for Environmental Excellence
AFVR	Aggressive Fluid Vapor Recovery
AS	Air Sparging
ASTM	American Society for Testing and Materials
bgs	below ground surface
BRAC	Base Realignment and Closures
BTEX	Benzene, toluene, ethylbenzene and xylene
CERCLA	Comprehensive Environmental Response, Compensation, and Liability Act
CNO	Chief of Naval Operations
COC(s)	Contaminant(s) of Concern
CSM	Conceptual Site Model
CSMoS	Center for Subsurface Modeling Support
DCE	cis-Dichloroethene
DNAPL(s)	Dense Non-Aqueous Phase Liquid(s)
DOD	Department of Defense
DON	Department of the Navy
DPE	Dual-Phase Extraction
DRMO	Defense Reutilization and Marketing Office
EC(s)	Engineering Control(s)
EFD/As	Engineering Field Division/Activities
EISB	Enhanced Insitu Bioremediation
EPA	Environmental Protection Agency
ER	Environmental Restoration
ESD	Explanation of Significant Difference
GAC	Granular Activated Carbon
GIS	Geographical Information System
HRC	Hydrogen Release Compound
HTRW CX	Hazardous, Toxic, and Radioactive Waste Center of Expertise
IC(s)	Institutional Control(s)
LNAPL	Light Non-Aqueous Phase Liquid
LTM	Long Term Monitoring
LTMgt	Long Term Management
LUC(s)	Land Use Control(s)
MCAS	Marine Corps Air Station
MCB	Marine Corps Base
MCL(s)	Maximum Contaminant Level(s)
MNA	Monitored Natural Attenuation
MPE	Multi-Phase Extraction
NAS	Naval Air Station
NAVFAC	Naval Facilities Engineering Command
NPL	National Priorities List
NPV	Net Present Value
NSB	Naval Submarine Base
NEX	Naval Exchange
NFESC	Naval Facilities Engineering Service Center
O&M	Operations and Maintenance
ORC	Oxygen Release Compound

LIST OF ACRONYMS (continued)

PCB(s)	Polychlorinated biphenyls
PDF	Portable Document Format
POTW	Publicly Owned Treatment Works
ppb	parts per billion
ppmv	parts per million by volume
RA	Remedial Action
RAO	Remedial Action Operation
RBCA	Risk-Based Corrective Action
RC	Response Complete
RCRA	Resource Conservation and Recovery Act
ROD	Record of Decision
RPM(s)	Remedial Project Manager(s)
RSE	Remediation System Evaluation
SVE	Soil Vapor Extraction
SVOC(s)	Semi-Volatile Organic Compound(s)
TCE	Trichloroethene
TI	Technical Impracticability
TPE	Two-Phase Extraction
TPH	Total Petroleum Hydrocarbon
TSDf(s)	Treatment, Storage, and Disposal Facilities
USACE	U.S. Army Corps of Engineers
UST	Underground Storage Tank
UV	Ultraviolet
VC	Vinyl Chloride
VOC(s)	Volatile Organic Compound(s)
VMP	Vapor Monitoring Points

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. As the attention has recently shifted toward remedy selection, remedial design, and remedial action construction, the number of Navy/Marine Corps sites in the remedial action operation (RAO) and long term management (LTMgt) phases is expected to increase. The growing number of Navy/Marine Corps sites advancing to the RAO and LTMgt phases will soon represent the majority of the ER Program budget requirements. Optimization is becoming a necessary process to allow the remedial project manager (RPM) to manage RAO programs within budgetary constraints.

The DON formed a Working Group to provide guidance to the DON activities for optimizing RAO and groundwater monitoring at Navy installations. This Working Group, led by the Naval Facilities Engineering Service Center (NFESC), is made up of engineers and scientists from NFESC, Naval Facilities Engineering Command (NAVFAC), Engineering Field Divisions/Activities (EFD/A), and Chief of Naval Operations (CNO).

This document provides guidance on the optimization of RAO programs and serves as a companion document to the *Guide to Optimal Groundwater Monitoring* (NFESC 2000).

1.1 What is Optimization and Why is it Important?

Optimization is a process to streamline RAO programs by maximizing remedial effectiveness and cost efficiency. 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 response complete (RC) and ultimately site closeout in the shortest amount of time and with the least possible expenditure.

Life cycle design is an important element in the optimization process. The concept of life cycle design helps the RPM focus on the main strategies necessary to optimize a remediation system. The basis of this concept is that the requirements for groundwater and/or soil remediation will change over time due to changes in contaminant concentrations. This concept will allow the RPM to understand the limitations of a remediation system and to design a remedial strategy that will address all the conditions encountered during remediation. Life cycle design is discussed in more detail in Section 3.2.3.

The benefits of RAO optimization include:

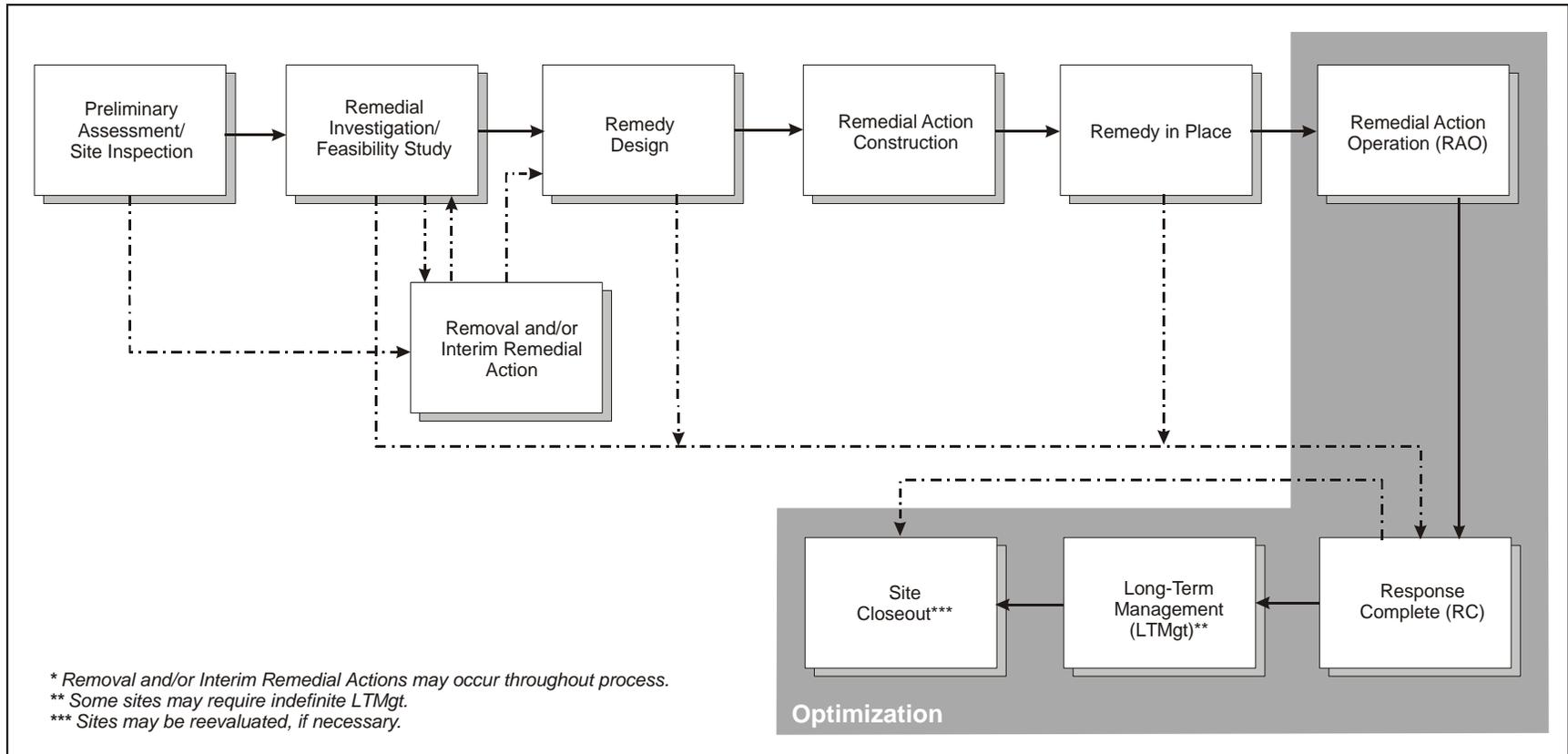
- Ensuring that the remedial action (RA) remains protective of human health and the environment
- Enhancing the effectiveness of RAs toward achieving remedial objective
- Reducing operation and maintenance (O&M) costs
- Accelerating the site closeout schedule

1.2 How Can This Manual Help?

The *Guidance for Optimizing Remedial Action Operation* focuses on the most significant ways to design and optimize RAO programs in order to maximize cost efficiency while maintaining remedial effectiveness. This guidance manual contains:

- Detailed explanations of the RAO optimization process
- References to tools that the RPMs may use in the RAO optimization process
- Technology-specific optimization strategies for common remedial system operational problems
- Summaries of RAO optimization case studies conducted at Navy/Marine Corps installations
- Examples of RAO optimization technical points and concepts based on “lessons learned” from the case studies

Although this guidance manual is primarily intended for the optimization of existing remediation systems, these optimization principles can also complement the remedial design process to promote the design and installation of more effective and efficient remediation systems.



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Figure 1-1. Department of Navy environmental restoration process for CERCLA sites.

2.0 What is the Remedial Action Operation Optimization Process?

The RAO optimization process is designed to evaluate the site remedial strategy, remedial system design, remedial effectiveness, and cost efficiency. Based on this evaluation, strategies 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, RAO programs may be evaluated and optimized as often as annually, or less frequently depending on the progress of the RAO in achieving its objectives.

In general, “lessons learned” from RAO optimization case studies performed at several Navy/Marine Corps installations were used to develop the RAO optimization process. These case studies cover a wide range of remediation technologies, including pump and treat, air sparging/soil vapor extraction, bioslurping, and in-situ chemical oxidation. 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 RAO programs. Specifically, the Air Force, Air Combat Command *Environmental Restoration Program Site Closure Guidance Manual* (1997) and the Air Force Center for Environmental Excellence (AFCEE) *Remedial Process Optimization Handbook* (AFCEE 1999) were used as models for this guidance document.

The RAO 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 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 should determine whether the existing remediation system is capable of achieving the RA objectives within a reasonable timeframe.

Step 3. Evaluate Cost Efficiency – After verifying that the remediation system can achieve RA objectives, the RPM should determine the cost efficiency of the system. By relating cost and performance data, the evaluation of cost efficiency verifies efficient operations of the remediation system.

Step 4. Identify Remediation Alternatives – Based on the evaluations of remediation effectiveness and cost efficiency, the RPM should identify alternatives for optimizing the remediation system. Remediation alternatives that may be considered include modifications to the existing remediation system, selection of alternative remediation systems, and the use of alternative regulatory mechanisms.

Step 5. Develop and Prioritize Optimization Strategies – The RPM should formulate optimization strategies from the potential remediation alternatives and prioritize these strategies based on a relative cost-benefit analysis of life cycle costs.

Step 6. Prepare Optimization Report – The RPM should document the findings of the remediation system evaluation and the preferred optimization strategy in an optimization report.

Step 7. Implement Optimization Strategy – The preferred optimization strategy should be implemented following the implementation plan developed by the RPM.

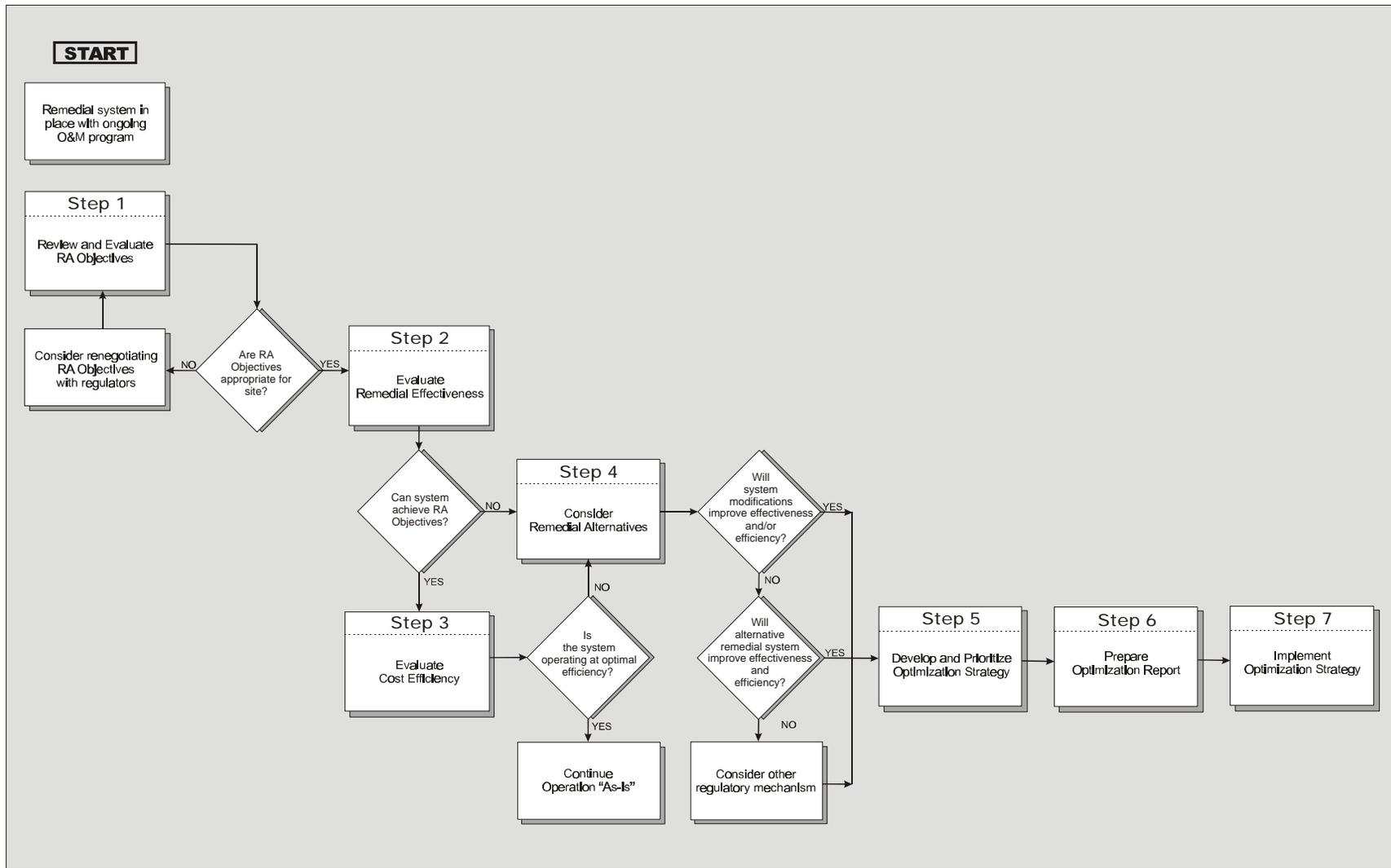


Figure 2-1. Remedial action operation optimization process .

3.0 Review and Evaluate Remedial Action Objectives

Content: *The first step of the RAO 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 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 the Conceptual Site Model

The CSM is the basis for defining the RA objectives, determining the restoration potential of the site, and evaluating the effectiveness of the existing remediation system. The verification and revision, if necessary, of the CSM ensures that changes in the site and the surrounding area, such as 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.

Verifying the CSM also provides an opportunity to update the CSM by incorporating the most recent O&M and monitoring data. The operating and monitoring data provides current information concerning:

- Hydrogeology
- Types of contaminants removed
- Lateral and vertical distribution of contamination
- Estimated volume of contamination
- Other factors that could affect decisions at the remediation site/monitoring locations, such as mission-related needs, site development and other land use changes

In some cases, additional field investigations may also be necessary to obtain information to update the CSM.

A detailed description of CSMs can be found in Section 2.2.1 of the Navy's *Guide to Optimal Groundwater Monitoring*. Additional information on CSMs can be found in the American Society for Testing and Materials (ASTM) *E1689-95 Standard Guide for Developing Conceptual Site Models for Contaminated Sites* (ASTM, 1995). An example of a CSM diagram is presented in Figure 3-1.

Example: *The review of current conditions at Marine Corps Base (MCB) Camp Lejeune OUI South site identified significant changes in the spatial distribution of the contaminant plume. Recent groundwater monitoring data were used to evaluate the size of the contaminant plume. The data revealed that the contaminant plume had stabilized and possibly decreased in size. The current conditions were incorporated into the CSM and used to support the recommendation to shut down the pump and treat system and to evaluate natural attenuation as the final remedy.*

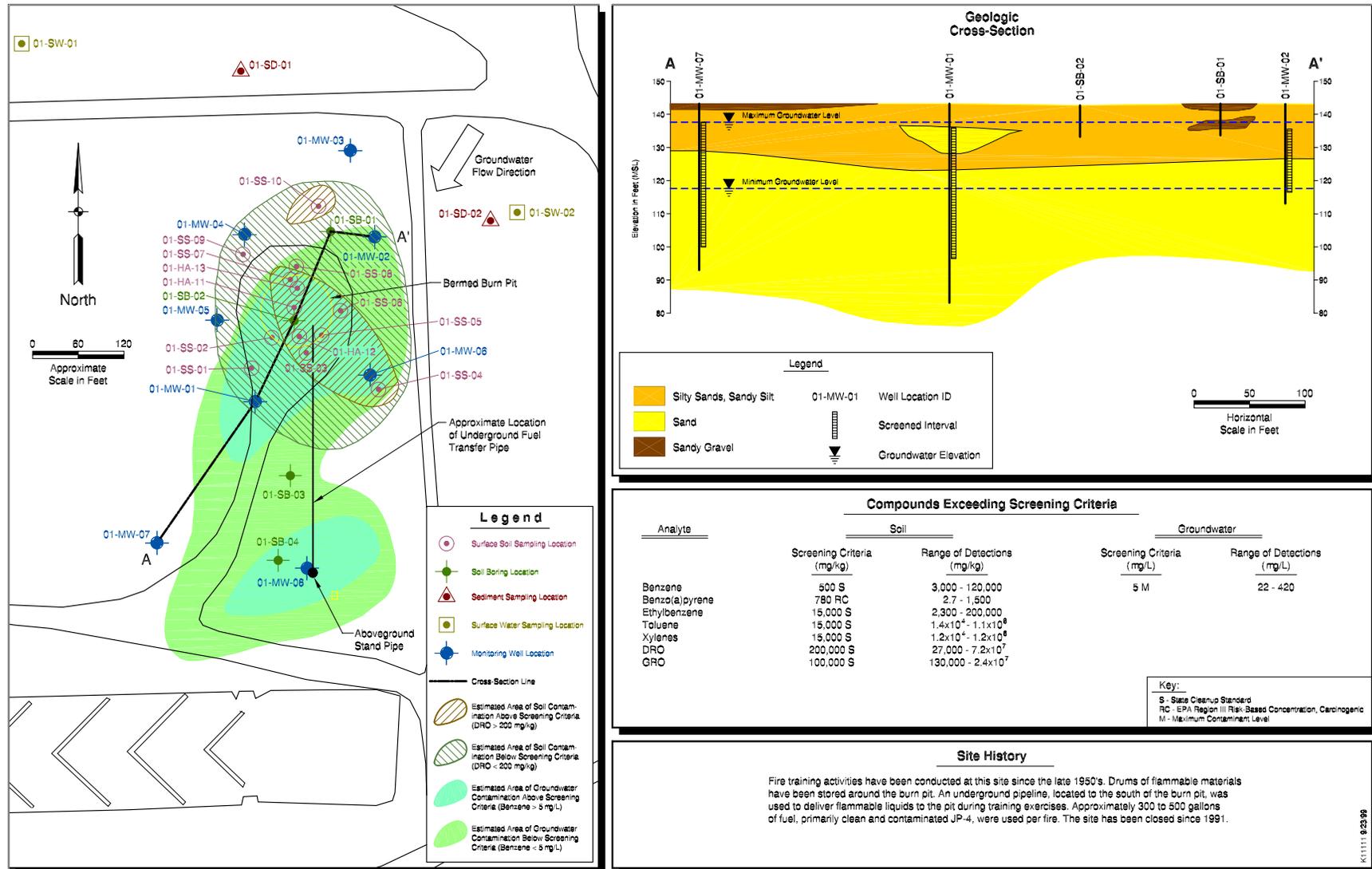


Figure 3-1. Example conceptual site model.

3.2 Verifying Remedial Action Objectives

The RA objectives are criteria that determine when site conditions are no longer considered a risk to human health or the environment, and site closeout may be pursued. The RA objectives must be as specific as possible in order to focus the remedy decision process and should specify:

- Contaminants of concern (COC)
- Exposure routes and receptors
- Cleanup goals (concentrations) for each exposure route

To verify RA objectives, these cleanup criteria should be reviewed and compared with the existing CSM and the life cycle design to determine whether they remain appropriate for the site. An example of RA objectives, presented as part of the regulatory framework for the remedial site, is provided in Table 3-1.

Table 3-1. Regulatory Framework Summary for MCB Camp Lejeune, OU1

Site	Description	Contaminated Media	Contaminants of Concern	Cleanup Goals	Remedial Action Objectives
21	Transformer Storage Lot 140	Soil	Pesticides and PCBs	<u>Groundwater:</u> Federal MCLs, state groundwater standards, risk-based levels <u>Soil:</u> EPA Region III RBCs	Three consecutive rounds in which samples have non-detect concentrations or concentrations protective of human health have been demonstrated to the satisfaction of the regulatory agencies.
24	Industrial Fly Ash Dump	Groundwater and soil	<u>Groundwater:</u> metals and heptachlor epoxide <u>Soils:</u> pesticides and metals		
78	Hadnot Point Industrial Area	Groundwater and soil	<u>Groundwater:</u> VOCs (BTEX and chlorinated solvents) and metals <u>Soils:</u> pesticides and SVOCs		

3.2.1 Exposure Routes and Receptors

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. The CSM represents the current conditions at the site and serves as the basis for this review. This review of the exposure routes and receptors should consider:

- Modifying the list of COCs based on the past year of monitoring
- Revising the exposure routes (i.e., groundwater, soil or surface water) based on current contaminant distribution
- Identifying any new receptors that may be affected by the contamination

It is also important that the monitoring well network reflects any changes in exposure routes and receptors. The purpose of each monitoring well should be clearly defined as an in-plume, background, point-of-compliance, or sentinel well. Also, the timeframe required for each of these monitoring wells 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 Navy's *Guide to Optimal Groundwater Monitoring*.

3.2.2 Cleanup Goals

Regulatory standards are commonly used to establish cleanup goals. More recently, risk-based goals have gained greater acceptance from the regulatory community. Cleanup goals should be reviewed to confirm that they remain appropriate for the remedial site.

Regulatory Goals – Regulatory programs, such as Resource Conservation and Recovery Act (RCRA), Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA), and state underground storage tank (UST) programs, commonly establish maximum contaminant levels (MCL) as the cleanup goals. These MCLs, however, are not always appropriate for a remedial site. For example, if the groundwater is not a potential drinking water source, cleanup to MCLs may be overly conservative. Also, MCLs do not consider the source of contamination or site conditions. Thus, cleanup goals may be established for compounds that are naturally occurring in the aquifer and not related to the release of contamination.

Example: At MCB Camp Lejeune OUI South, the COC include petroleum contaminants (i.e., benzene, toluene, ethylbenzene, and xylene [BTEX]), chlorinated solvents, and metals in groundwater. Results of remedial investigation indicated that concentrations of metals in groundwater were uniformly distributed across the site. Subsequent development of a database 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.

Risk-Based Goals – Under the Superfund program, the results of qualitative and quantitative risk assessments are used to establish the need for remedial action and determining remediation alternatives. Also, to simplify baseline risk assessments for Superfund sites, the EPA has developed generic soil screening guidance that differentiates between contamination levels that present no health risk and those that potentially require additional investigation. The EPA can also require the assessment of human health risk as well as ecological risk at a facility under the RCRA Corrective Action Program. If necessary, a baseline risk assessment is completed during the RCRA Facility Investigation and further analysis conducted during the CMS. The results of the assessment are used to establish cleanup goals and to prioritize cleanup of high-risk sites.

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 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.

Example: The evaluation of cleanup goals at the MCB Camp Lejeune, RR-72 site resulted in risk reclassification using risk-based standards for petroleum USTs. Under the previously applicable regulation, continued action was required to remediate the groundwater to the applicable drinking water standards. Recently adopted new regulations for petroleum USTs allowed sites to be re-evaluated using risk-based standards. Under these risk-based standards, it was recommended that the RR-72 site be reclassified as a low-risk site requiring no further action.

3.2.3 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 verifying the RA objectives. As the remediation system

continues to operate, contaminant concentrations decrease over time until asymptotic conditions are reached (Figure 3-2). 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
- O&M costs are not decreasing, despite the decrease in mass removal rate

The remediation strategy must account for the entire life of the project, not just the conditions found at the beginning of the project. When the remedial system removes and/or destroys high concentrations of contamination, the mass removal is limited by the remedial system's ability to "reach" the contamination. During this period, referred to as the mass removal portion of the life cycle, the number of pore volumes extracted by remediation system determine the amount of mass removal.

As contaminant concentrations decrease, diffusion processes limit the ability of the remedial system to remove contaminant mass. Different remediation technologies may have to be applied to a site at different periods of the life cycle curve. For example, a remedial site may use excavation, soil vapor extraction, pump and treat, and Monitored Natural Attenuation (MNA) as remediation technologies to address various periods of the life cycle curve.

The RA objectives should provide clear technical and/or cost-based criteria that can be used to determine when remediation technologies have reached their technical limits and alternative technologies should be implemented. These criteria may also be used to determine when cleanup goals cannot be achieved at a site and the RA objectives must be modified or alternative regulatory mechanisms must be employed.

Example: An overall plume management strategy has been implemented at Naval Submarine Base (NSB) Kings Bay and Naval Air Station (NAS) Pensacola. For each installation, a long-term pump and treat program was terminated after asymptotic conditions were achieved. In-situ chemical oxidation using Fenton's Reagent method was successfully implemented to substantially reduce source area concentrations and to ensure the protectiveness and timeliness of MNA as the final remedy.

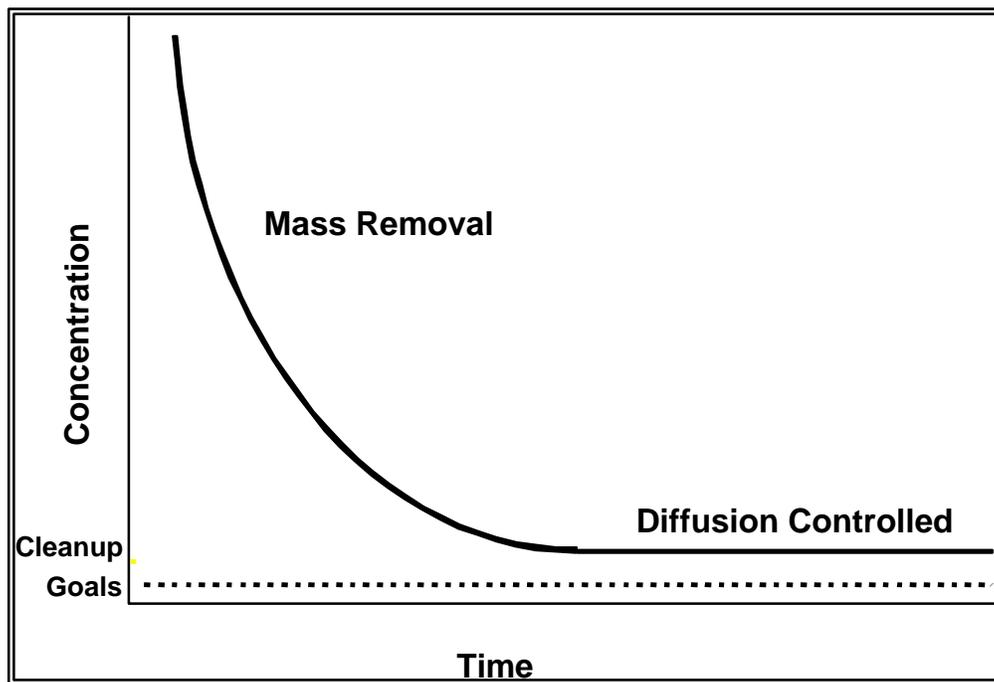


Figure 3-2. Reaching asymptotic conditions before achieving cleanup goals.

4.0 Evaluate Remediation Effectiveness

Content: *The second step of the RAO 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 is 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 contaminant concentrations
- Groundwater level monitoring, including free product levels
- System influent contaminant concentrations
- 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.

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, 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 gradients are established and maintained.	Inability to establish and/or maintain inward hydraulic 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.

These parameters can be evaluated by applying GIS tools to prepare plots of remedial performance data for each monitoring point and extraction well. Maps and cross-sections illustrating groundwater potential and contaminant distribution should also be prepared to analyze capture zones and dynamics of the contaminant plume, respectively. From these performance plots, maps and cross-sections, trends can be

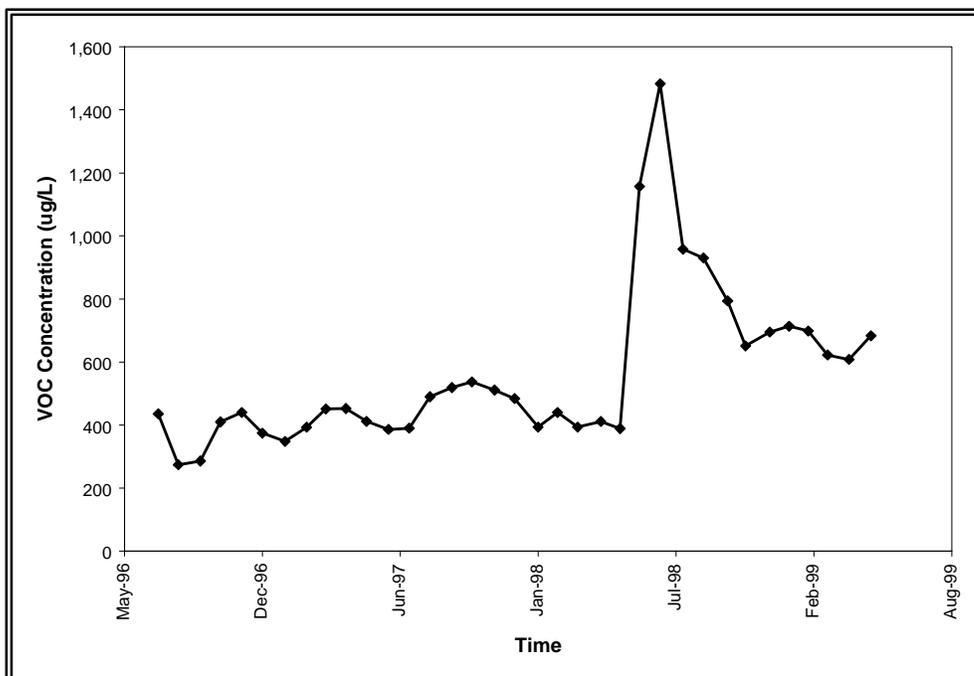
identified over time and distance to determine if the remediation system is capable of achieving cleanup goals.

Performance plots of contaminant concentrations versus time should also 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 may be used for time-series analysis to visualize contaminant trends for performance evaluation.

Figures 4-1 through 4-4 provide examples and evaluations of remedial performance plots for time-series data and spatial data.

Contaminant influent concentrations versus time – Time-series performance plots of contaminant influent concentrations 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 should be prepared for each individual extraction well, as well as the total system influent, to evaluate the remedial effectiveness of each extraction well and the overall remedial system.

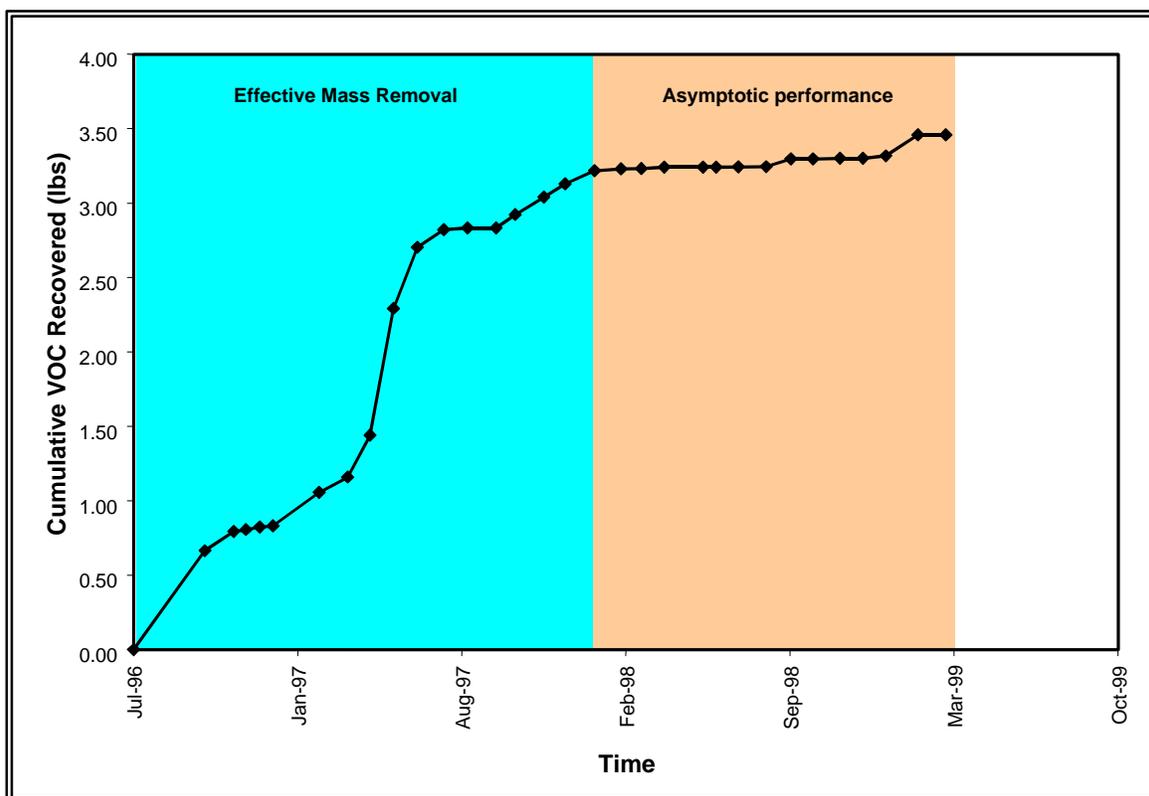
Example: A pump and treat system was installed to contain and remediate the Eastern Plume at NAS Brunswick. Figure 4-1 is a time-series plot of contaminant concentration in the influent to the treatment plant. In this example, total volatile organic compound (VOC) influent concentrations have generally increased since system start-up. The sharp increase in 1998 represents the addition of an extraction well within a contaminant hot spot in the plume. System performance was enhanced not only by properly locating the well within the plume, but by also isolating the well screen to the most contaminated interval in the aquifer.



**Figure 4-1. Contaminant influent concentrations versus time
NAS Brunswick, eastern plume.**

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 may 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.

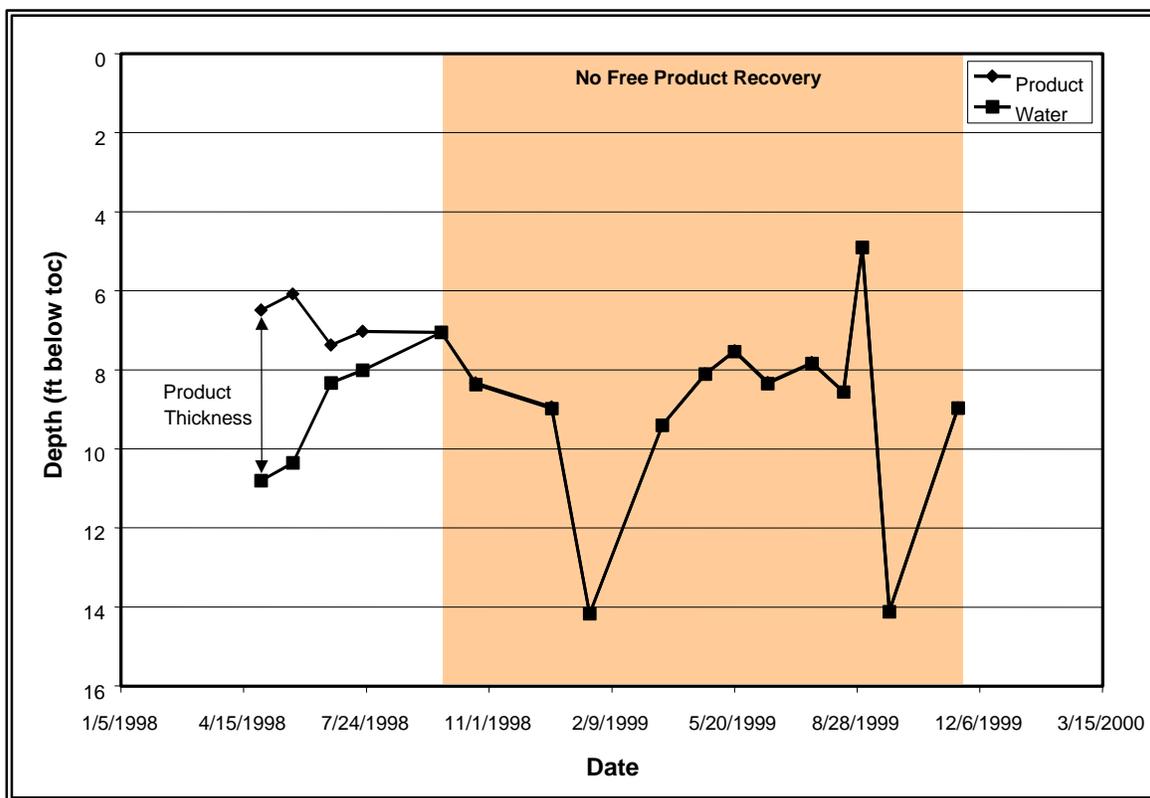
Example: A pump and treat system was installed to contain and remediate a plume at the Campbell Street Fuel Farm at Marine Corps Air Station (MCAS) New River. Figure 4-2 is a time-series plot of contaminant mass removed by the pump and treat system. In this example, the system has removed less than 3.5 pounds of contaminants during an operational period from July 1996 through March 1999. Less than 0.5 pounds of VOC have been removed since December 1997, which is manifested by the asymptotic condition depicted in the graph. Asymptotic conditions are a clear indication that the system is no longer productive and alternative remedies should be explored if site closeout cannot be justified.



**Figure 4-2. Cumulative mass recovered versus time
MCAS New River, Campbell Street Fuel Farm.**

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 an increase in product thickness indicates that the remedial system is either not recovering free product or there is a new or previously undiscovered source.

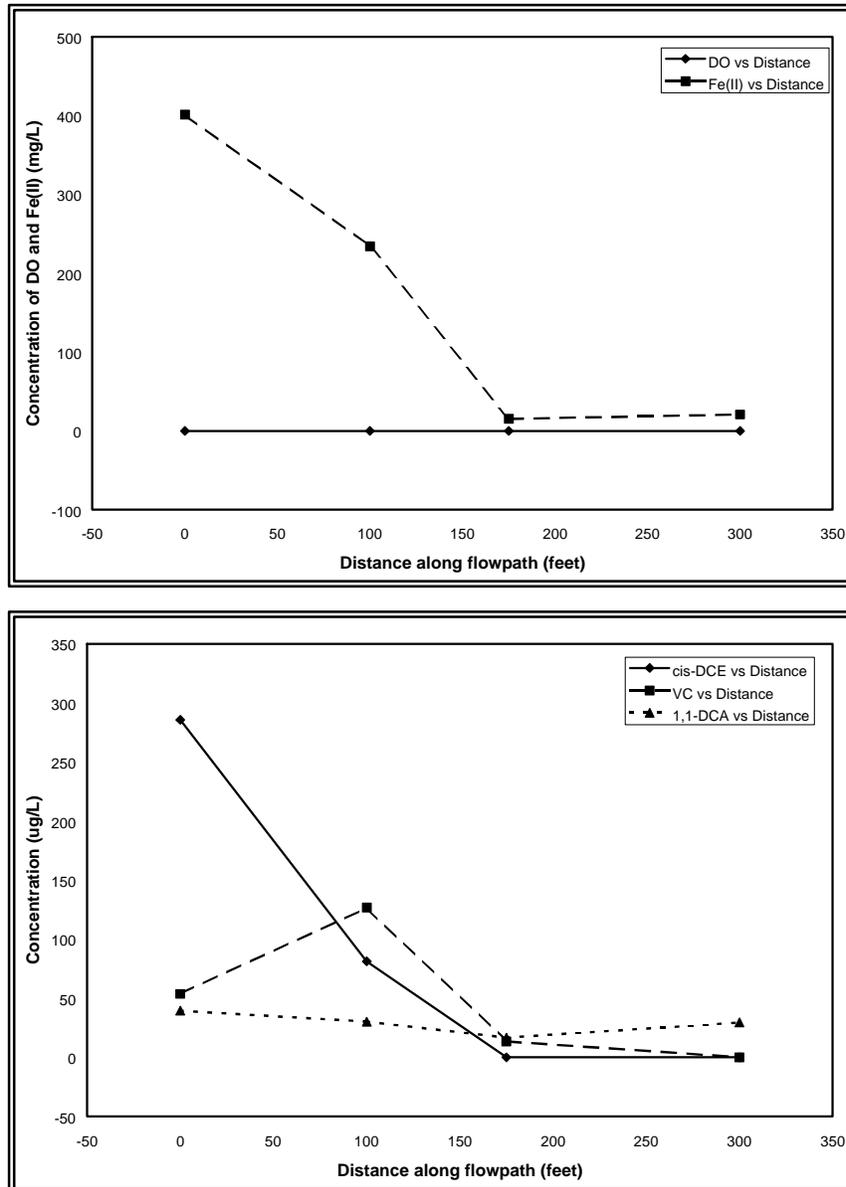
Example: A free product recovery system was constructed at MCAS New River, JP-5 Line Area to recover JP-5 fuel. Figure 4-5 illustrates the product measurements from a recovery well at the remedial site. The product measurement plot shows that no recoverable free product has been measured in the recovery well since September 1998. The recovery well has been in continuous operation for over a year without the presence of free product. This evaluation of free product thickness over time led to the conclusion that operation of the recovery well could be discontinued, as it is not contributing to restoring groundwater quality.



**Figure 4-3. Product measurement plot
MCAS New River, JP-5 line area.**

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 natural attenuation of chlorinated ethenes and benzenes in the groundwater system was assessed at NAS 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. Also, TCE and its biodegradation products were completely destroyed within 250 feet downgradient of the source area. As a result of this assessment, MNA was implemented as the final remedy for the site.*



**Figure 4-4. Natural attenuation trend analysis
NAS Pensacola, former sludge drying bed and surge pond site.**

4.2 System Performance

System performance is a measure of 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 rates
- 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

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).

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:** At MCB Camp Lejeune, the OUI South pump and treat system removed approximately 0.03 pore volumes of groundwater in 1998. This system performance is poor when compared to typical extraction well-field design criteria of 0.3 to 2 pore volumes per year. The inability of the extraction well network to meet the minimum design criterion is attributed primarily to the low permeability of the surficial aquifer, which precludes pumping at higher rates. Due to the limited potential of the surficial aquifer to yield water, approximately 10 additional extraction wells would be required to remove 0.3 pore volumes of contaminated water per year. As a result of poor remedial and system performance, and evidence of a stable contaminant plume, the remediation system at OUI South was discontinued in favor of evaluating alternative remedial technologies.*

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 4-5)
- **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.

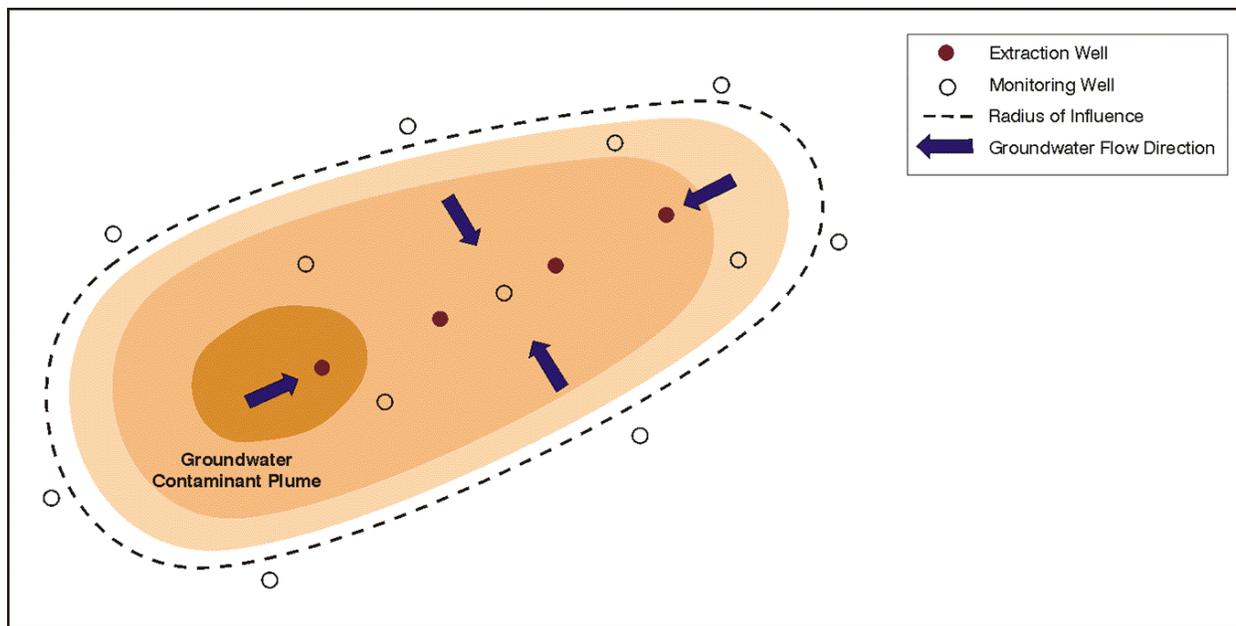


Figure 4-5. Radius of influence developed around plume by extraction wells.

- **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.

***Example:** An evaluation of the pump and treat system at the MCB Camp Lejeune OUI South site determined that the system was not suitable for achieving cleanup goals. A review of the remediation system and the CSM revealed that the extraction well network was not located within the contaminant plume or the source area. Also, the design of the pump and treat system was not suitable for the low permeability of the aquifer, which prevented adequate groundwater extraction.*

5.0 Evaluate Cost Efficiency

***Content:** The third step of the RAO optimization process is to evaluate the cost efficiency of the remediation system. This section describes the process to evaluate the cost efficiency 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 and Performance Data

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.

Cost and performance data typically 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 fuel, 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 wells, modifications to the aboveground treatment system, and upgrades of pumps.

5.2 Cost Efficiency Plots

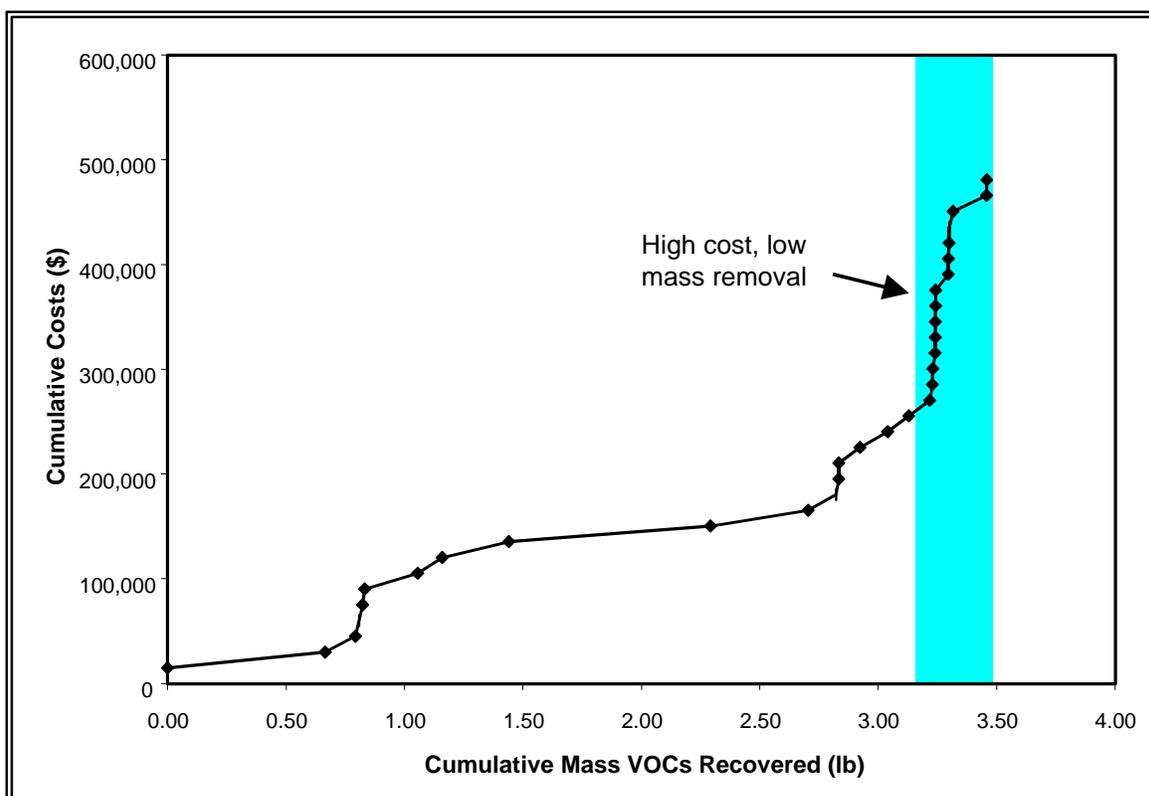
Plots of cost and performance data are tools used to assess cost efficiency. These plots should be used to track remediation system operation costs, mass of contaminant removed/destroyed, and cost per pound of contaminants removed/destroyed. The cost efficiency plots should be evaluated to identify trends 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.

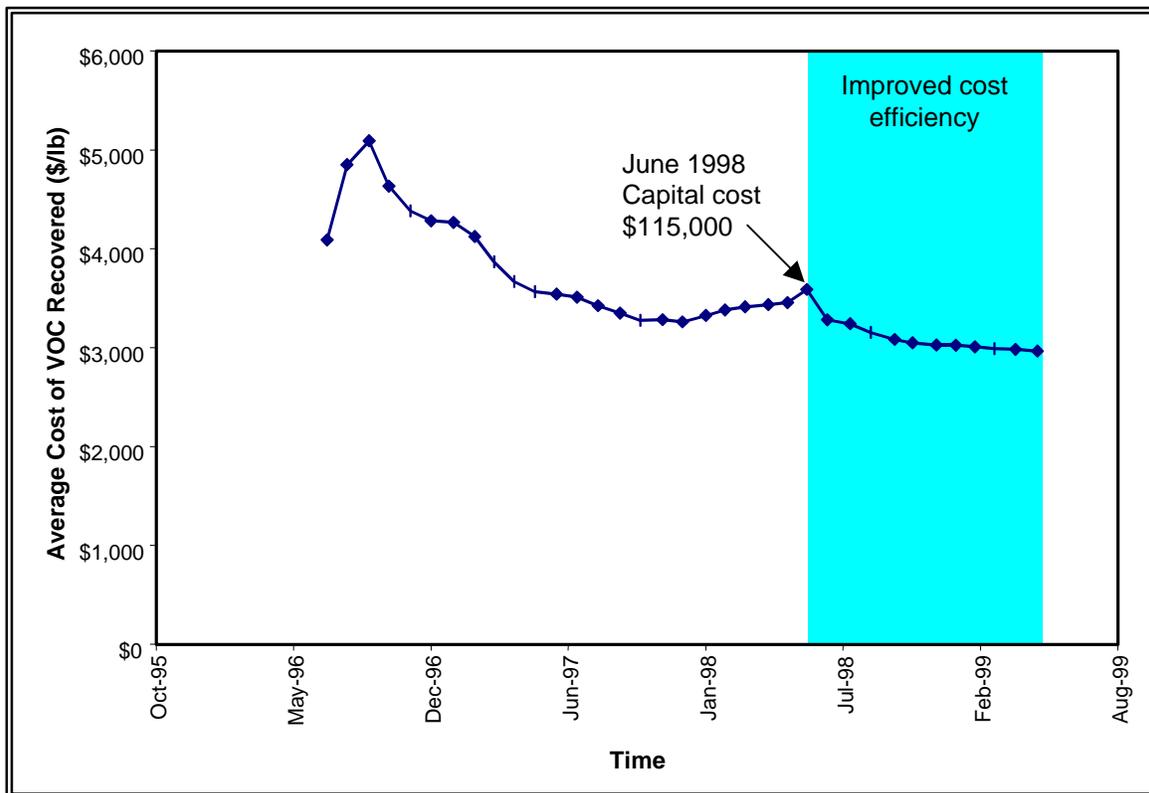
Example: Figure 5-1 is a plot of cumulative costs versus cumulative mass recovered for the pump and treat system at MCB Camp Lejeune, Campbell Street Fuel Farm. The plot clearly illustrates, by its nearly vertical slope, the cost ineffectiveness of operating a remediation system that has reached asymptotic levels of mass removal. In this example, approximately \$175,000 was spent to remove 3 pounds of contaminant mass. However, after asymptotic levels of mass removal were reached, only an additional 0.5 pounds of mass was removed at a cost of \$325,000.



**Figure 5-1. Cumulative costs versus cumulative mass recovered
MCAS New River, Campbell Street Fuel Farm.**

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, NAS 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.**

6.0 Identify System Modifications and Remediation Alternatives

Content: The fourth step of the RAO optimization process is to identify potential modifications and alternatives to the existing remediation system to improve its effectiveness and/or cost efficiency. This section describes the process to identify potential modifications and select alternatives based on the evaluation of RA objectives, remediation effectiveness and cost efficiency. The remediation alternatives discussed in this section include modifying the existing remediation system, selecting an alternative remediation technology, and considering alternative regulatory mechanisms.

6.1 Modifications to the Existing Remedial System

If the remedial effectiveness and cost efficiency evaluations determine that remedial progress is limited and that the remediation system is not operating at optimal efficiency, the RPM should first consider modifying the existing remediation system. Two methods to improve the remedial effectiveness and/or cost efficiency of a remediation system are enhancing performance and/or reducing O&M costs. 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 Enhancing Remedial Performance

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 RAO include:

- Modifying system operations to meet design specifications, such as adjusting flow rates and injection volumes
- 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

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

The optimization strategies should not only improve remedial effectiveness, but also cost efficiency. Optimization strategies to improve remedial performance may require additional capital expenditure and/or increase monthly O&M costs. However, any additional costs must 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: Recommendations were provided to modify the operation of pump and treat system to improve remedial performance at MCB Camp Lejeune OU2. On the basis of the data evaluation, the installation of additional shallow extraction wells within the plume was recommended. These additional extraction wells would supplement mass removal from “hot spots” and would improve the performance of the existing remedial system.

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 strategies 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.

Table 6-1. O&M Cost Minimization Strategies

Cost Category	Cost Minimization Strategy	Remarks
Labor	<ul style="list-style-type: none"> • 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 	<ul style="list-style-type: none"> • 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 RAO program.
Analytical	<ul style="list-style-type: none"> • 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 	<ul style="list-style-type: none"> • If the remedial system is subject to discharge requirements, analytical flexibility should be negotiated.
Power/ Utilities	<ul style="list-style-type: none"> • 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 	<ul style="list-style-type: none"> • 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	<ul style="list-style-type: none"> • 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 	<ul style="list-style-type: none"> • Maintaining accurate documentation regarding component failure may allow RPMs/contractors to pursue vendor warranties, which would reduce repair costs.

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 or bypassed without affecting remedial progress. 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

Example: Recommendations were provided to modify the operation of the aboveground treatment train at MCB Camp Lejeune OUI South. These recommendations included bypassing the oil/water separator and flocculation tank, replacing the polymer pump, and bypassing the granular activated carbon (GAC) units. These recommendations would not only maintain the quality of the treatment system effluent, but would also reduce labor and analytical costs.

6.2 Identify Alternative Remedial Technologies

If the evaluation of remedial effectiveness and cost efficiency indicates that the system cannot be modified to achieve RA objectives, the RPM should then identify alternative remedial technologies. The alternative remedial technologies must be capable of attaining RA objectives in a shorter timeframe and/or at lower costs. 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 may require the sequencing of several remediation technologies to achieve cleanup goals. For example, a soil vapor extraction system that has achieved asymptotic conditions may be followed by a bioventing system. Finally, a passive system may also be selected as a polishing remedy to achieve cleanup goals. Alternative remedial technologies can also be used to complement existing remediation systems. For example, in-situ chemical oxidation may be used for “hot spot” removal, while an existing pump and treat system operates to maintain containment of the downgradient contaminant plume.

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. The *Remediation Technologies Screening Matrix and Reference Guide* developed by the Federal Remediation Technologies Roundtable provides information on technology screening.

6.3 Alternative Regulatory Mechanisms

If an alternative remedial strategy cannot improve the remedial effectiveness and cost efficiency, the RPM should consider using alternative regulatory mechanisms to manage the site. These alternative regulatory mechanisms are used for sites where the specified cleanup goals cannot be achieved. Such mechanisms include:

- Revising cleanup goals and remediation objectives
- Land use controls (LUC)
- Technical Impracticability (TI) waivers

Most of these alternatives do not require remediation to cleanup goals, but provide measures for ensuring the protectiveness of human health and the environment. Although these alternatives are a viable option as part of a remedy, it is important to consider the long-term, life cycle costs of these alternatives. The implementation of these alternatives 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.

6.3.1 Revising Cleanup Goals and Remediation Objectives

The decision making framework for a remedial site may be modified to revise cleanup goals and remediation objectives. Whether revising cleanup goals or RA objectives, the remediation strategy must demonstrate the protection of human health and the environment. The remediation strategy must also satisfy the statutory and regulatory requirements of the appropriate regulatory program.

Alternate concentration limits (ACL) may be proposed in situations where it is not economically or technically feasible to achieve existing cleanup goals provided the ACLs are shown to be protective of human health and environment. ACLs provide alternative cleanup goals that may be established based on site characterization, risk assessment, and the regulation framework. Table 6-2 specifies the minimum conditions under which ACLs may be considered for use. For remedial sites where achieving cleanup goals is not possible, and the use of ACLs are not appropriate, the RA objectives may be revised from restoration to containment.

Table 6-2. Minimum Conditions for Using Alternate Concentration Limits

Regulatory Framework	RCRA ^a	CERCLA ^b
Minimum Conditions	Groundwater contamination plumes should not increase in size or concentration above allowable health or environmental exposure levels	Points of entry of contaminated groundwater into surface water are known and projected
	Increased facility property holdings should not be used to allow a greater ACL	There will be no statistically significant increase of hazardous constituents from contaminated groundwater into surface water
	ACLs should not be established so as to contaminate off-site groundwater above allowable health or environmental exposure levels	Remedial action includes enforceable measures that will preclude human exposure to contaminated groundwater at any point between the facility boundary and all known and projected points of entry of contaminated groundwater into surface water

^a Specific factors for groundwater contamination and surface water pathways are listed in 40 CFR 264.94(b).

^b CERCLA Section 121 (d)(2)(B)(ii)

6.3.2 Land Use Controls

LUCs refer to the use of engineering controls (EC) and institutional controls (IC) together. ECs are engineered remedies that contain and/or reduce contamination and limit access to property. Examples of ECs include fences, signs, landfill caps, and reactive walls. In contrast, ICs are a variety of legal devices imposed to ensure that the ECs stay in place or, where there are no ECs, to ensure the restrictions on land

use stay in place. Examples of ICs include deed restrictions, easements, notices/warnings, covenants, zoning, well drilling prohibitions, or well use advisories. The *DON Environmental Policy Memorandum 99-02; Land Use Controls (Interim Final – 25 May 1999)* documents the requirements for the use of LUCs at Navy installations.

LUCs should be considered when:

- Cleanup costs are prohibitive
- Risks associated with cleanup are greater than the contamination itself
- Remedial technology is limited in its effectiveness

LUCs act as an integral part of the remedial alternative, and are used to ensure protection of human health and the environment, to protect ongoing remedial activities and to ensure viability of the remedy. LUCs are more often applied to closing installations, but can be used at active installations. Whereas DON has the authority to impose restrictions on transferred property, DON does not have the authority to impose easements or covenants on property at active installations. ICs such as base master planning procedures and agreements with regulators are acceptable means of ensuring the viability of LUCs at active installations.

6.3.3 Technical Impracticability

The RPM may apply for a TI waiver for a remedial site that cannot achieve the cleanup goals. The TI waiver requires implementing an alternative remedial strategy that is technically practicable, protective of human health and the environment, and satisfies the statutory and regulatory requirements of the appropriate regulatory program.

Site-specific characterization and remedial performance data will be used in the TI evaluation. The TI evaluation should include the following components:

- Specific cleanup standards for which TI determinations are sought
- Spatial area over which the TI decision will apply
- Conceptual site model that describes site geology, hydrology, contamination sources, transport, and fate
- Evaluation of restoration potential of the site, including data and analysis that identify the factors limiting restoration
- Modeling to estimate the timeframe to achieve cleanup criteria
- Estimates of the cost of existing remedy solutions

Guidance on TI waivers is published in the *Guidance for Evaluating the Technical Impracticability of Ground-Water Restoration* (EPA, 1993).

7.0 Develop and Prioritize Optimization Strategies

Content: *The fifth step of the RAO optimization process is to develop and prioritize optimization strategies. This section describes the process to develop optimization strategies based on applicable remediation alternatives and to prioritize the strategies based on cost benefit analyses. This step allows the RPM to develop and select the appropriate optimization strategy to implement at a remedial site.*

7.1 Developing Optimization Strategies

The optimization strategy is developed to address the findings from the RAO program evaluation, including any limitations that may prevent the existing remedial system from achieving cleanup goals. Optimization strategies must demonstrate benefits to the RAO program, including:

- Improving remedial performance and operational costs for the existing remedial system
- Improving or at least maintaining progress towards achieving cleanup goals
- Improving or maintaining protectiveness of human health and the environment

The optimization strategy may consist of one or more remediation alternatives implemented simultaneously or in succession. For example, the use of an alternative remedy for the control of contaminant migration coupled with LUCs is a simultaneous implementation of remediation alternatives. For remediation alternatives implemented in succession, it is important to clearly define the criteria to transition from one alternative to the next.

Example: *Source areas of chlorinated solvents in groundwater have been effectively remediated using in-situ chemical oxidation at the NSB Kings Bay Landfill site and the NAS 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. In-situ chemical oxidation using the Fenton's Reagent method was selected as the technology for source reduction. The optimization strategy combined in-situ chemical oxidation for source control and MNA as the final remedy, and has been successful in demonstrating remedial progress toward the cleanup goals.*

7.2 Prioritizing Optimization Strategies

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

Cost-benefit analysis compares the current costs of system operations with the costs of the proposed alternatives after optimization. This cost-benefit analysis should compare the O&M costs of the existing system with both capital costs and O&M costs of the remediation alternative. The cost comparison should also consider life cycle costs based on the expected timeframe of the remediation strategy.

Net present value (NPV) calculations are used to determine the investment value of remedial costs. The NPV allows a more direct comparison of optimization strategies 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:

$$NPV = RF_{RP,i,n}$$

Where: R = Annual O&M costs

$F_{RP,i,n}$ = capital recovery factor, given $i\%$ interest rate and n year plant life

$$F_{RP} = ((1+i)^n - 1) / (i * (1+i)^n)$$

From Jelen's Cost and Optimization Engineering, Third Edition

Capital costs of remediation alternatives should be added to the NPV of its O&M costs to calculate overall NPV costs. An example cost-benefit analysis of life cycle costs is presented in Table 7-1.

Since budgets are based on expenditures not investment, a cost-benefit analysis based on actual cost over time may be more appropriate for budgeting remedial costs. Rather than calculating the investment value of remedial costs, 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: Two alternatives for the treatment of extracted groundwater are carbon units and air stripping. Both alternatives meet the flow rate and treatment requirements. The costs for the carbon units are \$4,200 for capital and \$17.30/day for O&M; the costs of the air stripping are \$18,500 for capital and \$9.90/day for O&M. The period of equal costs for these alternatives is 4.8 years. The life cycle costs for the carbon units are lower than those of the air stripping for a duration of less than 4.8 years; however, for a duration greater than 4.8 years, the life cycle costs are lower for air stripping. The cost-benefit analysis for these treatment alternatives is illustrated in Figure 7-1.

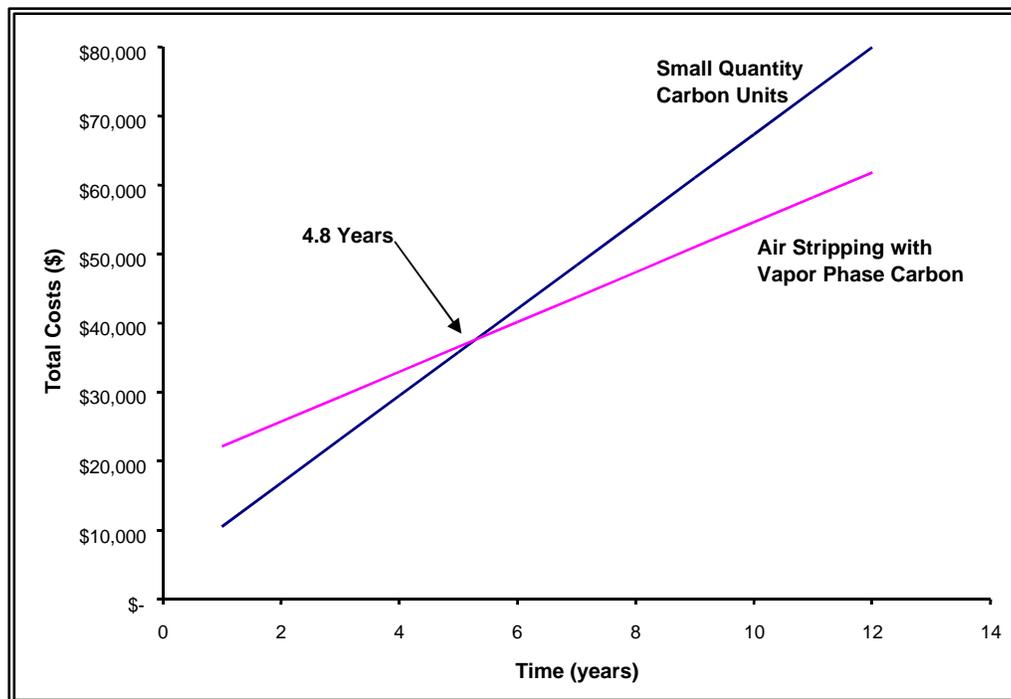


Figure 7-1. Cost-benefit analysis of treatment alternatives.

**Table 7-1. Life Cycle Cost Analysis for System Recommendations
MCAS New River, Campbell Street Fuel Farm**

Recommendations	Annual Costs				Net Present Value		
	Material	Labor	Analytical	Total	5 years	10 years	15 years
Continued operation of existing Pump and Treat “as is”				\$180,300	\$759,489	\$1.33M	\$1.75M
Implementation of MNA ¹	\$5,000	\$20,000	\$10,000	\$35,000	\$147,434	\$257,603	\$339,929
Repair or replace influent flow meters	No quantifiable annual cost benefit.						
Modify NPDES permits to allow GAC bypass for normal operation	(\$4,400)	(\$4,000)	(\$4,800)	(\$13,200)	(\$55,603)	(\$97,153)	(\$128,202)
Until GAC is bypassed, discontinue analysis for metals, TDS, and TSS after air stripper and between GAC			(\$2,100)	(\$2,100)	(\$8,846)	(\$15,456)	(\$20,396)
Eliminate dichlorobenzene analytes from Method 602 analysis			(\$200)	(\$200)	(\$842)	(\$1,472)	(\$1,942)
Replace sequestering agent with iron/metals removal system, such as ion exchange unit	\$1,800	\$1,800		\$3,600	\$15,165	\$26,496	\$34,964
Use AFVR on AS-143 hot spots ²		\$3,000		\$3,000	One time cost – no recurring impacts.		
Perform MNA screening		\$6,000	\$6,000	\$12,000	One time cost – no recurring impacts.		
Sample for PAH's at AS-4151		\$1,500	\$1,000	\$2,500	One time cost – no recurring impacts.		

(Figures in parenthesis indicate cost savings)

¹ Additional monitoring wells and/or characterization may be required. These costs are unknown until screening has been performed.

² More than one AFVR event may be required.

8.0 Prepare Optimization Report and Implement Optimization Strategy

Content: The final steps in the RAO optimization process are to prepare the optimization report and implement the optimization strategy. The optimization report details the evaluation of the RAO program, presents conclusions on the remedial effectiveness and cost efficiency of the remedial system and provides recommendations to optimize the program. The conclusions and recommendations from the optimization report should be incorporated into regulatory reviews prior to implementing the optimization strategy.

8.1 Report Format and Content

The evaluation of the RAO program should be properly documented in an optimization report. The RAO optimization report contains site-specific information concerning the remedial site, remedial system, remedial performance and cost, and recommendations to improve the RAO program. The content of the optimization report should follow the steps of the RAO optimization process. A sample outline for a RAO optimization report is shown in Figure 8-1.

RAO 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 Effectiveness Evaluation
3.1.	Remedial Performance Baseline
3.2.	System Performance
3.3.	System Suitability
4.	Cost Efficiency 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
6.2.	Cost-benefit Analysis
7.	Implementation Plan
7.1.	Annual regulatory review
7.2.	Regulatory documentation
7.3.	Schedule for Implementation

Figure 8-1. Example RAO optimization report outline.

8.2 Reporting Frequency

The Working Group recommends that RPMs perform annual reviews of RAO programs. The optimization reports produced from these annual reviews should be incorporated into regulatory reviews. The opportunities to present the recommendations to optimize the RAO program include annual program reviews, CERCLA Five-Year reviews, and RCRA permit modifications.

8.2.1 Annual Program Reviews

Regular program reviews of remedial sites should be conducted with regulatory agencies annually. The program reviews meet regulatory requirements to present cost and performance data. These reviews also provide an opportunity to discuss remedial progress with the regulators. The RAO evaluation should also be incorporated into the program reviews, to identify opportunities to optimize the remedial system. The routine involvement of the regulators in site evaluation will result in consensus conclusions and recommendations for changes and improvements in the RAO program.

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 Record of Decision (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 EPA is preparing a new guidance on five-year reviews. This final guidance is expected in April 2001. The draft EPA guidance on the five-year reviews is provided in *Five-Year Reviews - Version 3* (EPA, 1999). For National Priorities List (NPL) sites, EPA's role is to review the report and issue a finding of concurrence or non-concurrence. For non-NPL sites, EPA does not have any explicit role to review the Five-Year Review report. There are two types of reviews: Statutory and Policy. Statutory reviews are for sites where contaminants will be left on site after completion of the remedial action(s). Policy reviews are for sites where the remedial action(s) will remove contaminants to required levels, resulting in unlimited use and unrestricted exposure. As of March 2001, the DON is evaluating whether the policy reviews should be conducted at DON sites. For Statutory reviews, the trigger date for start of the 5-year review period is the beginning of RA construction, which is equivalent to the onsite mobilization date; whereas, for Policy reviews, the trigger date is the construction completion date. The RAO optimization evaluation should provide data and conclusions to directly support these Five-Year Reviews.

8.2.3 RCRA Permit Modifications

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.

8.3 Implementing the Optimization Strategy

The RPM should prepare a plan to implement the optimization strategy. The implementation of the optimization strategy may require additional regulatory documentation. For CERCLA sites, an explanation of significant difference (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. RCRA sites may require a permit amendment or modification, as discussed in Section 8.2.3.

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

9.0 What Tools Can I Use to Optimize My Remedial Action Operation Program?

Content: RAO optimization involves a broad range of activities. This section describes a number of tools that can be used to assist the RPM in evaluating RAO 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 website address:

www.environmental.usace.army.mil/library/guide/rsechk/rsechk.html

9.2 Geographical Information System

Geographical Information System (GIS) software is a useful tool for organizing and managing many types of data associated with RAO at a site. It facilitates data evaluation and interpretation through its visualization, analysis, and querying capabilities. It also allows the user to illustrate the data in real time presentation. An overview of GIS can be found in Section 9.3 of the Navy *Guide to Optimal Groundwater Monitoring*.

9.3 MNA Tools

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 (DON March 1998). 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.

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

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

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 EPA's web page at www.epa.gov.

AFCEE Technical Protocol for Implementing Intrinsic Remediation (Natural Attenuation) with Long-Term Monitoring Option for Dissolved-Phase Fuel Contamination in Groundwater (AFCEE, 1995).

9.4 Example Statement of Work for Optimizing Remedial Action Operation

The RPM may desire an independent third party to assess a RAO and to provide optimization recommendations. The following is an example Statement of Work that may be used to retain an independent contractor. 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 adequacy of the remedial action operation strategy and progress at (**insert appropriate installation, OUs and/or sites**). This evaluation will be done in accordance with the *DON Guidance for Optimizing Remedial Action Operation (RAO)*, and other applicable site-specific guidance documents and regulations. The primary purposes of the optimization assessment are to: 1) evaluate whether the current remedial action operation is making progress toward attaining site remedial action objectives; and 2) provide program optimization recommendations to increase the effectiveness of remedial action operation while reducing the overall cost. Both of these purposes 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) groundwater remediation experience
- *Regulatory analysis specialist* with experience specific to (**insert State and 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 remedial action operation 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 Engineering Field Divisions/Activities (EFD/A), and representatives from (***)insert installation(***). During the site visit, a formal project in-brief and out-brief 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 Remedial Action Operation, including regulatory framework, remedial action objectives, and site closeout strategy
- Adequacy of the CSM
- System description including extraction/injection wells or trenches and aboveground treatment train
- Design basis including specifications and design parameters, system upgrades and modifications, and total capital costs
- Baseline of system performance and cost including extraction/injection well network, monitoring well network, and aboveground treatment train
- Best technical and management practices already in place at the installation
- Frequency and approach for data evaluation, trend analysis, presentation, and reporting

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.

Table 9-1. Site Visit Data Collection Requirements

Data Requirement Categories	Specific Data Requirement
Understand Site Background and Conceptual Model	<ul style="list-style-type: none"> • Types of contaminants being removed and plume 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	<ul style="list-style-type: none"> • Risk Assessment of site/OU • 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	<ul style="list-style-type: none"> • 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 • Current or planned operations and maintenance manuals • Current or planned inspection/maintenance schedule
Baseline System Costs (Capital and O&M)	<ul style="list-style-type: none"> • Capital 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; and • Handling, repackaging, transportation, or disposal costs

9.5 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.

9.5.1 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.

9.5.2 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 remedial actions. After the initial startup, fixed-price contracts are preferable during remedial actions.

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 includes:

- 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	<ul style="list-style-type: none"> • 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 	<ul style="list-style-type: none"> • 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	<ul style="list-style-type: none"> • Ensures the contractor is operating and monitoring the system toward the ultimate goal of site closure 	<p>Example performance measures include the following:</p> <ul style="list-style-type: none"> • 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 • Zero permit violations • Maintaining a predetermined removal efficiency • Maintaining plume capture <p>Note: Contractor's scope must provide authority to implement changes to achieve goals.</p>
Issue work in bulk packages	<ul style="list-style-type: none"> • Reduced contract administrative burden • Reduced analytical and labor rates • Increased data quality 	<ul style="list-style-type: none"> • 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	<ul style="list-style-type: none"> • Provides program flexibility by allowing significant project parameters to be adjusted while not revising existing manuals or sampling plans 	<ul style="list-style-type: none"> • 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.

9.5.3 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 RAO optimization. State and local regulators should be contacted for state-specific and local regulatory requirements. Section 10 of the Guide to Optimal Groundwater Monitoring provides links to all 50 state environmental agencies.

10.1 Useful Web Sites

Naval Facilities Engineering Services Center (NFESC). The NFESC 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. <http://erb.nfesc.navy.mil>

Hazardous Waste Clean-Up 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 air sparging, 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>

Federal Remediation Technologies Roundtable (FRTR). Includes links and chapters to RAO technologies, workgroups, 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). Website provides multiple manuals and publications on remediation technology and services for the public and military. Useful programs include the Environmental Division and Base Realignment and Closure (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 Center for Environmental Excellence (AFCEE). AFCEE provides a range of environmental, architectural and landscape design, and planning and construction management services and products. AFCEE provides research findings, fact sheets, documents, and manuals on remediation technology easily accessed through their search engine. <http://www.afcee.brooks.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 United States Army Corps of Engineers Construction Engineering Research Laboratories. <http://www.denix.osd.mil>

Department of Defense Environmental Cleanup Home Page. DOD's Office of Environmental Cleanup is charged with developing policy and overseeing the Defense Environmental Restoration Program (DERP). This program focuses on reducing the risks to human health and the environment at

active, formerly used, and closing bases, while ensuring that DOD environmental cleanup policy conforms to existing laws and regulations. <http://www.dtic.mil/enviroDOD/index.html>

Global Network of Environment and Technology (GNET). GNET provides information on environmental technology and news that promotes the use of innovative environmental technologies. <http://www.gnet.org>

Ground-Water Remediation Technologies Analysis Center (GWRTAC). GWRTAC compiles, analyzes, and disseminates information on innovative ground-water remediation technologies. <http://www.gwrtac.org>

United States Department of Energy, Office of Environmental Management (EM). Technical guidance on remediation technologies, by state, is provided along with regulations and laws and publication searches. <http://www2.em.doe.gov>

United States Environmental Protection Agency (EPA). The EPA website 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) Enviro\$en\$e, 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>

United States Government Printing Office (GPO). Provides links to the Federal Register, Code of Federal Regulations, and other Government agencies. <http://www.access.gpo.gov>

10.2 Useful Documents

10.2.1 General Optimization

Radian International. December 1997. "Air Combat Command Environmental Restoration Program Site Closure Guidance Manual." – This document contains information on regulatory requirements and documentation, LTM/LTO performance evaluation, contracting strategies, LTO optimization (soil vapor extraction [SVE], bioventing, capping, pump and treat, multi-phase extraction, free product recovery, and MNA).

U.S. Army Corps of Engineers. September 30, 1999. "Engineering and Design - Safety and Health Aspects of HTRW Remediation Technologies." Washington, D.C. EM 1110-1-4007. 232 pp. (USACE) – This Engineering manual identifies and analyzes generic safety and health hazards for 25 remediation technologies used in clean-up operations at Hazardous, Toxic, and Radioactive Waste (HTRW) sites.

U.S. Air Force Environmental Restoration Program. December 1999. "Remedial Process Optimization Handbook."

10.2.2 Pertinent Guidance and Policy

Department of Navy. “Guide to Optimal Groundwater Monitoring” (January 2000).

Department of Navy. “Technical Guidelines for Evaluating Monitored Natural Attenuation at Naval and Marine Corps Facilities” (March 1998).

EPA Technical Protocol for Evaluating Natural Attenuation of Chlorinated Solvents in Groundwater (September 1998).

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

Department of Defense. “A Guide to Establishing Institutional Controls at Closing Military Installations.”

Kratina, Kevin. May 6, 1998. “Institutional Controls In Risk-Based Corrective Actions.” U.S. EPA; NJ DEP. (EPA) – This article provides a summary on the topic and use of institutional mechanisms in risk-based corrective actions. The article touches on Federal, State, and local laws and codes and examples of different types of institutional controls.

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

U.S. Department of Energy, December 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. May 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, air sparging, biosparging, natural attenuation, in-situ groundwater bioremediation, dual-phase extraction.

10.2.3 Cost Information

RACER is an electronic cost system that resides on an MS Access windows 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.

Battelle. Bioslurping Cost Estimating Program. Prepared for the Naval Facilities Engineering Service Center. (NFESC) – The bioslurping cost estimator is an Excel-based tool that allows the user to estimate and view costs by inputting parameters, and print reports. A help file for using the tool is also available.

Battelle. Bioventing Cost Estimator. (NFESC) – The bioventing cost estimator is an Excel-based tool that allows the user to print reports and estimate costs by inputting general assumptions and parameters. Additional modifications can also be incorporated into the analysis.

Battelle. Remediation by Natural Attenuation (RNA) Cost Estimating Program. Prepared for the Naval Facilities Engineering Service Center. (NFESC) – The natural attenuation cost estimator is an Excel-based tool that allows the user to generate detailed cost estimates, general cost estimates, cost summaries, and general RNA flowcharts. A help file for using the tool is also available.

Federal Remediation Technologies Roundtable. October 1998. “Guide to Documenting and Managing Cost and Performance Information for Remediation Projects.” EPA 542-B-98-007. 77 pp. (Clu-In) (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.

Radian International. May 1997. “U.S. Air Force Presumptive Remedy Engineering Evaluation/Cost Analysis (PREECA).” – This document provides a remedy selection process for various remediation technologies, including remedy selection justification and methodology, SVE, bioventing, capping, groundwater containment, and Multi-Phase Extraction (MPE).

Yager, Kathleen and Robert Greenwald. December 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 (P&T) 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

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

10.3 Remedial Technologies

Pump and Treat

U.S. EPA. July 1996. “Pump-and-Treat Ground-Water Remediation: A Guide for Decision Makers and Practitioners.” Washington, DC. (EPA) – EPA publication order number: EPA/625/R-95/005. This guide introduces pump-and-treat ground-water remediation and outlines the foundation for evaluating the appropriateness of different technology approaches. The document also addresses when pump-and-treat is an appropriate remediation approach, and what is involved in the “smart” application of pump-and-treat, among other questions.

U.S. EPA. 1990. “A Guide to Pump and Treat Groundwater Remediation Technology.” EPA/540/2-90/018. EPA publication order number: EPA540290018.

U.S. EPA. “Methods for Monitoring Pump-and-Treat Performance.” EPA publication order number: EPA 600-R-94-123.

Air Sparging/Soil Vapor Extraction

Miller, Ralinda. October 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. September 15, 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. November 30, 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 the 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. October 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. January 1995. "Draft: Test Plan and Technical Protocol for Bioslurping." Air Force Center for Environmental Excellence, Brooks AFB, TX. A324068. (AFCEE)

U.S. EPA Office of Solid Waste and Emergency Response. September 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. (NFESC). 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.

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

U.S. EPA. September 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 ground water 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 Office of Solid Waste and Emergency Response. April 1995. "In-Situ Remediation Technology Status Report: Thermal Enhancements." EPA/542-K-94-009. (EPA). EPA publication order number: EPA/542-K-94-009. The purpose of this document is to describe field demonstrations, commercial applications, and research on technologies. The report also includes a summary of research, demonstrations, and field applications of the technology.

Reactive Barriers/Treatment Walls

Radisav D. Vidic, Ph.D. and Frederick G. Pohland, Ph.D. October 1996. "Treatment Walls." Ground-Water Remediation Technologies Analysis Center. Pittsburgh, PA. 38 pp. (GWRTAC) (EPA). This document provides general information on treatment walls, its use, and advantages and disadvantages of this technology over ex-situ and other in-situ groundwater remediation approaches. The document discusses technology description, performance, technology applicability, cost, regulatory requirements, lessons learned, and references.

U.S. EPA. "NATO/CCMS Pilot Study: Evaluation of Demonstrated and Emerging Technologies for the Treatment of Contaminated Land and Groundwater (Phase III) Special Session: Treatment Walls and Permeable Reactive Barriers."

EPA publication order number: EPA542R98003.

U.S. EPA Office of Solid Waste and Emergency Response. April 1995. "In-Situ Remediation Technology Status Report: Treatment Walls." Technology Innovation Office. Washington, DC. EPA542-K-94-004 Treatment Walls. (EPA)

EPA Publication Order Number: EPA/542-K-94-004. The purpose of this document is to describe field demonstrations, commercial applications, and research on technologies. The report also includes a summary of research, demonstrations, and field applications of the technology.

Air Stripping

Dietrich, C., D. Treichler, and J. Armstrong. 1987. "An Evaluation of Rotary Air Stripping for Removal of Volatile Organics from Groundwater." USAF Environmental and Service Center Report. ESL-TR-86-46.

Elliott, M.G. and E.G. Marchand. 1990. "USAF Air Stripping and Emissions Control Research." Proceedings of the 14th Annual Army Environmental Symposium, USATHAMA Report. CETHA-TE-TR-90055.

Aboveground Treatment

Trach, Robert J. November 1996. "Ultraviolet/Oxidation Treatment." Ground-Water Remediation Technologies Analysis Center. Pittsburgh, PA. (GWRTAC). This report contains information on ultraviolet (UV)/oxidation treatment processes for the treatment of contaminated groundwater. The report discusses general principles and techniques associated with UV-OX, the applicability to groundwater remediation, data relating to results of its use, its advantages and limitations, and references.

U.S. EPA. 1990. "Innovative and Alternative Technology Assessment Manual." Office of Water Program Operations. EPA/430/9-78/009. (EPA)

Naval Energy and Environmental Support Activity. 1993. "Precipitation of Metals from Ground Water." NEESA Document Number 20.2-051.6. Port Hueneme, CA.

Air Force Center for Environmental Excellence. April 29, 1998. "Oil/Water Separation Technology." (AFCEE) – This document includes information on the benefits of the technology, background information, applicability, site visit information, resource support, points of contact, and program partners.

Air Force Center for Environmental Excellence. December 1996. "Fact Sheet: Oil/Water Separators." (AFCEE) – This document includes general technology information, a coalescing oil/water separator discussion, its applicability, the design of Air Force oil/water separators, operation and maintenance, regulatory aspects, an Air Force perspective, help information, and references.

Monitored Natural Attenuation

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

Sandia National Laboratories. June 19, 2000. Monitored Natural Attenuation (MNA) Toolbox™. (Sandia). This toolbox was developed to screen sites for the applicability of implementation of MNA. The Toolbox identifies primary attenuation pathways, and leads to processes that might mitigate

particular contaminants. Each contaminant module results in a scorecard that uses site-specific input parameters to measure the effectiveness of the technology.

U.S. Department of Energy, Office of Environmental Management. October 8, 1999. "Technical Guidance for the Long-Term Monitoring of Natural Attenuation Remedies at Department of Energy Sites." (EM). This guide provides DOE Remedial Project Managers with direction on the use of monitoring for implementation of natural attenuation systems, considerations for designing a monitoring network, and statistical approaches for interpreting monitoring data and improving conceptual models.

U.S. EPA. November 1997. "Draft EPA Region 4 Suggested Practices for Evaluation of a Site For Natural Attenuation (Biological Degradation) of Chlorinated Solvents." Version 3.0. 41 pp. (EPA) This report is a combination of information from the Draft AFCEE *Protocol for Evaluation of Natural Attenuation of Chlorinated Solvents in Ground Water* and other resources. The report discusses technical protocol, a summary of chlorinated aliphatic hydrocarbon biodegradation, the mechanisms associated with biodegradation, behavior of the plumes, protocol for quantifying degradation during remedial investigation, biodegradation determination and its indicators, groundwater characterization, refinement of the conceptual model, and completing premodeling calculations.

U.S. EPA, Office of Solid Waste & Emergency Response. April 1999. "Use of Monitored Natural Attenuation at Superfund, RCRA Corrective Action, and Underground Storage Tank Sites." Directive 9200.4-17P. (EPA). The purpose of this Directive is to clarify EPA's policy regarding the use of MNA for the cleanup of contaminated soil and groundwater in the Superfund, RCRA Corrective Action, and Underground Storage Tank programs. This document includes background information, advantages and disadvantages of MNA, implementation, a demonstration of the efficacy of natural attenuation through site characterization, case studies, performance monitoring and evaluation, contingency remedies, references, and other sources of information.

Wiedemeier T.H., J.T. Wilson, D.H. Kampbell, R.N. Miller, and J.E. Hansen. 1995. "Technical Protocol for Implementing Intrinsic Remediation with Long-Term Monitoring for Natural Attenuation of Fuel Contaminant Dissolved in Groundwater, Volumes I & II." Air Force Center for Environmental Excellence. (AFCEE)

Wiedemeier T.H., M.A. Swancon, D.E. Moutoux, J.T. Wilson, D.H. Kampbell, J.E. Hansen, P. Haas, and F.H. Chapelle. September 1998. "Technical Protocol for Evaluating Natural Attenuation of Chlorinated Solvents in Groundwater, Volumes I & II." 248pp. (AFCEE). This manual was prepared for the Air Force Center for Environmental Excellence, Technology Transfer Division, Brooks Air Force Base. This technical document identifies parameters in evaluating natural attenuation of ground water contaminated with mixtures of fuels and chlorinated aliphatic hydrocarbons and presents protocol for data collection and analysis to evaluate monitored natural attenuation through biological processes.

11.0 References

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ASTM, *E1689-95 Standard Guide for Developing Conceptual Site Models for Contaminated Sites*, 1995.

DON, *Technical Guidelines for Evaluating Monitored Natural Attenuation at Naval and Marine Corps Facilities*, March 1998.

Federal Remediation Technologies Roundtable, *Guide to Documenting and Managing Cost and Performance Information for Remediation Projects*, October 1998.

Naval Facilities Engineering Service Center, *Guide to Optimal Groundwater Monitoring, Interim Final*. January 2000.

USEPA, *Guidance for Evaluating the Technical Impracticability of Ground-Water Restoration, Interim Final*, September 1993.

USEPA, *Technical Protocol for Evaluating Natural Attenuation of Chlorinated Solvents in Groundwater*, 1998.

USEPA, *Five-Year Reviews – Version 3*, 1999.

Appendix A
Technology Specific Optimization Recommendations

Appendix A Technology Specific Optimization Recommendations

Content: *The objective of every RAO program should be to achieve cleanup standards as cost-efficiently as possible. To ensure that progress is made toward achieving cleanup standards through active remediation, technology-specific guidance for optimizing twelve selected remedial systems is presented in this appendix. This appendix includes the following information for each selected remedial system:*

- *A brief system description*
- *An example performance plot*
- *A table outlining common operational problems and typical optimization recommendations*

Examples included in this appendix are taken from case histories of remediation systems that were evaluated using the RAO optimization process. Summaries of these case studies are included in Appendices B and C of this guidance document.

Conventional remedial systems that have wide application such as pump and treat, soil vapor extraction, and air sparging are discussed first. Discussions of these remedial systems are followed by those of more innovative technologies and less commonly applied systems. This appendix also includes an overview on utilizing monitored natural attenuation as an alternative to active remediation systems. Finally, the appendix addresses various above ground components commonly used in treating vapor phase and liquid phase waste streams.

A.1 General Considerations

Before a remediation system is optimized, it should be evaluated against the criteria discussed in Sections 2.0 through 5.0 of this guidance document to first determine if the underlying technology is capable of achieving the site cleanup goals. The results of the evaluation must show that the operation of the existing remediation system is consistent with the overall remedial strategy and cleanup objectives for the site. If the results of the evaluation do not verify the effectiveness of the existing technology, the RPM should consider changing to a different remedial technology and proceed to make this case to the regulatory agency. Optimization of a system to improve its efficiency is justifiable only when it can be verified that the current technology is capable of achieving the cleanup objectives in a reasonable amount of time. For instance, no degree of optimization will improve the operational efficiency of an SVE system at a fuel release site where the remaining contaminants are semivolatile organic compounds, which are not removed by SVE. In such a case, it would be more appropriate to adopt a different technology that is known to be effective against these contaminants than to attempt to optimize the SVE system.

Technology-specific guidance for optimization is presented below to ensure that remediation systems that are verified to be operating effectively are also operating efficiently. For each of the twelve selected technologies, a brief description of the system and a discussion of performance evaluation are presented. These are followed by discussions of common operational problems and optimization strategies applicable to the technology.

Guidance for optimizing the following technologies is included in this appendix:

- Pump and Treat for Hydraulic Containment
- Pump and Treat for Contaminant Mass Removal
- Soil Vapor Extraction
- Air Sparging
- Bioventing
- Multi-Phase Extraction
- Free Product Recovery
- Permeable Reactive Barriers
- In-situ Bioremediation of Petroleum Constituents
- In-situ Bioremediation of Chlorinated Compounds
- In-situ Chemical Oxidation
- In-situ Thermal Treatment

A.2 Pump and Treat for Hydraulic Containment

A.2.1 System Description

Groundwater pump and treat systems are used to either (1) hydraulically contain the migration of a plume of dissolved contaminants, or (2) to contain and also remove the dissolved contaminants from the saturated zone. Pump and treat systems designed to only contain the migration of a plume are discussed in this section. Pump and treat systems designed for mass removal and aquifer restoration are discussed later in Section A.3.

Pump and treat systems designed for hydraulic containment are used in situations where site conditions preclude aquifer restoration, such as aquifers contaminated by dense nonaqueous phase liquid (DNAPL). Containment may also be used as an interim approach to protect receptors while a mass removal technology is active in a part of the plume. These systems incorporate wells equipped with pumps to extract groundwater and create a hydraulic capture zone that prevents horizontal and vertical migration of a contaminant plume. The extraction wells establish a capture zone by depressing water levels to form areas of low hydraulic head toward which the contaminated groundwater flows. Pump and treat systems for hydraulic containment typically include the following components:

- An extraction network, including wells and/or trenches
- A collection system, including groundwater pumps and conveyance piping
- An extracted groundwater treatment system and disposal option
- A monitoring system and program

Figure A-1 is a schematic diagram of a pump and treat system using a network of four vertical extraction wells to hydraulically contain a plume. The diagram also shows 12 monitoring wells for measuring water levels and collecting groundwater samples for chemical analysis. A pre-treatment unit, air stripper, and liquid-phase granulated activated carbon are used to treat extracted groundwater in this system prior to discharge. Treatment options for extracted water are discussed separately in Section A.15.2.

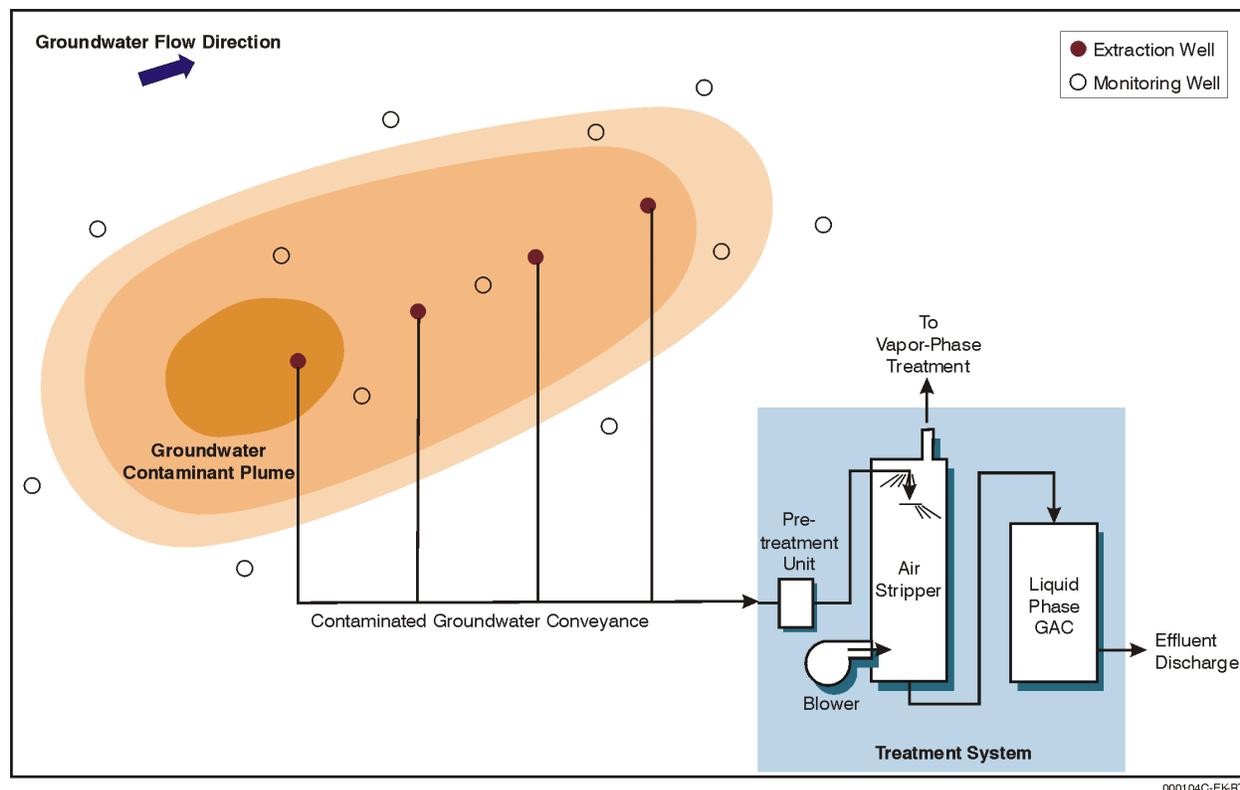


Figure A-1. Typical pump and treat system for hydraulic control.

A.2.2 Performance Plots

The effectiveness of a pump and treat system for hydraulic containment is assessed by periodically measuring and evaluating water levels (hydraulic head) and groundwater quality in the monitoring well network to verify that the contaminant plume is not migrating. Delineating the horizontal capture zone alone is adequate for hydraulic containment systems utilizing extraction wells that fully penetrate an aquifer. However, delineating the vertical capture zone using data collected from nested monitoring wells is also necessary if the extraction wells are only partially penetrating.

Evaluating the effectiveness of hydraulic containment systems involves comparing water levels within and beyond a plume to verify that inward gradients have been established. Inward gradients indicate that groundwater flow is toward the extraction wells and ensure that dissolved contaminants are captured by the extraction well network. The performance evaluation also involves examining contaminant concentrations and trends in monitoring wells, especially in those wells located near the edge of the plume, to verify that no contaminant migration is occurring. The water level and water quality data are most easily evaluated using maps and cross-sections to plot the potentiometric surface and contaminant extent. The presence of inward gradients can be interpreted from the potentiometric contour maps and cross-sections. Similarly, contaminant extent can be plotted to determine if the size and position of a plume remain stable. Overlaying the potentiometric contours onto the contaminant distribution map indicates if the entire plume is located within the hydraulic capture zone. Figure A-2 is a generalized plot showing a contaminant plume that is under the hydraulic control of a pump and treat system. The figure indicates that the entire plume is located within an area where potentiometric surface contour lines depict the presence of inward gradients.

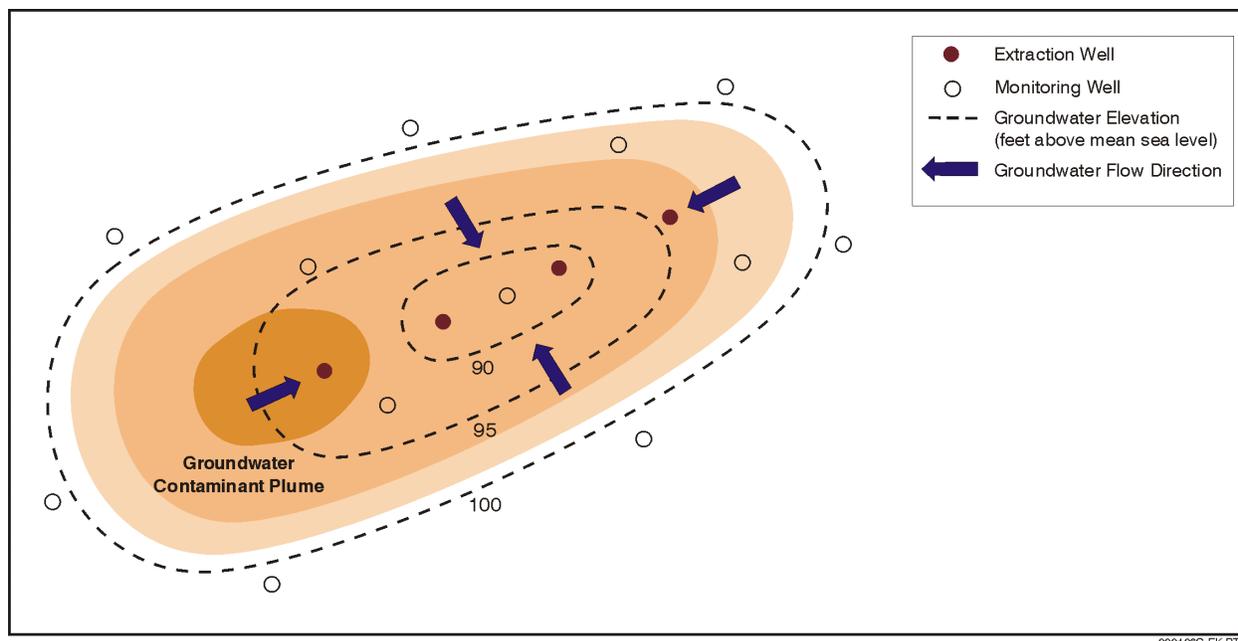


Figure A-2. Performance plot of a typical pump and treat system for hydraulic control.

A.2.3 Common Operational Problems

Operational problems common to pump and treat systems for hydraulic containment are typically associated with the extraction wells. Decreasing well yield is a particularly common problem that can result from screen incrustation and biological fouling. Corrosion is another cause of lowered well performance that can lead to screen failure, sand pumping, and pump damage. Regular measurement of well depth and specific capacity can provide warning of impending problems and indicate the need for well maintenance. Table A-1 lists these and other problems common to pump and treat systems used for hydraulic containment.

A.2.4 Common Optimization Strategies

The most significant optimization strategy for hydraulic containment systems is ensuring that the minimum quantity of groundwater is extracted to maintain plume containment. Some systems are operated at the maximum achievable extraction rates whether warranted or not. For other systems, excessive amounts of water may be extracted if the hydraulic containment design analysis was performed at a time when groundwater elevations were below normal. One remedy to these situations is to readjust the pumping rate and monitor the hydraulic response. The rate can be adjusted over a series of incremental steps until monitoring indicates that the lowest rate capable of maintaining capture has been attained. Another remedy that may be appropriate to highly characterized sites is to perform optimization modeling using analytical or numerical techniques. Available models range from simple graphical methods to complex models that have been combined with linear and nonlinear programming methods. At some sites, high long-term operating costs may justify installing low permeability barriers that limit the flow of clean water into contaminated portions of the aquifer and allow pumping rates to be decreased significantly. Table A-1 lists factors that should be considered to optimize the performance of pump and treat systems for hydraulic containment.

Table A-1. Common Operational Problems and Optimization Strategies for Hydraulic Containment Pump and Treat Systems

Operational Problem	Potential Causes	Potential Negative Impacts on Performance	Optimization Strategies
The extraction rate declines over time.	<ul style="list-style-type: none"> • Mineral incrustation of the well screens is occurring. • Biological fouling of the well screens is occurring. 	<ul style="list-style-type: none"> • Pumping below the design rate can result in a capture zone that shrinks in size and fails to maintain hydraulic containment. 	<ul style="list-style-type: none"> • Perform well rehabilitation using appropriate acids and/or biocides. • Redevelop the affected wells.
The design extraction rates have never been achieved in individual wells.	<ul style="list-style-type: none"> • The pumps are not properly sized. • The extraction wells were improperly designed, installed, or developed. • The aquifer yield is less than predicted. 	<ul style="list-style-type: none"> • The inability to achieve the design rate may result in a failure to establish a capture zone of sufficient size to contain the contaminants. 	<ul style="list-style-type: none"> • Install properly sized pumps. • Redevelop the poorly developed wells. • Replace the wells that are improperly designed or constructed. • Review and potentially revise the aquifer-testing results. Install additional wells, as necessary.
The wells are pumping sand or experiencing siltation.	<ul style="list-style-type: none"> • The pumps are improperly placed within the well screens. • The wells are poorly developed. • The wells were installed with inadequate sand packs or screens. 	<ul style="list-style-type: none"> • "Sand pumping" can lead to excessive well or treatment system downtime and result in the loss or diminished size of the capture zone. 	<ul style="list-style-type: none"> • Raise the pumps above the well screens and redevelop the affected wells. • Redevelop the poorly developed wells. • Replace the improperly installed wells.
The contaminant plume is migrating.	<ul style="list-style-type: none"> • The pumping rate is not sufficient to establish a capture zone. • The system is experiencing prolonged shut down. • The number of wells is not adequate or they are improperly located. 	<ul style="list-style-type: none"> • Failure to maintain containment will allow the plume to expand in size and potentially reach receptors. 	<ul style="list-style-type: none"> • Increase the well pumping rates. • Increase the system uptime through a preventive maintenance program. • Install additional wells.
Excessive volumes of water are being extracted.	<ul style="list-style-type: none"> • The system is arbitrarily being pumped at the maximum rate or the margin of safety in the pumping rate is overly conservative. • The design rate was based on an analysis of abnormal conditions. • The high permeability of the aquifer requires a high pumping rate to maintain the capture zone. 	<ul style="list-style-type: none"> • Pumping at rates greater than required to contain the plume results in unnecessary costs. 	<ul style="list-style-type: none"> • Incrementally adjust pumping to lower rates and monitor the hydraulic response until results indicate that the minimum pumping rate necessary to maintain the capture zone has been attained. • Perform analytical or numerical groundwater modeling to calculate optimum pumping rates. • Evaluate whether installing low permeability barriers will be cost effective in lowering the pumping rate in high yielding aquifers.

A.3 Pump and Treat for Contaminant Mass Removal

A.3.1 System Description

The ultimate goal of pump and treat systems designed for mass removal is aquifer restoration. Therefore, in addition to preventing plume migration, pump and treat systems designed for contaminant mass removal extract contaminated groundwater from an aquifer and enhance the flushing of contaminants that are sorbed to the aquifer matrix as quickly and efficiently as possible. The strategy for operating this type of system is to install extraction wells within a contaminated groundwater plume and operate them until the contaminant levels decrease to some predetermined level, or until a site-specific shut-down criterion is achieved. Prior completion of source removal is critical to achieving groundwater restoration using pump and treat. The major limitations associated with these systems are attributed to two phenomena known as tailing and rebound, which are discussed in Sections A.3.2 and A.3.3.

Like pump and treat systems for hydraulic containment, pump and treat systems for contaminant mass removal typically include the following components:

- An extraction network, including wells and/or trenches
- A collection system, including groundwater pumps and conveyance piping
- An extracted groundwater treatment system and disposal option
- A monitoring system and program

Figure A-3 is a schematic diagram of a pump and treat system with a network of vertical extraction wells installed to extract contaminant mass and to contain plume migration. The extraction wells are installed in the areas of greatest contamination; along the plume axis; and, in areas of the least mobile contaminants to, collectively, maximize mass removal, reduce the pumping of clean water, and minimize contaminant travel time to the extraction wells. The diagram also shows 12 monitoring wells for measuring water levels and collecting groundwater samples for chemical analysis. A pre-treatment unit, air stripper, and liquid-phase granulated activated carbon are used to treat extracted groundwater in this system prior to discharge. Treatment options for extracted water are discussed separately in Section A.15.2

A.3.2 Performance Plots

An objective inherent to groundwater pump and treat systems for contaminant mass removal is hydraulic containment of the contaminants. Therefore, the effectiveness of these systems in preventing plume migration should first be evaluated using the procedures described in Section A.2.2.

The effectiveness of the systems in removing contaminant mass and restoring groundwater quality should then be evaluated by plotting the contaminant concentrations measured in the system influent versus time. Groundwater pump and treat systems for contaminant mass removal typically exhibit a tailing effect in that the rate at which contaminant concentrations in the influent are reduced gradually declines. A plot of concentrations versus time for these systems will have an area of high initial contaminant concentrations, followed by a period of rapidly declining concentrations, and finally a period in which influent contaminant concentrations reach asymptotic levels. Figure A-4 shows a performance plot for a pump and treat system that has achieved an asymptotic level in the concentration of influent to the system. Similar plots should be prepared for individual monitoring wells by graphing contaminant concentrations in groundwater samples versus time. The concentrations in monitoring well plots will also eventually reach asymptotic levels as pumping continues.

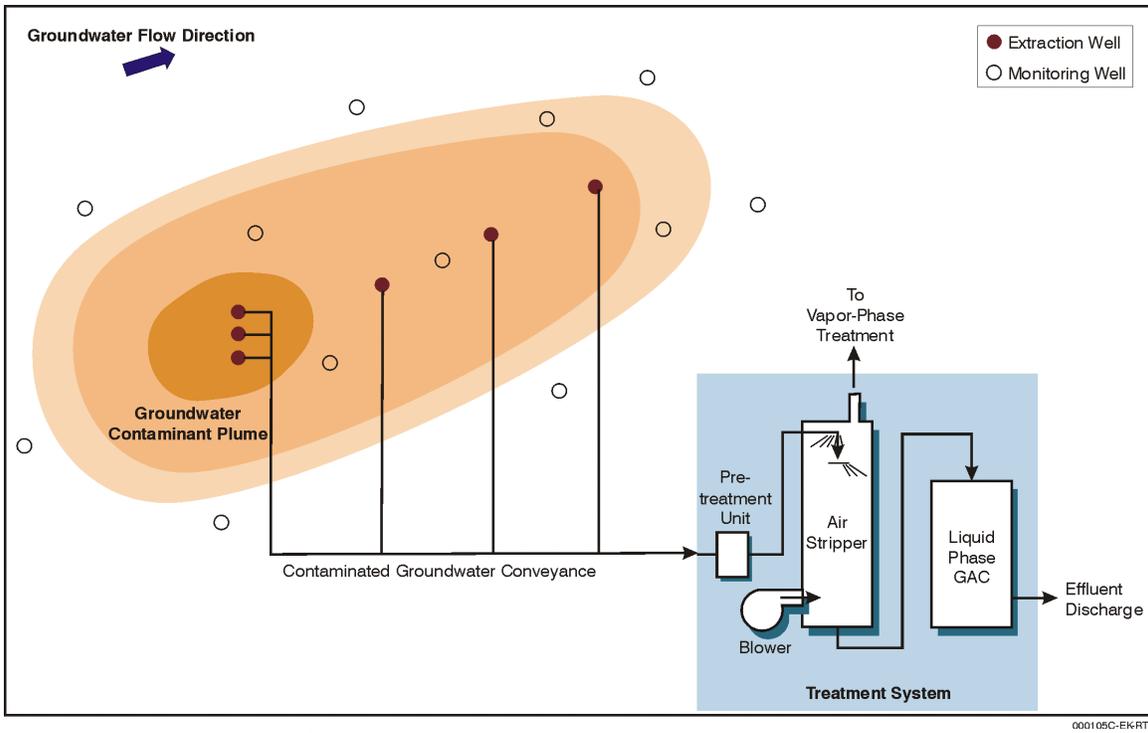


Figure A-3. Typical pump and treat system for mass removal.

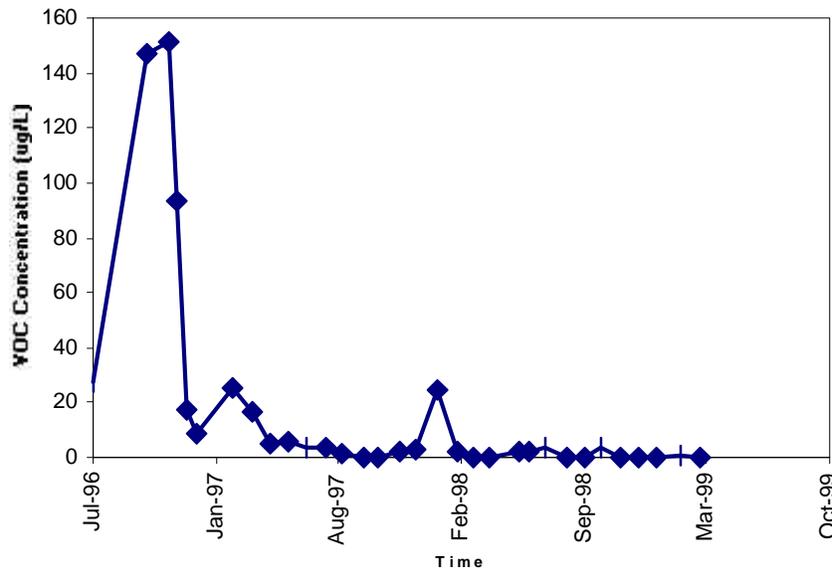


Figure A-4. Performance plot of groundwater pump and treat system MCAS New River, Campbell Street Fuel Farm, CST Trench.

Example: Figure A-4 shows that the CST Trench pump and treat system has reached asymptotic conditions. With the exception of two spikes, the total VOC concentration has been below 15 parts per billion (ppb) since December 1996. These results suggest that contaminants originally present in groundwater adjacent to the remediation system's interceptor trench have been removed and any contaminants remaining upgradient are stationary or receding. Consequently, the evaluation of monitored natural attenuation as a potential alternative remedy was recommended.

When pumping is terminated for at least several months, the contaminant concentrations in the groundwater will typically rebound to levels that exceed those measured during system operation, but which are below initial concentrations. The rebound in concentrations will be evident in monitoring well samples and in the influent of a system that is restarted. Figure A-5 illustrates several periods of rebound in the influent concentration of a pump and treat system that is alternately turned on and off in an operating procedure known as pulsing.

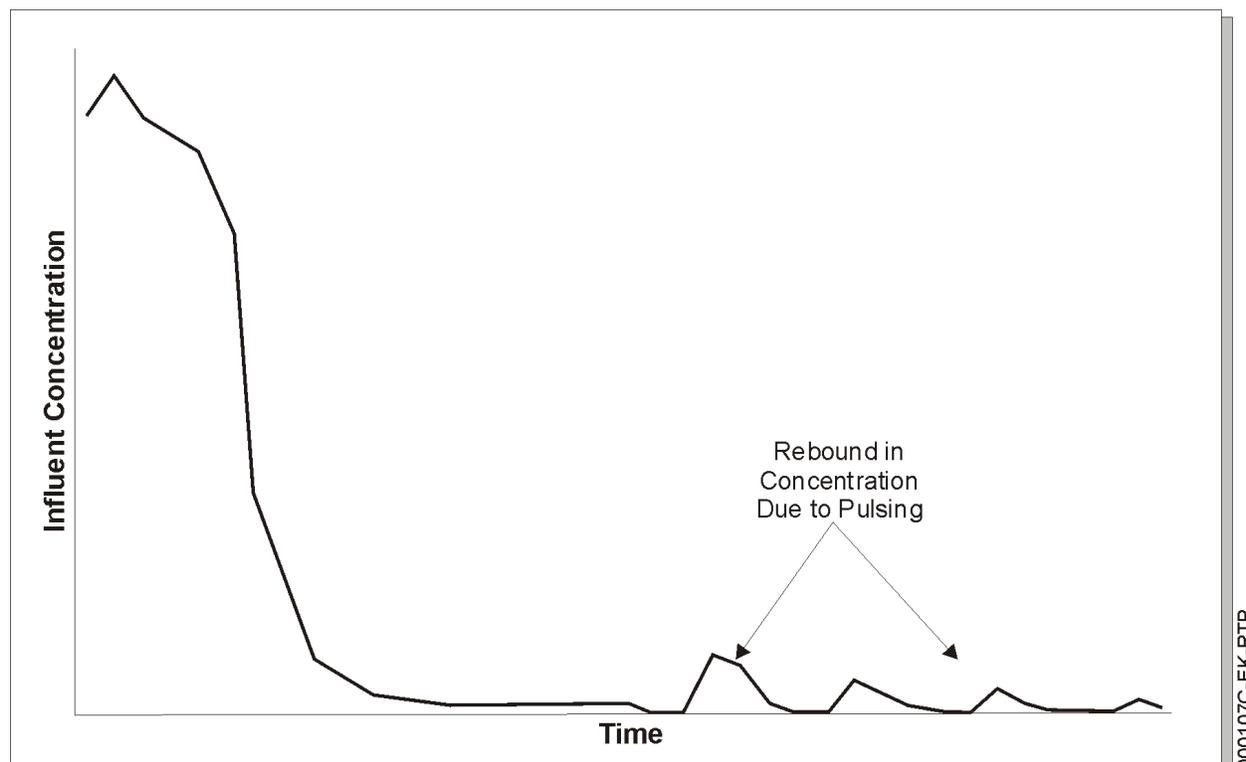


Figure A-5. Typical performance plot showing rebound in Influent concentration as a result of pulsing a pump and treat system.

A.3.3 Common Operational Problems

An unrealistic expectation that a pump and treat system alone can attain cleanup goals based on drinking water standards is a fundamental problem common to many sites. Practical application of the technology has shown that the feasibility of achieving cleanup to drinking water standards using pump and treat systems is difficult. Pump and treat systems are most likely to achieve this goal at sites involving mobile contaminants dissolved in groundwater in a permeable, homogeneous aquifer from which the source area has been completely removed. However, even under these ideal conditions several factors, including the presence of residual contaminants, slow contaminant desorption, and low hydraulic conductivity, can impose serious limitations on pump and treat performance. These factors contribute to the increasingly lower rate at which contaminant concentrations decline as pumping progresses, known as tailing; and, in the rebound of contaminant concentrations to higher levels when pumping is terminated. Both tailing and rebound increase the volume of water that must be extracted to achieve cleanup goals and, therefore, prolong the time necessary to complete remediation.

The contaminant source, including any nonaqueous phase liquid present at residual saturation, must be removed before a pump and treat system can potentially restore an aquifer. Otherwise, contaminants in the source area will continue to dissolve into groundwater and maintain concentrations above cleanup goals. Similarly, as pumping progresses and reduces the concentration of contaminants dissolved in groundwater, any contaminants sorbed to the aquifer matrix will partition into groundwater at rates that depend on the contaminant concentrations, their sorption properties, and the velocity of groundwater flow. When pumping first commences, increased groundwater flow rates cause a decrease in contaminant concentrations that ultimately tails off until the rate of desorption is again in equilibrium with the increased groundwater flow velocity. This tailing phenomenon is responsible for the asymptotic contaminant concentration levels typically seen in the performance plots of many pump and treat systems. Subsequently, if pumping is terminated, groundwater flow velocity decreases, contact time between the sorbed contaminants and groundwater increases, and dissolved contaminant concentrations rebound as higher equilibrium conditions are re-established.

Low aquifer hydraulic conductivity can limit the yield of extraction wells causing efforts to contain plume migration to fail. In addition, low extraction well yield may result in the insufficient flushing of the aquifer. Aquifer restoration requires that sufficient groundwater (typically 0.3 to 2 pore volumes annually) be flushed through the contaminated zone to extract both dissolved contaminants and contaminants that will desorb from the aquifer matrix (Cohen et al., 1994. *Methods for Monitoring Pump and Treat Performance*. EPA/600/R-94/123). Low hydraulic conductivity may restrict the ability to pump at the rates necessary to achieve this degree of flushing.

Other operational problems common to pump and treat systems are those associated with the extraction well network. Decreased well yield is a particularly common problem that can result from screen incrustation and biological fouling. Corrosion is another cause of lowered well performance that can lead to screen failure, sand pumping, and pump damage. Regular measurement of well depth and specific capacity can provide warning of impending problems and indicate the need for well maintenance. Table A-2 lists other problems common to pump and treat systems for contaminant removal.

A.3.4 Common Optimization Strategies

Optimizing groundwater flow through a contaminated zone to flush dissolved and sorbed contaminants from an aquifer can improve the effectiveness and efficiency of pump and treat systems in removing mass. This primarily involves optimizing pumping rates, well locations, and screen depths. These and other factors that should be considered in optimizing pump and treat performance for mass removal are listed in Table A-2.

In particular, because asymptotic levels of mass removal have been reached by many pump and treat systems, a commonly applicable optimization strategy is to alternate periods of pumping with periods of no pumping in a procedure known as pulsing. During each non-pumping period, contaminants sorbed to the aquifer matrix or residing in low permeability zones are allowed to reach chemical equilibrium in the groundwater resulting in the removal of the highest contaminant concentration for the minimum volume of water extracted. During pulsing, hydraulic containment must be maintained to prevent contaminant plume migration. In some cases, the plume may not migrate beyond the radius of the capture zone before pumping is resumed and inward gradients are re-established. In other cases, however, the plume may need to be contained by continuously pumping wells near the boundary while wells in the more highly contaminated portions of the plume are pulsed.

**Table A-2. Common Operational Problems and Optimization Strategies
for Pump and Treat Systems for Mass Recovery**

Operational Problem	Potential Causes	Potential Negative Impacts on Performance	Optimization Strategies
The contaminant concentrations have not declined in the system influent and in the monitoring wells.	<ul style="list-style-type: none"> • The pumping rate is too low to allow an adequate number of pore volumes of groundwater to be pumped through the contaminant plume. • Source areas or hotspots have not been adequately controlled. 	<ul style="list-style-type: none"> • The inability to remove contaminants due to ineffective flushing or lack of source control precludes aquifer cleanup. 	<ul style="list-style-type: none"> • Increase the pumping rates of existing wells and/or install additional wells to increase the number of pore volumes pumped through the contaminant plume. • Install source control wells or evaluate other source control measures. • Evaluate alternate technologies for possible implementation.
The contaminant concentrations in the system influent and in the monitoring wells have reached asymptotic levels and/or rebound to higher levels when pumping is terminated.	<ul style="list-style-type: none"> • The removal of contaminants sorbed to the aquifer matrix is limited by site-specific desorption rates. • The removal of contaminants within low permeability zones is diffusion limited. • The extraction wells are improperly located or continue to operate in areas where contamination has been reduced. • The extraction wells are inappropriately screened through zones of lesser contamination. • The contaminants remain at stagnation points that are not flushed by groundwater pumping. 	<ul style="list-style-type: none"> • The slower rate of contaminant removal will extend cleanup time. 	<ul style="list-style-type: none"> • "Pulse" the extraction wells or reduce the pumping rates to correspond to contaminant desorption and/or diffusion rates. • Identify unproductive extraction wells through sampling and decrease the pumping rates while increasing rates at more productive wells. • Replace the improperly screened wells with wells isolated to the contaminated intervals within the aquifer. • Rebalance the pumping rates between wells to eliminate stagnation points or install additional wells to enhance flushing through stagnation points.
The system is not effectively removing contaminants but the contaminant concentrations are decreasing or have reached asymptotic levels and the plume is stable or receding.	<ul style="list-style-type: none"> • The contaminants may be undergoing natural attenuation. 	<ul style="list-style-type: none"> • Continued active remediation may not be cost effective. 	<ul style="list-style-type: none"> • Evaluate the feasibility of MNA for site remediation. Shut down the pump and treat system if MNA is feasible.

Table A-2. Common Operational Problems and Optimization Strategies for Pump and Treat Systems for Mass Recovery (continued)

Operational Problem	Potential Causes	Potential Negative Impacts on Performance	Optimization Strategies
The contaminant plume is migrating.	<ul style="list-style-type: none"> • The pumping rate is not sufficient to establish a capture zone. • The system is experiencing prolonged shut down. • The number of wells is not adequate or they are improperly located. 	<ul style="list-style-type: none"> • Failure to maintain containment will allow the plume to enlarge in size and potentially reach receptors. The larger area of contamination will also result in increased remediation time and require expanding the pump and treat system. 	<ul style="list-style-type: none"> • Increase the well pumping rates. • Increase the system uptime through a preventive maintenance program. • Install additional wells.
The extraction rate declines over time.	<ul style="list-style-type: none"> • Mineral incrustation of the well screens is occurring. • Biological fouling of the well screens is occurring. 	<ul style="list-style-type: none"> • Pumping below the design rate can result in a capture zone that shrinks in size and fails to maintain hydraulic containment. 	<ul style="list-style-type: none"> • Perform well rehabilitation using appropriate acids and/or biocides. • Redevelop the poorly developed wells.
The design extraction rates have never been achieved in individual wells.	<ul style="list-style-type: none"> • The pumps are not properly sized. • The wells are poorly developed. • The extraction wells were improperly designed, installed, or developed. • The aquifer yield is less than predicted. 	<ul style="list-style-type: none"> • The inability to achieve the design rate may result in a failure to establish a capture zone of sufficient size to contain the contaminants. 	<ul style="list-style-type: none"> • Install properly sized pumps. • Redevelop the affected wells. • Replace the wells that are improperly designed or constructed. • Review and potentially revise the aquifer-testing results. Install additional wells, as necessary.
The wells are pumping sand or experiencing siltation.	<ul style="list-style-type: none"> • The pumps are improperly placed within the well screens. • The wells are poorly developed. • The wells were installed with inadequate sand packs or screens. 	<ul style="list-style-type: none"> • "Sand pumping" can lead to excessive well or treatment system downtime and result in the loss or diminished size of the capture zone. 	<ul style="list-style-type: none"> • Raise the pumps above the well screens and redevelop the affected wells. • Redevelop the poorly developed wells. • Replace the improperly installed wells.

Other optimization strategies are related to improving the operation of the extraction wells. Decreasing well yield is a particularly common problem that can result from screen incrustation and biological fouling. Corrosion is another cause of lowered well performance that can lead to screen failure, sand pumping, and pump damage. Regular measurement of well depth and specific capacity can provide warning of impending problems and indicate the need for well maintenance.

Example: *At NAS Brunswick, "uptime" for wells in the Eastern Plume pump and treat system was limited by high turbidity and "sand pumping." The operational history of the system indicated that these were recurring problems in wells whose design and construction required that the pumps be located in or near the screened portion of the wells. Therefore, it was recommended that the pumps be positioned above the well screen in all suitably constructed existing wells and in any new wells added to the system.*

A.4 Soil Vapor Extraction

A.4.1 System Description

SVE is applied to vadose zone soils, generally within source areas of contamination. This technique is most effective in soils with relatively homogenous soil lithology and high permeability to air. It is not effective where the water table is less than 3 feet below ground surface (bgs) and requires special controls such as groundwater pumping or horizontal wells at sites where the water table is less than 10 feet bgs. SVE wells are installed and screened above the water table, and should intersect the subsurface zone(s) of contamination as much as possible. The application of a vacuum to these wells induces air to flow from the atmosphere, through the contaminated vadose zone, and to the well screen. This flow of air causes contaminants with low vapor pressures to be volatilized from subsurface soils into the vapor phase and transported to the surface where the VOCs can be treated and/or discharged.

The primary components of a typical SVE system are shown in Figure A-6, which include extraction wells, transfer piping, a water-vapor separator, a vacuum pump, and a vapor treatment system. The figure also illustrates an air inlet well, which is sometimes included in the system design to enhance airflow in the subsurface. Most of the differences between individual SVE systems is associated with the type and size of the vacuum generating system and the vapor treatment system. The types of vacuum pumps typically used include regenerative, positive displacement, and liquid ring. SVE wells can be readily installed as vertical wells, angled wells, or horizontal wells depending on site-specific conditions. Treatment methods for extracted vapors include direct discharge (no treatment), carbon adsorption, and oxidation. Treatment options for extracted vapor are discussed separately in Section A.15.1

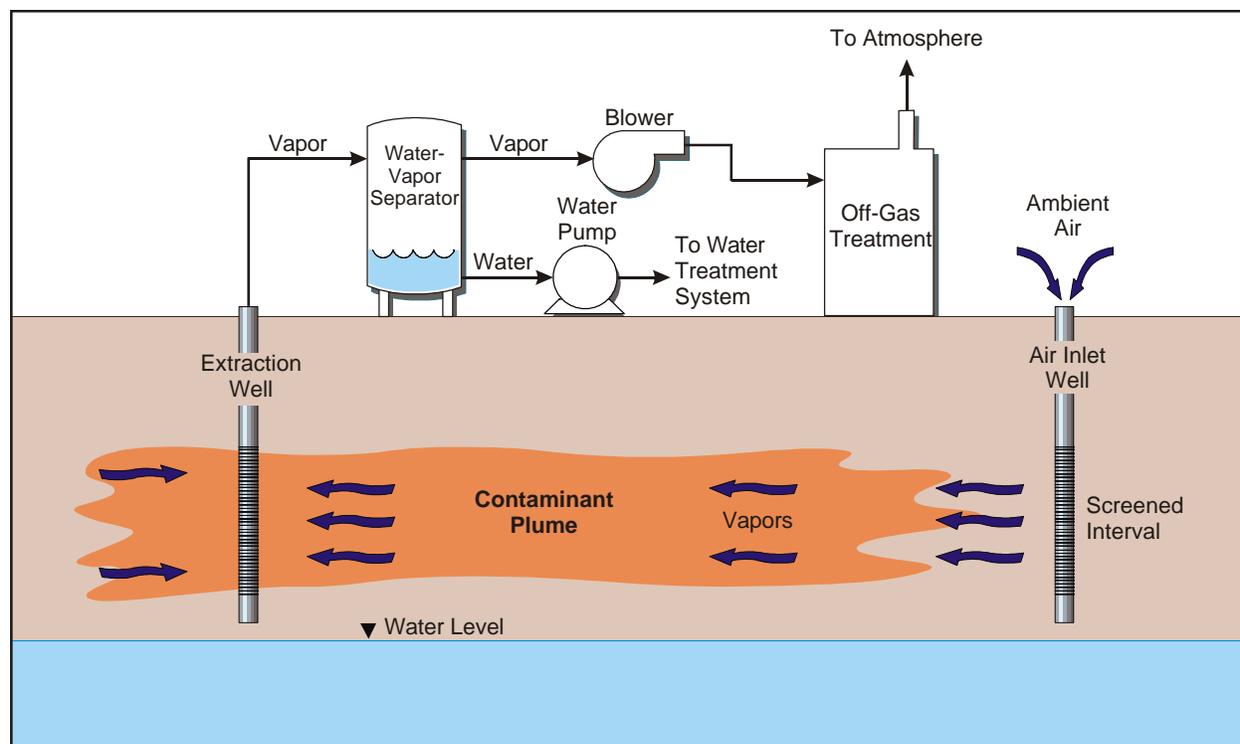


Figure A-6. Typical soil vapor extraction system.

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A.4.2 Performance Plots

The performance of SVE systems can be illustrated by plotting both contaminant vapor concentration and cumulative mass removal versus time. A typical contaminant concentration response curve for an SVE system is characterized by an area of initially high soil vapor concentrations in the extracted vapor, followed by a period of rapidly declining vapor concentrations, and finally a period in which influent vapor concentrations reach asymptotic low levels. A plot of cumulative contaminant mass removed by a SVE system is a mirror image of the contaminant concentration response curve. A plot of cumulative mass recovered versus time is shown in Figure A-7.

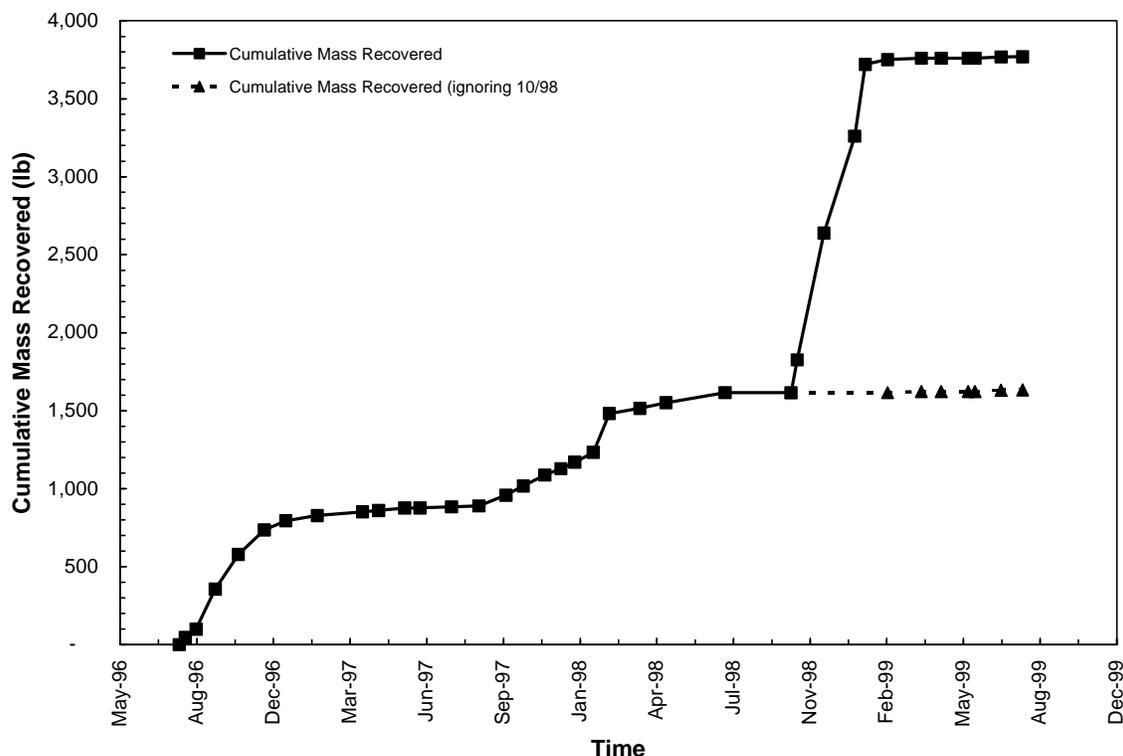


Figure A-7. Soil vapor extraction system performance at NSB New London.

Example: A soil vapor extraction system was installed in conjunction with an air sparging system at the Naval Exchange (NEX) Service Station at NSB New London. The combined system was designed to remediate soil and groundwater contaminated by a petroleum release from an underground storage tank system. Figure A-7 shows that the cumulative mass of contaminants removed through the SVE system since 1996 exceeds 3,500 pounds. Asymptotic levels of mass removal were reached by March 1998 but were interrupted in October 1998 by another release at the site. An additional 2,000 pounds of contaminants were removed before asymptotic behavior resumed. Because groundwater cleanup levels were achieved, termination of active remediation and implementation of groundwater monitoring to justify site closeout was recommended.

A.4.3 Common Operational Problems

Soil vapor extraction performance problems are commonly related to a system's inability to extract air from all areas of the remediation target zone. Generally, this problem is due to an under-designed system, short-circuiting or unanticipated site conditions. Conversely, an SVE system that is operating effectively will eventually reach a point at which the mass transfer of sorbed contaminants typically becomes desorption and/or diffusion limited. Table A-3 lists these and other problems common to SVE systems.

A.4.4 Common Optimization Strategies

Optimizing the operation of SVE systems requires reliable data collection on a routine basis to track both total extraction rate and the extraction rate of each individual well. The types of information needed to optimize SVE performance may include the following:

- Concentration of contaminants extracted prior to treatment
- Concentration of contaminants from each well
- Total system vacuum and individual well vacuums
- Condensate production rate
- Vapor flow rate at vacuum pump inlet and from individual wells
- Vacuum influence and contaminant concentrations at soil gas vapor monitoring points (VMP),
- Contaminant concentrations from groundwater samples

When the amount of mass recovered, or the constituent concentrations in the extracted vapor and in groundwater samples reach asymptotic conditions, pulsing the system should be considered in an effort to restore a higher mass removal rate. More aggressive measures such as installing additional extraction wells may also be evaluated. If asymptotic conditions persist after operational or system changes have been implemented continued operation of the SVE system will generally not result in the significant removal of additional mass. In this case, if further remediation is necessary, implementing another technology or monitored natural attenuation should be considered. Table A-3 provides other guidance on optimizing SVE system performance.

Table A-3. Common Soil Vapor Extraction System Operational Problems and Optimization Strategies

Operational Problem	Potential Causes	Potential Negative Impacts on Performance	Optimization Strategies
The design extraction rates and/or radius of influence have never been achieved in individual wells.	<ul style="list-style-type: none"> • The air permeability of the soil is lower than estimated. • Short-circuiting is occurring due to the presence of preferential flow paths. • The extraction wells have been incorrectly designed or installed. 	<ul style="list-style-type: none"> • The contaminants located outside the effective radius of the vacuum are not removed and prevent reaching cleanup goals. • The number of pore volumes of soil gas exchanged in the contaminated area is limited and results in low mass removal that increases cleanup time. 	<ul style="list-style-type: none"> • Perform a subsurface investigation to further characterize the soil permeability and the preferential flow paths. • Utilize Pneulog technology to profile vertical differences in the air permeability and contaminant mass and focus well screen placement to the appropriate depth intervals. • Install additional wells in the contaminated areas located outside the system's treatment zone. • Replace incorrectly designed or installed wells.
The contaminant concentrations have been reduced in some but not all wells.	<ul style="list-style-type: none"> • Treatment may be complete in some areas of the site. • The airflow to some areas of the site is inadequate. 	<ul style="list-style-type: none"> • Continued operation of nonproductive wells will not be cost effective. • The low airflow rates will limit mass removal and increase cleanup time. 	<ul style="list-style-type: none"> • Shut off the low producing wells or reduce their pumping rates while increasing rates at the more productive wells. • Install additional extraction wells in the areas where airflow is not adequate.
The contaminant concentrations in extracted vapor have reached asymptotic levels.	<ul style="list-style-type: none"> • The removal of contaminants sorbed to the soil is limited by site-specific desorption rates. • The removal of contaminants within low permeability zones is diffusion limited. • The extraction wells are not properly located or screened to treat all contaminated areas. • An uncontrolled source area continues to release contaminants. 	<ul style="list-style-type: none"> • The slower rate of contaminant removal due to desorption/diffusion limitations will extend cleanup time. • The presence of a continuing source of contaminants will prevent cleanup. 	<ul style="list-style-type: none"> • "Pulse" the wells or reduce airflow rates to correspond to contaminant desorption and/or diffusion rates. • Install additional wells in the contaminated areas located outside the system's treatment zone. • Install wells with screens isolated to the most productive soil layers or pack off unproductive intervals in existing wells. • Implement source control including excavation if feasible. • Evaluate alternate technologies such as thermally enhanced SVE or bioventing for petroleum-related contamination.

Table A-3. Common Soil Vapor Extraction System Operational Problems and Optimization Strategies (continued)

Operational Problem	Potential Causes	Potential Negative Impacts on Performance	Optimization Strategies
Low concentrations of contaminants are extracted during operation, but high concentrations reappear when the system is shut off.	<ul style="list-style-type: none"> • The removal of contaminants sorbed to the soil is limited by site-specific desorption rates. • The removal of contaminants within low permeability zones (tight soil layers) is diffusion limited. • The airflow rate is higher than necessary due to desorption and diffusion limits. • The airflow is short-circuiting due to preferential flow. 	<ul style="list-style-type: none"> • The slower rate of contaminant removal due to desorption/diffusion limitations or preferential flow paths will extend the cleanup time. 	<ul style="list-style-type: none"> • "Pulse" the wells or reduce the airflow rates to correspond to contaminant desorption and/or diffusion rates. • Temporarily shut off the system and perform equilibrium testing at vapor monitoring points to identify the more highly contaminated areas where SVE should be focused. • Identify and excavate any desorption/diffusion-limited hot spots, if feasible. • Evaluate alternate technologies such as thermally enhanced SVE or bioventing for petroleum-related contamination.
The contaminant concentrations in vapor monitoring points and in the extracted vapor remain high despite high mass removal rates	<ul style="list-style-type: none"> • An uncontrolled source area or free product may be present. 	<ul style="list-style-type: none"> • The presence of a continuing source of contaminants will preclude cleanup. 	<ul style="list-style-type: none"> • Perform further subsurface investigation to identify additional source areas and potential free product. • Identify and control any source areas including excavation if feasible.
The system extracts high volumes of water.	<ul style="list-style-type: none"> • The well screens are installed too close to the water table causing upwelling to occur. 	<ul style="list-style-type: none"> • Water table upwelling may occlude well screens causing lower mass removal that extends cleanup time. • The extraction of high volumes of water may result in excessive system downtime. 	<ul style="list-style-type: none"> • Replace the existing wells with shallower vertical wells or with horizontal wells. • Consider temporarily shutting down the system during periods of seasonal high water table. • Evaluate the use of an alternate technology that is not influenced by a high water table.

A.5 Air Sparging

A.5.1 System Description

Air sparging (AS) is an extraction technology that physically removes VOCs dissolved in groundwater and sorbed to soil. Biodegradation of nonhalogenated contaminants is also usually enhanced as a result of introducing oxygen. Like SVE, air sparging is most effective in relatively homogeneous lithology with high permeability. It is also most effective with VOCs that exhibit a high Henry's law constant and will transfer easily to the vapor phase. The technology involves injecting air into the contaminated portion of the saturated zone. The air is typically injected through vertical wells completed below the water table. In some cases, however, horizontal wells may be used to remediate larger areas. The injected air results in the transfer of dissolved and sorbed VOCs to the vapor phase. Although the vapor can be vented naturally to the surface, it is usually extracted through a SVE system (Section 4.3) installed to control vapor migration. The application of air sparging in conjunction with SVE is known as AS/SVE. Biosparging is a variation of air sparging in which air is injected at a lower rate than in air sparging. The remediation objective in biosparging is not to strip the contaminants but rather to enhance their biodegradation by introducing oxygen. Biosparging is typically applied to petroleum products, dichloroethene, and vinyl chloride. Unlike air sparging, which is limited to remediating VOCs, biosparging is also effective in remediating semivolatile organic compounds.

When the amount of mass recovered, or the constituent concentrations in the extracted vapor and in groundwater samples reach asymptotic conditions, pulsing the system should be considered in an effort to restore a higher mass removal rate. More aggressive measures such as installing additional air sparging wells may also be evaluated. If asymptotic conditions persist after operational or system changes have been implemented, continued operation of the AS system will generally not result in the significant removal of additional mass. In this case, if further remediation is necessary, implementing another technology or monitored natural attenuation should be considered.

The primary components of a typical AS system include air injection wells, manifold piping, and a blower or air compressor. Figure A-8 is an illustration of an air sparging system.

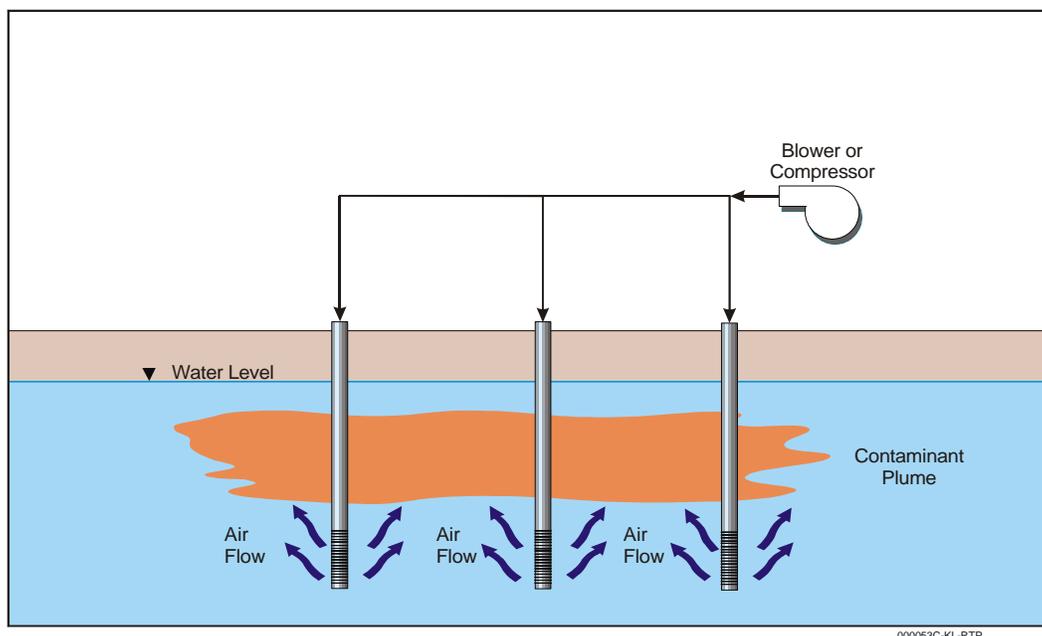


Figure A-8. Typical air sparging system.

A.5.2 Performance Plots

The performance of an AS system that is operated in conjunction with an SVE system should be assessed by plotting both the concentration of constituents in the extracted soil vapor and the amount of contaminant mass removed versus time. A performance plot of mass removed is similar to the illustration shown in Figure A-7. In addition, or in cases where a complementary SVE system is not operated, progress toward achieving cleanup objectives should be monitored by plotting the contaminant concentrations measured in groundwater samples collected from monitoring wells versus time. An example of this type of performance plot is shown in Figure A-9. All three types of plots will eventually exhibit asymptotic conditions as system performance declines as remediation progresses.

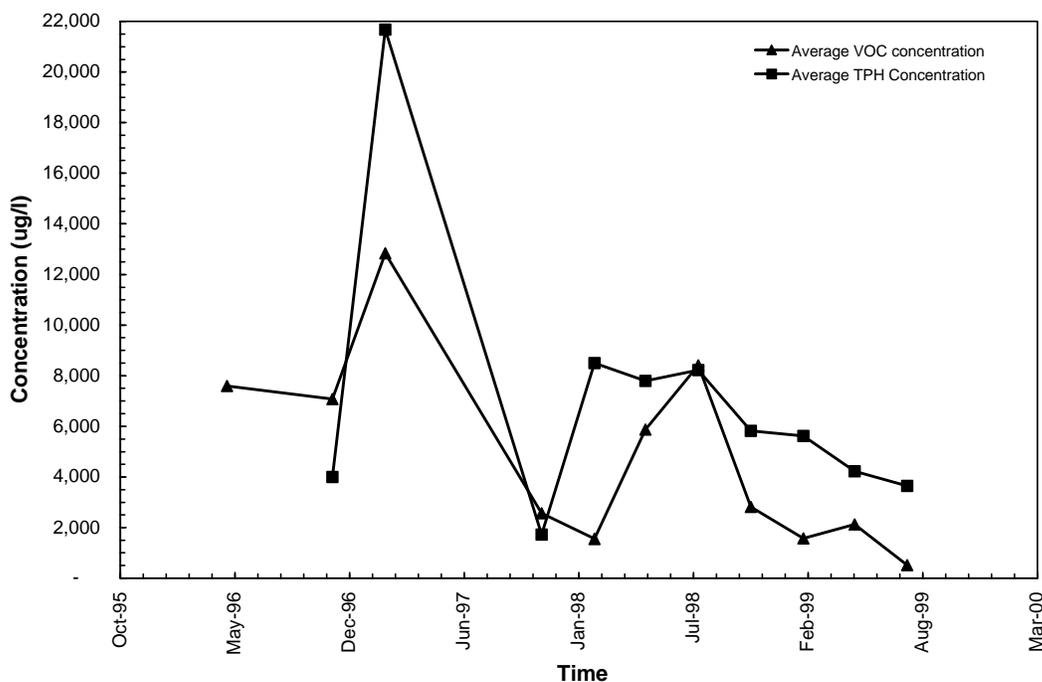


Figure A-9. Air sparging system performance at NSB New London.

Example: The remedial progress of the air sparging/soil vapor extraction system at the NEX site at NSB New London is evaluated through periodic groundwater monitoring. Figure A-9 illustrates a decrease in VOC and total petroleum hydrocarbon (TPH) concentrations in groundwater during the system's operation. Both curves show a general downward trend in concentration over a period during which at least 3,500 pounds of contaminants were removed by the remediation system. Because groundwater cleanup levels were achieved, termination of active remediation and collection of equilibrium samples to justify site closeout was recommended. Pulsing the air sparging system was recommended as a contingent remedy should contaminants in groundwater rebound to higher concentrations.

A.5.3 Common Operational Problems

A general problem common to AS systems is inadequate air distribution to all areas of the remediation target zone. Generally, this problem is due to an under-designed system, short-circuiting or unanticipated site conditions. Conversely, an AS system that is operating effectively will eventually reach a point at which the mass transfer of sorbed contaminants typically becomes desorption and/or diffusion limited. Table A-4 lists some of the underlying causes of inadequate air distribution as well as other problems that may affect the performance of air sparging systems.

A.5.4 Common Optimization Recommendations

When the various performance plots discussed in Section A.5.2 depict asymptotic conditions, pulsing the system should be considered in an effort to restore a higher mass removal rate. More aggressive measures such as installing additional air sparging wells may also be evaluated. If asymptotic conditions persist after operational or system changes have been implemented, continued operation of the AS system will generally not result in the significant removal of additional mass. In this case, if further remediation is necessary, implementing another technology or monitored natural attenuation should be considered.

If the AS system is combined with SVE, a determination should be made if the air sparge vapors must continue to be collected. In cases where receptors are absent, there may be no risk in allowing the vapors to migrate up through the unsaturated zone and to escape to the atmosphere. In certain other cases, biological processes that operate in the unsaturated zone may consume aerobically degradable contaminants present in the vapor. Table A-4 provides additional guidance on optimizing AS system performance.

***Example:** At NSB New London, an AS/SVE system at the NEX site reached low and asymptotic contaminant removal rates. The most recent groundwater monitoring results also indicated that the applicable remediation standards had been reached. Therefore, it was recommended that the system be shut down and post-remediation monitoring be initiated. Also, pulsed operation of the AS/SVE system or biosparging was recommended if rebound in contaminant concentrations occurred.*

Table A-4. Common Air Sparging System Operational Problems and Optimization Strategies

Operational Problem	Potential Causes	Potential Negative Impacts on Performance	Optimization Strategies
The zone of influence is insufficient or not as predicted.	<ul style="list-style-type: none"> The permeability of the soil is lower than estimated. Short-circuiting of air is occurring along the sparge well casings or subsurface utilities. Heterogeneous soil is causing channeling of the injected air. 	<ul style="list-style-type: none"> The airflow may not contact some areas of contamination resulting in insufficient cleanup. Cleanup will not be achieved or will take longer than estimated. 	<ul style="list-style-type: none"> Increase the airflow to the injection wells. Install additional wells in the contaminated areas located outside the system's treatment zone. Evaluate the system for evidence of short-circuiting; consider repairing, replacing, or relocating the affected wells.
Increasingly high injection pressure is needed to maintain flow.	<ul style="list-style-type: none"> The injection wells have been become plugged through mineral encrustation, biological fouling, or siltation. 	<ul style="list-style-type: none"> The airflow through the contaminated area will not be sufficient. Cleanup will not be achieved or will take longer than estimated. 	<ul style="list-style-type: none"> Rehabilitate the affected wells with appropriate acids and/or biocides. Redevelop the affected wells. Replace the affected wells if rehabilitation or redevelopment is not possible.
The contaminant concentrations in the target zone are not declining as anticipated	<ul style="list-style-type: none"> The airflow through the contaminated area is not sufficient. The airflow is short-circuiting. An uncontrolled source area is present. 	<ul style="list-style-type: none"> Cleanup will not be achieved or will take longer than estimated due to an inability to supply air to all areas of the contaminated zone. The presence of a continuing source will prevent achieving cleanup. 	<ul style="list-style-type: none"> Increase the airflow to the injection wells. Install additional wells in the contaminated areas located outside the system's treatment zone. Evaluate the system for evidence of short-circuiting; consider repairing, replacing, or relocating the affected wells. Identify the potential source area and implement control measures. Evaluate the use of alternate technologies.
The contaminant concentrations in the target zone have reached asymptotic levels and/or rebound to higher levels when sparging is terminated.	<ul style="list-style-type: none"> The removal of contaminants sorbed to the aquifer matrix is limited by site-specific desorption rates. The removal of contaminants within low permeability zones is diffusion limited. 	<ul style="list-style-type: none"> The slower rate of contaminant removal will extend cleanup time. The presence of a continuing source will prevent achieving cleanup. 	<ul style="list-style-type: none"> "Pulse" the injection wells to correspond to the contaminant desorption and/or diffusion rates. Install additional wells in the contaminated areas. Evaluate the use of alternate technologies including natural attenuation.
Sparging vapors are not properly controlled.	<ul style="list-style-type: none"> Sparging is not operated in conjunction with an SVE system or the SVE system is not operating properly. 	<ul style="list-style-type: none"> Sparging vapors may accumulate in, or migrate to, undesirable areas. 	<ul style="list-style-type: none"> Install an SVE system. Optimize the performance of the SVE system.

A.6 Bioventing

A.6.1 System Description

Bioventing is a source reduction technology primarily used to treat vadose zone soils contaminated with petroleum hydrocarbons. Bioventing works by introducing air into subsurface zones of contamination to simulate naturally occurring microorganisms to biodegrade the petroleum components. Airflow is induced through the use of either extraction wells or injection wells. However, unlike SVE or AS, the primary contaminant removal mechanism in bioventing is biodegradation of contaminants, not extraction. Therefore, bioventing systems are operated at lower airflow rates than SVE or AS systems and can treat both volatile and non-volatile petroleum hydrocarbons. In addition to the induced airflow, nutrients are sometimes also injected into the subsurface to facilitate microbial growth in nutrient-deficient soil. Biodegradation is an inherently slow process such that the systems are used with the understanding that operation may continue for several years to reach cleanup objectives. However, because it is simple and relatively inexpensive to use, bioventing is often the remedial technology selected for sites where historical practices have resulted in releases of various fuels.

Bioventing systems are usually installed as stand-alone remedial actions. Figure A-10 illustrates a typical bioventing system utilizing extraction to induce airflow. The primary components are identical to those used in SVE and include extraction wells, piping, and a blower. Off-gas treatment is usually not required unless contaminant concentrations in the extracted vapor exceed allowable limits. The bioventing system may also incorporate one or more nutrient addition wells or trenches if microbial growth is limited by a deficiency in naturally occurring nutrients.

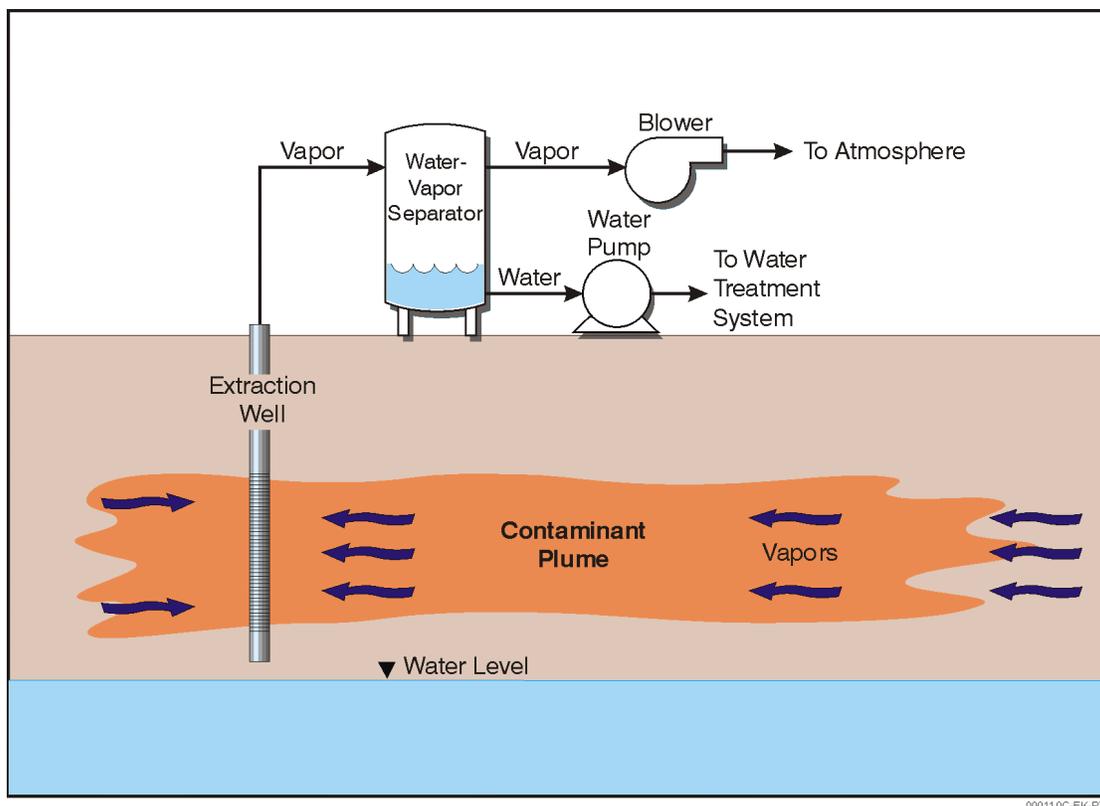


Figure A-10. Typical bioventing system.

A.6.2 Performance Plots

Because bioventing systems may reduce contaminant mass through volatilization and biodegradation, both mechanisms should be monitored to measure total mass reduction. Contaminant mass extracted can be estimated from the extracted vapor flow rate and the concentration of VOCs measured in the extracted vapor. The mass of contaminants that is biologically degraded can be interpreted from oxygen concentrations measured in soil gas respirometry tests, preferably, at vapor monitoring points, or in the extracted vapor. Carbon dioxide concentration may also be measured; however, it is not always a reliable indicator of aerobic biodegradation due to adsorption to soil moisture and buffering in alkaline soil. Performance monitoring of bioventing systems utilizing only injection wells is limited by an inability to collect extracted vapor. Figure A-11 shows a performance plot for a typical bioventing system. The figure illustrates that the system has achieved asymptotic levels with respect to VOC and carbon dioxide concentrations. The figure also shows that cumulative mass removed and degraded has similarly reached an asymptotic level.

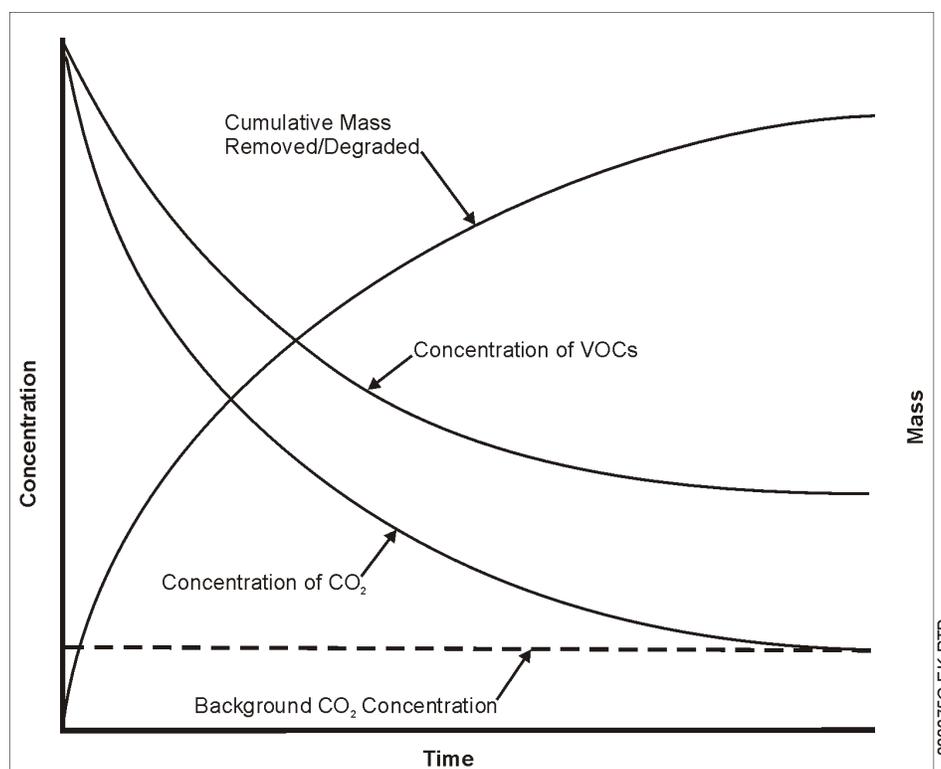


Figure A-11. Performance plot of a typical bioventing system.

A.6.3 Common Operational Problems

Two conditions must be met for bioventing to be successful. First, an adequate population of microbes must be present to sustain biodegradation. A natural population of these microbes is found at a majority of sites. Second, sufficient air must flow through the treatment zone to maintain aerobic conditions. As in the case of SVE systems, bioventing performance problems are commonly related to an inability of a system to induce airflow to all areas of the remediation target zone. Occasionally, other site conditions

may be only marginally suited to support efficient biodegradation, a situation that underscores the need for adequate bench and/or pilot-scale testing. Table A-5 lists these and other problems common to bioventing systems.

A.6.4 Common Optimization Strategies

Bioventing systems should be made as simple as possible to run continuously with little operator attention. Automatic dial-out equipment to notify operators of unplanned shutdowns is a convenient way to reduce the expense of routine system checks, and to optimize system up time. To optimize a bioventing system, system parameters are typically recorded weekly or biweekly and a review of the system performance should be conducted at a minimum of every 6 months. In-situ respiration tests should be performed at all injection or extraction wells and at soil vapor monitoring points to assess microbial activity if cleanup is taking longer than anticipated. Soil gas samples collected from these locations are typically analyzed for methane, carbon dioxide, and oxygen. This testing and sampling is to be used for assessing remedial progress and to ensure that biodegradation is continuing.

When asymptotic conditions for the constituents of concern and oxygen are first established in vapor monitoring points and extracted vapor, if applicable, alternative steps such as initially increasing the airflow rate should be explored in an effort to restore a higher degradation rate. Subsequently, the airflow may be pulsed when asymptotic conditions are re-established. Should asymptotic levels persist despite the modifications, continued operation of the bioventing system will generally not produce additional reduction in the concentration of the constituents. In this case, if further remediation is necessary, implementing either another technology or monitored natural attenuation should be considered. Generally, however, when the high-risk constituents (e.g., benzene) have been degraded, a case should be made to decommission the system and pursue site closeout. Table A-5 provides additional guidance on bioventing system operation and optimization.

Table A-5. Common Bioventing System Operational Problems and Optimization Strategies

Operational Problem	Potential Causes	Potential Negative Impacts on Performance	Optimization Strategies
The radius of influence is insufficient or not as predicted.	<ul style="list-style-type: none"> • The air permeability of the soil is lower than estimated. • The soil moisture content is too high and is limiting the air permeability of the soil. • Short-circuiting of the air is occurring along the well casings or subsurface utilities. 	<ul style="list-style-type: none"> • The airflow may not contact some areas of contamination resulting in insufficient cleanup. • Cleanup will not be achieved or will take longer than estimated. 	<ul style="list-style-type: none"> • Increase the system airflow rate. • Install additional wells in the contaminated areas located outside the system's treatment zone. • Terminate irrigation, prevent run-on, or install a surface seal to minimize the infiltration of surface water. • Evaluate the system for evidence of short-circuiting; consider repairing, replacing, or relocating the affected wells.
The contaminant concentrations are not decreasing as anticipated.	<ul style="list-style-type: none"> • The supply of oxygen in the subsurface is inadequate. • Nutrients necessary to sustain the microbial population are limited. • The soil temperature or moisture content is too low to support microbial activity. 	<ul style="list-style-type: none"> • Microbial action will slow due to rate limiting conditions so that cleanup will not be achieved or will take longer than estimated. 	<ul style="list-style-type: none"> • Perform respirometry testing to measure microbial activity. • Increase the airflow rate until oxygen concentrations in the vapor monitoring points range from 5 to 15 percent. • Evaluate the need for nutrient or moisture addition.
The contaminant concentrations in the vapor monitoring points have reached asymptotic levels and/or rebound to higher levels when system operation is terminated.	<ul style="list-style-type: none"> • The contaminants located in low permeability layers are not readily available for biodegradation. • The wells are inappropriately screened through zones of lesser contamination. • The threshold constituent level necessary to maintain microbial activity exceeds established cleanup objectives. 	<ul style="list-style-type: none"> • Cleanup will not be achieved or will take longer than estimated due to an inability to supply adequate oxygen and nutrients to all areas of the contaminated zone. • The bioventing process is not focused on contaminated zones resulting in less efficient system operation. 	<ul style="list-style-type: none"> • Initially, increase the airflow rate; pulse the airflow if asymptotic conditions persist. • Install additional wells in the low permeability areas within the contaminated zone. • Install additional wells in oxygen deficient areas within the contaminated zone. • Isolate well screen intervals to zones exhibiting oxygen concentrations below 5 percent. • Evaluate the feasibility of excavating hot spots. • Evaluate the need for further remediation using an alternate technology.

Table A-5. Common Bioventing System Operational Problems and Optimization Strategies (continued)

Operational Problem	Potential Causes	Potential Negative Impacts on Performance	Optimization Strategies
The contaminant concentrations remain consistently high.	<ul style="list-style-type: none"> • The contaminant concentrations are too high for microbial activity to be effective. • An uncontrolled source area is present. 	<ul style="list-style-type: none"> • The cleanup goals will not be achieved due to the presence of conditions that are toxic to microbial growth. • The cleanup goals will not be achieved due to the presence of a continuing source of contaminants. 	<ul style="list-style-type: none"> • Implement source control measures including excavating hot spots if feasible. • Evaluate use of an alternate technology.
The system airflow rate is excessive.	<ul style="list-style-type: none"> • The system is being operated at a higher rate than necessary to support microbial oxygen demands. 	<ul style="list-style-type: none"> • The operation of the system may not be cost efficient. 	<ul style="list-style-type: none"> • Reduce the airflow rate until oxygen concentrations in the vapor monitoring points range from 5 to 15 percent.

A.7 Multi-Phase Extraction

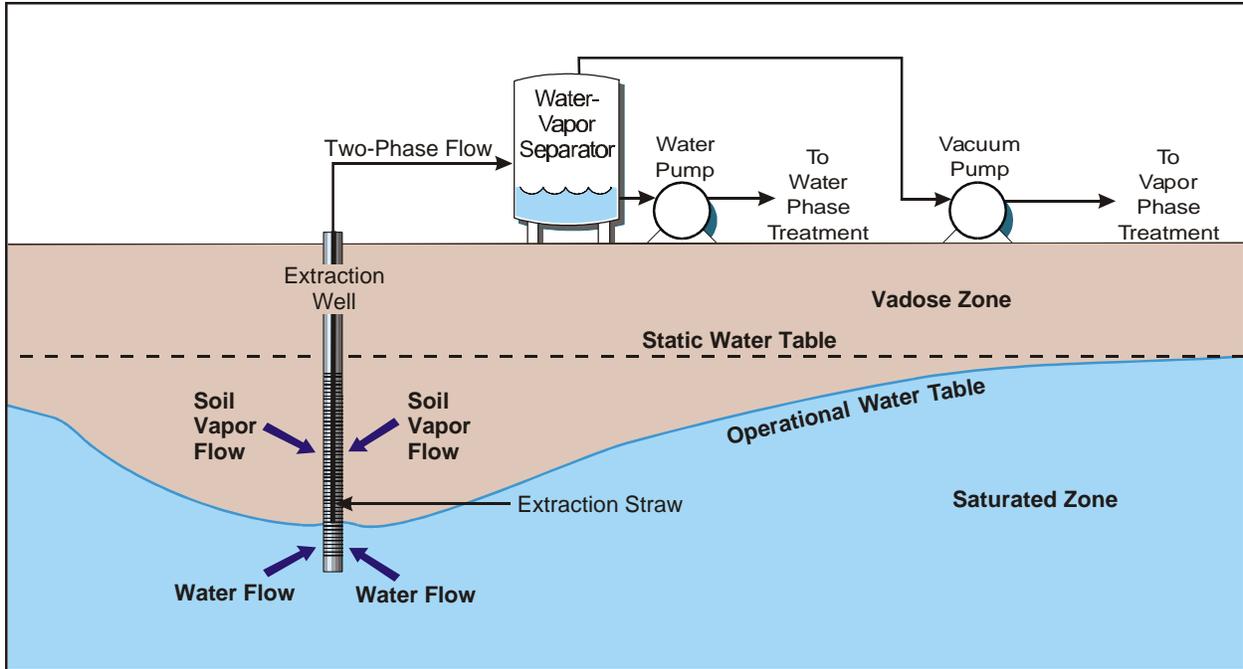
A.7.1 System Description

Multi-Phase Extraction (MPE) is an enhancement of SVE that simultaneously extracts contaminated soil vapor and groundwater. MPE is designed to depress the water table around each extraction well, creating a cone of depression. Vacuum applied to each extraction well generates pressure gradients in the subsurface and induces the flow of air through both the vadose zone and the previously saturated soil within the cone of depression. This induced airflow desorbs volatile contaminants from the surrounding soil and transports them to the surface where they can be treated and/or discharged. The increased airflow may also enhance the aerobic biodegradation of certain organic compounds. In addition, the induced pressure gradients enhance the yield of contaminated groundwater that is also conveyed to the surface for subsequent treatment and discharge.

MPE is most effective with halogenated VOCs in soil and groundwater. MPE is also effective at sites contaminated with poorly miscible nonhalogenated VOCs and may be appropriate if expedited cleanup is required. However, other technologies, which require a longer time to achieve cleanup such as enhanced bioremediation, may be more cost efficient than MPE for nonhalogenated VOCs.

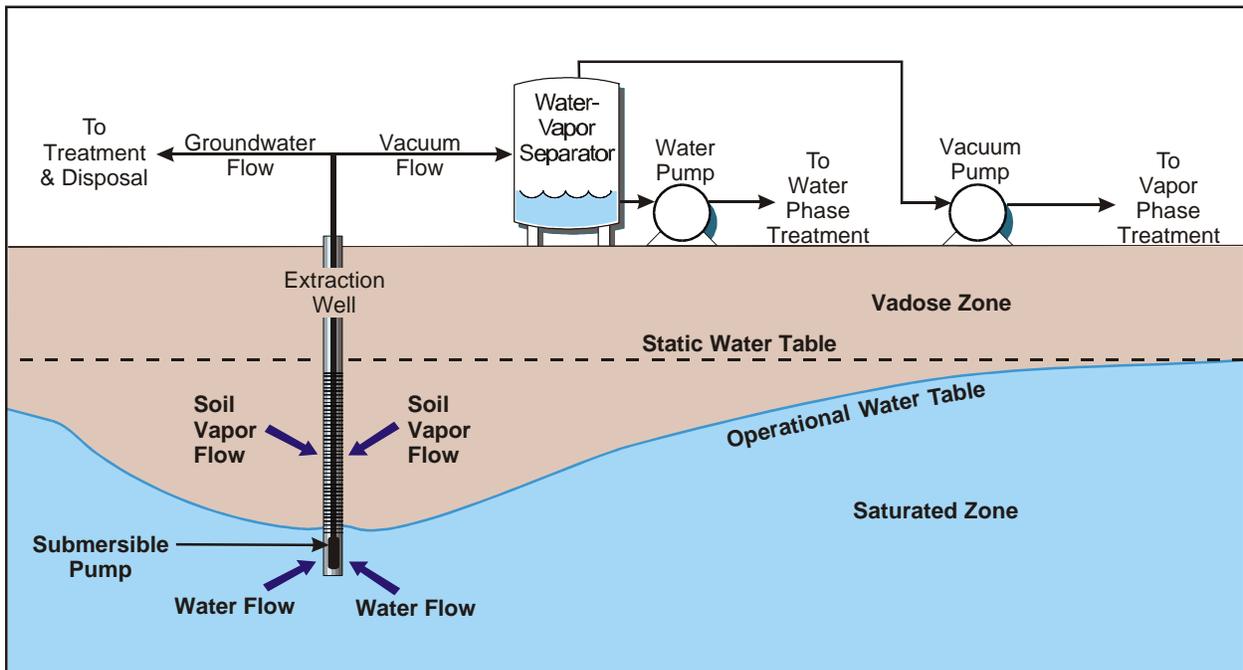
MPE refers to either two-phase extraction (TPE) or dual-phase extraction (DPE). TPE systems apply high vacuum (about 18 to 26 inches of mercury) through a suction pipe lowered into the extraction well to extract groundwater and soil vapor. In comparison, DPE can be operated as a high vacuum system or a low vacuum (about 3 to 12 inches of mercury) system. High vacuum DPE uses a submersible or pneumatic pump to extract groundwater and a high vacuum pump or low vacuum blower to extract soil vapor. Low vacuum DPE uses a submersible or pneumatic pump to extract groundwater and a low vacuum blower to extract soil vapor. Figures A-12 and A-13 illustrate TPE and DPE systems, respectively. Both systems utilize extraction wells, a vacuum pump or blower, an air-water separator, transfer piping, and aqueous- and vapor-phase treatment units.

Generally, TPE is most effective at low to moderately permeable sites. It is less effective at sites having high permeability because the high groundwater pumping rate needed to dewater the aquifers at these sites is not well suited to TPE. Low vacuum DPE is suitable at more permeable sites provided the aquifer can be dewatered.



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Figure A-12. Typical two-phase extraction system.



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Figure A-13. Typical dual-phase extraction system.

A.7.2 Performance Plots

An objective inherent to most MPE systems is hydraulic containment of the contaminants dissolved in groundwater. Therefore, the effectiveness of MPE systems in preventing plume migration should first be evaluated using the procedures described in Section A.2.2.

It is useful, from an operational standpoint, to plot the rate of vapor and groundwater extraction as shown in Figure A-14. The plot illustrates the following phenomena associated with MPE systems:

- Groundwater extraction rates decline gradually with time as the affected zone is dewatered and typically stabilize corresponding to recharge in the area.
- The rate of vapor extraction gradually increases with time because cones of depression are developed, subsurface drying of soils occurs, and channels for airflow are developed.

Plotting the vapor and water flow rates is useful in determining when steady-state conditions have been reached in the subsurface. Once such conditions occur, it is possible to quantify system performance in terms of mass removal rates and unit mass removal cost.

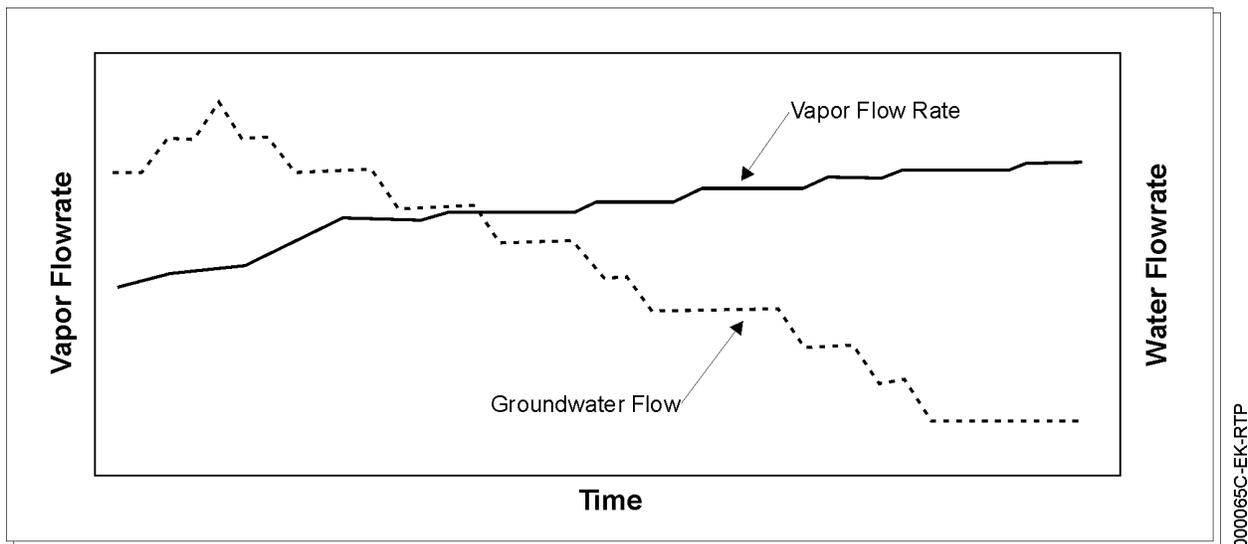


Figure A-14. Performance plot of a typical multi-phase extraction system.

The effectiveness of MPE systems in removing contaminant mass as vapor can be evaluated by plotting the contaminant concentrations measured in vapor monitoring points and in the extracted vapor versus time. A contaminant concentration response curve for a soil vapor extraction system was presented previously in Figure A-7. This type of curve is also typical of vapor extraction associated with MPE systems. The effectiveness of MPE systems in removing contaminant mass from groundwater can be evaluated by plotting the contaminant concentrations measured in the system influent versus time. Similar performance plots can be prepared for individual monitoring wells by graphing contaminant concentrations in groundwater samples versus time. A contaminant concentration response curve for a groundwater pump and treat system was presented previously in Figure A-4. This type of curve is also typical of groundwater extraction associated with MPE. As is typical of technologies that utilize extraction as a remedial process, MPE performance plots typically exhibit a tailing effect that ultimately reaches asymptotic levels.

A.7.3 Common Operational Problems

MPE essentially combines a soil vapor extraction system with a pump and treat system. Therefore, potential operational problems with MPE are those that are generally common to each of the two technologies. Table A-6 summarizes operational problems that are typical of MPE systems.

A.7.4 Common Optimization Strategies

Tracking the incremental costs of removing each additional unit of contaminant mass is a good indicator of MPE system efficiency, and a means of illustrating that the system has reached the practical economic limits of its usefulness. There are two ways to decrease the incremental cost per pound of operating MPE systems:

- Decrease the operating cost
- Increase the mass removal rate; adjustments should be made in both of these areas to maximize the cost-effectiveness of the remedial action and to satisfy regulatory criteria for accomplishing the site cleanup

Optimizing the operation of the MPE system requires that reliable data be collected on a routine basis to track extraction rates for the system as a whole and possibly the extraction rates of each individual well. The types of information that should be collected include:

- Concentration of contaminants extracted in liquid and vapor streams prior to treatment
- Concentration of contaminants in liquid and vapor from each well
- Total system vacuum and individual well vacuums
- Liquid flow rates for the overall system
- Vapor flow rate at vacuum pump inlet and from individual wells
- The vacuum radius of influence from vacuum monitoring points
- The hydraulic radius of influence from water levels in monitoring wells

When the rate of mass removal first reaches asymptotic conditions, alternative steps such as pulsing or operating at a lower, sustained extraction rate should be explored in an effort to restore a higher mass removal rate. If plume migration is a concern, any measures adopted should ensure that hydraulic containment is maintained. Should asymptotic levels persist despite operational or system changes, continued operation of the MPE system will generally not produce additional reduction in the concentration of the constituents. In this case, if further remediation is necessary, implementing either another technology or monitored natural attenuation should be considered. Table A-6 provides additional guidance on optimizing MPE system operations. Certain recommendations applicable to optimizing pump and treat and SVE systems are also applicable to MPE systems.

Table A-6. Common Multi-Phase Extraction System Operational Problems and Optimization Strategies

Operational Problem	Potential Causes	Potential Negative Impacts on Performance	Optimization Strategies
The vacuum radius of influence is insufficient or not as predicted.	<ul style="list-style-type: none"> • The air permeability of the soil is lower than estimated. • Short-circuiting is occurring due to the presence of preferential flow paths. • The extraction wells have been incorrectly designed or installed. 	<ul style="list-style-type: none"> • The lower mass removal results in incomplete remediation and increased remediation time. • Contaminants located outside the effective radius of the vacuum are not removed and preclude reaching cleanup goals. • The number of pore volumes of soil gas exchanged in the contaminated area is limited and results in low mass removal that increases cleanup time. 	<ul style="list-style-type: none"> • Perform a subsurface investigation to further characterize the soil permeability and preferential flow paths. • Install additional wells in the contaminated areas located outside the system's treatment zone. • Replace the incorrectly designed or installed wells.
The cone of depression is insufficient or not as predicted.	<ul style="list-style-type: none"> • The groundwater pumping rate is too low. • The extraction wells were improperly designed, installed, or developed. • The hydraulic conductivity is higher than estimated. 	<ul style="list-style-type: none"> • The aquifer will not be dewatered resulting in a lower mass removal rate that increases cleanup time. • Failure to maintain hydraulic containment will allow the plume to enlarge in size and potentially reach receptors. The larger area of contamination will also result in increased remediation time and require expanding the remediation system. 	<ul style="list-style-type: none"> • Increase the groundwater extraction rate. • Redevelop the poorly developed wells. • Replace the incorrectly designed or installed wells. • Review and potentially revise the aquifer-testing results. Install additional extraction wells, as necessary.
The vacuum levels are decreasing and the airflow rate is increasing.	<ul style="list-style-type: none"> • Short-circuiting is occurring due to preferential flow paths. • Short-circuiting is occurring through shallow or improperly sealed wells. 	<ul style="list-style-type: none"> • A lower rate of mass removal will result in incomplete remediation or increased remediation time. 	<ul style="list-style-type: none"> • Evaluate the system for evidence of short-circuiting; consider repairing, replacing, or relocating the affected wells.
The contaminant concentrations have been reduced in some but not all extraction wells.	<ul style="list-style-type: none"> • Treatment may be complete in some areas of the site. • The airflow to some areas of the site may be inadequate. 	<ul style="list-style-type: none"> • The continued operation of nonproductive wells is not cost effective. • The inadequate airflow will limit mass removal and increase cleanup time. 	<ul style="list-style-type: none"> • Shut off the low producing wells or reduce their pumping rates while increasing the rates at the more productive wells. • Evaluate the need to install additional wells in areas with high levels of contamination located outside the system's treatment zone.

Table A-6. Common Multi-Phase Extraction System Operational Problems and Optimization Strategies (continued)

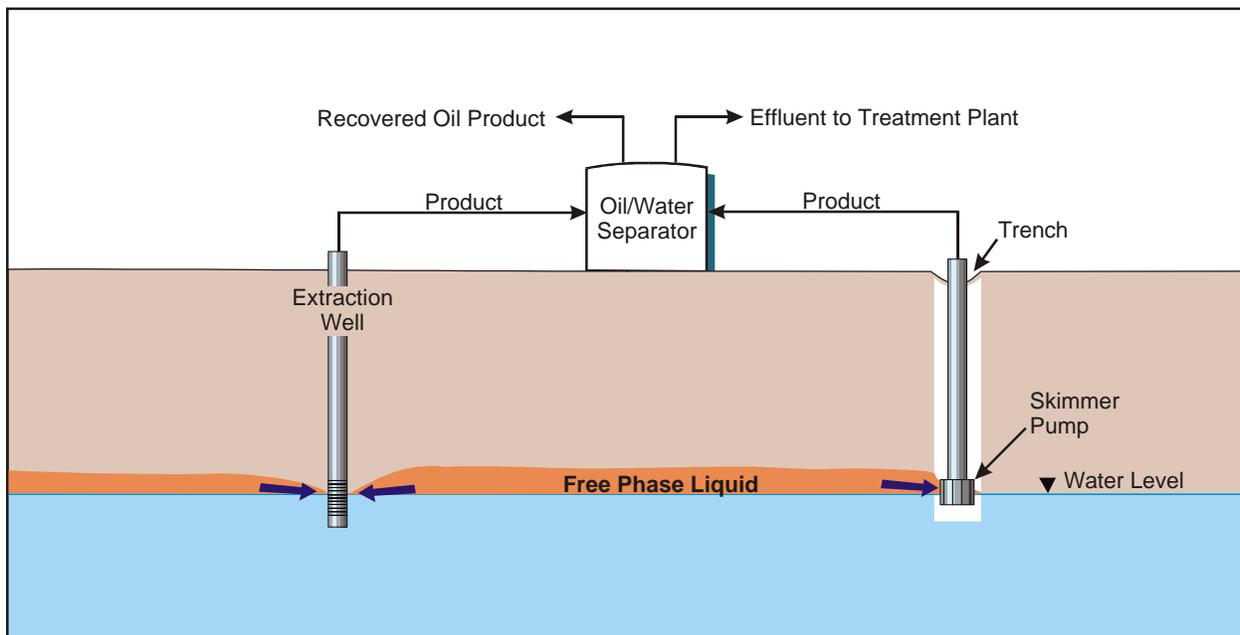
Operational Problem	Potential Causes	Potential Negative Impacts on Performance	Optimization Strategies
The contaminant concentrations in the extracted water and vapor and in the monitoring wells have reached asymptotic levels and/or rebound to higher levels when system operation is terminated.	<ul style="list-style-type: none"> • The removal of contaminants sorbed to the soil and aquifer matrix is limited by site-specific desorption rates. • The removal of contaminants within low permeability zones is diffusion limited. • The extraction wells are improperly located or continue to operate in areas where contamination has been reduced. • The extraction wells are inappropriately screened through zones of lesser contamination. • Contaminants remain at stagnation points that are not flushed by groundwater extraction. 	<ul style="list-style-type: none"> • The slower rate of contaminant removal due to desorption/diffusion limitations will extend cleanup time. 	<ul style="list-style-type: none"> • "Pulse" the wells or reduce the pumping rates to correspond to the contaminant desorption and/or diffusion rates. • Identify unproductive extraction wells through sampling and decrease the extraction rates while increasing the rates at the more productive wells. • Replace the improperly screened wells with wells isolated to the contaminated intervals within the aquifer. • Rebalance the pumping rates between wells to eliminate the stagnation points or install additional wells to enhance flushing through the stagnation points.
Low concentrations of contaminants are measured in the extracted vapor during system operation, but high concentrations appear in vapor monitoring points when the system is shut off.	<ul style="list-style-type: none"> • The removal of contaminants sorbed to the soil is desorption or diffusion limited. • The vapor extraction rate is higher than necessary. 	<ul style="list-style-type: none"> • Continued operation at the higher extraction rate may not be cost effective. 	<ul style="list-style-type: none"> • "Pulse" the extraction wells or reduce the vapor extraction rate of a DPE system.
The contaminant concentrations remain high despite high mass removal rates.	<ul style="list-style-type: none"> • An uncontrolled source area is present. 	<ul style="list-style-type: none"> • The presence of a continuing source of contaminants will prevent cleanup. 	<ul style="list-style-type: none"> • Perform further subsurface investigation to identify additional source areas and potential free product. • Identify and control source areas including excavation if feasible.
The contaminant plume is migrating.	<ul style="list-style-type: none"> • The groundwater extraction rate is insufficient to establish a capture zone. • The system is subject to prolonged shut down. • The number of extraction wells is inadequate or they are improperly located. 	<ul style="list-style-type: none"> • Failure to maintain hydraulic containment will allow the plume to enlarge in size and potentially reach receptors. The larger area of contamination will also result in increased remediation time and require expanding the remediation system. 	<ul style="list-style-type: none"> • Increase the groundwater extraction rate. • Increase the system uptime through a preventive maintenance program. • Install additional wells as necessary. • Evaluate other technologies.

A.8 Free Product Recovery

A.8.1 System Description

At sites where there has been a release of hydrocarbon (petroleum) products, it is usually necessary to recover free-phase petroleum that is found above the water table. Most petroleum cleanup regulations require the removal of free-phase liquid prior to or concurrent with implementing other soil and groundwater remediation systems. The remedial objective of free product recovery is to remove the liquid-phase contamination as quickly as possible to prevent continued contamination of the surrounding soil and groundwater. The various methods used to accomplish this are collectively known as free-phase product recovery.

Different techniques are used to recover free-phase petroleum product. Under shallow water table conditions, trench systems may be used to intercept and collect the free product as it migrates along the capillary fringe. Under deeper water table conditions, recovery wells screened across the water table can be used to recover free product. A wide variety of pumps may be used in the trenches and wells. Total fluids pumps establish a cone of depression and remove both free product and groundwater. Other pumps “skim” the free product from above the water table without pumping groundwater. These pumps may be used alone or in combination with water table depression pumps that are installed below the free product lens to remove groundwater and establish a cone of depression. Components of a typical free product recovery system include wells or trenches, pumping equipment, transfer piping, separation equipment, and liquid treatment units. Figure A-15 is an illustration of a free product recovery system showing both a recovery well and interceptor trench.



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Figure A-15. Free product recovery system.

Another technique, known as bioslurping, utilizes TPE (Section A.7) to recover the free phase petroleum product. Bioslurping combines TPE with bioventing to remove free product and to stimulate the aerobic biodegradation of petroleum contaminated soil in the unsaturated zone, respectively. In bioslurping, free product is removed from the water table and extracted from the capillary fringe by applying a high vacuum to the recovery wells. The vacuum provides the gradient for product recovery, eliminating the need for water-level depression, and minimizing the formation of a smear zone in the soil. Bioventing of the unsaturated zone occurs simultaneously as enhanced airflow is induced by also withdrawing soil gas through the recovery wells. Bioslurping systems utilize a suction pipe that is inserted into each recovery well to the level of the free product layer. Under the high vacuum, free product, some groundwater, and soil gas are extracted through the suction tube in a single process stream. Like TPE systems, bioslurping systems utilize recovery wells, a vacuum pump, an air-water separator, transfer piping, and aqueous- and vapor-phase treatment trains. Figure A-16 illustrates a typical bioslurping system. A variation of bioslurping, known as Aggressive Fluid-Vapor Recovery, utilizes a TPE unit mounted on a tanker tank that can mobilize to recovery wells containing free product.

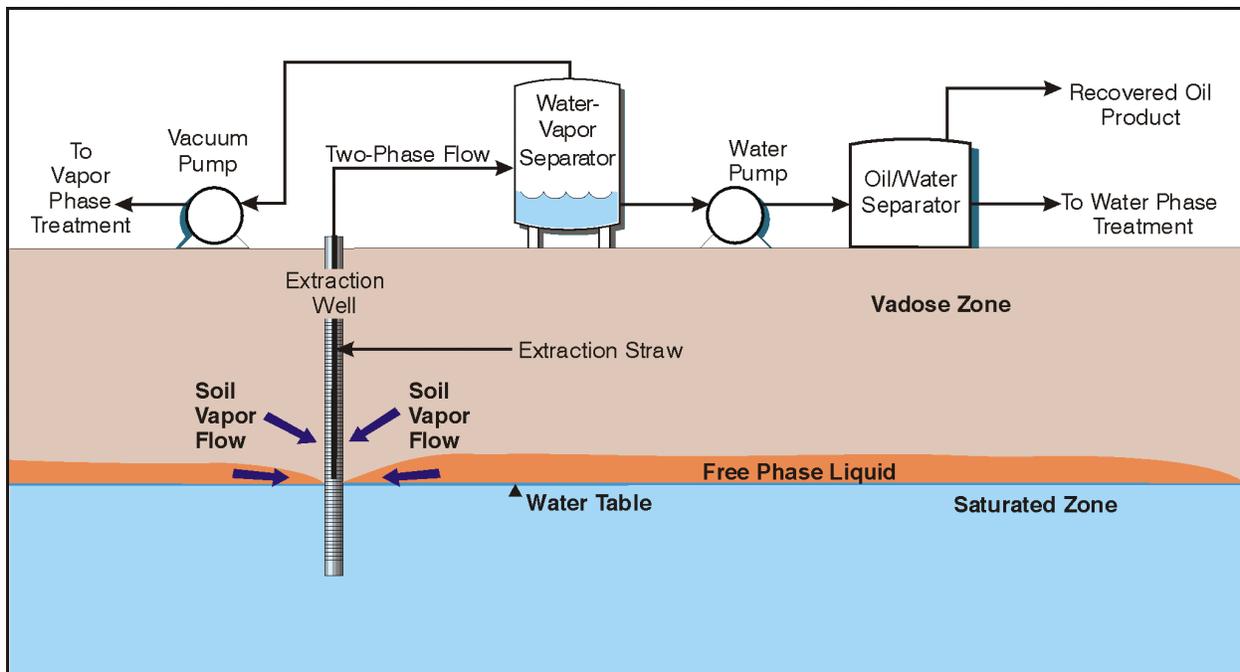


Figure A-16. Bioslurping system.

A.8.2 Performance Plots

Figure A-17 shows a performance plot for a free product recovery system. The plot illustrates the asymptotic behavior that is typical of the recovery rate for this type of system. Initially, product recovery is relatively rapid but soon decreases as the amount of recoverable free product is diminished. Ultimately, the recovery rate is reduced to only several gallon per month.

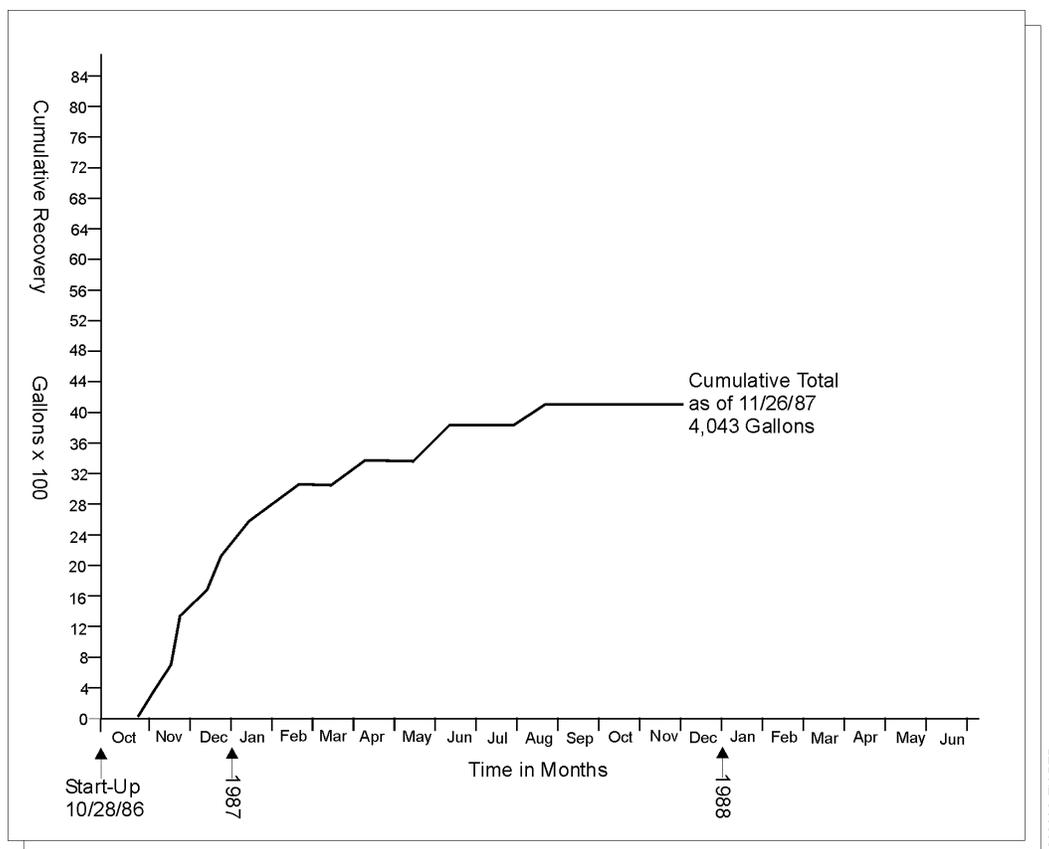


Figure A-17. Performance plot of free product recovery system at MCAS New River.

Example: The system represented in Figure A-16 was installed at MCAS New River, North Carolina, following the discovery of a release from a JP-5 line. The system, which was installed as an interim measure, operated for 1 year and recovered over 4,000 gallons of product. Of the total fuel volume recovered by the interim system, approximately 70% of the product was recovered in the first quarter of operation. Eighty-five percent was removed through the second quarter and nearly 100% of the total volume was removed by the end of the third quarter.

A.8.3 Common Operational Problems

Practical application of free product recovery systems has shown that even under favorable site conditions only a small percentage of the total product released can ever be recovered. Therefore, it is prudent to have established criteria for suspending free product recovery to avoid needless, nonproductive operation of the system. If not established by regulation, termination criteria may be based on the product recovery rate such as, less than 2 gallons recovered per month, or less than 0.02 percent of product recovered to water extracted. Alternatively, the criteria may be based on product thickness such as, less than 0.01 foot in recovery and monitoring wells. Following termination, monitoring should be conducted for a specified time period to ensure that product does not re-accumulate in the wells. Monitoring results should be compared to a pre-established thickness that serves as an action level for restarting the system.

Example: A bioslurping system is being used to recover free product at Naval Weapons Station (NWS) Earle, New Jersey. In addition to recommending equipment modifications to improve performance, it was recommended that an exit strategy be developed to justify turning the system off when recovery was complete to the extent practicable. The use of cost data (e.g., cost per gallon of product recovered is significantly higher than at the beginning of the project) was proposed as the criterion for terminating operation of the bioslurping system.

Table A-7 lists operational problems common to free product recovery systems. Many of the problems listed are related to the general operation and maintenance of the recovery wells and pumps. Table A-8 lists operational problems specific to bioslurping systems. Depending on the free product recovery technique used, problems included in Tables A-2 (Pump and Treat System), A-6 (Bioventing System), and A-7 (MPE) may also be applicable to free product recovery systems.

A.8.4 Common Optimization Recommendations

Reducing the time required to achieve the cleanup objectives can minimize long-term operating costs associated with operating a free product recovery system. Tables A-7 and A-8 identify optimization strategies for conventional free product recovery systems and bioslurping systems, respectively. Depending on the type of free product recovery system utilized, recommendations presented earlier for optimizing pump and treat, TPE, and bioventing systems may also be applicable.

Example: At MCAS New River, free product recovery by a single-pump system in the JP-5 Line Area has been sporadic and diminishing in return. By comparison, trial application of Aggressive Fluid-Vapor Recovery (AFVR) has shown promising results at less cost. Therefore, it was recommended that the existing free product recovery system be shut down and the frequency of fluid-level monitoring in the recovery and monitoring wells be increased. An action level for the accumulation of free product in the wells was established and serves as a "trigger" for implementing AFVR.

Table A-7. Common Free Product Recovery System Operational Problems and Optimization Strategies

Operational Problem	Potential Causes	Potential Negative Impacts on Performance	Optimization "Rules of Thumb"
The recovery rate declines over time.	<ul style="list-style-type: none"> • The pump membranes or intake screens are clogged. • Excessive water-level drawdown causes the product to "smear," or adsorb to previously saturated soil. • Biological fouling or mineral buildup of the well screens has occurred. 	<ul style="list-style-type: none"> • The lower recovery rate may extend duration of recovery system operation. 	<ul style="list-style-type: none"> • Clean pump membranes or intake screens. • Adjust the pumping rate to maintain recovery while minimizing drawdown. • Perform well rehabilitation using the appropriate acids and/or biocides.
The design recovery rate has never been achieved.	<ul style="list-style-type: none"> • Excessive water-level drawdown causes the product to "smear," or adsorb to previously saturated soil. • The wells are poorly developed. • The well screens do not intersect the water table. 	<ul style="list-style-type: none"> • The inability to meet design criteria will extend the duration of recovery system operation and allow the free product lens to migrate. 	<ul style="list-style-type: none"> • Adjust the pumping rate to maintain recovery while minimizing drawdown. • Redevelop poorly developed wells. • Replace wells that are improperly screened.
The ratio of fuel recovered to groundwater extracted is low despite the presence of measurable free product.	<ul style="list-style-type: none"> • The pumps are improperly placed in the recovery wells. • The pumping rate is greater than necessary. 	<ul style="list-style-type: none"> • The treatment and disposal of extraneous water will increase operating costs. 	<ul style="list-style-type: none"> • Adjust the pumping rate to maintain recovery while minimizing drawdown. • Modify skimmer settings to minimize water production. • Adjust the placement of pump in well. • Install additional recovery wells in "hot spots." • Consider implementing an alternate technology such as Aggressive Vapor/Fluid Recovery.
The free product lens is migrating or the radius of influence is limited.	<ul style="list-style-type: none"> • The pumping rate is not sufficient. • The system is experiencing prolonged periods of shutdown. • The number of recovery wells is inadequate or they are improperly located. 	<ul style="list-style-type: none"> • Failure to contain the free product will result in incomplete product recovery and increase the duration of system operation. 	<ul style="list-style-type: none"> • Increase the pumping rate in the recovery wells. • Increase the system uptime through a preventative maintenance program. • Install downgradient wells or an interceptor trench to halt product migration.

Table A-8. Common Bioslurping System Operational Problems and Optimization Strategies

Operational Problem	Potential Causes	Potential Negative Impacts on Performance	Optimization "Rules of Thumb"
The recovery rate declines over time.	<ul style="list-style-type: none"> Biological fouling or mineral buildup of the well screens has occurred. All recoverable product at some wells has been removed. 	<ul style="list-style-type: none"> The lower recovery rate may extend duration of recovery system operation. The continued operation of nonproductive wells generates excess groundwater and is not cost effective. 	<ul style="list-style-type: none"> Perform well rehabilitation using the appropriate acids and/or biocides. Pulse low producing wells based on the rate of product recovery. Shut off nonproductive wells or consider modifying them to a bioventing mode.
The design recovery rate has never been achieved.	<ul style="list-style-type: none"> The wells are poorly developed. The well screens do not intersect the water table. The bottoms of the suction tubes are above the water table, causing groundwater mounding, and preventing product flow to the wells. 	<ul style="list-style-type: none"> The inability to meet design criteria will extend the duration of recovery system operation and allow the free product lens to migrate. 	<ul style="list-style-type: none"> Redevelop poorly developed wells. Replace wells that are improperly screened. Measure the depth to water after several days of system shutdown and reposition the bottoms of the suction tubes accordingly.
The ratio of fuel recovered to groundwater extracted is low despite the presence of measurable free product.	<ul style="list-style-type: none"> The suction tubes extend below the free product layer in the recovery wells. 	<ul style="list-style-type: none"> The treatment and disposal of extraneous water will increase operating costs. Excessive water-level drawdown will cause product to "smear," or adsorb to previously saturated soil. 	<ul style="list-style-type: none"> Raise the bottoms of the suction tubes to the level of the water table. Monitor the depth to water regularly in areas subject to significant water table fluctuation and reposition the bottoms of the suction tubes accordingly.
The vacuum developed at each recovery well is low.	<ul style="list-style-type: none"> Short-circuiting is occurring. The vacuum pump is not properly sized. 	<ul style="list-style-type: none"> The inability to establish an adequate vacuum limits the pumping of product and the radius of influence of vacuum gradients and soil venting. 	<ul style="list-style-type: none"> Operate sections of the well system on a sequential cycle based on the rate of fuel recovery. Install a properly sized pump.
The free product lens is migrating or the radius of influence is limited.	<ul style="list-style-type: none"> The system is experiencing prolonged periods of shutdown. The number of recovery wells is inadequate or they are improperly located. 	<ul style="list-style-type: none"> Failure to contain the free product will result in incomplete product recovery and increase the duration of system operation. 	<ul style="list-style-type: none"> Increase the system uptime through a preventative maintenance program. Relocate and/or add recovery wells.
Product is inadequately separated from the process stream.	<ul style="list-style-type: none"> The mixing of fuel, water, and vapor in the process stream is inherent to the extraction technology. 	<ul style="list-style-type: none"> The incomplete separation of product from the process stream may lead to greater treatment costs, increased maintenance requirements, and potential wastewater discharge violations. 	<ul style="list-style-type: none"> Review the design and operation of the oil/water separator and other treatment system components.

A.9 Permeable Reactive Barriers

A.9.1 System Description

Permeable Reactive Barriers provide a semi-permanent, in-situ, low maintenance method for treating contaminants dissolved in groundwater. A permeable reactive wall is installed in the flow path of the contaminated groundwater, allowing the contaminants to be treated as the plume migrates through the reactive wall. The reactive agents in the permeable barrier vary depending upon the contaminants of concern and the desired remediation mechanism. Permeable Reactive Barriers have been designed to facilitate biological degradation, chemical oxidation/reduction, metals precipitation, removal via sorption, and air sparging. Contamination limited to the upper portion of a surficial aquifer may be addressed with a “hanging” reactive barrier, while deeper contamination may require that the reactive barrier extend to a lower confining layer to prevent underflow. A schematic drawing of a Permeable Reactive Barrier is shown in Figure A-18.

Capital costs associated with the construction of Permeable Reactive Barriers may be optimized by alternating low-cost, impermeable barriers with reactive barriers, forming a “funnel and gate” system. This method ensures that all contaminated groundwater flows through a reactive barrier, without requiring the installation of a continuous reactive wall.

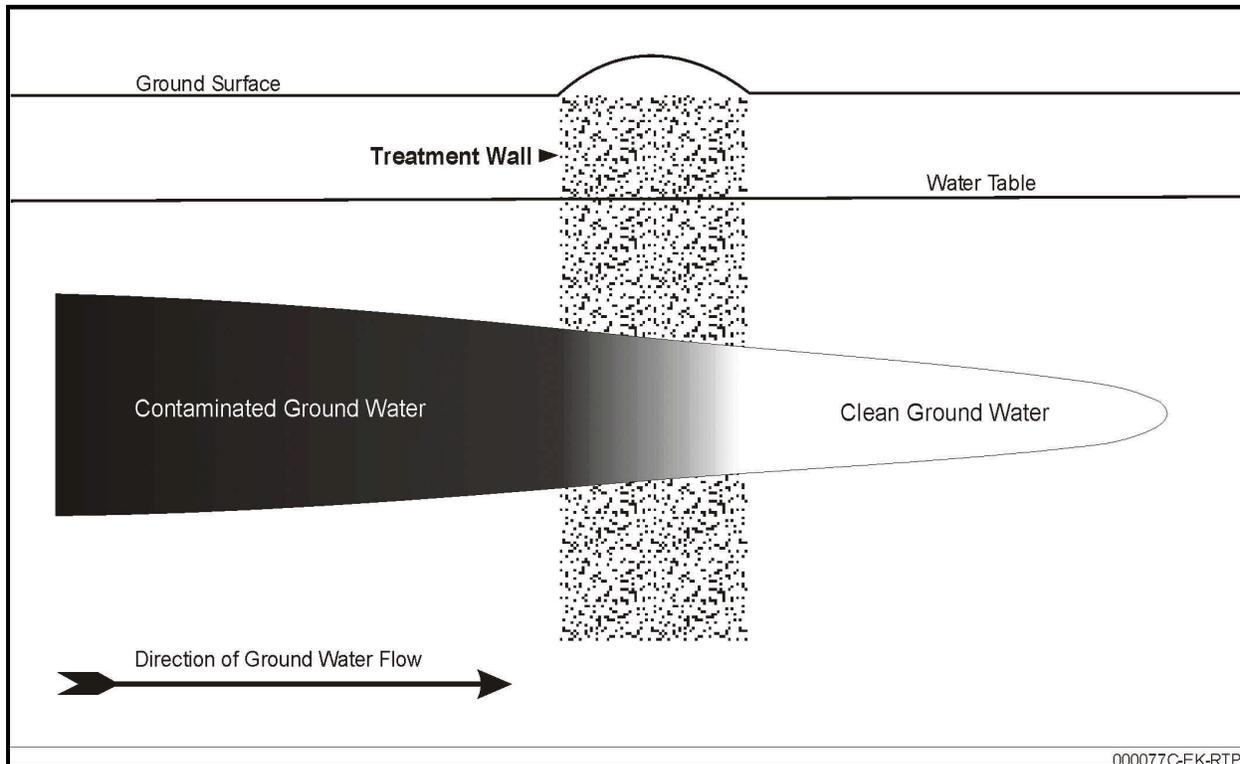


Figure A-18. Permeable reactive barrier.

The passive, in-situ nature of the Permeable Reactive Barrier system yields a system with low operating and maintenance costs. When designed correctly, the requirements for energy input, equipment repair and manpower are very low when compared to other remedial systems.

A.9.2 Performance Plots

Figure A-19 depicts a conceptual contaminant concentration profile along the flow path through a reactive barrier. The plot can be prepared from the results of sampling performance-monitoring wells located within and around the reactive barrier. As contaminants enter the reactive barrier, they are treated via the particular remediation mechanism selected. The reactive capacity of the wall will be depleted over time. Once the reactive barrier is not able to reduce contaminant concentrations to the required cleanup level, the reactive barrier will need to be replaced. Preferential flow paths may develop within the reactive barrier resulting in different flow velocities within different parts of the barrier. Consequently, the residence time of the contaminants within the reactive barrier may represent a range, rather than a value and a factor of safety should be included in the reactive barrier design.

Potentiometric surface maps should also be prepared from water levels measured in the monitoring wells. The maps should be evaluated for groundwater mounding upgradient of the reactive barrier and for other hydraulic evidence of changes in groundwater flow that could potentially transport contaminants around or beneath the reactive barrier.

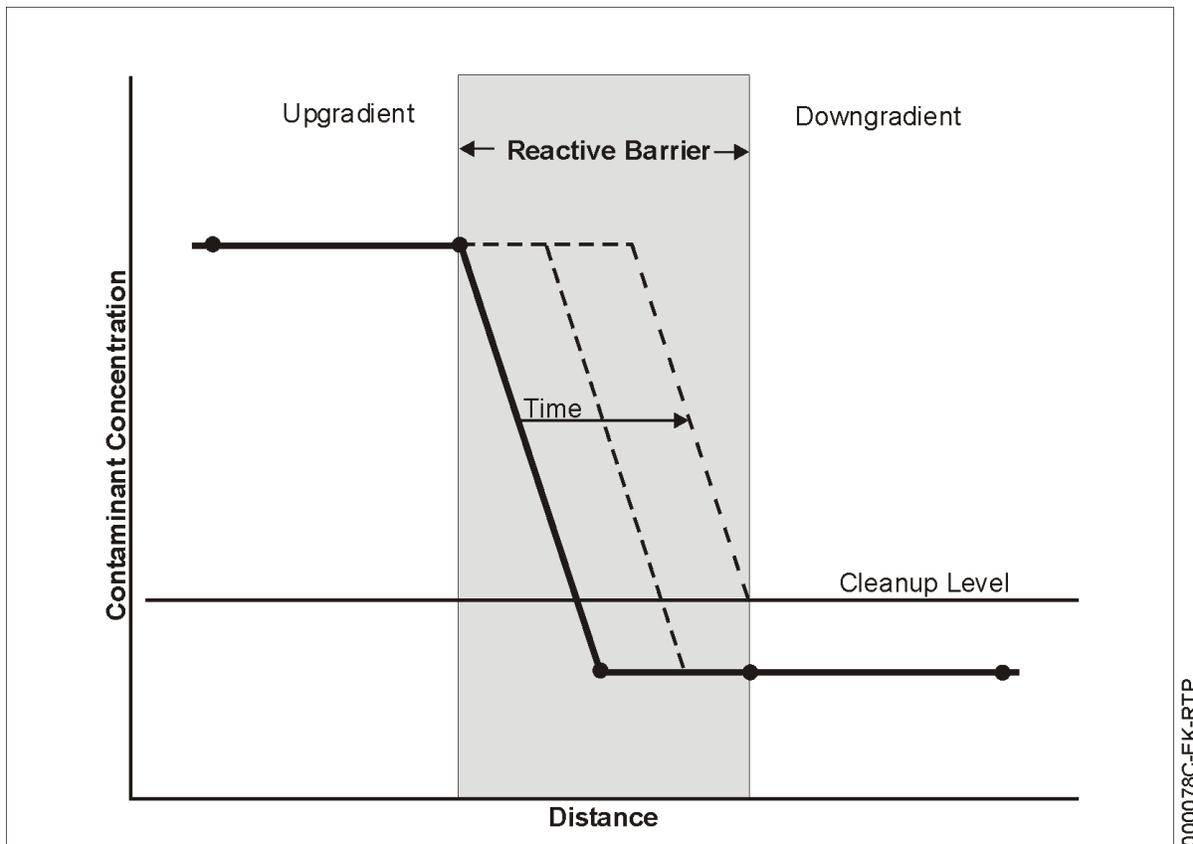


Figure A-19. Performance plot of a typical permeable reactive barrier.

A.9.3 Common Operational Problems

Thorough site characterization combined with careful design and construction techniques can minimize the potential of developing operational problems. Correcting problems that can develop will, by their nature, require significant effort and resources. Table A-9 lists problems applicable to Permeable Reactive Barrier Systems.

A.9.4 Common Optimization Recommendations

A groundwater monitoring system must be installed to track the performance of the Permeable Reactive Barrier and to identify breakthrough or bypassing of the system. The performance-monitoring program is likely to be a major expense associated with a Permeable Reactive Barrier system. Consequently, the greatest opportunity to minimize operating costs usually exists in optimizing the monitoring program. Table A-9 identifies optimization strategies for Permeable Reactive Barrier systems.

Table A-9. Common Permeable Reactive Barrier Operational Problems and Optimization Strategies

Operational Problem	Potential Causes	Potential Negative Impacts on Performance	Optimization Strategies
The system performance cannot be accurately evaluated.	<ul style="list-style-type: none"> The performance-monitoring program is not adequate. 	<ul style="list-style-type: none"> An inadequate performance-monitoring program may fail to or detect other potential problems identified in this table. 	<ul style="list-style-type: none"> Monitoring wells should be placed: Upgradient and downgradient of the reactive barrier to confirm treatment; Laterally to detect bypassing; and, Within the reactive barrier to warn against breakthrough.
The contaminated groundwater bypasses the reactive barrier.	<ul style="list-style-type: none"> The reactive barrier and/or funnel system are not wide enough to capture all of the contaminated groundwater. Bypass occurs at the junction between funnel and reactive barrier. Contaminated groundwater underflows the reactive barrier system 	<ul style="list-style-type: none"> Untreated contaminants will migrate downgradient allowing the plume to enlarge and potentially reach receptors. The larger area of contamination will also result in increased remediation time and require expanding the remediation system. 	<ul style="list-style-type: none"> Extend the reactive or impermeable barrier to intercept the path of the contaminated groundwater Use grout injection to seal post-installation leaks between the barrier and the funnel walls or the underlying confining layer.
The contaminated groundwater breaks through the reactive barrier.	<ul style="list-style-type: none"> Short-circuiting due to preferential flow paths is occurring. Mineral precipitation or sediment accumulation occurs in the reactive cell and reduces availability to the active media. 	<ul style="list-style-type: none"> Partially treated contaminants will migrate downgradient allowing the plume to enlarge and potentially reach receptors. The larger area of contamination will result in increased remediation time and require expanding the remediation system. 	<ul style="list-style-type: none"> Re-install the reactive barrier. Evaluate the use of an alternate technology if precipitation or sediment accumulation cannot be prevented.
The contaminated groundwater breaks through the funnel system.	<ul style="list-style-type: none"> The permeability of the funnel is greater than the design permeability. The impermeable barrier is not continuous. 	<ul style="list-style-type: none"> Contaminated groundwater will flow downgradient allowing the plume to enlarge and potentially reach receptors. The larger area of contamination will result in increased remediation time and require expanding the remediation system. 	<ul style="list-style-type: none"> Upgrade or re-install the impermeable barrier.
Permeability of the reactive barrier decreases.	<ul style="list-style-type: none"> Mineral precipitation or sediment accumulation occurs in the reactive cell and reduces or prevents the flow of contaminated groundwater through the reactive cell. 	<ul style="list-style-type: none"> The decreased permeability will result in groundwater mounding and bypassing the reactive barrier. Contaminated groundwater will flow downgradient allowing the plume to enlarge and potentially reach receptors. The larger area of contamination will result in increased remediation time and require expanding the remediation system. 	<ul style="list-style-type: none"> Re-install the reactive barrier. Evaluate the use of an alternate technology if precipitation or sediment accumulation cannot be prevented.

A.10 In-situ Bioremediation of Petroleum Constituents

A.10.1 System Description

Enhanced in-situ bioremediation (EISB) encompasses a group of technologies that increase the growth of microorganisms to enhance biodegradation of organic compounds in the saturated zone. Oxygen respiration, or aerobic oxidation, is the most effective mode for bioremediating petroleum constituents and other nonhalogenated organic compounds. In-situ bioremediation of petroleum constituents in groundwater involves the introduction of oxygen into the saturated zone and may also entail the addition of nutrients and, less frequently, microbial cultures to stimulate degradation. It can be used to remediate petroleum constituents dissolved in groundwater and sorbed to the aquifer matrix. Common methods for introducing oxygen are sparging air through injection wells (biosparging); injecting water saturated with air; adding dilute hydrogen peroxide through injection wells or an infiltration trench; and, emplacing oxygen release compound (ORC) in wells or trenches or directly injecting it using direct push technology. Biosparging is a variation of air sparging, which was addressed in Section A.5. Bioventing, discussed in Section A.6, is an in-situ bioremediation technology that is applicable to petroleum constituents in the unsaturated zone.

Figure A-20 illustrates a typical EISB system using an infiltration trench. In the example, groundwater is typically removed using extraction wells, aerated to introduce oxygen, mixed with nutrients, if necessary and re-injected upgradient of the contaminant plume. Injection wells or, in some cases, infiltration trenches are used to re-inject the water. The system operates as a closed loop and water is recirculated until cleanup levels are achieved. Extracted water that is not re-injected is treated and discharged. Treatment options for extracted water are discussed separately in Section A.15.2.

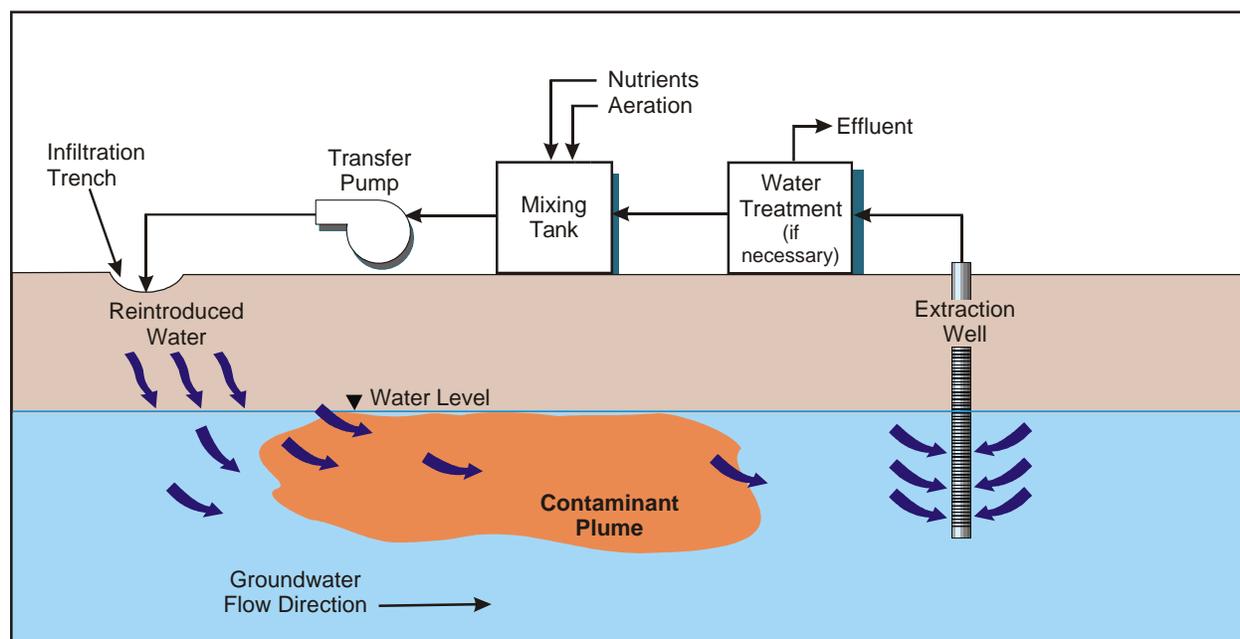


Figure A-20. In-situ bioremediation system for petroleum constituents.

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A.10.2 Performance Plots

A principal objective inherent to most EISB systems is to hydraulically contain the contaminants and prevent their spreading. Therefore, the effectiveness of the EISB systems in preventing plume migration should first be evaluated using the procedures described in Section A.2.2.

The effectiveness of EISB systems in restoring groundwater quality should then be evaluated by plotting contaminant concentrations measured in the extraction wells and monitoring wells over time. During in-situ bioremediation, the concentration of petroleum constituents measured in groundwater will decrease until an asymptotic level is reached. A plot of constituent concentration versus time for in-situ bioremediation systems will ultimately resemble a shape similar to that shown in Figure A-4 for pump and treat systems. Also, as in the case of many pump and treat systems, a plot of constituent concentration in groundwater may exhibit a rebound to higher levels after operation of the system is terminated.

A.10.3 Common Operational Problems

Provided treatability studies have previously verified that the technology is appropriate for the site conditions, performance problems with EISB systems for petroleum constituents are generally related to microorganism growth requirements and to the delivery system that supplies electron acceptors and nutrients. Table A-10 lists problems common to EISB systems, in general. Table A-1 should also be consulted to identify hydraulic containment problems potentially associated with closed loop systems that re-circulate groundwater.

A.10.4 Common Optimization Recommendations

Optimization recommendations for EISB systems should focus on ensuring that oxygen and nutrient levels are not rate limiting and that the delivery system is operating efficiently. In particular, when asymptotic conditions are first established the rate and concentration of oxygen and any nutrients being injected into the subsurface should be reviewed and adjusted in an effort to restore a higher degradation rate. However, should asymptotic levels persist, continued operation of the in-situ bioremediation system will generally not produce additional reduction in the concentration of petroleum constituents. In this case, if further remediation is necessary, implementing either another technology or monitored natural attenuation should be considered. Table A-10 provides guidance on optimizing EISB systems for petroleum constituents. For closed loop systems that re-circulate groundwater, additional recommendations for optimizing hydraulic control are included in Table A-1.

Table A-10. Common Operational Problems and Optimization Strategies of In-situ Bioremediation Systems for Petroleum Constituents

Operational Problem	Potential Causes	Potential Negative Impacts on Performance	Optimization Strategy
The contaminant concentrations have not declined in the system influent and in the monitoring wells.	<ul style="list-style-type: none"> • Source areas or hotspots have not been adequately controlled. • High concentrations of petroleum constituents (>50,000 ppm) may be present and toxic to the microorganisms. 	<ul style="list-style-type: none"> • The presence of a continuing source of contaminants will prevent cleanup goals from being achieved. • Microbial growth will not occur and cleanup goals will not be achieved. 	<ul style="list-style-type: none"> • Identify and control source areas and hotspots including excavation, if feasible • Evaluate the use of alternate technologies, such as physical removal of LNAPL.
The treatment zone is insufficient or not as predicted.	<ul style="list-style-type: none"> • The soil permeability is lower than estimated. • The number of injection points is not adequate or they are improperly located. 	<ul style="list-style-type: none"> • Oxygen and nutrients will not reach all contaminants and cleanup goals will not be achieved. 	<ul style="list-style-type: none"> • Install additional wells and/or enlarge the infiltration galleries.
Contaminant degradation is slow or incomplete.	<ul style="list-style-type: none"> • Oxygen distribution to the contaminated zone is not sufficient to maintain a residual concentration above 1 mg/L. • The pH of the groundwater is not between 6 and 8. • Deficiencies of inorganic nutrients such as nitrogen and phosphate may inhibit microorganism growth. • Low solubility constituents are not bioavailable. • Preferential air channels are formed by air injection systems causing most of the contaminants to be bypassed. 	<ul style="list-style-type: none"> • Microbial activity slows and cleanup will be incomplete or will take longer than estimated. 	<ul style="list-style-type: none"> • Increase the rate of oxygen injection or evaluate the need for additional wells and/or infiltration galleries. • Evaluate the need for nutrient addition and/or pH adjustment. • Evaluate the use of alternate technologies. • Pulse the air injection wells.
The contaminant concentrations in the system influent and in the monitoring wells have reached asymptotic levels and/or rebound to higher levels when pumping is terminated.	<ul style="list-style-type: none"> • Remediation may only be occurring in the more permeable units comprising the aquifer. 	<ul style="list-style-type: none"> • The inability to distribute oxygen, nutrients, and amendments to low permeability zones will extend cleanup time or prevent achieving cleanup goals. 	<ul style="list-style-type: none"> • Evaluate the use of alternate technologies, including monitored natural attenuation.

Table A-10. Common Operational Problems and Optimization Strategies of In-situ Bioremediation Systems for Petroleum Constituents (Continued)

Operational Problem	Potential Causes	Potential Negative Impacts on Performance	Optimization Strategy
Increasingly higher pressure occurs in the re-injection wells and/or infiltration galleries.	<ul style="list-style-type: none"> The wells and/or infiltration galleries have become plugged through mineral encrustation or biological fouling. 	<ul style="list-style-type: none"> Oxygen, nutrients, and amendments will not reach contaminants and cleanup will not be achieved or will take longer than estimated. 	<ul style="list-style-type: none"> Mechanically rehabilitate affected wells and/or trenches. Evaluate adding hydrogen peroxide to eliminate biomass. Perform routine cleaning and surging of the wells and/or trenches to prevent future mineral encrustation and biofouling. Install a filtration system to remove biomass and particulates. "Pulse" nutrients into the subsurface to discourage biofouling. Replace the affected wells and/or trenches that cannot be rehabilitated.
The contaminant plume expands during the operation of a liquid delivery system.	<ul style="list-style-type: none"> The extraction well pumping rates are not sufficient to re-circulate groundwater within the treatment zone. The number or placement of the extraction wells is not adequate. 	<ul style="list-style-type: none"> Failure to re-circulate groundwater will allow the plume to enlarge in size and potentially reach receptors. The larger area will also result in increased remediation time and require expanding the bioremediation system. 	<ul style="list-style-type: none"> Increase the pumping rates at the extraction wells. Install additional extraction wells. Expand the bioremediation treatment zone to include the impacted area.

A.11 In-situ Bioremediation of Chlorinated Compounds

A.11.1 System Description

In-situ bioremediation encompasses a group of technologies that increase the growth of microorganisms to enhance the biodegradation of organic compounds in the subsurface saturated zone. Depending on the particular technology utilized, in-situ bioremediation can be applied to various chlorinated compounds. These technologies may be used to remediate plumes and restore groundwater quality, to help provide containment of a chlorinated solvent plume, or to be part of a treatment train downgradient from a primary cleanup or containment system. Test and evaluation projects are on-going to develop or validate protocols for applying many of these technologies. Site-specific microcosm/pilot studies are essential to evaluate technical feasibility and to collect design information. Bioaugmentation may be required at some sites to provide the microbial population necessary for the biological process.

The major biological processes by which chlorinated solvents are degraded include anaerobic reductive dechlorination, also referred to as halorespiration; aerobic cometabolism; and, aerobic or anaerobic oxidation. A brief description of each process follows:

Anaerobic Reductive Dechlorination – A hydrogen source consisting of either H₂ or a dissolved biodegradable carbon source like lactic acid, molasses, or a slow release formulation like hydrogen release compound (HRC) is injected under pressure to initiate the step-wise replacement of chlorine atoms by hydrogen atoms. Microorganisms use the chlorinated solvents as electron acceptors in halorespiration and may also anaerobically cometabolize the chlorinated solvent. Reductive dechlorination/halorespiration is more effective on the highly chlorinated solvents but will be effective to some degree on most chlorinated solvents.

Aerobic Cometabolism – Oxygen is used as the electron acceptor in this reaction. Electron donors such as methane, ethane, propane, butane, toluene, phenol, and ammonia are injected under pressure in gas or liquid form to enhance bacterial growth. Enzymes produced by the microorganisms fortuitously oxidize the chlorinated solvents. Aerobic cometabolism is effective for a wide range of chlorinated solvents. It does not occur naturally and is ineffective against tetrachloroethene.

Aerobic oxidation – Oxygen is utilized as the electron acceptor and is delivered as air (sparging), peroxide, or Oxygen Release Compound. Microorganisms utilize the chlorinated solvents as a food source (electron donor) and gain energy and carbon from its biodegradation. This process is identical to the process typically used to bioremediate petroleum constituents and is limited to the less-chlorinated compounds such as vinyl chloride.

Anaerobic oxidation – In anaerobic oxidation, the chlorinated solvent is again used as the food source by the microorganisms. However, inorganic compounds other than oxygen serve as the electron acceptors. The process applies to a limited range of chlorinated solvents dependent on specific reducing conditions (i.e., nitrate reducing, sulfate reducing) that occur naturally in the environment and which can be induced by injecting the inorganic compounds under pressure.

Various types of delivery mechanisms are used, including dual vertical well recirculation, horizontal well recirculation, combinations of well-infiltration trench recirculation, direct liquid amendment injection using wells or direct push technology, gas amendment injection, and pass-through or reactive cell designs. The primary components of a typical in-situ bioremediation system utilizing injection wells are shown in Figure A-21.

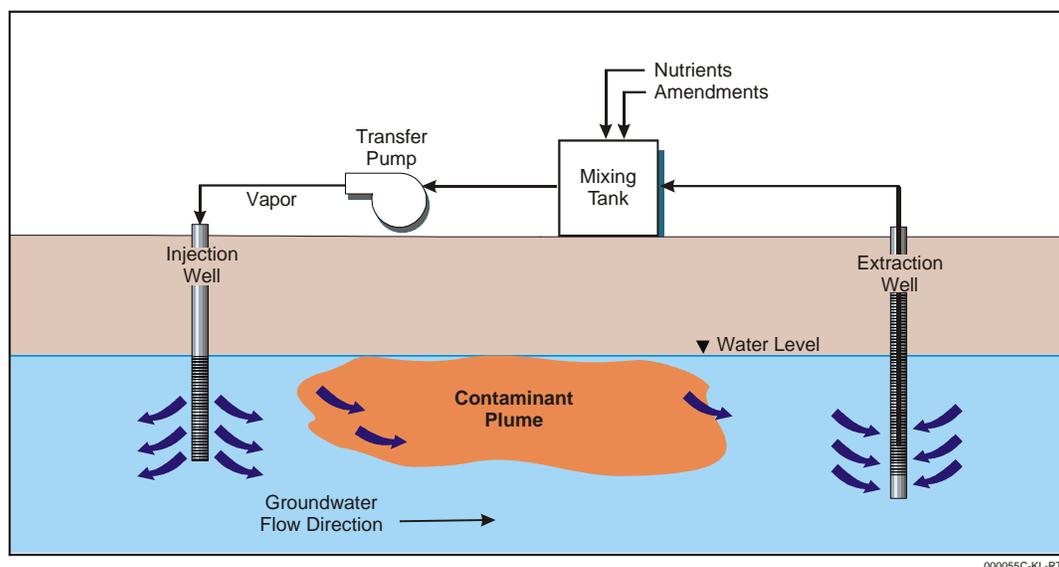


Figure A-21. In-situ bioremediation system for chlorinated compounds.

A.11.2 Performance Plots

A typical performance plot for reductive dechlorination is shown in Figure A-22. The figure shows the trend in molar concentrations of parent and daughter compounds in groundwater samples collected from a monitoring well at various times after EISB was implemented. The proportion of the compounds should change over time in a successful application of EISB. In Figure A-21, the concentration of trichloroethene (TCE) decreases while that of ethene increases. Intermediate compounds such as cis-dichloroethene (cDCE) and vinyl chloride (VC) first increase in concentration before decreasing. A performance plot for a system utilizing the aerobic oxidation process was discussed previously in Section A.10.

A.11.3 Common Operational Problems

A number of general problems are commonly associated with in-situ bioremediation systems for chlorinated compounds. As in the case of the previous technology, these problems are related to microorganism growth requirements and to the operation of the delivery system. The nature of the problems may vary from deficiencies in nutrients or substrate to fouling of the injection points. Table A-11 lists operational problems common to in-situ bioremediation systems for chlorinated compounds in general. Operational problems specific to each of the four particular bioremediation processes described above are beyond the scope of this section. Problems common to systems specifically utilizing an aerobic oxidation process are addressed in Section A.10.3.

A.11.4 Common Optimization Recommendations

Optimization recommendations should focus on ensuring that nutrient and substrate levels are not rate limiting and that the delivery system is operating efficiently. Recommendations for optimizing EISB systems for chlorinated compounds vary depending on the specific process utilized. The more common recommendations include adding substrate to ensure favorable oxidation-reduction conditions, pulsing the injection of nutrients to minimize biological fouling, or rehabilitating well screens that do become fouled. Table A-10 provides general guidance on optimizing EISB systems for chlorinated compounds.

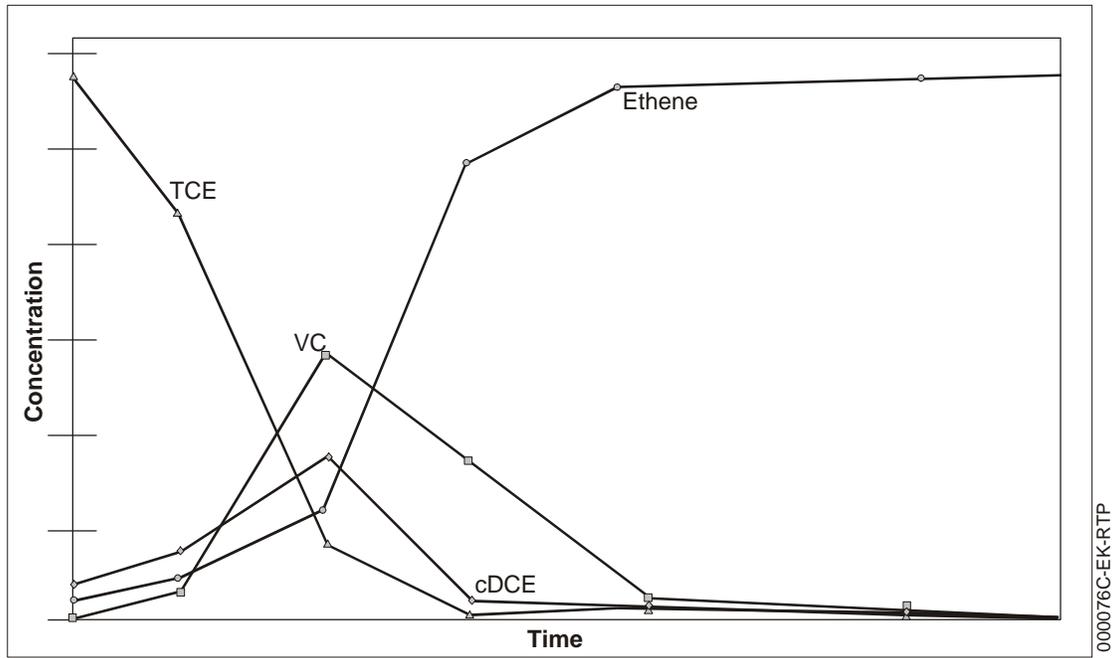


Figure A-22. Performance plot of a typical in-situ bioremediation system for chlorinated compounds.

Table A-11. Common Operational Problems and Optimization Strategies of In-situ Bioremediation Systems for Chlorinated Compounds

Operational Problem	Potential Causes	Potential Negative Impacts on Performance	Optimization Strategies
The contaminant concentrations have not declined in the system influent and in the monitoring wells.	<ul style="list-style-type: none"> Source areas or hotspots have not been adequately controlled. High concentrations of constituents are present and toxic to the microorganisms. 	<ul style="list-style-type: none"> The presence of a continuing source of contaminants will prevent cleanup goals from being achieved. Microbial growth will not occur and cleanup goals will not be achieved. 	<ul style="list-style-type: none"> Identify and control source areas and hotspots including excavation, if feasible. Evaluate the use of alternate technologies.
The treatment zone is insufficient or not as predicted.	<ul style="list-style-type: none"> The soil permeability is lower than estimated. The number of and placement of injection wells is not adequate. 	<ul style="list-style-type: none"> Organic substrate, electron acceptors, or other amendments will not reach all contaminants and cleanup goals will not be achieved. 	<ul style="list-style-type: none"> Install additional injection wells.
Contaminant degradation is slow or incomplete.	<ul style="list-style-type: none"> The delivery of substrate, electron acceptors, or other amendments is not sufficient to maintain biodegradation rates. Redox conditions are not favorable for the biodegradation process . An over abundance of competing electron acceptors is present and inhibits reductive dechlorination. Intermediate compounds that are toxic to microbes are formed during aerobic cometabolism. Preferential channels are formed by systems that inject gases such as hydrogen and methane causing most of the contaminants to be bypassed. 	<ul style="list-style-type: none"> Biodegradation rates slow and cleanup will be incomplete or will take longer than estimated. 	<ul style="list-style-type: none"> Increase the rate of injection or evaluate the need for additional wells. Evaluate the need for additional or different substrate, electron acceptors, or other amendments. Evaluate the need for Eh adjustment. For anaerobic and cometabolic systems, pulse substrate to minimize competitive inhibition of the substrate on the contaminants. Evaluate alternate technologies for possible implementation. "Pulse" the injection wells for gases such as hydrogen and methane.
The contaminant concentrations in the monitoring wells have reached asymptotic levels and/or rebound to higher levels when pumping is terminated.	<ul style="list-style-type: none"> Remediation may only be occurring in more permeable units comprising the aquifer. 	<ul style="list-style-type: none"> The inability to distribute organic substrate, electron acceptors, or other amendments to low permeability zones will extend cleanup time or prevent achieving cleanup goals. 	<ul style="list-style-type: none"> Evaluate alternate technologies, including monitored natural attenuation for possible implementation.

Table A-11. Common Operational Problems and Optimization Strategies of In-situ Bioremediation Systems for Chlorinated Compounds (Continued)

Operational Problem	Potential Causes	Potential Negative Impacts on Performance	Optimization Strategies
Increasingly higher pressure in re-injection wells and/or infiltration galleries.	<ul style="list-style-type: none"> • The re-injection points and/or formation have become plugged through mineral encrustation, biological fouling, or gas bubbles. 	<ul style="list-style-type: none"> • Organic substrate, electron acceptors, or other amendments will not reach contaminants and cleanup will not be achieved or will take longer than estimated. 	<ul style="list-style-type: none"> • Mechanically rehabilitate affected wells. • Perform routine cleaning and surging of wells to prevent future mineral encrustation and biofouling. • Install a filtration system to remove biomass and particulates. • "Pulse" amendments into the subsurface to discourage biofouling. • Replace affected wells that cannot be rehabilitated.
The contaminant plume expands during the operation of a liquid delivery system.	<ul style="list-style-type: none"> • The extraction well pumping rates are not sufficient to re-circulate groundwater within the treatment zone. • The number or placement of the extraction wells is not adequate. 	<ul style="list-style-type: none"> • Failure to re-circulate groundwater will allow the plume to enlarge in size and potentially reach receptors. The larger area will also result in increased remediation time and require expanding the bioremediation system. 	<ul style="list-style-type: none"> • Increase the pumping rates at the extraction wells. • Install additional extraction wells.

A.12 In-Situ Chemical Oxidation

A.12.1 System Description

In-situ chemical oxidation is a source reduction technology used to treat soil and groundwater contaminated with organic compounds. Chemical oxidation of organic contaminants is achieved by injection of chemicals into the contaminated soil and/or aquifer through injection wells. The chemicals are then distributed through the affected system by dispersion and diffusion. The chemical oxidation process rapidly transforms organic contaminants into less harmful degradation products. The technology is best suited for treating source areas exhibiting high concentrations of chlorinated compounds. The primary components of a typical in-situ chemical oxidation system are shown in Figure A-23.

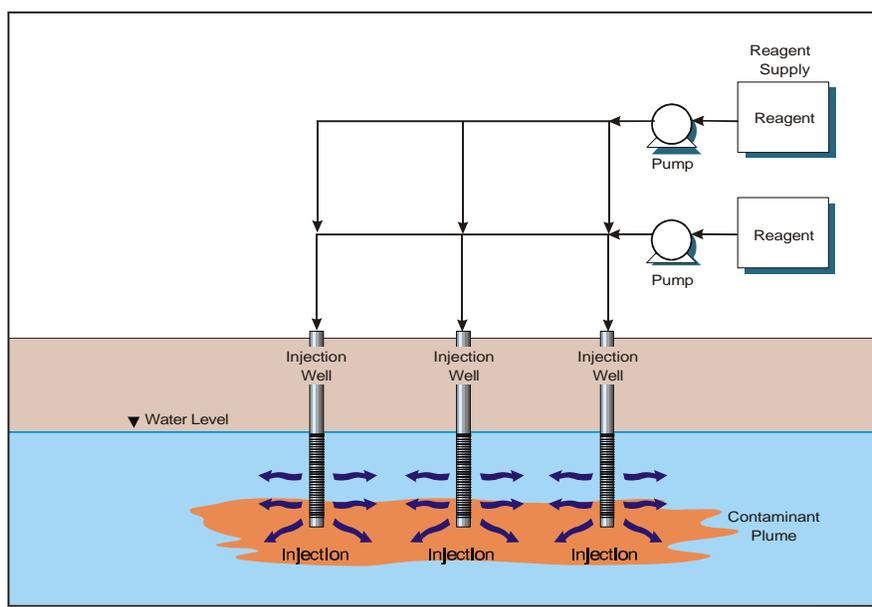


Figure A-23. In-Situ chemical oxidation treatment system.

The primary in-situ chemical oxidation processes include Fenton's Reaction and Permanganate Oxidation. A description of each in-situ chemical oxidation process follows.

Fenton's Reaction – Hydrogen peroxide and ferrous iron catalyst are used to initiate the chemical oxidation process in Fenton's Reaction. Hydroxide radicals produced from the hydrogen peroxide and ferrous iron catalyst oxidize contaminants in an exothermic reaction. The hydroxide radicals are strong non-specific oxidizers that transform the contaminants into carbon dioxide, water, and other byproducts.

Residual hydrogen peroxide rapidly decomposes to water and oxygen in the subsurface environment, due to its unstable nature. The soluble iron catalyst added to the aquifer in trace quantities is precipitated.

Permanganate Oxidation – Permanganate oxidation uses potassium permanganate or sodium permanganate to initiate the oxidation reaction. Permanganate oxidation is applicable in environments not as favorable for Fenton's reaction, such as areas characterized by low permeability soil where a slower and longer reaction time is beneficial. Unlike Fenton's reaction, permanganate acts as a metal-oxo reagent and does not rely on generation of a hydroxyl radical to oxidize organic contaminants.

The ability for most natural aquifer materials to consume permanganate reduces concern that the presence of permanganate in solution would emerge as a major contaminant problem at most sites. On the other

hand, permanganate oxidation reaction can release metals (e.g., Cr^{3+}) to the aqueous phase at concentrations that may be of regulatory concern. Other key reaction products include manganese dioxide and carbon dioxide.

A.12.2 Performance Plots

The effectiveness of in-situ chemical oxidation treatment may be determined through performance plots. The data that should be collected for an in-situ chemical oxidation treatment event are described below.

- Pre-injection sampling. Contaminant concentrations prior to chemical injection will provide the baseline for source reduction.
- Injection measurements. The volume and location of chemical injected will provide information on the system design. Groundwater quality measurements (e.g., pH, alkalinity, oxidation-reduction potential, and conductivity) will provide an understanding of changing site conditions. Contaminant concentrations during injection will allow an assessment of system design and treatment effectiveness.
- Post-injection sampling. Contaminant concentrations after treatment will determine the reduction of the source area and identify any rebound effects.

The data should be compared with remedial objectives and goals to determine the effectiveness of the in-situ chemical oxidation treatment event. The data will also allow the RPM to assess the conditions to optimize subsequent treatment events.

Example: In-situ chemical oxidation using the Fenton's Reagent method has been effectively used to remediate source areas of chlorinated solvents at the NAS Pensacola Industrial Wastewater Treatment Plant Sulfide Drying Bed/ Surge Pond site. The remedial objective was to substantially reduce concentrations of chlorinated hydrocarbons in the source area to ensure natural attenuation would be an effective remedy. Initial concentrations of TCE historically exceeded 3,000 ug/L in the source area. After two phases of injection, TCE concentrations in the source area ranged from less than 1 ug/L to 100 ug/L with no rebound – a reduction of more than 96%. The results of the in-situ chemical oxidation treatment at NAS Pensacola are shown in Figure A-24.

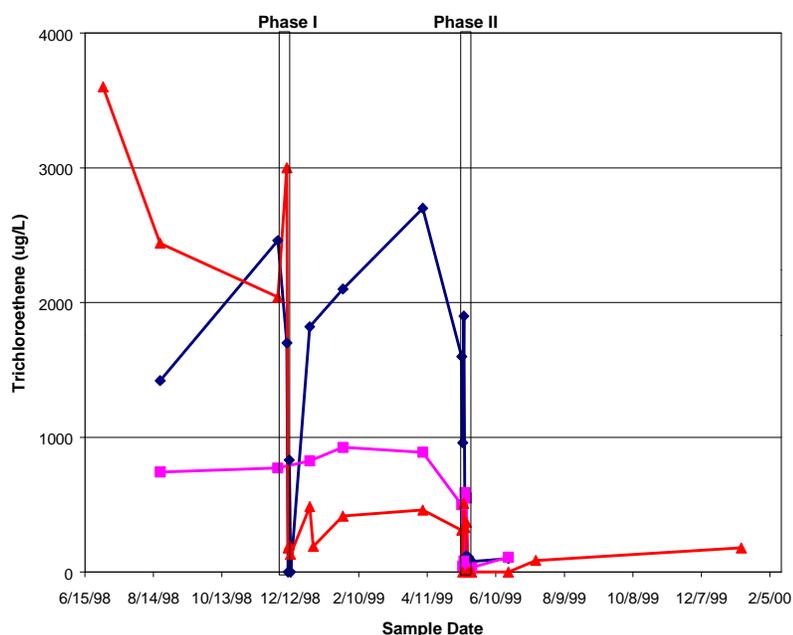


Figure A-24. In-situ chemical oxidation treatment at NAS Pensacola.

A.12.3 Common Operational Problems

Chemical oxidation treatments must be conducted under carefully controlled conditions. The existing site conditions must be evaluated to determine the appropriate use of this process. The effectiveness of in-situ chemical oxidation is dependent on site conditions, treatment design, and the consideration of post treatment effects. While there are differences in the applicability of the different chemical oxidation processes, the operational problems associated with these processes are similar. Common operational problems related to in-situ chemical oxidation are provided in Table A-12.

A.12.4 Common Optimization Recommendations

Optimization strategies typically cannot be applied during a chemical oxidation treatment event; instead, optimization strategies focus primarily on correcting operational problems for subsequent treatment events. Optimization problems resulting from most site condition limitations will require the use of an alternative technology. Other optimization recommendations include design modifications and the combined use of technologies. As these optimization recommendations are generic (i.e., the appropriate alternative technology and the magnitude of design modification must be determined on a site-specific basis), the expected cost impacts of these recommendations are unknown. Common optimization strategies for in-situ chemical oxidation are provided in Table A-12.

Table A-12. Common Oxidation Operational Problems and Optimization Strategies for In-Situ Chemical

Operational Problem	Potential Causes	Potential Negative Impacts on Performance	Optimization Strategies
Contaminant removal is not complete.	<ul style="list-style-type: none"> • Too much contamination is present for effective treatment. • An insufficient volume of chemical reagent was injected. • The reaction proceeds too rapidly due to the presence of a naturally high concentration of catalysts. • The injection wells are improperly located. • The aquifer material interferes with the reaction. 	<ul style="list-style-type: none"> • Oxidation of the contaminants will be incomplete. • The chemical reagents will not reach the contaminants. • The reaction rate is slowed or the chemical reagents are consumed by the aquifer material. 	<ul style="list-style-type: none"> • Increase the volume of chemical reagents injected. • Modify the design of the injection well network. • Evaluate implementing an alternate technology. • Perform additional site characterization.
The radius of influence is limited.	<ul style="list-style-type: none"> • The hydraulic conductivity is too low for effective treatment • An insufficient volume of chemical reagent was injected. • The reaction proceeds too rapidly due to the presence of a naturally high concentration of catalysts. • The aquifer material interferes with the reaction. • The reaction forms byproducts 	<ul style="list-style-type: none"> • Distribution of the chemical reagents will be limited. • Oxidation of the contaminants will be incomplete. • Chemical distribution limited by rapid reaction • The chemical reagents are consumed by the aquifer material • Plugging and flow diversion The reaction byproducts will cause plugging and divert flow. 	<ul style="list-style-type: none"> • Increase the volume of chemical reagents injected. • Inject additional chemical reagents to inhibit reaction catalyst • Evaluate the use of an alternate technology.
The contaminant concentrations rebound after treatment.	<ul style="list-style-type: none"> • The injection wells are improperly located. • Exothermic reaction effects • An upgradient source remains untreated. 	<ul style="list-style-type: none"> • The chemical reagents will not treat sources of contamination • Mounding and mobilization of the contaminants is occurring. 	<ul style="list-style-type: none"> • Modify the system design. • Use chemical oxidation in combination with other technologies.

A.13 In-Situ Thermal Treatment

A.13.1 System Description

In-situ thermal treatment technologies involve enhancing the movement of highly viscous fluids so that it can be more readily removed by groundwater or vapor extraction. Thermal treatment can be implemented at low temperatures (<100°C) using steam injection wells, hot water flooding, or in-situ steam generation by electrical resistance heating. A description of each thermal treatment system follows.

Steam Injection Treatment Process – Steam stripping may be applied to contaminated soils using a fixed system of wells or augers for steam injection. The injection of low-moisture steam heats the formation and vaporizes contaminants. The contaminated vapors are collected for treatment by applying vacuum to extraction wells or by a vacuum hood maintained over the augers. The primary components of a typical steam injection treatment system are shown in Figure A-25.

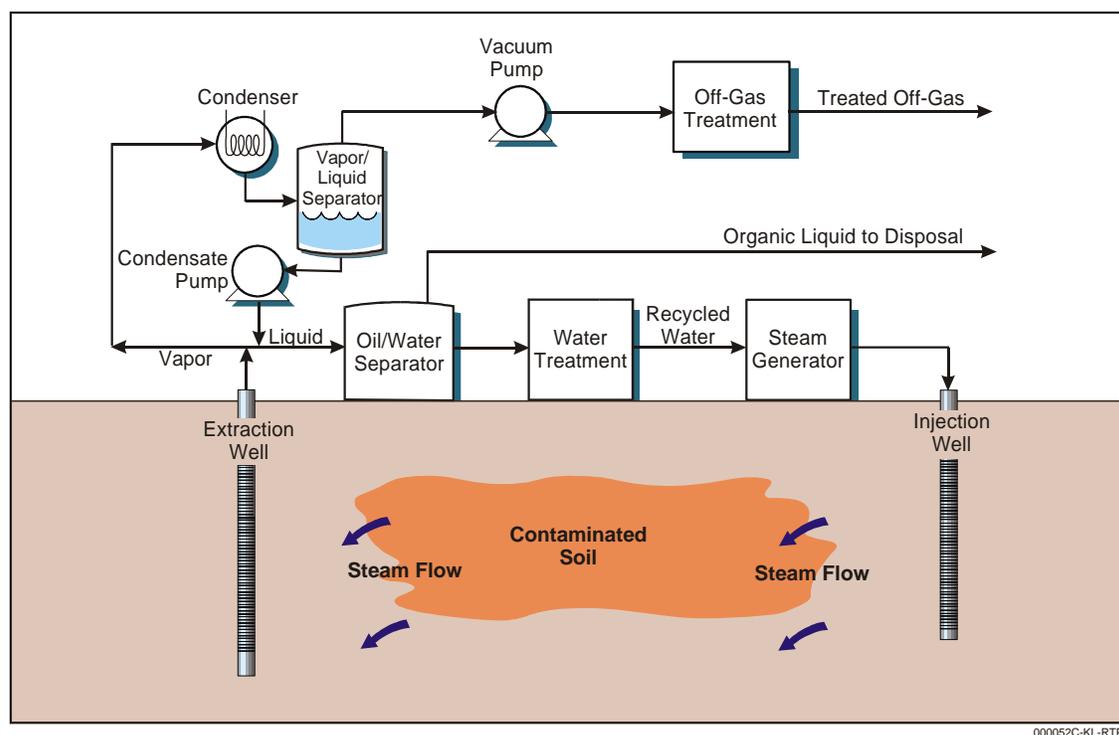


Figure A-25. Steam injection treatment system.

Hot Water Flooding Process – Hot water flooding uses hot water and steam injection to enhance and control contaminant mobility. The heat of the water and steam reduces the viscosity of the contaminants, and the flow displaces the contaminants toward extraction wells. The water flooding system requires a complex well system to simultaneously inject steam (for heating and mobilization), hot water (for mobilization and lateral confinement), and cool water (for vertical confinement) at separate elevations.

Electrical Heat Input Process – Electrical heat input process heats the soil to increase the volatility of VOC and semi-volatile organic compounds (SVOC) contaminants making them more susceptible to removal by soil vapor extraction techniques. Electrodes installed in the ground generate an electrical

current through the soil. The resistance to the flow of current in the soil matrix causes heat to be generated. Water vapors and volatilized contamination is then removed by soil vapor extraction.

A.13.2 Performance Plots

The effectiveness and efficiency of thermal treatment processes may be determined through performance plots. The data used to evaluate a thermal treatment system includes contaminant concentrations, the volume of gas and vapor treated, and cost of system O&M. Performance plots of this data should be compared with remedial performance and cost objectives to determine the effectiveness and efficiency of the thermal treatment system.

A typical plot of cumulative mass recovered and concentrations of contaminants (VOCs in this case) versus time is shown in Figure A-26. As shown in the figure, a typical contaminant concentration response curve for in-situ thermal treatment is characterized by initial high contaminant concentrations, followed by declining concentrations, and finally a period in which concentrations reach asymptotic low levels. A plot of cumulative contaminant mass removal is a mirror image of the contaminant concentration response curve. Initially, the cumulative mass of contaminant removed increases rapidly. The initial response is followed by a period during which mass removal rates steadily decrease until, ultimately, asymptotic conditions are reached.

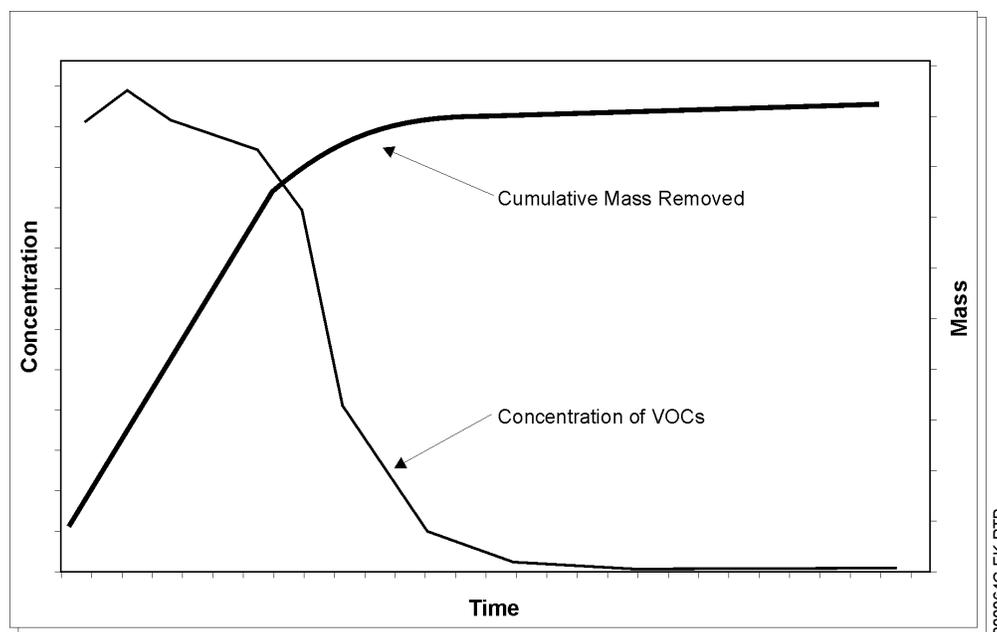


Figure A-26. Performance plot of a typical In-situ thermal treatment system.

A.13.3 Common Operational Problems

Thermal treatment processes must be applied uniformly across the area of contamination. The existing site conditions must be evaluated to determine the appropriate use of these processes. The effectiveness of thermal treatment processes is primarily dependent of site conditions and treatment system design. Operational problems resulting from improper treatment system design may result in the spread of contamination to clean areas. Common operational problems related to thermal treatment are provided in Table A-13.

Table A-13. Common Thermal Treatment Operational Problems and Optimization Strategies

Operational Problem	Potential Causes	Potential Negative Impacts on Performance	Optimization Strategies
The contaminant removal rate is low.	<ul style="list-style-type: none"> • There is insufficient heating due to heating source inadequacies and/or site conditions (e.g., high soil moisture). • The fluid flow is not uniform. • The permeability of the soil is lower than estimated. • The injection wells are not properly located. • There is interference from buried electrical conductors 	<ul style="list-style-type: none"> • Low temperatures will not allow contaminant removal • The heat will be unevenly distributed • The heat will be prevented from reaching the contaminants. 	<ul style="list-style-type: none"> • Increase the size or capacity of the heat source. • Relocate and/or modify the injection wells and recovery system. • Evaluate use of an alternate technology.
Undesired mobilization of the contaminants occurs.	<ul style="list-style-type: none"> • The injection and recovery system is not properly designed. 	<ul style="list-style-type: none"> • The contaminants may be spread to clean areas. 	<ul style="list-style-type: none"> • Relocate and/or modify the injection wells and recovery system

A.13.4 Common Optimization Recommendations

Optimization of operating problems resulting from site condition limitations will require the use of an alternative technology. Design modifications may also be used to optimize thermal treatment systems. Common optimization strategies for thermal treatment systems are provided in Table A-13. These optimization recommendations are generic as the appropriate alternative technology and the magnitude of design modifications must be determined on a site-specific basis.

A.14 Monitored Natural Attenuation

Natural attenuation includes any of a number of biological, chemical, and physical processes that can effectively reduce contaminant toxicity, mobility, or volume to levels that are protective of human health and the environment. Some processes such as biodegradation and chemical transformation destroy the contaminants. Other processes such as dispersion, dilution, sorption, and volatilization simply reduce the contaminant concentrations.

Natural attenuation processes operate to some degree at all contaminated sites. However, the effectiveness of the processes in reducing contaminant mass or concentration depends on the type and amount of contaminants present and on the hydrogeology of the site. Natural attenuation is most effective against petroleum constituents. Aerobic and anaerobic biodegradation are the two main attenuating mechanisms for petroleum constituents.

Under the proper site conditions, natural attenuation is also effective against chlorinated compounds but the processes are harder to predict. Incomplete degradation can also produce breakdown products that are more toxic than the original compounds. The primary attenuating mechanism of chlorinated compounds is anaerobic reductive dechlorination.

MNA is a cleanup remedy that combines reliance on natural attenuation processes with a program designed to monitor the progress of natural attenuation toward achieving cleanup objectives. The performance monitoring results are used to calculate the rate at which natural attenuation is occurring, which is compared to the rate predicted from site characterization data.

MNA is gaining acceptance by regulatory agencies as a stand-alone remedy or as a component in a more comprehensive approach incorporating engineered remediation systems. MNA can usually be implemented only after source control measures have eliminated the source of contamination. MNA also requires a contingency plan in the event that performance monitoring indicates that a cleanup objective (i.e., such as a pre-defined amount of plume spreading) will not be achieved.

In certain situations, MNA can be an effective remedy and the most appropriate way to cleanup a contaminated site. For example, sites contaminated with petroleum constituents are excellent candidates for MNA because petroleum constituents are among the compounds most easily destroyed through biodegradation. MNA may also be a good option at sites that have undergone some active remediation that has reduced contaminant concentrations. In particular, MNA may be acceptable to regulators when active remediation systems have reached asymptotic conditions and are no longer effective or efficient at reducing contaminant concentrations. However, natural attenuation requires a longer time to achieve remedial objectives and typically requires more extensive site characterization and performance monitoring than active remedial systems.

The following conditions are an initial indication that natural attenuation is occurring at a site:

- A contaminant plume that is stable or decreasing in size as documented by monitoring results
- A consistent decreasing trend in contaminant concentrations as documented by monitoring results
- The presence of daughter products, other metabolic byproducts, and process-specific geochemical indicators

If these conditions occur at a site, the RPM is encouraged to assess and evaluate natural attenuation occurrence and to develop plans to implement MNA, if it is deemed appropriate and cost effective.

A proposal to implement MNA must first include a demonstration that the natural attenuation processes will occur at a rate capable of reducing contaminants to acceptable concentrations before reaching a receptor. The demonstration is based on the site's conceptual model and supplemented by an evaluation of nutrients, electron donors, and electron acceptors and by information regarding natural attenuation rates. The data are incorporated in a model that predicts the time-of-travel and the distance and direction that contaminants will migrate prior to being degraded. Second, the proposal must include a plan for monitoring the progress of natural attenuation. The plan should identify a sufficient number of properly located wells for monitoring the constituents of concerns, biodegradation byproducts, and relevant geochemical parameters. The plan should specify the sampling frequency based on various site-specific factors including proximity to receptors and constituent time-of-travel estimates. Third, the proposal must include a contingency plan in the event that performance monitoring indicates that natural attenuation is not occurring as predicted. The contingency plan should identify the alternative technology selected and clearly specify the criteria under which it is to be implemented.

Procedures for preparing a demonstration of MNA can be found in a number of readily available documents. These include *Technical Guidelines for Evaluating Monitored Natural Attenuation at Naval and Marine Corps Facilities* (DON, 1998), *Technical Protocol for Implementing Intrinsic Remediation with Long-Term Monitoring for Natural Attenuation of Fuel Contamination Dissolved in Groundwater* (Air Force Center for Environmental Excellence, 1995), and *Technical Protocol for Evaluating Natural Attenuation of Chlorinated Solvents in Groundwater* (USEPA, 1998). Tools that may be helpful in evaluating MNA are discussed in Section 9 of this document.

A.15 Above Ground Treatment Systems O&M

There are many liquid phase and vapor phase treatment technologies available for use with remedial systems. An effluent treatment system can be a combination of many treatment components depending on the characteristics of the contamination. The best way to optimize the operational cost involved with using effluent treatment technologies is to:

- Use the simplest technology possible
- Apply the technology properly
- Modify/change systems as contaminant characteristics/concentrations change
- Look for economical pretreatment processes to reduce maintenance

This section provides an overview of effluent treatment technologies and general guidelines for reducing operational costs of effluent treatment systems.

A.15.1 Vapor Phase Treatment Technologies

The most common remedial technologies that generate contaminated vapors are SVE systems, MPE systems, and water treatment systems using air strippers. The appropriate regulatory agency should be consulted to determine the control level required for the system. Vapor phase treatment technologies discussed in this section include thermal oxidation, catalytic oxidation, and granular activated carbon (GAC). A brief summary of each technology is provided below.

The range of anticipated soil vapor concentrations that will be encountered throughout the project should be considered when selecting a vapor treatment system. Sequential implementation of more than one treatment system (e.g., catalytic oxidation while high removal rates are occurring followed by activated carbon when the concentrations decrease) may be necessary. Table A-14 lists the concentration ranges where the technologies are applicable.

Table A-14. Applicability of Vapor Treatment Technologies

Technology	Influent Concentration (ppmv)
Thermal oxidation	1,000 to 5,000
Catalytic oxidation	100 to 3,000
Granular activated carbon	1 to 300

Table A-15 identifies optimization guidance for vapor treatment technologies. This guidance can be used to remedy common problems encountered with these technologies.

Thermal Oxidation – Thermal oxidation is accomplished by direct heating of contaminated vapor stream at elevated temperatures (1,200 to 1,600°F) with resultant production of combustion gases, such as carbon dioxide and water vapor. Thermal oxidation units typically are used to treat halogenated and non-halogenated VOCs and SVOCs, and polychlorinated biphenyls (PCB). This technology is often utilized during the initial phase of site remediation when contaminant concentrations are high. As concentrations drop, power and fuel consumption generally rises dramatically.

Table A-15. Vapor Treatment System Optimization Guide

Condition Requiring Optimization	Probable Cause	Potential Impacts to Performance	Potential Actions to Optimize Performance
Thermal Oxidation System			
Operating costs rapidly increasing	<ul style="list-style-type: none"> Incoming vapor concentration dropping Incoming vapor composition changing 	<ul style="list-style-type: none"> Increase in supplemental fuel use 	<ul style="list-style-type: none"> Consider other less expensive treatment technologies
Air emissions constituents are rapidly increasing	<ul style="list-style-type: none"> Incorrect operating temperature Incorrect fuel/vapor/dilution air ratios 	<ul style="list-style-type: none"> Decrease in destruction removal efficiency 	<ul style="list-style-type: none"> Reset operating temperature Reset fuel, vapor, and dilution feed valves
System components experience "burn through"	<ul style="list-style-type: none"> Excessive combustion temperature Refractory brick damage Insulation damaged 	<ul style="list-style-type: none"> System shutdown 	<ul style="list-style-type: none"> Check thermocouple and fuel inlet and influent valves for proper operation Replace refractory brick Replace insulation
Catalytic Oxidation Systems			
Air emissions constituents are rapidly increasing	<ul style="list-style-type: none"> Incorrect operating temperature Incorrect fuel/vapor/dilution air ratios 	<ul style="list-style-type: none"> Decrease in destruction removal efficiency 	<ul style="list-style-type: none"> Reset operating temperature Reset fuel, vapor, and dilution feed valves
System components experience "burn through"	<ul style="list-style-type: none"> Excessive combustion temperature 	<ul style="list-style-type: none"> System shutdown 	<ul style="list-style-type: none"> Check thermocouple and fuel inlet and influent valves for proper operation
Activated Carbon Adsorption			
Frequent carbon bed replacement	<ul style="list-style-type: none"> Incorrect inlet temperature High relative humidity Incorrect sizing of bed 	<ul style="list-style-type: none"> Substantially less adsorption performance Operational time decreased 	<ul style="list-style-type: none"> Incoming vapor stream temperature between 80 and 100°F Condition vapor stream through heat exchangers Properly size the unit for flow and mass that is to be treated
Low flow through the carbon bed	<ul style="list-style-type: none"> Biological growth on carbon High particulate loading 	<ul style="list-style-type: none"> Reduced adsorption performance Frequent changeout of containers 	<ul style="list-style-type: none"> Pre-treatment of vapor stream prior to carbon adsorption treatment
55-gallon containers develop leaks	<ul style="list-style-type: none"> Influent chemistry incompatible with container materials 	<ul style="list-style-type: none"> Frequent changeout of containers prior to reaching carbon capacity 	<ul style="list-style-type: none"> Choose a container that is constructed of material that is compatible with effluent being discharged and treated
55-gallon containers develop bulges on top/bottom	<ul style="list-style-type: none"> Incorrect pressure of incoming waste stream 	<ul style="list-style-type: none"> Frequent changeout of containers/leaking containers 	<ul style="list-style-type: none"> Install valving to control the pressure of the incoming effluent stream

Catalytic Oxidation – Catalytic oxidation thermally oxidizes the contaminated vapor stream by passing the vapor over an inert catalyst bed, which promotes the oxidative destruction of the contaminants to combustion gases. The catalyst allows the reaction to occur at much lower temperatures (600 to 1000°F) than during normal combustion processes, which decreases need for supplemental fuel. Because of the catalyst costs, catalytic oxidizers usually will have a higher capital cost than a thermal oxidizer, although the operating costs are usually lower.

As with thermal oxidation, catalytic oxidation can be used to treat halogenated and non-halogenated VOCs and SVOCs, and PCBs. A key consideration for catalytic oxidation systems, however, is the potential for catalyst poisoning or erosion. Materials such as halogens, heavy resins, or heavy solvents can poison or mask the catalyst material, thus requiring either periodic cleaning or premature replacement of the catalyst bed. Vapor streams containing high particulate levels can have a similar effect by eroding the catalyst material.

Granular Activated Carbon – GAC treatment is performed by passing a contaminated vapor stream through one or more vessels containing activated carbon, which removes contaminants from the vapor by adsorption. GAC is used because its high surface area allows for significant adsorption over a wide range of concentrations and chemicals. The amount of adsorption is determined by the chemical, temperature, and pressure at which the adsorption takes place. GAC is used to treat halogenated and non-halogenated VOC and SVOC and PCBs; GAC has limited adsorption capacity for ketones and generally poor adsorption of volatile alcohols.

A.15.2 Liquid Phase Treatment Technology

An extracted water treatment system can be a combination of many treatment components, depending on the characteristics of the contamination. The most effective treatment technology during the early stages of the remedial action may not be the most cost-effective during latter stages. In fact, the question of whether any treatment is needed should be periodically examined as the remediation progresses. Liquid phase treatment technologies discussed in this section include air stripping, GAC, ultraviolet oxidation, and metals precipitation. A brief summary of each technology is provided below.

Table A-16 identifies the optimization guidance for liquid treatment technologies. Optimization of pretreatment methods commonly associated with these treatment technologies is also included. This guidance can be used to remedy common problems encountered with these technologies.

Air Stripping – Air stripping is used to separate contaminants from groundwater by increasing the surface area of the contaminated water and exposing it to air. Types of aeration methods include packed towers, diffused aeration, tray aeration, and spray aeration. Air stripping is used to remove halogenated and non-halogenated volatile organic compounds, and is less effective for contaminants with low vapor pressure of high solubility.

Granular Activated Carbon – Liquid-phase GAC treatment is performed by pumping groundwater through one or more vessels containing activated carbon, which removes contaminants from the water stream by adsorption. Liquid-phase GAC is especially effective for polar compounds and can be used to treat halogenated and nonhalogenated VOCs, SVOCs, and PCBs. Carbon adsorption is effective for removing contaminants at low concentrations (less than 1 mg/L) from water at nearly any flowrate, and for removing higher concentrations of contaminants from water at low flowrates.

Table A-16. Liquid Treatment System Optimization Guide

Condition Requiring Optimization	Probable Cause	Potential Impacts to Performance	Potential Actions to Optimize Performance
Pretreatment Systems			
Free-phase oil is entering groundwater treatment system	<ul style="list-style-type: none"> Oil/water separator is not functioning correctly Clay/anthracite filter vessel is clogged 	<ul style="list-style-type: none"> Reduced treatment efficiency of treatment system 	<ul style="list-style-type: none"> Clean oil/water separator Adjust the skimming or coalescing plates in the oil/water separator Replace the clay/anthracite filter vessel
Suspended solids are entering treatment system components	<ul style="list-style-type: none"> Filters are clogged, torn, or undersized 	<ul style="list-style-type: none"> Creates backpressure on treatment equipment or clog treatment equipment, which will make the treatment less efficient 	<ul style="list-style-type: none"> Resize bag filters to accept a higher flow Replace the bag filter with a new one Consider placing the bag filters in series for greater efficiency. Use large pore size on the first filter with decreasing pore size on subsequent filter(s)
Suspended solids are being “created” in the treatment system and clogging system components	<ul style="list-style-type: none"> Oxidation of metals (iron or manganese) Scaling due to carbonates 	<ul style="list-style-type: none"> Premature plugging or coating of tubing, piping, vessel walls, packing materials, filters, and carbon 	<ul style="list-style-type: none"> Use a water softener or adjust the pH Chelate metals using an oxidation tank Use a sequestering agent
Air Stripping System			
Flooding of stripping tower	<ul style="list-style-type: none"> Tower packing is clogged 	<ul style="list-style-type: none"> Loss of treatment efficiency due to short circuiting or clogging 	<ul style="list-style-type: none"> Clean tower packing and install pretreatment equipment (filters or oxidation tanks) Use sequestering agent Check influent flow rate into tower
Effluent concentration from tower suddenly or slowly rises over time	<ul style="list-style-type: none"> Tower packing is clogged Air blower is not functioning correctly or duct is leaking 	<ul style="list-style-type: none"> Loss of treatment efficiency 	<ul style="list-style-type: none"> Clean tower packing and install pretreatment equipment Adjust air/water ratio to correspond to the design concentrations of contaminants for the removal efficiency
Activated Carbon Adsorption			
Effluent flow and pressure drops suddenly	<ul style="list-style-type: none"> Carbon media is clogged 	<ul style="list-style-type: none"> Loss of treatment efficiency 	<ul style="list-style-type: none"> Replace carbon media Install pretreatment filters prior to carbon media
Pressure vessels leak or bulge	<ul style="list-style-type: none"> Carbon vessel designed for low flows 	<ul style="list-style-type: none"> Shutdown of treatment system 	<ul style="list-style-type: none"> Replace with fiberglass vessels that are designed for higher flow rates
Significant increase in effluent concentrations	<ul style="list-style-type: none"> Carbon media is “spent” 	<ul style="list-style-type: none"> Loss of treatment efficiency 	<ul style="list-style-type: none"> Replace spent carbon Install pretreatment units prior to carbon vessels
Ultraviolet-Oxidation			
Significant increase in effluent concentrations	<ul style="list-style-type: none"> High turbidity causes interference Fouling of quartz sleeves High concentrations of chemical additives 	<ul style="list-style-type: none"> Loss of treatment efficiency 	<ul style="list-style-type: none"> Install pretreatment units prior to UV-oxidation system Adjust chemical additive concentrations

Table A-16. Liquid Treatment System Optimization Guide (Continued)

Condition Requiring Optimization	Probable Cause	Potential Impacts to Performance	Potential Actions to Optimize Performance
Metal Precipitation			
Increase in total residual metals concentration	<ul style="list-style-type: none"> • Presence of organic and inorganic species (other than hydroxide) resulting in the formation of soluble species with metal ions increasing total residual metals concentration (particularly cyanide, ammonia, EDTA, and carbonate) • Process stream temperature variations • Insufficient detention times (i.e., rapid mix, floc, settling, filtration) • Improper coagulant dosing • Presence of multiple metal species • Improper pH adjustment • Improper rapid mix and flocculation mixing rates 	<ul style="list-style-type: none"> • Decrease in treatment efficiency • Deviations between calculated and observed values of metal removal 	<ul style="list-style-type: none"> • Conduct periodic jar tests to determine optimal chemical selection and dosing, and optimal overflow rates • Modify rapid mix and flocculation mixing rates based on jar test data
Increase in quantity and moisture content of sludge	<ul style="list-style-type: none"> • Improper reagent (i.e., coagulant, flocculant, caustic, acid) dosing • Improper mixing rates 	<ul style="list-style-type: none"> • Increase in sludge handling costs 	<ul style="list-style-type: none"> • Conduct periodic jar tests to ensure optimal chemical selection and dosing • Modify rapid mix and flocculation mixing rates based on jar test data
Decrease in settling and filtration efficiencies	<ul style="list-style-type: none"> • Excess sludge accumulation in filtration and settling units 	<ul style="list-style-type: none"> • Decrease in treatment efficiency 	<ul style="list-style-type: none"> • Perform O&M on settling and filtration unit (e.g., remove sludge)

Ultraviolet-Oxidation – Ultraviolet (UV) light is a destruction process that photochemically oxidizes organic contaminants in wastewater. The oxidation reactions are achieved through irradiation with UV light supplemented by the addition of chemical oxidizing compounds to produce active hydroxyl radicals that breakdown contaminants to carbon dioxide, water and salts. Ultraviolet-oxidation can be used to treat any organic contaminant that is reactive with hydroxyl radicals, including halogenated and non-halogenated VOCs, SVOC, PCBs, and ordnance compounds.

Metals Precipitation – Metals precipitation involves adding a chemical precipitant to extracted groundwater to remove inorganic contaminants. The dissolved metals are converted to an insoluble form by a chemical reaction between the soluble metal compounds and the precipitant. The resultant suspended solids are separated out by settling in a clarifier. Chemical precipitants include calcium hydroxide (lime), sodium hydroxide, ferrous sulfide, sodium sulfide, sodium hydrosulfide, sodium carbonate, calcium carbonate, and sodium borohydride. Target contaminant groups are heavy metals.

A.15.3 Discharge and Disposal Options

Treated water disposal/discharge alternatives can include:

- Discharge to local publicly owned treatment works (POTW)
- Discharge to surface water
- Reinjection
- Other (i.e., irrigation, industrial reuse such as dust control, or use as washwater)

The implementation of these options is highly site-specific, and should be evaluated on a site-specific basis.

A.15.4 Remedial System Decommissioning

After decommissioning, the entire remedial system or its components may be reused or salvaged. Ideally, the entire remedial system or its components would be reused at another remedial site on the given installation, used for another purpose at the installation, or used at another DOD site or installation. A less desirable option is to sell components for salvage value.

Equipment Reuse – RPMs should consider the applicability of existing equipment to their site. The transfer of remediation equipment between sites would result in significant cost savings, as well as provide other benefits. The following steps should be conducted to determine whether a particular remedial system can be reused:

- **Maintain an Accurate Remedial System Inventory.** The inventory should include pertinent details of process equipment, such as discharge pump sizes, blower sizes, treatment system type, maximum and minimum system throughput, and instrumentation provided with the system. This information will allow RPMs at other installations to determine whether a particular system will meet the needs of their particular site.
- **Maintain a Current Site Closeout Schedule.** If a remedial system is determined to be suitable for use at another site or installation, the remedial system must be available for use at the

required time. Knowing when a suitable system is available for reuse can allow RPMs to proactively negotiate a schedule extension if reuse of a system can save significant funding.

- Inform Other Parties of Equipment Availability and Schedule. Other parties should be informed of equipment inventory and availability. Facilities and engineering support groups may identify a need for the remedial system or system components.

Equipment Salvage – If equipment reuse options are not identified, equipment salvage should be pursued. The Defense Reutilization and Marketing Office (DRMO) is usually the appropriate agency to coordinate equipment resale. The DRMO temporarily stores excess materials before reutilization or public sale. Because DRMOs are permitted hazardous materials/waste treatment, storage, and disposal facilities (TSDF), they could appropriately handle any contaminated equipment and possibly determine appropriate reuse or disposal options.

Appendix B

Summary of Remedial Action Operation Optimization Case Studies

FINAL

**Marine Corps Base Camp Lejeune
Operable Units 1 and 2**

Remedial Action Operation (RAO) Optimization Case Studies

Contract No. N47408-99-C-7017

Prepared for:

Department of the Navy
Naval Facilities Engineering Service Center (NFESC)
1100 23rd Avenue
Port Hueneme, CA 93043-4370

Prepared by:

Radian International
1600 Perimeter Park Drive
Morrisville, NC 27560

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EXECUTIVE SUMMARY

ES.1 Purpose of the Case Study Report

This case study report includes an effectiveness evaluation for three separate groundwater pump and treat (P&T) systems located at Marine Corps Base (MCB) Camp Lejeune, North Carolina. The systems evaluated within this report are the North and South P&T systems within Operable Unit 1 (OU1), and the Operable Unit 2 (OU2) P&T system. The primary purpose of the evaluation is to assess the ongoing remedial action operation (RAO) program for these three systems, and provide recommendations resulting in attainment of site remedial action objectives and ultimate closure for optimal life cycle costs. For the purposes of this report, optimal is defined as the minimum cost without sacrificing data quality or decision-making.

This project was conducted for the Naval Facilities Engineering Service Center (NFESC) under a Broad Agency Announcement (BAA) contract. NFESC is leading a Department of the Navy (DON) working group in developing guidance on optimizing monitoring and remedial action operations for Navy/Marine Corps activities. This working group is comprised of members from NFESC, Atlantic Division (LANTDIV), other Engineering Field Divisions/Activities (EFD/A), Naval Facilities Engineering Command (NAVFAC), and Chief of Naval Operations (CNO).

ES.2 Optimization Approach

The approach employed in this RAO optimization project to achieve site closeout for optimal life cycle cost is outlined in the steps below. A site visit at MCB Camp Lejeune was conducted from April 27-30, 1999 to gather the required information for this report.

- Gain a detailed understanding of the remedial decision-making framework, remedial action objectives, and site closure criteria for each site.
- Describe and understand past investigation and remedial actions taken to date, and how they have affected the current evolution and understanding of the conceptual site model.
- Describe the current conceptual site model, i.e., geology, pathways, receptors, and contaminants of concern (COC).
- Gain an understanding of other remedial actions and associated data at MCB Camp Lejeune having potential applicability at OU1 and OU2.
- Describe the system design basis and operational objectives for the P&T systems, including extraction well network, at each operable unit.
- Baseline the past and current cost and operational data for each system.
- Compare the cost and performance data with the system design basis.

- Assess the need for additional system operation.
- Provide the future decision strategy framework and prioritized recommendations to improve total system performance and achieve site remedial action objectives for optimal cost.

ES.3 Operable Unit 1 (OU1) North and South System Descriptions

The OU1 North and South P&T systems were evaluated over an operating period of approximately 2.5 years (September 1996 to March 1999). The treatment systems are of identical design and include oil-water separation, followed by air stripping, granular activated carbon (GAC), and discharge to the sanitary sewer system. The systems were designed to accommodate influent flowrates up to 80 gallons per minute (gpm). The extraction well fields consist of three active wells for OU1 North and seven active wells for OU1 South. Extraction wells were expected to produce up to 5 gpm each.

Remedial action objectives for both systems are covered under a Record of Decision (ROD) signed in 1994 which specifies plume capture and treatment to a combination of federal Maximum Contaminant Levels (MCL), State of North Carolina (NC) standards, and risk-based standards. The point of compliance for these treatment objectives is throughout the contaminated plume at OU1. Current total VOC contaminant levels in the influent are 200 to 500 parts per billion (ppb).

ES.4 OU1 North and South System Performance Summary

The technical and cost effective performance for the North and South systems for the period from September 1996 to March 1999 has been poor. It also appears that both the North and South plumes have been stable for several years and are no longer migrating. The overall performance for both systems is summarized below:

- Low hydraulic conductivity of the shallow aquifer has resulted in influent treatment plant flowrates of less than 9% of design capacity.
- Combined total mass removal for both systems has been limited to approximately 23 pounds in 2.5 years of operation.
- The average cost per pound of contaminant removed has been approximately \$30,000.
- There is little evidence to suggest that either system can achieve ROD-specified cleanup objectives throughout the aquifer in their current configuration and mode of operation.
- Both systems have a history of significant maintenance problems and associated downtime.

ES.5 OU1 North System Recommendations

Based on the information reviewed and presented in Section 3.0 of this report, several primary recommendations can be made for the OU1 North P&T system. Complete implementation of these recommendations will likely require an Explanation of Significant Difference (ESD) or a ROD amendment to the current OU1 ROD.

1. Perform a monitored natural attenuation (MNA) assessment on the OU1 North plume, according to established Department of Defense (DOD) and Environmental Protection Agency (EPA) protocols.
2. In parallel with recommendation 1, continue to operate the OU1 North P&T system on an interim basis until contaminant mass removal from extraction wells RW-10, 11, and 12 reach asymptotic levels.
3. Shut down the OU1 North system upon achievement of objectives in recommendation 2.
4. Should state guidelines permit risk assessment in the future, consider revising the baseline human health risk assessment assumptions and associated cleanup level calculations to reflect an industrial future land use category as the most probable scenario.
5. If MNA does not prove feasible as the long-term remedy for OU1 North, consider applying remedial options currently in use at Hadnot Point Fuel Farm (HPFF), along with enhanced biodegradation remedies. These alternative remedies could include air sparging/soil-vapor extraction (AS/SVE) and application of hydrogen releasing compound (HRC).
6. Leverage the performance assessment within this report, as well as the data and information from implementation of the above recommendations, as the foundation for the upcoming five-year review at OU1.

In addition, detailed recommendations are provided to help optimize the OU1 North P&T system during its interim operation period. Several of these recommendations may also be applicable for future remedial actions. All recommendations for the extraction and monitoring well network and the aboveground treatment trains for the OU1 North P&T system are summarized in Table 4-1.

ES.6 OU1 South System Recommendations

Based on the information reviewed and presented in Section 5.0 of this report, several primary recommendations can be made for the OU1 South P&T system. As with OU1 North, complete implementation will likely require an ESD or ROD amendment to the current OU1 ROD.

1. Shut down the operation of the OU1 South system at the earliest opportunity. Continued active pumping is difficult to justify given the low permeability of the

aquifer, current total VOC concentrations, and the likelihood of passive natural attenuation processes already at work.

2. In parallel with recommendation 1, perform a monitored natural attenuation (MNA) assessment on the OU1 South plume according to established DOD and EPA protocols. Data gaps to better define the extent of the plume in three dimensions can be filled as part of the MNA assessment.
3. Should state guidelines permit risk assessment in the future, consider revising the baseline human health risk assessment assumptions and associated cleanup level calculations to reflect an industrial future land use category as the most probable scenario.
4. If MNA does not prove feasible as the long-term remedy for OU1 South, consider applying remedial options currently in use at HPFF, along with enhanced biodegradation remedies. These alternative remedies could include AS/SVE and application of hydrogen releasing compound (HRC).
5. Leverage the performance assessment within this report, as well as the data and information from implementation of the above recommendations, as the foundation for the upcoming five-year review at OU1.

In addition, recommendations are provided to optimize the OU1 South P&T system as it is currently operating if system shutdown cannot be immediately implemented. Recommendations are summarized in Table 6-1.

ES.7 OU2 System Description

The OU2 P&T system was evaluated over an operating period of approximately 2 years (January 1997 to March 1999). There are two, co-located aboveground treatment trains for this system; one for the shallow aquifer zone, and one for the combined flow of both the shallow and deep aquifer zones. Water from the shallow aquifer is first treated for iron removal (mix tank, clarifier, and sludge thickening) prior to being combined with extracted groundwater from the deep aquifer zone. The combined flow is treated via air stripping, filtration, and granular activated carbon, and then discharged to Wallace Creek. The system capacity flow is 500 gpm. The shallow zone and deep zone extraction well fields consist of six and four wells, respectively.

Remedial action objectives for the system are covered under a Record of Decision (ROD) signed in September 1993 which specifies plume capture and treatment to federal MCLs or State of North Carolina (NC) standards, whichever is more stringent. The point of compliance for these treatment objectives throughout the contaminated plume at OU2. Influent volatile organic compounds (VOC) contaminant levels at OU2 average 21 parts per million (ppm), indicating the presence of dense non-aqueous phase liquids (DNAPL) in the subsurface aquifer.

ES.8 OU2 System Performance Summary

The performance of the OU2 treatment system from both mass removal and cost-effectiveness standpoints has been good. Average flow into the system is 60% of the design capacity of 500 gpm, and more than 40,000 pounds of contamination have been removed from the aquifer at an average cost of only \$49 per pound. However, the likely presence of DNAPL coupled with the existence of several critical data gaps, make it highly unlikely that OU2 can be remediated to ROD-specified cleanup levels with existing technology. The data gaps and overall performance of the OU2 system are summarized below:

- The system has cost-effectively removed significant contaminant mass from the aquifer (more than 40,000 pounds at \$49 per pound)
- The vertical and lateral extent of contamination in both the shallow and deep aquifer zones is unknown
- DNAPL source areas require better delineation and definition
- Data to support natural attenuation and passive biodegradation processes for the dissolved phase portions of the plume has not been collected for the shallow and deep aquifer zones
- Plume capture in the shallow zone cannot be confirmed with the current monitoring network
- Due to a dilution effect, the five downgradient extraction wells in the shallow zone are reducing the mass removal effectiveness of the extraction network
- Plume capture in the deep zone is likely but the hydraulic gradients are insufficient to prevent further downward migration of DNAPL
- Mass removal from the deep aquifer zone may be diluted due to wells being screened over most of the well depth, instead of being targeted at zones containing the highest concentrations of contaminants

ES.9 OU2 Recommendations

The primary recommendation for OU2 is to pursue separate but integrated remedial activities for the DNAPL source areas and dissolved phase portions of the plume, both in the shallow and deep aquifer zones. The initial phase in this approach requires that existing data gaps be filled to the extent practicable. In particular:

- The extent of contamination in the shallow and deep zones should be delineated, including the DNAPL source areas

- Natural biodegradation data in the wetlands area of Wallace Creek, and monitored natural attenuation data for the dissolved phase portions of the plume should be collected
- Discussions should begin with the regulatory agencies to establish alternate concentration limits (ACL) for groundwater discharging to Wallace Creek

For the shallow zone, additional recommendations include monitoring the mass removal from each extraction well, and installing additional extraction wells in the vicinity of the current hot spot. For the deep zone, other recommendations include the use of diffuser sampling bags to delineate the vertical distribution of contamination, and performing additional investigations to better define stratigraphy and contaminant extent. Based on an analysis of this data, additional deep zone extraction wells may be required.

For the aboveground treatment plant, recommendations include:

- Modifying the National Pollution Discharge Elimination System (NPDES) permit to allow bypass of the GAC polishing step during normal operation
- Replacing the existing polymer feed pump
- Monitoring mass removal from individual extraction wells to optimize operation and placement of future wells

FINAL

**Marine Corps Base Camp Lejeune
Campbell Street Fuel Farm**

Remedial Action Operation (RAO) Optimization Case Studies

Contract No. N47408-99-C-7017

Prepared for:

Department of the Navy
Naval Facilities Engineering Service Center (NFESC)
1100 23rd Avenue
Port Hueneme, CA 93043-4370

Prepared by:

Radian International
1600 Perimeter Park Drive
Morrisville, NC 27560

January 2000

EXECUTIVE SUMMARY

ES.1 Purpose of the Case Study Report

This case study report includes an effectiveness evaluation for the Campbell Street Fuel Farm (CSFF) groundwater pump and treat (P&T) system located at Marine Corps Air Station (MCAS) New River, which is co-located with Marine Corps Base (MCB) Camp Lejeune, North Carolina. The primary purpose of the evaluation is to assess the ongoing remedial action operation (RAO) program for this system, and provide recommendations resulting in attainment of site remedial action objectives and closure for optimal life cycle costs. For the purposes of this report, optimal is defined as the minimum cost without sacrificing data quality or decision-making.

This project was conducted for the Naval Facilities Engineering Service Center (NFESC) under a Broad Agency Announcement (BAA) contract. NFESC is leading a Department of the Navy (DON) working group in developing guidance on optimizing monitoring and remedial action operations for Navy/Marine Corps activities. This working group is comprised of members from NFESC, Atlantic Division (LANTDIV), and other Engineering Field Divisions/Activities (CEFD/A).

ES.2 Optimization Approach

The approach employed in this RAO optimization project to achieve site closure for optimal life cycle cost is outlined below:

- Gain a detailed understanding of the remedial decision-making framework, remedial action objectives, and site closure criteria for each site.
- Describe and understand past investigation and remedial actions taken to date, and how they have affected the evolution and understanding of the conceptual site model (CSM).
- Describe the current conceptual site model, i.e., geology, pathways, receptors, and contaminants of concern (COC).
- Gain an understanding of other remedial actions and associated data at MCB Camp Lejeune having potential applicability at CSFF.
- Describe the system design basis and operational objectives for the P&T system, including the extraction trench and well network.
- Baseline the past and current cost and operational data.
- Compare the cost and performance data with the system design basis.

- Assess the need for additional system operation.
- Provide the future decision strategy framework and prioritized recommendations to improve total system performance and achieve site remedial action objectives for optimal cost.

A site visit at MCB Camp Lejeune was conducted from April 27 - 30, 1999 to gather the required information for this report.

ES.3 Campbell Street Fuel Farm (CSFF) System Description

The CSFF P&T system was evaluated over an operating period of approximately 2.5 years (July 1996 to March 1999). The system was installed to remove fuel-related contaminants from the groundwater. The treatment system is a skid-mounted package unit and includes oil/water separation, followed by air stripping, granular activated carbon (GAC), and discharge to a surface drainage ditch (See Figure 3-6). The system was designed to accommodate influent flow rates up to 30 gallons per minute (gpm).

The extraction system consists of a single recovery trench at each of the three contaminated sites: Campbell Street Fuel Farm, AS-143, and AS-4151. Four recovery wells (RW) were recently installed (two RWs at AS-143, one RW at each of the other sites) to address hot spot contamination and improve contaminant recovery. These extraction wells contain pneumatic submersible pumps rated at 1 gpm.

Remedial action objectives for this system are regulated under the State of North Carolina underground storage tank (UST) program. Corrective Action Plans addressing each of the three contaminated sites were submitted in 1994. The proposed corrective actions included soil removal, free product recovery, operation of a P&T system, and long-term monitoring. Groundwater cleanup standards are those listed in the State of North Carolina Groundwater Standards.

ES.4 CSFF System Performance Summary

The technical performance and cost effectiveness of the CSFF system for the period from July 1996 to March 1999 has been poor. The overall performance for the system is summarized as follows:

- The monitoring well network is inadequate to define the plume capture zones; however, it appears the plumes are stable due to natural attenuation processes.
- Influent treatment plant flow rates are less than 10% of design capacity.
- Cumulative mass removal for the system has been limited to approximately 3.5 pounds in more than 2.5 years of operation.

- Total volatile organic compound (VOC) contaminant levels in the influent are now 440 parts per billion (ppb) in the AS-143 recovery trench and non-detect (ND) in the AS-4151 and Campbell Street recovery trenches.
- The AS-4151 recovery trench has shown consistent non-detect VOC contaminant levels for 20 months. Additionally, the Campbell Street recovery trench has hovered around non-detect for the last 12 months. This asymptotic performance supports discontinuing active remediation in favor of monitored natural attenuation (MNA).
- The cost per pound of contaminant removed has averaged \$95,000.
- There is little evidence to suggest that the active pumping has had any significant impact in achieving site-specific cleanup objectives.

ES.5 CSFF System Recommendations

Recommendations for the CSFF System should be implemented in a phased approach. The AS-4151 and Campbell Street trenches should be shut down immediately, having reached asymptotic ND levels of contaminants. Based on contaminant spikes at the AS-143 site, hot spot removal should continue on an interim basis. If the newly installed recovery wells prove to be of limited benefit, Aggressive Fluid Vapor Recovery (AFVR) should be considered as a more cost effective means of addressing further hot spots. Finally, MNA data should be gathered to confirm the potential of a passive remedial approach for AS-143 once the remaining hot spots have been removed.

FINAL

**Naval Submarine Base New London
Naval Exchange (NEX) Service Station and the
Dolphin Mart Service Station
Air Sparge / Soil Vapor Extraction**

Remedial Action Operation (RAO) Optimization Case Study

Contract No. N47408-99-C-7017

Prepared for:

Department of the Navy
Naval Facilities Engineering Service Center (NFESC)
Code ESC413
1100 23rd Avenue
Port Hueneme, CA 93043-4370

Prepared by:

Radian International
1600 Perimeter Park Drive
Morrisville, NC 27560

May 2000

EXECUTIVE SUMMARY

ES.1 Purpose of the Case Study Report

This case study report includes effectiveness evaluations for the Naval Exchange (NEX) Service Station and the Dolphin Mart Service Station (Dolphin Mart) air sparging/soil vapor extraction (AS/SVE) systems located at Naval Submarine Base (NSB) New London, Groton, Connecticut. The primary purposes of the evaluations were to: assess the ongoing remedial action operation (RAO) program for this system; and provide recommendations resulting in attainment of site remedial action objectives and ultimate closure for optimal life-cycle costs. For the purposes of this report, optimal is defined as the minimum cost without sacrificing data quality or decision-making. NSB New London and Northern Division (NORTHDIV) view this independent confirmation of their optimization plan as an important, proactive step toward operating and maintaining a cost-effective and protective remedy.

This project was conducted for the Naval Facilities Engineering Service Center (NFESC) under a Broad Agency Announcement (BAA) contract. NFESC is leading a Department of the Navy (DON) working group in developing guidance on optimizing monitoring and remedial action operations for Navy/Marine Corps activities. This working group is comprised of members from NFESC, NORTHDIV, other Engineering Field Divisions/Activities (EFD/A), Naval Facilities Engineering Command (NAVFAC), and Chief of Naval Operations (CNO).

ES.2 Optimization Approach

The approach employed in this RAO optimization project to achieve site closure for optimal life-cycle cost is outlined below:

- Gain a detailed understanding of the remedial decision-making framework, remedial action objectives, and site closure criteria for each site.
- Describe and understand past investigation and remedial actions taken to date, and how they have affected the evolution and understanding of the conceptual site model.
- Describe the current conceptual site model, i.e., geology, pathways, receptors, and contaminants of concern (COC).
- Describe the system design basis and operational objectives for the AS/SVE system, including the sparge and extraction well network.
- Baseline the past and current cost and operational data for the system.
- Compare the cost and performance data with the system design basis.

- Assess the need for additional system operation.
- Provide the future decision strategy framework and prioritized recommendations to improve total system performance and achieve site remedial action objectives for optimal cost.

A site visit at NSB New London was conducted from November 9 - 10, 1999 to gather the required information for this report.

ES.3 NEX Remedial Action Overview

The NEX AS/SVE system was evaluated over an operating period of approximately 3 years (July 1996 to August 1999). The system was designed to inject air (air sparging) into the groundwater at the NEX and extract (SVE) the volatilized contaminants in the vapor phase from the vadose zone. This AS/SVE system was designed with the dual purpose of removal of contaminants through volatilization from the light non-aqueous phase liquids (LNAPL), subsurface soils, and groundwater, and to promote aerobic biodegradation by providing oxygen to the subsurface. Air is injected into the groundwater through a network of vertical sparging wells, and air and contaminant vapors are extracted through a network of vertical wells. Contaminated vapor and entrained water are then treated and discharged to the atmosphere and to the Thames River via the storm drain system, respectively.

The site is regulated by the Connecticut Department of Environmental Protection (CTDEP). CTDEP, when notified on 11 October 1989 of the release of fuel to groundwater, directed that site investigation and remediation be conducted to mitigate environmental impact. Activities implemented in response to the directive are conducted under a voluntary program in which the regulatory agency performs no direct oversight of the responsible party. Groundwater at the NEX has been classified as GB by the CTDEP.

ES.4 NEX System Performance Summary

The overall performance of the AS/SVE well network and treatment system is summarized below:

- Through AS/SVE operation, contaminant concentrations in groundwater have been reduced to below remediation standards.
- Typically, the percentage of vapor extraction and air sparging wells operating at any time has been approximately 50% and 30%, respectively.
- While in operation, the air sparge system has operated at an average flow rate of 53 scfm, approximately 35% of its design flow rate of 150 scfm. The soil vapor extraction system has operated at an average flow rate of 299 scfm, approximately 36% of its design flow rate of 840 scfm.

- Total mass removal has been 3,769 pounds of VOCs in 3 years of operation at a cost of \$1.5 million. Approximately half of this mass removal occurred during a suspected new release in October 1998.
- The average cost per pound of contaminant removed is approximately \$255.

ES.5 NEX System Recommendations

The primary recommendations of the case study are summarized as follows:

- *Discontinue operation of the AS/SVE system at the NEX site.* The AS/SVE system should be shut down because: (1) groundwater monitoring results from August 1999 indicate that remediation standards applicable to the NEX site have been attained, and (2) the AS/SVE system has reached very low and asymptotic removal rates.
- *Continue groundwater monitoring.* Initiate post-remediation groundwater monitoring until results show a consistent trend of attaining remediation standards. August 1999 was the first quarter where all concentrations were detected below the remediation standards. Groundwater monitoring may be discontinued once eight consecutive quarters of monitoring show all contaminants below remediation standards.
- *Implement groundwater monitoring recommendations.* Several recommendations are provided in Section 4.3 to eliminate redundant sampling points, discontinue the analysis of unnecessary parameters, and improve the current understanding of contaminant extent and trends.
- *Implement limited AS/SVE or Biosparging as needed for rebound.* If monitoring results begin to show an increase in groundwater concentrations (rebound) above remediation standards, perform limited biosparging or limited, pulsed AS/SVE to reduce concentrations to below remediation standards.
- *Pursue closure for groundwater.* When monitoring results show that groundwater concentrations remain below remediation standards for eight consecutive quarters, pursue negotiations with the regulatory agencies to achieve closure for the site.
- *Soil Closure.* Determine if soil remediation standards applicable to the site have been met and, if not, discuss with the regulatory agency how the presence of residual soil contamination may influence site closeout.

Additional hot spot removal, extraction and monitoring well, and AS/SVE optimization recommendations are provided in Section 4.0. Data analysis, trend evaluation, and reporting recommendations are provided in Section 7.0.

ES.6 Dolphin Mart Remedial Action Overview

Air sparging and soil vapor extraction at the site began 29 June 1996. The Dolphin Mart system has the same objectives and basic design elements as the NEX AS/SVE system. Contaminated vapor and entrained water are treated and discharged to the atmosphere and to the sanitary sewer system, respectively.

ES.7 Dolphin Mart System Performance Summary

The remediation system began operating on 29 June 1996. In approximately 3 years of operation, the AS/SVE system extracted 2,200 pounds of contamination. By 1998, the mass removal rate had reached asymptotic levels and groundwater concentrations were near remediation levels. Appropriately, the air sparging component was shut down on 30 January 1999, and the vapor extraction component was shut down on 21 May 1999 (IT Corporation, August 1999). Consequently, performance of the remediation system was not evaluated. The groundwater monitoring program has been continued, because the Dolphin Mart site has not yet met the regulatory remediation standards. The evaluation of the Dolphin Mart site was limited to the monitoring well network and the groundwater monitoring program.

ES.8 Dolphin Mart System Recommendations

Primary recommendations for the Dolphin Mart should incorporate the following elements:

- *Evaluate monitored natural attenuation (MNA).* Evaluate the site's potential to support natural attenuation to justify having shut down the system prior to attaining remediation standards.
- *Implement groundwater monitoring recommendations.* Modify the monitoring well network as recommended in Section 6.3 and continue groundwater monitoring until conditions allow site closure.
- *Implement limited Biosparging.* Consider performing limited biosparging to reduce concentrations in persistent, localized areas of contamination.
- *Pursue Soil Closure.* Determine if soil remediation standards applicable to the site have been met and, if not, discuss with the regulatory agency how the presence of residual soil contamination may influence a transition to a passive remedy such as MNA.

FINAL

**Eastern Groundwater Plume
Naval Air Station Brunswick**

Remedial Action Operation (RAO) Optimization Case Study

Contract No. N47408-99-C-7017

Prepared for:

Department of the Navy
Naval Facilities Engineering Service Center (NFESC)
Code ESC413
1100 23rd Avenue
Port Hueneme, CA 93043-4370

Prepared by:

Radian International
1600 Perimeter Park Drive
Morrisville, NC 27560

January 2000

EXECUTIVE SUMMARY

ES.1 Purpose of the Case Study Report

This case study report includes an effectiveness evaluation for the Eastern Groundwater Plume (Eastern Plume) pump and treat (P&T) system located at Naval Air Station (NAS) Brunswick, Maine. The primary purpose of the evaluation is to assess the ongoing remedial action operation (RAO) program for this system; and provide recommendations resulting in attainment of site remedial action objectives and ultimate closure for optimal life-cycle costs. For the purposes of this report, optimal is defined as the minimum cost without sacrificing data quality or decision-making. NAS Brunswick and Northern Division (NORTHDIV) view this independent confirmation of their optimization plan as an important, proactive step toward operating and maintaining a cost-effective and protective remedy.

This project was conducted for the Naval Facilities Engineering Service Center (NFESC) under a Broad Agency Announcement (BAA) contract. NFESC is leading a Department of the Navy (DON) working group in developing guidance on optimizing monitoring and remedial action operations for Navy/Marine Corps activities. This working group is comprised of members from NFESC, NORTHDIV, other Engineering Field Divisions/Activities (EFD/A), Naval Facilities Engineering Command (NAVFAC), and Chief of Naval Operations (CNO).

ES.2 Optimization Approach

The approach employed in this RAO optimization project to achieve site closure for optimal life-cycle cost is outlined below:

- Gain a detailed understanding of the remedial decision-making framework, remedial action objectives, and site closure criteria for each site.
- Describe and understand past investigation and remedial actions taken to date, and how they have affected the current evolution and understanding of the conceptual site model.
- Describe the current conceptual site model, i.e., geology, pathways, receptors, and contaminants of concern (COC).
- Gain an understanding of other remedial actions and associated data at NAS Brunswick having potential applicability at the Eastern Plume.
- Describe the system design basis and operational objectives for the P&T system, including extraction trench and well network.
- Baseline the past and current cost and operational data.
- Compare the cost and performance data with the system design basis.

- Assess the need for additional system operation.
- Provide the future decision strategy framework and prioritized recommendations to improve total system performance and achieve site remedial action objectives for optimal cost.

A site visit at NAS Brunswick was conducted from July 20 - 21, 1999 to gather the required information for this report.

ES.3 Eastern Plume Remedial Action Overview

The Eastern Plume pump and treat (P&T) system was evaluated over an operating period of approximately 3 years (July 1996 to May 1999). The treatment system is comprised of a network of extraction wells (EWs) with treatment using ultraviolet oxidation (UV-Ox). The system was designed to accommodate influent flow rates up to 110 gallons per minute (gpm). The extraction system consists of 5 EWs. These extraction wells contain pumps rated at over 20 gpm.

Remedial action objectives for the system are covered under the United States Environmental Protection Agency (US EPA) Comprehensive Environmental Response, Compensation and Liability Act (CERCLA) program. A Record of Decision (ROD) for this site was signed in February 1998. The remedial action proposed included operation of a P&T system and long term monitoring. Groundwater cleanup levels are those listed in the State of Maine Maximum Exposure Guidelines (MEGs). Current total volatile organic compound (VOC) contaminant levels in the influent average 500 parts per billion (ppb).

ES.4 Eastern Plume System Performance Summary

The performance of the Eastern Plume system from July 1996 to May 1999 has been fair, with increased performance following the addition of a new extraction well in July 1998. The overall performance is summarized below:

- Influent treatment plant flow rates are adequate, averaging 70 percent of design capacity.
- Total mass removal has been 536 pounds of VOCs in 3 years of operation at a cost of \$3.4 million.
- The average mass removal rate of the system has been approximately 15 pounds per month.
- The average cost per pound of contaminant removed is approximately \$7,800.

ES.5 Eastern Plume System Recommendations

The primary recommendation of this case study is to implement four primary, strategic recommendations. These four parallel activities are as follows:

- As groundwater monitoring results indicate that the downgradient edge of the Eastern Plume has not changed position since 1995, focus future investigations on confirming that the plume is stable or receding, and begin a formal evaluation of Monitored Natural Attenuation (MNA).
- Pursue negotiations with the regulators to establish risk-based cleanup levels for the entire Eastern Plume, and Alternate Concentration Limits (ACLs) for any groundwater discharging to Mere Brook.
- Continue and enhance contaminant mass removal in the Eastern Plume.
- Modify the aboveground treatment system to allow effluent discharge to surface water or to an infiltration gallery after confirming the most effective and efficient option based on a detailed technical review and life cycle cost analysis.

These four parallel activities will enable NAS Brunswick to prepare to work with regulators during any current and future performance evaluations. In addition, this discussion should be used to reach an agreement on how to implement required changes to the ROD, i.e., via explanation of significant difference (ESD), or a ROD amendment.

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FINAL

**Remedial Action Operation Optimization Case Study
JP-5 Line Area
Marine Corps Air Station New River, North Carolina**

Contract No. N47408-99-C-7035

Prepared for:

Environmental Management Department
Installation Restoration Division
Building 58
Camp Lejeune, North Carolina 28542-5000

Prepared by:

Radian International
1600 Perimeter Park Drive
Morrisville, NC 27560

May 2000

EXECUTIVE SUMMARY

ES.1 Purpose of the Case Study Report

This case study report includes an effectiveness evaluation for the JP-5 Line Area recovery system located at Marine Corps Air Station (MCAS) New River, which is co-located with Marine Corps Base (MCB) Camp Lejeune, North Carolina. The primary purpose of the evaluation is to assess the ongoing remedial action operation (RAO) program for this system and provide recommendations that will result in attainment of site remedial action objectives and closure at minimal life cycle costs. In addition, site conditions that would allow enhancement of free product recovery and monitored natural attenuation (MNA) actions were assessed.

ES.2 Optimization Approach

The goal of this case study report is to provide a decision framework and associated recommendations to achieve site remedial action objectives and closure, while optimizing life cycle costs. For the purposes of this report, optimal costs are defined as the minimum expenditures for remediation that do not sacrifice data quality or the ability to reach sound decisions. The approach employed in this RAO optimization project to achieve this goal is outlined by the steps below:

- Gain a detailed understanding of the remedial decision-making framework, remedial action objectives, and site closure criteria for the site.
- Describe and understand past investigation and remedial actions taken to date, and how they have affected the evolution and understanding of the conceptual site model.
- Describe the current conceptual site model, i.e., geology, pathways, receptors, and contaminants of concern (COC).
- Gain an understanding of other remedial actions and associated data at MCB Camp Lejeune having potential applicability at the JP-5 Line Area.
- Describe the system design basis and operational objectives for the recovery system, including the recovery well network.
- Compare the past and current cost and operational data for the system with the system design basis.
- Assess the need to continue operating the system.
- Evaluate site conditions for ways to enhance free product recovery and demonstrate that natural attenuation is occurring.
- Provide the future decision strategy framework and prioritized recommendations to improve total system performance and achieve site remedial action objectives for optimal cost.

A site visit at MCB Camp Lejeune was conducted from October 27 - 28, 1999 to gather the required information for this report. Field work at MCB Camp Lejeune was conducted from 29 November to 2 December 1999 to collect soil and groundwater samples.

ES.3 JP-5 Line Area Recovery System Description

The recovery system at the JP-5 Line Area has been in operation since February 1994. The system was designed to recover free product and to remediate contaminated groundwater. The treatment system includes oil-water separation, followed by air stripping, granular activated carbon (GAC) treatment, and discharge into the Base WWTP (see Figure 3-3). An interim recovery system operated at the site from October 1986 until discontinuation and removal in November 1987.

The current recovery system consists of two recovery wells located within the contaminant plume. The recovery wells are designed to prevent migration of the contaminant plume, recover free product, and extract contaminated groundwater. Each recovery well is equipped with one recovery pump.

Remedial action objectives for this system are based on the State of North Carolina corrective action rule (15A North Carolina Administrative Code, Subchapter 2L, Section .0106). The JP-5 Line Area was classified as a Class B discharge based on previous site assessment activities. A corrective action plan (CAP) for the site was submitted in 1991. The proposed corrective actions included free product recovery, operation of an extraction and treatment system, and long-term monitoring. Groundwater cleanup standards are those listed in the State of North Carolina groundwater standards.

A risk-based approach for assessment and cleanup of discharges and releases from petroleum underground storage tanks was adopted on 2 January 1998. According to the new rule, Class AB discharges for which a comprehensive site assessment (CSA) was submitted prior to the effective date must continue to comply with previously issued notices. The new rule may be applied, however, if it will result in a more cost-effective cleanup of the discharge or release.

ES.4 JP-5 Line Area Recovery System Performance Summary

The technical performance and cost effectiveness of the JP-5 Line Area recovery system have diminished for the period from February 1998 to November 1999. The overall performance for the system is summarized as follows:

- Diminishing free product removal rates. Approximately 238 gallons of free product were removed from June 1998 to November 1999, in comparison to a cumulative 4,764 gallons removed since October 1986, of which 4,043 gallons were removed by the interim system during 1 year of operation ending November 1987.
- Very low rate of dissolved contaminant removal from water. Approximately 1.1 pounds of dissolved contaminant was removed from June 1998 to November 1999.

- Little evidence that the groundwater extraction system is significantly contributing to the restoration of the aquifer. Concentrations of most contaminants in the extracted groundwater have been below North Carolina groundwater standards.
- Accelerated removal of product by aggressive fluid vapor recovery (AFVR) when product is present. In September 1999, 78% of the total monthly product recovered was removed in approximately two hours with AFVR.
- Greater cost effectiveness in the use of AFVR as a remedial alternative to the recovery system. The average cost of product removed by AFVR is approximately \$210/gallon, which is 45% of the average cost of product removed for the current system (\$470/gallon).

ES.5 JP-5 Line Area Conclusions

The presence of measurable free product in RW-1 requires continued action to recover free product from the JP-5 Line Area. An investigation performed as part of this optimization study indicates that free product occurs in discrete pockets, rather than as a continuous lens. The free product is limited to the east side of White Street, with no recoverable free product present on the west side.

The presence of free product in discrete pockets results in intermittent recovery and reduces the effectiveness of the continuous recovery system. The asymptotic conditions illustrated by the product recovery plots justify the implementation of an alternative remedial approach. The use of AFVR at the JP-5 Line Area has proved to be an efficient and effective method to enhance product recovery when product is present.

Soil sampling conducted during the site assessment phase of this study indicated that residual fuel exists in the soil. The residual fuel, however, is no longer contributing to groundwater contamination.

The evaluation of natural attenuation conditions indicates that natural attenuation is occurring at the site.

ES.6 JP-5 Line Area Recommendations

Based on the conclusions, additional source control should be considered and the current recovery system at the JP-5 Line Area, including product recovery and groundwater extraction and treatment, should be discontinued. To recover remaining free product, AFVR should be implemented as the remedial action. Natural attenuation processes will continue to reduce any remaining contamination in the groundwater. Once recoverable free product is removed, reclassification of the JP-5 Line Area as a low-risk site should be pursued under the risk-based corrective action rule. As a low risk site, no further action will be required at the JP-5 Line area.

SSR-2563-ENV

FINAL

**NAVAL WEAPONS STATION EARLE
SITE 16F BIOSLURPING UNITS #1 AND #2
REMEDIAL ACTION OPERATION
OPTIMIZATION CASE STUDY**

Prepared for

**NAVAL FACILITIES ENGINEERING SERVICE CENTER
1100 23rd AVENUE
PORT HUENEME, CA 93043**

Prepared by

**BATTELLE
505 KING AVENUE
COLUMBUS, OHIO 43215**



July 11, 2000

Executive Summary

Naval Weapons Station (NWS) Earle is located in the town of Colts Neck, in east-central New Jersey. The objective of this project is to provide recommendations for optimizing the operation of the bioslurper system (Units #1 and #2) and site closeout at Site 16F. These recommendations are based on review of the design and operation documents for the site and on an observation of the system and site conditions made during a site visit. The scope of this project includes an overview of the design and installation of the current system; and recommendations for exit strategies, system optimization, effluent treatment, and monitoring. An analysis of the costs of implementing the recommended changes is included also. Recommendations are specific to the bioslurper system at NWS Earle, but the general recommendations may be extended to bioslurper systems at other sites.

Site 16F, located in the north-central portion of NWS Earle, consists of several areas that contain fuel-related contaminants. These areas include a light, nonaqueous-phase liquid (LNAPL) plume southeast of Building C-16, an LNAPL plume northwest of Building C-50, and a former gas station near Building C-17. The LNAPL plume adjacent to Building C-16 is suspected to have been caused by a leaking underground diesel fuel transfer line which led from an underground storage tank (UST) at the northwest corner of Building C-18 to a fuel dispenser located between the railroad tracks north of Building C-50. The leak was detected in 1997, and the use of the transfer line was discontinued. As of 1997, this transfer line was still in place. Air samples from bioslurper Unit #1 indicate that some residual gasoline contamination also may be associated with this plume, perhaps due to releases from the former gas station. The plume at Building C-50 is reported to be the result of minor spills at the former diesel dispensing station.

The document review and the site visit revealed several factors that reduce the effectiveness of the bioslurper systems at Site 16F. These factors include:

- Cost of the aqueous effluent treatment system
- Restricted hours of operation
- Inadequate extraction well network

Several recommendations to optimize the bioslurper system have been made based on the evaluation of site-specific data and experience with the bioslurping technology at other sites. Battelle has made several recommendations to optimize the systems at Site 16F. The first recommendation is the installation of additional wells to gain a better understanding of the extent of the LNAPL plume. The plume is poorly delineated, and the bioslurper status reports reviewed by Battelle indicate that the current extraction network does not adequately cover the LNAPL plume. In addition, these wells should be used to improve the recovery of LNAPL. Other recommendations include adjusting the placement of the drop tube, replacing the oil/water separator, monitoring and possibly discontinuing off-gas treatment, reprogramming the alarm system, addition anti-scaling compound to the heat exchangers, and collecting aqueous effluent treatability data.

Upon implementing these recommendations, the system should be operated continuously. System performance and operating costs may then be evaluated further. Additional system modifications and/or operational procedures may be implemented based on revised cost and performance data. A flow chart for bioslurper system optimization and site closure at Site 16F is included with the recommendations in Section 4.0 of this report.

Appendix C
Navy Internal Case Studies

NSB Kings Bay, GA**Summary Report****Remedial Action
Operation Optimization**

Site 11, Old Camden County Landfill Remedial Action Operation

Summary

During the early 1990s, a plume of chlorinated aliphatic compounds (CAC) was discovered in groundwater moving toward a residential area located near Site 11, Old Camden County Landfill, Naval Submarine Base (NSB) Kings Bay. The major contaminants of the groundwater plume included tetrachloroethene (PCE), and its breakdown products, trichloroethene (TCE), and cis-1,2-dichloroethene (DCE). To prevent further offsite contamination from reaching the residential area, a pump and treat (P&T) system was designed and installed to hydraulically contain the plume at the perimeter of the landfill and adjacent to the residential area.

During the early stages of the Resource Conservation and Recovery Act (RCRA) Facility Investigation, the P&T system was expected to be the final remedy for the site. Further investigation of the landfill identified a source of contamination near the edge of the landfill. In addition, the natural attenuation capacity of the aquifer was determined to be very effective at this site. Instead of relying solely on the P&T approach, in-situ chemical oxidation was implemented to reduce contaminant concentrations at the source areas and monitored natural attenuation (MNA) was to be implemented to address residual concentrations.

After two in-situ chemical oxidation treatments, contaminant concentrations were observed at levels below cleanup objectives. A third treatment is expected to address additional sources of contamination. As a result of the success of the in-situ chemical oxidation treatments, the P&T system was shut down, and MNA was implemented. Based on predictions from a numerical model, MNA at the site is expected to meet maximum contaminant levels (MCL) within 5 years.

The modification of remedial action operations (RAO) reduced long-term P&T for hydraulic containment from a period that was expected to exceed many decades to less than two months after the chemical oxidation treatments. Additionally, this modification resulted in savings in excess of several million dollars over the life of the remedy.

NAS Pensacola, FL**Summary Report****Remedial Action
Operation Optimization**

Optimization of Remedial Action Operation to Treat Chlorinated Hydrocarbons in Groundwater

Summary

The Navy, in conjunction with regulators, optimized remedial action operations (RAO) at a former sludge drying bed and surge pond site at Naval Air Station (NAS) Pensacola, Florida. The RAO optimization implemented over the past several years has resulted in improvements in the monitoring program, a modification in remedial strategy, accelerated site cleanup, and significant cost savings.

The monitoring program improvements reduced the sampling frequency and the number of constituents being analyzed. Additionally, the number of monitoring wells was reduced from 19 to 15, and the contract type was changed from a cost plus to a fixed price contract. These actions have saved the Navy over \$200,000 in annual monitoring costs.

Modifications to the remedial strategy have progressed from optimizing the existing pump and treat (P&T) remedy, including reducing the number of recovery wells from seven to three, to redirecting the project to a passive final remedy, monitored natural attenuation (MNA). The remedy was redirected by assessing the natural attenuation capacity of the aquifer and implementing an aggressive source reduction technology, in-situ chemical oxidation, to reduce the relatively high concentrations of trichloroethene (TCE) and other chlorinated volatile organic compounds (CVOC).

The in-situ chemical oxidation treatment substantially reduced contaminant concentrations in the source area and ensured natural attenuation processes would remediate remaining downgradient contamination in a reasonable timeframe and protect the closest receptor, Pensacola Bay. As a result, the regulatory agency has allowed the P&T system to be permanently discontinued, and the corrective action plan (CAP) and Resource Conservation and Recovery Act (RCRA) permit are being modified to specify MNA as the final remedy. Engineering this more cost-effective remedy has saved the Navy approximately \$2,000,000 in remedial action costs.