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DEPARTMENT OF THE NAVY GUIDANCE FOR PLANNING AND OPTIMIZING MONITORING STRATEGIES

Prepared for
Naval Facilities Engineering Service Center

Prepared by
Battelle
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Columbus, Ohio 43201

November 2010

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Department of the Navy Guidance for Planning and Optimizing Monitoring Strategies

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14. ABSTRACT

This guidance document provides Navy RPMs comprehensive information for optimizing monitoring programs at remediation sites. Part I of the document, discusses key concepts such as conceptual site model, data quality objectives, monitoring program goals, and regulatory framework. This part also discusses approaches to optimize monitoring locations, monitoring frequency, list of analytes, data analysis, and reporting. Part II contains specific information on optimizing monitoring strategies for various media and site types including groundwater, sediments, groundwater discharge to surface water, ecological resources, vadose zone, landfills, and land use controls. This guidance document has been updated to include the main elements in designing and optimizing monitoring programs for Vapor Intrusion sites.

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Abbreviations and Acronyms

ACL	alternate concentration limits
AFB	Air Force Base
AFCEE	Air Force Center for Environmental Excellence
ANOVA	analysis of variance
ARARs	applicable or relevant and appropriate requirements
ASTM	American Society for Testing and Materials
BCM	Base Closure Manager
BEC	BRAC Environmental Coordinator
bgs	below ground surface
BOD	biological oxygen demand
BRAC	Base Realignment and Closure
BRI	Benthic Response Index
CAD	Computer Aided Design
CECOS	Civil Engineer Corps Officers School
CERCLA	Comprehensive Environmental Response, Compensation, and Liability Act
CERP	Comprehensive Everglades Restoration Plan
COC	contaminant of concern
COD	chemical oxygen demand
COPEC	contaminant of potential ecological concern
CRWQCB	California Regional Water Quality Control Board
CSM	conceptual site model
DEM	Digital Elevation Maps
DERP	Defense Environmental Restoration Program
DHS	United States Department of Homeland Security
DI	deionized
DNAPL	dense non-aqueous phase liquid
DoD	United States Department of Defense
DOE	United States Department of Energy
DON	United States Department of the Navy
DQA	Data Quality Assessment
DQO	Data Quality Objective
DTSC	California Department of Toxic Substances Control
EC	engineering control
EMAP	Environmental Monitoring and Assessment Program
ER	Environmental Restoration
ESTCP	Environmental Security Technology Certification Program
ET	evapotranspiration
EVS	Environmental Visualization System
FID	flame ionization detector
FSP	Field Sampling Plan
GIS	geographic information system
GPS	Global Positioning System

GTS	Geostatistical Temporal/Spatial
GWPS	groundwater protection standard
HVAC	heating, ventilating and cooling
IC	institutional control
ICAP	induction coupled argon plasma spectrometry
IDW	Investigation-Derived Waste
IR CDQM	Navy Installation Restoration Chemical Data Quality Manual
IRP	Installation Restoration Program
ISRAP	Interactive Sediment Remedy Assessment Portal
ITRC	Interstate Technology and Regulatory Cooperation
LDPE	low-density polyethylene
LTM	long-term monitoring
LTMP	long-term monitoring plan
LTMgt	long-term management
LNAPL	light non-aqueous phase liquid
LUC	land use control
LUCTERM	LUC Termination Request
LUCWAIVE	LUC Waiver Request
MAROS	Monitoring and Remediation Optimization System
MCB	Marine Corps Base
MCL	Maximum Contaminant Level
MDL	method detection limit
MIP	membrane interface probe
MNA	monitored natural attenuation
MNR	monitored natural recovery
MOA	Memorandum of Agreement
MTBE	methyl tertiary butyl ether
NAPL	non-aqueous phase liquid
NAS	Naval Air Station
NAS	Natural Attenuation Software
NAWC	Naval Air Warfare Center
NAVFAC	Naval Facilities Engineering Command
NEDD	Naval Electronic Data Deliverable
NEMI	National Environmental Methods Index
NERP	DON Environmental Restoration Program
NFESC	Naval Facilities Engineering Service Center
NIRIS	Navy Installation Restoration and Information System
NJDEP	New Jersey Department of Environmental Protection
NOAA	National Oceanic and Atmosphere Administration
NPL	National Priority List
NRC	National Research Council
NS&T	NOAA Status and Trends Program
NWIRP	Naval Weapons Industrial Reserve Plant
O&M	operation and maintenance
OD	outer diameter

OSI	organism sediment index
OU	Operable Unit
PAH	polycyclic aromatic hydrocarbon
PA/SI	Preliminary Assessment/Site Inspection
PCB	polychlorinated biphenyl
PCE	tetrachloroethene
PDB	passive diffusion bags
PID	photoionization detector
POC	point of compliance
ppbv	parts per billion by volume
ppm	parts per million
PQO	project quality objective
PRG	Preliminary Remediation Goal
QAPP	Quality Assurance Project Plan
QA/QC	quality assurance/quality control
RAO	remedial action objective
RA-O	remedial action operation
RAWP	Remedial Action Work Plan
RCDM	regenerated-cellulose dialysis membrane
RD	Remedial Design
RI/FS	Remedial Investigation/Feasibility Study
RCRA	Resource Conservation and Recovery Act
ROD	Record of Decision
RPM	Remedial Project Manager
RWQCB	Regional Water Quality Control Board
SADA	Spatial Analysis and Decision Assistance
SAP	Sampling and Analysis Plan
SCCWRP	Southern California Coastal Water Research Project
SECDEF	Secretary of Defense
SI	Site Inspection
SMD	sub-membrane depressurization
SPI	Sediment Profile Imaging
SPMD	Permeable Membrane Devices
SPME	Solid-Phase Micro-Extraction
SSD	sub-slab depressurization
SSI	statistically significant increase
SSV	sub-slab venting
SVE	soil vapor extraction
SVOC	semivolatile organic compound
TAL	Total Analyte List
TCE	trichloroethene
TCL	Total Compound List
TNRCC	Texas Natural Resources Conservation Commission
TSDF	Treatment, Storage and Disposal Facility
UFP-QAPP	Uniform Federal Policy for Quality Assurance Project Plans

USEPA	United States Environmental Protection Agency
USGS	United States Geological Survey
UST	underground storage tank
UTL	upper tolerance limit
VI	vapor intrusion
VOA	volatile organic analysis
VOC	volatile organic compound
VSP	Visual Sample Plan
XRF	x-ray fluorescence

PART I

GENERAL MONITORING OPTIMIZATION INFORMATION

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Chapter 1.0: Introduction

As the Department of the Navy (DON) Environmental Restoration Program (NERP) has progressed, many sites have advanced through the remedy evaluation, selection, design, and construction phases and are currently undergoing Remedial Action Operation (RA-O) and Long-Term Management (LTMgt). Continued monitoring at these sites has indicated that some remedies are not meeting remedial action objectives (RAOs) as planned and that options are available to modify or "optimize" systems and monitoring programs to ensure RAOs are met and Site Closeout is achieved in a timely and cost-effective manner. As a result, the Department of Defense (DoD) issued specific guidance to ensure continual optimization (Chapter 20 of the *Management Guidance for the Defense Environmental Restoration Program* [DERP], September 2001) and the DON issued a policy to mandate that all remedies be continually optimized (Policy for Optimizing Remedial and Removal Actions Under the Environmental Restoration Program, April 2004). In addition, the DON has issued a series of optimization guidance documents to aid remedial project managers (RPMs) and their contractors in the optimization process and to ensure optimization concepts are applied during planning stages for remedial action and monitoring programs. The DON optimization guides include:

- Naval Facilities Engineering Command (NAVFAC) *Guide to Optimal Groundwater Monitoring* (January 2000)
- NAVFAC *Guide for Optimizing Remedial Action Operation* (April 2001)
- NAVFAC *Guidance for Optimizing Remedy Evaluation, Selection and Design* (April 2004).

The first of these optimization guides was developed in 2000 by the NAVFAC Environmental Restoration Optimization Work Group. It provides information that RPMs and their contractors can readily implement to:

- design new groundwater monitoring programs that will cost-effectively meet monitoring objectives, and
- optimize existing groundwater monitoring programs to reduce monitoring costs while maintaining program effectiveness.

While many of the concepts in the *Guide to Optimal Groundwater Monitoring* (NAVFAC, 2000) can be applied to other types of media, it focuses primarily on groundwater monitoring. The majority of monitoring programs within the NERP will be focused solely or partially on groundwater; however, there are several other environmental media that RPMs will need to consider such as sediments, vadose zone, landfills, surface water, and monitoring of land use controls (LUCs).

The NAVFAC Environmental Restoration Optimization Work Group has developed this guidance document to replace the *Guide to Optimal Groundwater Monitoring* (NAVFAC, 2000) and to provide RPMs and contractors with more comprehensive information on optimization strategies for monitoring programs that is specific to various media and site types, including:

- Groundwater
- Monitoring Groundwater Discharge to Surface Water
- Sediments
- Ecological Resources
- Vadose Zone Monitoring
- Landfills

- Monitoring of Land Use Controls, and
- Vapor Intrusion (VI).

As the focus of the previous guidance documents was limited to optimizing groundwater monitoring programs, it is important to remember that this guidance provides optimization strategies for monitoring programs addressing all the above listed media and site types. Furthermore, the differentiation between monitoring and site characterization should be recognized. Both seek to collect representative samples that can be used to develop and refine the conceptual site model (CSM) for the site. Thus, these activities may share many common features and use similar sampling methods. The two key issues that distinguish monitoring from characterization sampling are 1) the goal of monitoring is to observe or detect changes over time, and 2) monitoring points need not represent all site conditions as long as they can be used to detect/track the trend of interest for decision making purposes.

The information provided is intended to be general enough to apply to a variety of site conditions, but at the same time provide specific guidance for monitoring program design and optimization. The intent of this guidance is to provide RPMs and Navy contractors with strategies, tools, and resources which can be applied to the design and optimization of monitoring programs. This guidance manual is not intended to guide the reader through the general site characterization process or the CSM development process.

1.1 Organization of this Document

This guidance document contains a large volume of information ranging from general monitoring issues to media-specific monitoring details. Therefore, to make it easier for the reader to quickly access the information pertinent to their needs, this guidance is divided into two Parts. Part I presents general planning and optimization considerations that are applicable to all monitoring programs. Part II provides individual chapters that focus on monitoring for specific media types or specific site types, such as sediment and landfills. Thus, if an RPM or contractor is interested in general information about planning and optimizing monitoring programs, only Part I needs to be read. However, if more site- or media-specific information about monitoring is desired, then the RPM or contractor should read both Part I and the appropriate chapter(s) within Part II.

Part I includes:

Chapter 1: Introduction – A brief introduction to the objectives and organization of this guidance.

Chapter 2: Common Concepts – Regardless of the type of media or site, there are basic universal steps and considerations that can be applied when defining or redefining monitoring goals, data objectives and decision criteria. This chapter introduces data and management objectives, conceptual site models, common monitoring factors to help define monitoring goals and strategies to ensure regulators and other stakeholders participate effectively on the monitoring team.

Chapter 3: Selection and Distribution of Monitoring Locations – The first step to designing or optimizing a monitoring program is to identify monitoring points that provide the right amount of coverage in the right locations. Chapter 3 explains the basics of monitoring network design.

Chapter 4: Monitoring Frequency and Duration – This chapter discusses tools such as decision criteria, trend analysis, and statistics for determining appropriate monitoring frequency and duration.

Chapter 5: Contaminant Monitoring – Tailoring the data collection and quality assurance practices to the goals of the monitoring program will ensure that excess amounts of data are not managed and reported. Chapter 5 stresses the importance of collecting the right types of data and defining appropriate quality assurance requirements.

Chapter 6: Data Collection, Management, Evaluation and Reporting – Periodic monitoring reports shouldn't be just a "data dump." They should be clear, concise, and easy to understand. From managing and evaluating monitoring data to reporting and presenting the data, this chapter provides ideas and several statistical tools that can be applied to save time and money while improving the understanding of the site.

Part II includes:

Chapters 7-14: Media-Specific Chapters – Each of these chapters presents monitoring information that is specific to a type of media or site, including monitoring and data objectives, monitoring technologies and methodologies, and specific optimization considerations. The chapters are presented in the following order:

- Chapter 7: Groundwater Monitoring
- Chapter 8: Monitoring Groundwater Discharge to Surface Water
- Chapter 9: Sediment Monitoring
- Chapter 10: Ecological Resources Monitoring
- Chapter 11: Vadose Zone Monitoring
- Chapter 12: Landfill Monitoring
- Chapter 13: Monitoring of Land Use Controls
- Chapter 14: Vapor Intrusion Monitoring

Chapter 15: Resources – There are many resources for designing and optimizing a monitoring program. Chapter 15 provides a partial list of readily available optimization resources. This list includes United States Environmental Protection Agency (USEPA) publications, technical papers, and useful web sites.

Chapter 16: References – This chapter provides a list of the documents cited in this guide.

1.2 Key Points of this Guide

This guide focuses on the most significant ways to design and optimize monitoring programs in order to maximize cost-effectiveness without compromising program and data quality. The first key to success is in defining or redefining the monitoring goals/objectives, then identifying the specific data requirements for decision support. Once the data objectives have been established, there are five general components that ensure a cost-effective monitoring program:

- Optimizing the number and placement of monitoring points;
- Minimizing monitoring duration and/or frequency;
- Simplifying analytical protocols;
- Ensuring efficient field procedures and techniques; and
- Streamlining data management, evaluation and reporting.

Ideally, these principles are applied when designing a program and are continually revisited as the monitoring program progresses.

Another key point emphasized within this document is the importance of creating a dynamic monitoring plan including a sampling and analysis plan (SAP), which consists of a field sampling plan (FSP) and quality assurance project plan (QAPP). A dynamic monitoring plan is an important tool in conducting an efficient monitoring program as it contains the decision criteria for optimizing monitoring programs and supporting site closeout. The monitoring plan is dynamic because it should always be reviewed and revised as necessary based on the data collected during monitoring events and evaluated against predetermined decision criteria.

1.3 Key Resources

In part, "lessons learned" from monitoring optimization case studies performed at several Navy installations were used to write the *Guide to Optimal Groundwater Monitoring* (NAVFAC, 2000). These case studies covered a wide range of remediation sites with differing monitoring requirements. Examples from these case studies have been retained in this guidance and are provided throughout to highlight technical points and concepts. Summaries of several optimization case study reports are provided in Appendix A of this document.

Several reports and documents were referred to for additional ideas on optimizing monitoring programs at military installations in the development of this guidance document. Specifically, this guide is a revision of the *Guide to Optimal Groundwater Monitoring* (NAVFAC, 2000), which was originally modeled after the *Air Force Center for Environmental Excellence (AFCEE) Long-term Monitoring Optimization Guide* (AFCEE, 1997). The AFCEE optimization guide was updated in November 2006 (AFCEE, 2006), and the more recent guidance was also consulted during the development of this guidance. The USEPA *Guidance for Monitoring at Hazardous Waste Sites: Framework for Monitoring Plan Development and Implementation*, OSWER Directive No. 9355.4-28 (2002a) was also a strong source of information for this guide. Another very good source for optimization guidance and fact sheets is the Interstate Technology Regulatory Counsel (ITRC) Remedial Process Optimization web site at http://www.itrcweb.org/gd_RPO.asp. Chapter 15 lists other monitoring optimization resources.

Chapter 2.0: Common Concepts

This chapter introduces the key concepts necessary to develop and optimize a monitoring program and presents important considerations that can be used to define the monitoring program objectives. These include:

- CSMs;
- Data quality objectives (DQOs);
- Regulatory framework;
- Monitoring plans; and
- Annual program reviews.

2.1 Optimization of Monitoring Programs

As the NERP matures, more funding is required for monitoring. As costs for monitoring program become a significant portion of the NERP budget, it becomes increasingly important to evaluate these programs in terms of cost-effectiveness.

The primary objective of optimizing monitoring programs is to minimize monitoring costs without compromising program quality or effectiveness. To this end, the optimization process focuses on collecting relevant data of the appropriate quality to achieve NERP goals. The key is to clearly define the monitoring program goals, identify the key decisions to be made during the monitoring program, identify the specific data objectives, update the CSM and specify decision criteria to help make decisions and ultimately closeout the monitoring program. This can be done by evaluating the following components of the monitoring program in light of the overall program goals and regulatory requirements:

- The number and location of monitoring points;
- The frequency and duration of monitoring;
- The analyte list and quality assurance/quality control (QA/QC) samples;
- The sampling procedures;
- The data evaluation, management, and reporting procedures.; and
- The updated CSM.

These aspects cannot be applied or evaluated effectively until specific monitoring goals, data objectives and decision criteria have been identified and agreed upon. The remainder of this chapter is aimed at defining monitoring goals through systematic planning to effectively evaluate the above points.

2.2 Defining and Documenting Monitoring Program Goals

Before designing an effective monitoring program, the goal(s) of the monitoring must be well defined. The goals or objectives of a monitoring program will depend directly on the specific monitoring activity and associated management objectives. The monitoring objectives and design may also vary depending on the physical, chemical, and biological nature of the site (such as a freshwater polychlorinated biphenyl [PCB] compound site, a soil lead site, or a prairie restoration site). Regardless, the monitoring plan objectives must ultimately support a management objective (i.e. decision process) for the site.

The monitoring plan will become the definitive document for operational guidance on a specific monitoring program. This chapter provides information to help guide RPMs in defining and documenting their monitoring program goals and developing monitoring plans, including the following:

- The CSM;
- The regulatory framework;
- Systematic planning (e.g., DQOs); and
- Decision criteria.

2.2.1 Types of Monitoring. Many types of monitoring, such as baseline monitoring (to establish a point of reference) and performance monitoring (to evaluate remedy effectiveness), may be conducted at a site. Depending on the nature of the site and regulatory requirements, one or more types of monitoring may be necessary and each type will have its own specific monitoring objectives. Monitoring objectives can be placed into four general categories:

- Identification of changes in site conditions (sometimes called "baseline" monitoring);
- Demonstration of the effectiveness of a particular activity ("performance" monitoring);
- Provide insurance that the remedial action remains protective to human health and the environment in accordance with the RAOs ("detection" monitoring);and
- Demonstration of compliance with regulatory requirements ("compliance" monitoring), usually associated with Resource Conservation and Recovery Act (RCRA) permit facilities.

A brief introduction to different monitoring types is presented below.

2.2.1.1 Baseline Monitoring. The purpose of baseline monitoring is to establish a point of reference for site conditions. Specifically, baseline monitoring provides the background information for the environmental constituents of interests (e.g., contaminants of concern). The effectiveness of selected remediation strategies can be determined using the baseline monitoring data as a reference when compared to performance monitoring.

2.2.1.2 Performance Monitoring. The primary purpose of performance monitoring is to provide the quantity and quality of data necessary to make informed decisions regarding remedial system operation, and to verify progress toward overall remediation goals. A properly designed performance monitoring system will provide feedback on the effectiveness of the site remedy and supply the data necessary to assess progress toward remediation goals. An effective performance monitoring network should:

- Track the horizontal and vertical extent of contamination;
- Measure the change in contaminant concentration resulting from treatment (including monitored natural attenuation [MNA]) and estimate the mass of contaminant reduction;
- Compare data to the technology-specific remedial action performance objectives (criteria) developed to discontinue a technology and transition to a new one or discontinue treatment (e.g., compare groundwater concentrations to criteria to trigger when to transition from air stripping to granular activated carbon for cost effectiveness);
- Compare data to all decision criteria and exit points;
- Measure the rate and direction of any contaminant migration to confirm containment; and
- Determine the effects of contaminant source areas on remedy effectiveness.

Performance monitoring results should be incorporated into a CSM as the monitoring program progresses. In this manner, the CSM will provide a current picture of conditions at the site. Because conditions change over time, especially where active treatment is taking place, it is necessary for an ongoing process of examining sample locations, frequencies, and analytical methods to ensure that the right amount and type of data are being collected.

2.2.1.3 Detection Monitoring. The primary purpose of detection monitoring is to provide insurance that the remedial action remains protective to human health and the environment in accordance with the RAOs documented in a Record of Decision (ROD) or other decision document. Detection monitoring may include goals of monitoring any contaminant migration, changes in contaminant concentrations, or any other changes in site conditions (sometimes referred to as ambient monitoring). Within the NERP, detection monitoring is used to ensure the contaminant concentrations at a designated "point of compliance" remain below RAOs. (Note: the term "point of compliance" is used in many different ways. Within the RCRA framework, it has a specific definition (for purposes of RCRA Treatment, Storage and Disposal Facilities (TSDFs) groundwater monitoring, the point of compliance is the vertical point where a TSDF owner and operator must monitor the uppermost aquifer to determine if the leak exceeds the groundwater protection standard. Often, within the NERP, points of compliance are defined as the physical locations where soil, water, or other environmental media (e.g., sediments or plants) are monitored for constituents of concern within a remediation site. The point of compliance is often the point at a site where specific contaminant concentration must not be exceeded in order to remain protective of human health and environment.)

2.2.1.4 Compliance Monitoring. Since the NERP includes sites that fall under the RCRA regulatory framework, it is important for RPMs and contractors to understand RCRA monitoring terminology when communicating with regulators who may be accustomed to working within the RCRA framework and therefore use RCRA monitoring terminology. While terms like "compliance monitoring" and "detection monitoring" may be used loosely within the NERP to define certain monitoring activities, it should be understood that these terms have specific meanings within the RCRA framework.

For RCRA permitted facilities, a groundwater monitoring program is required, which consists of three phases: detection monitoring, compliance monitoring, and corrective action monitoring (if required). Each facility must design, install, and operate a groundwater monitoring program based upon the site's specific geology and hydrology, as well as the type of waste management unit and the characteristics of the waste being managed.

The specific sampling requirements and procedures (including frequency of sampling) are specified in the facility's RCRA permit. Typically these requirements are included in a SAP. All data collected as part of a facility's groundwater monitoring program must be maintained in the facility's operating record.

RCRA Detection Monitoring. Detection monitoring is the first phase of the RCRA groundwater monitoring program. Under this phase, facilities monitor for detection and characterization of the releases of hazardous constituents into the uppermost aquifer. Samples are taken from the monitoring wells and analyzed for specific indicator parameters and any other waste constituents or reaction products indicating that a release might have occurred. Samples taken from the point of compliance are compared to the background samples taken from the upgradient well(s). These samples are analyzed to determine if a statistically significant increase (SSI) in the levels of any of the monitored constituents has occurred. If an SSI is detected, the facility must switch to a compliance monitoring program, unless the owner/operators can demonstrate that the SSI was due to a sampling, analysis, or statistical analysis error (or is due to natural variations in the groundwater chemistry).

RCRA Compliance Monitoring. The purpose of a RCRA compliance monitoring program is to ascertain whether the constituents released to the uppermost aquifer are exceeding acceptable concentration levels and threatening human health and the environment. The first step in this process is establishing a groundwater protection standard (GWPS). A facility must submit a permit modification application to switch from detection monitoring to compliance monitoring when an SSI is detected. As part of this modified permit, the EPA Regional Administrator specifies the GWPS for the facility. The GWPS establishes:

- The list of hazardous constituents for which to monitor (from Part 261, Appendix VIII).
- The concentration limits for each of the listed constituents based either on background levels, Clean Water Act Maximum Contaminant Levels (MCLs), or alternate concentration levels (ACLs) determined by the EPA Regional Administrator.
- The point of compliance, which is the vertical surface at which the facility must monitor the uppermost aquifer to determine if the GWPS is being exceeded.
- The compliance period during which the GWPS applies and compliance monitoring must be continued.

If the level of any of the constituents exceeds the GWPS, the owner/operator must notify the EPA Regional Administrator in writing within 7 days. The owner/operator also must submit a permit modification application to establish a corrective action program. Compliance monitoring must be continued during this period.

RCRA Corrective Action Monitoring. Once an exceedance of the GWPS has been detected, the facility must take action to bring the constituent concentration levels back into compliance with the GWPS. To achieve this, the owner/operator must either remove the hazardous constituents or treat them in place. The EPA Regional Administrator will approve the facility’s selected corrective action method and specify the timeframe in which it must take place. Any hazardous constituents that have migrated beyond the point of compliance also must be remediated. The facility must continue corrective action until the GWPS has not been exceeded for three consecutive years, at which point, the facility may return to compliance monitoring.

2.2.2 Conceptual Site Model. The first step in identifying goals and defining the data objectives is to understand the site conditions. A CSM is useful in the initial and on-going description of all parameters relevant to contamination at a site. Figure 2-1 shows one example of a CSM. In essence, the CSM provides a picture − both historical and current − of the environmental conditions that must be addressed. The CSM consists of chemical, physical and biological data that are organized into text, graphics, tables, or some other useful representation (or “model”) able to support site decisions. Key CSM elements typically include the following:

- Nature and extent of contamination
- Geology
- Hydrogeology
- Biological and geochemical conditions
- Fate and transport properties of contaminants
- Potential transport pathways of contamination
- Potential monitoring points
- Potential receptors
- Potential exposure scenarios and pathways
- Potential areas of unacceptable risk to be addressed
- Potential target treatment zones
- Historical and future site uses.

Different decisions may require focus on different aspects of the CSM. For example, decisions about groundwater contamination migration or cleanup need a CSM that emphasizes hydrogeology and contaminant concentrations and fate information; whereas decisions about contaminant exposure require a CSM that focuses on identifying all potential receptors and exposure pathways. A geologic cross section is an effective method to show man-made and natural features that affect contaminant transport and receptor exposure. A complex site may have several depictions of the CSM, each of which addresses a different medium or subset of the decisions to be made or represents one of multiple hypotheses that need to be clarified by getting more data. A detailed description of CSMs can be found in the American Society for Testing and Materials (ASTM) *Standard Guide for Developing Conceptual Site Models for Contaminated Sites* (ASTM, 1995).

Development of a CSM begins with information about land use, records of chemical use, other historical data, and expectations about how contaminants may have been released into the environment. Contaminant release mechanisms determine how variable contaminant concentrations are likely to be across the site. When new data are collected, they are used to revise the CSM to help determine whether contamination is present and where, whether the contamination can pose current or future risks to potential receptors, and if so, how that risk can be mitigated. The CSM, monitoring data, and monitoring plan are tightly coupled in a feedback loop: the CSM feeds the monitoring plan, which guides the collection of data, but the CSM is also updated as those new results are integrated into it. The monitoring plan is revised based on the updated CSM, which then guides the collection of more data, which is further used to update and refine the CSM. It is important for the project team, including stakeholders and regulators, to understand that the monitoring plan should be "dynamic" to reflect the continuous development of the CSM and understanding of the site characteristics.

The *Uniform Federal Policy for Quality Assurance Project Plans* (IDQTF, 2005) provides policy and guidelines to Federal departments, agencies, and programs for developing QAPPs for the management of environmental data collection and use. The QAPP is a key element of the SAP for a monitoring program. The UFP-QAPP directs an annual review of the QAPP. This review of the QAPP, as well as the review of the other monitoring plan elements, should be built into the monitoring program to help the continuous development of the CSM and optimization of the program.

Decisions, such as adjustments in sampling frequency or whether to terminate monitoring, should be determined with the input of stakeholders and the approval of regulators. If too little information is available or if the wrong information is collected for making informed program decisions, then the monitoring plan must be adjusted. Using a dynamic monitoring plan approach, the monitoring requirements can be updated whenever the revised CSM suggests that a change is warranted for the next monitoring event. The revision/updating cycle of the monitoring requirements should be a group decision made by team members, including regulators, and should be a logical process based on predetermined decision criteria.

2.2.3 Regulatory Framework. Whether already imposed or otherwise anticipated, it is the host of Federal, State, and local regulations that effectively drive all response actions (including monitoring) at environmental restoration sites. These regulations have the common theme of providing protection to human health and the environment. Nevertheless, distinctions in which regulatory program, or framework, that a site falls under will help in determining the overall goal of the monitoring program. For instance, regulatory requirements for groundwater monitoring design at a site may vary based on whether it is regulated under the RCRA, Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA), or a state underground storage tank (UST) program. Accordingly, the regulatory endpoints for specific contaminant concentrations required for achieving closure requirements may also differ based on the regulatory framework.

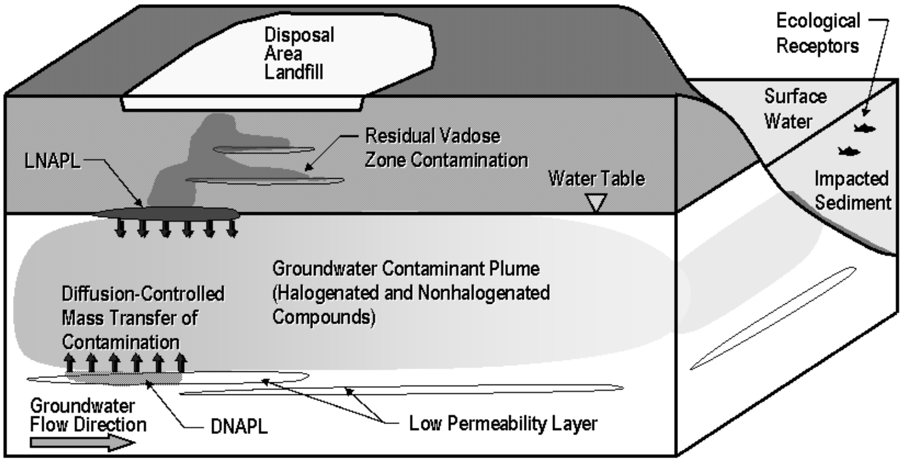


Figure 2-1. Example Conceptual Site Model.
(Source: *Guidance for Optimizing Remedy Evaluation, Selection, and Design*, NAVFAC, 2004)

A standardized list of regulatory requirements is not available because they depend on site-specific conditions. For this reason, identification of applicable or relevant and appropriate requirements (ARARs) must be done on a site-specific basis. Applicable requirements are those cleanup standards, standards of control, and other substantive environmental protection requirements, criteria, or limitations promulgated under federal or state law that specifically address a site-specific situation. An applicable federal requirement is an ARAR. An applicable state requirement is an ARAR only if it is more stringent than federal ARARs. Relevant and appropriate requirements are those cleanup standards, standards of control, and other substantive environmental protection requirements, criteria, or limitations promulgated under federal or state law that, while not applicable, address problems or situations similar to other site-specific circumstances. In some cases, the regulatory endpoint, or preliminary remediation goals (PRGs) may be identified through the site-specific ARARs, and in the absence of such ARARs, cleanup goals may be negotiated with regulators based on studies such as localized background concentrations or the findings of a baseline risk assessment for that site.

In many cases, state-specific ARARs can be identified by researching information available on the state environmental agency’s web site. Many states post their regulations in a searchable format. Virtually all states have an Internet site that, at the very least, provides contact information for key personnel at the state environmental agency. Chapter 15 provides internet addresses for the environmental agencies of all 50 states. If state-specific regulations for a given site cannot be identified, then a set of goals that satisfy all regulatory requirements should be established through negotiations with regulators.

2.2.4 Systematic Planning. Monitoring programs require a comprehensive and systematic planning approach including QA/QC measures in order to obtain data of appropriate quality for the intended purpose. Systematic planning is simply using a methodical, or ordered, approach to planning. Systematic planning ensures that all participants understand the needs and expectations of the monitoring program and the product or results to be obtained. It also results in a project’s logical development, efficient use of resources, clarity of goals and objectives, defensibility of project results, and appropriate documentation. Elements of systematic planning for monitoring projects might include:

- Identification and involvement of the project manager, project personnel, stakeholders, scientific experts, etc.;
- Description of the project goals, objectives, questions and issues to be addressed;
- Identification of project schedule, resources (including budget), milestones, and any applicable requirements (e.g., regulatory requirements, contractual requirements);
- Identification of the type of data needed and how the data will be used to support the project's objectives;
- Determination of the quantity of data needed and specification of performance criteria for measuring quality;
- Description of how, when, and where the data will be obtained and identification of any constraints on data collection;
- Specification of needed QA and QC activities to assess the quality performance criteria (e.g., QC samples for both the field and laboratory, audits, technical assessments, performance evaluations, etc.); and
- Description of how the acquired data will be analyzed (either in the field or the laboratory), evaluated (i.e., QA review, validation, verification), and assessed against its intended use and the quality performance criteria.

The USEPA's DQO Process and the UFP-QAPP Manual are good examples of systemic planning processes, and are discussed in more detail in the following chapters. In addition, the USEPA's Triad Approach for site characterization utilizes systematic planning as one of its three primary components.

The information that follows in this chapter illustrates how utilization of the DQO process and the UFP-QAPP Manual ultimately lead to monitoring plans that have well-defined goals and objectives, are accepted by the entire project team, and contain decision criteria to allow for adjustments in the plan. The combination of these elements, the data quality assessment process and the continuously updated CSM, in effect, make a "dynamic" monitoring plan. Through this process, the monitoring program is continuously optimized until it is determined that monitoring can be discontinued.

2.2.4.1 Monitoring Data Objectives. Clearly defined monitoring goals and corresponding decision criteria are central to a well-defined and well-managed monitoring program. These are also critical to the dynamic nature of a monitoring plan. All data should be collected with an understanding of how the data will be used and how they contribute to a decision regarding the continued response action or monitoring at a site. In short, monitoring should focus on well-defined objectives, not merely on collecting data. The DQO process can help define data objectives and decision criteria based on the data collected.

Data Quality Objectives. The DQO process integrates the work of a multidisciplinary team for planning action-oriented environmental data collection activities. It encourages thoughtful consideration of the following: what decisions need to be made; what data type, quality, and quantity are needed to support the decisions; what portion of the environment (and/or what timeframe) shall be represented by data; how data will be used to support the decision; and what level of decision certainty (and, therefore, data quality) is desired.

The DQO process is iterative and the final outcome is a design for collecting data (e.g., the number of samples to collect, and when, where, and how to collect samples), together with limits on the probabilities of making decision errors. The full DQO process is described in USEPA's *Guidance of Systematic Planning Using the Data Quality Objectives Process* (2006) and includes the following steps:

1. State the Problem
2. Identify the Goal of the Study
3. Identify Information Inputs
4. Define the Boundaries of the Study
5. Develop the Analytic Approach
6. Specify Performance or Acceptance Criteria
7. Develop the Plan for Obtaining Data.

The result of the DQO process is the development of the SAP for the monitoring program.

2.2.4.2 Sampling and Analysis Plan. The SAP is a planning document that combines an FSP and a QAPP into one document. The SAP documents the details of all field activities and laboratory analyses before monitoring is initiated. In addition to ensuring consistency in the sampling and analytical methods, it provides a mechanism for review and approval by regulatory agencies and stakeholders. The SAP describes the objectives and locations of sampling activities, field methods and procedures for sample collection, procedures for analyzing collected samples, and data management and reporting procedures. NAVFAC has introduced a SAP template to streamline the SAP development and review process.

Field Sampling Plan. The purpose of the FSP is to detail a “plan of action” for the field sampling effort to ensure that proper sampling techniques are employed to obtain samples that retain their scientific integrity and are legally defensible. A properly prepared FSP that is correctly implemented will allow the sampling objectives to be met, help avoid confusion in the field, preserve health and safety, and ultimately save time and money. Chapter 3 of the *Uniform Federal Policy for Quality Assurance Project Plans* (IDQTF, 2005) provides guidance for developing a FSP. Topics that should be addressed in an FSP include:

- Sampling Process Design (Experimental Design);
- Sampling Methods;
- Equipment Required;
- Sampling Locations;
- Sample Handling and Custody;
- Sample Containers and Preservation;
- Decontamination Procedures;
- Disposal of Residual Materials;
- Analytes of Concern and Analytical Methods;
- Quality Control;
- Instrument/Equipment Testing, Inspection, and Maintenance;
- Instrument/Equipment Calibration and Frequency;
- Inspection/Acceptance of Supplies and Consumables;
- Non-direct Measurements; and
- Data Management.

Quality Assurance Project Plans. A QAPP is a formal document that comprehensively details the necessary QA/QC, and other technical activities that must be implemented to ensure that the results of the monitoring program will satisfy the stated objectives. The QAPP presents the steps that should be taken to ensure that monitoring data are of the correct type and quality required for a specific decision. It also presents an organized and systematic description of the ways in which QA and QC should be applied to the collection and use of monitoring data.

The NAVFAC SAP template and UFP-QAPP Manual should be used to document monitoring program information and requirements. As all the details discussed in the UFP-QAPP are relevant to the NAVFAC SAP template, both forms of guidance provide instructions for preparing QAPPs for environmental data collection using a standardized, systematic planning approach. Specifically, the UFP-QAPP Manual:

- Incorporates the DQO process and is consistent with USEPA requirements for preparing QAPPs (EPA QA/R5 and EPA QA/G-5).
- Provides standardized instructions and worksheets for preparing QAPPs and FSPs for environmental data collection.
- Has been endorsed by Deputy Under Secretary of Defense for immediate implementation as documented in the memorandum signed on April 11, 2006.

The level of detail and format required for individual QAPPs will depend on the complexity of the project. However, each QAPP incorporates the following elements:

- **Project Management and Objectives:** The QAPP shall include information that outlines the project history and objectives (including DQOs), and roles and responsibilities of participants.
- **Measurement/Data Acquisition:** The QAPP shall detail how monitoring data will be collected, measured, and documented. In addition, the QAPP shall identify the QC activities that will be performed during each monitoring event.
- **Assessment/Oversight:** The QAPP shall define actions to be taken to ensure that planned monitoring activities are implemented properly, and the protocols are employed to identify and document conformity and nonconformity (e.g., management reports, laboratory and field audits).
- **Data Review:** Data Review is the process by which data are examined and evaluated. The QAPP shall detail the project data review requirements. The level of review will vary, and will depend on project needs. In addition, reviews are conducted by a variety of personnel who have different responsibilities within the data management process. The data review process includes:
  - **Verification:** Confirmation that the specified requirements (sampling and analytical) have been completed (i.e., a completeness review).
  - **Validation:** Evaluation of compliance with method, procedure, or contract requirements. The purpose of validation is to assess the performance of the sampling and analysis processes to determine the data quality.
  - **Usability Assessment:** Assessing whether the process execution and resulting data meet project objectives (including the identification of limitations on data usability).

In March 2005, the Under Secretary of Defense formally adopted policy for using UFP-QAPPs at federal facility hazardous waste sites. The Secretary of Defense (SECDEF) Instruction Environmental Quality Systems (Feb. 2006) implements policy for establishing environmental quality systems for DoD activities and programs involving the collection, management, and use of environmental data. This instruction assigns responsibilities and prescribes procedures regarding the implementation of the UFP-QAPP. This was followed by a memorandum from the Deputy Under Secretary of Defense (April 2006) to DoD components requesting immediate implementation of the UFP-QAPP. Related documents, instructions, and training references on the UFP-QAPP, DQOs, and the systematic planning process can be found at the following Web sites:

http://www.clu-in.org/char1_edu.cfm, http://www.navylabs.navy.mil/training.htm
http://www.hanford.gov/dqo/training/cover.html,
http://www.qe3c.com/dqo/training/cover.html

Information and resources regarding specific content to be included in QAPPs is available at the USEPA's *Quality System* Web site (http://www.epa.gov/quality/qapps.html.)

Training specific to quality assurance as it applies to environmental restoration is available through the Civil Engineer Corps Officers School (CECOS), https://www.cecos.navy.mil.

Triad Approach. When performing a site inspection (SI) or remedial investigation/feasibility study (RI/FS), it is recommended that the Triad Approach be considered for site characterization and remediation. The Triad Approach is a proven and technically defensible methodology that leverages less expensive field screening/characterization tools and mobile laboratories/analytical equipment in conjunction with an appropriate amount of data from fixed laboratories, in order to manage overall decision uncertainty. The use of field screening methods can extend sampling coverage and reduce "sampling error" while data from monitoring wells and fixed laboratories reduce analytical error.

Triad refers to three primary components: (1) systematic planning, (2) dynamic work strategies, and (3) real-time measurement systems. Systematic planning includes the identification of decision endpoints needed to support site goals. Implementation of the Triad Approach allows project managers to obtain real-time data to support rapid decision-making. The collection of real-time data also is a necessary element to allow sampling to be continued without a delay and remobilization. The term "real-time" often includes rapid turnaround time (i.e., minutes to hours) that can only be obtained by having analytical instrumentation available in the field, or nearby.

The Triad Approach can be applied to any media, including soil, groundwater, surface water, and sediment, and is endorsed by the USEPA. Its use has the greatest impact on subsurface soil, sediment, and groundwater sampling as these media have high sampling cost and a high degree of variability. Although the Triad Approach is most effective during the characterization phases, it is important that Navy RPMs consider how some of the elements, including systematic planning, dynamic work plans and field screening technologies might be applicable to monitoring programs for increased efficiency.

Further information regarding Triad can be found at the following Web sites: www.triadcentral.org; and http://fate.clu-in.org/sysplan.asp.

2.2.4.3 Decision Criteria. Decision criteria are important tools for making decisions in the monitoring program. Decision criteria set predetermined requirements for deciding when an action will take place. Ultimately, decision criteria will provide the mechanism for ending the monitoring program at a site.

Monitoring decision criteria take the form of generalized decision rules that define the conditions that would cause the decision maker to choose an action. In other words, it establishes the exact criteria for making a choice between taking and not taking an action. In a monitoring program, the decision criteria should establish the basis for continuing, stopping, or modifying the monitoring program and/or declaring Response Complete or Site Closeout. An example decision criterion for elimination of wells from a monitoring program might be "Monitoring at locations with contaminants of concern (COCs) that remain below the MCL for four consecutive sampling rounds will be discontinued."

As the monitoring program is being designed and specific data needs are identified, the decision criteria are revisited and refined so they specifically relate to the monitoring objectives. Depending on the nature of the site activity and the monitoring goals and objectives, a number of monitoring decision criteria may be required to address monitoring point minimization, monitoring frequency and duration minimization, and minimization of the analyte list. The monitoring team should strive to ensure that the refined decision criteria are as clear and concise as possible, since they will serve as the primary basis for program decisions.

Figure 2-2 demonstrates an example of how decision criteria can be used to develop a decision diagram that ultimately becomes an “exit” strategy for remediation and monitoring programs. In this case, performance monitoring plays a key role in the decision of whether to discontinue the remediation system or to keep operating and monitoring. This decision is made based on the comparison of monitoring data to the performance objectives established at the beginning of the program. This is a good example of the continuous cycle of data collection, evaluation and decision making that is the dynamic monitoring plan and optimization process. As stated earlier, it is the inclusion of these decision criteria into the monitoring plan that allow it to be dynamic and continually optimized.

2.2.5 Data Quality Assessment. The Data Quality Assessment (DQA) process completes the three-step data quality life cycle of planning, data collection, and assessment. While the DQO process is used during the planning stage to define criteria for determining the data to collect and a level of decision confidence, the DQA process is used post data collection to evaluate whether the planning objectives were achieved by systematically determining if the data support their intended use. The DQA process may be integrated into the decision criteria and dynamic monitoring plans during systematic planning, and may be applied during data evaluation, reporting, and periodic reviews.

Like the DQO process, the DQA process is iterative. DQA begins with a review of the planning documents and ends with an understanding of how well the data answer the study questions. The full DQA process to evaluate environmental data is described in USEPA’s *Guidance for Data Quality Assessment* (2000) and includes the following five steps:

- **Review the DQOs and Sampling Design**: Make sure the sampling design is consistent with the DQOs. Specify DQOs before evaluating the data if DQOs have not been developed.
- **Conduct a Preliminary Data Review**: Review QA/QC reports, calculate preliminary statistics, generate data graphs.
- **Select the Statistical Test**: Base the statistical methods for data analysis on the DQOs and the sampling design. Identify the underlying assumptions for the selected statistical methods.
- **Verify the Assumptions of the Statistical Test**: Evaluate how well the underlying statistical assumptions hold using the collected data.
- **Draw Conclusions from the Data**: Apply the statistical tests and draw conclusions from the results.

The USEPA’s DQA guidance document demonstrates statistical tools for performing DQA. Statistical methods for data evaluation are also discussed further in Section 6.3.

2.2.6 Monitoring Plan. The monitoring plan is essentially where the results of the systematic planning process are documented. The primary purposes of the monitoring plan are to specify how the monitoring program will be conducted in order to meet the project-specific objectives and to document the decision criteria that will be utilized to continually optimize the monitoring program. It allows for consistent data collection and comparability and documents the monitoring approach in the event of

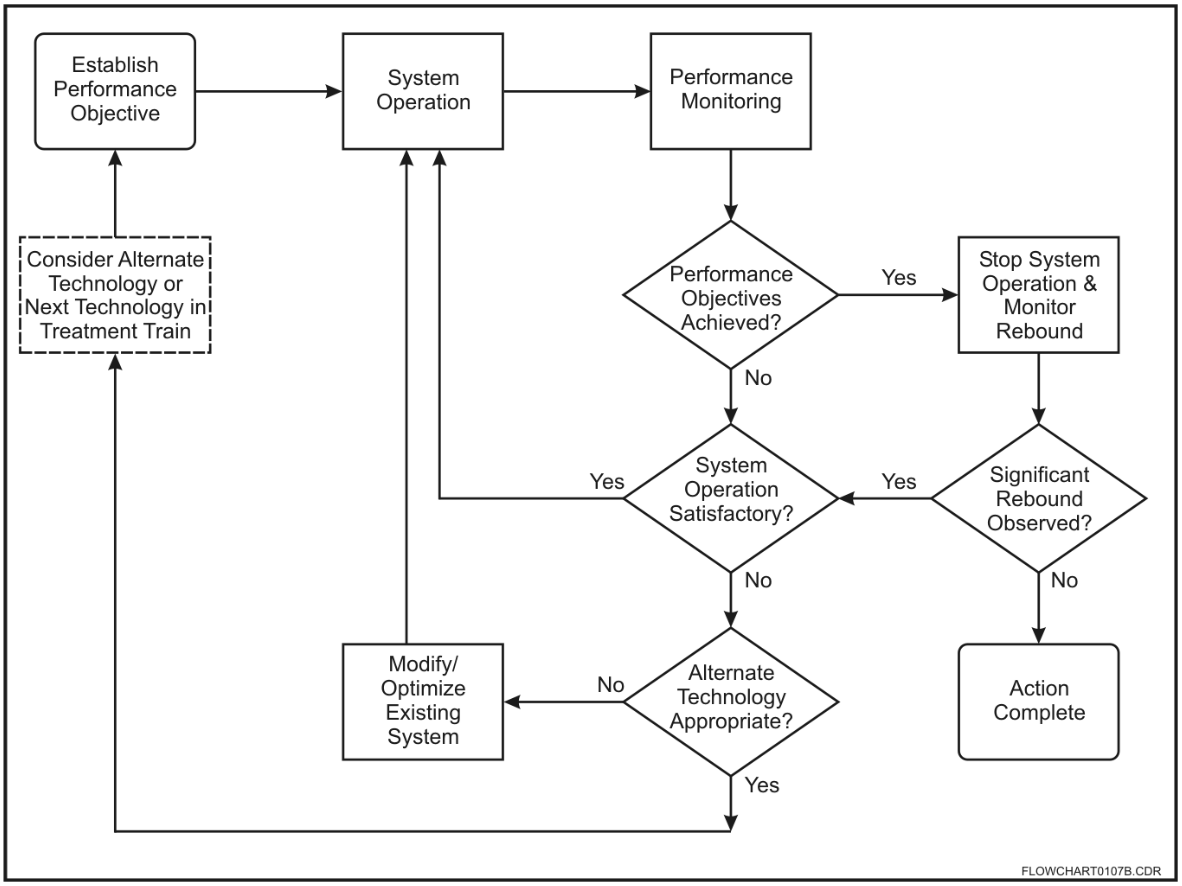


Figure 2-2. Generalized Optimization and Exit Strategy.
(Source: Modified from *Guidance for Optimizing Remedy Evaluation, Selection, and Design*, NAVFAC, 2004)

installation, contractor, or regulatory personnel turnover. The SAP (QAPP and FSP) is the key element in the monitoring plan. The following components should be included in the monitoring plan:

- Brief introduction describing the project and statement of program goals;
- Brief description of site background and history (refer to previous site reports and documents for details as much as possible);
- Site maps indicating relative location of the site and the location of monitoring points;
- Discussion of DQOs;
- Description of the proposed monitoring network;
- Frequency and anticipated duration of monitoring and reporting;
- Decision criteria (including exit strategies) and review process to periodically optimize the plan; and
- Contents of SAP:
    - Specific field procedures (e.g., purging, sampling, decontamination, record keeping, etc.);

  - Analytical methods, sample handling requirements (e.g., containers, preservation), and QA/QC sample collection rates;
  - Data handling and reporting procedures.

The project team should discuss the format and development of the monitoring plan and determine the most effective and efficient way to develop the monitoring plan without creating redundant documentation. Since the SAP will provide much of the information for the monitoring plan, it might make sense to develop the monitoring plan around the format of the existing SAP rather than using elements from the SAP to create a monitoring plan.

The monitoring plan should remain closely tied to the CSM throughout the duration of the monitoring program. As previously discussed, the CSM should be revised regularly as new data are collected and evaluated. In turn, the monitoring plan should be revised based on the CSM and the decision criteria developed and agreed to by the Navy, regulators and stakeholders. This dynamic monitoring plan approach allows for flexibility in achieving program goals in the most efficient and effective manner.

Section 2.3 provides additional information on using a regular review process to optimize the monitoring program and modify the monitoring plan.

2.2.6.1 Including Regulatory Agencies in the Monitoring Plan Design. Achieving and maintaining regulatory agency approval and agreement for a monitoring program is an ongoing process; ideally, it should start with the monitoring program design activities. In fact, the state, local, and federal regulatory agencies should be part of the planning, design, review, and approval of the monitoring plan. This will ensure the entire team is onboard with the monitoring objectives, management decisions, CSM, data objectives, and decision criteria. This also ensures that the entire team is in agreement with the dynamic nature of the monitoring plan.

Although a regulator’s perspective of the content requirements for a monitoring plan may differ from the Navy RPM’s, a monitoring plan that considers only regulatory agency requirements will usually be incomplete and insufficient from the Navy RPM point of view. Typically, regulatory agencies will want to confirm that the monitoring plan adequately addresses the following points:

- Will the goals and objectives in the monitoring plan satisfy the requirements in applicable installation decision documents, e.g., RODs, Statement of Basis, and/or permits?
- Does the monitoring network in the monitoring plan provide adequate coverage for the contaminated plume?
- Are the monitoring plan procedures consistent with local, state, and federal regulations?
- Are the analytical methods and QA/QC procedures consistent with DQOs?

Navy RPMs, however, should also consider other requirements in which the agencies may not be interested. In particular, close attention should be given to performance monitoring requirements for active and passive remedial actions. One specific example is the collection of data to verify the occurrence and rate of MNA at the site. This information is almost always useful to the RPM, but the regulatory agencies may not be as interested.

Once the monitoring plan has been written and approved by the entire team, the process shifts toward maintaining regulatory agency acceptance during the program implementation phase, often lasting many years. The main points to remember in this process are proactive communication, reporting, and periodic program evaluations and review.

2.3 Reevaluating the Monitoring Program Goals

It is important to reevaluate the goals of the monitoring program on a regular basis. Annual and 5-year reviews are opportunities to make changes to the monitoring program and the monitoring plan, if necessary. Although 5-year reviews are required by CERCLA and many RCRA permits, an annual optimization review process is required by Navy policy (Policy for Optimizing Remedial and Removal Actions Under the Environmental Restoration Program, 23 April 2004) for maintaining an optimal monitoring program.

2.3.1 Annual Reviews. Annual reviews should be conducted to determine if the monitoring goals have been achieved, or if the past year of site data result in any changes to the program goals. It may be helpful to conduct annual reviews well in advance of budgeting for the next fiscal year. This way, if any changes in funding are identified during the annual review, they can be incorporated into the budget requests in a timely manner.

Some of the steps that may be needed during the annual review of the monitoring program include:

1 Review all analytical data generated during the last year. Does the new information validate the historical data? Or are there significant changes to contaminant concentrations or plume size and shape (nature and extent)?

2 If applicable, review any available MNA data, such as dissolved oxygen, total organic carbon, etc., to confirm that conditions are still suitable for this process to occur.

3 Review any hydrogeologic data collected during the last year. Are groundwater levels relatively constant? Or are there marked seasonal fluctuations? Are groundwater flow directions and flow rates consistent with the original hydrogeologic model formulated for the site?

4 If there is a remedial action being performed at the site (including MNA), is adequate progress being made toward the cleanup goals? On the basis of all data available, does it look like the cleanup goals will be achieved in a reasonable timeframe? Does the remedial action still appear to be a protective option? Or are there new or different technologies that may be more efficient?

5 If a risk assessment was conducted for the site, verify that the assumptions used are still valid. Have any new pathways and/or receptors been introduced at the site?

6 Have any new regulatory standards or requirements been introduced? If so, how do site data compare to the new standards?

If any of the original assumptions that went into formulating the monitoring plan or the data objectives have changed, the program goals may need to be modified. An updated CSM should be produced to reflect the new site understanding.

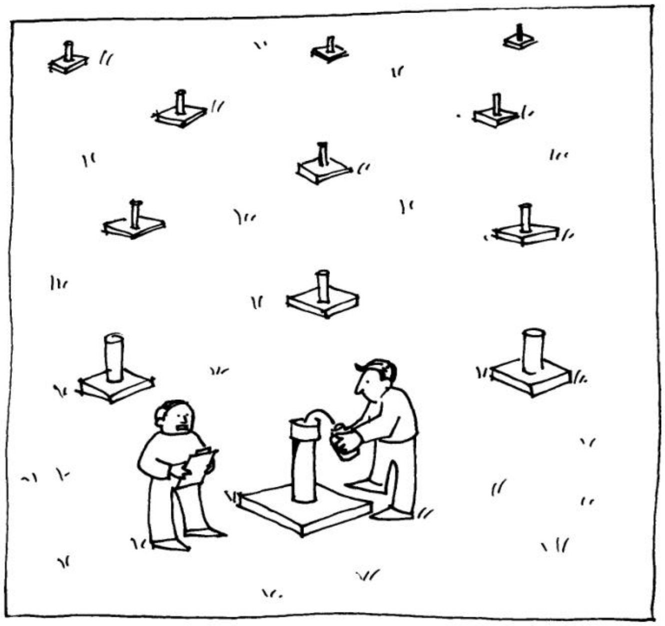
Example: *Marine Corps Base (MCB) Camp Lejeune regularly analyzes groundwater monitoring data, performs trend analysis, and contours the data to make recommendations for program improvements and to ensure that monitoring objectives are being met. The monitoring team (Base personnel, regulators, and contractor personnel) meets every two months to update current understanding of site conditions and make consensus recommendations for changes and improvements.*

Chapter 3.0: Selection and Distribution of Monitoring Locations

This chapter discusses the basic considerations for designing and optimizing a monitoring network that effectively addresses the goals of the program without being excessive. Tools for choosing and optimizing monitoring locations discussed in this chapter include:

- Decision criteria; and
- An introduction to data evaluation techniques.

3.1 Designing a Monitoring Network



Hurry up... it's almost time to start the next sampling round!

(Source: *Guide to Optimal Groundwater Monitoring*, NAVFAC, 2000)

The geographic (spatial) area from which monitoring data are to be collected should be a function of the nature and objectives of both the remedial action and the data objectives. For example, if the remedial action is groundwater remediation and the monitoring objectives are to determine whether the remediation has successfully reduced groundwater COC concentrations to acceptable levels, then the monitoring plan would likely include groundwater sampling from on-site, upgradient, and downgradient locations. In contrast, if the site activity is a habitat mitigation, then sampling activities would likely be restricted to the immediate site boundary (and reference area if available).

If systematic planning is used and specific DQOs are identified, the monitoring program will avoid having too many unnecessary monitoring points (as depicted in the cartoon) or too few monitoring points. The number and placement of monitoring points needed to ensure adequate monitoring of contamination will not only be a function of the objectives of the monitoring program, but also a function of many site-specific characteristics. For example, performance monitoring of in-situ source zone treatment may require more closely spaced monitoring points than long-term natural attenuation monitoring of a large groundwater plume. The placement of monitoring wells may also be impacted by site-specific characteristics, such as locations of primary fractures at sites where contaminated groundwater is present in bedrock. Tools which can be used for optimizing the number and location of monitoring points are discussed in Section 3.2. In addition, there are factors unrelated to site characteristics that may affect the design of the monitoring program, including regulatory and community relations considerations.

A comprehensive review of applicable regulatory requirements should be conducted. In many cases, state regulatory agencies will have mandatory guidelines for the types and placement of compliance monitoring points. Ultimately, the CSM and the data objectives (including DQOs) required to make decisions will be the basis for determining monitoring locations. Each monitoring point should be established with the deliberate intention of providing specific data that will refine the CSM and help the project team make decisions. Decisions will include how to refine the monitoring program, optimize the remedial action, or whether to discontinue monitoring or the remedial action. As monitoring points are established based on specific data objectives, the decision criteria for monitoring each point can then be identified. This is a key factor in the development of the dynamic monitoring plan and future optimization of the program.

Chapter 7 (Groundwater Monitoring) includes a figure depicting an idealized illustration of the types of wells that may be required for monitoring at a given site (Figure 7-1), and a table describing these types of wells in more detail (Table 7-1). Inclusion of additional sampling points at property boundaries or near other sensitive areas of interest may be warranted for community relations purposes.

Example: *The regulatory framework and monitoring objectives were considered when recommending which wells to include in the groundwater monitoring program at Naval Weapons Industrial Reserve Plant (NWIRP) Dallas. The Texas Natural Resources Conservation Commission (TNRCC) provided minimum requirements for the use of background wells, point of compliance (POC) wells, corrective action observation wells, and optional supplemental wells. The concerns of the surrounding community were also addressed by continued sampling of off-base wells. By interpreting the regulatory framework in light of the geohydrological model for the site, 56 wells were chosen from an existing groundwater monitoring network of nearly 300 wells.*

3.2 Optimizing the Monitoring Locations

As discussed in Chapter 2, monitoring programs should be developed using a systematic planning approach to create a dynamic monitoring plan which can be optimized as site conditions change. Simply sampling every monitoring location at a site is not the optimal approach as monitoring data are collected and the CSM evolves. Rather, the objectives of the monitoring program should be reevaluated on an annual basis. If the information provided by a monitoring point does not contribute to the data objectives, monitoring objectives or a program decision, then it may be appropriate to discontinue use of that monitoring point. However, as discussed in Section 3.1, discontinuing the use of monitoring points must be conducted while keeping regulatory and community concerns in mind.

Example: *MCB Camp Lejeune regularly analyzes groundwater monitoring data, performs trend analysis, and contours the data to make recommendations for monitoring point reductions. These types of recommendations are made as part of the regular reporting process.*

3.2.1 Use of Decision Criteria and Data Evaluation Techniques for Monitoring Optimization.

If decision criteria have already been established for eliminating monitoring points at the site, then the annual review should include determining if any of the decision criteria have been met. If decision criteria have not been established, they should be created based on monitoring objectives. Table 3-1 provides examples of decision criteria.

Data collected as part of the monitoring program must be periodically evaluated to determine if any decision criteria have been met and to optimize the number and location of monitoring points necessary to achieve the program goals. Data evaluation can include the use of statistical tools or data visualization through geographic information system (GIS) applications.

Spatial statistical methods, or geostatistics, can be used to evaluate the spatial pattern and correlation of contamination across a region, helping to determine which locations continue to have unacceptably high concentrations. For example, identifying areas with unacceptably high concentrations can help determine where continued active remediation or more frequent monitoring is required. As illustrated in the example below, uncertainty maps (maps of uncertainties associated with kriging predictions) can indicate

Table 3-1. Example Decision Criteria for Optimizing Monitoring Points

Monitoring Program Objective	Example Decision Criteria	Data Evaluation Required
Track contaminant concentrations which are above some regulatory standard or remediation goal	Use of monitoring points that remain below the regulatory standard or remediation goal for the COC for four consecutive sampling rounds will be discontinued.	Depending on requirements, either a direct comparison of site data to the applicable criteria or a statistical evaluation to determine which points are consistently and reliably below the criteria (see Chapter 6).
Evaluate performance of a remedial system	Use of original plume-edge wells will be discontinued when changes in plume size or shape make other wells more appropriate for plume-edge monitoring.	Use of a GIS to track plume shape and size for all COCs (see Chapter 6).
Ensure that contaminants do not affect receptor	Monitoring points upgradient of the receptor will be monitored until it can be shown that contaminants from the site do not exceed 50% of the regulatory standard or remediation goal at any point for four consecutive sampling rounds.	Create Navy Installation Restoration and Information System (NIRIS) queries to generate automatic reports of all contaminants exceeding the applicable criteria, keeping a running tally for four sampling rounds (see Chapter 6).
Ensure that contaminants do not migrate off site	Point of compliance wells will be monitored until it can be shown that contaminant concentrations exceeding the regulatory standard or remediation goal cannot migrate off site.	Conservative groundwater modeling to predict future concentrations at the installation boundary (see Chapter 7).

whether excess data are being collected or if additional sampling points may be useful to help make decisions. Regression analyses can identify data trends by determining if the regression model provides a good fit and by identifying how strongly concentrations correlate with time. For example, use of monitoring points with decreasing data trends and contaminant concentrations which have remained below the approved regulatory criteria or remediation goals for several monitoring periods may be discontinued.

GIS and modeling applications also have many uses in optimizing monitoring programs, particularly for visualizing and comparing monitoring data to decision criteria. The ability to continuously track and/or predict a plume’s size and shape allows for decision-making in regard to which wells to sample or when to discontinue active remediation systems. For instance, consider the following:

- If a plume is determined to be shrinking, monitoring points once within the plume may become downgradient points and monitoring points further downgradient may become obsolete and may be discontinued.
- If changes to plume size and contaminant concentrations become insignificant over time, consideration may be given to discontinuing active remediation and allowing MNA to take place.
- If a plume appears to be growing, additional monitoring points may need to be identified or installed to track the plume edge. In addition, changes may be needed to the remediation system to prevent off-site migration of contaminants.

Groundwater modeling software can be a very effective tool for evaluating changes in plume size and optimizing the monitoring program accordingly. Groundwater monitoring concepts, including modeling, are discussed in Chapter 7. Further discussion of how various statistical tools and GIS can be applied to optimize monitoring programs is provided in Chapter 6 and Appendix B.

Example: *As part of the monitoring program at Naval Air Station (NAS) Brunswick, a geostatistical assessment was performed to evaluate the monitoring network. One of the objectives of the geostatistical assessment was to identify data gaps and surpluses within the groundwater plume. To accomplish this, ordinary kriging was performed using the GEO-EAS program. This technique allows for the identification of areas with high and low predictive confidence. Areas with low predictive confidence may need additional monitoring points, whereas areas with very high predictive confidence may be providing redundant data. As a result of the geostatistical analysis, NAS Brunswick determined that it could eliminate 19 monitoring wells from the network, but that five additional wells must be installed and sampled to fill data gaps.*

Chapter 4.0: Monitoring Frequency and Duration

This chapter discusses planning and optimization concepts used to support decisions regarding monitoring frequency and duration. Tools for optimizing monitoring frequency and duration discussed in this chapter include:

- Decision criteria;
- Trend analysis; and
- Statistical tools (see also Chapter 6).

4.1 Determining Appropriate Monitoring Frequency and Duration

The purpose of monitoring is to track the location, distribution, and type of contaminants present at a site, and to monitor the fate and transport of those contaminants. The optimal monitoring frequency for a particular site or monitoring point can be dependent on many factors. When planning (and optimizing) the frequency and duration of a monitoring program, consider the following:

- **Seasonal variability.** Observation of seasonal variability may indicate that the highest contaminant concentrations are present each year during the wet season, supporting the decision to monitor only once annually during this period. In such a case, annual monitoring may provide adequate data to evaluate long-term trends focusing on the highest concentrations observed each year.
- **Data trends.** A decreasing data trend may support less frequent monitoring, while a monitoring point with an increasing data trend or highly variable data may require more frequent monitoring. Data from more frequency monitoring can be used to gain a better understanding of site conditions which could be causing increasing or unstable contaminant concentrations.
- **Transient site conditions.** Transient conditions are often created during remedial system startup. Typically, more frequent monitoring is conducted during the startup of a remedial system in order to optimize system operation and better understand changing site conditions; less frequent monitoring can then be implemented at a later stage of operation after data trends are better defined.
- **Monitoring point locations.** Site boundary and point of compliance monitoring points may require more frequent sampling than a source area monitoring point in order to ensure protection of potential off-site receptors.

Monitoring data should be used to continually update the CSM and should be evaluated in light of the monitoring program goals and decision criteria. As discussed previously, the use of data evaluation to address decision criteria and updating the CSM are key components in the monitoring program optimization process. Use of pre-determined decision criteria can effectively optimize monitoring frequency, for example, decreasing monitoring from quarterly to semi-annually at locations with steady or decreasing concentration trends.

Monitoring duration is often controlled by regulatory requirements and remedial performance; however, the duration of a monitoring program can also be optimized to some degree by developing an exit strategy within the monitoring plan, which consists of the decision criteria that direct the decision to discontinue monitoring at either a single monitoring point or at an entire monitoring program. Including exit strategy decision criteria in the monitoring plan enables the frequency and duration of monitoring to be optimized throughout the monitoring program.

4.1.1 General Approach. When starting a new monitoring program, it is often a good idea to collect four rounds of quarterly data, particularly if investigation data for the site are limited (e.g., from one round of sampling, or from only one time of year) or obsolete (e.g., more than three years old). Four quarters of analytical and water level data will help establish the presence of any temporal (such as seasonal) and spatial variability. In addition, four data points are often considered the minimum for conducting any sort of statistical evaluation. *It is essential that all monitoring data be collected using the same sampling and analytical methods to ensure comparability. The monitoring plan should be used to document these methods (see Chapter 2).* If a recent, well-designed site investigation has been conducted, starting a monitoring program with semiannual or even annual monitoring may be more appropriate.

Following the first year of quarterly data collection, monitoring frequency may be reduced as appropriate by following decision criteria built into the monitoring plan. Specific decision criteria (exit strategy) should be included for determining when monitoring may be discontinued at the site. A review period, most likely annual, should be specified in the monitoring plan to periodically evaluate the potential for discontinuing the monitoring program based on monitoring data and the exit strategy.

The purpose of a monitoring point should be taken into account when determining the sampling frequency. Downgradient site boundary monitoring points generally require more frequent sampling than upgradient or background monitoring points. Special purpose monitoring points, such as sentinel or points of compliance, may need to be sampled more often to ensure protection of human health.

***Example:** Quarterly monitoring for the first year, along with a built-in annual review with state regulators, was recommended for the NWIRP Dallas monitoring program. Following a year of quarterly sampling, they could then seek a decrease in monitoring frequency, tailoring frequency to the function of the well. Whereas POC and corrective action observation wells were recommended for semiannual sampling, upgradient, background, and supplemental wells could be dropped to annual sampling. If approximately half the monitoring wells at the site were decreased to semiannual sampling, while the other half were decreased to annual sampling, over 60% of analytical costs could be saved in the second year of sampling. Based on analytical costs of $350/sample for 60 samples per round, an annual savings of $52,000 could be realized in analytical costs alone. Field labor costs would decrease from approximately $20,000 to $8000 annually, and mobilization and demobilization costs would be cut in half by eliminating two quarterly sampling rounds.*

4.1.2 Decision Criteria for Reducing Frequency and Duration. After each sampling event, or at least annually, the objectives of the monitoring program should be reevaluated (see Section 2.3). Compare the monitoring data with the decision criteria and determine if the frequency or duration of monitoring at a site or individual monitoring point can be optimized. Table 4-1 presents example decision criteria for reducing monitoring frequency and duration. The following section discusses data evaluation methods for evaluating the monitoring data against the decision criteria.

4.1.3 Trend Analysis and Statistics to Optimize Monitoring Frequency and Duration. The optimal monitoring frequency can often be proposed by identifying data trends at the site and evaluating the data in terms of the decision criteria stated in the monitoring plan. By evaluating trends in several rounds of data for a single monitoring point, decisions can be made regarding that monitoring point. For example:

- If contaminant concentrations appear to be decreasing, use of the monitoring point may be discontinued or monitored less frequently, depending on its location.

Table 4-1. Example Decision Criteria for Reducing Monitoring Frequency and Duration

Monitoring Program Objective	Example Decision Criteria	Data Evaluation Required
Frequency		
Identify contaminant trends	Monitoring points that exceed the regulatory criteria or remediation goals but do not display a significant upward trend will be reduced to semiannual sampling.	Time trends or statistical evaluation of data to determine which points have concentrations with a significant upward trend (see Chapter 6).
Evaluate performance of a remedial system	Once system performance has reached a plateau, site monitoring will be decreased to annually.	System performance data (e.g. pounds removed per unit time) or statistical evaluation of analytical data to determine which points have concentrations with a significant upward trend (see Chapter 6).
Identify seasonal variability	If seasonal trends exist, reduce sampling to annually during the period of highest observed contaminant concentrations.	Time trends or statistical evaluation of data to determine seasonal trends are significant (see Chapter 6).
Duration		
Track contaminant concentrations which are above some regulatory standard	Following three consecutive rounds of all COCs detected at less than the regulatory criteria or remediation goals, monitoring at the site will be stopped.	Manage data in NIRIS and develop queries to generate automatic reports of all contaminants exceeding MCLs, keeping a running tally for three sampling rounds (see Chapter 6).
Ensure that contaminants do not migrate off site	If COC concentrations at POC monitoring points do not exhibit concentrations above the regulatory criteria or remediation goals within 5 years and exhibit stable or decreasing trends, monitoring at the site will be stopped.	Conservative groundwater flow calculations to predict contaminant transport rates and statistical analysis to confirm contaminant trends at the installation boundary (see Chapter 7).

- If contaminant concentrations have leveled off, the monitoring point may be proposed for less frequent monitoring. Monitoring may be decreased from quarterly to semiannually, and then further decreased to annually after collecting and evaluating additional data.
- If contaminant concentrations appear to be increasing, the monitoring point should be kept in the groundwater monitoring program and monitored at the current frequency.

Identifying trends in seasonal variability may also help determine an optimal monitoring frequency. If the highest contaminant concentrations are observed at the same time each year, then annual monitoring during this period may be sufficient to evaluate long-term trends. Figure 4-1 shows an example of a time-series plot that illustrates seasonal variability. In this case study, the concentrations are consistently highest during the third quarter, indicating possible seasonality.

If the trends of concentration over time are not clear, it may be helpful to conduct temporal trend analysis using the statistical methods outlined in Chapter 6 and Appendix B. Temporal trend analysis methods typically include plotting chemical concentrations as a function of time and identifying a trend by using

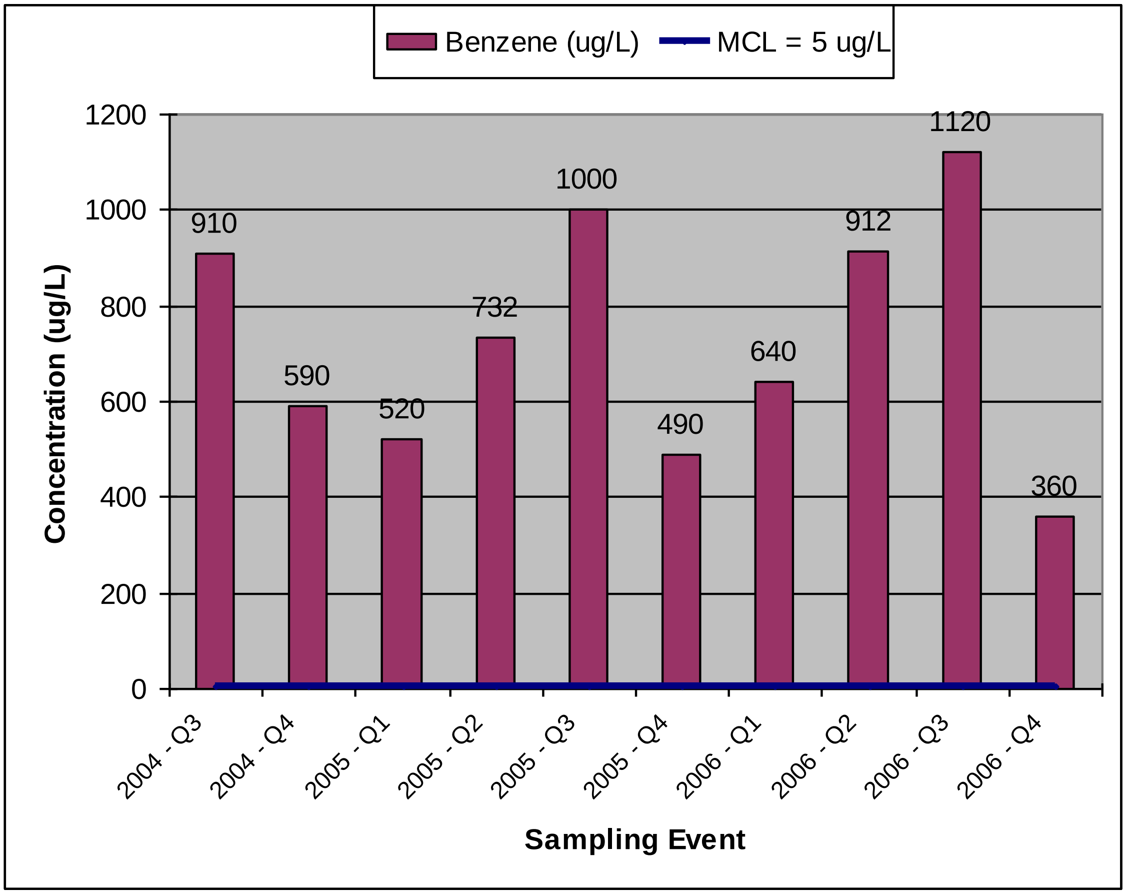


Figure 4-1. Example Time-Series Plot.
(Source: *Guide to Optimal Groundwater Monitoring*, NAVFAC, 2000)

the Mann-Kendall trend test or a regression analysis. Trend analysis methods are discussed in more detail in Scenarios 6 and 7 of Appendix B.

Trend analysis or statistics may also be used to support the exit strategy to stop monitoring at a particular monitoring point or a site if contaminant concentrations are found to be stable over a long period of time. It may be possible to statistically show that there is not a significant difference between upgradient and downgradient concentrations of target analytes at a site. In this case, it may also be appropriate to stop monitoring at the site, depending on the objectives and exit strategy decision criteria of the program. Scenario 8 of Appendix B provides more details about this type of comparison.

Other data evaluation techniques, such as predictive modeling, can also be used to help determine the optimal monitoring frequency. If data trends are stable across a site, or in a particular area of a site, then predictive modeling can be used to predict contaminant transport rates and potentially support the decision to monitor less frequently. See Chapter 7 for a discussion of groundwater modeling.

More specific information regarding the statistical tests discussed in this chapter is presented in Chapter 6 and Appendix B. In addition, *Statistical Analysis of Ground-Water Monitoring Data at RCRA Facilities, Interim Final Guidance* (USEPA, 1989) and *Methods for Evaluating the Attainment of Clean-up*

Standards, Volume 2: Groundwater (USEPA, 1992) are comprehensive references for statistical applications at monitoring sites.

4.2 Considerations for Optimizing Monitoring Duration and Frequency

Decreasing the number of samples through reductions in sampling duration and/or frequency is an important aspect of optimizing an existing monitoring program. Reducing monitoring frequency by 50% will decrease sampling labor, analysis, validation, and reporting costs by a like percentage. The general approach to this type of optimization is essentially the same as presented for designing a new program (see Section 4.1). The important difference is that existing monitoring programs may not have pre-approved decision criteria and exit strategies for optimizing frequency and duration. Chapter 2 of this guidance document offers some tips on gaining regulatory concurrence. The statistical methods described in Chapter 6 and Appendix B will also help support decisions to optimize monitoring frequency and duration.

Example: *Monitoring program data are reviewed annually at MCB Camp Lejeune to determine where reductions in sampling frequency can be made. The entire groundwater monitoring program has been reduced to semiannual or less frequent monitoring. MCB Camp Lejeune also has approved decision criteria in place for removing sites from its monitoring program. Using these decision criteria, approval has been given for halting monitoring at one site and the removal of three more sites is anticipated.*

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Chapter 5.0: Contaminant Monitoring

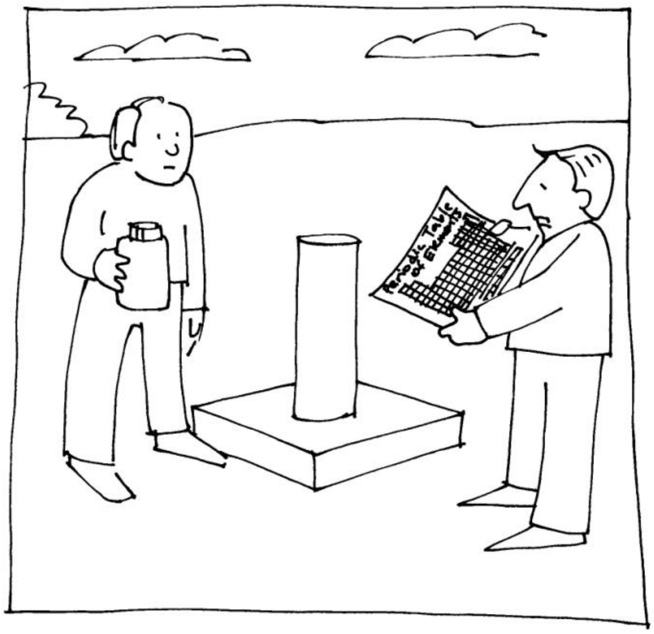
It is important to consider the appropriate contaminant monitoring needs during design of a monitoring plan, and to continually evaluate monitoring data to optimize the analyte list throughout the monitoring program. This chapter focuses on the types of data needed to ensure that the monitoring program objectives are met and the data are of the appropriate quality. Tools which can help optimize the analytical data and QA/QC needs include:

- Historical data;
- Updated CSM;
- Statistical tools (see Chapter 6);
- Decision criteria; and
- Existing Navy and regulatory guidance.

5.1 Analyte Selection

Since analytical costs make up a significant portion of monitoring program expenses, streamlining the analytical approach is a viable way to minimize overall monitoring program costs. Minimizing the number of analytes at a site and ensuring there is no overlap in analytical methods are examples of streamlining the analytical program.

5.1.1 Identifying Analytes for Initial Monitoring. Including only the necessary compounds in the analyte list not only reduces analytical costs, but reduces data management, validation, interpretation, and reporting costs. The analyte list should be driven by the DQOs determined to make program decisions and meet objectives. Even if receiving data for the total analyte list of a given method is no more costly than receiving data for only certain analytes, it is beneficial to eliminate the extra analytes. Including only the analytes of interest will result in clear, concise reports.



OK... here's what we're sampling for...

(Source: *Guide to Optimal Groundwater Monitoring,* NAVFAC, 2000)

As discussed in Chapter 2, the CSM is an important consideration in developing an optimized monitoring plan. The following information is gathered during development of the CSM, and should be reviewed to determine which contaminants to monitor during the initial rounds of the monitoring program:

- Site history (for example: landfill, refueling station, or vehicle maintenance);
- Historical analytical data for all environmental media at the site (e.g., data from the preliminary assessment/site inspection [PA/SI] or RI/FS).
- Historical analytical data from upgradient sites that may impact groundwater quality;

- Regulatory criteria applicable to monitoring at the site.
- Background concentrations of potential target analytes in uncontaminated soil, water, and other pertinent media; and
- Results of previous baseline risk assessments performed at the site (including contaminant fate and transport, potential receptors, and exposure pathways).

Reviewing historical practices at the site will focus sampling efforts on those contaminants needed to demonstrate cleanup progress. For example, the groundwater underlying a refueling station may be contaminated with fuel components but would probably not require analyses for pesticides and PCBs. However, samples underlying a landfill may require analyses for a wide array of compounds.

Historical analytical data are better tools than site history for determining which analytes to monitor initially. Comparing historical data to regulatory criteria or RAOs, or background or upgradient data, will help identify those contaminants that need to be monitored because they approach or exceed some standard. Historical analytical data, if collected regularly over a period of time, may also be used to determine if any of the contaminants have historically exhibited increasing trends, indicating a potential active source at the site. Section 6.3 and Appendix B discuss statistical tools that can be used to differentiate between upgradient and downgradient concentrations (or site and background concentrations), and identify contaminants with increasing trends.

The results of a risk assessment (if conducted) will be valuable in determining which contaminants to monitor. If any of the site contaminants were found to pose a risk to human health and/or the environment, they should be included in the initial monitoring program. Contaminants that were found to pose no risk may have a strong basis for elimination from the program.

5.1.2 Modifying the Analyte List. Monitoring data should be continuously evaluated, and the CSM updated to support monitoring program optimization decisions. Decision criteria for optimizing the list of analytes should be developed and agreed upon during the monitoring plan development. As monitoring progresses, the list of analytes for a site may be optimized to focus only on COCs and associated degradation products. For example, groundwater contaminated with tetrachloroethene, a solvent historically used to degrease and clean metal, may also be analyzed for degradation products (trichloroethene, dichlorethene(s), and vinyl chloride). However, analyses for other volatile organic compounds (VOCs) may no longer be necessary if the CSM indicates that other VOCs are likely not present and have not been observed during previous monitoring events. To identify other parameters that may be eliminated, the data should be reviewed to identify those that have not been detected above the reporting limit (i.e., all results not detected or detected only at concentrations indistinguishable from laboratory blanks) in the first four quarters of sampling.

With regulatory approval, this list may be further optimized by evaluating the detected analytes against regulatory standards. For example, metals may be eliminated from the analyte list based on a comparison to background levels, determined by collecting and analyzing groundwater samples from uncontaminated areas of the installation using methods that achieve representative analytical results for metals in groundwater (i.e., filtered or non-turbid samples). The background data can then be used to determine which contaminants are present at concentrations significantly above expected background concentrations, and therefore require continued monitoring (see Chapter 6 and Appendix B).

Another approach is to use faster-moving contaminants as indicator species. For example, consider the case of a landfill with the potential for almost any type of contaminant. To date, nothing significant has been detected downgradient of the site boundaries, but the state wants groundwater monitoring for a minimum of five years before closing the site. Instead of analyzing for a complete list of potential site contaminants, a monitoring plan could be developed to only monitor for the fastest migrating contaminants, or indicator species, expected to result from site activities. Monitoring of these indicator species can continue until the five-year monitoring period has elapsed. However, if indicator species are detected within the five years, analysis of other potential site contaminants should begin.

Assessing whether there are correlations between site conditions and contaminants can also be useful for optimizing monitoring plans. For example, at a NAS El Centro Landfill, an evaluation of site data demonstrated that the contaminant release mechanism was related to a rise in the water table (i.e., COCs were released only when waste in the landfill came in contact with groundwater). The monitoring program was optimized by reducing the analytical monitoring frequency to once every five years (i.e., at the 5-yr review period) and continuing regular monitoring of groundwater levels only.

Example: *At a RCRA landfill in Ohio, a short list of analytes, including several VOCs and inorganics, are used as indicator species in the monitoring program. If any of the indicator species are detected at a particular well, then a full suite of parameters (VOCs, semivolatile organic compounds (SVOCs), PCBs, pesticides, dioxins, furans, and inorganics) are analyzed at that well. For naturally-occurring parameters, concentrations of indicator species are compared to established background levels to determine if a true detection has occurred which would indicate a potential release and trigger analysis of the full suite of parameters. In monitoring for the full suite of parameters, if certain analytes are not detected after several rounds of monitoring, then the monitoring plan is again modified by sampling for those parameters less frequently.*

5.1.3 Decision Criteria to Evaluate Analytes for the Monitoring Program. After each sampling event, or at least annually, objectives of the monitoring program should be reevaluated (see Section 2.3). The specific decision criteria for reducing the number of analytes being monitored should be tied to the objectives established for the monitoring program.

Table 5-1 presents example decision criteria for optimizing the number of analytes as the monitoring program progresses.

Example: *Following historical sampling that consisted of total compound list (TCL) organics, total analyte list (TAL) metals, and hexavalent chromium at NWIRP Dallas, the monitoring team proposed including only the COCs (VOCs, metals, and hexavalent chromium) in the monitoring program. This proposed analyte list represents a significant cost savings compared with the original analyte list: $351/sample versus $811/sample, or a 57% decrease in the analytical budget.*

In addition to eliminating entire methods (in this case, methods for SVOCs and pesticides/PCBs), it was recommended that the contractor consider the elimination of individual compounds within methods. Although this does not always result in significant analytical cost savings, it does save data management, validation, and reporting costs. A review of the site-wide sampling round data that were collected in 1994, 1995, and 1997 was conducted to determine whether further decreases could be made to the analyte lists for VOCs and metals. VOCs that have not been detected above reporting limits and metals that have never exceeded background values were identified for elimination from the monitoring program. On the basis of this analysis, the following ten VOCs were proposed for elimination from the monitoring program at NWIRP Dallas:

- *1,1,2,2-tetrachloroethane*
- *dibromochloromethane*

Table 5-1. Example Decision Criteria for Reducing Analytes

Monitoring Program Objective	Example Decision Criteria	Data Evaluation Required
Track contaminant concentrations which are above some regulatory standard	Analytes that remain below the regulatory standard for four consecutive sampling rounds will be eliminated from the monitoring program.	Depending on requirements, a one to one comparison or a statistical evaluation to determine which points are consistently and reliably below regulatory standards (see Chapter 6).
Identify continuing sources	Analytes that are below the regulatory standard and display no significant upward trend will be eliminated from the monitoring program.	Statistical evaluation of data to determine which analytes display a significant upward trend, and which analytes have stabilized (see Chapter 6).
Evaluate performance of a remedial system	Any contaminant that displays a decreasing trend and then has two quarters of data below remediation goals will be eliminated from the monitoring program.	Statistical evaluation of data to determine which analytes display a significant downward trend, and have stabilized below remediation goals (see Chapter 6).
Ensure that contaminants do not affect potential receptors	Any contaminants that do not exceed 50% of the regulatory criteria for four consecutive sampling rounds will be eliminated from the monitoring program.	Manage data in NIRIS and create queries to generate automatic reports of all contaminants exceeding regulatory criteria, keeping a running tally for four sampling rounds (see Chapter 6).

- *1,3-dichlorobenzene*
- *m&p xylenes*
- *1,4-dichlorobenzene*
- *styrene*
- *bromoform*
- *trans-1,3-dichloropropene*
- *bromomethane*
- *vinyl acetate.*

On the basis of this analysis, few metals were proposed for elimination from the upcoming monitoring program at NWIRP Dallas. Only sodium, magnesium, and manganese had never exceeded the background upper tolerance limits for the site. However, in more recent sampling rounds, the use of micropurging had decreased the concentrations of metals in groundwater samples. Looking only at data for 1997 samples, which were collected using micropurging techniques, it appeared that calcium, copper, and iron could also be eliminated from the program on the basis that they did not exceed the expected background values for the site.

5.2 QA/QC Procedures for a Monitoring Program

The UFP-QAPP Manual (2005) and *Navy Installation Restoration Chemical Data Quality Manual* (IR CDQM) (Naval Facilities Engineering Service Center [NFESC], 1999) provide information on data quality issues related to the NERP. The following subsections offer a summary of information provided in these manuals and generally accepted approaches for ensuring that QC sample and data validation rates are appropriate.

5.2.1 Field QC Samples. Quality control for field samples is measured by the results of field duplicates, field blanks, equipment blanks, and split samples. Part 2B of the UFP-QAPP (the QA/QC Compendium) establishes the following minimum specifications for the types and frequencies of QC samples to be used in the CERCLA program:

- **Field Blank** (including volatile organic analysis [VOA] Trip Blank): Minimum 1 per shipment cooler per analytical group per concentration level.
- **Equipment Blank** (rinsate blank): Minimum 5% per analytical group per matrix per sampling procedure per sampling team.
- **Field Duplicates** (including co-located samples and subsamples): Minimum 5% per analytical group per matrix per sampling procedure per sampling team.
- **Split Samples**: As specified by method and based on project quality objectives (PQOs).

The UFP-QAPP QA/QC Compendium identifies those QC samples that either provide the most reliable information on overall data quality or identify specific sources of error. Section 2.2 of the UFP-QAPP QA/QC Compendium contains further rationale for QC sample selection.

Note that many QC samples that are standard requirements in analytical methods are not included in the UFP-QAPP QA/QC Compendium. Many (but not all) analytical methods will also specify QC practices. While the minimum QC activities provided in the UFP-QAPP QA/QC Compendium are for all phases in the CERCLA process, these activities may also be appropriate for other environmental programs.

5.2.2 Data Review and Validation. Like QC sample requirements, data review and validation should be geared toward achieving the DQOs and can be changed as the monitoring program progresses. Also, as with QC sample requirements, data validation rates and decision criteria for optimizing them should be documented in the approved monitoring plan.

Appendix H of the IR CDQM (NFESC, 1999) provides Navy requirements and guidance for data review and validation. This document defines data review as a “systematic approach for the review of laboratory data,” and data validation as a “thorough assessment of data and supporting QC documentation without making any assumption to the quality of the data provided.” The UFP-QAPP QA/QC Compendium also provides guidelines for conducting and streamlining the data review process at CERCLA sites. The USEPA’s *Guidance on Environmental Data Verification and Data Validation* (2002c) is also a good resource.

In *data review*, only the sample results and limited project documentation are typically reviewed. The end user of the data is responsible for conducting a 100% review of laboratory data for completeness. This type of review is referred to as a summary or low level review and includes the following elements:

- Completeness;
- Holding times;
- Chain of custody;
- Method and reporting limits;
- Dilution factors/concentration units;
- Preparation/analysis methods;

- Matrix spike results (if provided); and
- Surrogate recoveries (if provided).

Data validation is more thorough and involves an evaluation of reported data, raw data, supporting information, and project documentation to determine if the data are of sufficient quality to satisfy the project DQOs. The elements of data validation may be specified by project or program guidance, or may be taken from the UFP-QAPP and IR CDQM in the absence of such guidance. The data validation rate may be 100% for a project providing input for high-risk decisions, or may be very limited for routine monitoring data. The validation process and frequency, as well as decision criteria for reducing them, must be based on the project DQOs and documented in the monitoring plan.

Chapter 6.0: Data Collection, Management, Evaluation and Reporting

This chapter presents a brief introduction to some of the considerations in selecting and optimizing data collection techniques, and also discusses several specific tools to manage and evaluate data, and methods to streamline reporting. Specifically, the following data evaluation and presentation techniques are discussed:

- NIRIS and GIS;
- Statistical and geostatistical tools; and
- Graphical and tabular formats.

6.1 Data Collection

Due to the inherent variability of environmental restoration sites, sampling techniques should be evaluated and chosen specifically for each site and each sampling purpose. Choosing the most appropriate sampling technique or tool depends largely on the DQOs, site accessibility, and the QA/QC requirements.

But we've always done it this way...

(Source: *Guide to Optimal Groundwater Monitoring,* NAVFAC, 2000)

For a specific data need there may be a variety of approaches to collecting the necessary data; some may be more costly or difficult to implement than others. For example, suppose the surface soil concentration of a particular metal was identified as a data need for the monitoring program. Determining metal concentrations in soil may be quicker and less costly using field portable x-ray fluorescence (XRF) methods than using laboratory-based induction coupled argon plasma spectrometry (ICAP). The most appropriate analytical method for this example would depend on the expected activity outcome and on the monitoring objectives. If the monitoring objective is to determine whether soil remediation has successfully reduced the soil concentration to 100 parts per million (ppm) or less, the higher detection levels of the XRF may be sufficient to gather the data needed to meet the monitoring objectives. However, if the target soil concentration is less than 5 ppm, that level is below the capabilities of field portable XRF, and the more costly and time-consuming ICAP analysis would be needed.

Sampling methods have evolved greatly over the past 20 years. Relatively new sampling methods, such as passive sampling devices for groundwater and sediments, direct push monitoring wells, in situ sensors, and field analytical techniques, may offer lower costs and, in many cases, more representative data than methods that historically have been widely applied. That is why it is very important to define specific data objectives for the program and to ensure that the latest sampling/monitoring techniques are considered as part of the monitoring program.

Each of the media-specific chapters in this guide presents sampling techniques that should be considered by project teams during development and optimization of monitoring programs. There are numerous technology-based web sites available from many sources, including the NAVFAC Environmental Restoration (ER) and Base Realignment and Closure (BRAC) Web site (known as the ERB Website), which should be consulted during the development of a monitoring plan. In addition, each chapter provides links to resources that will help in the selection of sampling tools.

6.2 Data Management using Naval Installation Restoration Information Solution and Geographical Information Systems

In 2005, NAVFAC developed a centralized database to facilitate the management and use of ER data through GIS and web-based applications in a consistent and cost-effective manner over the life of the NERP. NIRIS can be used by DON RPMs, DON contractors, and other team members who are granted access to manage and access NERP data, documents and records. NIRIS ensures that the quality of NERP data, documents and records is maintained and that they are accessible over the lifecycle of the NERP (and beyond) by providing a standardized, web-based solution that all of NAVFAC will use to manage ER data. NIRIS also minimizes duplication of effort, facilitates data sharing, reduces the learning curve for users, facilitates easy access to ER information, and provides standardized data management, collaboration, document management, analysis and visualization tools.

NIRIS is primarily for DON RPMs and contractors to manage NERP data, documents and records at a detailed technical level (e.g., analytical results by location and time). NIRIS stores various types of NERP data including:

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

The Naval Electronic Data Deliverable (NEDD) includes standard formatted tables for all ER data typically collected. ER data are compiled into the NEDD tables and uploaded to NIRIS using the web-based Data Checker and Data Loader system which ensures that data for all sites are consistently loaded to the database. The data uploaded to NIRIS is stored on a central, web-based database to allow authorized users easy access to, and the ability to share ER data.

NIRIS is not only a centralized data repository, it is also a tool for data evaluation and visualization. NIRIS is linked to GIS packages which can help display data spatially and can also be used to construct and track plume or other types of concentration-over-area maps (see Figure 6-1). By linking GIS directly to the NIRIS database, data handling is streamlined and errors associated with redundancy between multiple sources of data storage are reduced. Standard GIS functions include the ability to pan, zoom in, zoom out, and other standard navigation tools. All of these features can be used for an effective presentation because of the ability to provide real-time responses to any data requests the audience may have. Presentations to regulators and the community can be greatly enhanced by using such a system. Regulator agreement may be obtained during a data visualization meeting, rather than awaiting comments on bulky documents.

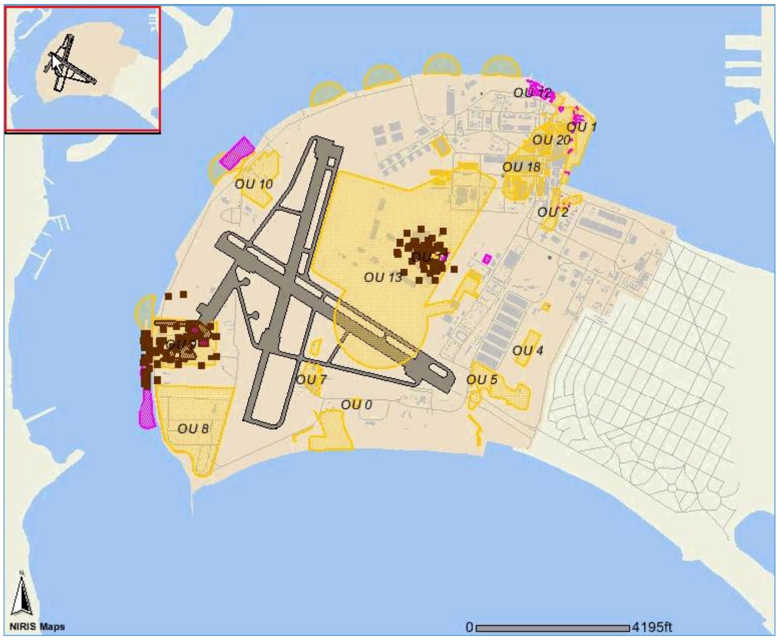


Figure 6-1. Sample GIS Map Generated from NIRIS
(Source: RITS on Long Term Management, NAVFAC ESC, 2007)

NIRIS is also compatible with other web-based data analysis and visualization tools, including:

- Custom Map Viewer for viewing information in NIRIS
- ArcIMS® Web-based GIS
- Results Query Tool
  - Allows the user to enter parameters to narrow the locations, related samples, and results of interest.
- Query Results View
  - Compiles sample and analytical result records based on the query.
  - Allows the user to zoom to selected locations.
- Query Results Export
  - Exports data to various formats including: Google™ Earth, GMS (a comprehensive groundwater modeling software package), Spatial Analysis and Decision Assistance (SADA) (free software that incorporates tools from environmental assessment fields into an effective problem-solving environment) and Microsoft® Office.

In short, NIRIS does not provide new tools, but it makes it much easier to use existing tools to help visualize and evaluate the data.

6.3 Statistical Data Evaluation Methods

This chapter describes statistical tools that can be used to achieve some typical monitoring program objectives, as discussed in previous chapters (e.g., monitoring point location, monitoring frequency). Appendix B discusses statistical methods in more detail, and the following references have useful summary tables and demonstrations of how to set up and use appropriate statistical tools and methods.

- Gilbert, R.O. 1987. *Statistical Methods for Environmental Pollution Monitoring*. Von Nostrand Reinhold, New York, NY.
- USEPA. 2002. *Guidance on Choosing a Sampling Design for Environmental Data Collection*. EPA/240R-02/005. Office of Environmental Information, Washington DC.
- USEPA. 2000. *Guidance for Data Quality Assessment*. EPA/600/R-96/084. Office of Environmental Information, Washington DC.
- USEPA. 1992. *Preparation of Soil Sampling Protocols: Sampling Techniques and Strategies*. EPA/600/R-92/128. Office of Research and Development, Washington DC.
- USEPA. 1989. *Methods for Evaluating the Attainment of Cleanup Standards*, Volume 1: Soils and Solid Medi*a*. EPA 230/02-89-042. Office of Policy, Planning, and Evaluation, Washington DC.
- USEPA. 1992. *Methods for Evaluating the Attainment of Cleanup Standards*, Volume 2: Ground Water, EPA 230-R-92-14, Office of Policy, Planning, and Evaluation, Washington DC.
- USEPA. 1992. *Statistical Methods for Evaluating the Attainment of Cleanup Standards*, Volume 3: Reference-Based Standards for Soil and Solid Media, EPA 230-R-94-004, Office of Policy, Planning, and Evaluation, Washington DC.

Statistical methods are recommended in all phases of the program as a means for evaluating data. These methods provide an objective methodology for making specific decisions based on the data. Because statistical tests can be used to quantify uncertainty in data, they provide answers to what the data mean and how certain are the conclusions. A wide range of statistical tools may be applied to monitoring, depending on the specific objectives of the program. In terms of project objectives, questions that these tools can address include:

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

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

A more detailed discussion of the tests described above is provided in the following subsections. Statistical methods specific to the analysis of environmental background data for soil, sediment and groundwater can be found in the three-volume *Guidance for Environmental Background Analysis* (NAVFAC, 2002, 2003, 2004).

6.3.1 Identify Concentrations that Exceed Specified Limits. Monitoring programs are generally designed to monitor concentrations of certain constituents and compare them to specified limits such as risk-based concentrations, state or federal standards, maximum concentration limits, water quality criteria, etc. There are several methods for comparing concentrations to these levels, depending on the project objectives.

Direct Comparison. In general, it is usually adequate to compare each detected result to the limit. This method is simple and, with minimal effort, summaries can be produced showing how many detected results exceed the criteria. However, this technique is unforgiving when it comes to infrequent, anomalous, high values. If a few anomalously high concentrations are resulting in continued monitoring at a site, it is worthwhile to conduct a more in-depth data evaluation using one of the following methods, or those described in Section 6.3.2.

Upper Tolerance Limit. If the objective is to identify chemicals that have some percentile of concentrations that exceed the limit, then an upper tolerance limit (UTL) is calculated. If the UTL does not exceed the limit, then there is a high level of certainty that the specified percentile of the data do not exceed the limit.

Means Comparison. If the objective is to identify chemicals that have concentrations typically (on average) greater than the limit, then a one-sample means comparison should be used. A one-sample means comparison determines if concentrations are, on average, greater than criteria.

6.3.2 Identify Outliers or Extreme Concentrations. The purpose of identifying outliers (extremely high or low values) is to ensure that anomalous values are not erroneous and do not unduly influence data interpretation. Once an outlier has been identified, the project team should review the data to determine if there is a reason why the outlier should be disregarded. In general, outliers should not be excluded from data evaluation without a specific reason, such as evidence of contamination, laboratory error, or transcription error. If a plausible reason can not be found for removing a statistical outlier, the result should be treated as a true but extreme value. Although the value should not be excluded from the data set, additional evaluation may be conducted so that they do not unduly influence statistical calculations, such as the mean. This may involve computing two different sets of summary statistics, both with and without the outlier.

Statistical methods that identify outliers are useful for classifying results that are extremely small or large compared to the rest of the data. Statistical outliers can be identified using a box plot or an outlier test.

Box Plots. Box plots are useful graphical tools for displaying extreme concentrations as well as the central tendency and variability of the data. Using a box plot, investigators can identify more than one result as an outlier. Outliers can be present at both ends of the concentration range (see Figure 6-2).

Outlier Test. An outlier test is provided by the USEPA (*Statistical Analysis of Ground-Water Monitoring Data at RCRA Facilities*, 1989, and *Statistical Analysis of Ground-Water Monitoring Data at RCRA*

Facilities: Addendum to Interim Final Guidance, 1992). Unlike box plots, this test is limited to identifying one point, either maximum or minimum, as an outlier.

6.3.3 Identify Differences in Concentrations Between Two Populations. Generally when two sets of data are compared, several statistical comparisons can be performed. These include two-sample means comparisons, individual comparisons, and quantile tests. Each of these comparisons is useful and provides different information about the data. Two-sample means comparisons can provide an overall picture of the differences between downgradient and upgradient data ranges. Individual comparisons can provide information about "hot spots" for specific sampling locations and chemicals. Quantile tests view downgradient results as a whole, rather than as individual results. Only the means comparisons and individual comparisons provide a systematic way of quantifying decision uncertainty.

Two-Sample Means Comparison. If the objective of the program is to identify any chemical with an average downgradient concentration that exceeds the average upgradient concentration, then a two-sample means comparison is appropriate. Two-sample means comparisons determine if downgradient concentrations are, on average, greater than upgradient concentrations.

Individual Comparison and Quantile Test. If the objective of the program is to identify cases when any downgradient concentrations differ from concentrations seen in upgradient samples, then an individual comparison or a quantile test is more appropriate.

6.3.4 Identify Differences in Chemical Concentrations. The appropriate statistical method to use when more than two sets of data are compared is an ANOVA, in conjunction with multiple comparison tests or contrast tests. An ANOVA is similar to a two-sample means comparison (as described in Section 6.3.3) except that averages for several different groups can be evaluated simultaneously. An ANOVA may be useful in instances where it is suspected that concentrations or trends in concentration of one or more contaminants are related in some way (e.g., as in the degradation of trichloroethene [TCE] and the production of daughter products such as cis-1,2 dichloroethene). Another example of ANOVA would include a statistical comparison to determine the significance of spatial variability at a site. By performing an ANOVA on data from upgradient or background wells, a determination on the significance of spatial variability at the site can be ascertained. This data could be helpful in explaining variability in data collected from wells affected by contamination, helping delineate plume boundaries, movement, and total mass. Statistical verification of such trends can have important implications for remedial design and operation as well as regulatory approvals.

6.3.5 Test for a Trend. As discussed earlier, spatial and temporal trend analyses are effective methods for evaluating the monitoring data to optimize monitoring point locations and monitoring frequency in terms of the decision criteria in the monitoring plan. For example, if it is determined that contaminant concentrations are decreasing at a particular monitoring point, use of that monitoring point may be discontinued or the monitoring frequency may be reduced, depending on the monitoring point location and the contaminant concentration with respect to the monitoring goal.

Typically, spatial and temporal trend analyses start by visually inspecting plots of analytical results for a monitoring point or group of monitoring points over time or as a function of distance from the source. Visual examination of such data is a highly sensitive means of detecting trends or potential trends in the data. Statistical tests can then be used to verify the presence and significance of any observable trends by calculating the likelihood that the trend might have resulted purely from random variability. To identify trends in individual monitoring points using statistics, methods such as linear regression analysis, the Mann-Kendall test, and the Sen test may be used. Additional information regarding these and other statistical trend analysis methods is discussed further in Appendix B.

Parametric linear regression analysis involves fitting a linear regression to the data from a monitoring point to test for the presence of a linear trend over time. Regression analysis may be appropriate for assigning numerical values to trends identified as significant, as in calculating natural attenuation rates, contaminant mass removal, or rates of plume advance or retreat.

The Mann-Kendall test can be interpreted as a test for an increasing or decreasing trend of concentrations as a function of time. This test is typically not performed on a small number of samples; a rule of thumb is to perform trend analyses with at least four samples. Although the Mann-Kendall test can detect the presence of a trend, it gives no estimate of its magnitude. Sen (1968) developed a nonparametric method for estimating a trend that is used here in conjunction with the Mann-Kendall result.

Modifications to the Mann-Kendall test can be made to accommodate multiple measurements per well per sampling event or to correct for seasonal effects. These modifications to the Mann-Kendall test would be appropriate if pronounced seasonal variation were noted in monitoring data or if duplicate samples were to be included in the analysis. One drawback to correcting for seasonal effects is that a longer time series of data is needed before the statistical analysis can be usefully implemented.

6.3.6 Evaluate Data Spatially. Spatial data analysis includes statistical tools that can be applied to optimize the number of monitoring points necessary to achieve monitoring program goals. Spatial statistical methods, or geostatistics, are used to evaluate the spatial pattern and correlation of contamination across a region and can identify which locations continue to have unacceptably high concentrations. These results can be applied to monitoring data as a basis for ceasing to monitor at a particular point and/or a COC.

Semivariograms. Semivariograms can help define plume(s) or spatial variation by quantifying relationships between samples taken at different monitoring point locations. Separating monitoring points into various regions or plumes can decrease the variability of concentrations and can allow for more accurate statistical tests and decision making. This method may also provide information for effective remedial design by distinguishing areas that require remediation from those that do not.

Kriging. Kriging maps can be used to delineate areas of contamination and to develop decisions about further sampling by providing a powerful visual argument that the current delineation is either adequate or not. This type of information can be extremely useful in discussions with regulators. Uncertainty maps (maps of uncertainties associated with kriging predictions) can indicate whether additional sampling locations would be useful. Also, if estimated chemical concentrations are substantially lower than comparison values (regulatory limits, upgradient UTLs, etc.), even after accounting for uncertainty, then it may not be necessary to collect additional samples, even when sampling is sparse across that area or well.

6.3.7 Statistical Software Tools. New software that can aid in completing statistical evaluations for optimizing monitoring programs is continually developed. For example, Summit Monitoring tools (created by Hazard Management Systems, Inc.) was created to automate the monitoring optimization process. The software can create geostatistical models of spatial and/or temporal trends based on historical data, identify optimal sampling location and/or frequency adjustments, and track data based on historical trends or predetermined site-specific data quality objectives. For specifics on tools for optimizing groundwater monitoring such as Monitoring and Remediation Optimization System (MAROS) and Geostatistical Temporal/Spatial (GTS) Algorithm, see Section 7.6.

Visual Sample Plan (VSP) is a software tool for selecting the appropriate number and location of groundwater samples so that the results of statistical tests performed on the data collected via the sampling plan have the required confidence for decision making. VSP provides sample designs and sample-size equations needed by specific statistical tests appropriate for several types of groundwater contamination situations. VSP can be used in conjunction with USEPA's systematic planning process (USEPA, 2000) by assisting with Step 7 of the DQO process (Optimize the Design for Obtaining Data). The user must complete Steps 1 through 6 of the process in order to have the inputs VSP needs, and VSP uses this as input to the formula for finding the optimal design for the current problem.

The VSP software allows the user to input sample results, display the results, execute statistical tests, and draw conclusions from the data. VSP performs the required calculations for sample size and sample location and outputs a sampling design that can be displayed in multiple formats. VSP addresses the trade-off between repeated analytical measurements on a single sample to reduce overall sample result variability and provides a sensitivity table for comparing analytical methods of varying accuracy and cost. VSP can be used to develop a new sampling design and to compare alternative designs. The software automates the mechanical details of calculating sample size, specifying random sampling locations, and comparing sample costs with decision error rates. These activities can be accomplished in the context of a site map displayed onscreen with various sampling plans overlain on proposed sample areas. The program output is a conclusion that can be drawn based on the results of statistical tests applied to the sample results. In addition, VSP can allow the user to define a sampling plan when there are multiple goals associated with the monitoring program. VSP is a publicly available software program (http://dqo.pnl.gov/vsp/) designed by USEPA, U.S. Department of Energy (DOE), U.S. Department of Homeland Security (DHS), and DoD.

Spatial Analysis and Decision Assistance is free software sponsored by the USEPA Office of Solid Waste and Emergency Response, Technology Innovation Program. SADA integrates modules for data visualization, geospatial analysis, and statistical analysis, among others, for effective problem solving. The capabilities of SADA can be used independently or collectively to address site-specific concerns when determining the location of future sample points and designing a remedial action. A fully functional freeware version is available at http://www.tiem.utk.edu/~sada/.

6.4 Data Presentation Tools

It can be difficult to evaluate monitoring data from a spreadsheet and even more difficult trying to present and explain it to others. Data evaluation tools can help clearly summarize monitoring data, compare data against decision criteria, and draw appropriate conclusions about the data. Data presentation tools help ensure that data interpretation and evaluation of decision criteria are clear and logical to others.

6.4.1 Graphical Formats. Graphical data visualization is a powerful technique that can be used to illuminate trends, data anomalies, or systematic patterns that would not otherwise be apparent. Many graphical formats can be used to provide quick assessments of concentration ranges, extreme concentrations, or potential trends such as plume locations and seasonal trends. With readily available software, many of these plots are simple to create and evaluate. Graphical data display formats include the following:

- **Box plots** (Figure 6-2): These diagrams summarize the statistical distribution of the data in a graphical format. They are useful for showing average and extreme values.
- **Time trend plots of concentrations** (Figure 4-1 and 6-3): Concentrations can be plotted versus sampling date in order to visually assess trends, seasonal fluctuations, and anomalous values. It may be useful to include meaningful comparison values on such plots. For example, a line may be drawn across the plot at the MCL, or at the upgradient or baseline values.

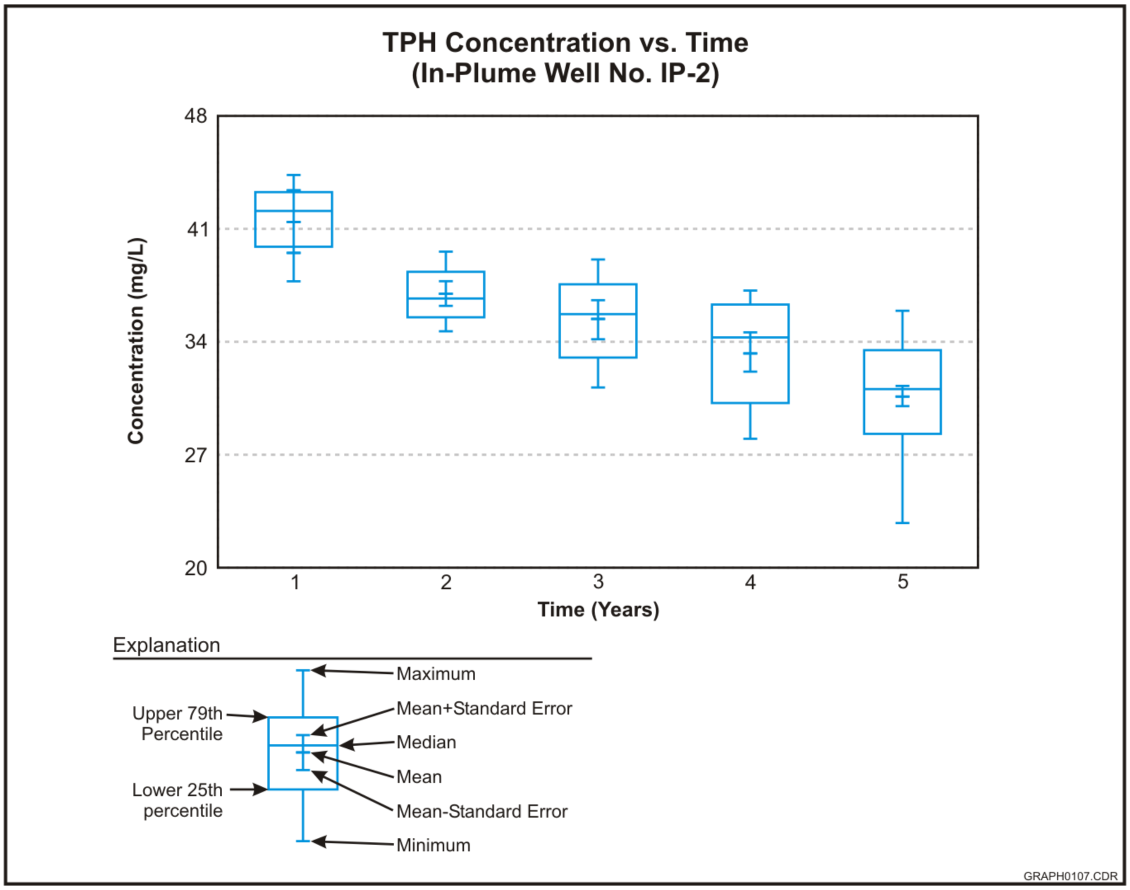


Figure 6-2. Example Box Plot of TPH Concentration Data.
(Source: *Guide to Optimal Groundwater Monitoring*, NAVFAC, 2000)

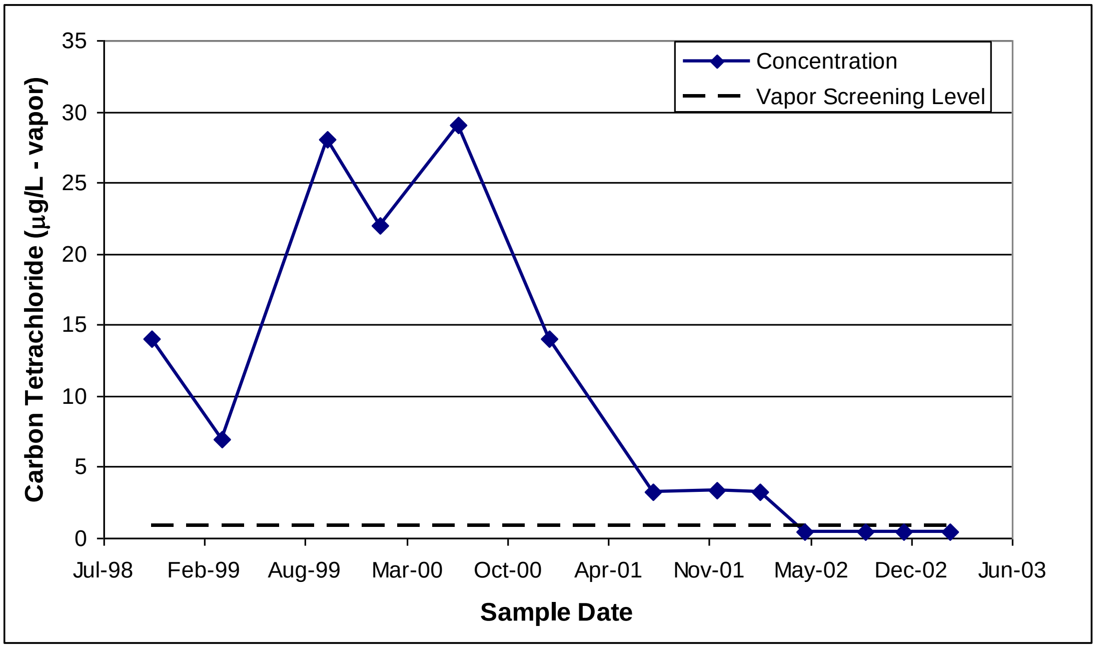


Figure 6-3. Example Time Trend Graph of Soil Vapor Concentrations

- **Spatial maps of concentrations** (Figure 6-4): For a given sampling event, concentrations can be displayed by plotting symbols of a certain size or color at the sample location. Contour maps also can be constructed. Like those described above, these plots also use colors or lines to indicate the concentrations at different locations. However, with contour plots, concentrations are mapped for the entire area by extrapolating data to areas that have no monitoring points.

6.4.2 Tabular Data Formats. Tabular formats can be used to support conclusions from more in-depth data evaluations. Although more rigorous data evaluations are often required to objectively evaluate the data and to support decisions, tabular displays provide a convenient method for presenting quantitative information.

Tabular displays can present an informative summary of statistics and of results from statistical tests. Shading or other unique formatting may be used to emphasize values above some criteria. Table 6-1 is an example of the type of information that can be provided in a tabular format. Tables summarizing concentration levels observed over a period of time can be constructed for a given monitoring point. Tables can also provide details of the statistical means comparisons by displaying summary statistics necessary for the comparisons.

6.4.3 Data Visualization. GIS provides a powerful tool for interpreting site data by helping to display data spatially and by constructing and tracking plume or other types of concentration-over-area maps. As discussed in Chapter 5, the ability to continuously track a plume's size and shape allows for monitoring program optimization by deciding which monitoring points to sample or when to shut down active remediation systems. Figure 6-4 shows an example of a GIS-generated figure that includes comprehensive site data.

A minimal amount of base mapping will be necessary to fully realize the power of GIS programs. At a minimum, coverage of monitoring point locations, important facilities, remediation systems, supply wells, property boundaries, and relevant off-site features should be included. The use of field global positioning system (GPS) receivers allows for inexpensive horizontal surveying with sub-meter accuracy.

Data Evaluation. GIS offers a means for interpreting many types of data associated with a site. In general, GIS offers a broad spectrum of capabilities including visualization, analysis, and querying of electronic data. Most commercially available GIS programs accept the use of common base mapping formats, including computer aided design (CAD) drawings, DXF files, and United States Geologic Survey (USGS) Digital Elevation Maps (DEMs). Overlapping field sampling data with geo-referenced base mapping can provide data analysts, engineers, decision-makers and stakeholders with an accurate, scaled representation of a site's contaminant plume or concentration variability. Since different "layers" of information can easily be toggled on and off, users can look separately at any number of analytical parameters, site physical features, and hydrogeological data. Alternatively, it is just as easy, and in some cases very useful, to view different combinations of parameters at the same time. Querying capabilities and inter-program connectivity features offered by GIS packages allow for retrieval and storage of data sorted by any number of parameters including date, location, analyte, and depth-to-sample.

As discussed in Section 6.2, the NIRIS data management system is integrated with GIS, allowing real-time maps to be generated as soon as analytical lab data are received and uploaded. By generating sequential realizations of monitoring data, the mass of contaminant, plume movement, plume size, and changes in contaminant migration directions can be effectively estimated. Transposing these graphical data with "real world" base mapping allows for continued review and identification of suspected source areas and contaminant hotspots as well as easy identification of downgradient receptor locations that may be impacted in the future.

Table 6-1. Example Table of Summary Statistics
Monitoring Well #1 Data from Last Eight Monitoring Events

Compound	**Number Detected Results/Total Samples**	**Range of Detected Values**		**Mean**	**Standard Deviation**	**Lower 95% Confidence Limit**	**Upper 95% Confidence Limit**	**Upgradient UTL**	**Baseline UTL**	**Regulatory Standard (i.e., RBC)**
		Minimum	**Maximum**							
Metals (mg/L)										
Chemical A	8/8	0.794	**37.6**	6.3	6.75	0.656	11.9	4.23	7.31	21
Pesticides/PCBs (µg/L)										
Chemical B	7/8	0.842	**9.86**	3.43	1.9	1.84	5.02	5.48	6.46	0.81
Chemical C	8/8	0.211	**8.02**	2.7	2.86	0.309	5.25	7.52	5.8	0.14
Chemical D	5/8	0.0927	**1.86**	0.382	0.38	0.0643	0.7	0.568	0.398	0.021
Semivolatiles (µg/L)										
Chemical E	6/8	0.234	**2.68**	1.34	1.3	0.253	2.43	0.683	0.919	0.81
Chemical F	2/8	0.834	**10.5**	2.65	1.86	0.305	4.21	3.37	11.2	0.14

Shaded values are greater than regulatory standard.
Bolded values are greater than upgradient UTL.
Italicized values are greater than baseline UTL.
Mean, standard deviation, and confidence limits are estimated using proxies and detected results.

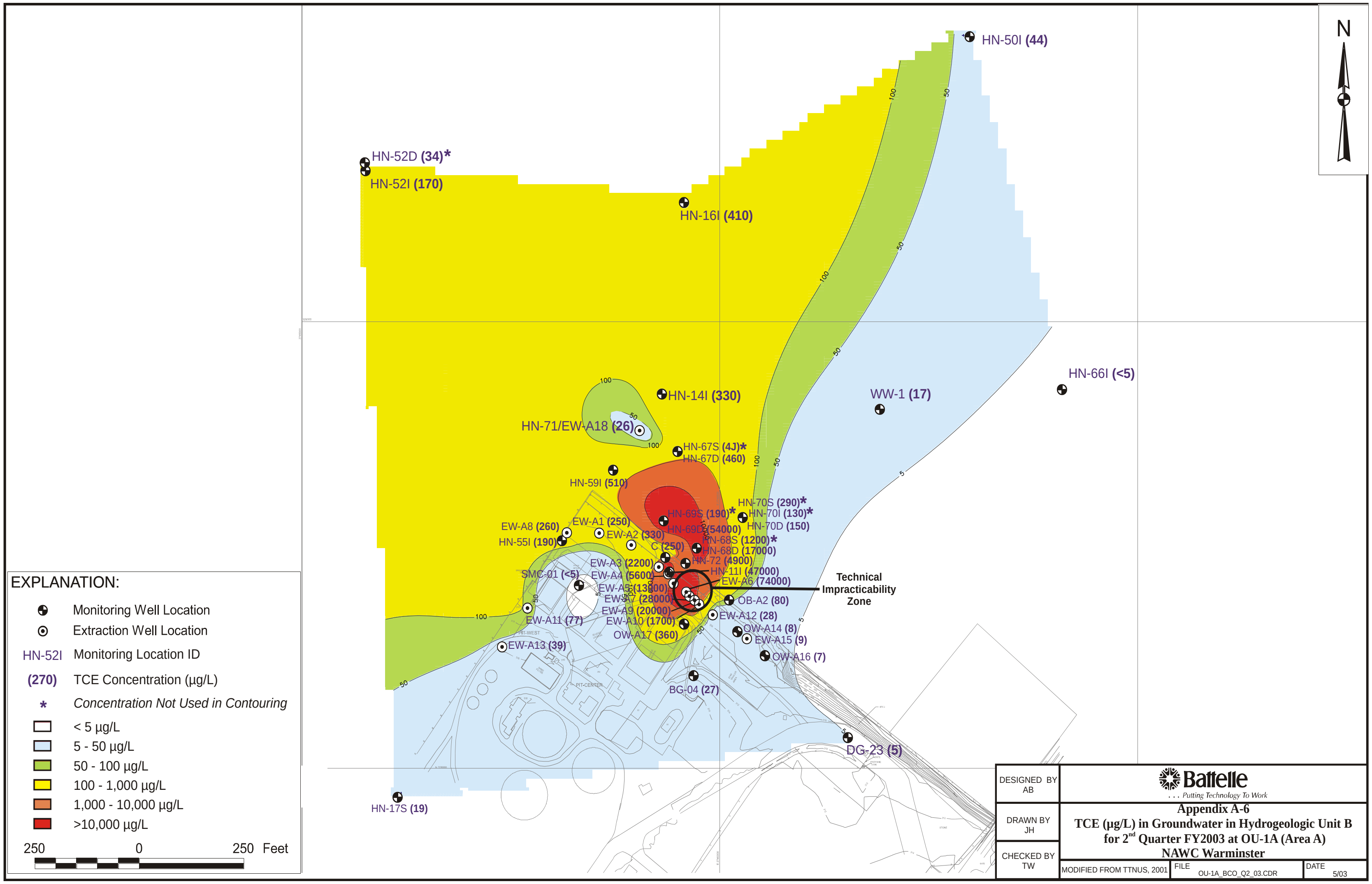


Figure 6-4. GIS-Generated Contaminant Concentration Contour Map.
(Source: *Final Quarterly Monitoring Report for the March 2003 Performance Monitoring Event (Second Quarter FY 2003) for Long-Term Environmental Monitoring at Operable Units 1A, 3, and 4 at the Former NAWC, Warminster, PA.* August, Battelle, 2003)

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

- ESRI ArcView® with ESRI 3-D Analyst extension;
- Environmental Visualization System (EVS) from C-Tech;
- EVS for ArcView from C-Tech; and
- Visual Groundwater from Scientific Software Group.

Real Time Presentations. By selecting a site, a COC, and a sampling round, a custom query can be generated. The concentration data from the query can be subsequently contoured and displayed on the screen. A table containing the query data can also be displayed.

By clicking on a monitoring point, building, source area, or other feature in the GIS map, specific data describing the chosen feature can be displayed. For example, clicking on a specific well may bring up well construction, water level, or contaminant concentration data. Clicking on a site or Operable Unit may bring up pertinent information such as COCs, site activities, and dates of operation.

Standard GIS functions include the ability to pan, zoom in, zoom out, and other standard navigation tools. All of these features can be used to give an effective presentation with the ability to provide real-time responses to any data requests the audience may have.

As discussed previously in Section6.2, the NIRIS database allows the user to utilize all of these GIS features as long as the historical information for the specific site is uploaded and properly checked for quality. NIRIS is the Navy's common data management and evaluation solution and is all accessible from the users' desktop.

6.5 Report Streamlining

Report streamlining is another method to significantly minimize monitoring costs and manage and evaluate monitoring data more efficiently, especially in a program with quarterly monitoring requirements. Use of the NIRIS data management system increases accessibility of the large volumes of data often associated with monitoring programs. Focusing reports on tabular and graphic presentation styles helps to reduce review time, and presenting a summary table of the data, using shading or some other method for highlighting detections that exceed some standard, increases the readability of the information. NIRIS can be used to efficiently prepare these data summary tables, statistics summaries and concentration contour maps, all of which are important components of periodic monitoring reports. Monitoring reports should also present clear recommendations for future optimization based on the site-specific decision criteria and data evaluation.

Monitoring optimization recommendations, implementations and results should be tracked in NORM. NORM is NAVFAC's Web-based computer system that does environmental site registration, cradle-to-grave tracking, relative risk ranking, cost-estimating, budgeting and reporting functions for the ER Program. The NORM Optimization Module tracks optimization measures in all phases of a site cleanup, including:

- Remedial and removal action screening,

- Evaluating,
- Selecting,
- Designing,
- Implementing,
- Long-term operating, and
- Long-term managing.

When preparing hard copies of monitoring reports, an increasingly common approach is to prepare and maintain a ring binder each year. This “living” document is tabbed to provide space for quarterly and semiannual monitoring results once the data are available. Then, on a yearly basis, a more formal annual monitoring report is submitted and inserted in the front of the document. Although the annual reports are submitted in draft and final versions, quarterly or semiannual reports may be submitted only once or the draft may be submitted electronically.

This approach allows for several other efficiency improvements. First, all general “cut and paste” information (e.g. site history, background, etc.) in the quarterly reports can be eliminated, minimizing the amount of text that must be produced. If only data are submitted, it is unlikely that there will be any comments, thus eliminating the need for a draft. If changes are necessary due to a data reporting error, replacement pages may be submitted. Raw data, purging logs, and so forth, should be submitted as an appendix, either on a quarterly or annual basis.

Other information, such as sample chain-of-custody forms, should be kept in project folders for reference as necessary. Copying these forms into an appendix for each report takes up space and is of little use to the average report reader.

PART II

MEDIA-SPECIFIC PLANNING AND OPTIMIZATION INFORMATION

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Chapter 7.0: Groundwater Monitoring

This chapter focuses on the design and optimization of groundwater monitoring programs, and includes a discussion of monitoring objectives, groundwater monitoring program design and optimization, selection of monitoring locations and analytes, monitoring frequency and duration, parameter monitoring and sample collection methods, tools for evaluating groundwater monitoring data, and references that can assist the user during the design and optimization process. It should be noted that groundwater monitoring specifically associated with landfill closures is covered in Chapter 12.

7.1 Groundwater Monitoring Objectives

The general goals and objectives of a monitoring program are defined in the site monitoring plan, which is discussed in Chapter 2. Groundwater-specific monitoring objectives typically fall into one or more of the following categories:

- Validate the CSM and the conclusions of the site investigation and remedial technology selection
- Determine if contamination is migrating to a downgradient receptor or off site
- Track contaminants exceeding defined limits (i.e., MCLs)
- Track the changes in shape, size, or position of a contaminant plume
- Assess the performance of a remedial system (including MNA)
- Assess the practicability of achieving complete remediation; or
- Satisfy regulatory requirements (for example, detection monitoring to meet RCRA requirements and other ARARs).

The primary objective of optimizing groundwater is to ensure capture of required data at least cost. Accordingly, the optimization process focuses on collecting relevant data of the appropriate quantity and quality to achieve program goals.

7.2 Groundwater Monitoring Program Design and Optimization

As with all monitoring programs, the monitoring program design should be developed to include the site-specific goals, a description of the CSM, identification of baseline data (if applicable), data objectives (the systematic planning/DQO process should be used to identify these), decision and exit criteria, as well as a specific work plan including a SAP. Establishing clearly defined monitoring objectives and corresponding exit criteria is central to any well defined, well managed and optimized monitoring program. Exit criteria should be used to help decision-makers determine when they can move on to other steps in the groundwater management process.

In optimizing the monitoring program, all data should be collected with an understanding of how the data will be used and how they contribute to a validation of remedy performance and success. The number and placement of monitoring points needed to ensure adequate monitoring of groundwater contamination will be a function of many site-specific characteristics and the objectives of the monitoring program. Ultimately, the CSM and the data objectives (including DQOs) required to make management decisions will be the basis for determining monitoring locations. Each monitoring point should be established with the deliberate intention of providing specific data that will refine the CSM and help the project team make management decisions. As monitoring points are established based on specific data objectives, the decision criteria for monitoring each point can then be identified and optimized. In addition, there are factors unrelated to site characteristics that may affect the design of the monitoring program, including regulatory and community relations considerations. A comprehensive review of applicable regulatory requirements should be conducted (see Chapter 2). In many cases, state regulatory agencies will have mandatory guidelines for the types and placement of compliance monitoring wells.

7.3 Selection and Distribution of Monitoring Locations

Figure 7-1 provides an idealized illustration of the types of wells that may be required for groundwater monitoring at a given site; Table 7-1 describes these types of wells in more detail. An idealized cross section further illustrating the types of monitoring locations is shown in Figure 7-2.

Table 7-1. Types of Groundwater Monitoring Points

Well Type	Location Relative to Source	Description
Upgradient	Upgradient	Upgradient wells are located away from the source of contamination in the direction from which groundwater flows. Concentrations in these wells represent contaminants flowing onto the site, if any. An uncontaminated upgradient well may be used as a background well.
Background	Upgradient or crossgradient	Background wells are located where they cannot be affected by contamination from the site. They are used to determine background concentrations of contaminants, usually metals or other naturally-occurring compounds. An upgradient or crossgradient well may serve as a background well.
Crossgradient	Crossgradient	Crossgradient wells are located adjacent to the source of contamination in a direction perpendicular to the direction of groundwater flow. These wells may be used to ensure that diffusion, dispersion, or temporal variations in groundwater flow direction do not result in the additional spread of contamination from a site.
Plume-edge	Downgradient or crossgradient	Plume-edge wells are located immediately downgradient or crossgradient of a plume and are used to track plume movement by advective groundwater flow, diffusion, or dispersion. The location of designated plume-edge wells may need to change as the plume size and shape change. Plume-edge wells may be part of a remedial system.
In-plume	Downgradient	In-plume wells are located both vertically and horizontally within the known extent of groundwater contamination. These wells are used to track concentration changes over time and can be used to assess remedial performance of in situ remedies. These wells also may serve as extraction wells for a remedial system. Downgradient wells are located in the direction of groundwater flow from the source of contamination and are used to track the concentration and movement of contaminants in groundwater from a site. Nested wells may be desirable when it is necessary to monitor at several discrete depths at a single spatial location. In-plume, plume-edge, POC, and sentinel wells all may be downgradient wells.
Downgradient	Downgradient	Downgradient wells are located in the direction of groundwater flow from the source of contamination. Downgradient wells are used to track the concentration and movement of groundwater contaminants from a site. In-plume, plume-edge, POC, and sentinel wells all may be downgradient wells.

Table 7-1. Types of Groundwater Monitoring Points (Continued)

Well Type	Location Relative to Source	Description
Point-of-compliance	Downgradient	POC wells are generally defined by an installation's RCRA or other permit, and are often located at the site boundary downgradient of the source area. These wells are used to ensure that contamination is not migrating off site or affecting a sensitive receptor (see also "Sentinel" well).
Sentinel	Downgradient	Sentinel wells are positioned downgradient of the contamination and upgradient of a sensitive receptor, such as a drinking water source. Sentinel wells must be screened at an interval appropriate to what they are protecting.
Off site	Anywhere off site	Off-site wells may be installed and monitored in response to concerns from neighboring communities.

Note that upgradient, background, and downgradient wells should be completed in the same aquifer in order to make valid comparisons to in-plume monitoring data. Nested wells may be installed and are desirable when it is necessary to monitor at several discrete depths at a single spatial location. Inclusion of additional monitoring points at property boundaries or sensitive areas of interest may be warranted to track plume migration.

The next step is to evaluate the wells that currently exist on and around the site. In most cases, the design of a groundwater monitoring program will follow some degree of site investigation, during which some monitoring points were installed. By nature, investigation studies are designed to determine where and how much contamination exists, the location of potential sources and hotspots, the direction in which a plume may be moving, and the contaminants present in groundwater at the site. Answering these questions usually results in the installation of a significantly greater number of monitoring wells than are typically necessary for a well designed groundwater monitoring program. If monitoring well installation is required as part of the monitoring program, appropriate state and/or local guidelines should be followed, such as those outlined in the *Handbook of Suggested Practices for the Design and Installation of Ground-Water Monitoring Wells* (USEPA, 1991). In general, monitoring points should be chosen (or installed) with DQOs in mind, including the assessment of plume stability, and to provide feedback on performance of both active and passive remedial measures.

When designing the monitoring program, consideration also should be given to inclusion of upgradient and/or crossgradient monitoring locations. This monitoring is designed to evaluate levels of COCs and any parameters of interest that may be migrating onsite from an external location. An adjacent land use property search and evaluation of background chemical levels collected during initial site assessment activities will provide information regarding the optimal placement and target monitoring parameters of these wells.

When installing a monitoring well, selection of the appropriate screened interval is crucial to establishing an effective monitoring program, and project DQOs should be considered in the selection process. In general, monitoring wells should be located and screened to bound the horizontal and vertical extent of contaminant plumes. Screen length should be kept to a minimum (e.g., ≤5 ft) to ensure representative samples are collected and minimize the potential for underestimating concentrations by averaging across large intervals. If necessary, nested wells can be installed to monitor several discrete depths at a given.

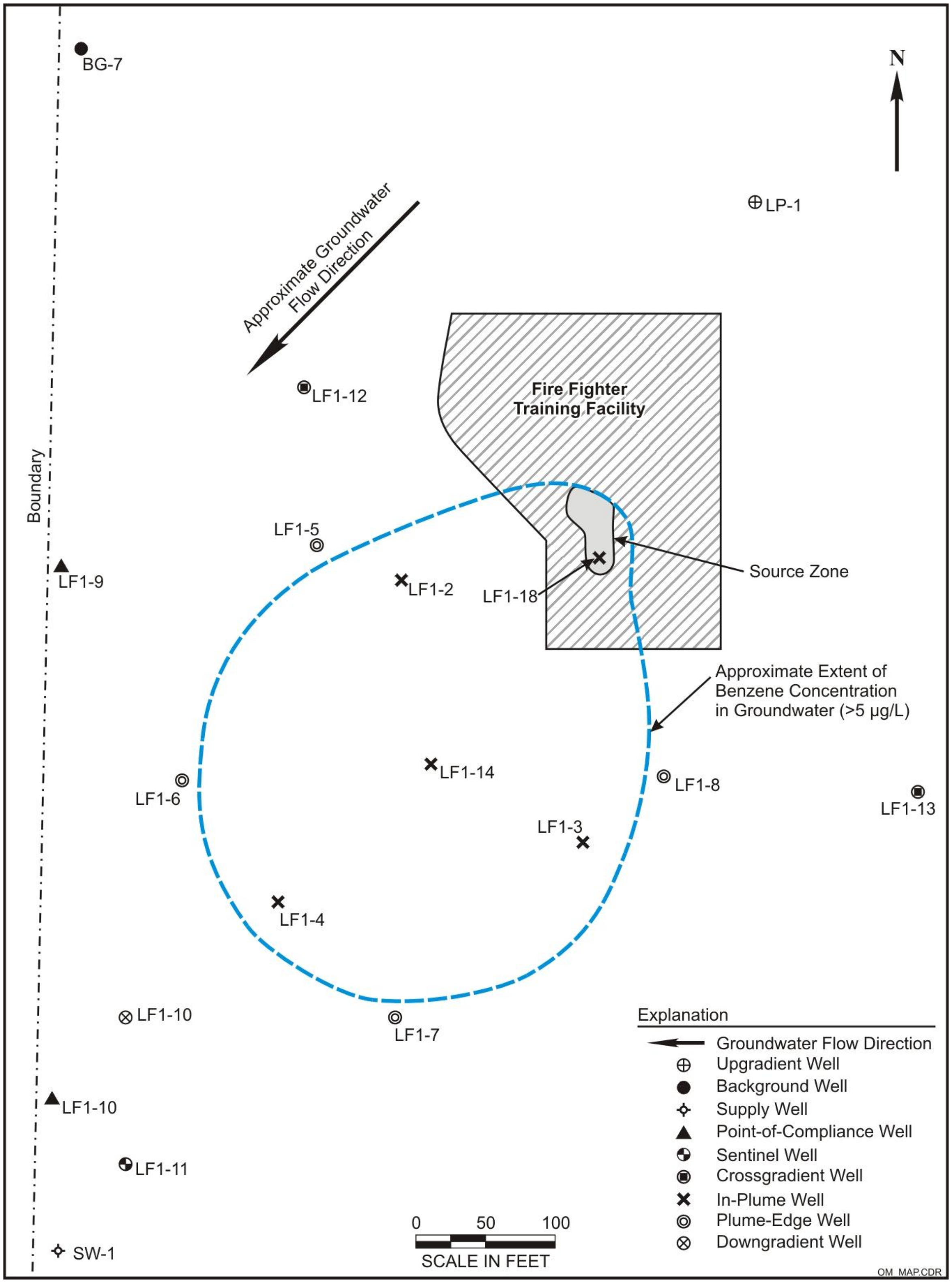


Figure 7-1. Idealized Monitoring Well Network
(Source: Modified from *Guide to Optimal Groundwater Monitoring*, NAVFAC, 2000)

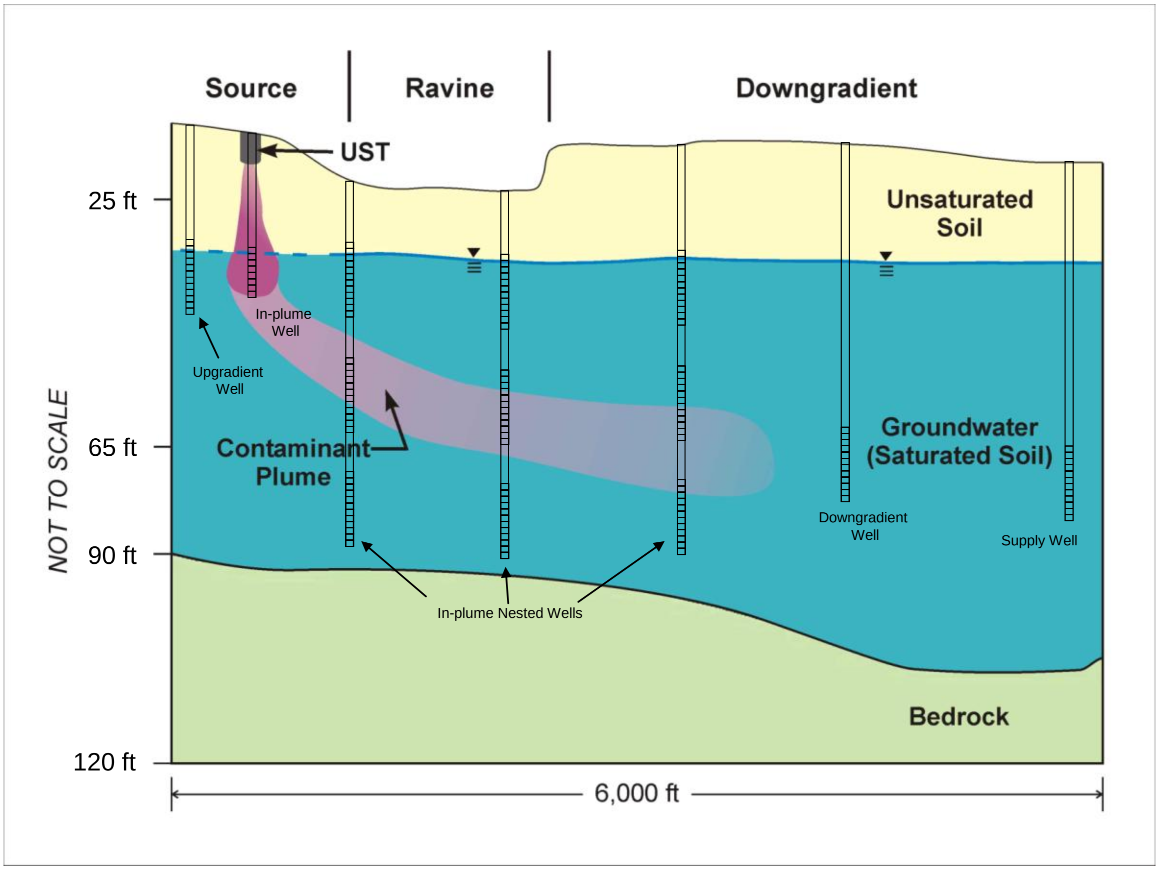


Figure 7-2. Monitoring Well Cross Section

location. If larger screen lengths are present, discrete depth sampling within the well can create a concentration profile used to target future monitoring depths

When installation of monitoring wells is not technically or economically practical, the use of piezometers is an inexpensive and useful option to consider. Piezometers can be installed rapidly and are used primarily to monitor groundwater-level elevations, although they also may be used to collect groundwater samples from discrete depths. Nested piezometers may be desirable when it is necessary to monitor at several discrete depths at a single spatial location.

Where applicable and feasible, groundwater or vadose zone source areas or hotspots should be monitored to assess whether a source zone is still contributing to the plume in question. Chapter 11 discusses strategies for vadose zone monitoring. The network design also may include monitoring extraction or treatment wells to track the performance of a remedial system.

When evaluating placement of monitoring wells, groundwater flow calculations and/or groundwater modeling may provide insight for determining the number and location of corrective action observation wells and/or POC wells. The application of groundwater flow calculations and more complex groundwater modeling is discussed in Section 7.7.3.

The objectives of the groundwater monitoring program should be reevaluated at least on an annual basis, with attention paid to the procedures outlined in Chapter 2. Decision criteria are important tools for optimizing a groundwater monitoring program, and set pre-determined requirements for deciding when a monitoring well should be added or removed from the program. There are several methods to optimize the number of monitoring points necessary to achieve monitoring program goals, including the use of spatial data analysis and time series plots. Statistical methods for data analysis are discussed in more detail in Chapter 6 and Section 7.7.1. If the value of the information provided by a monitoring point does not justify the cost of data collection and analysis, then it may be appropriate to eliminate the data point from the monitoring network. If decision criteria have already been established for eliminating monitoring points at the site, the annual review should include determining if any of the decision criteria have been met. However, regulatory and community concerns must be kept in mind when considering elimination of monitoring points. Although it is important to ensure that an adequate number of monitoring points are maintained at the site to provide program flexibility, it is equally important to eliminate points that do not address program objectives and are unlikely to in the future. Should the decision be made to eliminate monitoring locations, wells should be abandoned in accordance with applicable regulations.

7.4 Sampling Frequency and Monitoring Duration

The initial sampling frequency will depend on the monitoring objectives. As stated in Section 4.1.1, typically a minimum of four quarterly rounds of groundwater sampling data is recommended for the first year of monitoring. Four data points are often considered the minimum for statistical evaluation and will help establish temporal (such as seasonal) and spatial variability. Future sampling frequency and monitoring duration can be evaluated using four quarters of sampling data. In some cases, additional data points may be necessary before the frequency can be reduced to allow for a better interpretation of seasonal trends and result in a more accurate and meaningful statistical evaluation. Use of recent site assessment data also should be incorporated into analytical or statistical evaluations and could serve as the basis for starting a monitoring program with less frequent sampling. As always, all data should be collected using the same sampling and analytical methods to ensure comparability. If methods do change between sampling rounds, in some cases, a comparison may be appropriate between the new and old methods to correlate the results between different methods.

Following the first year of quarterly data collection, sampling frequency may be reduced as appropriate, following decision criteria built into the monitoring plan. Specific decision criteria should be included for determining when monitoring may be discontinued or conducted at a reduced frequency at the site. Monitoring at an individual well or across the site may be discontinued when the selected monitoring goals (see Section 2.2) have been reached. A review period, most likely annual, should be specified in the monitoring plan to periodically evaluate the potential for monitoring optimization or site closure based on sampling data and closure decision criteria.

The purpose of a well should be taken into account when determining the sampling frequency in the design process. Table 7-2 provides examples of sampling frequencies, based on the purpose of the wells. Downgradient, plume-edge wells generally require more frequent sampling than an upgradient or background well. Transect wells, which are located within and downgradient of the plume along a centerline parallel to the direction of groundwater flow, may be sampled more frequently than other in-plume wells as they provide a cross-section of plume concentrations and can be used to evaluate plume migration. Chemical concentration data from transect wells also can be used to evaluate MNA parameters, including biodegradation. Special purpose wells, such as sentinel and POC wells, may need to be sampled often to confirm plume stability and safeguard human health. Likewise, off-site wells may need to be sampled more frequently than on-site wells to help maintain good faith between the site and neighboring communities.

Under some conditions, groundwater-level monitoring can be substituted for the standard combination of groundwater-level and contaminant concentration monitoring. Groundwater-level monitoring alone is

Table 7-2. Sampling Frequency Examples for Different Types of Groundwater Wells

Well Type	First 1-2 Year Frequency	First Optimization Frequency	Second Optimization Frequency	Considerations
Upgradient	Quarterly	Annual	Every 5 Years	On-site migration of contaminants
Crossgradient	Quarterly	Semiannual	Every 2 Years	Dispersion of site contaminants
Plume-edge	Quarterly	Semiannual	Semiannual	Plume migration
In-plume	Quarterly	Semiannual	Every 2 Years	Remediation progress if applicable
Transect	Quarterly	Quarterly	Annual	Plume status and migration
Downgradient	Quarterly	Semiannual	Annual	Migration of site contaminants
Point-of-compliance	Quarterly	Semiannual	Semiannual	Maintaining community relations
Sentinel	Quarterly	Quarterly	Quarterly	Safeguarding human health and maintaining community relations
Off-site	Quarterly	Semiannual	Every 2 Years	Maintaining community relations
Piezometer	Quarterly	Quarterly	Quarterly	Inexpensive to collect and can provide information regarding plume migration

Note: Annual- = Annual or less frequent sampling

considerably less expensive, and can provide useful information regarding the status of the contaminant plume by indicating whether the groundwater flow field has changed significantly from previous sampling events. Detection of only minor variations in the flow field indicates the plume is relatively stable, and concentrations have not likely changed or migrated significantly since the previous monitoring event.

Groundwater flow calculations can be used to determine the initial sampling frequency and monitoring duration by estimating the rate of groundwater flow at a site. Although the rate of contaminant movement is usually not as fast as groundwater movement (see adjacent box), the use of simple flow equations can provide a conservative estimate of how long it will take contamination to reach a particular point, such as the installation boundary or a supply well. A contaminant-specific retardation factor (based on site-specific conditions) also can be applied to the groundwater flow calculation to better estimate contaminant migration rates. This flow rate information can then be used to determine an appropriate sampling frequency and monitoring duration. Additionally, if contamination is not detected in downgradient wells within a reasonable timeframe based on flow calculation results, it may be determined that contamination will not reach the site boundary and monitoring may be discontinued.

Groundwater Flow Estimation

Estimation of groundwater flow and chemical transport rates are useful in optimizing the design and monitoring frequency of a monitoring program. Migration rates can assist in initial well placement by estimating the maximum expected downgradient extent after select time periods; this can eliminate the potential for extraneous downgradient monitoring wells. Groundwater flow can be estimated using the following equation:

$$v = \frac{K}{n_e}\frac{\partial h}{\partial l}$$

where: v = advective groundwater flow velocity
K = hydraulic conductivity
n_e = effective porosity
dh= change in head between monitoring locations
dl = distance between monitoring locations

Decreasing the number of monitoring points through reductions in monitoring duration and/or sampling frequency is an important aspect of optimizing an existing groundwater monitoring program. A reduction in sampling frequency will decrease sampling labor, analysis, validation, and reporting costs. The general approach to this type of optimization involves an evaluation of the decision criteria for sampling frequency and monitoring duration. Evaluation of groundwater flow calculations, application of trend analyses and statistical methods, and groundwater modeling also support decisions to optimize sampling frequency and monitoring duration. An important difference between determining initial sampling frequency and optimizing existing programs is that existing programs may not have pre-approved decision criteria for optimizing sampling frequency and monitoring duration.

7.4.1 General Decision Criteria. The objectives of the groundwater monitoring program should be reevaluated to determine if any of the decision criteria for reducing the sampling frequency or monitoring duration at a site or individual monitoring point have been met. For examples of decision criteria for reducing sampling frequency and monitoring duration, see Chapter 4, Table 4-1. Figure 7-3 illustrates an example of a decision diagram for determining sampling frequency of wells at a site. It should be noted that this decision diagram is an example and that decision criteria will vary depending on site-specific characteristics. As the size and concentration of chemical plumes are reduced (supported by plume maps and statistical evidence), less frequent sampling (i.e., biennial) can be introduced into the decision diagram.

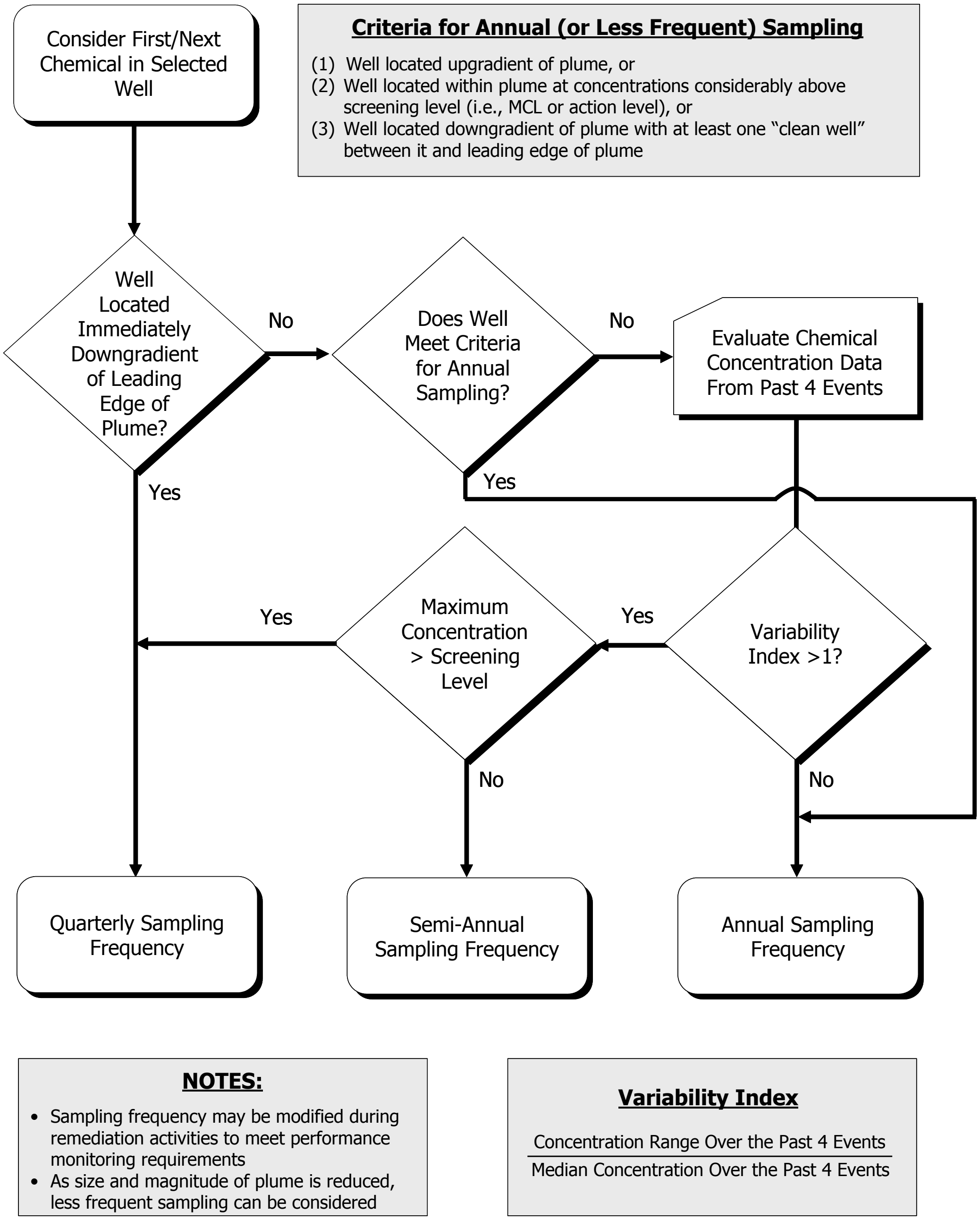
As shown in Figure 7-3, determinations on sampling frequency are tied to a variability index. Variability is characterized by a distribution-free version of the coefficient of variation: the range divided by the median concentration. This statistic corrects for the influence of magnitude on variability, an important consideration given that the range of concentrations in VOCs routinely varies over three orders of magnitude. The cut-off value for distinguishing high versus low variability is typically derived empirically from site-specific data distributions.

7.4.1.1 Using Groundwater Flow Data as Decision Criteria. Groundwater-level data are relatively quick and inexpensive to collect, and can provide valuable information on the stability of the flow field and plume migration. These data can be plotted and used to estimate the hydraulic gradient at a site. The hydraulic gradient can then be used in conjunction with select aquifer parameters (i.e., hydraulic conductivity and porosity) to estimate groundwater flow velocities. Under some conditions, groundwater-level monitoring can be substituted for the standard combination of groundwater-level monitoring and sampling for contaminant concentrations if historical data indicate a stable flow field. As discussed previously, groundwater flow calculations can be used to select and optimize the sampling frequency and monitoring duration by estimating the rate of groundwater flow at a site. The use of simple flow equations can provide a conservative estimate of how long it will take contamination to reach a particular point, such as the installation boundary or a supply well. Groundwater flow and contaminant transport models also can be developed to more accurately predict migration time, but involve a significantly greater amount of effort. Estimates of groundwater flow and contaminant transport can then be used to reduce the sampling frequency and monitoring duration.

Monitoring Frequency

Annual monitoring should not be thought of as the least frequent schedule for data collection. Biennial sampling and/or collection once every three to five years also can be considered if one or more of the following criteria are met:

- An established LTM program is in place
- Many wells are currently sampled on an annual frequency
- There is no active remedy in place at the site
- The size and magnitude of chemical concentration plumes have been reduced



Criteria for Annual (or Less Frequent) Sampling

(1) Well located upgradient of plume, or
(2) Well located within plume at concentrations considerably above screening level (i.e., MCL or action level), or
(3) Well located downgradient of plume with at least one "clean well" between it and leading edge of plume

NOTES:

- Sampling frequency may be modified during remediation activities to meet performance monitoring requirements
- As size and magnitude of plume is reduced, less frequent sampling can be considered

Variability Index

$$\frac{\text{Concentration Range Over the Past 4 Events}}{\text{Median Concentration Over the Past 4 Events}}$$

Figure 7-3. Example of Groundwater Sampling Frequency Decision Diagram.

7.4.1.2 Data Trend Analysis and Statistics.. After a minimum number of data points (e.g., four) have been collected at a site, trend analyses and statistical methods can be applied to the monitoring data (i.e., chemical concentrations) in an attempt to optimize the sampling frequency. The identification of data trends provides support for selection of the appropriate sampling frequency. For example, if a simple concentration versus time plot of the data indicates that concentration trends in target analytes are not changing rapidly, sampling may be performed on a less frequent schedule from quarterly to semiannually. Following a year of semiannual data collection, a similar analysis can be performed to see if a reduction to annual sampling or less frequent might be implemented. Figure 7-4 shows an example of a time-series plot that may be used for this type of analysis.

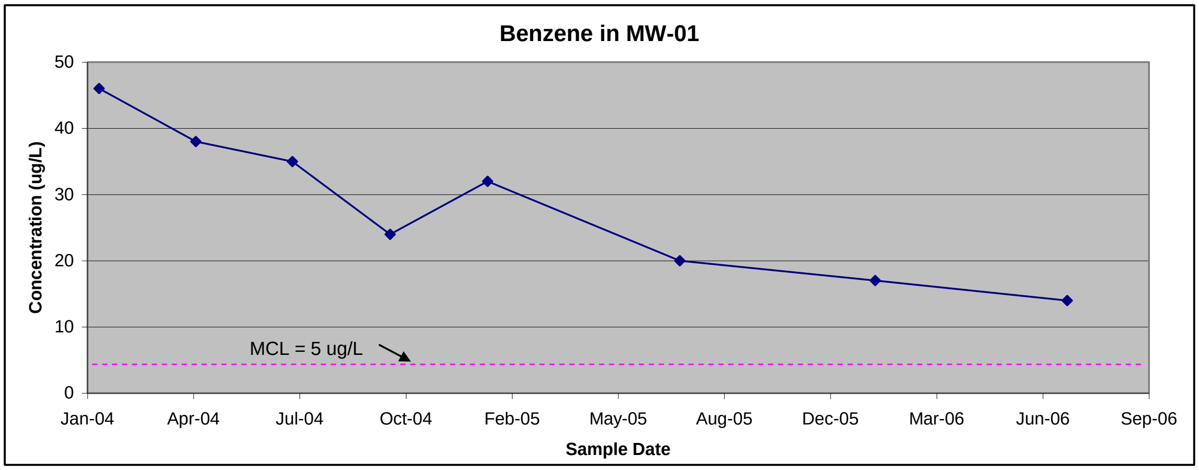


Figure 7-4. Sample Time-Series Plot.
(Source: *Guide to Optimal Groundwater Monitoring*, NAVFAC, 2000)

If the concentration trends over time are not visually apparent on time-series plots, it may be helpful to conduct temporal trend analysis using one or more trend analyses or statistical methods outlined in Section 6.3, Appendix B, and Section 7.7. Temporal trend analysis methods typically include plotting a well's chemical concentrations as a function of time and identifying a trend by using the Mann-Kendall trend test or a regression analysis.

Trend analysis or statistics may also be used to support a decision to stop monitoring at a well or a site if contaminant concentrations are found to be stable over a long period of time. It may be possible to statistically show that there is not a significant difference between concentrations of target analytes at upgradient wells and other wells associated with the site. In this case, it also may be appropriate to stop monitoring at the site. Comprehensive references for statistical applications at monitoring sites are provided in *Statistical Analysis of Ground-Water Monitoring Data at RCRA Facilities, Interim Final Guidance* (USEPA, 1989; USEPA, 1992a), ASTM standard D6312-98 (2005), and *Methods for Evaluating the Attainment of Clean-up Standards, Volume 2: Ground Water* (USEPA, 1992b).

7.5 Contaminant Monitoring

The following information should be taken into consideration when determining which groundwater analytes to sample during the initial rounds of the monitoring program:

- Site history (e.g., landfill, refueling station, vehicle maintenance, etc.);
- Historical analytical data for both soils and groundwater at the site (e.g., data from PA/SI or RI/FS);
- Historical analytical data from upgradient sites that may impact groundwater quality;
- COCs and contaminants of potential ecological concern (COPECs) identified in the RI;
- Regulatory criteria applicable to groundwater monitoring at the site;
- Data necessary to evaluate an existing remedial action (e.g., daughter products and MNA parameters);

- Background concentrations of potential target analytes in uncontaminated soil, water, and other pertinent media (for inorganic compounds only); and
- Results of risk assessments performed at the site.

As stated in Chapter 5, reviewing historical practices at the site and incorporating risk assessment results (if a risk assessment was conducted for the site) will enable the development of a groundwater monitoring plan that addresses those analytes needed to demonstrate the progress of cleanup and those contaminants found to pose a risk to human health and/or the environment.

Historical analytical data, if available, are better tools than site history for determining the initial analyte list. Comparing historical data to regulatory criteria, risk assessment results, or background (or upgradient) data will assist in identifying those contaminants that need to be monitored because they approach or exceed a previously defined limit (e.g., MCL or risk-based concentrations). Historical data, if collected regularly over a period of time, also may be used to determine if any of the contaminants have historically exhibited increasing trends, indicating a potential active source at the site. Section 7.7 (Chapter 6 and Appendix B) discusses statistical tools that can be used to differentiate between upgradient and downgradient concentrations (or site and background concentrations) and identify contaminants with increasing trends.

Including only the necessary compounds in the analyte list not only reduces analytical costs, it reduces data management, validation, interpretation, and reporting costs. Even if receiving data for the total analyte list of a given method is no more costly than receiving data for only certain analytes, it is beneficial to eliminate the extra analytes. Including only the analytes of interest results in clearer, more concise data evaluation and reporting.

As monitoring progresses, it is expected that the list of analytes will be reduced to COCs and other parameters needed to evaluate the performance of the remedy rather than analyzing for the full analytical suite. For example, groundwater contaminated with tetrachloroethene (PCE), a solvent historically used to degrease and clean metal, also may be analyzed for degradation products (TCE, dichlorethene(s), and vinyl chloride). However, analyses for other VOCs may no longer be necessary. To identify other parameters that may be eliminated, it is necessary to review the data to identify those analytes that have not been detected above the analytical reporting limit (i.e., all results not detected or detected only at concentrations indistinguishable from laboratory blanks) in the first four quarters of sampling.

With regulatory concurrence, the analyte list may be further reduced by evaluating the detected analytes against regulatory standards. Metals are commonly some of the first analytes to be removed from the monitoring program. If they have not been removed already, metals may often be eliminated from the analyte list based on a comparison to background levels, which are determined by collecting and analyzing groundwater samples from uncontaminated areas of the installation using methods that achieve representative analytical results for metals in groundwater (i.e., filtered or non-turbid samples). The background data can then be used to determine which contaminants are present at concentrations significantly above expected background concentrations, and therefore require continued monitoring (see Section 7.7 and Appendix B).

Use of faster-moving contaminants, such as VOCs, as indicator species is an additional approach that can be implemented to reduce the analyte list. For example, consider the case of an unrestricted landfill with the potential for almost any type of groundwater contaminant. To date, nothing significant has been detected downgradient of the site boundaries, but the regulators are requiring groundwater monitoring for a minimum of five years before closing the site. Rather than analyzing for a complete list of potential site contaminants, monitoring could be proposed for only the fastest migrating contaminants, or indicator species, expected to result from site activities. Monitoring of these indicator species can continue until the five-year monitoring period has elapsed. However, if indicator species are detected within the five years, analysis of other potential site contaminants should begin. An alternative approach would be to monitor for the indicator species more frequently (i.e., quarterly) than other potential site contaminants (i.e., annually).

After each monitoring event, or at least annually, the objectives of the groundwater monitoring program should be reevaluated (see Section 7.1). To streamline the overall site review process, the annual review can be performed in conjunction with the annual SAP review specified by the UFP-QAPP. The specific decision criteria for reducing the number of analytes being sampled should be tied to the objectives established for the groundwater monitoring program. For specific examples of decision criteria for reducing the number of analytes as the monitoring program progresses, see Chapter 5, Table 5-1.

7.6 Sample Collection Methods

Accurate data measurement and sample collection is a critical component of the groundwater monitoring program. The quality of analytical data can only be brought into question if parameters are not measured accurately and samples are not collected, handled, or documented properly. This section discusses innovative monitoring approaches and sampling techniques that are designed to optimize the monitoring program by improving data quality and ultimately reducing monitoring program costs.

7.6.1 Innovative Monitoring Systems. This section discusses the use of several innovative monitoring approaches for collecting groundwater samples, including multilevel groundwater monitoring, direct push well installation, and use of dedicated sampling equipment.

7.6.1.1 Multilevel Groundwater Monitoring. Groundwater concentrations vary vertically as well as horizontally, making it desirable to monitor groundwater at different elevations at a single spatial location. In addition, monitoring at multiple depths within a single boring may be useful to evaluate the complex nature of groundwater flow under adverse conditions (i.e., fractured bedrock or heterogeneous aquifers). Multilevel (or nested) monitoring allows for collection of detailed three-dimensional data, while maximizing the information obtained at a site. Several techniques have been developed to monitor groundwater at discrete intervals within a single borehole, including the Westbay System and the Waterloo System. These systems are similar in design, and generally include the use of multiple packers, couplings, and valved ports to seal and provide access to multiple monitoring zones and prevent unnatural cross-flow and cross-contamination between zones. A suite of portable monitoring probes can be installed inside the casing to collect monitoring data (e.g., pressure and select chemical parameters) and collect groundwater samples from each screened interval at formation pressure. Low-flow purging is typically used for sample collection from the sealed monitoring zones. Monitoring software allows for remote operation of the probes and data collection of select parameters.

7.6.1.2 Direct Push Wells. Direct Push wells offer an alternative to conventionally drilled wells and can be installed quickly without first having to construct an open borehole. They are installed by either a static push or dynamic push force, and offer lower costs, faster installation, decreased contaminant exposure, and decreased waste production than conventionally drilled wells. Sensors and tools used in Direct Push explorations (e.g., cone penetrometer sensors) are capable of soil type classification, chemical measurement, plume and lithology mapping, and can be used to collect soil and water samples. Operators can pre-select the number of monitoring wells desired and strategically incorporate these into the site delineation effort, leading to optimized well placement while reducing the time and level of logistical support. Results from short-term and long-term groundwater monitoring studies have indicated that groundwater samples taken from Direct Push wells are comparable in quality to those obtained from conventionally-constructed wells (ITRC, 2006a). However, it should be noted that there are several limitations associated with Direct Push wells, including limits on well diameter, restrictions to unconsolidated material, and the potential for cross-contamination of aquifers. In addition, usage of Direct Push wells for long-term monitoring (LTM) is prohibited in many states by existing regulations that require a larger annular space than can be obtained with Direct Push methods.

7.6.2 Sampling Techniques. This section discusses options for collecting groundwater samples from monitoring wells at a site, including low-flow purging, passive diffusion bag (PDB) sampling, no-purge sampling, and use of dedicated sampling equipment. The goal of implementing a new sampling technique is to reduce the effort and associated costs of groundwater sampling while maintaining or improving the quality of data obtained. If a traditional sampling technique (e.g., three well volume purge method and stabilized water quality parameters) is currently being implemented at a site, it is imperative that a SAP be developed to describe the newly proposed sampling method and outline the DQOs that specify the quality and quantity of data required to support program decisions. Typically, a monitoring event is conducted during which groundwater samples are collected using both sampling techniques, and the data are compared to a set of evaluation criteria (e.g., concentrations equal to or greater than those collected using traditional methods) to determine whether data collected using innovative methods are representative of actual site conditions and can be implemented at the site.

Use of innovative sampling techniques often results in collection of data that are more representative of actual site conditions than those collected using traditional methods. This situation commonly occurs when data from a series of discrete samples collected throughout the screened interval of a well are compared to data from a single sample collected after purging the well. Data from one or more of the discrete samples may exhibit higher concentrations than the traditional sample, which typically represents an average concentration from the entire screened interval. In this instance, the monitoring program design criteria should be reevaluated, and a modification to the sampling frequency or duration of monitoring may be warranted.

7.6.2.1 Low-Flow Purging. Low-flow purging, or "micropurging," is a widely accepted purging and sampling technique that has many benefits, including:

- Improved sample quality and representativeness (i.e., lower turbidity);
- Decreased purging volumes and time;
- Decreased investigation-derived waste (IDW) handling; and
- Less wear and tear on monitoring wells (via overdevelopment).

Another benefit that may result from low-flow purging is a decrease in metal concentrations associated with high sample turbidity. Metal concentrations may be decreased by two orders of magnitude compared with traditional purging methods. If metals are among the contaminants of concern at a site, it is strongly recommended that low-flow purging techniques be considered.

The goal of the low-flow purging technique is to eliminate vertical movement of groundwater within the well casing during purging. In doing this, the well may be purged from one small section of the screened interval without mixing stagnant casing water and fresh formation water. Therefore, purge times and volumes are significantly decreased. Wells are purged only until water quality parameters, such as pH, conductivity, temperature, and dissolved oxygen, have stabilized. Stabilization is typically accomplished after just a few liters of water have been purged from the well. It should be noted that chemical concentrations reported in monitoring wells sampled using traditional methods represent an average concentration across the entire screened interval, and may underestimate the actual concentrations observed in the aquifer, especially in monitoring wells with a long screened interval (e.g., >10 ft). Therefore, it may initially be necessary to collect low-flow samples from multiple levels within a large screened interval to develop a concentration profile within the screened interval and determine the optimal depth for future monitoring (i.e., depth with highest chemical concentrations). For screened intervals greater than 15 ft, the number of samples can typically be limited to a maximum of three by optimizing placement through an evaluation of lithology (placement in high permeability or target areas) and/or chemicals of interest (density considerations).

Before implementing low-flow purging, it is essential to determine if this technique is appropriate for the site in question. The primary question to answer is whether all of the wells that are essential to the monitoring program have adequate recharge rates to support low-flow purging. If it is not possible to maintain drawdown at less than 0.3 ft at pumping rates of between 0.1 and 0.5 L/min, the site is probably not a candidate for low-flow purging. If minimal drawdown cannot be maintained, traditional purging techniques should be used, but only as a last resort. In virtually all other situations, low-flow purging will result in better quality samples, lower labor costs, less IDW, and less wear and tear on the monitoring well.

Although dedicated bladder pumps are the preferred equipment for successfully applying low-flow purging (Puls and Barcelona, 1995) and may save money in the long run, a considerable up-front capital expenditure is required. If a dedicated system is not deemed feasible, but low-flow purging is appropriate for the site, rental of two non-dedicated pumps should be considered. With two pumps, one can be placed in a well and allowed to stabilize while purging, sampling, and decontamination are taking place at another monitoring point. It should be noted that sample pumps should be carefully selected based on project DQOs, taking into account factors such as monitoring frequency, desired results, and project budget.

7.6.2.2 Passive Diffusion Sampling Using an LDPE Membrane. Diffusion sampling technology is an inexpensive and accurate method to collect VOC samples from monitoring wells. Information regarding the accepted and current guidance standards for implementation of PDB samplers is presented in the User's Guide for Polyethylene-Based Passive Diffusion Bag Samplers to Obtain Volatile Organic Compound Concentrations in Wells, Part 1 (Vroblesky, 2001) and in the Technical and Regulatory Guidance for Using Polyethylene Diffusion Bag Samplers to Monitor Volatile Organic Compounds in Groundwater (ITRC, 2004).

A typical, standard size PDB sampler is 1- or 2-ft long and manufactured of 4-mm-thick, 2-inch-wide low-density polyethylene (LDPE) lay-flat tubing and filled with deionized water. The PDB sampler acts as a semipermeable membrane that allows certain VOCs to diffuse into the deionized (DI) water over time until equilibrium is established between the VOCs dissolved in the groundwater and in the deionized water. The LDPE membrane is only useful for the collection of VOCs because metals and other inorganic compounds will not diffuse through the membrane. Diffusion sampling offers many of the same benefits as low-flow purging with the potential to save more money on equipment and labor costs for programs where VOCs are the only COCs.

Diffusion sampling of VOCs is well suited for wells that have negligible mixing between water within the screened and unscreened intervals of the casing. As such, the suitability of diffusion samplers should be confirmed at the onset of the sampling program by comparing results of samples collected in the diffusion samplers to those collected by flow-extraction methods. Mixing of water within the well can result in lower detected concentrations of VOCs for the samples collected from diffusion samplers due to volatilization within the well bore. The PDB sampling method has several advantages as well as several limitations when compared to standard sampling techniques, a complete listing of which is provided in the *User's Guide for Polyethylene-Based Passive Diffusion Bag Samplers to Obtain Volatile Organic Compound Concentrations in Wells, Part 1* (Vroblesky, 2001). The primary advantages of PDB samplers include reduced costs and level of effort associated with implementation, a reduction in IDW production, and the vertical profiling capability. The primary disadvantages of PDB samplers include limited chemical applicability and the potential for vertical in-well mixing to distort results.

Multiple PDB samplers can be deployed within a single borehole. It is recommended that during the initial deployment, one standard PDB sampler (approximately 1 to 2 ft in length) be used for every 5 ft of screened interval within each monitoring well, with the PDB sampler centered in the midpoint of each 5-ft screened interval. Placement of PDB samplers can be optimized through the use of geophysical and/or lithologic data, whereby the PDB samplers should be placed in zones where fractures or high permeability lenses are present. This deployment technique will provide a concentration profile that is used to determine the optimal depth for future monitoring (e.g., monitor the interval with the highest concentration). The amount of time that the PDB samplers should be left in the well depends upon two factors: (1) the amount of time needed for the water in the PDB sampler to reach equilibrium with the ambient groundwater, and (2) the time required for any disturbances caused by deployment of the sampler to restabilize. Results from several laboratory and field studies indicate that a minimum 14-day equilibrium time is recommended for most applications.

7.6.2.3 Passive Diffusion Sampling Using a Regenerated-Cellulose Dialysis Membrane (RCDM). RCDM samplers were developed for sampling inorganic and organic constituents in groundwater using a diffusion-type sampler. The RCDM sampler is similar in concept and design to the LDPE sampler, with the main advantage of the RCDM sampler being that the dialysis membrane allows the passage of both dissolved inorganic and organic contaminants into the sampler. RCDM samplers have successfully been tested in the laboratory and in the field for a variety of water quality parameters, including VOCs, major cations and anions, nutrients, trace metals, specific conductance, total dissolved solids (TDS), dissolved organic carbon, dissolved gases, sulfide, and explosive compounds. Laboratory equilibration testing has shown that RCDM samplers equilibrate within 1 to 3 days for anions, silica, methane, dissolved organic carbon, and all VOCs, within 3 to 7 days for most cations and trace metals, and within 7 to 14 days for most explosive compounds. In addition to the disadvantages associated with LDPE PDB samplers, RCDM samplers have several additional disadvantages, including:

- RCDM samplers must be kept hydrated between the time of construction and the time of deployment to preserve the permeability, flexibility, and strength of the membrane
- RCDM can biodegrade with time in groundwater systems, although this is typically not a problem due to the relatively short deployment times
- Dialysis samplers lose a small percentage of their water volume with time.

7.6.2.4 Passive Diffusion Sampling Using a Rigid Porous Polyethylene Sampler (RPPS). An RPPS typically consists of a 1.5-inch outer diameter (OD), 6- to 7-inch-long, rigid polyethylene tube that is filled with reagent grade water and capped on both ends. The tube is constructed from thin sheets of foam-like porous polyethylene with pore sizes of 6 to 15 microns. The RPPS is similar in concept and design to the LDPE sampler, with the main advantage of the RPP sampler being that the construction allows the passage of both dissolved inorganic and organic contaminants into the sampler. In addition to the disadvantages associated with LDPE PDB samplers, RPP samplers have several additional disadvantages, including:

- RPPSs have limited (~120 mL) sample volumes (use of a longer sampler would result in leakage of sampled water out of the sampler walls due to the higher head pressure present in the sampler)
- Iron and other metal precipitates that form from oxidation can result in overestimates of total metals and underestimates of soluble metals

- The porous polyethylene sampler pores tend to retain air even when submerged; therefore, the air entrained in the pore space must be removed by flushing with water prior to deployment if the sampler is to be used for nonvolatile solutes
- Limited commercial availability.

7.6.2.5 No-Purge Sampling. No-purge sampling involves collection of an undisturbed groundwater sample from a user-defined interval in the well borehole, usually within the well screen. The sample is collected without purging and with very little downwell disturbance, thus minimizing turbidity. The HydraSleeve^{TM} and Snap Sampler^{TM} are two of the most common techniques used to collect no-purge samples. The HydraSleeve^{TM} consists of a weight attached to one or more sealed, disposable polyethylene bags that are lowered into the borehole. After allowing the well to equilibrate, a one-way reed valve on the HydraSleeve^{TM} is activated by pulling on the string, thus allowing groundwater to fill the bag as it moves upward through the desired interval of the water column. Once the sampler is full, the valve collapses, preventing mixing of extraneous, non-representative groundwater during recovery. At the surface, groundwater from the HydraSleeve^{TM} is decanted into appropriate sampling containers and preserved accordingly.

The Snap Sampler^{TM} technique consists of specially designed, open-ended sampling containers (either 40-mL glass VOA or 125-mL polyethylene) that are placed inside the Snap Sampler^{TM} groundwater sampler and deployed in the well at a user-defined depth in the open position. Each well must be outfitted with a dedicated Snap Sampler^{TM} trigger line. After an equilibration period, the trigger line attached to the sampler(s) is pulled, and the caps on either end of the sampling container seal the unit shut, preserving an in situ sample that is not exposed to ambient air once retrieved at the surface. Acid preservative can be added to a specially-sized cavity in one of the end caps, and standard septa screw caps are placed on each end of the sample bottle after it is removed from the Snap Sampler^{TM} prior to shipment. The Snap Sampler^{TM} is intended for redeployment in the same well from which it came, so extensive decontamination is not required prior to redeployment.

Advantages to no-purge sampling compared to traditional sampling methods are as follows:

- No purge water is generated, thereby significantly reducing IDW
- The method is effective for all analytical parameters
- No-purge sampling is effective in low yield wells
- Samples can be collected at in situ pressure with almost no aeration or degassing
- No-purge sampling allows rapid installation and sample collection
- Allows for discrete sampling, and multiple samplers can be deployed to provide a vertical contaminant profile.

Disadvantages to no-purge sampling include the potential for collection of stagnant water (if flow in the well is limited) and expensive capital cost. Additional discussion of no-purge and other passive groundwater sampling techniques can be found in the *Technology Overview of Passive Sampler Technologies* (ITRC, 2006b).

7.6.2.6 Dedicated Sampling Equipment. Independent of purging and sampling techniques, dedicated sampling equipment offers sample quality and cost benefits. Although dedicated sampling equipment is often more expensive than reusable equipment, significant cost avoidance can be realized by:

- Eliminating labor costs associated with equipment decontamination;

- Eliminating labor and analytical costs associated with collecting and analyzing equipment blanks;
- Eliminating costs associated with handling and disposing of decontamination wastes.

In addition, the potential for cross contamination of samples and associated resampling can be significantly reduced or eliminated. Dedicated equipment also can include sensors with real-time monitoring capabilities that can allow for immediate data analysis of parameters such as temperature, pH, and groundwater levels.

7.7 Tools for Groundwater Monitoring Optimization

Several tools can assist in the groundwater monitoring optimization process, including statistical analyses, monitoring network optimization software, and groundwater modeling. These tools are discussed in detail in the following sections.

7.7.1 Statistics. Statistical techniques (including geostatistics) provide objective methodologies for making specific decisions based on the monitoring data. Because statistical tests can be used to quantify variability uncertainty in data, they provide insight as to what conclusions can be drawn from the data and the degree of certainty associated with these conclusions. Chapter 6 of this guidance describes statistical tools that can be used to achieve some typical monitoring program objectives, and includes useful references that provide detailed tools and discussions on conducting statistical tests, setting up hypothesis tests, and verifying statistical assumptions.

7.7.2 Monitoring Network Optimization Software. There are several software packages available that incorporate statistical methods to optimize groundwater monitoring networks, including the MAROS software, Summit Monitoring tools, the GTS algorithm, and the Naval Installation Restoration Information Solution (NIRIS) system. Chapter 6 of this guidance further describes statistical software tools that can be used to optimize the groundwater monitoring network.

7.7.2.1 MAROS. MAROS was developed for AFCEE and provides users with a strategy for formulating appropriate long-term groundwater monitoring programs that can be implemented at lower costs. MAROS is a decision support tool that accounts for relevant current and historical site data as well as hydrogeologic factors and the location of potential receptors. Based on this site-specific information, the software uses both temporal methods (Mann-Kendall, linear regression, or cost-effective sampling) and spatial methods (delaunay triangulation or moment analysis) to determine the minimum number of wells and the minimum sampling frequency required for future compliance monitoring at the site. Graphical and spatial visualization tools within the software assist the user in assessing the trend results at each monitoring point.

7.7.2.2 Summit Monitoring Tools. Developed by Summit Envirosolutions, Inc., this set of desktop software tools support comprehensive evaluation of LTM data relative to remedial targets. The software is designed to assist engineers, geologists, chemists, and others in reviewing site data. The main objectives of the software are to assist in the identification of (1) areas where sampling may not be necessary, as well as areas where more sampling could be helpful, and (2) wells where anomalous concentration data suggest that further investigation could be warranted. Application of the Summit Monitoring tools can reduce redundancy in LTM data, track trends in individual wells, and track performance relative to site-wide remediation targets.

There are three components that comprise the Summit Monitoring tools. The first, Model Builder, creates geostatistical or statistical models of spatial and temporal data. The second, Sampling Optimizer, identifies redundant sampling locations and frequencies in historical data, along with highlighting areas of significant data uncertainty that may benefit from additional sampling. The third, Data Tracker, enables users to create time-dependent, site-wide remediation targets (e.g., expected reductions in mass) or well-specific targets (e.g., expected concentration trends) and evaluate new data relative to those targets, providing automated alerts of unexpected deviations.

The Summit Monitoring tools will be available at no cost for use at government sites (visit the Environmental Security Technology Certification Program (ESTCP) website for further information).

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

7.7.2.4 NIRIS. NIRIS is a software tool designed for managing and facilitating the use of IR data through web-based GIS applications in a consistent and cost effective manner. For more information on NIRIS, see Section 6.2. NIRIS is used by NAVFAC to ensure that Navy and Marine Corps IR Program data are maintained and accessible over the lifecycle of the IR program and beyond. NIRIS uses web and desktop based GIS and related tools to effectively analyze the spatial distribution and correlate large volumes of data.

7.7.3 Groundwater Modeling. Groundwater modeling, in its different forms, can provide valuable information for management of monitoring programs, including estimation of groundwater flow velocities, contaminant transport velocities, plume movement, and plume spreading/degradation. This information can be used to assist with the design and optimization of groundwater monitoring programs. Groundwater modeling can range in complexity from simple "back-of-the-envelope" analytical calculations, to multiphase stochastic numerical models that account for heterogeneous geology, hydrodynamic dispersion, contaminant mass loss, and thermodynamic chemical equilibria. This section discusses some common applications for groundwater modeling relevant to monitoring programs, along with a brief discussion of general modeling limitations.

7.7.3.1 Flow Velocity Modeling. Groundwater flow velocity modeling can provide order-of-magnitude estimates of groundwater flow velocity. In general, estimates of the groundwater gradient (from potentiometric surface maps), and media hydraulic conductivity and porosity (from site characterization data) are required to estimate flow velocity. The use of simple flow equations can provide a conservative estimate of how long it will take contamination to reach a particular point, such as the installation boundary or a supply well. Groundwater flow velocity modeling also can be performed using more complex analytical (i.e., AT123D) and numerical (i.e., MODFLOW and FEFLOW) models to more accurately predict migration time and pathways, but these models typically involve a significantly greater amount of effort to construct and implement.

Flow velocity information is valuable in assisting with the optimization of monitoring frequencies for a program, as discussed in Section 7.4. When estimating flow velocities, it should be noted that the velocity of groundwater movement is not always equal to the velocity of dissolved constituents. Due to physical adsorption onto the soil and other factors, such as chemical transformation and biological degradation, a plume of contamination may move slower than the groundwater in which it is dissolved. Plumes of different contaminants at the same site may also move at different velocities, or a plume may separate (degrade) over time into different constituents, as some contaminant compounds may adsorb or degrade faster than others.

7.7.3.2 Contaminant Transport Modeling. Contaminant transport models are used in conjunction with groundwater flow models to provide better understanding and prediction capability of contaminant movement. There are many analytical and numerical groundwater fate and transport models available for use, and depending upon the capabilities of a particular model, modeling input needs and processing time will vary. Complete groundwater modeling software packages (such as Groundwater Modeling Software [GMS]) provide tools for every phase of a groundwater simulation including site characterization, model development, calibration, post-processing, and visualization. Once calibrated accordingly, these models can provide useful, three-dimensional realizations of groundwater and contaminant plume movement. For example, models can assist in visualizing and evaluating the consequences of different pumping schemes in a pump and treat system, and evaluating plume diversion or capture. In evaluating the placement of monitoring wells, a calibrated model could provide insight into where contamination would most likely leave a site, or how potential off-site hydraulic influences (such as a pumping well) might change future groundwater gradients at a site. Lateral spreading of a plume by hydrodynamic dispersion or attenuation of a plume by sorption and biodegradation also could be approximated by fate and transport models. Results from the modeling simulations can be used to determine the number and location of plume-edge and/or POC wells.

BIOSCREEN and BIOCHLOR are two examples of analytical groundwater flow and contaminant transport models that can be used as screening tools to simulate remediation through natural attenuation. The software is programmed into Microsoft® Excel spreadsheets and has the ability to simulate natural attenuation mechanisms. BIOSCREEN simulates biodegradation of dissolved hydrocarbons by both aerobic and anaerobic reactions, whereas BIOCHLOR simulates biodegradation of dissolved chlorinated solvents via reductive dechlorination following a sequential first-order decay process. Simulations can be prepared fairly quickly and used as screening tools to estimate downgradient chemical concentrations and migration rates that in turn can be used to determine the number and location of monitoring wells.

Natural Attenuation Software (NAS) is an additional MNA screening tool that consists of a combination of analytical and numerical solute transport models designed to estimate remediation timeframes for MNA to lower groundwater contaminant concentrations to regulatory levels. In addition, the software assists in decision-making on the level of source zone treatment in conjunction with MNA using site-specific remediation objectives. NAS models are implemented in three main interactive modules to provide estimates for a target source concentration that is required for a plume extent to contract to regulatory limits, the time required for a plume extent to contract to regulatory limits after source reduction, and the time required for non-aqueous phase liquid (NAPL) contaminants in the source area to attenuate to a predetermined target source concentration.

7.7.3.3 Groundwater Modeling Limitations. Not all sites are well suited for groundwater flow or fate and transport modeling. Aquifers that are relatively geologically homogeneous and isotropic and are well characterized lend themselves to more useful fate and transport modeling. In general, as geologic complexity of a site increases, the cost of modeling increases while the modeling accuracy decreases. Sites that are geologically highly variable (either horizontally or vertically) are, for practical purposes, not good candidates for using deterministic groundwater models. The accuracy of groundwater flow models depends on the amount and quality of site data, primarily the hydraulic conductivity parameter. The physical parameters going into the model need to be carefully scrutinized to determine how they were identified, and modeling findings should be qualified accordingly with uncertainty analyses. In the absence of quality site-specific data, a range of probable estimates can be used, although care should be taken to refine parameter estimates to those that can be realistically expected. The extension of groundwater flow models into contaminant fate and transport models introduces an additional set of assumptions and physical/chemical parameters that must be characterized. Again, the overall accuracy of the model will depend directly on the quality of the data used for the input parameters.

7.8 Lessons Learned in Groundwater Monitoring

Groundwater monitoring must be a transient process, and it will only be effective if the monitoring data are continually compared to decision criteria and evaluated to ensure progress is being made toward the monitoring objectives. Some common pitfalls associated with groundwater monitoring are related to errors or inconsistencies in sample collection, a lack of understanding of site conditions, failure to review monitoring data, and improper use of optimization techniques such as statistical evaluation and groundwater modeling. Fortunately, the common pitfalls associated with groundwater monitoring can be easily avoided through review of the site CSM, review of remedial action monitoring data, and continued optimization. Common pitfalls associated with groundwater monitoring and methods that can be implemented at a site to avoid the more common mistakes associated with groundwater monitoring are listed in Table 7-3.

Table 7-3. Common Pitfalls Associated with Groundwater Monitoring and Suggested Avoidance Methods

Groundwater Monitoring Pitfalls	Avoidance Methods
CSM not updated	• Evaluate most recent version of CSM and apply recently collected site data to update the model. • Follow ASTM guidelines for CSM update
The monitoring well is not appropriately designed to meet DQOs	• Evaluate well logs, geologic cross sections, and isoconcentration contour maps to determine appropriate screened interval and spatial distribution of wells • Consider installation of multi-level monitoring wells to accurately identify and monitor actual or potential pathways for contaminant migration • Reevaluate CSM • Locate and screen new wells to bound the horizontal and vertical extent of contaminant plume • Implement an innovative sampling technique (e.g., PDB samplers), which may result in collection of data that are more representative of actual site conditions than those collected using traditional methods. Collect data from discrete samples throughout the screened interval of a well and compare them to existing monitoring data. Data from one or more of the discrete samples may exhibit higher concentrations than a traditional sample, which typically represents an average concentration from the entire screened interval.
Statistical evaluation methods are applied incorrectly	• Reevaluate and update (if necessary) the site CSM and groundwater monitoring DQOs • Collect additional time-series monitoring data. Although future sampling frequency and monitoring duration can be evaluated using four quarters of sampling data, eight quarters are preferred because it allows for a better interpretation of seasonal trends and result in a more accurate and meaningful statistical evaluation. • Use additional monitoring locations in the statistical analyses • Incorporate multiple statistical analyses and compare the results.
Redundant monitoring data (too many wells or analytes)	• Review the monitoring objectives and corresponding exit criteria • Reevaluate the objectives of the groundwater monitoring program to determine if any of the decision criteria for reducing the sampling frequency or monitoring duration at a site or individual monitoring point have been met. • Review the monitoring data to identify those analytes that have not been detected above the analytical reporting limit (i.e., all results not detected or detected only at concentrations indistinguishable from laboratory blanks) or below regulatory levels (e.g., MCLs) in the four most recent monitoring events • Perform a statistical evaluation of the data to determine declining trends or locate redundant monitoring locations • Perform an annual review of the monitoring data in conjunction with the annual SAP review required by the UFP-QAPP
Monitoring does not delineate the source area of contamination	• Include groundwater monitoring in upgradient, background, and/or cross-gradient locations • Locate monitoring wells should be placed so that background levels of COCs and any parameters of interest can be obtained.

Table 7-3. Common Pitfalls Associated with Groundwater Monitoring and Suggested Avoidance Methods (Continued)

Groundwater Monitoring Pitfalls	Avoidance Methods
Improper model application	• Evaluate modeling objectives to determine their applicability • Reevaluate CSM to insure input data are appropriately estimated and selected • Perform model sensitivity analysis • Ensure there is a sufficient amount of data to support model construction • Ensure model is accurately calibrated
Incorrect analyte list	• Review site history, historical analytical data for both soils and groundwater at the site historical analytical data from upgradient sites, COCs identified in the RI, applicable regulatory criteria, remedial action (e.g., MNA) information, background contaminant concentrations, list of daughter products of known contaminants, and results of risk assessments
Outdated monitoring strategy and/or approach	• Review decision criteria and optimize strategy based on recent monitoring data • Perform annual reviews
Premature elimination of monitoring points	• Review monitoring objectives and decision criteria • Evaluate regulatory and community concerns
New monitoring technique produces lower quality monitoring data	• Prepare/review SAP designed to describe the proposed new sampling method and outline the DQOs that specify the quality and quantity of data required to support program decisions. • Conduct a monitoring event during which groundwater samples are collected using both sampling techniques, and the data are compared to a set of evaluation criteria (e.g., concentrations equal to or greater than those collected using traditional methods) to determine whether data collected using innovative methods are representative of actual site conditions and can be implemented at the site. • Reevaluate CSM and compare to limitations of proposed technology because conditions may not suitable for innovative monitoring technique
Cross contamination of samples	• Implement dedicated sampling equipment • Review SAP/QAPP • Collect field blanks to determine source of cross contamination

Case Study: Monitoring Optimization at the Former Naval Air Warfare Center, Warminster, PA

Project Summary

The former Naval Air Warfare Center (NAWC) Warminster is the location of chlorinated solvent plumes resulting from historical waste releases, including paints, solvents, sludges, and waste oils. Three separate groundwater operable units (OUs) are currently being remediated using groundwater extraction and treatment coupled with institutional controls to satisfy the project objectives, which are to maintain hydraulic control of source area groundwater and to reduce concentrations below MCLs. The primary contaminants at the site are PCE, TCE and carbon tetrachloride (CCl_4). Groundwater is present in fractured bedrock, and the aquifer is divided into separate hydrogeologic units varying with depth. The effectiveness of the treatment system is monitored using the extraction wells and a network of OU-specific monitoring wells to collect groundwater-level elevations, contaminant concentrations, and extraction well flow rate data.

Optimization Strategy Employed

A two-phased approach was used to optimize the monitoring program at the site. The first phase involved replacing conventional sampling methods with PDB samplers. This phase involved preparation of a PDB SAP that outlined methods for confirmation sampling and presented data evaluation techniques and acceptance criteria. A monitoring event was performed during which conventional samples and those collected using PDB samplers were collected concurrently, and the data were analyzed according to the criteria outlined in the SAP. PDB samplers were proven to be equally or more effective than conventional sampling for two of the three OUs.

The second optimization phase involved updating the Long-term Monitoring Plan (LTMP) based on historical data and results from the first optimization phase. A decision diagram that incorporated geostatistics and trend analysis was designed and applied to reduce the number of monitoring wells and the frequency of data collection. In addition, because of stable flow fields, groundwater-elevation data were substituted for contaminant concentration data in alternating monitoring events, and reporting requirements were significantly reduced.

As a result of the phased optimization strategy, monitoring costs were significantly reduced, as illustrated in Tables 1 and 2. The total number of groundwater samples was reduced by over 50%, and the estimated 10-year cost savings was over $1.2 million with minimal investment.

Frequency	OU-1A		OU-3		OU-4	
	Current	Future	Current	Future	Current	Future
Annual	0	28	0	1	0	20
Semiannual	16	6	11	1	13	5
Quarterly	46	20	6	9	25	8
Yearly Total	216	120	46	39	126	62

Table 1. Summary of Reduction in Sampling Frequency

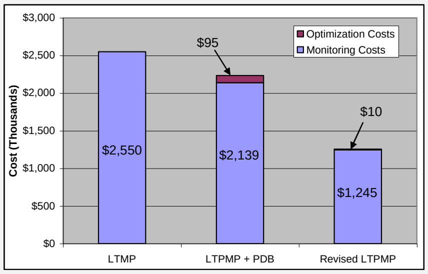


Table 2. Summary of Estimated 10-Year Cost Savings

Groundwater Monitoring Program Development Checklist

Identify Monitoring Objectives

- ☐ Validate the CSM and conclusions of RI/FS (follow ASTM guidelines for CSM update)
- ☐ Determine if contamination is migrating to a downgradient receptor or off site
- ☐ Track contaminants exceeding defined limits (e.g., MCLs)
- ☐ Track the changes in shape, size, or position of the contaminant plume
- ☐ Assess the performance of a remedial system (e.g., MNA, hydraulic control)
- ☐ Assess the practicability of achieving complete remediation
- ☐ Satisfy regulatory requirements

Selection and Distribution of Monitoring Locations

- ☐ Review applicable regulatory requirements
- ☐ Evaluate wells that currently exist on and around the site
- ☐ Choose monitoring locations to consistent with monitoring DQOs (e.g., obtain bound the horizontal and vertical extent of contamination, assess plume movement, and evaluate remediation
- ☐ Perform groundwater flow calculations to assist with well placement

Determine Monitoring Frequency and Duration

- ☐ Review the updated CSM, including time series monitoring data
- ☐ Perform groundwater flow calculations to assist with well sampling frequency and duration
- ☐ Determine whether groundwater elevation data alone are sufficient to monitor the site
- ☐ Develop decision criteria for modifications (e.g., decision diagram)
- ☐ Incorporate flexibility to allow for continual assessment of program needs
- ☐ Plan for collection of 4 quarters of groundwater level and contaminant concentration data to allow for statistical evaluation and consider season trends

Identify Analytes for Initial Monitoring

- ☐ Review site history and historical analytical data for groundwater and soils
- ☐ Review regulatory criteria and risk assessment results
- ☐ Review historical upgradient and background data
- ☐ Review important geochemical or MNA parameters

Determine Groundwater Sampling Technique

- ☐ Evaluate historical lithologic and chemical concentration data
- ☐ Evaluate historic sampling techniques
- ☐ Evaluate well design and construction details
- ☐ Determine whether innovative sampling technologies are feasible and cost effective

Groundwater Monitoring Program Optimization Checklist

Evaluate Monitoring Objectives

- ☐ Evaluate monitoring objectives on an annual basis (including a review of changing regulations)
- ☐ Confirm monitoring objectives have been met

Update CSM

- ☐ Revise and update CSM based on monitoring results
- ☐ Validate CSM with current understanding of site conditions

Optimize Monitoring Network

- ☐ Determine whether decision criteria have been met on a well-by-well basis
- ☐ Apply temporal trend analysis and geostatistics to optimize monitoring points
- ☐ Apply monitoring network optimization software
- ☐ Properly abandon unwarranted monitoring wells

Optimize Monitoring Frequency and Duration

- ☐ Evaluate decision criteria and apply decision diagram
- ☐ Evaluate flow field and perform groundwater flow calculations to estimate flow rates and directions
- ☐ Apply geostatistics and temporal trend analysis

Optimize Analyte List

- ☐ Evaluate decision criteria
- ☐ Identify analytes not detected above water quality objectives (e.g., regulatory levels or risk-based concentrations)
- ☐ Compare detected analytes against water quality objectives and background levels
- ☐ Evaluate potential for indicator species monitoring
- ☐ Apply geostatistics and temporal trend analysis to optimize analyte list
- ☐ Ensure identified COCs and associated daughter products are included

Optimize Groundwater Sampling Technique

- ☐ Evaluate historical chemical concentration data
- ☐ Evaluate whether innovative sampling techniques are feasible and cost effective
- ☐ If conventional sampling is being performed, conduct a monitoring event during which groundwater samples are collected using current and proposed sampling techniques concurrently, and compare data to a set of evaluation criteria

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http://www.epa.gov/ada/csmos/models/biochlor.html

BIOSCREEN Model
http://www.epa.gov/ada/csmos/models/bioscreen.html

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http://www.tiem.utk.edu/~sada/

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https://www.niris-nedd.org/

Groundwater Monitoring System
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Chapter 8.0: Monitoring Groundwater Discharge to Surface Water

This chapter discusses the design and optimization of surface water monitoring programs, and is focused on ER sites where a groundwater plume is currently discharging or could potentially discharge to surface water. Included is a discussion of monitoring objectives, CSM development, monitoring program design and optimization, selection of monitoring media, locations, and analytes, monitoring frequency and duration, sample collection methods, and references that can assist the user during the design and optimization process. For specific information on groundwater or sediments, see Chapter 7 or 9, respectively.

8.1 Surface Water Monitoring Objectives

Understanding contaminant fate and transport in the surface water-groundwater interaction zone is important to the USEPA's hazardous waste site cleanup programs across the nation because approximately 75% of RCRA and Superfund sites are located within a half mile of a surface water body, and almost half of all Superfund sites have impacted surface water (USEPA, 2000a). Considering the majority of Navy sites are located near coastal zones and other surface water bodies (including bays, estuaries, and wetlands), the Navy is focused on ensuring the use of technically strong and defensible approaches to monitoring groundwater discharge to surface water.

The general goals and objectives of a site-specific monitoring program are defined in the site monitoring plan, which is discussed in Chapter 2. Surface water discharge monitoring is commonly performed in conjunction with groundwater, sediment monitoring, and ecological (see Chapters 7, 9 and 10, respectively). Surface water discharge-specific monitoring objectives typically fall into one or more of the following categories:

- Validate the CSM and the conclusions of an RI/FS
- Determine if dissolved groundwater contamination is currently discharging or could potentially discharge to surface water
- Track contaminants exceeding defined limits (i.e., PALs or surface water standards)
- Track the changes in shape, size, or position, or mass flux of groundwater discharge to surface water
- Assess the performance of a remedial system (including MNA)
- Assess the practicability of achieving complete remediation
- Collect information for use in fate and transport modeling
- Perform mixing zone analysis to determine alternate concentration limits
- Satisfy regulatory requirements (for example, detection monitoring to meet RCRA requirements and other ARARs).

The primary objective of optimizing surface water monitoring is to ensure capture of required data at minimum cost. Accordingly, the optimization process focuses on collecting relevant data of the appropriate quantity and quality to achieve program goals.

8.2 Surface Water Conceptual Site Model

Once the surface water monitoring objectives have been identified, the site CSM should be carefully developed and/or updated with the most recent site characterization data. Effective conceptualization for surface water monitoring includes gaining an understanding of the physical characteristics of the site, the various on-site contaminant sources that may influence the surface water, potential transport pathways, likely discharge points, and potentially affected biological and ecological populations. Figure 8-1 provides a general cross section associated with a CSM showing groundwater discharge to surface water in a coastal system. It should be noted that the groundwater discharge in coastal systems will be affected by density differences, the actual magnitude and location of which is determined based on site specific conditions. A thorough understanding of site conditions is essential for determining potential surface water monitoring locations. Hydraulic head and chemical concentration profiles should be prepared along a groundwater plume transect to better illustrate and understand potential offshore discharge areas. Results from a human health or ecological risk assessment should be included to better understand the potential exposure risks (toxicity) associated with surface water discharge. As the monitoring program progresses and new data are collected and analyzed, the CSM should be updated and the monitoring program, including data objectives and management decisions, should adapt to these data.

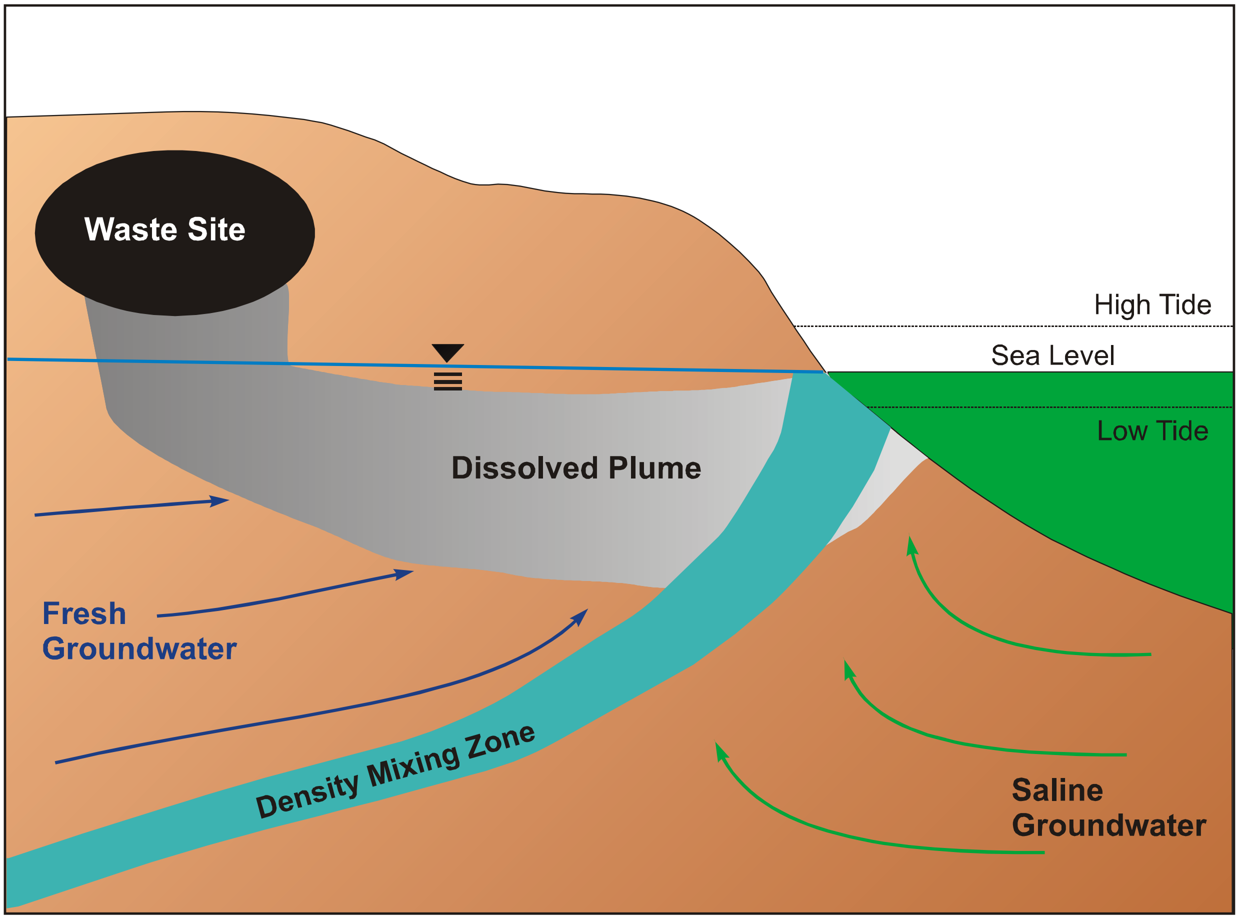

Figure 8-1. Conceptual Model of Fate and Transport of Chemicals in a Coastal System (Source: Modified from RITS on Coastal Contamination Migration Monitoring, NAVFAC ESC, 2003)

8.3 Surface Water Discharge Monitoring Program Design

As with all monitoring programs, the surface water discharge monitoring program design should be developed to include the site-specific goals, a description of the CSM, identification of baseline data (if applicable), data objectives (the systematic planning/DQO process should be used to identify these), decision and exit criteria, as well as a specific work plan including a SAP. Establishing clearly defined monitoring objectives and corresponding exit criteria is central to any well defined, well managed and optimized monitoring program. Exit criteria should be used to help decision-makers determine when surface water monitoring can be ceased or certain monitoring points discontinued. The following subsections outline the design of the surface water discharge monitoring program.

8.3.1 Surface Water Monitoring Locations. A common approach to designing a monitoring network in offshore areas is to establish monitoring locations along a regularly spaced sampling grid in areas where groundwater discharge to surface water is reasonably anticipated to occur. The sampling points can be identified and referenced using a handheld GPS unit either through wading or use of a boat. Actual initial grid spacing should be based on the magnitude of the estimated discharge area, the monitoring objectives, and the budget. The sampling grid can be modified during implementation of the monitoring effort based on results of initial monitoring. Once a comprehensive initial monitoring effort has been undertaken to identify and delineate the offshore discharge areas (based on indicator parameters), subsequent offshore monitoring locations can be streamlined, focusing on areas where offshore discharge is occurring. Surface water samples are commonly collected at a pre-determined uniform distance (i.e., 1 ft) above the sediment surface.

Depending on the monitoring objectives, flow pathways, source strengths, and/or loading rates may need to be determined to better understand and evaluate current and future groundwater discharge (flux) to surface water. This type of information will require collection of groundwater samples at shoreline, near-shore, and/or source area locations. Nested monitoring points, with screened intervals at target depths or lithologic contacts, are useful to provide insight into the potential stratification of offshore discharge and also will assist in the understanding of vertical and horizontal groundwater hydraulic gradients.

8.3.2 Surface Water Monitoring Parameters. When designing the surface water monitoring program, physical and chemical indicators of groundwater seepage to surface water must be identified and quantified. These indicators commonly include near-shore and offshore hydraulic head, water quality and chemical indicator parameters, contaminant concentrations, sediment characteristics, and direct seepage measurements. The following subsections provide a more detailed discussion on the type and location of parameters that are used to monitor potential groundwater plume discharge to surface water. It should be noted that not all parameters need to be monitored at each proposed monitoring location.

8.3.2.1 Hydraulic Head. Hydraulic head should be measured within the sediment porewater and in the overlying water column at the proposed offshore sampling locations. These measurements are commonly collected using temporary piezometers. A positive upward gradient at these locations would indicate potential for groundwater discharge to the water column above and can assist in delineating areas of offshore discharge. When using hydraulic head to monitor for groundwater plume discharge to a coastal surface water body, measurements should be collected at various times during the tidal cycle, noting that groundwater discharge to coastal surface water is typically greatest during low tide. To complement and optimize the hydraulic head measurements in surface water, hydraulic head also should be measured at near-shore locations including shoreline individual or nested piezometers and/or monitoring wells. These data can be used to create horizontal and vertical gradient maps to illustrate potential offshore discharge locations and estimate the magnitude of horizontal and vertical gradients. These data also can be used to refine the offshore surface water monitoring grid. Hydraulic head measurements, coupled with permeability estimates, can subsequently be used to estimate groundwater velocity and chemical mass flux.

8.3.2.2 Indicator Parameters. Measurement of several water quality and chemical indicator parameters also can be useful in monitoring groundwater discharge to surface water because groundwater and surface water commonly have unique water quality signatures. Water quality parameters that are commonly used to indicate potential groundwater discharge areas include temperature, conductivity, and pH. Differences in chemical composition (chloride and certain redox sensitive species, such as iron, nitrate, and sulfate) between groundwater, sediment porewater, and surface water also can be evaluated. The site CSM should be reviewed to determine the timeframe during which maximum differences between surface water and groundwater can be expected to occur, thus maximizing the potential for viable data collection. Spring and fall are typically advantageous for data collection because of differences in temperature between the surface water and groundwater. Similar to hydraulic head measurements, coastal indicator parameter data should be collected at various times during the tidal cycle, noting that groundwater discharge to coastal surface water is typically greatest during low tide.

8.3.2.3 Chemical Concentrations. Surface water chemical concentrations can be a direct indicator that a groundwater plume is discharging to surface water. However, a conclusion that a groundwater plume is discharging to surface water does not necessarily mean it is or has been contributing to contamination in the sediment and surface water. These media could have become contaminated through other pathways, including surface runoff and storm water discharge. An evaluation of background chemical concentrations in surface water will assist in developing a baseline for comparison. In addition, historical and current chemical concentrations in groundwater prior to discharge (in near-shore piezometers and/or monitoring wells) should be verified. The composition and magnitude of upland sources and the current groundwater plume will have a bearing on the magnitude and duration of mass flux to surface water, thus directly affecting the monitoring strategy and selected analytes.

Considering that chemical concentration monitoring is typically more labor and cost intensive than other recommended surface water monitoring parameters (e.g., hydraulic head and water quality), it may be advantageous to minimize the number of monitoring locations. The results of hydraulic head and indicator parameter monitoring can be used to delineate areas of maximum groundwater discharge, and chemical concentration monitoring can be focused on these locations. It should be noted that discharge water quality will likely vary seasonally, so an appropriate monitoring schedule should be chosen (see Section 8.3.3).

For Navy ER sites, VOCs and polyaromatic hydrocarbons are common COCs seen in groundwater and have the potential to discharge to surface water; other SVOCs and metals are observed less frequently but should not be overlooked. Most COCs have defined regulatory federal water quality criteria or state standards for the protection of living resources and human populations. The constituents, contaminants, and regulations must be considered during the design of surface water monitoring programs, as the criteria and standards often drive considerations in developing management decision criteria.

8.3.2.4 Groundwater Seepage. A common component of a surface water monitoring program is to determine the presence and actual measurement of the rate of groundwater seepage (loading) to surface water. These measurements can be used in conjunction with chemical concentrations to estimate the magnitude of groundwater flux. In addition to indirect estimation of groundwater seepage estimates using other measured field parameters (i.e., hydraulic head) or computer models, direct measurements of flux can be made using in situ seepage meters. Seepage meters can range from relatively simple and inexpensive devices such as streambed permeameters, which are manually installed and monitored, or more complex devices such as an UltraSeep®, which electronically records and samples groundwater discharge and chemical concentrations. Groundwater seepage estimates ultimately assist in determining the monitoring duration and frequency. Site-specific sediment properties that can influence chemical mass flux, such as particle size distribution, porosity, and permeability, are useful for calculating mass flux to surface water. These parameters should be initially collected as part of the surface water monitoring program.

8.3.3 Surface Water Sampling Frequency and Monitoring Duration. Depending on the water body type, surface water monitoring design can be affected by many factors. The frequency of sampling can be based on the expected variability in the data and temporal information. This variability includes the effect of diurnal processes (e.g., tides), seasonal factors (e.g., temperature and precipitation), and meteorological events (e.g., storms that increase water movement and water flow velocities and volumes). Variability in temporal data can range from hourly to daily to weekly to monthly to seasonally to annually to longer time scales.

The frequency and duration of monitoring depends on the monitoring objectives and the scales of variability in the system. Typically, high variability in a system requires higher frequency in monitoring. Similarly, steep or varying chemical or hydraulic gradients require more locations and higher frequency monitoring. In the initial rounds of sampling, intensive monitoring may be needed to describe the characteristic scales of variability and can serve as the basis for statistical optimization of LTM. Specifically, short and long term scales can be used to describe an appropriate sampling frequency which is tied to the level of uncertainty the program accepts. Overall duration of a program depends on the decision requirements and uncertainty that is acceptable to the program. The duration may be defined by the effectiveness of the remedy or the length of time needed to define a statistically significant decreasing trend. Also, if the program is a compliance program, the program duration may be dependent on the permit expiration date. Furthermore, if program requirements include achieving a certain water quality criteria (e.g., DO >5 mg/L or chemical concentrations below action levels), the program duration may depend on the number of sampling periods where the standard must be met before the program can be reduced or dropped. As can be seen with the above examples, sampling frequency and duration vary from site to site and are highly dependent on the monitoring objectives.

Spatial and temporal monitoring is vital to establish the interaction between groundwater and surface water. For coastal and shoreline environments, groundwater discharge to surface water will vary throughout the tidal cycle, but is typically greatest during falling tide. Differences in the characteristics of groundwater and surface water (i.e., temperature, salinity, dissolved oxygen and pH) will vary seasonally; in order to capture maximum potential discharge areas, care should be given to monitor during the timeframe when the differences are greatest.

Following the first year or two of data collection, sampling frequency may be reduced as appropriate, following decision criteria built into the monitoring plan. Site-specific decision criteria should be included for determining when monitoring may be discontinued or conducted at a reduced frequency at the site. A decision diagram, such as that shown in Figure 7-3, can be applied and used for determining the monitoring frequency at a site. Monitoring at an individual location or across the site may be discontinued when the selected monitoring goals (see Section 2.2) have been reached. A review period, most likely annual, should be specified in the monitoring plan to periodically evaluate the potential for monitoring optimization or site closure based on sampling data and closure decision criteria.

8.3.4 Monitoring Techniques. Surface water monitoring programs should be built around both traditional and emerging data acquisition methodologies and technologies. Overall, the monitoring program should be flexible and adapted as an understanding of site conditions evolve, as technology improves, and as monitoring questions are answered or modified. To ensure consistency, the spatial location of monitoring stations should be referenced using a GPS device. The following subsections document common approaches and techniques for monitoring parameters that can be used to identify groundwater discharge to surface water. It should be noted that sediment sampling devices are discussed in Chapter 9, and groundwater monitoring procedures are discussed in Chapter 7.

8.3.4.1 Surface Water Sampling (Water Column Sampling). Surface water sampling methods include the deployment of traditional water survey techniques, including discrete water samples with laboratory analysis, hydrocasts with sample bottles (e.g., Niskin bottles, Go-Flow Bottles, pumped samples) (Figure 8-2), bucket samples, or water quality probes. For field sample analyses, in situ data acquisition systems can be used where one probe (e.g., Hydrolab Datasonde3® and in situ peepers) takes readings for parameters such as salinity, conductivity, temperature, and DO. It should be noted that sampling in saline environments (as opposed to freshwater) generally requires modifications to the sampling protocol; often, the sampling devices need to be re-calibrated to adjust to the increase in ionic strength. Vertical profiles in surface water can be taken using a vertical hydrowire where all samples are taken in a single cast. Standard bottles (e.g., Niskin and Go-Flow) can be attached to a hydrowire as well as a rosette sampler for replicate samples at the same depth. For chemical and physical analyses, surface water samples are collected and shipped off site for analyses.

Figure 8-2. Hydrocast Surface Water Sampling Device.
(Source: http://oceanexplorer.noaa.gov/technology/tools/sonde_ctd/media/ciwsam1.html)

8.3.4.2 Surface Water to Groundwater Interface Monitoring Techniques. The following subsections discuss sampling techniques for monitoring groundwater discharge to surface water.

Temporary Piezometers. Temporary piezometers can be installed in the sediment at previously defined locations or along the sampling grid at the desired depth to collect the sediment porewater samples and head measurements. The piezometers are commonly co-located with surface water samples for comparative purposes. The piezometers are typically purged prior to sample collection so that a representative porewater can be collected.

Polyethylene-Membrane Passive-Vapor Diffusion (PVD) Samplers. PVD samplers have been shown to be an effective and economical reconnaissance tool for detecting and identifying VOCs in bottom sediments of surface-water bodies in areas of groundwater discharge (Church et al., 2002). The PVD samplers consist of an empty glass vial enclosed in two layers of polyethylene membrane tubing. Samplers are commonly placed manually in the sediment at a depth of 1 to 2 ft, with the bottle opening facing downward. When samplers are placed in contaminated sediments, the air in the vial equilibrates with VOCs in sediment porewater. The time required for vapor in the air-filled bottle to equilibrate with VOC concentrations in the saturated sediment has been shown to be 24 hours or less in a controlled laboratory setting (Vroblesky and Robertson, 1996). Analysis of the vapor samples indicates the presence or absence of VOCs and the likely magnitude of concentrations in porewater. These results are used to provide insight about contaminant distributions and groundwater-flow patterns in discharge areas, and can be used to assist in the design of focused characterization activities.

Trident Probe. The Trident probe is a direct-push, integrated temperature sensor, conductivity sensor, and porewater sampler that can be used to monitor for potential groundwater discharge (SPAWAR, 2003). The sensors are mounted on a lance that is pushed into the sediment to the desired depth with a 12-m push rod. Ambient conductivity and temperature are measured with a second sensor set mounted above the sub-bottom sensors. A GPS unit is mounted on the top of the probe's deployment push rod to record the sampling locations. The Trident probe can be used as a screening tool to determine contrasts in temperature and conductivity between surface water and groundwater that indicate areas of groundwater discharge to a surface water body. Once the potential discharge areas have been delineated, the porewater sampler can be used to collect samples for detailed chemical characterization of contaminants.

Figure 8-3. Trident Probe Prior to Inserting into Sediment (left); Top of Trident Probe after Placement in Sediment (right); (Source: RITS on Coastal Contamination Migration Monitoring, NAVFAC ESC, 2003)

Figure 8-4. UltraSeep® Surface Water Sampling Device
(Source: RITS on Coastal Contamination Migration Monitoring, NAVFAC ESC, 2003)

UltraSeep. After mapping the extent of potential offshore discharge areas using the Trident probe, temporary piezometers, other techniques, or a sampling device such as the UltraSeep can be deployed at observed discharge locations. The Ultraseep meter can be used to quantify the discharge rate (or flux) of groundwater into the surface water body and collect groundwater discharge samples for analysis. The seepage through the UltraSeep is measured with a specially developed flow meter, and groundwater discharge is conditionally sampled when threshold levels of previously defined levels of conductivity, temperature, or flow are exceeded (SPAWAR, 2003).

8.3.5 Analytical Methods. The choice of analytical methods is an important aspect of surface water monitoring program design and depends on the specific project requirements. Analytical methods should be selected through application of a DQO approach. Part of the DQO process is to establish acceptable method detection limits (MDLs) and acceptable levels of the uncertainty in the sampling and laboratory methods. Of special note for surface water measurements is that not all methods are applicable to both fresh and salt water due to matrix interferences imparted to the instrumentation by the salt content of ocean water. If the project includes marine waters, the selection of analytical methods should include consultation with experts who regularly practice sea water measurements.

A source of analytical methods is the National Environmental Methods Index (NEMI), available at http://www.nemi.gov/. NEMI is a free, searchable clearinghouse of methods and procedures for both regulatory and non-regulatory monitoring processes for water, sediment, air and tissues. In addition to the information presented in this guidance, several books and many papers have been published for developing monitoring programs that can help ensure optimal design and implementation. The concepts expressed in *Managing Troubled Waters: The Role of Marine Monitoring* (National Research Council [NRC], 1990) and the *Guidance for the Data Quality Objectives Process* (USEPA, 2000b) give basic information on approaches and are especially relevant to surface water monitoring. These documents provide a structured approach to setting up and defining an optimal monitoring program. Understanding and practicing the information provided in these documents, coupled with guidance provided in *Evaluation Guidelines for Ecological Indicators* (USEPA, 2000c) and *Indicator Development for Estuaries* (USEPA, 2005), provide a solid foundation for water quality monitoring and are helpful documents for designing and optimizing environmental measurement programs.

8.4 Optimization of the Groundwater Discharge Monitoring Program

In optimizing the monitoring program, all data should be collected with an understanding of how the data will be used and how they contribute to a validation of remedy performance and success. As discussed above, an initial effort to delineate potential offshore areas using indicator parameters should be performed. Once the discharge areas have been defined, a more detailed effort is applied to quantify the concentration and magnitude of groundwater discharge. The number and placement of monitoring locations needed to ensure adequate monitoring of groundwater discharge to surface water will be a function of the results of the initial discharge area delineation and many site-specific characteristics and the objectives of the monitoring program. Optimization of the monitoring program rests on evaluating the initial round of data and adjusting the sampling schedule, sampling locations, analyte list, and sampling methodology to achieve an acceptable level of uncertainty.

Ultimately, the CSM and the data objectives (including DQOs) required to make management decisions will be the basis for determining monitoring locations. Each monitoring point should be established with the deliberate intention of providing specific data that will refine the CSM and help the project team make management decisions. As monitoring points are established based on specific data objectives, the decision criteria for monitoring each point can then be identified and optimized. In addition, there are factors unrelated to site characteristics that may affect the design of the monitoring program, including regulatory and community relations considerations. A comprehensive review of applicable regulatory requirements should be conducted (see Chapter 2). In many cases, state regulatory agencies will have mandatory guidelines for the types and placement of compliance monitoring locations.

Historical groundwater and surface water monitoring data can be used to develop site-specific groundwater monitoring criteria (i.e., action levels) that can be used to optimize the monitoring program by providing a trigger for potential elevated chemical concentrations in surface water. A dilution/attenuation or mixing factor can be estimated (general rule of thumb is an order of magnitude) or calculated by correlating measured surface water concentrations to the nearest upgradient groundwater monitoring well; groundwater action levels can be back-calculated accordingly knowing the surface water criteria. Similarly, a groundwater flow and chemical transport model can be calibrated and used to estimate groundwater action levels based on known surface water criteria.

If surface water monitoring data indicate elevated chemical concentrations due to groundwater discharge, consideration should be given to applying a mixing zone approach. Mixing zones are often used in discharge situations where effluent quality does not meet surface water quality standards and where state regulations allow for additional effluent mixing in the receiving water body. The mixing zone approach is used to define a limited area in a surface water body where ambient concentrations may exceed acute or chronic surface water quality standards but acutely toxic conditions are prevented. Use of this type of approach can assist with optimization of groundwater discharge monitoring by better focusing the monitoring locations.

An important attribute of groundwater discharge to surface water, especially in proximity to coastal water bodies, is its transient nature that is primarily due to tidal effects. Physical factors of the site and the chemistry/geochemistry of the compounds of interest must be understood for effective monitoring design. Temporal and spatial scales, seasonal and tidal cycles, and long-term trends are an important consideration in optimization of monitoring programs focusing on groundwater discharge to surface water.

Results of associated monitoring (surface water and on-shore groundwater) and other investigations (human health or ecological risk assessment) also should be taken into consideration during optimization of the offshore discharge monitoring program. Understanding the potential risks associated with offshore discharge can be helpful in establishing LUCs or other restrictions that can optimize or reduce the number of locations that need to be monitored.

8.5 Lessons Learned in Monitoring Discharge to Surface Water

Monitoring groundwater discharge to surface water must be a transient process, and it will only be effective if the monitoring data are continually compared to decision criteria and evaluated to ensure progress is being made toward the monitoring objectives. Some common pitfalls associated with monitoring discharge to surface water are related to a lack of understanding of site conditions, errors or inconsistencies in sample collection, improper monitoring locations, and failure to review monitoring data. Fortunately, these common pitfalls can be avoided through review of the site CSM, review of remedial action monitoring data, and continued optimization. Common pitfalls associated with monitoring groundwater discharge to surface water and methods that can be implemented at a site to avoid them are listed in Table 8-1.

Table 8-1. Common Pitfalls Associated with Monitoring Discharge to Surface Water and Suggested Avoidance Methods

Discharge Monitoring Pitfalls	Avoidance Methods
CSM not updated	• Evaluate most recent version of CSM and apply recently collected site data to update the mode. • Follow ASTM guidelines for CSM update
Discharge area not effectively delineated; offshore monitoring conducted at inappropriate locations	• Establish offshore sampling grid • Monitor all grid locations for indicator parameters to delineate potential discharge areas; focus subsequent and more intense monitoring on discharge areas
Monitoring conducted at inappropriate depth	• Review site CSM to determine potential discharge areas • Perform discrete depth sampling to develop a chemical concentration profile with depth • Install nested wells/piezometers
Conflicting or inconsistent discharge monitoring results	• In an attempt to achieve consistent flux and chemical concentration measurements, perform monitoring (for coastal systems) during similar tide cycles • Collect sufficient monitoring data to determine whether elevated biological activity at the interface is affecting sampling results

Case Study: Evaluation of Groundwater Discharge to Surface Water, NCBC Davisville, North Kingstown, RI

Project Summary

Site 07 at the former Naval Construction Battalion Center (NCBC) Davisville is the location of dissolved chlorinated solvent plumes resulting from historical waste releases. Groundwater beneath the site has been divided into three separate zones (shallow, deep, and bedrock), and flows radially outward from the suspected source toward coastal water bodies. The current remedy of LTM of groundwater and sediment in conjunction with deed restrictions and five-year reviews was designed to satisfy the RAOs, which are to prevent human exposure to COCs in deep bedrock groundwater and to ensure that the discharge of groundwater to wetlands and offshore areas continues to pose no unacceptable risks from COCs. The primary COCs at the site are 1,1,2,2-PCA, TCE, and *cis*-1,2-DCE. The effectiveness of the remedy is evaluated using groundwater samples collected from monitoring wells and shoreline piezometers and offshore sediment and surface water samples.

CSM Revision and Offshore Investigation

Due to the presence of elevated chemical concentrations in downgradient shoreline monitoring wells and piezometers, the site CSM was revised to verify the appropriateness of the current site remedy and to optimize the LTM program. A 3-D block diagram was constructed to further evaluate the geologic and hydrogeologic conditions at the site, and to better understand chemical distribution and potential migration pathways. Statistical analyses were performed on site data, and plume transects were prepared using chemical concentration and hydraulic head to identify the presence of potential offshore chemical migration and subsequent discharge to surface water. Based on the results of the updated CSM, including the presence of the elevated chemical concentrations in downgradient shoreline monitoring wells and piezometers and upward vertical gradients adjacent to the shoreline, an offshore investigation was conducted to determine the nature and extent of the chemical discharge to adjacent surface waters. The goal of the investigation was to effectively delineate the distribution of groundwater discharge and chemical concentrations into the surface waters adjacent to the site, and to quantify discharge rates and concentrations in areas where discharge is identified. The technologies utilized during the investigation included the Trident screening probe for determining where groundwater may be discharging and an integrated seepage meter and water sampling system (UltraSeep) for quantifying discharge rates and chemical loading.

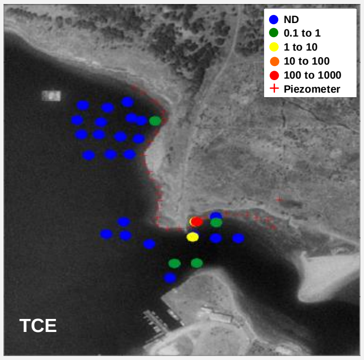

Figure 1. Porewater Sampling Results (µg/L) from the Offshore Investigation

The Trident probe was used to collect indicator parameters (temperature and conductivity) along an offshore sampling grid and revealed three primary areas of potential offshore groundwater discharge (Figure 1). Water quality analyses generally indicated that sediment porewater is more reducing than surface water. VOCs were detected in sediment porewater at several offshore locations, with only vinyl chloride exceeding an action level at two locations. Low-level VOCs (below action levels) also were detected in the surface water sample at these offshore locations. UltraSeep deployments indicated a tidal influence and varying levels of positive discharge (VOCs below action levels) at locations where VOCs were detected in the sediment porewater.

The results of the CSM revision and the offshore investigation were used to optimize the LTM program. In addition to recommending less frequent monitoring at select locations, several monitoring points were added and continued offshore monitoring was recommended to confirm the protectiveness of the remedy.

Groundwater Discharge to Surface Water Monitoring Program Development Checklist

Identify Monitoring Objectives

- ☐ Validate the CSM and conclusions of RI/FS (follow ASTM guidelines for CSM update)
- ☐ Determine if dissolved groundwater contamination is currently discharging or could potentially discharge to surface water
- ☐ Track contaminants exceeding defined limits (e.g., PALs)
- ☐ Track the changes in shape, size, or position, or mass flux of groundwater discharge to surface water
- ☐ Assess the performance of a remedial system (e.g. MNA, hydraulic control)
- ☐ Assess the practicability of achieving complete remediation
- ☐ Satisfy regulatory requirements

Selection and Distribution of Monitoring Locations

- ☐ Choose monitoring locations to be consistent with monitoring DQOs
- ☐ Establish monitoring locations in areas where groundwater discharge to surface water is reasonably anticipated to occur (preferably along a regularly spaced sampling grid)
- ☐ After a comprehensive initial monitoring effort has been undertaken to identify and delineate the offshore discharge areas, subsequent offshore monitoring can be streamlined, focusing on areas where offshore discharge is occurring
- ☐ Depending on the monitoring objectives, source strengths or loading may need to be determined to better understand and evaluate current and future groundwater flux (will require collection of on-shore and near-shore groundwater samples)
- ☐ Choose locations to identify background levels and ensure protection of receptors
- ☐ Review applicable regulatory requirements
- ☐ Consider nested locations to better understand vertical gradients and chemical stratification

Selection and Distribution of Monitored Parameters

- ☐ Evaluate CSM and update if needed
- ☐ Identify and quantify physical and chemical indicators of groundwater seepage to surface water, including near-shore and offshore hydraulic head, water quality and chemical indicator parameters, contaminant concentrations, sediment characteristics, and direct seepage measurements

Determine Monitoring Frequency and Duration

- ☐ Base sampling frequency on the expected variability in the data and temporal information, including the effect of diurnal processes (e.g., tides), seasonal factors (e.g., temperature and precipitation), and meteorological events
- ☐ Review the updated CSM, including time series monitoring data
- ☐ Calculate hydraulic gradient and groundwater flux to assist with sampling frequency and duration

- ☐ Develop decision criteria for modifications (e.g., decision diagram)
- ☐ Incorporate flexibility to allow for continual assessment of program needs

Identify Analytes for Initial Monitoring

- ☐ Review site history, the CSM, and groundwater COCs to develop the list of analytes that could reasonably be expected to discharging to surface water
- ☐ Consider that for surface water measurements, not all methods are applicable to both fresh and salt water due to matrix interferences
- ☐ Review regulatory criteria and risk assessment results
- ☐ Review historical upgradient and background data
- ☐ Review important geochemical or MNA parameters

Determine Monitoring Techniques

- ☐ Consider using sensors to monitor indicator parameters to delineate offshore discharge areas, followed by a more detailed focused evaluation of discharge areas
- ☐ Evaluate historic sampling techniques
- ☐ Evaluate well design and construction details
- ☐ Determine whether innovative sampling technologies are feasible and cost effective

Groundwater Discharge to Surface Water Program Optimization Checklist

Evaluate Monitoring Objectives

- ☐ Evaluate monitoring objectives on an annual basis (including a review of changing regulations)
- ☐ Confirm monitoring objectives have been met

Update CSM

- ☐ Revise and update CSM based on monitoring results
- ☐ Validate CSM with current understanding of site conditions

Optimize Monitoring Network

- ☐ Determine whether decision criteria have been met at monitoring locations
- ☐ Review surface water discharge monitoring data to identify critical areas for continued focus and eliminate monitoring (or reduce frequency) of non-critical areas
- ☐ Evaluate data trends for surface water monitoring to reduce spatial redundancies (See Chapter 3)
- ☐ Apply temporal trend analysis and geostatistics to optimize monitoring points

Optimize Monitoring Frequency and Duration

- ☐ Review surface water discharge monitoring data to identify critical areas for continued focus and reduce frequency of non-critical areas
- ☐ Evaluate decision criteria and apply decision diagram
- ☐ Evaluate discharge area and perform hydraulic gradient and groundwater flux calculations to estimate discharge
- ☐ Apply geostatistics and temporal trend analysis

Optimize Analyte List

- ☐ Evaluate decision criteria
- ☐ Identify analytes not detected above water quality objectives (e.g., regulatory levels or risk-based concentrations)
- ☐ Compare detected analytes against water quality objectives and background levels
- ☐ Evaluate potential for indicator species monitoring
- ☐ Apply geostatistics and temporal trend analysis to optimize analyte list
- ☐ Ensure identified COCs and associated daughter products are included

Optimize Sampling Technique

- ☐ Evaluate which monitoring technologies are most feasible and cost effective
- ☐ Determine whether innovative monitoring technologies are feasible and cost effective

8.6 References

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Chapter 9.0: Sediment Monitoring

This chapter discusses considerations for the development and optimization of LTM strategies for sediment remedy effectiveness, with focus on the three primary sediment remedies: monitored natural recovery (MNR); in-situ or in-place sediment capping; and dredging or excavation. Included is a discussion of monitoring objectives, the conceptual site model, monitoring techniques, selection and distribution of monitoring location and monitoring frequency and durations.

9.1 Sediment Monitoring Objectives

Sediment sites vary in size and complexity and generally require more consideration when developing a LTMP than some terrestrial sites. This is because sediment sites are often contaminated with a mixture of COCs from multiple sources; they involve multiple mediums (water, sediment, biology) and concerns (sediment chemistry, sediment stability and transport, bioaccumulation, etc.); and they generally tend to be large sites incurring spatial and temporal trends.

At sediment sites any combination of physical, chemical and/or biological endpoints may be used to help evaluate monitoring objectives. Monitoring plan objectives, decision criteria and management decisions will all depend on the type of remedial action at the sediment site. Currently, there are three general categories of remedial action for sediments including: (1) MNR; (2) in situ capping; and (3) dredging.

Overall, the monitoring objectives for environmental restoration programs should be focused on assessing whether progress toward sediment cleanup levels is occurring, cleanup levels have been achieved, and evaluating the long-term protectiveness of the remedy. Some examples of more global and remediation technology specific monitoring objectives are provided below. They have been derived from a variety of sources including, the Navy's *Policy on Sediment Site Investigations and Response Action* (DON, 2002); *Biomonitoring Guide for the use of Biological Endpoints in Monitoring Species, Habitats, and Projects* (NAVFAC, 2007); *Guide for Habitat Restoration Monitoring* (NAVFAC, 2004); *Policy for Conducting 5-Yr Reviews under the Installation Restoration Program (IRP)* (DON, 2004); and the USEPA's *Contaminated Sediment Remediation Guidance for Hazardous Waste Sites* (USEPA, 2005):

- Assess initial compliance with design and performance standards of the remedy;
- Assess short-term remedy performance and effectiveness in meeting sediment cleanup levels;
- Evaluate long-term remedy effectiveness in achieving RAOs and in reducing human health and/or environmental risk;
- Assess impact of disturbing the system (e.g., concern over dredging residuals);
- Determine impact of remedial system on river hydrodynamics and sediment transport;
- Evaluate levels of sediment contamination (e.g., decrease over time for natural attenuation or extent of surface sediment recontamination for dredging);
- Assess the health/recovery of benthic community; and
- Assess the health/recovery of higher trophic species.

Establishing clearly defined monitoring objectives and corresponding exit criteria is central to any well defined, well managed and optimal sediment monitoring program. With respect to exit criteria, the endpoints will vary greatly from project to project, but often take the form of negotiated numeric reductions in sediment contaminant loads, reductions to background sediment levels, reductions in tissue levels in ecologically important higher order organisms (e.g., fish and waterfowl), or reductions in tissue levels of ecological organisms for human consumption (e.g., fish and crab). This chapter will focus on sediment monitoring and ecological monitoring will be identified (where appropriate). A more detailed discussion of ecological organisms and methods of ecological monitoring is provided in Chapter 10.

9.2 Description of the Conceptual Site Model

The CSM developed during the investigation phase of the project should be well understood by the time a monitoring program is implemented and can be an important element for evaluating risk and risk reduction approaches. A CSM that was developed to understand all the sources of contamination contributing to the sediment site and has incorporated elements of the watershed is of most benefit to the Navy RPM.

Essential elements of a CSM generally include information about contaminant sources, transport pathways, exposure pathways, and receptors. Summarizing this information in one place usually helps in testing assumptions and identifying data gaps and areas of critical uncertainty for data objectives. It is important to update the CSM as new data become available to document additional source, pathway, and contaminant information collected throughout the monitoring program. Natural resource trustee agencies and other stakeholders may have new information about the ecosystem that is important and can be used to revise the CSM, and it is recommended that they be consulted. Project managers should also be aware of the spatial and temporal dimensions to the processes depicted in a CSM and consider their relevance when developing or modifying the monitoring program. A successful monitoring program is one that continuously considers the relationship between the CSM, the monitoring objectives and the monitoring techniques or approaches. These elements when working together will optimize the monitoring program and assist the user in making informed management decisions. The USEPA defines the typical elements commonly considered for a sediment site in its *Contaminated Sediment Remediation Guidance for Hazardous Waste Sites* (USEPA, 2005). These elements are shown in Table 9-1.

Table 9-1. Typical Elements of a Conceptual Site Model for Sediment

Sources of Contaminants of Concern: • Upland soils • Floodplain soils • Surface water • Groundwater • NAPL and other source materials • Sediment depositional areas that may act as secondary sources • Outfalls, including combined sewer outfalls and storm water runoff outfalls • Atmospheric contaminants • Ships, boats, watercraft, etc. **Contaminant Transport Pathways:** • Sediment resuspension/deposition • Surface water transport • Runoff • Bank erosion • Groundwater advection • Bioturbation • Food chain	**Exposure Pathways for Humans**: • Fish/shellfish ingestion • Dermal uptake from wading, swimming • Water ingestion • Inhalation of volatiles **Exposure Pathways for Biota**: • Fish/shellfish/benthic invertebrate ingestion • Incidental ingestion of sediment • Direct uptake from water **Human Receptors**: • Recreational fishers • Subsistence fishers • Waders/swimmers/birdwatchers • Workers and transients **Ecological Receptors**: • Benthic/epibenthic invertebrates • Bottom-dwelling/pelagic fish • Mammals and birds (e.g., mink, otter, heron, bald eagle) • Sensitive habitats or protected species Source: *Contaminated Sediment Remediation Guidance for Hazardous Waste Sites* (USEPA, 2005)

9.3 Monitoring Techniques/Approaches

There are many factors to consider when determining what to monitor to determine remedy effectiveness. The specific data objectives of the program will drive the decision, but generally there are three categories of measurements to consider: (1) physical measurements which may include measurements of erosion and/or deposition of sediment, groundwater advective flow, sediment particle size, surface water flow rates, and sediment homogeneity/heterogeneity; (2) chemical measurements which may include metals and organic contaminants in the upper biological surficial zone and/or deeper sediments, biodegradation of contaminants, contaminant partitioning to pore water, and total organic carbon; and (3) biological measurements which can include toxicity bioassays or examining biological assemblages to document problems, evaluate restoration efforts, and/or address toxicant bioaccumulation and food chain effects.

For complex sediment sites, a combination of physical, chemical and biological monitoring methods may be appropriate to determine whether a sediment remedy is meeting goals, clean-up levels or RAOs. Table 9-2 provides a brief summary of the general physical, chemical and biological monitoring techniques and approaches that the Navy RPM may consider when developing a long-term sediment site monitoring plan. Any combination of these approaches may be used for evaluating the three sediment remedial alternatives (MNR, capping, or dredging/excavation), depending on the site-specific goals or action levels.

9.3.1 Physical, Chemical, and Biological Monitoring. There are many published methods for monitoring contaminated sediment sites. The cost and data quality produced by various field sampling techniques should be matched with program data objectives and decision criteria. Selection of field and laboratory methods that are appropriate to the monitoring objectives and media of concern are important aspects of an optimal measurement program.

For biological and chemical approaches, emphasis should be placed on separating out the effects due to inorganic and anthropogenic background conditions. These approaches should be considered only if key COCs specific from the release can be targeted and/or comparisons can be performed between chemical/biological data in the area of concern to data collected at accepted reference locations. This is particularly important for highly industrialized areas where other non-Navy sources are present.

The *Navy Interim Final Policy on the Use of Background Chemical Levels* (DON, 2000) stresses the importance of eliminating background chemicals from the list of chemicals of potential concern (COPCs) carried through the risk assessment, and setting cleanup levels above the background range. The policy specifically requires the following:

- Chemicals that may have been released at the site must be clearly identified to ensure that the Navy is focusing on remediating COPCs associated with the release.
- Chemicals detected at concentrations below the upper bound of the background range must be excluded from the full baseline risk assessment. All chemicals screened out as a result of background considerations must be discussed and documented in the risk characterization sections of the baseline risk assessment report.
- Cleanup levels must not be below the upper bound of the background range.

The Navy's *Guidance for Environmental Background Analysis Volume II: Sediment* (Battelle, 2003) focuses on analytical methods and procedures that can be used to identify background chemicals in the sediment medium (whether from anthropogenic or natural sources), and can be used to estimate the chemical concentration ranges that represent site-specific background conditions.

Table 9-2. Summary of Physical, Chemical and Biological Monitoring Techniques and Approaches

Monitoring Technique or Approach	Classification	Description of Potential Use	Considerations/Limitations
Geophysical	**Physical**	Evaluation of the sediment geological consistency and integrity most often by deep core sampling; results may be used to estimate contaminant bioavailability, to support fate and transport modeling, and to evaluate post-remedy benthic rehabilitation	Subject to sediment coring effects such as sediment compression or consolidation. Sediment shear stress can be determined using a variety of techniques including SedFlume
Bathymetry	**Physical**	Sonar system used to collect depth information (sediment contours); data can be used to evaluate post-dredging and post-capping sediment surface elevations for comparison to baseline conditions or design specifications; can also be employed to evaluate sediment re-distribution or stability over time during MNR.	Single-beam transducers generally are portable and can be transferred from vessel to vessel. Multi-beam transducers (which provide far greater resolution) are less portable. Multi-beam units provide large data sets that require more data editing, processing and storage
Side-Scan Sonar	**Physical**	Displays a photographic image of the sediment bed that can be used post-dredging or post-capping to identify different types of bottom effects (i.e., mud, smooth sand, rippled sand, rock outcrops, and canyons)	For most applications, water depth must be greater than 2 m; verification using physical sampling may be necessary; cannot be used for bathymetric determinations
Acoustic Sub-Bottom Profile	**Physical**	Displays differences in the sub-surface sediment strata and can be used to evaluate post-cap thickness (consolidation or degradation) over time; or to characterize benthic habitats relative to sub-surface sediment structure in places where more invasive techniques such as physical coring or sediment profile imaging (SPI) cannot be employed	Usually limited by narrow swath-width and penetration is limited by the density of the overlying layer and the presence of gas pockets such as methane. For post-cap applications, may not work well if the cap material is similar to the underlying sediment with respect to particle size or density.
Settlement Plates	**Physical**	A plate with riser that is installed to monitor the thickness of a cap or dredge disposal unit. It is generally used to monitor the extent of compaction of the disposed or placed layer.	Can be difficult to install the plates and may require dive support for installation and recording measurements. The risers on the plates can be prone to disturbance from anchors, moorings, cables, fishing nets, etc.

Table 9-2. Summary of Physical, Chemical and Biological Monitoring Techniques and Approaches (Continued)

Monitoring Technique or Approach	Classification	Description of Potential Use	Considerations/Limitations
Water Parameters	**Physical/Chemical**	Physical water parameters, such as turbidity, total suspended solids, pH, dissolved oxygen, and conductivity can be measured using an instrument probe or by collecting a whole water sample. Real-time measurement of pH, dissolved oxygen and conductivity are generally preferred using the probe technique. Measurement of chemical concentration in water can be conducted with whole-water samples (although surrogate samplers have been used-as described below). Whole water samples allow the user to differentiate between contaminants in the dissolved and suspended (or particulate) phase. Both approaches are commonly used during dredging or capping; however, for LTM they are often employed to record general water quality for MNR, capping, and dredging; in all cases mid-water column depth and near-sediment surface sample collection or measurements are preferred.	Whole-water grab samples may be confounded by fine suspended sediments and RPM/analyst will need to decide the impacts relative to RAOs or other goals. In-situ instrumentation may be complicated by high solids content or biofouling if left in place for extended periods of time. Need to consider use of chemical data. For instance, if interested in dissolved-phase contaminant concentrations only, the RPM will need to consider sampling handling and or in-field processing and associated quality assurance/quality control.
Sediment Profile Imaging	**Physical/Biological**	Photographic image of the sediment layer used to evaluate the benthic community (population size and diversity) (Figure 9-1a); to evaluate sediment physical characteristics (particle size, stratification, gas bubbles, bioturbation, or redox conditions). Can be used in conjunction with LTM approaches to evaluate benthic recovery on in situ caps, in MNR, or after dredging. Can also be employed to estimate cap thickness or consolidation or to estimate the extent of sedimentation at an MNR site; or to estimate the extent of dredge residuals. Decision criteria that include recovery of infaunal benthic populations can be very costly, since separation and taxonomic identification is very labor intensive. SPI technology can be used to optimize monitoring if reductions in traditional sampling processing can be reduced or eliminated.	Imaging is limited to the photographic plate dimensions (generally less than 30 × 30 cm) and distance of the window relative to the bottom of the unit. Deployment limited to soft sediments that unit can penetrate. Thin sediment layers over hard-bottom may inhibit successful deployment and use.
Hydrodynamics/Sediment Transport	**Physical**	A collection of measurements including Acoustic Doppler Current Profiler (ADCP) to measure current direction and velocity; SedFlume (Figure 9-1b) or similar shear stress measurements to measure sediment stability; level loggers to monitor water depth; sediment	Data usually are incorporated in a site specific model. Model validation is needed and impact estimates are limited to the constraints of the model.

Table 9-2. Summary of Physical, Chemical and Biological Monitoring Techniques and Approaches (Continued)

Monitoring Technique or Approach	Classification	Description of Potential Use	Considerations/Limitations
		traps to monitor sediment settling in an effort to understand the hydrodynamics or sediment transport and depositional properties relative to site goals. Can be employed to monitor sediment stability and transport properties at a MNR site to assess impacts to contaminant burial or to monitor the longevity and integrity of a in-situ cap. May also be used to assess the ecological impacts of a remedy such as evaluating the impact of a cap on flow dynamics in a wetland area	
Sediment Coring	**Physical/Chemical**	Sediment deep coring conducted using a variety of methods, (i.e., gravity, piston, vibracore, etc.) is the current way to obtain intact cores for examining the vertical profile of the sediment chemistry, stratification, age, deposition or geophysical consistency; also used to assess contaminant migration through an in-place sediment cap and to obtain porewater samples. The use of flexible polyethylene core liners for vibra-core tubes minimizes core tube damage, maintain integrity of core and facilitate easy removal of sediments.	Currently the only way to obtain adequate sample at depth; however can be problematic with unconsolidated sediments or for larger particles such as sand; limited to the depth constraints of the coring device; generally the cost of sampling increases with sediment depth.
Surface Sediment	**Physical/Chemical**	Performed using a variety of surface grab samplers that are readily available from manufacturers and usually consist of a spring loaded trap/jaw that is triggered by a weighted messenger. Samples are used primarily to assess the surface sediment chemistry or to obtain sample for benthic assessments. The use of dual surface sediment grab samplers (e.g., dual Van Veen grab; shown in Figure 9-1c) enables the collection of sediments for chemical analysis and infauna with a single deployment.	Many devices are portable; however, some are large and heavy enough to be committed to a sampling vessel; most sample approximately the first 15 to 30 cm (generally defined to be the biological active or benthic zone); sampling can be complicated by surface debris or detritus interferences. Does not allow user to obtain sample at accurate depth.

Table 9-2. Summary of Physical, Chemical and Biological Monitoring Techniques and Approaches (Continued)

Monitoring Technique or Approach	Classification	Description of Potential Use	Considerations/Limitations
Passive Samplers	**Chemical**	Permeable Membrane Devices (SPMDs), Solid-Phase Micro-Extraction (SPMEs), Tenax, and thin films are surrogate samplers or membranes some of which are readily available from vendors used to measure dissolved organic contaminants in the water column or at/near the sediment-water interface.	SPMDs - used specifically for organic contaminant monitoring; subject to biofouling for long-term deployments and require the use of laboratory calculated constants for calibration. SPMEs-Innovative technology, still under research to determine effective methods of preparation and deployment, calibration, processing and analysis.
Seepage Meters	**Chemical**	Device used to measure the flux of groundwater through the sediment and has the capability to collect water samples for chemical analysis. Used in any situation where contaminant flux may be a concern, such as the migration of contaminated groundwater through an in-place sediment cap, CAD unit, or at an MNR site. One such device is the Benthic Flux Sampling Device (BFSD). The BFSD is an automated, in situ water sampling device designed to collect data for quantifying the flux of trace metals, including arsenic, cadmium, copper, nickel, lead, and zinc across the sediment-water interface in marine and aquatic environments. The BFSD collects and filters discrete water samples periodically over a deployment period of up to four days, which are then preserved at the end of the deployment and delivered to an analytical laboratory for analysis. The technology provides a means to assess contaminant mobility by directly measuring and quantifying the contaminant flux across the sediment-	Requires a specialized service vendor or operator. Some constraints on sample volumes.

Table 9-2. Summary of Physical, Chemical and Biological Monitoring Techniques and Approaches (Continued)

Monitoring Technique or Approach	Classification	Description of Potential Use	Considerations/Limitations
		water interface. The BFSD can also be equipped with a variety of instrumentation that continuously monitors critical sediment, sediment-water interface, and near bottom water parameters. The BFSD, combined with seepage and a pore water sampler, can be used to provide a direct, quantitative assessment of the amount of contamination reaching the water body of concern. This valuable information can then be used to support progress toward assessment criteria, or define the endpoint for a negotiated monitoring program exit point.	
Radiochemistry	**Chemical**	Considers the use of chemical isotopes as an approach for age-dating sediment core profiles and surface sediments. Although this method is not commonly used for LTM, it may be applicable to MNR or capping to assess long-term sedimentation rates to predict natural recovery periods. Isotopes commonly used include: ^{7}Be, found naturally on atmospheric particles and in surface sediments and soils to a depth of approximately 0-15 cm; ^{210}Pb found naturally in air, dust soil and sediment as a daughter product of radon with higher activities in surface sediments, decreasing with depth. ^{137}Cs, Introduced from aboveground nuclear weapons testing with peak production in 1963. Normally found in the sub-surface sediments, depending on sedimentation rate.	Due to the short half-life (53 days), ^{7}Be is used to determine the depth of the mixed layer in sediments and can be useful in sediment transport studies. ^{210}Pb and ^{137}Cs are commonly used to age date core profiles up to 100 years old, but can be confounded by sand or non-organic lenses that generally don't contain the radionuclides.
Sediment Red-ox State	**Chemical**	The use of instrumental probes or grab samples to rapidly assess the oxidation/reduction state of the sediment; can be used for assessing reductive conditions for anaerobic dechlorination of PCBs at MNR sites.	Grab samples are problematic for these types of measurements due to rapid oxygenation effects. In situ monitoring is preferred but can be logistically challenging.
Indigenous (Fish/Invertebrate)	**Biological**	The collection and chemical analysis of indigenous organisms (such as fish and invertebrates) for bioaccumulation assessments, monitoring trophic transfer or food web effects in an effort to understand the long-term ecological recovery of the system. Can be used to evaluate the long-term effectiveness of	Consideration should be given to seasonal and the migrational effects when collecting fish; appropriate statistical approaches should be used in order to evaluate long-term trends; careful consideration should be given to species,

Table 9-2. Summary of Physical, Chemical and Biological Monitoring Techniques and Approaches (Continued)

Monitoring Technique or Approach	Classification	Description of Potential Use	Considerations/Limitations
		MNR, capping or dredging.	age, and sex of fish that are captured for chemical measurements.
Caged Deployments (Fish/Clams/Mussels).	**Biological**	The deployment of caged organisms to evaluate the change in rate of bioaccumulation of contaminants over specified periods of time. Can be used to evaluate the long term effectiveness of MNR, capping, or dredging.	The user must be sure to be in compliance with local and federal laws in regards to species deployment to ensure that there are no inadvertent releases of invasive or non-indigenous species.
Toxicity Testing	**Biological**	Laboratory testing with sediment or water samples from the site to assess the chemical impacts on growth, survival and reproduction in representative species. Can be used to evaluate the long term effectiveness of MNR, capping, or dredging.	A useful tool if a significant relationship between the contaminant and toxicity is established (i.e., chemical analysis should be conducted on test organisms).
Benthic Population/Community Analysis	**Biological**	Physical assessment conducted from a sample collected at the site to determine population diversity and size. Can be used to evaluate the long term effectiveness of MNR, capping or dredging.	Consider statistical approach to obtain quantity and representative samples for assessment.

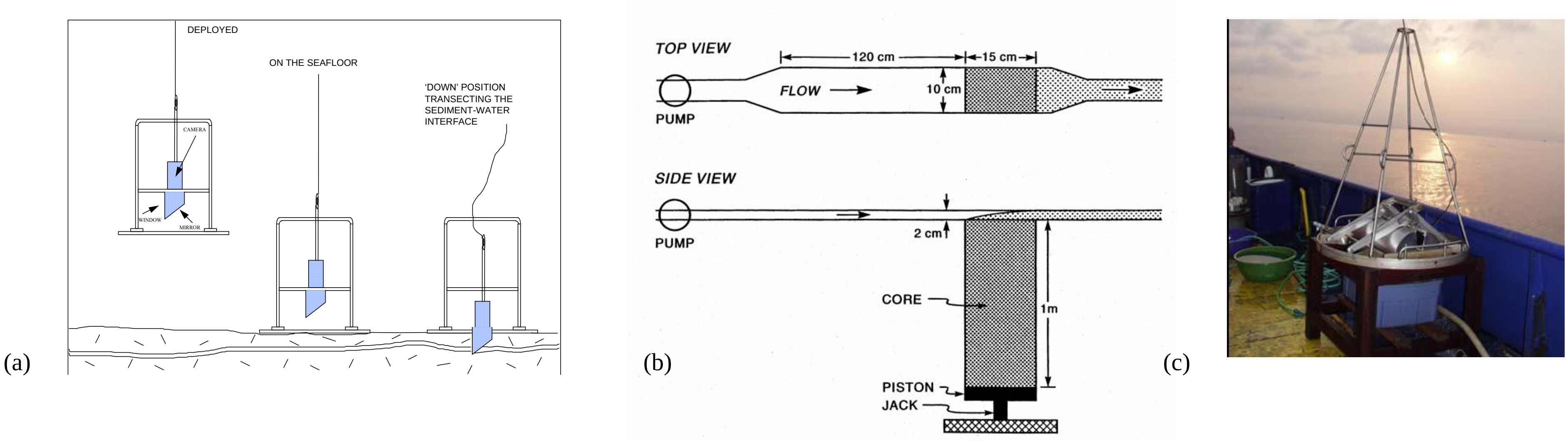

Figure 9-1. Sampling Techniques: (a) Sediment Profile Imaging (SPI) Device; (b) Sedflume Schematic; (c) Dual Stainless Steel Van Veen Sediment.
(Source: (a) from Germano 1995 (b) from McNeil et al. 1996 (c) Photo Courtesy of Battelle Ocean Sciences Laboratory)

This section briefly discusses the types of monitoring tools and approaches that can be used to evaluate physical, chemical and biological parameters for sediments. In general, physical and chemical data are relatively less complicated to interpret than biological data and the RPM should pay careful attention to the appropriateness of the biological method being used in the monitoring plan to ensure that it fits the intended criteria.

For instance, caged organisms such as clams or mussels deployed at a site over a defined period of time can be used as a method to determine changes in bioavailability of select contaminants; whereas seasonal or annual indigenous fish or invertebrate collection can address the long-term ecological response of the system. On the same accord, acute toxicity endpoints are intended to quantify short-term effects on an organism and would best be used for monitoring the short-term effectiveness or impact of a remedy; whereas other tests may better evaluate the longer term responses in community growth and reproduction. Ecological resource monitoring is described in more detail in Chapter 10.

It is important to note that the field of sediment monitoring is in a state of advancement and that the RPM should be vigilant for the introduction of new techniques that offer more simplistic field approaches, additional accuracy or reduced cost. In some cases it may be advantageous to compare traditional methods against new advances in the field to determine if method modifications are appropriate for the LTMP that has been established.

In this respect, the Navy is currently developing the “Interactive Sediment Remedy Assessment Portal” or ISRAP. ISRAP will be internet accessible and is being designed to assist the RPM in developing a LTMP. ISRAP will be made available for Navy RPMs in the latter part of 2008.

9.3.2 Monitoring Considerations. The use of the following monitoring tools, techniques and approaches can be especially complicating and the results from these approaches can often be difficult to interpret. They should be given careful evaluation if being considered for use so that the RPM can ensure that an effective monitoring plan will be developed.

Sediment Fate and Transport. The transport of sediment and associated contaminants is a complex interaction of the properties of sediment particles and the sediment bed, circulation, bathymetry, and turbulent shear stresses applied by waves and current. Before an effective sediment monitoring program can be designed or optimized, it is imperative that the project team have a good understanding of all the possible fate and transport mechanisms at the site, particularly the fate and transport of the sediments themselves. Sediment stability has been identified by the USEPA as a key concern for contaminated sediment sites (USEPA, 2002). Assessment and prediction of the fate and transport of contaminated sediments is an important component of risk assessments, remedial decision making, remedy design and verification of success. Seasonal and activity-related changes in the velocity and location of water currents can change a location from a depository environment in which sediments are being added, burying older sediments, to a scouring environment in which older sediments are being exposed and transported. This can have the most impact where MNR has been implemented and remedial goals will be achieved primarily by burial. For an optimal and effective sediment monitoring program, it is imperative to understand the transitory nature of the overlying water currents and to correlate monitoring locations and sampling events to match the conditions to satisfy data objectives.

Common long-term management questions associated with sediment transport in and around monitored sites are:

- Can erosion of the sediment bed lead to the exposure of buried contamination?
- Can deposition of sediment result in a decrease in potential exposure/transport?

- Will sediment transport lead to the redistribution of contamination within the site, or movement of contamination off site?
- Are contaminated sediments (surface and subsurface), or contaminants alone, moving at rates that will significantly change their current contribution to human health and ecological risk?

In terms of resuspension and deposition, most sediment transport is associated with the sequence of short, infrequent events such as storms, or even dredging activities. When monitoring a site with nearby potential influences from other remedies, one should prepare a monitoring plan to address impacts from other operations. Characteristics of various hydrodynamic and coupled hydrodynamic/sediment transport models have been summarized by the USGS (2002). The *Interim Guide for Assessing Sediment Transport at Navy Facilities* (SSC, 2004) provides descriptions of seven contemporary numerical models and discusses how these models can be used to support sediment monitoring studies. Utilizing a modeling approach, supplemented by site specific data, can help optimize the monitoring program by greatly reducing the uncertainty associated with location of monitoring stations and even the frequency of sampling (see Appendix B of SSC, 2004). Information derived from these models can also be used to help identify potential holes in the distribution of long term sediment monitoring stations, or where station density may be excessive. Optimization recommendations, such as a reduction in or relocation of monitoring stations, can be supported by accepted sediment transport modeling.

Aquatic Vegetation. Acute effects on plants (emergent and aquatic vegetation) are generally considered temporary (i.e., in most areas they recover at a reasonable rate). Plants, however, are often considered in CSMs because of the tendency to transport contaminants to higher trophic levels. Some aquatic plants, such as eelgrass [*Zostera marina*]) play an immensely important role in marine ecosystems, providing a variety of habitat functions in near shore systems. Eelgrass, which is known to be extremely sensitive to environmental impacts, responds unfavorably to imbalances in local habitats (Weitkamp, 1998). In some cases fatality may be caused by the COC at hazardous waste sites; other times, fatality may be due to subtle changes in the ecosystem that are not well understood.

Bioturbation. Sediments remaining relatively stable even during large flow events may still undergo active mixing due to biological activity, or bioturbation, by benthic macrofauna living in the surficial sediments. Bioturbation is caused by the action of macrofauna burrowing, moving and sometimes eating sediments. It occurs in the uppermost layers of sediment in which the animals reside, with the most intensive activity in surficial sediments (generally on the order of centimeters), and a decrease in activity with increasing depth (SSC, 2004). Bioturbation can modify the physical properties of the sediments (i.e., bulk density and cohesion) and redistribute contaminated sediments. Biological activity can increase or decrease the ability of the sediment bed to resist erosion. The effects of bioturbation are site-specific and can exhibit spatial and seasonal variation.

***Biological Indicators*.** The use of biological indicators or biomonitoring in LTM can be complicated because it involves the collection and evaluation of data from living organisms under natural conditions. As such, monitoring results may be impacted by environmental conditions or other natural variables occurring randomly during sampling events. These variables may be difficult if not impossible to identify, characterize, and control and may be unrelated to NERP-related activities or releases.

Other complications include unfavorable climate conditions, reduced food supply, disease outbreak all of which may be completely unrelated to NERP activities or conditions. Other concerns include temporal relevance and/or magnitude, frequency, and duration of the COC(s) and species sensitivity to exposure of the COC.

The Navy's Guidance on Biomonitoring (NAVFAC, 2007) provides a framework that can be used to develop and implement scientifically defensible and appropriate biomonitoring plans at NERP sites. This guidance addresses the development of the logic and rationale needed to support a decision to design and implement at NERP sites a monitoring program using biological endpoints. Specifically, this guidance addresses the development of defensible monitoring objectives and hypotheses that focus the biomonitoring program, and the development of decision criteria that will support site management decisions related to the biomonitoring program.

Macroinvertebrates. Benthic macrofauna are recognized as effective sentinel or indicator organisms for monitoring of point source and temporal impacts due to their relative immobility, typically short life spans and sensitivity to physical-chemical features of the sediments. Changes in sediment structure, organic carbon, and contaminant load can impact benthic macrofauna as a result of discharges and seafloor accumulation of contaminants, and chronic low level release of chemicals bound to local sediments. Long lasting effects from a variety of discharges, such as dredge materials, include smothering, organic enrichment, and toxicity from heavy metals and hydrocarbons. Patterns of total infaunal abundance (the total number of organisms per fixed area), species richness (the number of unique species in a given sample especially those that are considered contaminant tolerant), biomass (wet weight of organisms per fixed area), and distribution of major taxa (most often annelids, mollusks, echinoderms, arthropods, and all lesser groups combined) are typically examined and statistically compared to uncontaminated reference areas.

There is substantive debate focused on the usefulness of monitoring resident benthic organisms to assist in the determination of sediment health. Simple community measures can be unduly influenced by local small scale factors (e.g., storms, decreases in fish predation); therefore, it may be necessary to consider additional sampling events specific to season in the monitoring plan, or to conduct additional sampling around unique storm events. The latest in a long line of community indices attempting to describe organism distribution is the Benthic Response Index (BRI), which is being championed by the Southern California Coastal Water Research Project (SCCWRP). The BRI is designed as a quantitative evaluation of the benthic community's response to pollution and may be more robust in deviations caused by natural phenomena. Comparisons of BRIs between remedy and reference areas must be considered when measuring biological recovery.

Bioaccumulation and Toxicity Tests. Bioaccumulation and sediment toxicity testing are often required monitoring elements, either during baseline investigations, or during subsequent LTM projects. These tests are costly, difficult to perform and must be tailored to the monitoring need.

Detailed information regarding bioaccumulation evaluations can be found in the following publications: *Methods for Measuring the Toxicity and Bioaccumulation of Sediment-Associated Contaminants with Freshwater Invertebrates* (USEPA, 2000a); *Bioaccumulation Testing and Interpretation for the Purpose of Sediment Quality Assessment* (USEPA, 2000b); and the Washington State Department of Ecology Web site, which is a searchable site containing many documents specific to toxicity/bioaccumulation testing of sediments.

9.4 Sediment Monitoring Program Design and Optimization

Optimal sediment monitoring programs are designed to recognize uncertainty that must be managed through focused data collection and some degree of uncertainty mitigation (i.e., using monitoring data, probabilistic modeling, and contingency planning to counteract the impacts that may arise from unexpected conditions [DOE, 1997; 1999]). Sources of uncertainty that should be closely considered and addressed when developing sediment monitoring programs include:

- Vertical and lateral extent of sediment contaminants and associated exposure pathways to ecological receptors
- Contaminant transport dynamics in aquatic environments, including partitioning rates and magnitude, soluble transport, sedimentary transport, and biological transport
- Historic and future sedimentation rates
- Sediment stability and resistance to erosion
- Historic and future hydrodynamic conditions
- Future changes to site use and subsequent impacts on sedimentation, sediment stability, and chemical stability
- Impacts caused by a remedy, such as capping, on aquatic ecology
- Background contaminants and ecological stressors, which may or may not be related to the contaminants of concern
- Definition and control of contaminant source.

As with all monitoring programs, a monitoring design should facilitate timely and cost-effective management decisions (e.g., site closures) while protecting human health and the environment. Monitoring programs should be developed to include the specific goals, a description of the CSM, identification of baseline data (if applicable), data objectives (the DQO process should be used to identify these), decision and exit criteria, and the major management decision. Sediment monitoring programs should adequately link sampling and analytical methods to remedial action objectives, address natural variability, consider changing environmental conditions, and basic uncertainty, in order to have a reasonable probability of producing useful data to ultimately meet program objectives. The RPM should employ the use of the UFP-QAPP to address these parameters. Furthermore, exit criteria should be used to help decision-makers determine when they can move onto other steps in the sediment management process. For instance, the question “how clean is clean,” can be addressed by linking cleanup or recovery criteria to pre-negotiated numeric sediment concentrations.

The quantity and quality of baseline data must be seriously evaluated prior to designing a monitoring program and during the RI phase to ensure that the baseline data are robust and the site is well characterized with respect to the endpoints of interest. Baseline data must include accurate estimates of contaminant levels that are considered local, or background. To the extent possible, monitoring approaches (including monitoring tools) should be similar (or identical) in pre- and post-remediation monitoring programs to facilitate direct data comparison. It is from the baseline data that success or failure will be determined, and from which ongoing monitoring can be modified and optimized. Establishing a useful baseline from which recovery or a remedy can be compared is perhaps the most extensive activity in terms of data collection and analysis, cost, and effort. Baseline data should include historic inputs, the nature and extent of existing contamination levels, and levels of contamination at reference and control areas against which remedy comparisons will be made.

USEPA’s Monitoring Guidance (USEPA, 2004a) describes six key steps that are recommended in developing and implementing a monitoring program. The guidance was developed for use at all types of hazardous waste sites. The reader is referred to this monitoring guidance for more detailed information; however, the six steps and a brief description are provided as follows:

> Step 1: Identify Monitoring Plan Objectives. The RPM should closely examine the intended outcome at the site and identify clear and concise monitoring objectives to fit the outcome. Physical, chemical and/or biological endpoints should be established for each monitoring

objective. RPMs should involve stakeholders if identifying monitoring objectives other than those established in the enforcement documents.

Step 2: Develop Monitoring Plan Hypotheses. The RPM should formulate a hypothesis that identifies the relationship between the remedy and the expected outcome. USEPA suggests developing a "monitoring conceptual model" to aid in this process. This step is analogous to Step 1 of the DQO process.

Step 3: Formulate Monitoring Decision Rules. The RPM should establish decision rules to determine whether to continue, stop, or modify monitoring once a goal has been reached.

Step 4: Design the Monitoring Plan. The RPM needs to identify the frequency, location, collection methods and analytical methods of the plan.

Step 5: Conduct Monitoring Analyses and Characterize Results. Execute the plan and determine the results. The RPM should evaluate the data with regard to the objectives and the hypotheses and implement any decision rules as appropriate.

Step 6: Establish the Management Decision. The RPM should solidify any decisions made in the previous step.

Optimization decisions should be based on quality data and not simply on expediency, or cost reduction. The primary goal of an optimization is that it enhances the product, eliminates redundancy, reduces waste, simplifies presentations of complex information, and lastly reduces project cost. As in other monitoring programs (such as groundwater monitoring), the geostatistical techniques can be used to optimize a sediment monitoring program (see Chapter 6 and Appendix B for more geostatistical information). For example, kriging is one geostatistical method of spatial data interpolation that can be used to optimize the number of samples and monitoring locations in a sediment monitoring program. Graphical presentations generated from geostatistical software are very useful tools for regulatory and stakeholder information transfer. As illustrated by these examples, including a statistician in the initial design and planning phase of the monitoring program will also benefit the credibility, success, and efficiency of the program.

9.4.1 Selection and Distribution of Sediment Monitoring Locations. Vertical and lateral extent of sediment contaminants must be well defined to permit reliable input into CSMs linking exposure pathways to receptors. The numbers, locations, and sediment depths sampled are driven by the project data objectives and data evaluation methods. USEPA's systematic planning process (USEPA, 2006a) provides guidance for a variety of problems associated with monitoring station selection including selection between clearly defined alternatives [Step 7 of the DQO process], studies where a confidence interval on an estimated parameter is needed, or determination of whether a hot spot or target exists. Additionally, the question of "how good" the answer has to be (Step 6 of the DQO Process) is addressed. Statistical guidance on assessing data quality criteria and performance specifications is available in *Data Quality Assessment: Statistical Methods for Practitioners* (USEPA, 2006b). The philosophies and techniques behind these functional documents have been incorporated into an extremely useful software tool developed specifically to assist in the design of monitoring programs. VSP is said to provide simple, defensible tools for defining an optimal, technically defensible sampling scheme for sediment characterization and monitoring programs (see Chapters 7 and 8 for more discussion). Using tools, such as the VSP, when initially defining a sediment monitoring program, has the advantage of supporting measurement criteria, or regulatory benchmarks in an a priori fashion. This initial optimization of a monitoring program's experimental design avoids the pitfalls of traditional random/stratified random sampling designs that are historically common. Furthermore, statistical software can help optimize the monitoring plan after initial samples indicate where critical areas are located.

9.4.2 Frequency and Duration of Sediment Monitoring. The frequency of monitoring is dependent on the questions being asked, the specific objectives of the program, and the general environment under consideration. For a general discussion of frequency and duration of monitoring, see Chapter 4. Most often monitoring frequency is defined by the regulatory statutes under which the program falls. Generally, it is wise to consider the potential impact of seasonality on the monitoring program; however, it may not be necessary to incorporate a temporal component in the monitoring program if the question being asked can be isolated to a single season. For example, if dredging is the remedy for the removal of PCB-contaminated sediment followed by natural sedimentation, it should not be necessary to sample more than once per year since the effect of seasonal events such as storms and high water flow are cumulative and evident throughout the year. Additionally, there is typically not a need to identify short-term trends whereas long-term changes should be evaluated across years to establish progress toward a goal. Unlike groundwater monitoring, sediment sampling should be done at lower frequencies, such as every two to five years. Quarterly sediment monitoring should be avoided. Sampling strategies designed to optimize existing monitoring programs by reducing the frequency of sampling from, for example, annual to every two years, must be supported by credible information gathered to address the specific objectives of the program. Such strategies should focus on progress toward a goal (e.g., the reduction of a contaminant concentration below a defined benchmark) and exit endpoint. Simple statistical correlations coupled with sediment transport modeling and geostatistical analysis can be used to reinforce a line of reason that reduces sampling frequency, without compromising project objectives.

Similarly, the duration of monitoring is coupled to the questions asked, the specific objectives of the program, and the environment under consideration. Progress toward meeting exit criteria using simple models derived from periodic monitoring surveys can be used to optimize the monitoring plan and potentially reduce overall duration of the sediment monitoring program. In order to reduce the frequency and/or duration of a sediment program, the following items are typically necessary: robust data with sufficient quality for decision making, a sound baseline assessment, clear goals and objectives, measurable milestones, clear exit criteria, and sound statistical analyses.

9.5 Monitoring Approaches for MNR, Capping and Dredging/Excavation

The following subsections discuss remedy-specific monitoring approaches for contaminated sediments. While the following subsections focus on the three specific remedies independently (MNR, capping and dredging/excavation), it is important to note that cleanup at many contaminated sediment sites involves multiple remedy approaches and monitoring plans including a consortium of monitoring techniques to evaluate short- and long-term success. As the effectiveness of sediment remedies is currently being understood, knowledge about the design and implementation of monitoring plans is constantly updated. The following sections merely give samples of approaches. Site-specific monitoring strategies will depend on site specific data and objectives.

9.5.1 Monitoring for Natural Recovery. For MNR the RPM is essentially trying to determine whether natural processes are effectively reducing the measurable risk in an identified timeframe. Therefore, it is appropriate to include the measure of natural processes, such as biodegradation, accumulation of clean sediments, and/or sediment or contaminant transport either from seasonal circumstances or severe events in the monitoring strategy to measure the chemistry in the water column, sediment and biota, and to assess biota recovery as a function of population and diversity or toxicity assessments.

The monitoring approach summarized in Table 9-3 considers an MNR site where there is a fish advisory. In this example, the RAO has been established to reduce concentrations in Hybrid Bass to 0.10 ppm to eliminate the need for the advisory. In an effort to achieve the RAO, the action level in the first 0 to

Table 9-3. Example Monitoring Strategy for MNR

Matrices	Purpose/Objective	Monitoring Method	Classification	Frequency	Consideration
Sediment	To evaluate sediment thickness	Sediment Coring	Physical	Every 3-5 years unless there are concerns of impacts from extreme storm event	If previous age-dating is available; sediment accumulation rates could be calculated so that physical checks can be made less frequently. Should monitor after extreme storm event to estimate potential impacts to recovery process.
Sediment	Evaluate level of contamination in the core profile to assess decrease in the upper sediments and observe degradation byproducts	Sediment coring is suggested since the clean-up goal specifies the sediment depth to 15 cm. A grab sampler can be used if all parties agree that the sampler will achieve a representative depth.	Chemical	Every 1-3 years unless there are concerns of impacts from extreme storm events. If there is evidence of reduced concentrations then the RPM, with the consent of the appropriate regulatory agency, may choose to skip a sampling event with expectations that the cleanup goal will be reached in subsequent samples. Provisions should be made in the LTM to allow for this type of flexibility. Once cleanup level has been reached, may consider sampling only during suspected disturbances and focus on area of known impacts.	Chemical evaluation can be done concurrently with sediment thickness measurements if a coring approach is used.
Water	Evaluate contaminant flux into the water column	Whole-water sampling or Passive Sampling Devices (SPMDs, Tenax, etc.)	Chemical	Annual	May be an overly conservative method for assessment of potential bioaccumulation, but generally a good spatial indicator of contaminant flux from sediment and not prone to the same variability as will be found in sediment
Biota	Assess recovery of the indigenous fish population(s)	Indigenous fish catching via electroshocking to conduct chemical analysis	Biological	Annual at first to establish short-term trend; may consider reducing to biannual events depending on sediment data.	Develop a statistical approach that will allow for variability in diverse habitat situations. Consider the age, sex and species of fish collected to achieve goal(s).

15 cm of the sediment layer (surficial sediment) has been set at 1.0 ppm. Therefore, the long-term goal is to achieve the RAO and the short-term goal is to achieve the sediment clean-up goal. The RPM should consider the frequency of sampling in this scenario so that enough data can be collected to assess the long-term trends, but also to reduce unnecessary sampling and analysis.

Monitoring strategies for MNR sites may be initially developed with a more intensive monitoring campaign in the beginning of the recovery period, and should be developed with provisions to reduce specific monitoring efforts after the establishment of initial short-term trends. Likewise, the plan should accommodate the occasional need for additional monitoring, such as when there may be concern of sediment bed disruption or potential contaminant migration or displacement due to severe weather, prop-wash or other events or concerns.

Monitoring to confirm the effectiveness of source control is highly important at the MNR site. Continued contaminant releases could severely confound data interpretations and significantly impact the chances for developing an adequate assessment of the remedy performance.

USEPA's Sediment Guidance (2005) suggests that RPMs strongly consider making periodic comparisons of monitoring data to rates of recovery expected for the site in an MNR monitoring program. The monitoring strategy should accommodate for contingencies if or when performance is not comparable to predictions. Such contingencies may simply include a plan to increase the sampling frequency or may require the addition of a sand cover in locations at the site where there has been significant sediment disturbance or the remedy is not adequately protective of the ecology or human health. Following attainment of RAO and cleanup levels, it may still be necessary to periodically assess sediment thickness, especially if contaminant burial is the primary mechanism for achieving risk reduction.

9.5.2 Monitoring for Capping. Monitoring the long-term effectiveness of a cap usually involves determining whether the cap maintains the structure and integrity for which it was designed, assessing that it is effectively retaining contaminants and isolating them from the water column, and in some cases that benthic recolonization or rehabilitation has resulted after cap placement. Table 9-4 outlines a sample monitoring strategy for an in-place sediment cap where all three of these objectives are considered.

Cap monitoring should be designed so that the frequency of monitoring can be reduced significantly if it is performing as expected and there is no severe weather event or other natural event (such as an earthquake) that may have jeopardized the cap's performance. However, the RPM may wish to consider less frequent monitoring even if performance has proven effective in the event that other nearby remedies that could potentially impact the cap surface via transport of suspended contaminated sediments are being implemented.

9.5.3 Monitoring Considerations for Dredging. Long-term strategies at dredging sites are generally designed to ensure that the dredged area is not re-contaminated by additional sources or that dredge residuals left during the initial operation are not disturbed or redistributed. RPMs may consider the same grab samples to assess the benthic recovery at the site via benthic community consensus monitoring. Monitoring the sediment surface chemistry may take place at a frequency that is commensurate with the data quality objectives established in the monitoring sampling strategy/plan. Decision criteria should include specific confidence levels to be met in order to ascertain that goals have been achieved.

9.6 Lessons Learned in Sediment Monitoring

Sediment monitoring, whether in the form of baseline assessments, ecological risk characterization, remedial investigations, or remedy validation, often viewed as straight forward, is in fact extremely

Table 9-4. Example Monitoring Strategy for an In-Place Sediment Cap

Matrices	Purpose	Monitoring Method	Classification	Frequency	Consideration
Sediment surface	To evaluate physical isolation and cap integrity	Sub-bottom profile and/or bathymetry to evaluate the cap thickness and determine if there has been any significant erosion.	Physical	Every 5 years	Monitoring can be reduced or eliminated if cap has demonstrated sufficient integrity; unless there are concerns of impacts from extreme storm event(s)
Sediment surface, or porewater	To assess contaminant migration or breakthrough	Sediment coring for sediment chemistry; peepers, seepage meters or flux meters for porewater flux and porewater chemistry	Chemical/Physical	Every 5 years	Monitoring can be reduced or eliminated if cap has demonstrated sufficient integrity; unless there are concerns of impacts from extreme storm event(s)
Biota	Assess recovery of benthos	SPI camera and/or grab samples for benthic community analysis to determine re-colonization, population, and diversity	Physical/Biological	1-3 years	Develop a statistical approach that will allow for variability; may reduce or increase frequency pending initial recolonization rates.

complex and can be very costly. Most of the common pitfalls associated with sediment monitoring programs relate to inadequate up front planning. No program design should be blindly followed, or quickly thrown together. Preparing for changes in staffing, regulatory guidelines, and environment is the best way to avoid confusion and the successful conclusion of the project. Frequent, clear communication with regulators, timely deliverables, and clear concise reports will play an important role in moving towards progressive, cost reducing optimization strategies. Common pitfalls associated with sediment monitoring and methods that can be implemented to avoid these pitfalls are listed in Table 9-5. However, common pitfalls can be avoided if proper systematic planning is correctly followed and documented in the UFP-QAPP.

Table 9-5. Common Pitfalls Associated with Sediment Monitoring and Suggested Avoidance Methods

Sediment Monitoring Pitfalls	Avoidance Methods[(1)]
Monitoring plan lacking flexibility	• Build in the ability to re-examine monitoring program design based on incoming data. • Build in flexibility by incorporating decision logic within the LTM plan that would allow adjustments to be made based on results of previous sampling efforts.
Statistical evaluation methods are applied incorrectly	• Reevaluate and update (if necessary) the site CSM and sediment monitoring DQOs • Collect additional time-series monitoring data. Although future sampling frequency and monitoring duration can be evaluated using four quarters of sampling data, eight quarters are preferred because it allows for a better interpretation of seasonal trends and result in a more accurate and meaningful statistical evaluation. • Use additional monitoring locations in the statistical analyses • Incorporate multiple statistical analyses and compare the results
Sediment Monitoring Pitfalls	**Avoidance Methods**
Failure to account for environmental factors in data analysis	• Recognize the influence of environmental factors on data collection, analysis methods, and interpretation. • Mitigate environmental factors with small modifications in experimental design or timing of sampling events when possible
Impact of small scale spatial variance not addressed	• Increase sampling density within a limited area to understand the impact of the variance but keeping costs low
Impact of extreme heterogeneity not addressed	• Recognize this potential when a single very high sample exceeded critical benchmark criteria. • Ensure thorough baseline data collection to identify areas of extreme heterogeneity
Improper model application	• Evaluate modeling objectives to determine their applicability • Reevaluate CSM to insure input data are appropriately estimated and selected • Perform model sensitivity analysis • Ensure there is a sufficient amount of data to support model construction • Ensure model is accurately calibrated
Incorrect analyte list	• Review site history, historical analytical data for both soils and groundwater at the site historical analytical data from upgradient sites, COCs identified in the RI, applicable regulatory criteria, remedial action (e.g., MNA) information, background contaminant concentrations, list of daughter products of known contaminants, and results of risk assessments
Outdated monitoring strategy and/or approach	• Review decision criteria and optimize strategy based on recent monitoring data • Perform annual reviews
Incomplete/poor data analysis	• Re-evaluate DQOs/objectives against all data after every round of sampling

Table 9-5. Common Pitfalls Associated with Sediment Monitoring and Suggested Avoidance Methods (Continued)

Sediment Monitoring Pitfalls	Avoidance Methods[1]
New monitoring technique produces lower quality monitoring data	• Prepare/review SAP designed to describe the proposed new sampling method and outline the DQOs that specify the quality and quantity of data required to support program decisions. • Conduct a monitoring event during which samples are collected using both sampling techniques, and the data are compared to a set of evaluation criteria (e.g., concentrations equal to or greater than those collected using traditional methods) to determine whether data collected using innovative methods are representative of actual site conditions and can be implemented at the site. • Re-evaluate CSM and compare to limitations of proposed technology because conditions may not suitable for innovative monitoring technique
Cross contamination of samples	• Implement dedicated sampling equipment • Review SAP/QAPP • Collect field blanks to determine source of cross contamination

(1) Changes in the sampling design and decision-making process must be documented. The RPM should be aware that individuals responsible for decision making have been clearly defined and communication pathways have been established.

Case Study: LTM and Remedy Optimization of an In-Situ Sediment Cap at the Wyckoff-Eagle Harbor Superfund Site[*]

Project Summary

Eagle Harbor, a shallow marine embayment of Bainbridge Island, WA was formerly the site of the Wyckoff wood-treatment facility where large quantities of creosote were used from the early 1900s to 1988 (Figure 1). Historical creosote seepage into the harbor and metals from a nearby shipyard resulted in substantial polycyclic aromatic hydrocarbon (PAH) and metals contamination in the harbor sediments over time.

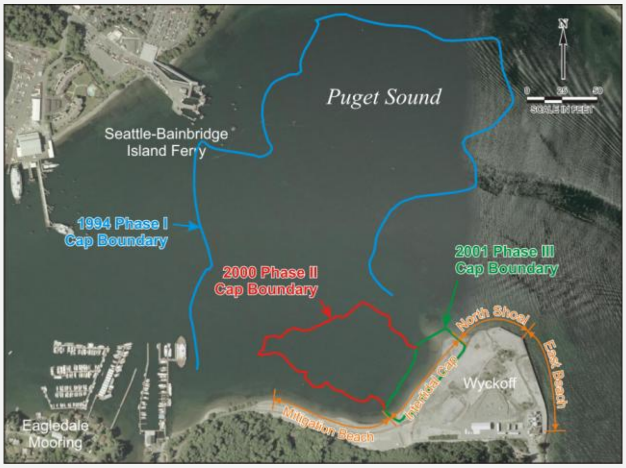

Figure 1. Eagle Harbor Site Map

The 1993-1994 Remedial Action (RA) (time critical) consisted of placing a sediment cap composed of 211,000 m^3 of clean sand from the Snohomish River over 21.4 hectares of chemically contaminated bottom sediments (Phase 1). Three monitoring studies to determine the long-term efficacy of the cap were conducted in 1995 (Year 1), 1997 (Year 3), and 1999 (Year 5) in accordance with the comprehensive cap monitoring program set forth in the 1995 Operations, Maintenance and Monitoring Plan (OMMP) (USEPA et al., 1995). The 1995 OMMP was developed to implement monitoring and provide additional information for potential further remediation needs; however its primary goal was to determine if the cap was physically stable and remained at the desired thickness; to determine if the cap was effectively isolating the underlying contaminated sediments; to determine if the sediments in the biologically active zone (0-10 cm) remained clean relative to the Washington State Sediment Management Standards; and to determine if the cap was being recolonized by bottom-dwelling benthic organisms. Physical stability and cap thickness (erosion) was monitored using bathymetric surveys and sediment transport was measured using SPI. Sediment coring and surface sediment grab samples were collected to determine if there was contaminant migration and if the cap was effectively isolating underlying contaminated sediments. Surface sediment grab samples were collected and analyzed to determine the extent of surface contamination in the 0-10 cm. Hierarchal cluster analysis (PAH concentrations, physical and biological parameters) was performed to determine if cap surfaces from various areas displayed similar characteristics. SPI conducted for objective 1 above was used to determine if there was a discrete layer of detritus and if the cap layer was being colonized by benthic infauna.

LTM Refinement

The Year 1, 3, and 5 monitoring reports which examined the changes to the Phase 1 subtidal cap over time were used to develop necessary additional RAs. Figure 1 shows the subtidal cap

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[*] Integral and U.S. Army Corps of Engineers, Seattle District. 2004. 2002-2003 Year 8 Environmental Monitoring Report, Wyckoff/Eagle Harbor Superfund Site, East Harbor Operable Unit, Bainbridge Island, Washington. Prepared for USEPA and USACE, Seattle District. August.

constructed in Phase II (2000). It extended onto Phase 1 cap areas of the southern boundary, where surface sediment PAH concentrations exceeded SQS based on 1999 Year 5 monitoring results. Phase III (2001) subtidal cap which extends shoreward from the Phase II cap overlaps the Phase I and Phase II caps and was placed over uncapped shallow subtidal sediments and intertidal sediments. The Phase III cap was extended into the intertidal zone in 2001 and a sheet pile wall was constructed to minimize continued source contamination. Other areas of concern included the North Shoal, East Beach, and Mitigation Beach (planted in 2000-2001 to provide continuous intertidal habitat around the site and replace habitat area removed for sheetpile wall installation).

Optimization Strategy Employed

A revised OMMP was developed in 2002 that veered slightly away from the 1994 Phase 1 cap LTM and placed additional focus on the newly remediated areas for the Year 8 LTM effort, since previous monitoring events indicated that the vast majority of the Phase I cap was isolating the underlying contaminated sediments and was providing suitable benthic habitat. The revised strategy focused on the following:

- Subtidal cap surface sediment collection (top 10 cm) – Methodologies were the same but sampling locations were changed.
- Subtidal cap subsurface sediment collection – the method for collection was changed to vibracoring rather than gravity coring and core sectioning protocol was changed to accommodate new cap thicknesses.
- Intertidal surface sediment collection – focused on new sampling locations.
- Intertidal subsurface Sediment Collection – focused on new sampling locations and used vibracoring rather than gravity coring.
- Habitat surveys – Habitat surveys were added to the LTM program after construction of the mitigation beach, which included removal of multiple bulkheads and recontouring of the area between +14 - 0 ft MLLW. The focus was to monitor the intertidal areas as habitat for avian, terrestrial and marine organisms and to evaluate the establishment of planting at the mitigation beach.
- Bathymetry of the subtidal caps to ensure continued stability of the cap
- Beach elevation surveys were used to assess the physical stability of the intertidal remedial construction efforts.
- PAH fingerprinting analysis was added to differentiate between creosote or off-site PAH sources on surface sediments.
- Sediment Vertical Profiling System (SVPS), photography, underwater video and benthic infauna collections were no longer implemented. The results from previous surveys indicated that the subtidal sediment cap was being utilized by benthic infauna, epifauna and finfish. These data indicate that the subtidal cap provides suitable habitat and monitoring efforts are now focused on the recently remediated areas.

Sediment Monitoring Program Development Checklist

Identify Monitoring Objectives

- ☐ Assess initial compliance with design and performance standards of the remedy
- ☐ Assess short-term remedy performance and effectiveness in meeting sediment cleanup levels
- ☐ Evaluate long-term remedy effectiveness in achieving RAOs and reducing human health and/or environmental risk
- ☐ Assess impact of disturbing system (e.g., concern over dredging residuals)
- ☐ Determine impact of remedial system on river hydrodynamics and sediment transport
- ☐ Evaluate levels of sediment contaminant (e.g., decrease over time for natural attenuation or extent of surface sediment recontamination for dredging)
- ☐ Assess the health/recovery of benthic community
- ☐ Assess the health/recover of high tropic species

Selection and Distribution of Monitoring Locations

- ☐ Choose monitoring locations to obtain background levels, bound the horizontal and vertical extent of contamination, assess contaminant transport, evaluate recovery and evaluate impacts of disturbing systems and remedial systems
- ☐ Use CSM, including contaminant fate and transport modeling to select sampling locations
- ☐ Apply monitoring network optimization software (e.g., VSP)

Determine Monitoring Frequency and Duration

- ☐ Consider the potential impact of seasonality on the monitoring program
- ☐ Use CSM, including contaminant fate and transport modeling to select sampling frequency and duration
- ☐ Plan for sufficient sampling events to evaluate trends of contaminant concentration, recovery of benthic communities and high tropic species

Identify Analytes for Initial Monitoring

- ☐ Review site history and contaminants found above applicable criteria to develop the list of analytes
- ☐ Consider physical, chemical and/or biological measurements depending on objectives

Determine Monitoring Technique

- ☐ Consider using Rapid Sediment Characterization techniques to optimize sampling
- ☐ Determine whether innovative monitoring technologies are feasible and cost effective

Sediment Monitoring Program Optimization Checklist

Evaluate Monitoring Objectives

- ☐ Evaluate monitoring objectives on an annual basis
- ☐ Confirm monitoring objectives have been met

Update CSM

- ☐ Revise and update CSM based on monitoring results
- ☐ Validate CSM with current understanding of site conditions

Optimize Monitoring Network

- ☐ Review sediment monitoring data to identify critical areas for continued focus and eliminate monitoring (or reduce frequency) of non-critical areas
- ☐ Evaluate data trends for sediment monitoring to reduce spatial redundancies (See Chapter 3)
- ☐ Consider using geostatistical techniques to optimize a sediment monitoring program
- ☐ Develop adaptive monitoring program which can be modified based on new data based on decision criteria for each management decision

Optimize Monitoring Frequency and Duration

- ☐ Review sediment monitoring data to identify critical areas for continued focus and reduce frequency of non-critical areas
- ☐ Evaluate trends in sediment chemical concentrations and/or conditions to determine if frequency can be reduced (See Chapter 4)

Optimize Analyte List

- ☐ Compare contaminant concentration in sediment to applicable criteria to determine if parameters can be eliminated
- ☐ Evaluate data trends for sediment monitoring to reduce spatial and temporal redundancies (See Chapters 3 and 4, respectively)
- ☐ Consider field sampling techniques by evaluating the cost and data quality produced

Optimize Sampling Technique

- ☐ Evaluate which monitoring technologies are most feasible and cost effective

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Chapter 10.0: Monitoring Ecological Resources

This chapter discusses some of the key issues associated with optimization of ecological monitoring, including:

- Identifying objectives for ecological resource monitoring programs;
- Developing an ecological resource monitoring program; and
- Utilizing optimization strategies for ecological monitoring.

In addition, sampling methodologies are presented for various biological resources in terrestrial and aquatic habitats. Sampling methods in abiotic media such as groundwater, surface water, and sediment are not presented in this chapter, but the reader is referred to Chapters 7, 8, and 9, respectively, of this guidance document for details related to these media.

10.1 Ecological Resource Monitoring Objectives

Ecology is generally defined as the study of living things and their interaction with the living (i.e., biotic) and non-living (i.e., abiotic) environment. Therefore, the term *ecological resource* refers to any number of living organisms and the environment in which they live, including either terrestrial or aquatic. Aquatic (including freshwater, estuarine, and marine) environments may include streams, rivers, ponds, marshes, lakes, estuaries, and near/off-shore coastal areas. Terrestrial environments include various types of forest, savannah, prairie, and other grassland habitats. Wetlands represent a combination of aquatic and terrestrial habitats and may be located inland around freshwater bodies or along the coast in more estuarine/marine environments.

The scope of monitoring the ecological resources at a restoration site will be determined by the site-specific project objectives. For a general discussion on goals and objectives for monitoring programs, see Chapter 2. Typical monitoring objectives identified for ecological resources include the following:

- Identifying impacts to ecological receptors (biotic and abiotic constituents) due to activity or contamination at the site;
- Assessing the ecological recovery of specific animal and plant species after hazardous waste remediation;
- Assessing contaminant levels in ecological receptors for human consumption;
- Evaluating trends in ecological receptors;
- Aiding in rehabilitation of ecological resources post remedial action; and
- Monitoring vegetation abundance and diversity.

Monitoring objectives should consider the specific restoration endpoints and approaches that have been selected to accomplish the project goals. For example, the endpoints for an intertidal salt marsh restoration project might consist of a number of different indicators of success including percent coverage or aboveground biomass after a specified period of time or preventing colonization of invasive species (e.g., *Phragmites* sp.). The approach to restoration might consist of planting salt grass (e.g., *Spartina* sp.) plugs and/or adjusting the hydrologic regime to favor the desired plant species.

On a national level, programs such as the Environmental Monitoring and Assessment Program (EMAP) and the National Oceanic and Atmospheric Administration‘s (NOAA’s) Status and Trends Program

(NS&T) are designed to monitor ecological resources to assess ecological conditions and a change in various resources over broad spatial and temporal scales. Monitoring of ecological resources at individual sites is also often a critical element of CERCLA/RCRA and individual state hazardous waste programs supporting site-specific remediation and/or habitat restoration activities. Monitoring is generally conducted: (1) before the onset of remediation/restoration activities to establish baseline conditions, (2) during the restoration itself to assess short-term impacts, and (3) following the completion of the restoration activities to evaluate attainment of remedial or restoration objectives. Although the focus of this chapter is on the monitoring associated with evaluating the remedial restoration objectives, the concepts and specific protocols developed to support national and regional programs are applicable and will be discussed, as necessary, throughout this chapter. Other documents that provide guidance on developing efficient monitoring programs for ecological resources include: *Guidance for Habitat Restoration Monitoring: Framework for Monitoring Plan Development and Implementation* (NAVFAC, 2004); *NOAA Fisheries Technical Guidance Manual for Success Criteria in Restoration Projects* (Pinit et al., 2004); and *A Framework for Conducting Effectiveness Evaluations of Watershed Restoration Projects* (Gaboury and Wong, 1999).

It is critical that Natural Resource Trustees and other stakeholders be involved in the development of monitoring objectives for restoration projects (NAVFAC, 2004). Different stakeholders may have different goals and objectives for the program, and a consensus should be reached on what will be monitored and the objectives of the monitoring. If the goals and objectives cannot be clearly defined because of uncertainties associated with specific activities or restoration activities on the biological environment, an adaptive management approach to the monitoring program should be considered (see Section 10.2.4).

10.2 Ecological Resource Monitoring Program Design and Optimization

Any ecological monitoring activities should be documented in a detailed monitoring plan that states the objectives of the monitoring program, the management decisions to be made, and the decision criteria to be used. Methods for assessing interim data (e.g., trend analysis, reference/background comparison) should be included in the monitoring plan, as the ongoing data evaluation process may uncover incorrect assumptions with respect to the ecological receptors made during the development of the CSM, therefore requiring adjustments to the data collection procedures. These changes may require specific adjustments to the plan or optimizing the current plan. The monitoring plan should also include an “exit” strategy that defines the program goals and the metrics to be used for determining when the goals have been achieved.

In an assessment of marine environmental monitoring programs by the NRC, the following five specific evaluation factors were identified to provide a useful framework for both project planning and subsequent periodic review:

- **Simplicity/affordability.** A monitoring program should be sufficiently flexible to allow for modification when changes in conditions of new information suggest the need, and should have adequate resources to conduct the necessary data collection, analysis, and evaluation components for the required time period to realize the program objectives.
- **Comparability against regulatory standards/criteria.** A monitoring program should consider comparability or adequate interpretation of gathered data with respect to a regulatory or site-specific standard, reference data, or baseline condition. The monitoring program should be integrated into the decision-making system, with the decision points and feedback loops clearly established before the data are collected. For CERCLA sites, regulatory requirements are usually referred to as ARARs. USEPA provides Superfund policy guides

for applying ARARs to CERCLA sites. Consult the USEPA Superfund web site (www.epa.gov/superfund/policy/remedy/) for more on CERCLA.

- **Implementability and site appropriateness.** Appropriateness of the monitoring program should be evaluated, ensuring that the monitoring program can answer the question being posed, a quality assurance program can be applied, and the data can be interpreted. The goals established should be achievable on a scientific, technological, logistical, and financial basis.
- **Social relevance.** A monitoring plan should clearly articulate the social relevance of the program goals and objectives to the public. For example, most anglers and local residents want to know: "Can I eat the fish?" and "Can I swim in the water?"
- **Communicability of findings.** Findings from the monitoring program should be clearly communicated to the public so that the program is useful and meaningful to them. These generally include numerical and quantifiable data that are presented clearly with finite conclusions such as food safety, risk from exposure, etc.

These factors are fundamental to a sound monitoring program design and necessary for its successful implementation (NRC, 1990). Regardless of the scope or the monitoring activity, it is helpful to periodically revisit each of these factors to optimize the plan for efficiency and to address any necessary issues. The project manager and other team members should challenge each other to justify current monitoring program elements and to be receptive of changes to existing practices as redundancies and efficiencies are recognized.

It is recommended that, like monitoring programs for abiotic media such as water, groundwater, soil, and sediment, biological monitoring programs also implement the DQO process to the full extent practicable to help identify the specific data objectives that will help make the key management decisions for the program. In the DQO process, design optimization is conducted during the last phase; however, this is only possible if study objectives and decision criteria have been clearly and logically developed previously.

10.2.1 Ecological Considerations

10.2.1.1 Abiotic Constituents. The types of necessary abiotic information will obviously depend on the biological systems being monitored and the specific questions that the program is designed to address. If the focus is to access ecological recovery following remediation, then abiotic data influencing contaminant bioavailability (e.g., sediment organic content), fate and transport, or toxicity (e.g., freshwater hardness) may be necessary information. Any environmental data relating to the physiological tolerances of organisms that are being introduced to the site should be included in the monitoring program design if such factors could limit the rate of recovery. The monitoring design for a restoration project should include the prophylactic collection of appropriate physical and chemical information that can be used to diagnose and allow informed midcourse decision-making in the event that a problem is encountered. For instance, abiotic soil property data (such as texture, porosity, pH, cation exchange capacity [CEC], and nutrient levels) might be included in a plant revegetation project.

The *Guidance for Habitat Restoration Monitoring: Framework for Monitoring Plan Development and Implementation* (see Tables 4.1 and 4.2, NAVFAC, 2004) presents useful summaries of the physical and chemical data categories routinely included in habitat mitigation and restoration projects. In addition, the project team should consider any unique site aspects that could influence the success of the project.

10.2.1.2 Biotic Constituents. Developing monitoring programs for "biological" organisms depends on the site location and the reason for monitoring (NAVFAC, 2007). For example, is some type of activity occurring on the site that will alter the current use of the land? Is the site undergoing a restoration activity that might influence particular plant and animal populations? Will the current activity be detrimental to any threatened and endangered species on the site? Will the activity impact the reproductive capabilities of particular species living on the site? Will the activity occurring on the site modify or change feeding grounds, nursery areas, or migratory pathways? Will the current activity result in ingestion of contaminated food sources?

Land use/land cover change. On many sites, activities change the site's landscape. In these cases, it may be necessary to monitor the abundance and diversity of vegetation. A calculation of the number of a particular species or multiple species may also be required, particularly if any threatened or endangered vegetation species, or invasive species, are located on the site. Changing vegetation patterns may also have an impact on use of the area by a variety of animal species, including species which may be listed as threatened or endangered. If the area was used as a breeding/nursery or a key location for feeding, the shifts in vegetation may impact the animals using the area. These considerations must be addressed when defining objectives to determine what types of monitoring are necessary.

Population impacts. In many habitat restoration projects, the objectives seek to identify impacts to specific plant and animal populations. To monitor these impacts, studies may consist of calculating the abundance and distribution of the population. Other examples of monitoring may include counting the number of nests (for birds), egg production, progeny, runoff to aquatic environments, habitat contaminant monitoring, fish and invertebrate surveys, organisms' disease and pathology, and other behavioral observations.

Contaminant issues. At many environmental restoration sites, biological exposures to chemical or radiological stressors are the principal concern. When deciding whether to evaluate tissue contaminant concentrations in various species, it is critical to consider the food web pathway from abiotic media through higher trophic levels. The CSM will determine how chemical constituents are physically transported to and within the study area, and how they biologically move through the food chain. Fate and transport modeling can be used to determine the likelihood of contaminants becoming either buried due to deposition or growth in vegetation, or available because of physical or biological mechanisms. Physical conditions such as the solubility of contaminants or their affinity for organic matter, tidal action or river flow, or storm events, are all considered in transport modeling. Biological mechanisms include such considerations as bioturbation of organisms, contaminant uptake in plant roots, lipophilic nature of contaminants and their ability to bioaccumulate in fat bodies of organisms up the food chain. Whether tissues from a specific species or multiple species from specific trophic levels are needed should be defined early on when developing the monitoring plan. At some sites, trophic species may be similar and the focus could be placed on one species and assumptions used to extrapolate the information to additional species.

Temporal issues. The goals of restoration projects will usually not be fully achieved for many years and even decades for some habitats (e.g., red maple or cypress/tupelo communities). Because of the time involved, it is important to include intermediate indicators of success as the composition and abiotic conditions of the species continually change throughout the successional period. Whereas the ultimate restoration goal might be the development of a fully functioning forested swamp, some intermediate indicators of success could include (i) an increase in the abundance of desirable species or the continued exclusion of exotic plants, (ii) the establishment of favorable abiotic conditions such as anaerobic soils or a specified hydrological regime, and (iii) the increase in aerial coverage of the target plant species (NAVFAC, 2004). Monitoring programs also need to consider that impacted areas may not return to original conditions. In complex, physically and biologically dynamic systems, the stipulation that the disturbed system must recover to a pre-construction state implies that the system exists in steady-state equilibrium, when it is more likely that an ecosystem has "alternative" (or multiple) stable states (Scheffer et al., 2001) in which it can exist. The notion of alternative stable states implies that the "final" ecosystem state is not predictable in the sense of having the same community structure as pre-impact. In essence, the pre-construction state is a moving target and unattainable post-construction unless it is defined by its spatial and temporal variation (Wiens and Parker, 1995; Parker and Wiens, 2005).

10.2.2 Selection and Distribution of Monitoring Locations. When designing any monitoring program, it is important to note that the more variable the media or organisms being monitored, the more samples that are necessary. Many available statistical programs allow the user to calculate the number of samples that need to be collected given the specific objectives of the program and the variability in the system. One such program is the Visual Sampling Plan. This software is described in more detail in Chapter 7, but also applies to the sampling of ecological resources. Many monitoring programs include a statistician on the planning team to assist with determining the number of samples. Additionally, these individuals can provide the probabilities associated with meeting a specific goal and objective when optimizing the monitoring program.

Other considerations when evaluating the selection and distribution of monitoring locations must include the number and size of the different habitats within a site, as well as which abiotic media (soil, sediment, air, water) must be monitored. The more diverse the habitat types, the more sampling locations may be needed. Similarly, the more abiotic media that must be evaluated, the more sampling locations may be needed. For example, if the aerial extent of a site is large and has five distinct habitat types, sampling may need to be conducted for all habitat types. Depending on the variability of the habitat, substantial sampling may be necessary within each habitat. If the aerial extent of the site is small and only one habitat type is present, the selection of sampling locations may be fairly straightforward.

Landscape characteristics, including topography and elevation of the site, the hydrology of the region, and whether or not the site is tidally influenced, should also be considered in the selection and distribution of sampling locations. For example, soil or vegetation samples collected from higher elevations may be very different from those collected at lower elevations simply due to elevation, and not necessarily due to some activity occurring on the site. Soil samples and the macroinvertebrate population collected from areas that are periodically inundated with water may be very different from those collected from areas that are always dry. Again, this may or may not be due to some activity occurring on the site. Therefore, it is important that the location of sampling address these confounding factors. A statistician can assist in determining the appropriate statistical spatial design (i.e., split plot, randomized block, etc.) of the program to ensure the appropriate information is collected.

For sampling in different types of water bodies, physical characteristics such as water depth, width (of the stream or river), substrate differences (hard or soft bottom), and distance of sample location from the shoreline need to be considered in the design. Similar to elevation and/or topography in terrestrial environments, abiotic characteristics and biological organisms may be very different depending on their location within a particular water body. Organisms living in sediment in the middle of a lake under 100 feet of water may be very different from organisms in the sediment under a few inches of water. Likewise, physical water properties may be very different in the surface water layers of an estuary than in the deeper waters of the same estuary. These differences may or may not be due to activities at the site. Therefore, it is important to include these factors in the spatial design of the monitoring program.

Deposition rates should also be considered when identifying sample locations. If a sampling area is expected to receive an influx of new sediments through physical conditions such as river flow, erosion, or other sediment transport mechanisms, the monitoring program should consider whether contaminated surface sediments would continue to be available to ecological receptors. Some organisms may dig or bury and receive exposure to subsurface contaminants while other organisms may only be impacted by surface or water conditions. Monitoring to ensure sediment deposition is actually occurring and at what rate may be more important as a monitoring objective than collecting sediments from an area that is expected to change.

Prior to selecting monitoring locations, it can be highly advantageous to determine whether existing data and information are available for the site and surrounding area. Many federal, state, or local agencies may also be conducting LTM efforts at a particular site. If the type of information that can be used to address a specific goal or objective already exists, this can be a large cost savings if the organization is willing to share the information. If the program is not designed to collect the exact information needed, it still may be used to supplement the current design and help optimize the monitoring program.

Finally, when selecting monitoring locations, it may be beneficial to consider sampling in a reference location. This will depend entirely on the objectives of the monitoring program, but in instances where an action (e.g., a construction project) is to be undertaken, if a location that is similar to the site in many physical and ecological aspects can be found but not impacted by the study site, then sampling from this location can help gauge the impacts that may be resulting from the action. For example, if three shellfish beds are adjacent to an area to be dredged, and modeling suggests that there will be no sediment deposition in the beds, sampling of a reference location can help in the interpretation of the results of monitoring shellfish beds before, during, and after the dredging activity.

Optimization in terms of reducing the number of sampling locations can begin after the initial sampling period and baseline conditions have been assessed. Once the source zone is delineated, habitats as well as other locations not impacted by the contaminant can be sampled less frequently or removed from the monitoring plan pending regulatory agreement.

10.2.3 Selection of Monitoring Frequency and Duration. Similar to determining the number and distribution of monitoring locations, the design of the monitoring program must take into account the frequency of sampling as well as the duration of the monitoring program. The frequency and duration of monitoring will vary greatly depending on the abiotic media or biota being monitored and the questions being asked to address the goals and objectives of the program.

Depending on the area of the country where the monitoring program is located (i.e., more temperate or sub-tropical latitudes), seasonality may need to be considered in the design of the program. Many parameters measured in abiotic media (such as water) will vary with seasons. Hydrological characteristics will also change depending on the season. In more sub-tropical systems, the “rainy” season can increase flow and volume of rivers and streams. In more temperate regions, snow melt will likely change the flow and volume of streams and rivers. Enclosed water bodies in different regions of the country may experience stratification and mixing with different seasons. The design of the monitoring program will need to take these factors into consideration. Researching the effect of seasonality on the ecological resources should be considered during the development of the monitoring plan to focus sampling frequency and duration on the impacted areas.

Monitoring plant and animal populations may also need to consider seasonality. Depending on the organism(s), species abundance and diversity can change as temperature, daylight, and other physical conditions in the environment change. Certain plant species may undergo dormancy during seasonal changes. Certain sizes or age classes of species may be important in determining maximum and average contaminant exposure and uptake. For terrestrial mammals in temperate regions with harsh winters, hibernation may occur and monitoring during this season may not be feasible. Migration and inhibitory patterns of some organisms are generally tied to season. Monitoring during periods when the organisms are migrating through the site may not provide useful information and would not be particularly cost effective. Some aquatic macrobenthic communities experience shifts in species composition with season.

Again, many of these factors should be considered during the design and optimization of the monitoring program.

The question of how long the monitoring program should continue will depend on the ultimate goals and objectives of the program. For example, after the removal of a landfill, the rehabilitation of ecological resources could be bounded by specific monitoring objectives for organisms' abundance and/or diversity. If one goal of the program is to evaluate trends, a longer duration for the program will be required. Another example involving an operating landfill could rely on groundwater and adjacent embayment monitoring to determine if the landfill is impacting the ecological system. Involving a statistician early on in the planning of the monitoring program can help optimize the sampling frequency and duration. Similar to defining the numbers and distribution of sampling locations, statisticians may employ various analyses to evaluate how powerful a design will be in terms of addressing the specific questions.

10.2.4 Optimization through Adaptive Management. As discussed above, a monitoring program should be flexible to allow for modification when changes in conditions suggest the need. Given the uncertainties associated with ecological systems in general and regarding how best to achieve desired restoration outcomes, continual optimization of the program, sometimes referred to as adaptive management, is an important tool in ensuring that the program continues to meet the objectives in the most efficient manner. Management is adaptive when management actions are measured and evaluated both before and after they have been implemented and the resulting information is then used to refine the next round of decisions or to adjust underlying assumptions. Monitoring results are incorporated to collect information that is then used to gauge the relative success of the selected actions. Use of the adaptive management approach compels restoration and ecosystem project managers to be open and explicit about what is and what is not known about how best to achieve conservation and management objectives.

In many situations, the project CSM will identify scientific uncertainties in the ecological processes or interrelationships between measured indicators and the state of the system. The empirical nature of adaptive management techniques can often be employed in these situations to garner additional information necessary to reduce initial uncertainties and "fine-tune" the process. Figure 10-1 demonstrates how an adaptive management approach is structured based on an example concerning the management of invasive exotic plants. A key element of this approach is that management objectives are established with incomplete information and adjusted as the knowledge base improves following implementation and monitoring of the management plan. Adaptive Management is a critical element of the Comprehensive Everglades Restoration Plan (CERP) with the program periodically conducting interim assessments of progress towards achieving restoration objectives. Where progress is not satisfactory, assumptions (including those with respect to ecological resources in the CSM) are reassessed and a determination made whether the unsatisfactory response is due to some component of the restoration plan or external to it.

10.2.5 Sample Collection Methods. There are a variety of sampling methods for many of the ecological resources presented below. A literature and/or internet search will yield methods employed by federal, state, local and private institutions for assessing and monitoring specific ecological resources. The following sections present key ecological resources that are frequently evaluated in monitoring programs. Links to sampling methodologies for these resources are provided below:

- Wetlands
    - http://www.epa.gov/owow/wetlands/bawwg/
    - http://www.epa.gov/owow/wetlands/monitor/
- Streams

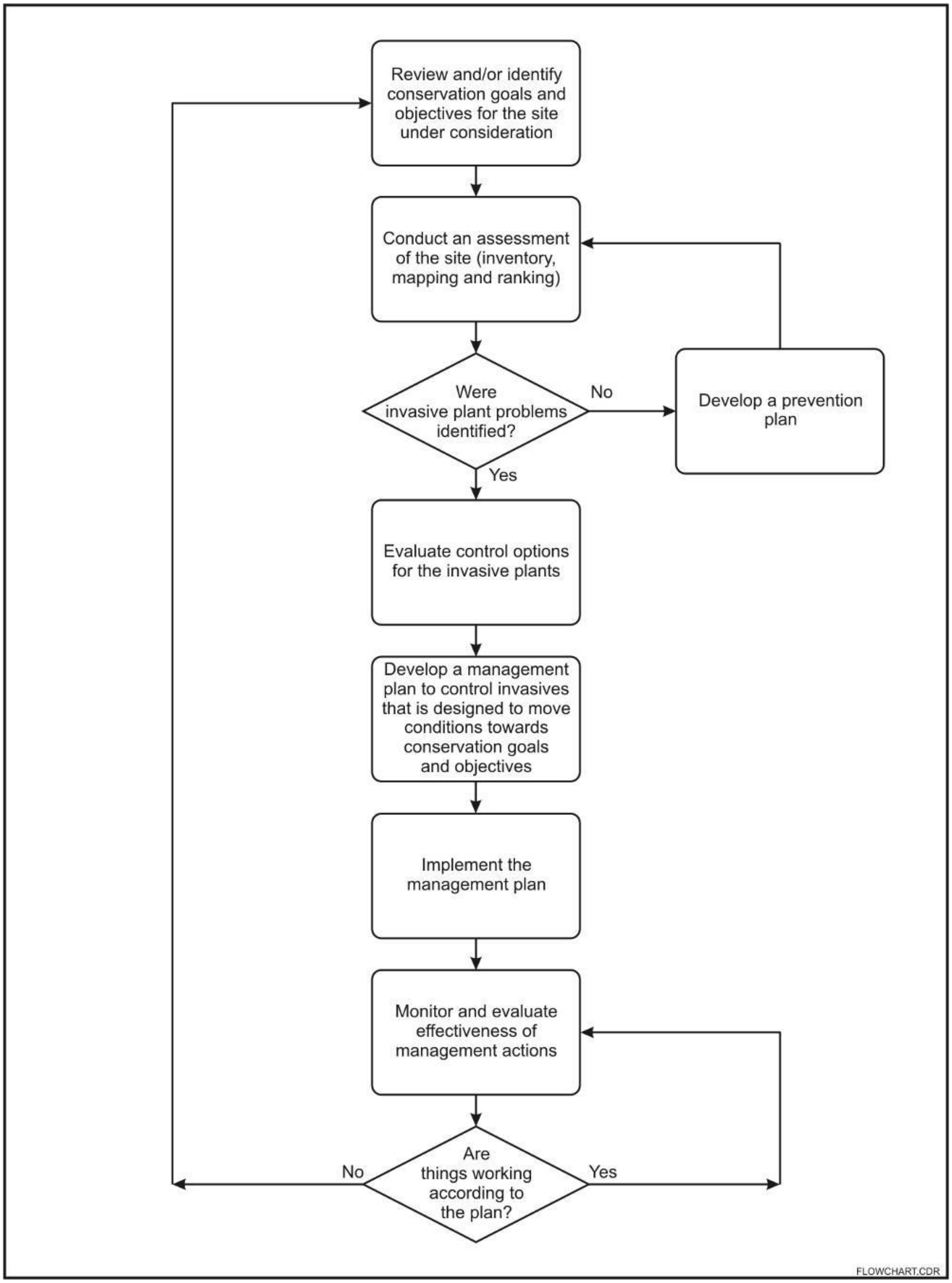

Figure 10-1. Adaptive Management Approach Applied to Controlling Invasive Exotic Plants. (Source: Pennsylvania Department of Conservation and Natural Resources [http://www.dcnr.state.pa.us/])

    - http://www.epa.gov/owow/streamsurvey/index.html

- Lakes/reservoirs
    - http://www.epa.gov/owow/monitoring/tech/lakes.html

- Estuaries and coastal marine waters:
    - http://www.epa.gov/ost/biocriteria/States/estuaries/estuaries1.html
    - http://www.epa.gov/owow/oceans/nccr/H2Ofin.pdf
    - http://coastalscience.noaa.gov/ecosystems/estuaries/restoration_monitoring.html
    - http://www.epa.gov/superfund/policy/pdfs/dir9355.pdf

Personnel with specific sampling experience should be involved during the design phase to ensure that the sampling options (and advantages and disadvantages of each) are clearly understood. The final selection of a particular sampling method/approach should then represent a balance between what is optimum from a data collection perspective and other considerations (e.g., need for specialized training, equipment availability, sample collection time, and cost). It should be emphasized that even after a restoration project has been initiated, opportunities for continued optimization include evaluating new or previously unavailable methodologies that can reduce costs or time (NAVFAC, 2004). In addition, ongoing review of the monitoring data and consideration of the study objectives can lead to the identification of data redundancies.

10.2.5.1 Plankton. Within the aquatic environment (both freshwater and marine systems), the planktonic component is often a resource that should be monitored. Phytoplankton, the primary producers in many aquatic systems, and zooplankton, the secondary trophic link in the aquatic food web, are useful indicators of environmental conditions. The planktonic community can be sensitive to any number of anthropogenic changes including changes in hydrology (timing of flow and volume of flow), stormwater runoff and water quality.

The sampling methods used for monitoring the plankton community depend on the environment, water column, diurnal and nocturnal migration, and related constraints on the sampling equipment. Monitoring in streams, lakes, and coastal areas may require slightly different sampling equipment and methods, but in general, a net or bottle can be used. Depending on the particular water body to be sampled, a plankton net may be towed from a vessel for a specified period of time, and then the organisms identified and counted. In flowing streams, a net may be staked so that water flows through the net for a specified period of time. The organisms are then identified and counted. Another method for collecting plankton where nets are not feasible is the use of bottles. Water samples are collected, sieved, and the organisms identified and counted. Light/dark bottles are used if calculation of photosynthetic rates is required.

10.2.5.2 Vegetation. Aquatic vegetation may be submerged, emergent, or floating. Within the aquatic environment (marine or freshwater), aquatic vegetation serves as a primary producer in the aquatic food web, helps to stabilize sediments, immobilizes nutrients and pollutants, and serves as habitat for a variety of invertebrate and vertebrate species. Sampling methods for aquatic vegetation are highly variable depending on the system and questions being asked. If contaminant tissue concentrations need to be monitored, physical samples from the plant (i.e., leaves, stems, flowers, etc.), water, and sediments must be collected, processed, and chemically analyzed.

If species abundance and distribution of vegetation is required, any number of survey methods (e.g., species identification, density, and coverage through planview photography and plant growth parameters such as shoot growth, rhizomes and leaf production) may be employed and will depend to some extent on the specific system (i.e., stream, lake, estuary, coast, etc.). Remote sensing technologies are being used more often to characterize benthic habitat in aquatic systems. Diver surveys are frequently conducted and will employ some type of quadrant or transect sampling to quantify the density of vegetation. Site specific stormwater runoff and soil erosion characteristics must also be monitored in conjunction with vegetation monitoring. Various monitoring programs throughout the country have guidance for their specific vegetation monitoring methods. Links are provided in Section 10.2.5.

Figure 10-2. Sediment Sampling Using a 0.04 m^2 Van Veen Grab Sampler (Photo Courtesy of Battelle Ocean Sciences Laboratory)

10.2.5.3 Invertebrates. Benthic macroinvertebrates live in bed sediments of rivers, streams, and coastal areas. They can also be found attached to hard substrates in these same areas. The types of organisms range from tube dwelling worms to insect larvae to various small crustaceans. In estuaries and coastal areas, macroinvertebrates may also include larger organisms living on the sediment surface including lobsters and crabs. Sampling methods for benthic invertebrates also vary by type of habitat. For larger organisms (such as lobsters, crabs or crayfish), sampling may include use of traps or pots that are baited and set for a period of time before they are hauled. In some areas, seines or other nets towed along the bottom may catch larger macroinvertebrate species. Other types of sampling methods include suction samplers that can sample the epifauna (organisms living in the interstitial spaces of such habitats as glacial till or rocky surfaces) and underwater photography to capture random locations of hard bottom habitats and the invertebrates (e.g., corals, sponges, tunicates, barnacles, algae) living on these surfaces.

Figure 10-3. Sediment Sampling Using a 0.1 m^2 Van Veen Grab Sampler (Photo Courtesy of Battelle Ocean Sciences Laboratory)

For macrobenthic organisms living in sediments, grab sampling is generally the preferred method of collection (Figures 10-2 and 10-3). Ponar grabs or other similar equipment (Eckman grabs, scoops, box cores, etc.) are dropped to the sediment and then brought on board for sieving and/or processing. Sediment is sifted through various sized sieves and the resulting organisms are identified and counted. Links to specific guidance for collection and processing of benthic invertebrates are provided in Chapter 10. Another method of collecting macrobenthic invertebrates, such as clams, is using a hydraulic dredger (Figure 10-4) that trawls for a specific distance or time within known shellfish harvesting areas.

Figure 10-4. Shellfish Sampling Using Commercial Hydraulic Dredge (Photo Courtesy of Battelle Ocean Sciences Laboratory)

To evaluate organisms living in sediments, an SPI camera is very useful and efficient by penetrating and taking a photograph of the top 23 centimeters (9 inches) of sediment, depending on sediment type (Figure 10-5). SPI surveys are very informative in evaluating the processes structuring the sediment-water interface and for obtaining in situ data on benthic habitat conditions. Multiple images can be collected quickly and efficiently in varying environments (from shallow waters to deep offshore) and evaluated for such parameters as prism penetration, surface relief, apparent color redox potential discontinuity layer, sediment grain size, subsurface features, successional stage, and organism sediment index (OSI).

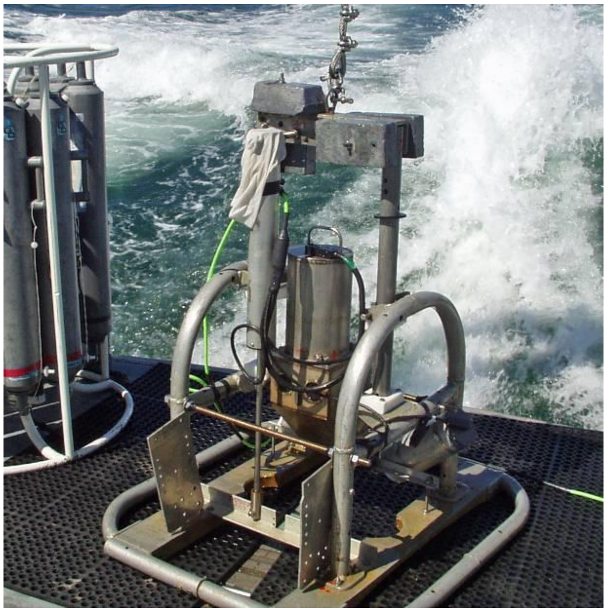

Figure 10-5. SPI Camera (Photo Courtesy of Battelle Ocean Sciences Laboratory)

10.2.5.4 Fish. Like sampling for other biotic resources, sampling for fish will also vary by type of habitat. Depending on the size of the stream, river, lake, or coastal water body, different methods must be used. Many sampling methods are used to get a snapshot of the fish population during a specific sampling period. These include electrofishing, trap netting, gill netting, fyke netting, trammel netting, seining and trawling. These methods can also be used to collect sufficient numbers of fish if tissue analysis is necessary. In general, the various types of net traps differ in application (e.g., pulled from boat, operated by hand, from shore, and set versus active operation), the type of aquatic conditions that they operate most effectively (e.g., deepwater/ shallow; marine/freshwater), and the size and preferred habitat of the target species. Overall, electrofishing is very effective at collecting all types of data if conditions are suitable (e.g., freshwater or low conductivity and shallow conditions).

In addition to these methods, targeted species surveys are often used to get specific information on population size structure, recruitment, growth, and mortality of species. New technologies are also being applied to fish monitoring programs. These new technologies include underwater video, fish tagging studies, and acoustic telemetry technologies, which can be used to collect specialized information on fish behavior, movements, foraging patterns, migratory patterns, etc. Fish, unlike other biotic resources, are mobile and the monitoring plan design needs to consider this.

10.2.5.5 Mammals. Aquatic mammals include both freshwater species such as river otters, and marine species such as otters, seals, manatees, and various cetacean species. Many marine mammals are listed as threatened and endangered species, and therefore any monitoring program needing to evaluate these organisms must be discussed with the appropriate federal agency (i.e., NMFS) for specific guidance. NMFS may have all the information needed for the specific species and the program may simply need to access the appropriate life history information (e.g., habitat preferences, seasonality/phenology, early life stage biology).

For freshwater and terrestrial species not listed as threatened and endangered, consultation with the U.S. Fish and Wildlife Service and U.S. Geological Survey or the specific state wildlife service can provide insight into monitoring methods for these species. If physical information about the animal is to be obtained (i.e., weight, sex, etc.) or if tissue analysis is warranted, some animals may be trapped using any number of trapping devices (e.g., live traps [Sherman, Havahart, Tomahawk], sticky and snap traps, mist nets [bats], and pitfall structures). If physical collection of the species is not necessary to address specific questions, monitoring may consist of surveys to locate and count individuals. To monitor seal and manatee haul out areas, boats or planes can be used to conduct visual surveys of animal numbers. Tagging studies, including radiotelemetry, may also be used to evaluate migratory behavior. When selecting a monitoring method, the primary determinants are animal size, specific data requirements, monitoring objectives, and cost.

10.3 Lessons Learned in Ecological Resources Monitoring

The most common pitfalls associated with ecological resource monitoring are related to a lack of understanding of environmental systems, failure to review and adapt to monitoring data, and a misunderstanding of the project's goals. Fortunately, these common pitfalls can be avoided through active communication, review of the site CSM and Conceptual Ecological Model (CEM), review of remedial action monitoring data, and continued optimization. Table 10-1 lists the common pitfalls associated with ecological resources monitoring and methods that can be implemented at a site to avoid these mistakes.

Table 10-1. Common Pitfalls Associated with Ecological Resources Monitoring and Suggested Avoidance Methods

Ecological Resource Monitoring Pitfalls	Avoidance Methods
Lack of understanding the environment in question	• Conduct rigorous CSM and CEM investigation • Invite local experts so that a refined and heuristic CEM can be developed and effectively used in plan design • Understand and document restoration goals
Insufficient resources	• Address budgetary constraints early in the project • Agree on monitoring objectives that are achievable within budget • Determine how indicator species and generic approaches will be used to meet monitoring objectives at reduced cost
Lack of understanding the critical monitoring objectives	• Establish explicit monitoring objectives • Determine how indicator species and generic approaches will be used to meet monitoring objectives • Obtain regulatory agency input and approval early and often
Stagnant program no longer meets DQOs	• Challenge assumptions and investigate DQO deviations. • Continually optimize program based on evaluation of monitoring data, updated CSM/CEM and monitoring objectives

Case Study: Optimization of Wetland Restoration at Naval Amphibious Base Little Creek, Norfolk, VA

Project Summary

Site 8 at Naval Amphibious Base (NAB) Little Creek is located roughly 500 meters upstream from Little Creek Cove and was used as a construction/demolition debris landfill from 1971-1979. Between March to May 2006, the landfill material was removed from Site 8, and a wetland was created. The Little Creek Salt Marsh (LCSM) is a semi-circular tidal channel that curves around a smooth cordgrass (*Spartina alterniflora*) flat. At high tide, the flat is partially submerged. To help with the restoration of the created wetland, vegetation similar to salt marshes in the area was planted in the LCSM. The objective of the monitoring study was to determine the main factors contributing to the restoration of a created salt marsh for optimizing the management strategies for sustaining this habitat.

LCSM Restoration and Optimization

The objectives for this study were to determine the predominant factors influencing habitat restoration. Thus, strategies for sustaining this habitat could be optimized by focusing LTM on the main factors. Monitoring of biotic and abiotic factors, such as soil attributes, hydrology, and plant cover, was performed to identify the main mechanisms for shaping the wetland. After one year of creating an LCSM, the following factors were considered critical:

- Tidal hydrogeology,
- Use of native plants, and
- Control of invasive plant species.

Tidal hydrogeology with respect to the groundwater infiltration impacted the soil structure and led to the collapse of a goose exclusion fence. By allowing geese access, a biotic effect was seen in the decrease in plant establishment. Nevertheless, native plants, as observed in the adjacent, natural salt marsh were planted and survived (when not affected by the geese). Specifically, *Spartina patens* and *Morella cerifera* were located in the LCSM because of their salinity and flooding tolerance. The non-native *Phragmites australis* presented itself upgradient in the tidal channel where groundwater seepage could impact the wetland. The recognition of points of entry for invasive species helps optimize the number of sampling locations. Ultimately, knowing where potential issues can occur will improve the rate of restoration as well as sustain the habitat once established.

Overall, identifying the main factors influencing the restoration of the LCSM can be used to direct the LTM effort. For example, the maintenance of the goose exclusive fence will improve the sustainability of the habitat and reduce the time needed to meet site-specific restoration goals.

Ecological Resources Monitoring Program Design Checklist

Identify Monitoring Objectives

- ☐ Identify impacts to ecological receptors (biotic and abiotic constituents) due to activity or contamination at the site
- ☐ Access the ecological recovery of specific animal and plant species after hazardous waste remediation
- ☐ Evaluate trends in ecological receptors
- ☐ Aid in rehabilitation of ecological resources post remedial action
- ☐ Monitor vegetation abundance and diversity
- ☐ Select monitoring objectives for “biological” organisms depending on site location
- ☐ Identify impacts to specific plant and animal populations for habitat restoration projects

Selection and Distribution of Monitoring Locations/Habitats/Media

- ☐ Determine the number and size of the different habitats within a site, as well as which abiotic media (soil, sediment, air water) must be monitored
- ☐ Consider the landscape characteristics including topography, elevation, regional hydrology, and tidal influence
- ☐ Determine the impact of physical characteristics such as water depth, width (of the stream or river) and distance of sample location from the shoreline. Include changes in physical characteristics due to seasonal changes as well (dries up, floods, etc)
- ☐ Utilize a reference location for interpretation of the results of monitoring before, during and after restoration

Determine Monitoring Frequency and Duration

- ☐ Select abiotic media and biota for monitoring
- ☐ Incorporate seasonality in the design and optimization of the program
- ☐ Remember that species abundance and diversity can change with temperature, daylight, etc.
- ☐ Involve a statistician early to help optimize

Determine Sampling Methods

- ☐ Select the appropriate sampling methods for plankton, vegetation, invertebrates, fish and mammals
- ☐ Conduct literature and/or internet search to yield methods employed by federal, state, local and private institutions for assessing and monitoring specific ecological resources

Ecological Resources Monitoring Program Optimization Checklist

Evaluate Monitoring Objectives

- ☐ Evaluate monitoring objectives on an annual basis
- ☐ Confirm monitoring objectives have been met

Update CSM

- ☐ Revise and update CSM based on monitoring results
- ☐ Validate CSM with current understanding of site conditions

Optimize Monitoring Network

- ☐ Review ecological resources monitoring data to identify critical areas for continued focus and eliminate monitoring (or reduce frequency) of non-critical areas
- ☐ Continually optimize monitoring plan based on evaluation of monitoring data, updated CSM/CEM and monitoring objectives

Optimize Monitoring Frequency and Duration

- ☐ Review ecological resources monitoring data to identify critical areas for continued focus and reduce frequency of non-critical areas
- ☐ Evaluate data trends for ecological resources monitoring to reduce spatial and temporal redundancies (See Chapters 3 and 4, respectively)

Optimize Analyte List

- ☐ Determine how indicator species and generic approaches will be used to meet monitoring objectives at reduced cost

Optimize Sampling Technique

- ☐ Evaluate which monitoring technologies are most feasible and cost effective

10.4 References

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Chapter 11.0: Vadose Zone Monitoring

This chapter describes the key points for designing and optimizing a vadose zone monitoring program. Monitoring of the vadose zone may require sampling of one or any combination of the following types of media:

- Soil vapor;
- Soil; and
- Soil-pore water.

Optimization of vadose zone monitoring to address site-specific objectives, including landfill monitoring and VI, is addressed in this guidance document (see Chapters 12 and 14). This chapter focuses on vadose zone monitoring associated with the remedial action and LTMgt phases of site remediation.

11.1 Vadose Zone Monitoring Objectives

The vadose zone, or unsaturated zone, is the area extending from the top of the ground surface to the top of the water table. For the purposes of this document, air within the vadose zone is termed either soil vapor or soil gas, and water retained within the vadose zone is termed soil-pore water. Monitoring of the vadose zone is important because contaminants in the vadose zone can present a risk to human health, and can also serve as a long-term source of groundwater contamination.

The extent of monitoring and the specific methods used will be determined by the specific project objectives identified for the site. The types of monitoring commonly implemented for the vadose zone include performance monitoring and detection monitoring. As discussed in Chapter 2, each type of monitoring can have several objectives. The primary objectives of performance monitoring include collecting data to make informed decisions regarding remedial system operation, and to verify progress toward overall remediation goals. Detection monitoring objectives include monitoring contaminant migration and changes in contaminant concentrations. Example monitoring objectives for the vadose zone are shown in Table 11-1.

Table 11-1. Vadose Zone Monitoring Objectives

Monitoring Objective	Vadose Zone Monitoring Example
Monitor remedial system operation	Monitor in situ parameters (e.g., vacuum, oxygen levels, soil moisture content) to verify/optimize remedial system operation.
Monitor remedial system effectiveness	Conduct soil vapor monitoring to verify progress toward overall remediation goals.
Monitor risk to potential receptors	Monitor potential vapor migration as a result of remedial system operation (e.g., air sparge implementation resulting in vapor migration in the vadose zone; generation of vinyl chloride as a result of bioremediation).
Monitor potential migration to groundwater resources	Conduct soil vapor monitoring to identify potential contaminant migration to groundwater resources.

11.2 Vadose Zone Monitoring Program Design and Optimization

Clearly defined monitoring objectives, along with corresponding decision criteria, are central to developing and optimizing the monitoring program. All data should be collected with an understanding of how the data will be used and how they contribute to a decision regarding the continued remedy or monitoring at a site.

In a monitoring program, the decision criteria should establish the basis for continuing, stopping, or modifying the monitoring program. For example, at a site where a remedy has been implemented, detection monitoring may be required following completion of active remediation to demonstrate that contaminant concentrations do not rebound. An appropriate decision criterion for completion of this detection monitoring may be “If significant rebound does not occur within 6 months of remedial system shut down, then soil vapor monitoring will be discontinued.” Example decision criteria for performance monitoring associated with various remedial actions are shown in Table 11-2.

The monitoring plan should be continually optimized as additional monitoring data are collected at the site. One effective approach for optimizing the monitoring plan is to develop a dynamic monitoring plan. A dynamic monitoring plan should clearly define how the monitoring program will be conducted in order to meet the project-specific objectives, and include the decision criteria that will be utilized to continually optimize the monitoring program. Refer to Chapter 2 for a discussion of dynamic monitoring plans. Vadose zone specific decisions for monitoring plan optimization may include the use of permanent soil vapor probes over temporary ones for LTM, or the use of handheld detectors over laboratory analysis for remedial system performance monitoring. Additional detail regarding monitoring plan optimization is included in the following subsections.

11.2.1 Selection and Distribution of Monitoring Locations. A well defined CSM (see Chapter 2 for more information) and clearly identified monitoring objectives will help determine the most effective monitoring approach. DQOs for an effective monitoring network may include:

- Tracking the horizontal and vertical extent of contamination (e.g., detection monitoring such as that for landfill gas monitoring or underground storage tank release monitoring);
- Measuring the change in contaminant concentration resulting from treatment;
- Providing data for comparison to all decision criteria and exit points;
- Measuring the rate and direction of any contaminant migration; and
- Determining the effects of contaminant source areas on remedy effectiveness.

Spatial designs include monitoring locations in profiles or grid patterns at a single depth or multiple depths. Statistical tools for spatial data analysis which can be applied to optimize the number of monitoring points necessary to achieve monitoring program goals are discussed in Section 6.3.6. In general, the location and distribution of vadose zone monitoring points will depend on the geologic complexity of the site, extent of contamination, and proximity of potential receptors, as defined in the CSM. Sites with highly heterogeneous geology may require more tightly spaced monitoring locations, both vertically and horizontally, in order to better monitor site conditions, contaminant distribution, and remedial effectiveness in the vadose zone. A lower number of monitoring locations may be adequate at a site with very homogeneous geology. Depth profiling can also be useful in tracking potential contaminant migration in the vadose zone.

The media to be sampled should also be considered when determining the optimal distribution of monitoring locations. Specifically, soil gas sampling or soil screening methods (see Section 11.3.2) can

Table 11-2. Vadose Zone Performance Monitoring Decision Criteria

Remedial Action	Monitoring Data	Decision Criteria
Soil Vapor Extraction (SVE)	In situ vacuum measurements at monitoring wells	Adjust SVE operating parameters to obtain adequate radius of influence for each extraction well.
	Air flow, vacuum, and contaminant concentration at extraction wells	Estimate mass removal from each extraction well and optimize system operation to maximize contaminant mass removal; discontinue SVE operation when contaminant mass removal reaches asymptotic levels.
	Soil vapor contaminant concentration monitoring	Discontinue SVE operation when remedial objectives have been achieved, or when a statistically significant stable trend (asymptotic conditions) has been reached.
Biosparge	Soil emission flux monitoring	If soil flux rates exceed acceptable levels, then implement vapor migration control measures (e.g., pulsed air injection, pure oxygen injection, SVE).
	Oxygen and carbon dioxide monitoring	Adjust biosparge operating parameters to achieve desired radius of influence; discontinue biosparge operation if in-situ respiration rates indicate that active biodegradation is no longer occurring (AFCEE, 2004).
	Soil vapor contaminant concentration monitoring	Discontinue biosparge operation when remedial objectives have been achieved, or when a statistically significant stable trend (asymptotic conditions) has been reached.
Thermal Treatment	Subsurface temperature monitoring	Adjust treatment system operating parameters as necessary to ensure adequate heating is achieved throughout the treatment area.
	In situ vacuum measurements	Adjust treatment system operating parameters as necessary to achieve pneumatic control.
	Soil vapor contaminant concentration monitoring	Monitor perimeter soil vapor wells and adjust treatment system operating parameters as necessary to control contaminant migration in the vadose zone.
Air Sparge	In situ vacuum measurements	Adjust treatment system operating parameters as necessary to achieve pneumatic control.
	Soil vapor contaminant concentration monitoring	Monitor perimeter soil vapor wells and adjust treatment system operating parameters as necessary to control contaminant migration in the vadose zone.
Phytoremediation	Vadose zone soil moisture monitoring	Adjust plant irrigation as necessary to ensure adequate water is available for plants, but to also avoid over-watering which can result in downward contaminant migration (ITRC, 2001).
	Soil pH and nutrient monitoring	Amend soil as necessary to provide optimal conditions for plant growth.
	Soil monitoring	Conduct periodic soil monitoring to demonstrate system effectiveness; discontinue monitoring when remedial action objectives have been achieved.
In situ Bioremediation	Soil vapor contaminant concentration monitoring	At sites with a potential for migration to indoor air, monitor concentrations of bioremediation daughter products (e.g., DCE, VC) and mitigate impacts to indoor air if necessary.

optimize the sampling plan by indicating where soil samples should be collected and, as a result, can reduce sampling costs and the number of soil samples required. The soil samples will confirm the soil vapor results and can also provide a basis for the conversion between soil vapor and soil contaminant concentrations at sites where soil vapor sample results will be used to monitor changes in soil concentrations over the long term (California Regional Water Quality Control Board [CRWQCB], 1996). Table 11-3 summarizes monitoring network design considerations for the objectives identified in Section 11.1.

Table 11-3. Vadose Zone Monitoring Network Design Considerations

Monitoring Objectives	Monitoring Design Considerations
Monitor remedial system operation	The treatment area may require a higher density of monitoring locations than those areas upgradient (background locations) or downgradient of the source in order to effectively monitor operation of the remedial system.
Monitor remedial system effectiveness	Focus monitoring efforts in the area and/or depth range with the highest concentrations.
Monitor risk to potential receptors	Monitor at the location of a potential exposure risk (e.g., adjacent to a building to monitor VI).
Monitor potential migration to groundwater resources	Focus monitoring efforts beneath the source zone and/or in the depth interval above the groundwater table to identify potential downward contaminant migration.

11.2.2 Sampling Frequency and Monitoring Duration. Optimization of the sampling frequency and monitoring duration can be dependent on many factors. One should consider the purpose and location of a monitoring point, historical data trends, transient site conditions, the media to be sampled (i.e., soil, soil vapor, and soil-pore water), and the monitoring method when determining the sampling frequency. The following list shows examples of how these considerations relate to vadose zone monitoring:

- **Monitoring point locations.** Special purpose monitoring points, such as sentinel or points of compliance, may need to be sampled more often to ensure protection of human health. For example, more frequent soil vapor monitoring may be necessary near an occupied building as opposed to less frequent monitoring in an undeveloped portion of the site.
- **Data trends.** The optimal monitoring frequency can often be proposed by identifying data trends at the site and evaluating the data in terms of the decision criteria stated in the monitoring plan. A decreasing data trend may support less frequent monitoring, while a monitoring point with an increasing data trend or highly variable data may require more frequent monitoring. Data from more frequent monitoring can be used to gain a better understanding of site conditions which could be causing increasing or unstable contaminant concentrations. For example, at a site with a light non-aqueous phase liquid (LNAPL) source zone, more frequent soil vapor monitoring near the water table may be necessary to understand how water table fluctuations affect contaminant concentrations in the vadose zone.
- **Transient site conditions.** Transient conditions are often created during remedial system startup. Typically, more frequent monitoring is conducted during the startup of a remedial system in order to optimize system operation and better understand changing site conditions; less frequent monitoring can then be implemented at a later stage of operation after data

trends are better defined. Conversely, conditions may not be expected to change quickly at a landfill site where LTM is required. In this case, monitoring as infrequently as once every five years may be acceptable to demonstrate compliance.

- **Media to be sampled.** Frequent soil sample collection for monitoring changes in contaminant concentration over time can be cost prohibitive. Depending on the contaminants of concern, soil vapor sampling may be a more cost-effective method for contaminant monitoring, with collection of soil samples conducted only periodically to confirm remedial effectiveness. Soil-pore water samples taken after/during significant precipitation can aid in evaluating the impact of recharge on the transport of contaminants. The frequency and duration of soil-pore water monitoring can be designed and optimized based on the project-specific monitoring objectives. If an objective is to monitor contaminant migration in the vadose zone to understand fate and transport or gauge effectiveness of a remedy, then an appropriate sampling schedule may be based on precipitation events.
- **Monitoring method.** Initially, elevated detection limits may be adequate for monitoring VOC concentrations, allowing for less expensive monitoring methods to be used on a more frequent basis. For example, a photoionization detector (PID) may be used to monitor changes in VOC concentrations daily during startup of an SVE system, with less frequent collection of samples for laboratory analysis to confirm results of the field screening or quantify removal efficiencies.

Including an exit strategy for discontinuing monitoring activities at a site will aid in optimizing the overall duration of a monitoring program. Exit strategies associated with treatment system operation will optimize the performance monitoring duration. For example, continue operating the remedial system until contaminant concentrations reach asymptotic conditions, then monitor for an additional six months to document potential contaminant rebound. If concentrations do not rebound, then discontinue system operation.

11.2.3 Contaminant Monitoring. The monitoring plan should be developed to demonstrate the progress of a remedial action and/or to monitor for contaminants that pose a risk to human health or the environment. Typical primary target compounds in the vadose zone will depend on the media to be sampled, and may include VOCs, SVOCs (PAHs), PCBs, pesticides and metals. Many VOCs, including most halogenated solvents and petroleum hydrocarbons, can be monitored in soil vapor, as these compounds have high vapor pressures and will volatilize in the vadose zone. Compounds such as PCBs and metals are most often monitored through soil sampling, as these compounds will preferentially sorb to the soil matrix.

USEPA publication SW-846, entitled *Test Methods for Evaluating Solid Waste, Physical/Chemical Methods* (2004), includes analytical and sampling methods that have been evaluated and approved for use in complying with RCRA regulations. These SW-846 analytical methods are the most commonly used methods for analyzing contaminants in soil and soil-pore water at naval sites.

USEPA has developed a separate series of analytical methods for measuring VOCs in air, known as the *Compendium of Methods for the Determination of Toxic Organic Compounds in Ambient Air* (also commonly referred to as the TO-methods) (USEPA, 1999). The USEPA methods typically used for air sampling with pre-evacuated canisters are methods TO-14a and TO-15. The primary difference between these methods is that the procedures for Method TO-15 reduce the loss of water-soluble VOCs. Because of this, the analyte list for Method TO-15 includes both polar (e.g., methanol, alcohols, and ketones) and non-polar VOCs (e.g., toluene, benzene), whereas Method TO-14a measures only non-polar VOCs. Detection limits for both methods range from 0.2 to 25 parts per billion by volume (ppbv). Other TO-methods used for VOC analysis include TO-1, TO-2, and TO-17. These methods are used for analysis of samples collected on sorbent material (e.g., Tenax® or a carbon molecular sieve).

At some sites, particularly those with active remediation systems, the use of field screening techniques in addition to laboratory analysis may be useful for contaminant monitoring. Field screening is most often implemented to gain real-time data associated with soil vapor monitoring. Handheld PIDs and flame ionization detectors (FIDs) can be used to monitor total VOC concentrations in soil vapor. While contaminant-specific concentrations cannot be discerned, a PID or FID can indicate whether or not total VOC concentrations have declined as compared to the previous monitoring event. Real-time contaminant-specific concentrations can be obtained by using sorbent tubes for soil vapor monitoring. These field monitoring techniques have elevated detection limits compared to laboratory analysis; therefore, these techniques are most applicable for monitoring during the early stages of a remedial action when contaminant concentrations are highest.

If handheld detectors will be used, split samples can be taken for at least one sampling round to compare the results between the laboratory and field analysis. A correlation factor can be calculated and then the more frequent analysis can be done with the low cost field reading with periodic re-establishment of the correlation factor. When using the field instrumentation, it is important to use the same type of device (e.g., lamp type for a PID) because each device has a different response factor. In addition, if methane is present but not the target analyte, the use of an FID, which detects methane, would not allow for a good correlation between the field reading and the target VOCs. In that case, a PID, which does not detect methane, would allow a better correlation.

In addition to contaminant monitoring, field measurements of other parameters (e.g., vacuum response, temperature, oxygen and carbon dioxide) are often used to indirectly monitor treatment system effectiveness. Field instruments are adequate for this purpose and provide real-time data which can be used to optimize operation of the treatment system.

11.3 Sample Collection Methods

Decisions on the sampling methods and technologies to use in a monitoring program should be based on consideration of a variety of criteria that include the following:

- Required sampling depths;
- Required sample volumes;
- Soil characteristics;
- Required durability of the samplers;
- Required reliability of the samplers;
- Installation requirements of the samplers;
- Operational requirements of the samplers;
- Commercial availability; and
- Costs.

Various methods for soil vapor, soil, and soil-pore water sampling are discussed below.

11.3.1 Soil Vapor Sampling. Soil vapor monitoring can be used as an indirect measure of the location and distribution of residual VOC contamination in soil, and also as a direct measure of contaminants in the soil gas at a site where VI is a potential concern. Soil vapor samples can be collected through various active or passive sampling techniques. Active soil vapor sampling is most commonly used for vadose zone monitoring. Flux chamber methods have also been used, but are not as widely accepted by the regulatory community. They can been used in certain situations to evaluate the vapor flux from the soil in cases where a planned structure has not yet been constructed, or to monitor contaminant flux from the vadose zone to the ambient air as a result of active remediation processes (e.g., air sparging or chemical oxidation). For more information on flux chambers, the reader is referred to Hartman (2003) and Kienbusch (1986).

11.3.1.1 Active Soil Vapor Sampling. Active soil vapor sampling involves withdrawing soil vapor from the subsurface through permanent or temporary soil vapor probes.

- ***Permanent Soil Vapor Probes*** are constructed of small-diameter (e.g., ¼-inch) inert tubing (e.g., polyethylene, nylon, stainless steel, copper) that has a short (e.g., 1 ft) section of screen attached at the bottom and placed at the desired sampling depth. The soil vapor probe is made permanent by installing a sand pack surrounding the screen, a bentonite seal above the sand pack, and benonite-cement grout in the overlying annular space. Also, the tubing is closed off at land surface using a gas-tight fitting or valve and, if necessary, a utility vault or similar means for protecting the tubing. Soil vapor probes can be installed using a number of methods, including hand augering or various types of drilling; however, some drilling methods are not considered appropriate for installing soil vapor probes (mud rotary) and others may require extensive equilibration times following drilling because of their affect on subsurface soil gas (air rotary, and rotosonic). Also, using a slam bar is discouraged because it may produce highly variable results (USEPA, 2002). Figure 11-1 shows a permanent soil vapor probe consisting of copper tubing and a Geoprobe screen. Several advantages and disadvantages of permanent soil vapor probes are summarized in Table 11-4.
- ***Temporary Soil Vapor Probes*** are left in place only long enough to collect a sample; therefore, emplacement of a sand pack and bentonite/grout is not required. However, hydrated bentonite should be used to seal around the drive rod at ground surface to prevent ambient air intrusion from occurring. Temporary soil vapor probes are most commonly installed using direct push methods (e.g., Geoprobe™) whereby the drive rod is driven to a predetermined depth and then pulled back to expose the inlets of the soil vapor probe. Several advantages and disadvantages of temporary soil vapor probes are summarized in Table 11-4.

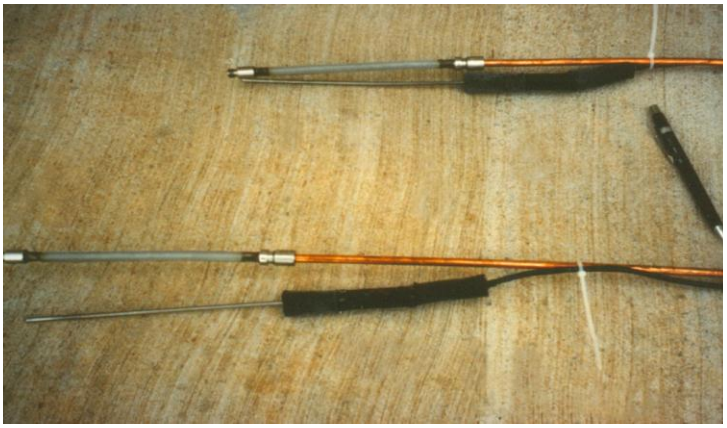


Figure 11-1. Example Permanent Soil Vapor Probes Constructed with Copper Tubing and Stainless Steel Screen (Source: Seminar on Indoor Air Vapor Intrusion, USEPA, 2003)

Table 11-4. Comparison of Permanent and Temporary Soil Vapor Probes

Advantages	Disadvantages
Permanent Soil Vapor Probes	
• Less prone to leakage and therefore likely to provide more reliable results. • Provide a means for repeat sampling (monitoring), which may be necessary to determine temporal variability. • Depth/geology usually not a limiting factor.	• More expensive (per point) than temporary soil vapor probes. • Access requirements are typically greater. • Don't provide real-time data.
Temporary Soil Vapor Probes	
• Installed quickly and less costly than permanent soil vapor probes. • Provide real-time data for decision making. • Can be installed in areas with restricted access. • Ideal for screening/locating where a problem might exist.	• Do not provide a means for repeat sampling. • More prone to leakage than permanent points. • Depth/geology may limit their use.

Soil vapor samples can be collected from either permanent or temporary probes using vacuum methods, including pre-evacuated canisters (e.g., Summa® canister), or by the use of a vacuum pump (Figure 11-2). When using a vacuum pump, samples can be collected into containers such as gas-tight syringes, which are particularly convenient when samples are being analyzed on site with the use of a mobile laboratory.

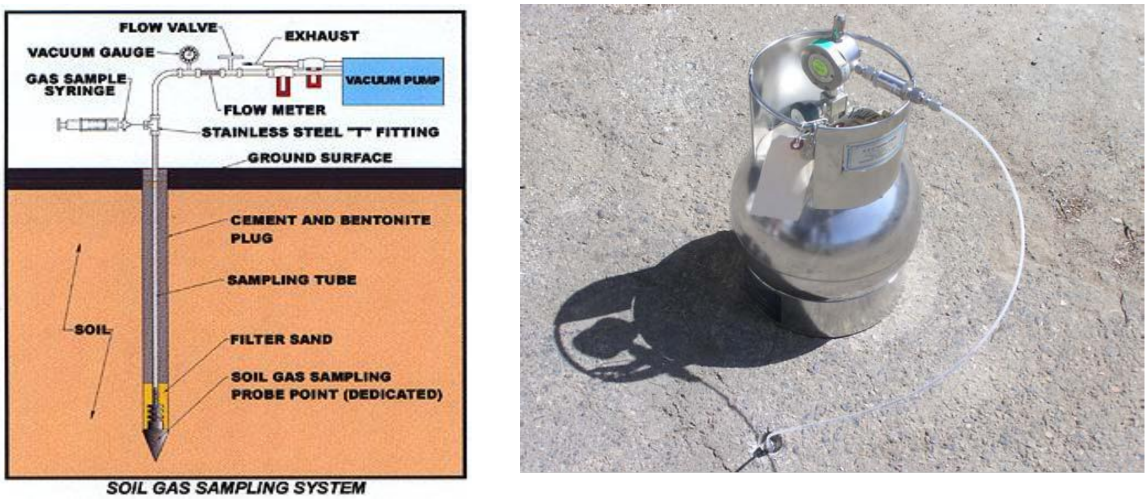


Figure 11-2. Example Sampling Train for Soil Vapor Using Vacuum Pump and Syringe (left) and Pre-Evacuated (Summa®) Canister (right).
(Source: Seminar on Indoor Air Vapor Intrusion, USEPA 2003 [left] and ©H&P Mobile Geochemistry [right])

Purging and sampling of soil vapor probes should be conducted at low flow rates and at vacuums that are matched to the soil lithology to prevent stripping contaminants from the soil, which may result in overestimating concentrations, and to ensure that representative samples are collected. A sampling rate of

100 to 200 milliliters per minute (mL/min) is recommended. If a pre-evacuated canister is used to collect samples, a flow regulator should be placed between the probe and the canister to restrict air flow and ensure the canister is filled at an appropriate flow rate. Also, large extraction volumes (e.g., 6-L Summa® canisters) increase the potential for pulling soil gas from a different depth or location than where the screen/inlet is placed. However, large volumes may be required to achieve the necessary detection limits for some compounds with very low risk-based screening criteria (e.g., trichloroethylene and vinyl chloride). In some cases, smaller canisters (e.g., 350 to 400 cc "mini-cans" or 1-L Summa® canisters) may be adequate.

When a vacuum pump is used, samples should be collected on the intake side of the vacuum pump to prevent potential contamination from the pump. Gas-tight containers (syringes) and valves should be used to ensure that the samples are not diluted from outside air. Tedlar™ bags are not advised unless sample analyses can be performed on site (i.e., mobile laboratory).

11.3.1.2 Passive Soil Vapor Sampling. Passive sampling techniques (e.g., EMFLUX® or GORE-SORBER®) rely on diffusion and adsorption and are generally used for longer-duration sampling periods. A slam bar or electric rotary hammer-drill is used to create a pilot hole for sample deployment. Collectors housing adsorbent materials are placed in the pilot hole and left for a period of time. Organic vapors migrating through the subsurface encounter the collector and are "passively" collected onto the adsorbent material. Passive samplers use hydrophobic adsorbent material or house the adsorbent in a waterproof membrane to prevent the uptake of water vapor, which can limit VOC adsorption. One advantage of passive samplers over active sampling techniques is that passive samplers can be used for both VOCs and SVOCs. Another advantage is that they work in tight soils where active sampling may be difficult or impossible. Also, passive samplers can be a cost effective method for delineating source and/or impacted areas compared to active soil-gas sampling. Data are reported in units of mass of analyte adsorbed onto the sample cartridge, which is converted to mass per unit volume of air in the laboratory based on a "cartridge collection constant." This constant requires knowledge of the volume of vapor that passed by the buried adsorbent during the burial time period and there is no established protocol for estimating this volume. A disadvantage of the passive samplers is that they are typically only installed at depths of approximately 3 ft below ground surface (bgs). However, passive samplers are cost effective and easily implemented tools that are useful for qualitative purposes, including:

- determining presence/absence of VOCs for source delineation;
- helping to identify/locate preferential pathways; and
- finding the bounds of contamination (determining where the problem does not exist).

For more information on passive-diffusive sampling methods, see USEPA (1998a and 1998b).

11.3.2 Soil Sampling. Due to the high cost of implementation and the destructive nature of common soil sampling techniques, soil sampling is not often selected as a means of LTM. If soil sampling is necessary, the need to collect undistributed samples should be considered when selecting the soil sample collection methods. Collection of undisturbed samples can be useful in determining in situ physical and chemical properties, but is not typically necessary for LTM. LTM is primarily associated with laboratory analysis of contaminants, and the most common sample collection method includes collection of grab samples using augers or other drilling/direct push techniques.

Various field screening techniques are also available for soil monitoring (for example, ultraviolet fluorescence, membrane interface probes [MIP] and ribbon NAPL samplers [RNS]). These methods are less expensive than traditional soil sample collection and laboratory analysis and can provide real time data useful in some projects, such as guiding an in situ remedial action. For example, using a field screening method to obtain real-time data may identify those locations which require additional chemical oxidation treatment without the expense and additional time associated with collection of soil samples for laboratory analysis. Traditional laboratory methods can provide more accurate data and will lower detection limits; however, depending on the project objectives, this degree of accuracy may not always be necessary. Therefore, the specific data quality objectives for a project will dictate the appropriateness of these field screening techniques during remediation or LTM. A discussion of these field screening techniques is provided below. Additional techniques are described in Appendix B of the NERP Manual (DON, 2006).

- Ultraviolet fluorescence testing measures the fluorescence response of a sample which corresponds to the concentration of VOCs or PAHs in the soil. Testing can involve the use of field test kits to screen soil grab samples, or the use of direct push instrumentation such as laser-induced fluorescence (LIF). Detection limits achievable using ultraviolet fluorescence will vary depending on the particular method used and the constituents being tested; however, the detection limits are usually in the range of 0.05 to 0.5 ppm with field test kits and 50 to 1,000 ppm using LIF. Use of ultraviolet fluorescence may be valuable when monitoring the effectiveness of a remedial action for treatment of heavier gasoline constituents which cannot be monitored in the soil vapor.
- The MIP is a direct-push logging tool most often used during site characterization; however, it also has potential applications associated with monitoring progress of a remedial action. The MIP provides rapid, real time, detailed characterization of stratigraphy and relative VOC concentrations with depth (Figure 11-3). Advantages of this technology include wide availability, simultaneous logging of VOCs and soil conductivity, vadose and saturated zone operation, use in delineating NAPL source zones, relatively inexpensive cost, and rapid site screening. Disadvantages include a high detection limit (5 ppm), qualitative analytical data, high contaminant carry over, and limitations with ground penetration resistance.

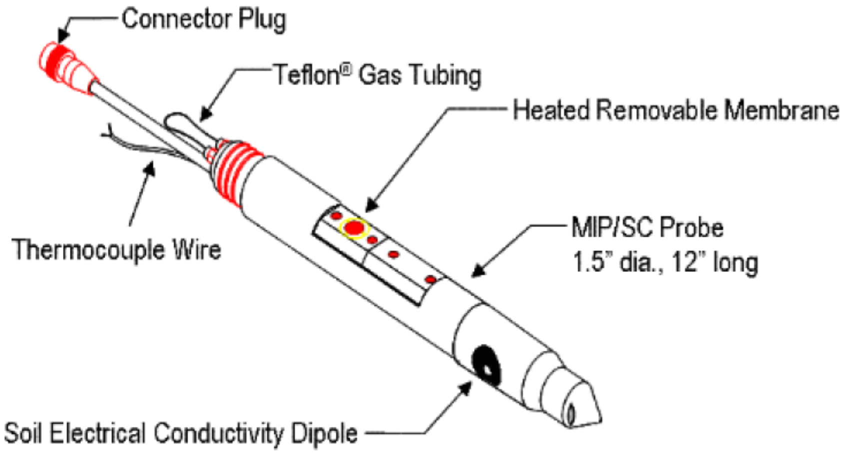


Figure 11-3. Membrane Interface Probe.
(Source: DNAPL Web Tool from NAVFAC T2 Website [http://www.ert2.org/ert2portal/DesktopDefault.aspx])

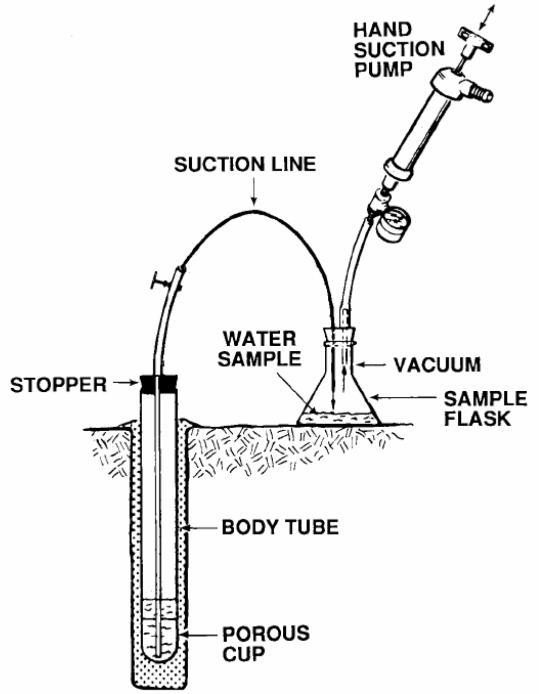
- RNS is used for monitoring free product distribution in the subsurface. It has a flexible membrane with a color-reactive hydrophobic cover that is installed downhole. NAPL wicks into the cover, leaches dye from its surface, and visibly stains the white backside of the reactive material. The liner/cover is inverted out of the hole to prevent cross contamination of the cover. The liner is then stripped from the cover to inspect the white side of the cover for stains. Advantages of RNS are that it is a simple, direct, and cost effective method, it provides a continuous record of NAPL distribution with depth in a borehole, and it can be deployed in a variety of borehole types. Limitations include heterogeneity limiting the value of the information, some NAPLs only have a relatively faint reaction, wicking may exaggerate NAPL presence, an existing potential for false positives and false negatives, and an existing potential for cross contamination. RNS may be a cost effective option for remedial monitoring at a site where a performance based remediation goal is in place, such as removing the NAPL source zone.

11.3.3 Soil-Pore Water Sampling. Soil-pore water sampling provides water quality data and can be important for understanding contaminant migration in the vadose zone. Soil-pore water monitoring can be particularly important during implementation of phytoremediation. Moisture sensors placed in the soil surrounding the root zone can automatically notify an irrigation system when the plants need watering, then apply the necessary amount of water. Lysimeter sampling of vadose zone soil-pore water can determine if irrigation water is migrating downward past the root zone of the plants to avoid over-watering. Water collected from a lysimeter can be analyzed for the contaminants of concern to determine the degree of potential downward contaminant migration associated with over-watering or precipitation events.

Various types of lysimeters can be used to monitor soil-pore water, including vacuum lysimeters (Figure 11-4), pressure-vacuum lysimeters (Figure 11-5), and high pressure-vacuum lysimeters. The maximum suction lift of water using a vacuum lysimeter is about 7.5 m; therefore, these samplers cannot be operated below this depth. In practice, these samplers are generally used to about 2 m below the surface. They are primarily used for monitoring the near-surface movement of contaminants such as those from land disposal facilities and those from irrigation return flow. Pressure-vacuum lysimeters can be used to collect samples at depths greater than 7 m because pressure is used for retrieval. However, at depths over 15 m, the increased pressure could force a portion of the sample back out of the sampler, or the increased pressure could damage the sampler. High pressure-vacuum lysimeters overcome the problems of fluid loss and overpressurization through the use of an attached chamber or a connected transfer vessel. The high pressure-vacuum lysimeters are not preferred at shallower depths because they are more expensive and they have more moving parts resulting in a higher possibility of failure.

11.4 Lessons Learned in Vadose Zone Monitoring

Vadose zone monitoring must be a transient process, and it will only be effective if the monitoring data are continually compared to decision criteria and evaluated to ensure progress is being made toward the monitoring objectives. The most common pitfalls associated with vadose zone monitoring are related to a lack of understanding of site conditions, failure to review monitoring data, and improper use of monitoring equipment. Fortunately, these common pitfalls can be avoided through review of the site CSM, review of remedial action monitoring data, proper training on equipment, and continued optimization. Table 11-5 lists the common pitfalls associated with vadose zone monitoring and methods that can be implemented at a site to avoid these more common mistakes.



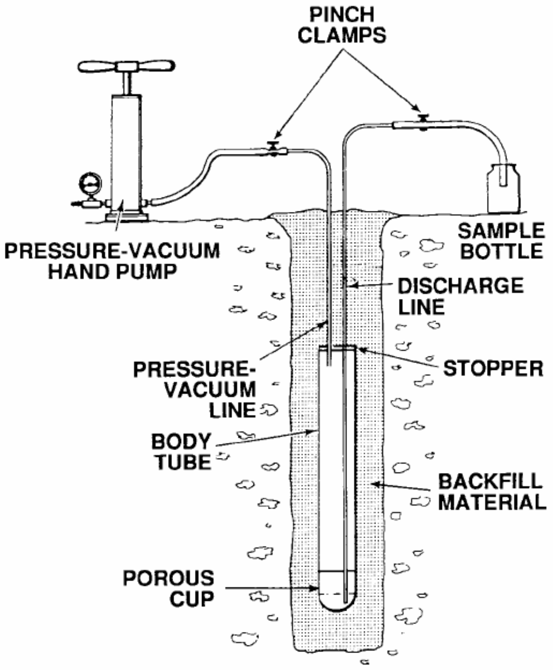


Figure 11-4. Vacuum Lysimeter.
(Source: ASTM, 2000)

Figure 11-5. Pressure Vacuum Lysimeter.
(Source: ASTM, 2000)

Table 11-5. Common Pitfalls Associated with Vadose Zone Monitoring and Suggested Avoidance Methods

Vadose Zone Monitoring Pitfalls	Avoidance Methods
Use of soil gas results as stand alone monitoring method	• Soil gas monitoring should be used in conjunction with other methods such as groundwater sampling, soil sampling, and/or soil-pore water sampling to obtain an accurate understanding of the contamination present in the subsurface
Inadequate number of vadose zone monitoring locations	• Reevaluate and update (if necessary) the site CSM and groundwater monitoring DQOs
Depth of the vadose zone monitoring is incorrect	• Take vadose zone samples at several discrete depths at a single spatial location and to accurately identify and monitor actual or potential pathways for contaminant migration • Locate and screen the monitoring well to bound the horizontal and vertical extent of contaminant plume
Statistical evaluation methods are applied incorrectly	• Reevaluate and update (if necessary) the site CSM and groundwater monitoring DQOs • Collect additional time-series monitoring data. Although future sampling frequency and monitoring duration can be evaluated using four quarters of sampling data, eight quarters are preferred because it allows for a better interpretation of seasonal trends and result in a more accurate and meaningful statistical evaluation. • Use additional monitoring locations in the statistical analyses • Incorporate multiple statistical analyses and compare the results.
Redundant monitoring data (too many locations or analytes)	• Review the monitoring objectives and corresponding exit criteria • Reevaluate the objectives of the vadose zone monitoring program to determine if any of the decision criteria for reducing the sampling frequency or monitoring duration at a site or individual monitoring point have been met. • Review the monitoring data to identify those analytes that have not been detected above the analytical reporting limit (i.e., all results not detected or detected only at concentrations indistinguishable from laboratory blanks) or below regulatory levels (e.g., VSL) in the four most recent monitoring events • Perform a statistical evaluation of the data to determine declining trends or locate redundant monitoring locations • Perform an annual review of the monitoring data in conjunction with the annual SAP review required by the UFP-QAPP
Incorrect analyte list	• Review site history, historical analytical data for both soils and groundwater at the site historical analytical data from upgradient sites, COCs identified in the RI, applicable regulatory criteria, remedial action (e.g., MNA) information, background contaminant concentrations, list of daughter products of known contaminants, and results of risk assessments
Atmospheric air contamination	• Take samples from at least 3 to 5 feet below ground surface • If shallow depths (< 3 feet) required, recognize the influence of ambient air and take special care to prevent sample contamination
Loss of contaminant vapor due to pilot holes	• Avoid pilot holes when direct push techniques can be used • Exceptions are to drill through surface coverings (concrete or asphalt)
Loss of contaminant vapor sample	• Insure that soil gas sampling equipment has the same size diameter for connections between probe, tip, and connectors

Table 11-5. Common Pitfalls Associated with Vadose Zone Monitoring and Suggested Avoidance Methods (Continued)

Vadose Zone Monitoring Pitfalls	Avoidance Methods
Incorrect sorbent tube selection/results	• Insure compatibility between contaminant and sorbent. Remember that not all types of contaminants sorb to and/or desorb from all types of media. • If contaminant concentration higher than expected, breakthrough may occur in the sorbent tube which would only indicate that the contaminant concentration is greater than a certain concentration. • A way to overcome this situation is to collect two samples. One sample has with a high volume of vapor passed through it in order to get a low detection level, and the other sample sees a low volume of vapor that is analyzed only if breakthrough occurs in the first tube.
Loss of sample	• Avoid using Tedlar™ bags when shipping to off-site laboratories due to breakage during air shipments. This can be avoided by using alternate media, such as Summa® canisters, adsorbent tubes or vials. • Avoid Teflon® coated syringes should not be used due to sorption of some contaminants (e.g., 1,1,1-TCA).

Case Study: Chlorinated Solvent Contamination in the Vadose Zone at a DoD Site in California

Project Summary

Historical operations resulted in chlorinated solvent (i.e., carbon tetrachloride [CCl_4], TCE, and 1,2-dichloroethene [DCE]) contamination in the vadose zone at a DoD facility in California. During the site investigation, elevated VOC concentrations were identified at depths ranging from approximately 20 ft to 200 ft below ground surface. Results of the risk assessment did not identify any unacceptable risk to human health or the environment due to the soil or soil vapor contamination; however, it was determined that VOCs in the vadose zone soil could potentially migrate and adversely impact the drinking water aquifer beneath the site. Given the nature of the contaminants and the site geology, SVE was selected as the remedial action in the vadose zone. Performance-based RAOs were developed in the ROD, including overall reduction in VOC concentrations; achieving asymptotic mass removal; and operating the SVE system only as long as it is cost-effective.

Optimization of the LTM

Based on the selected remedy, objectives were identified for the long-term soil vapor monitoring, including using the results to determine the extent of VOC reduction, if SVE operations should be adjusted, or if a new approach must be taken at some point in the remediation. Due to the depth of contamination, nested soil vapor monitoring probes were installed to adequately monitor changes in the lateral and vertical distribution of VOCs and the effectiveness of the cleanup. The frequency of the soil vapor sampling was reduced as the uncertainty regarding the soil vapor plume behavior was reduced. Results from the LTM were used to calculate mass remaining in the vadose zone, and to demonstrate overall reduction in VOC concentrations over time. Data indicated that the total VOC mass in the vadose zone prior to SVE operation was approximately 737 lb, compared to 44 lb at the time the SVE system operation was completed.

In addition, an exit strategy for the soil vapor monitoring program was established as part of the remedial action work plan. The remedial action work plan stated that after the performance objectives were achieved, the SVE system would be idled and soil vapor monitoring continued to evaluate rebound. If significant rebound occurred, the SVE system would be reinitiated; otherwise the SVE system would be permanently shut down. Significant rebound was defined as a rebound value of greater than 0.2 (i.e., less than one order of magnitude of post-shut down increase for each five orders of magnitude of initial decrease) based on the following equation (Bass et al., 2000):

$$\text{Rebound} = \text{Log}\,(C_r/C_f)/\text{Log}\,(C_o/C_f)$$

Where:
C_o = Initial VOC concentration prior to SVE system operation.
C_f = VOC concentration at last periodic sampling event prior to SVE system shutdown.
C_r = VOC concentration after system shutdown (i.e., rebound concentration).

Bass, D.H., N.A. Hastings, and R.A. Brown. 2000. “Performance of Air Sparging Systems: A Review of Case Studies.” *Journal of Hazardous Materials*. (72) 101-119.

Vadose Zone LTM Program Development Checklist

Identify Monitoring Objectives

- ☐ Monitor remedial system operation
- ☐ Monitor remedial system effectiveness
- ☐ Monitor risk to potential receptors
- ☐ Monitor potential migration to groundwater resources

Selection and Distribution of Monitoring Locations

- ☐ Review applicable regulatory requirements
- ☐ Choose monitoring locations to bound the horizontal and vertical extent of contamination, assess contaminant migration, and evaluate remediation
- ☐ Determine grid pattern spacing (horizontal and vertical) based on CSM (contaminant distribution and degree of subsurface heterogeneity)
- ☐ Determine the relative number of samples for soil vapor, soil, and soil-pore water necessary to achieve the project objectives
- ☐ Develop decision criteria to optimize the monitoring plan

Determine Monitoring Frequency and Duration

- ☐ Review site characterization data and update CSM
- ☐ Incorporate flexibility in the monitoring plan to allow for continual assessment of program needs
- ☐ More frequent monitoring may be necessary when transient site conditions are anticipated (e.g., remedial system startup)
- ☐ Evaluate the need for soil-pore water sampling during wet and dry periods

Identify Analytes for Initial Monitoring

- ☐ Review site history and historical analytical data for groundwater and soils
- ☐ Review regulatory criteria and risk assessment results
- ☐ Plan for on-site laboratory analysis for initial sampling rounds
- ☐ Evaluate the appropriateness of field screening techniques based on the established DQOs

Determine Sampling Methods

- ☐ Evaluate historical lithologic data and determine the sampling depths which are required
- ☐ Consider the frequency of sample collection to be completed when identifying the appropriateness of permanent or temporary sample probes
- ☐ Evaluate real time vs. off site soil sampling methods
- ☐ Evaluate the need for in situ soil-pore water sampling devices

Vadose Zone LTM Program Optimization Checklist

Identify Monitoring Objectives

- ☐ Evaluate monitoring objectives on an annual basis
- ☐ Update the conceptual site model
- ☐ Confirm monitoring objectives have been met

Update CSM

- ☐ Revise and update CSM based on monitoring results
- ☐ Validate CSM with current understanding of site conditions

Optimize Monitoring Network

- ☐ Determine whether decision criteria have been met per sampling location
- ☐ Apply geostatistics and temporal trend analysis to optimize monitoring points
- ☐ Apply monitoring network optimization software
- ☐ Properly abandon unwarranted sampling locations

Optimize Monitoring Frequency and Duration

- ☐ Evaluate decision criteria and prepare decision diagram
- ☐ Apply geostatistics and temporal trend analysis

Optimize Analyte List

- ☐ Evaluate decision criteria
- ☐ Identify analytes not detected above vapor screening levels
- ☐ Compare detected analytes against groundwater and background soil levels
- ☐ Evaluate potential for field screening monitoring
- ☐ Apply geostatistics and temporal trend analysis to optimize analyte list
- ☐ Ensure identified COCs and associated daughter products are included

Optimize Sampling Techniques

- ☐ Evaluate historical chemical concentration data
- ☐ Evaluate whether innovative sampling or field screening methods are feasible and cost effective

11.5 References

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Chapter 12.0: Landfill Monitoring

This chapter describes the critical elements to consider while designing and optimizing a monitoring program at landfill sites. The specific monitoring requirements that apply at landfill sites depend on the type of cover installed over the landfill waste, the type of liner (if any), the associated regulations, and the media of concern at the site. For optimization of monitoring programs that include groundwater and vadose zone media such as soil and soil vapor, please refer to Chapters 7 and 11, respectively.

12.1 Landfill Monitoring Objectives

Many Navy landfill sites managed under the NERP are on the CERCLA National Priority List (NPL), which requires that the substantive requirements of applicable regulations be met through the ARARs process (USEPA, 1988). However, most of the landfill sites currently existing under the NERP were created between 1920 and 1950 before environmental regulations (RCRA in 1976) were promulgated for landfills and are not NPL list sites. Nevertheless, these Navy landfills have monitoring requirements similar to NPL sites. In general, the presumptive remedy approach for landfills (USEPA, 1996), which consists of source containment in the form of a landfill cover, groundwater control and containment, leachate collection and treatment, landfill gas collection and treatment, and institutional controls (ICs) to supplement engineering controls (ICs and engineering controls are collectively referred to as LUCs, see Chapter 13), is the most common remedial approach that has been applied at Navy landfill sites. It should be noted that most Navy landfills do not have leachate collection and treatment systems. Figure 12-1 depicts a conceptual representation of the four major monitoring issues (i.e., cover integrity, leachate management, groundwater monitoring and landfill gas monitoring) as they relate to landfill sites.

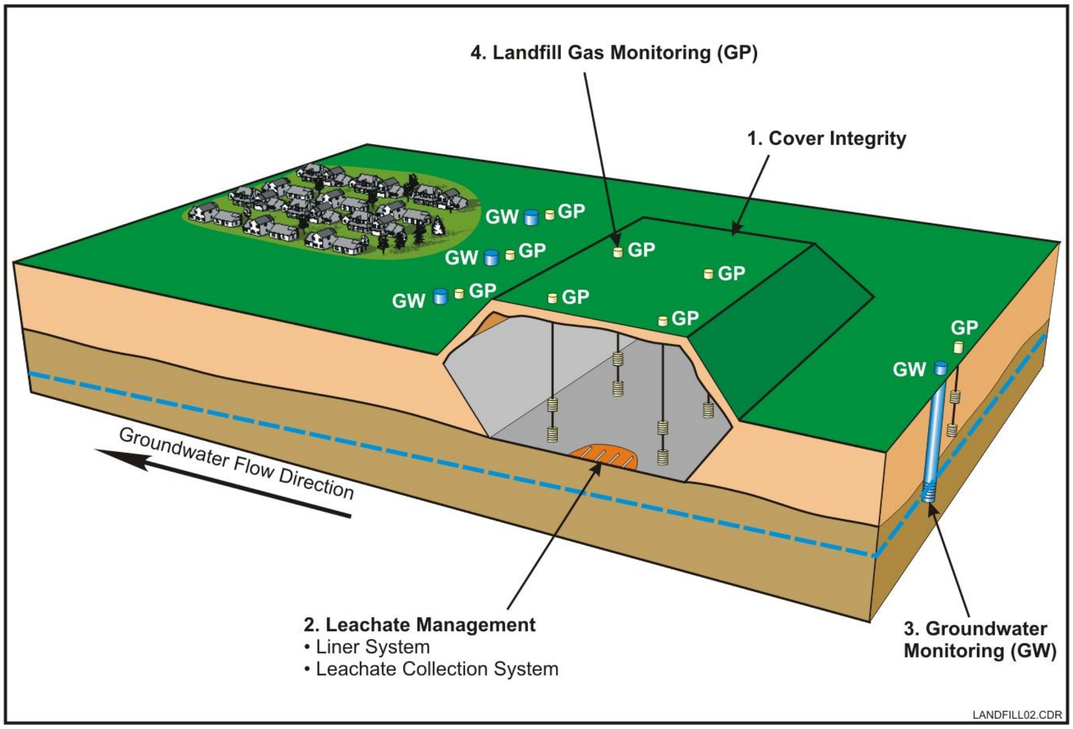

Figure 12-1. Major Monitoring Elements for Landfill Sites
(Source: *Technical and Regulatory Guidance for Design, Installation, and Monitoring of Alternative Final Landfill Covers*, ITRC, 2003)

The actual application of the presumptive remedy can vary widely depending on the site-specific characteristics, which in turn affect the monitoring objectives that need to be considered when developing or optimizing a monitoring program. For example, groundwater would need to be controlled or contained if there were contaminants of concern in groundwater that were presenting an unacceptable risk to current or future receptors. In addition, landfill gas collection (and any associated monitoring) would need to be performed if the degradation of waste within the landfill produced potentially explosive gases. Finally, a cap monitoring and maintenance plan will collect data needed to insure the protection of human health and the environment by confirming that the landfill cover system is preventing exposure to (or the escape of the waste disposed of) in the landfill, as well as providing control of the leachate and/or gases that are the decomposition by-products in the landfill.

To isolate and prevent escape of these materials, the cover must provide containment of the materials until such time that they are no longer a threat. A variety of final landfill cover designs and capping materials are available. Most landfill cover designs are multi-layered to conform to the design standards required by RCRA; however, single-layered designs are also used for special purposes when the regulatory agencies are agreeable to a non-conventional (i.e., alternative) cover. The selection of capping materials and a cover design is influenced by specific factors, such as local availability and costs of cover materials, desired functions of cover materials, the nature of wastes being covered, local climate and hydrogeology, and projected future use of the site in question (ITRC, 2003).

As stated earlier, there are five basic monitoring elements including cover integrity associated with closure and post-closure monitoring: cover integrity monitoring, LUC monitoring, groundwater monitoring, landfill gas monitoring, and leachate monitoring (when applicable). Performance requirements for each monitoring element are provided in Table 12-1.

Table 12-1 summarizes the types of monitoring requirements that may be applicable at landfill sites to address the basic issues presented above, and the associated objectives. Note that each type of monitoring discussed in the table may not be required at each landfill site. As mentioned previously, most Navy landfill sites are under the jurisdiction of the NERP (i.e., CERCLA program). While RCRA is generally identified as an ARAR that drives most of the monitoring program requirements under the NPL program, only the substantive requirements of RCRA are to be met and there may be some level of flexibility in the way the monitoring program is ultimately administered at the site. In large part, the level of monitoring required will rely on the regulatory program under which the site is managed and the site-specific conditions.

12.2 Landfill Monitoring Program Design and Optimization

The following subsections provide a summary of the network design required to monitor cover integrity, leachate management, groundwater, and landfill gas, and describes optimization techniques that should be considered when designing a monitoring network. The *Technical and Regulatory Guidance for Design, Installation, and Monitoring of Alternative Final Landfill Covers* (ITRC, 2003) is a valuable resource in identifying the following monitoring network design details, and despite the fact that this guidance manual was prepared specifically for alternative covers (namely evapotranspiration [ET]), the same general monitoring requirements apply to each type of landfill cover. As with the specific types of monitoring required at a landfill site, the selection and distribution of monitoring locations and frequency depends on site-specific characteristics in addition to negotiations with the regulatory agencies.

12.2.1 Cover Integrity Monitoring. In general, a regulatory-approved monitoring plan should be prepared that details the frequency and spatial distribution of the techniques used to inspect the integrity of the landfill cover system. In addition,

Table 12-1. Monitoring Requirements at Landfill Sites and Associated Objective(s)

Type of Monitoring	Objective(s)
Cover Integrity Monitoring	
• Cover Inspections	Cover inspections should be conducted as part of a LTM program to determine the need for maintenance.
• Settlement Monitoring	Subsidence inspections can be used to determine the location and amount of settlement that have occurred underneath or within the cover to ensure settlement is within design specifications, and that the cover integrity is not being compromised.
• Erosion Monitoring	The cover should be inspected for rills, gullies, intrusion by humans and/or animals, and damage by vehicle traffic to determine the location and amount of erosion, and whether or not maintenance is necessary.
• Vegetation Monitoring	Inspect cover vegetation for burned areas, excessive grazing, disease or pests, and weed infestations. Vegetation may also require formal sampling to demonstrate compliance with predetermined performance requirements.
LUC Monitoring	Comply with land-use restrictions, zoning ordnances, and deed restrictions. Control access to the site as well as insure protection of human health and the environment.
Groundwater Monitoring	Detect any potentially harmful release from a landfill site as soon as possible. Track the occurrence of natural attenuation mechanisms in order to potentially achieve site closure with no active remediation of groundwater. Track hydraulic changes after installation of landfill cover.
Landfill Gas Monitoring	Ensure methane is not accumulating in the landfill and becoming a potential explosive hazard (e.g., lower explosive limit [LEL] of 5%), and is not migrating off-site. Odor control is not typically covered in regulations, but depending on the location of the landfill and the proximity to the public, landfill gas monitoring may also be focused on ensuring no offensive odors impact nearby citizens.
Leachate Monitoring(a)	Leachate sampling should be performed to ensure the quantity and quality of leachate is within regulated design specifications (see 40 Code of Federal Regulations [CFR] Part 258).
Flux Monitoring(b)	Measure flux or soil pore moisture through the cover via lysimeters to ensure that: 1) the landfill cover has been constructed to design standards, and 2) flux through the cover is consistent with predicted or allowable levels.

(a) Leachate monitoring is only required if the landfill site is required to operate a leachate collection system, which is not common among Navy landfill sites regulated under the CERCLA NPL.

(b) Flux monitoring is generally not a common form of monitoring required at Navy landfill sites, and will therefore not be discussed in detail in later portions of this Chapter. If additional information related to flux monitoring is required, please refer to ITRC (2003) or Chapter 11 on Vadose Zone Monitoring.

all on-site inspections should be performed in accordance with a health and safety plan. Each of the monitoring techniques described below is conducted by making visits to the site to ensure the integrity of the landfill cover. Annual inspections of the landfill cover are standard, but under certain circumstances when substantial data have been collected to show the cover integrity has not been compromised over time, it may be possible to negotiate less frequent (e.g., every other year or every 5 years) inspections. Chapter 4 provides general considerations for optimizing the frequency of monitoring events. Although the examples provided in Chapter 4 pertain to monitoring contaminants and evaluating the concentration of contaminants, the same concepts can be applied to cover integrity monitoring. A history of having no deterioration of the cover at a particular location would be analogous to having a history of meeting a contaminant compliance criterion.

12.2.1.1 Cover Inspections. The general approach for cover inspections consists of conducting visual observations of the cover and documenting any notable damage that could affect the integrity of the cover. These inspections may consist of site visits to conduct visual inspections along transects at predetermined spacing. Activities that may be accomplished during the cover inspections include collection of data from erosion control monuments, settlement monuments, vegetation condition, and staking deficient areas. All findings of the cover inspection events should be documented in annual site inspection reports so potential issues associated with changes in the cover integrity can be easily tracked. The use of a portable GPS can help document the locations of cover damage and reduce the monitoring costs associated with conventional land surveying.

In the event that any notable cover damage requires maintenance or repair, it is important that such activities are not performed at times when additional damage may be done to the cover. Examples of such conditions include times of excessive soil moisture following a precipitation event, excessively dry soils, or windy conditions. Nevertheless, damage should be repaired as soon as possible given appropriate environmental conditions.

Optimizing the transect spacing is an important consideration and thus the spacing should be evaluated on a routine basis. Transect spacing can vary depending on the site, and the level of inspection that has been done in the past. For example, if a landfill cover was recently installed and had not gone through any cover inspections, then a more thorough and complete coverage (e.g., 25 to 50 ft transects) over the cover area should be performed. After five or more annual inspections have been completed with no maintenance required, optimization may include increasing the transect spacing to reduce annual monitoring cost. Furthermore, future inspections should be optimized to focus on problem areas in particular.

12.2.1.2 Settlement Monitoring. Landfill settlement can be caused by a number of reasons such as poor landfill construction integrity (e.g., diverse waste that is poorly compacted can settle over time), geotechnical, and seismic activity. Settlement monitoring is conducted by using settlement plates to physically measure and distinguish between the amount of settlement for the cover and foundation materials. The settlement plate is placed on the foundation material of the cover during construction and cover materials are placed at the specified design density around the vertical rod that is attached to the settlement plate and up to the marking ring located on the rod. Measurements are taken of the northing, easting, and elevation of the rod tip using a GPS with sufficient horizontal and vertical accuracy (i.e., ±0.10 feet) and recorded for later comparison.

During cover inspections, the northing, easting and elevation of the respective settlement plate rod tip can be measured again using the GPS, and movement of the surface of the soil in reference to the marking ring on the rod indicates that either erosion or settlement of the cover materials has occurred. If the rod tip has moved from the reference measurement, settlement below the cover and in the foundation has occurred. Settlement can also be observed by inspecting the surface for areas where water has ponded or where soil cracking or sliding has occurred. It is recommended that photographs be taken of areas where settlement and erosion have occurred to provide documentation of the impact.

Locations of settlement monitoring may be optimized based on specific information indicating that a particular area of the cover may be more prone to settlement over time due to the type of waste underlying the cover. Presenting sound justification of the proposed settlement monitoring locations to the regulatory agencies may allow the number of locations to be minimized while still meeting the objectives of ensuring that the cover integrity has not been compromised. In addition, the locations and frequency of monitoring can be re-evaluated over time to focus on those areas where settlement has been an issue and reduce the frequency in areas where the cover has proven to be stable.

Figure 12-2. Settlement Monument
(Source: *UMTRC Annual Report, Maybell, Colorado*, U.S. DOE, 2006)

12.2.1.3 Erosion Monitoring. Measurements collected during erosion inspections should be used to determine the location and amount of erosion that has occurred at the surface of the cover, so an assessment of necessary repairs can be performed. Visual inspection for erosion includes monitoring for rills (small cracks less than 6 inches wide and 4 inches deep), gullies (cracks large than rills), animal or human activities (e.g., burrowing, trails, and vehicular damage), and shifts in levels of the erosion control monuments (ITRC, 2003). Similar to settlement plates, erosion control monuments can be installed during landfill cover construction to indicate the amount of subsequent surface erosion. Each erosion control monument is placed at an elevation that is representative of the surrounding ground elevation. The elevation and state plane coordinates of erosion control monuments should be surveyed in conjunction with the topographic survey that is likely performed at the completion of the cover construction project.

To determine erosion, use a GPS to measure the cover surface at each erosion control monument and at four elevations evenly spaced and approximately 10 feet from the control monument. The average of the four measurements can be compared to the baseline established during the initial site survey to assess the extent of and/or potential for erosion. Surveying the elevations outward from the erosion control monument and comparing those elevations to the baseline elevations determines the extent of the deficient area (ITRC, 2003). As the database of erosion monitoring measurements grows over time, some locations may be removed from the list if erosion is not found to be an issue; in certain circumstances, some locations may be added to the list based on visual observations during regular inspections.

12.2.1.4 Vegetation Monitoring. It is critical that sustainable vegetation growth be established on landfill covers and it is important to conduct frequent (e.g., quarterly) inspections at the site during the first one to two years after cover installation to ensure sufficient vegetative cover is repopulating the site. Vegetative growth reduces the forces of erosion caused by overland runoff and wind. Vegetation is not only important from a perspective of controlling erosion and promoting more efficient evapotranspiration, but stressed vegetation can indicate potential issues associated with landfill off-gassing or leachate seeps. As with cover integrity inspections in general, the frequency of vegetation monitoring over time may be reduced as results indicate the health and viability of the vegetation is sustainable over time. Note that the climate and average precipitation rates in certain parts of the country and during certain seasons may have a bearing on when and how often vegetation monitoring should be performed. For example, the vegetation making up a landfill cover during the summer months in northern California versus Michigan may be more prone to stress due to the lack of rainfall, thus warranting more active inspection and maintenance during the dry season.

12.2.2 LUC Monitoring. As stated previously, LUC monitoring is part of the presumptive remedy approach for landfills (USEPA, 1996), which consists of source containment. For a general discussion of each type of LUC, see Chapter 13. For LUCs dealing with landfills, the remedial approach consists of both ICs and engineering controls (ECs) and can be referred to as custodial care. This term refers to monitoring of the landfill site with respect to the institutional controls of complying with land-use restrictions, zoning ordnances, and deed restrictions as well as controlling access to the site with engineering controls. ITRC (2006) recognizes LUC monitoring as critical to long-term management because it represents the culmination of post-closure monitoring of the cover, groundwater, landfill gas, and leachate production. LUC monitoring is needed for insuring continued source containment.

12.2.3 Groundwater Monitoring. The objectives of groundwater monitoring at landfills are to detect any potentially harmful release from a landfill site as soon as possible, to track the impact of landfill system shutdown (e.g., landfill gas system or leachate collection system) on the environment, and to determine the hydraulic changes after installation of a landfill cover. Given that a thorough understanding of the hydrogeologic properties of the site and a CSM (see Chapter 2 regarding the critical elements of a CSM) are essential for designing the groundwater monitoring network, it is important to recognize the site specific monitoring objectives at landfill sites. For examples at sites without a leachate collection system, groundwater monitoring will be ongoing during post-closure to monitor for potential releases and ensure protection of human health and the environment at the POC (ITRC, 2006). For sites with leachate collection systems, the groundwater monitoring program will ensure that the discontinuation of the leachate collection system does not pose an increased threat to the environment.

Per typical groundwater monitoring network design, it is critical to locate groundwater monitoring wells upgradient and downgradient of the landfill site in order to track background conditions and potential downgradient impacts from the landfill. If there are any sensitive receptors in close proximity to the landfill, consideration should be given to locate monitoring wells between the landfill and the receptor to ensure there are no potential adverse effects caused by the landfill. The proposed number, spacing, and depths of groundwater monitoring wells at landfill sites are determined based on the following:

- Aquifer thickness, groundwater flow rate, groundwater flow direction including seasonal and temporal fluctuations in groundwater flow
- Saturated and unsaturated geologic units and fill materials overlying the uppermost aquifer, materials comprising the uppermost aquifer, and materials comprising the confining unit defining the lower boundary of the uppermost aquifer (including, but not limited to, thicknesses, stratigraphy, lithology, hydraulic conductivities, porosities and effective porosities).

The development of the list of constituents when monitoring should be optimized based on background samples as well as long-term remedial goals. When MNA is a potentially appropriate remedial strategy for groundwater contamination at a landfill site, care should be taken to include this strategy in the constituent list (i.e., incorporate MNA parameters as standard analytes) prior to and leading up to finalizing the ROD. These data may be instrumental in promoting a natural attenuation remedy as part of the final ROD, rather than being forced to implement a more costly, active remediation system for groundwater.

Chapter 7 provides a more detailed discussion regarding the important issues that need to be considered when developing a groundwater monitoring network for a landfill site with groundwater contamination. The primary optimization strategies for a groundwater monitoring program consist of the following, which can be reviewed in detail in Chapter 7: minimize monitoring points, assure efficient field procedures, minimize monitoring frequency, simplify analytical protocols, streamline data management and reporting, and use of innovative sampling techniques.

12.2.4 Landfill Gas Monitoring. As summarized in Section 12.1, the primary objectives of a landfill gas monitoring program are to ensure that: 1) methane and other related landfill gases are not being produced at a rate that creates an explosive risk and are not migrating off-site; and 2) that offensive odors are not emitted to any nearby residents. It is noteworthy to mention that methane is lighter than air; therefore, as it is produced during waste decomposition, it tends to rise toward the landfill cover. Given this condition, a landfill gas management system can be installed in the cap to allow landfill gas to evacuate the landfill. For example, passive systems consist of gas vents where permeable screens allow landfill gas to vent into the environment (ITRC, 2003). Where passive systems are installed, gas monitoring can be conducted at the gas vents with standard gas monitoring equipment (see Chapter 11 for soil gas monitoring). For landfills without a landfill gas management system, landfill gas monitoring probes should be installed around the perimeter of the landfill at shallow depths (e.g., approximately 5 feet bgs), but it is also reasonable and appropriate to install gas monitoring probes throughout the vadose zone (and deeper) if the thickness of the vadose zone is greater than 8 feet. The number and location of gas probes is site-specific and highly dependent on subsurface conditions, land use, and location and design of facility structures. Monitoring for gas migration should be within the more permeable strata. Multiple or nested probes are useful in defining the vertical configuration of the migration pathway.

Critical monitoring locations are locations where gas may accumulate as well as locations near receptors, such as the property boundary or structures, where gas migration may pose a danger. Other monitoring methods/locations may include: sampling gases from probes or passive gas vents within the landfill unit or from within the leachate collection system (if one exists).

The primary analyte to monitor in landfill gas is methane, although in some instances VOCs and odors may also need to be monitored at a landfill site if residents are in close proximity to the site. In addition, although not required by regulations, collection of data such as the presence and level of groundwater, gas probe pressure, ambient temperature, barometric pressure, and the occurrence of precipitation during the sampling event provides useful information in assessing landfill gas monitoring results. For example, falling barometric pressure in some cases may cause increased subsurface gas pressures.

Section 11.3.1 describes active soil-gas sampling, which involves withdrawing soil vapor from the subsurface through permanent or temporary soil-gas probes. Sample soil-gas sampling techniques include handheld flame ionization detectors (FID) units, temporary soil-gas probes attached to Summa canisters, and passive sorbent units (EMFLUX® or GORE-SORBER®). These same techniques should be used to monitor landfill gas in and around landfill sites to ensure the landfill cover is effectively protecting human health and the environment. If a landfill gas collection system is in place, vapor samples should be collected from sampling ports installed prior to any treatment and/or release.

When optimizing a landfill gas monitoring program, it is important that the objectives of each monitoring point be identified. For example, points inside the landfill boundary may be expected to contain methane, VOCs and/or odors so the objectives for these locations are to evaluate landfill conditions (e.g., bioactivity) and to determine trends. If conditions appear to be consistent from one location to the next and/or over time, optimization should include reducing spatial and temporal redundancies. Tools for reducing spatial redundancies and optimizing the number and location of monitoring points are presented in Chapter 3. Tools for reducing temporal redundancies and optimizing the frequency of sampling are presented in Chapter 4.

For monitoring points located outside of the landfill, the objective of the monitoring point is typically to evaluate contaminant migration. This is particularly important when levels inside the landfill indicate a potential for unacceptable migration or contaminants and/or odors. In these cases, the monitoring done from the soil vapor locations should be selected based on the most likely migration pathways to receptors. If, however, monitoring at worst case conditions within the landfill (for example, area of highest risk or concentrations, or area of most permeable layers) indicate landfill gas is not an issue, consideration should be given to terminating the perimeter monitoring program. For cases where gas venting/collection is part of the remedy, limited monitoring on the upgradient and downgradient side of the venting/collection system along with low-cost pressure/vacuum measurements can be implemented to document the effectiveness of the remedy.

12.2.5 Leachate Monitoring. Leachate samples are only necessary if a leachate collection system is in place at the site. In general, the leachate is removed by an extraction system that consists of a sump pump placed on the bottom layer of the landfill. Extracted leachate is pumped to a treatment facility (if necessary) before being discharged. Samples of the leachate are collected through sampling ports that are installed along the extraction piping network, prior to treatment/discharge. For specifics on the requirements for managing a leachate monitoring system, see 40 CFR Part 258.

The types of analytes that should be monitored at a landfill site depend on the site-specific contamination and types of waste disposed of in the landfill. Leachate monitoring parameter lists should be designed to detect those constituents that could reasonably be expected to leach from the waste streams. This list should contain constituents that are generally more soluble and mobile. It might also be valuable to monitor a list of chemical constituents that are indicators of changing groundwater chemistry (e.g., biological oxygen demand [BOD] and chemical oxygen demand [COD]). For more information on suggested analytes, see 40 CFR Part 258, Appendix I.

To optimize the leachate monitoring program, the list of analytes should be re-evaluated on a routine basis with consideration given to the rate of change of the concentration of each parameter, and to the concentration of each parameter compared to appropriate criteria, such as a discharge limit. A low rate of change in concentration would indicate that the frequency of analysis may be reduced. A detailed description of how to evaluate temporal data trends is provided in Chapters 4 and 7.

12.2.6 Optimizing Landfill Monitoring Frequency and Duration. For a general discussion centered on reducing the monitoring frequency and duration, see Chapter 4. For the suggested monitoring frequency and duration that may be required at a landfill site, Table 12-2 provides some general guidelines to consider. As is the case at many environmental restoration sites, more frequent monitoring is generally required at the beginning of the remedial process to ensure the remedy is operating as it was designed and that it is effectively protecting human health and the environment and meets the objectives of the remedy. After sufficient data have been collected to confirm these objectives are being met, the frequency of the monitoring can be reduced in most cases, if not eliminated altogether. Annual optimization reviews of the monitoring should be conducted, and the results should be discussed with the regulatory agencies.

A critical optimization step that should be considered while the site monitoring plan is being prepared is to develop clearly defined decision criteria that can be applied at the site to reduce the monitoring frequency and duration, and to ultimately define an exit strategy. These decision criteria need to be prepared in close consultation with the regulatory agencies so a consensus can be reached and they can be documented in a regulatory-approved monitoring plan. General criteria for reducing monitoring frequency and duration can be found in Chapter 4, Table 4-1.

There are special circumstances surrounding the monitoring frequency of cover integrity on ET covers (Table 12-2). During the first two years of ET cover installation, it is critical that sustainable vegetation growth be established; therefore, comprehensive inspections that include the majority of the cover area should be performed more frequently (e.g., quarterly) during the first two years.

Table 12-2. Suggested Frequency and Duration of Monitoring at Landfill Sites

Type of Monitoring	Suggested Frequency[(a)]	Considerations to Optimize Monitoring Frequency
Cover Integrity	Quarterly for the first two years after cover installation, semi-annually for 8 years, and annually thereafter.	Identify critical locations based on construction details and historical monitoring and eliminate or reduce frequency in non-critical areas.
Groundwater	Quarterly for at least one year, followed by semiannual until sufficient data exist to show statistically significant stable to decreasing trends, at which time annual/biannual/5-year sampling should be negotiated with the regulatory agencies.	Use decision logic along with statistical and geostatistical methods to reduce temporal and spatial redundancies (see Chapter 7).
Landfill Gas	The minimum monitoring frequency at RCRA landfills is quarterly. At the Navy’s CERCLA landfills it may be possible to negotiate annual or biannual monitoring after sufficient data exist to indicate no explosives hazard exists in or around the landfill.	Evaluate trends (particularly from within landfill) to determine if frequency can be reduced (see Chapter 4). Evaluate need for perimeter monitoring based on potential for migration considering levels within landfill and effectiveness of migration control systems.
Leachate Quality, Quantity	Track the quality and quantity of leachate production with annual grab samples for constituent analyses.	Evaluate trends to determine if quantity of leachate has decreased over time. If so, leachate monitoring system can reduce pumping frequency and potentially eliminated when leachate production stops. Compare analyte levels to applicable criteria (background and historic levels) to determine if parameters can be eliminated and if leachate quality is improving.

(a) If routine monitoring indicates any potential problems or releases of contamination, the frequency of monitoring should be increased to assess the nature of the potential problem.

RCRA Subtitle D regulations require that the post-closure landfill monitoring duration be 30 years unless the regulatory agencies decide to extend or shorten it based on site-specific information. The decision to shorten or extend the duration of monitoring is usually based on whether the landfill site presents an unacceptable risk to human health or the environment. Barlaz et al. (2002) identifies and evaluates parameters (e.g., leachate production and gas production) that can be used to define the end of the post-closure monitoring period and presents a conceptual framework for an investigation of whether post-closure monitoring can be terminated at a landfill site.

12.3 Lessons Learned in Landfill Monitoring

Landfill monitoring must be a transient process, and it will only be effective if the monitoring data are continually compared to decision criteria and evaluated to ensure progress is being made toward the monitoring objectives. The most common pitfalls associated with landfill monitoring are related to a lack of understanding of site conditions and failure to modify the monitoring program based on a review of monitoring data. Many common pitfalls associated with landfill monitoring can be easily avoided through review of the site CSM and monitoring data, along with continued optimization. Common pitfalls associated with landfill monitoring and methods that can be implemented at a site to avoid the more common mistakes associated with landfill monitoring are listed in Table 12-3.

Table 12-3. Common Pitfalls Associated with Landfill Monitoring and Suggested Avoidance Methods

Landfill Monitoring Pitfalls	Avoidance Methods
Inadequate or faulty location for monitoring network of landfill gas migration pathways to nearby sensitive receptors	• Reevaluate and update (if necessary) the site CSM and landfill gas monitoring DQOs • Ensure monitoring probes are placed in the most likely migration pathways, including intervals of permeable material or utility corridors • Develop an accurate understanding of future land use plans of adjacent property, and continually update as necessary; adjust landfill gas monitoring network to optimally locate sampling points between potential source areas and sensitive receptors.
Impact to cover integrity from erosion (wind or flooding), settling, lack of vegetation, or burrowing animals is not observed, and results in potentially complete exposure/migration pathways of landfill waste	• Perform regular cover inspections along adequate spatial coverage to observe problem areas, and repair as soon as possible • Ensure future inspections focus on problem areas in particular
The location of the groundwater monitoring wells do not effectively detect off-site migration, or migration on-site from an upgradient source	• Continually reevaluate and update (if necessary) the site CSM with groundwater flow directions and gradients, and adjust groundwater monitoring DQOs • Install a sufficient number of monitoring wells at an appropriate spacing along the downgradient boundary of the landfill to ensure chemicals in groundwater do not migrate off-site • Be aware of potential upgradient sources of contamination and optimally locate groundwater monitoring wells to detect potential impacts from upgradient sources to ensure the associated liability does not fall on the landfill owner
Redundant monitoring data (too many cover inspection transects, groundwater monitoring wells, landfill gas monitoring probes or analytes)	• Review all applicable monitoring objectives and exit criteria • Reevaluate the objectives of the entire monitoring program to determine if any of the decision criteria for reducing the sampling frequency or monitoring duration at a site or individual monitoring point have been met • Review the monitoring data to identify analytes not detected above analytical reporting limit (i.e., all results not detected or detected only at concentrations indistinguishable from laboratory blanks) or below regulatory levels (e.g., MCLs for groundwater or LEL of 5% for methane) in the four most recent monitoring events • Perform a statistical evaluation of the data to determine declining trends or locate redundant monitoring locations • Perform an annual review of the monitoring data in conjunction with the annual SAP review required by the UFP-QAPP

Case Study: Optimizing the Long-Term Monitoring Scheme for NAF El Centro Site 1, Magazine Road Landfill

Background

Drainage improvements and an engineered cap were installed as part of a non-time critical removal action (NTCRA) at El Centro's Magazine Road Landfill. The cap covers and prevents direct exposure to waste and contaminated soil left in place. The NTCRA prevented surface water infiltration and percolation through the waste and contaminated soil, thereby protecting groundwater. The NTCRA also included restrictions on agricultural irrigation.

Chemicals of concern are metals, VOCs, pesticides, PCBs, and herbicides. Site monitoring conducted over nearly 15 years as part of site characterization activities and 5 years of post NTCRA monitoring demonstrated that groundwater had not been significantly impacted by landfill contents. However to satisfy landfill related ARARs for the final remedy, it was necessary to include groundwater detection monitoring to insure that the remedy continues to be protective. The conceptual site model for the site concluded that the most likely release mechanism after cap construction would be from groundwater coming into direct contact with landfill wastes. The water table was previously high enough for groundwater to contact the landfill wastes, but by restricting agricultural irrigation in nearby fields, the water table has been lowered and is currently 9 to 12 feet below the bottom of the waste.

Remedial Action Objectives

- Prevent direct contact with contaminated soil and landfill wastes.
- Prevent the release of COCs to groundwater
- Satisfy ARARs for landfill closure and monitoring

Remedy Optimization and LTM

The final remedy for the site was documented in a ROD that included land use controls and LTM. LTM includes groundwater monitoring and inspection and maintenance of the cap and drainage improvements, but does not require landfill gas monitoring. Landfill gas LTM was avoided by documenting that waste management practices at the landfill included monthly burning, which reduced the volume of biodegradable waste, and demonstrating that gases were not being generated after installation of the cap. Prior to signing the ROD, landfill cap gas vents were monitored quarterly for 5 years; no generation of gases was observed. Long term groundwater monitoring was optimized by minimizing analytical requirements. This site will rely solely on groundwater level monitoring for periodic monitoring. Analytic samples will only be collected in conjunction with five-year reviews or if groundwater levels rise to a level where contact with wastes is probable. The Record of Decision states; "Groundwater monitoring consisting of routine water-level monitoring and periodic water-quality monitoring will be used to assure that the remedy remains protective of human health and the environment. Groundwater monitoring results will be used to indicate whether or not a release has occurred at the site." The specific groundwater monitoring requirements are documented in a Land Use Control Remedial Design Plan. Documenting specifics in the LUC/Remedial Design (RD) Plan allows operational changes to the groundwater monitoring program while still meeting the broader requirements of the ROD without incurring the need to change the ROD.

Landfill Monitoring Program Development Checklist

Identify Monitoring Objectives

- ☐ Confirm landfill cover integrity
- ☐ Confirm leachate is within quality and quantity requirements (if necessary)
- ☐ Quickly detect any potentially harmful release from the landfill in groundwater
- ☐ Track hydraulic changes of groundwater flow over time to ensure effectiveness of monitoring network
- ☐ Confirm landfill gas is not causing unacceptable odors or explosive conditions inside or along the property boundary of the landfill, particularly in areas of adjacent receptors

Selection and Distribution of Monitoring Locations

- ☐ Cover integrity inspections consist of site visits to conduct visual inspections
- ☐ Settlement and erosion measurements can be collected using settlement plates and erosion monuments, respectively
- ☐ Choose groundwater monitoring locations to obtain background levels, assess plume movement, bound horizontal and vertical extent of contamination, and ensure protection of nearby receptors
- ☐ Critical landfill gas monitoring locations include soil between the landfill and either the property boundary or structures such as nearby residential homes, where gas migration may pose a danger

Determine Monitoring Frequency and Duration

- ☐ Inspect cover integrity more frequently during the first two years following installation until there is a sufficient body of data to show less frequent monitoring is sufficient
- ☐ Groundwater monitoring frequency should be at least quarterly for 1 year, followed by semiannual until sufficient data exist to show statistically significant stable to decreasing trends, at which time annual or biannual sampling should be negotiated with the regulatory agencies
- ☐ The minimum monitoring frequency at RCRA-permitted landfills is quarterly. At NERP landfill sites it may be possible to negotiate annual or biannual monitoring after sufficient data exist to indicate no explosives hazard exists in or around the landfill

Identify Analytes for Initial Monitoring

- ☐ Review site history and types of waste historically disposed of in the landfill to develop the list of analytes that could reasonably be expected to leach from the waste stream
- ☐ The groundwater analyte list should contain constituents that are generally more soluble and mobile, and would be expected at the leading edge of any contaminant plume originating from the waste disposal area
- ☐ Landfill gas should be analyzed for methane and VOCs (if present)

Determine Monitoring Technique

- ☐ Determine whether innovative monitoring technologies are feasible and cost effective

Other

- ☐ Landfill sites under the NERP are to meet the substantive requirements of RCRA regulations established for permitted landfills, but there may be some level of flexibility in the way the monitoring program is ultimately administered at the site. In large part, the level of monitoring required will rely on the regulatory program under which the site is managed and the site-specific conditions

Landfill Monitoring Program Optimization Checklist

Update CSM

- ☐ Revise and update CSM based on monitoring results
- ☐ Validate CSM with current understanding of site conditions

Evaluate Monitoring Objectives

- ☐ Evaluate monitoring objectives on an annual basis
- ☐ Confirm monitoring objectives have been met
- ☐ Update CSM

Optimize Monitoring Network

- ☐ Review landfill design, contents, and surrounding topography to determine most critical locations for cover inspections
- ☐ Review cover monitoring data to identify critical areas for continued focus and eliminate monitoring (or reduce frequency) of non-critical areas
- ☐ Review checklist in Chapter 7 regarding groundwater monitoring
- ☐ Evaluate data trends for in-landfill gas monitoring to reduce spatial redundancies (See Chapter 3)
- ☐ Determine if in-landfill monitoring and/or migration control system monitoring is sufficient to demonstrate that gas migration is no longer a concern and if so, consider eliminating off-landfill monitoring.
- ☐ If gas migration to receptors is a concern, ensure monitoring point locations have been selected based on the most likely migration pathways to receptors.

Optimize Monitoring Frequency and Duration

- ☐ Consider the use of high resolution aerial photography to reduce cover inspection frequency
- ☐ Review cover monitoring data to identify critical areas for continued focus and reduce frequency of non-critical areas
- ☐ Review checklist in Chapter 7 regarding groundwater monitoring
- ☐ Evaluate trends in leachate chemical concentrations or production rate to determine if frequency can be reduced (See Chapter 4)
- ☐ Evaluate data trends for in-landfill gas monitoring to reduce temporal redundancies (See Chapter 4)

Optimize Analyte List

- ☐ Review checklist in Chapter 7 regarding groundwater monitoring
- ☐ Compare contaminant concentration in leachate to applicable criteria to determine if parameters can be eliminated

Optimize Sampling Technique

- ☐ Evaluate which monitoring technologies are most feasible and cost effective (See Chapter 7 for information on groundwater sampling and analysis and Chapter 11 for information on soil vapor sampling and analysis)

12.4 References

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Chapter 13.0: Monitoring of Land Use Controls

This chapter introduces the key concepts necessary to develop and optimize a monitoring program for areas containing LUCs. LUCs can include both ICs and ECs and are used when the remedial action results in residual contamination are left behind, thus restricting future exposure to and use of the site.

13.1 Land Use Controls Monitoring Objectives

LUCs are restrictions, such as administrative tools (ICs) and/or physical controls (ECs), used to protect human health and the environment from potential exposure to residual contamination during or after completion of a response action. Because the failure of a LUC could lead to exposure and harm to the environment or human health, it is essential to have a well-defined LUC monitoring plan to ensure long-term integrity and implementation of the LUCs. The following are the primary LUC monitoring objectives:

- Determine whether the mechanisms of the LUC remain in place;
- Determine whether the LUCs are still providing the necessary protection;
- Ensure prompt response to a LUC failure or violation; and
- Ultimately, prevent exposure to residual contamination.

Guidelines for LUC monitoring should be linked to the monitoring objectives and milestones set forth for other components of the remedial action, and not necessarily for a specified time period. For example, if maximum soil or groundwater concentrations fall below a certain concentration (i.e., MCLs or PRGs), then the LUCs and their associated monitoring schedule can potentially be modified accordingly to reflect current site conditions.

13.2 Land Use Controls Monitoring Program Design and Optimization

In this chapter, the types of LUCs are discussed as well as the principles and procedures for LUC monitoring. In addition, LUC monitoring optimization is presented with a discussion of requirements and recommendations for LUC monitoring frequency, and available LUC management and reporting tools. For additional information on LUCs, see *Monitoring and Enforcement of Land Use Controls* (DON, 2003) and *CERCLA ROD and Post-ROD Policy* (OSD, 2004).

13.2.1 Types of Land Use Controls. There are two categories of LUCs: ICs, which consist of administrative and/or legal mechanisms, and ECs, which consist of engineered or physical controls. The following subsections present important definitions, principles, and monitoring and enforcement strategies for each type of LUC.

13.2.1.1 Engineering Controls. ECs consist of engineering measures designed to minimize the potential for human exposure to contamination by limiting direct contact with contaminated areas, reducing contamination levels, or controlling migration of contaminants through environmental media. ECs can be remedies designed to contain and/or reduce contamination, and/or physical barriers intended to limit access to property. Measures taken to prevent direct contact are determined primarily based on the type of contamination, for example whether it is soil or groundwater, and may include obstructing direct contact with soil, impeding wind blown soil, inhibiting the migration of groundwater or vapors, and creating groundwater flow barriers (Kastman, 2005). ECs may include fences, signs, guards, landfill caps, provision of potable water, slurry walls, sheet pile, trenches, covers, caps, and dikes.

13.2.1.2 Institutional Controls. ICs are non-engineered instruments such as administrative and/or legal controls that are designed to minimize the potential for human exposure to contamination by limiting land or resource use and/or by providing information to help modify or guide human behavior at the site (USEPA, 2003; 2006). They are designed to maintain the viability and effectiveness of the selected remedy and any ECs. ICs are imposed to ensure that the ECs stay in place, or where there are no ECs, to ensure a restriction on land use. There are four main categories of ICs: governmental controls, proprietary controls, enforcement and permit tools with IC components, and informational devices. Each category of IC serves in different ways to define and limit use of land legally in order to enforce restrictions developed by the remedial party. ICs are often most effective when more than one is in place, and if they are layered or implemented in series, thus enhancing the protectiveness of the remedy. A summary of each type of IC is presented in Table 13-1.

Table 13-1. Summary of Institutional Controls (USEPA, 2000)

Type of IC	Purpose	Example	Enforcement
Governmental Control	Use government to impose land use restrictions on citizens	Zoning/ordinances Building codes/permits Drilling permit requirements State or local groundwater use regulations Property condemnation	Commanding Officer (active installation) or State/Local Governments (closed installation)
Proprietary Control	Controls based on private property law to limit land use	Easement Restrictive covenant Equitable servitude Reversionary interest State use restrictions Conservation easements	State Court of Law
Enforcement and Permits Tools with IC Components	Federal enforcement tools in order to prohibit certain parties to certain activities	Administrative Orders Consent Decrees Permits	USEPA under CERCLA and RCRA or the State
Informational Devices	Tools used to provide public knowledge of information with regards to contamination and remediation	Deed notices State registries LUC tracking systems Advisories	Not legally enforceable

13.2.2 Guidelines for LUC Implementation

13.2.2.1 DON/U.S. EPA Principals and Procedures. Table 13-2 summarizes the established principles and procedures for specifying, monitoring, and enforcing LUCs. Essentially, these principles emphasize that the objectives of the LUCs shall be specified in the ROD, similar to other elements of the remedy. The specific LUC implementation actions, including monitoring, shall be specified in the Remedial Action Work Plan (RAWP) or RD. Therefore, no additional document should be necessary for the design or implementation of LUCs. However, for sites where the existing RD or RAWP does not include LUC-specific information, documentation may be necessary for monitoring of LUCs. Also, five-year reviews under CERCLA are required to include an assessment of the effectiveness of the LUCs. Further detail is provided in *Principles and Procedures for Specifying, Monitoring and Enforcement of Land Use Controls and Other Post-ROD Actions* (DON and USEPA, 2003), which is included as Attachment 1 to the *CERCLA ROD and Post-ROD Policy* (OSD, 2004).

Table 13-2. Requirements of Navy Documents with Regard to Monitoring (OSD, 2004)

Document	Mention of Monitoring
ROD	With regard to LUCs, the ROD should describe the LUC objectives, explain why and for what purpose the LUCs are necessary, where they are necessary, and the entities responsible for implementing, monitoring, reporting on, and enforcing the LUCs. The ROD at transferring properties will need to be crafted based on the responsibilities of the new owner and state-specified laws and regulations regarding LUCs. At transferring properties, compliance with the LUC performance objectives may involve actions by the subsequent owners in accordance with deed restrictions; however, ultimate responsibility for assuring that the objectives are met remains with DON as the party responsible under CERCLA for the remedy.
RD or RAWP	The RD or RAWP will describe short and long-term implementation actions and responsibilities for the actions in order to ensure long-term viability of the remedy, which may include both LUCs (e.g., ICs) and an engineered portion (e.g., landfill caps, treatment systems) of the remedy. The term "implementation actions" includes all actions to implement, operate, maintain, and enforce the remedy. These actions can include conducting a five-year CERCLA remedy review, conducting periodic monitoring or visual inspections of LUCs, reporting monitoring inspection results, notifying regulators of changes in risk or land use found from the inspection, and including a map of the area where LUCs are imposed. For active installations, the RD or RAWP should outline the development of internal-DON policies and procedures with respect to LUC monitoring, reporting and enforcement (e.g., as part of the Base Master Plan). This is necessary to institutionalize the monitoring procedure and to ensure base personnel are aware of restrictions and precautions that should be taken. For closed installations, the RD or RAWP should define the responsibilities of the DON, the new property owner, and state/local government agencies regarding monitoring, reporting and enforcement of the LUCs.

13.2.2.2 LUC Implementation Actions at Active Installations. At active DON installations, typical LUCs at remediation sites may include restrictions on well drilling, soil excavation, and construction, or long term inspection and maintenance of an impervious cap, fencing, or signage. Implementation actions may include reviewing current site use to ensure compliance with all ICs, or periodic inspections to confirm the integrity of ECs such as an asphalt cap or fence. There are several tools commonly used for helping to ensure that LUCs are effectively monitored and adhered to during the remedial action and LTMgt of a site at an active installation:

- Record the LUC in the Base Master Plan
- Prepare a survey plot of the LUCs showing associated boundaries
- Develop and implement Base procedures requiring excavation and changes in land use at remediation sites to be approved by the RPM and appropriate Base personnel.
- Maintain a comprehensive list of LUC boundaries and expected durations that is used for reference during routine monitoring
- Track LUC implementation, monitoring, and enforcement requirements in available databases (e.g., NIRIS, RSIMS, or utility tracking tools; see also Section 13.2.4)

Implementation, management, and monitoring of LUCs are ultimately the responsibility of the Facilities Engineering Command as long as the site remains funded under Environmental Restoration, Navy (DON, 2006).

13.2.2.3 LUC Implementation Actions for BRAC Installations. Typical LUCs at BRAC installations may be similar to those at an active installation, including restrictions on well installation, soil excavation, future land use, or long-term maintenance of all ECs, such as an impervious cap. However, in the case of BRAC installations, such requirements associated with LUCs are documented in the property deed in the form of easements or restrictive covenants when the property is transferred to a new owner. When property is to be transferred to a non-federal entity at the completion of or during the LTMgt phase, the RPM, real estate manager, and legal counsel need to ensure that the LUCs are practiced and legally enforceable under state law (DON, 2006).

The mix of responsibilities among DON, the new property owner, and other government agencies with respect to LUC implementation, monitoring, reporting, and enforcement depends on state and federal laws and regulations that are applied in the state. While compliance with the LUC performance objectives may involve actions by the subsequent owners in accordance with deed restrictions, the ultimate responsibility for assuring that the objectives are met remains with DON as the party responsible under CERCLA for the remedy (OSD, 2004).

13.2.3 Requirements and Recommendations for LUC Monitoring Frequency. Initially, at least an annual schedule for LUC monitoring and reporting should be established; however, this schedule may become less frequent (e.g., every 2 to 5 years) depending on the LUC objectives, vulnerability of the LUC, the remedial action monitoring frequency at the site, and specified implementation actions. It is essential to have a well-defined LUC monitoring plan to ensure long-term integrity and implementation of the LUCs. Requirements and recommendations for LUC monitoring are few; however, in accordance with Section 121(c) of CERCLA, a five-year review is required if a remedial action that results in hazardous substances, pollutants, or contaminants remaining at levels not allowing for unlimited use and unrestricted exposure is selected. If five-year reviews are required, then reporting of LUC monitoring should be included in the Five-Year Review report. It is also important to note that individual states may have their own requirements with respect to LUC monitoring. These requirements should be addressed accordingly in the RD or RAWP.

The frequency of monitoring each component of the EC can be optimized based on design expectations along with the results of historical monitoring. For a small, easily accessible site, there may be little impact on cost between monitoring certain ECs during a site visit versus monitoring all ECs. However, for large remote sites or where portions of the site are difficult to reach, there may be significant cost savings associated with monitoring only some of the ECs during the more frequent site visits and all ECs for less frequent visits. For example, if an EC includes rip rap installed on an embankment where it is difficult and costly to achieve safe access, the EC monitoring plan can be optimized by evaluating the need for frequent monitoring of this particular location. If the design expectation has a very low likelihood of failure for this EC and historical monitoring supports this expectation, it is reasonable to optimize the LUC monitoring plan by reducing the frequency of monitoring in this area. For the same site, there may be evidence of vandalism to signs and fencing near a public road. For this EC, the monitoring frequency may need to be increased. Similarly, LUCs in areas near base development activities may require more frequent monitoring to ensure compliance with all site restrictions. In summary, the monitoring frequency for ECs should initially be optimized based on design expectations and continually re-evaluated based on results of historical findings and current base activities.

As with other elements of the remedial approach, optimization of LUCs is an integral component of the LTM strategy. As discussed earlier, LTM results and goals from other facets of the remedial action (e.g., soil and/or groundwater monitoring) should be reviewed in conjunction with the LUCs to see whether the boundary or duration of the LUC can be optimized to include only those areas currently affected by residual contamination at unacceptable levels. If LTM results are favorable, boundaries, and ultimately the duration of LUC monitoring, may be reduced.

13.2.4 LUC Management and Reporting Tools. LUCs are effective only if their existence is widely known or easily ascertainable, thus many government entities and/or interested parties are developing tracking systems to facilitate LUC implementation, monitoring, and enforcement. NAVFAC has developed three LUC management tools to assist with the LUC management process: a LUC tracking tool (LUC Tracker [Figure 13-1]; Navy 2005), a LUC waiver process tool (LUCWAIVER), and a LUC termination process tool (LUCTERM). LUC Tracker, LUCWAIVER, and LUCTERM will be available from NIRIS.

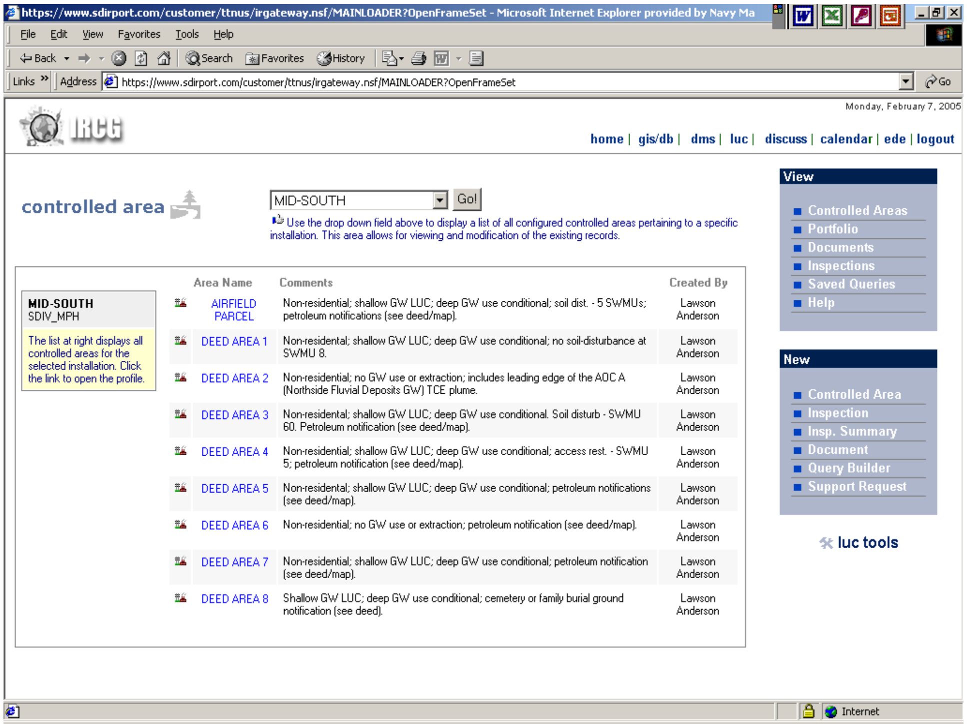
These tools provide a web-based process for actively managing interim LUCs placed on parcels transferred under the early transfer process and also long-term LUCs associated with remedial actions. The applications track LUCs and provide automatic reminders to the Navy RPM, BRAC Environmental Coordinator (BEC), or Base Closure Manager (BCM) of inspection, reporting and certification requirements, as well as the means to both facilitate and document implementation of these requirements through the generation of standard and custom forms and reports. In the event of a LUC violation, it can notify the appropriate parties and track the status of corrective action efforts. LUCWAIVER and LUCTERM augment the LUC Tracker modules (Figure 13-1) to assist those responsible for implementing, enforcing, and/or complying with LUCs (NAVFAC, 2005).

Activity-specific LUC Tracker content includes site-specific LUCs, points of contact, inspection, certification and reporting requirements, advance notice of upcoming inspections, reminders of scheduled inspections, and links to related documents (deeds, LUC management plans, maps, etc.). LUC Tracker allows the user to create/enter new LUCs, review existing LUCs, access inspection templates and maps, enter inspection results and create inspection reports, document and track deficiencies noted and corrective action taken, notify appropriate parties of non-compliance, and certify compliance and access applicable forms. The application will track and can be queried for such things as inspection results, types and frequencies of violations, and contaminants driving LUCs. The LUC Tracker allows for better data access, standardized data format, and efficient tracking of LUC integrity and compliance.

At active installations, it may also be beneficial to track LUCs in the Regional Shore Installation Management System (RSIMS). RSIMS is a web-based GIS reporting tool that allows Navy personnel to query and analyze facilities information for shore installations using an interactive map. RSIMS may be the preferred source of facilities information at some installations, and therefore use of this tool for tracking LUCs will further ensure that the LUCs are widely known by all base development departments, real estate personnel, and facilities personnel.

LUCWAIVER provides detailed instructions that guide users through evaluations of proposed project requests at former and active Navy sites where LUCs have been implemented. Certain proposed reuse, redevelopment, and construction activities may require a LUC waiver from the Navy and/or State and Federal regulators prior to initiation of project activities. LUCWAIVER identifies the types of information that should be submitted with a request, walks the user through the evaluation process and documents the final decision.

The Navy has also developed detailed instructions for terminating a LUC at former and active Navy sites. The LUCTERM process compiles the information needed to evaluate a LUC termination request, documents the decision-making process, and results in a package that can be forwarded to the appropriate regulatory authorities for concurrence.



controlled area

MID-SOUTH Go!

Use the drop down field above to display a list of all configured controlled areas pertaining to a specific installation. This area allows for viewing and modification of the existing records.

MID-SOUTH
SDIV_MPH

The list at right displays all controlled areas for the selected installation. Click the link to open the profile.

Area Name	Comments	Created By
AIRFIELD PARCEL	Non-residential; shallow GW LUC; deep GW use conditional; soil dist. - 5 SWMUs; petroleum notifications (see deed/map).	Lawson Anderson
DEED AREA 1	Non-residential; shallow GW LUC; deep GW use conditional; no soil-disturbance at SWMU 8.	Lawson Anderson
DEED AREA 2	Non-residential; no GW use or extraction; includes leading edge of the AOC A (Northside Fluvial Deposits GW) TCE plume.	Lawson Anderson
DEED AREA 3	Non-residential; shallow GW LUC; deep GW use conditional. Soil disturb - SWMU 60. Petroleum notification (see deed/map).	Lawson Anderson
DEED AREA 4	Non-residential; shallow GW LUC; deep GW use conditional; access rest. - SWMU 5; petroleum notification (see deed/map).	Lawson Anderson
DEED AREA 5	Non-residental; shallow GW LUC; deep GW use conditional; petroleum notifications (see deed/map).	Lawson Anderson
DEED AREA 6	Non-residential; no GW use or extraction; petroleum notification (see deed/map).	Lawson Anderson
DEED AREA 7	Non-residential; shallow GW LUC; deep GW use conditional; petroleum notification (see deed/map).	Lawson Anderson
DEED AREA 8	Shallow GW LUC; deep GW use conditional; cemetery or family burial ground notification (see deed).	Lawson Anderson

Figure 13-1. LUC Tracker Screen Shot: List of Facility-Specific LUCs. (Source: *Winter Navy RPM Newsletter*, Navy, 2005)

13.3 Lessons Learned in Land Use Control Monitoring

As stated earlier, the existence of LUCs at a site must be widely known or easily ascertainable in order for them to be considered as an effective remedial approach. LUCs will be effective only if stakeholders understand and adhere to the LUC. The most common pitfalls associated with LUCs are related to the conditions associated with ICs, and failure to update LUCs based on remedial action monitoring data. Common pitfalls associated with LUCs are summarized in Table 13-3. Fortunately, the common pitfalls associated with LUC monitoring can be easily avoided through active communication, visible signage, review of remedial action monitoring data, and continued optimization. Table 13-3 presents some of the methods that can be implemented at a site to avoid the more common mistakes associated with LUC monitoring.

Table 13-3. Common Pitfalls Associated with LUC Monitoring and Suggested Avoidance Methods

LUC Monitoring Pitfalls	Avoidance Methods
Uncertainty regarding existence of LUC	• Record the LUC in the Base Master Plan • Maintain a comprehensive list of LUC boundaries and expected durations to be used for reference during routine monitoring • Issue public advisories • Post signage • Enter site into LUC Tracker • Record LUCs in RSIMS
Uncertainty regarding location of LUC boundary	• Record the LUC in the Base Master Plan • Maintain a comprehensive list of LUC boundaries and expected durations to be used for reference during routine monitoring • Issue public advisories • Install fencing and/or post signage • Prepare a and post a map of the LUC boundaries • Enter site into LUC Tracker • Record LUCs in RSIMS
LUCs not tied to other remedial action monitoring objectives	• Enter site into LUC Tracker • Review remedial action LTM data and integrate LUC monitoring • Optimize LUCs based on remedial action LTM goals
Damage to ECs potentially resulting in exposure	• Evaluate the required inspection frequency of each EC based on design expectations, historical monitoring results, and risks associated with EC failure
Failure to meet LUC objectives	• Record the LUC in the Base Master Plan • Enter site into LUC Tracker and implement automatic reminders of monitoring schedule • Develop and implement Base procedures requiring excavation and changes in land use to be approved by appropriate Base personnel • Maintain a comprehensive list of LUC boundaries and expected durations that is used for reference during routine monitoring • Review remedial action LTM data and integrate LUC monitoring

Case Study: LUCs Monitoring at NAS Key West

LUC and IR warning signs have been installed as part of the temporary or permanent remedy at various sites at Naval Air Station (NAS) Key West. The signs are installed at locations determined to provide adequate notification to the public, base personnel, and possible trespassers as to the potential risks at each site. The initial installation, documentation, and the ongoing management of these signs are critical to the successful implementation of the LUCs associated with each site.

The LUC signs at NAS Key West can be subject to some severe weather conditions, including hurricanes and tropical force winds. The signs were initially installed either on posts or directly to fences/gates, and each of the sign locations was determined via Global Positioning System (GPS) and recorded in the Geographic Information System (GIS) database. Long-term operation and maintenance (O&M) for these LUCs includes periodic sign inspection and replacement as necessary to ensure effectiveness of the LUCs. The inspection schedule is tracked using LUC Tracker which automatically notifies the appropriate personnel of upcoming inspections to ensure that they are scheduled on a timely basis. Optimization efforts for the long-term O&M activities included (1) minimizing mobilization and site activities by combining the sign assessment and replacement activities, (2) identifying local materials vendors, (3) using GPS reacquisition and electronic data collection, and (4) using LUC Tracker to ensure the inspection schedule is maintained.

The LUC implementation work plan called for completion of all assessment and inspection activities in conjunction with the physical replacement tasks. By using LUC Tracker, the overall costs associated with implementing the LUCs were minimized The following list highlights areas where cost savings were realized.

- Use of locally fabricated heavy duty aluminum signs in lieu of shipping them from an offsite source resulted in a savings of approximately $4,000.
- Use of electronic data collection and reacquisition of the sign locations via GPS was conservatively estimated to have saved approximately 120 hours of field labor over the inspection and reporting tasks.
- A single mobilization saved both travel and personnel costs.

Figure 1. Damaged sign after hurricanes in 2005, and typical newly installed sign.

LUC Monitoring Program Development and Optimization Checklist

Identify Monitoring Objectives

- ☐ Determine whether the mechanisms of the LUC remain in place
- ☐ Determine whether the LUCs are still providing the necessary protection
- ☐ Ensure prompt response to a LUC failure or violation
- ☐ Ultimately, prevent exposure to residual contamination

Update CSM

- ☐ Revise and update CSM based on monitoring results
- ☐ Validate CSM with current understanding of site conditions

Site Information

- ☐ Installation/Activity
- ☐ Ownership History
- ☐ Contaminant Information
- ☐ Contamination Map

Points of Contact

- ☐ Current Owners/Operators
- ☐ Transferee, Leasee
- ☐ Federal, State, Local Regulators

Identify Type of LUC

- ☐ Engineering Controls
- ☐ Institutional Controls
  - ○ Governmental Control
  - ○ Proprietary Control
  - ○ Enforcement and Permits Tools with IC Components
  - ○ Informational Devices
- ☐ LUC Restrictions (Base-wide and Site Specific)
- ☐ LUC Requirements (Inspections, Notifications, Reports)

Inspection, Certification, and Reporting

- ☐ Include LUC objectives in the ROD
- ☐ Review LUC implementation actions
  - ○ Evaluate monitoring requirements
  - ○ Assess frequency for inspection of each EC and IC
  - ○ Adhere to specific reporting requirements
  - ○ Report violations
  - ○ Follow land use certification requirements and forms
- ☐ Use LUC Tracker management and reporting tool
- ☐ Document LUCs appropriately
  - ○ Deeds
  - ○ LUC Plans
  - ○ Maps
  - ○ Administrative Record
  - ○ Base Master Plan

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Chapter 14.0: Vapor Intrusion Monitoring

This chapter describes the main elements in designing and optimizing a LTM program for VI. The discussion addresses monitoring at sites where it has been determined that VI is occurring and where human exposure (prior to mitigation or remediation) was above acceptable risk levels. This includes monitoring exposure concentrations and mitigation system effectiveness so that adjustments can be made to further reduce exposure concentrations when necessary. The chapter also covers "sentinel" monitoring at sites where VI is not currently occurring or is below target risk levels, but where there is potential for volatile contaminants to migrate below buildings or increase in concentration at some time in the future. This chapter does not address sampling at sites that are still undergoing initial site characterization. The *DoD Vapor Intrusion Handbook* (DoD, 2009) provides information on sampling at sites undergoing initial evaluation.

14.1 Vapor Intrusion LTM Objectives

VI is the migration of volatile compounds from subsurface sources of contamination in groundwater or soil into overlying buildings (Figure 14-1). Volatile compounds are defined as those having a Henry's Law constant $\geq 1 \times 10^{-5}$ atm-m^3/mol (USEPA, 2002). VI contaminants can include petroleum hydrocarbons (e.g., benzene), chlorinated solvents (e.g., TCE), mercury (the only volatile metal), various semi-volatile organic compounds (e.g., naphthalene), and certain pesticides. When VI is occurring or has the potential to occur, the objectives of LTM may include:

- Detecting any potentially harmful intrusion of vapors into a building;
- Tracking contaminant concentration changes in soil vapor, sub-slab vapor and indoor air;
- Confirming performance and effectiveness of the VI mitigation system;
- Confirming that remediation has been completed and was effective;
- Confirming that risk levels for building occupants exposed to indoor air are below the target thresholds; and/or
- Detecting when migrating contaminants with potential for VI are approaching an occupied building or causing COC concentrations to increase above acceptable risk thresholds.

Monitoring might focus on the underlying contamination that drives the potential VI risk and/or it might focus on determining if mitigation or remediation systems are working as designed and preventing unacceptable inhalation risk. VI sites will likely require long-term management and monitoring until it can be demonstrated that subsurface volatile contaminant sources no longer pose an unacceptable VI risk. LTM should be limited to the compounds specifically identified as COCs for the VI exposure pathway at the site.

14.2 Vapor Intrusion LTM Program Design and Optimization

The optimization strategy for LTM related to VI will depend on the site-specific scenario and the type of mitigation or remediation selected for the site. The LTM program for VI should be designed to meet site-specific objectives and include an exit strategy that clearly establishes when the site no longer poses an unacceptable VI risk and monitoring can be discontinued. The activities and schedule for monitoring VI sites should be site-specific and documented in a SAP following the UFP-SAP. The SAP should consider the risk level, exposure scenario(s) and receptors (e.g., residential, industrial, commercial, school), size

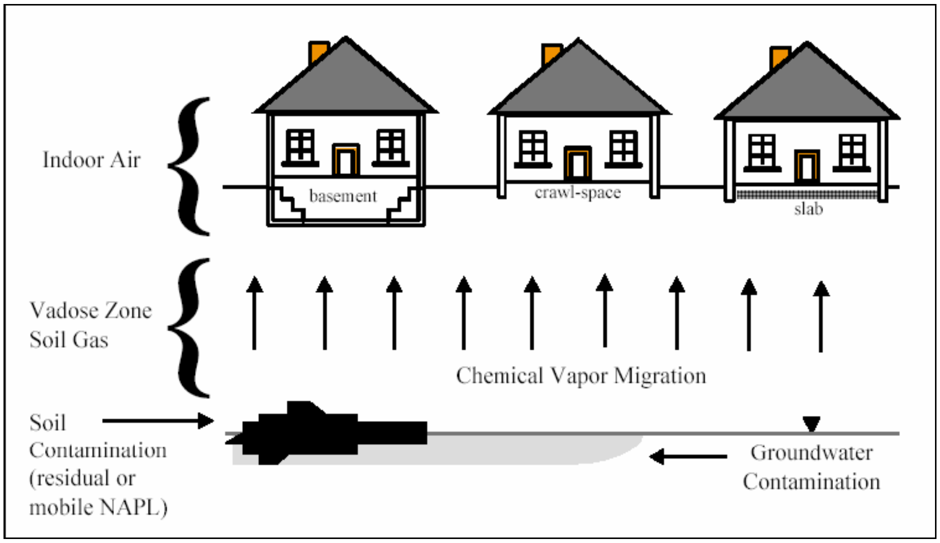

Figure 14-1. Illustration of VI
(Source: USEPA, 2002)

and type of building(s), and existing or planned mitigation systems. The SAP should provide guidance on evaluating decision points and/or exit criteria, determining the need for mitigation system adjustments, and determining when site remediation is complete and monitoring can be discontinued. Monitoring should focus on measuring parameters that will ensure that receptors are not being exposed to concentrations above acceptable risk levels and should address the decision points and/or exit criteria. In addition, it is important to ensure that ICs are maintained at the site during LTM.

Several types of data can be used to monitor the VI pathway. The selection of data will depend on the CSM and the DQOs. The potential for VI to occur is usually determined by examining multiple lines of evidence (DoD, 2009). These may include concentrations of volatile COCs in groundwater, soil, soil gas, and/or indoor air. Soil-gas data can be collected near the groundwater table, from sub-slab locations, from near-slab locations, or in the vicinity of preferential pathways, such as utility corridors. If groundwater or soil gas are being used in LTM, refer to Chapters 7 or 11, respectively, for specific recommendations relevant to those media. Note that if groundwater data are being used as part of LTM for sites where action is driven by VI, then groundwater samples need to be collected near the water table. Also, both groundwater and near-slab soil gas samples should be collected as close as possible to the occupied buildings being investigated for VI. In addition, at sites where mitigation systems are installed, performance data for the mitigation system will be required, at least initially, to ensure that it is functioning properly. This monitoring will depend on the type of system installed and is discussed further in Section 14.3.1.

When developing a monitoring strategy for RAO or LTM of VI, the type of data collected for LTM should be discussed with the regulators responsible for the specific location. Indoor air sampling provides a direct measure of volatile chemical concentrations inside buildings, and this type of data is frequently collected during LTM at sites where VI poses a potential risk to current occupants. Indoor air data are also used to confirm that mitigation measures are working as intended. Monitoring points should be placed in locations that can be measured over time and can provide representative data associated with the most significant VI exposure pathways. Soil-gas or groundwater sampling may be included in LTM for VI in some cases if data correlate well with VI risk and if risk-based clean-up criteria can be established. Subsurface data are less prone to background interference from consumer products and other contaminants that can potentially make interpreting indoor air samples difficult. Groundwater and/or soil gas also may be sampled as supporting evidence that remediation of the source has decreased concentrations sufficiently to eliminate the VI exposure pathway.

Indoor air data are easily influenced by transient activities and background concentrations of chemicals and it is important to understand the background contributions from both indoor and outdoor sources that do not result from VI. The background sources can best be evaluated when sub-slab soil gas and indoor and outdoor air data were collected simultaneously during the investigation of the VI exposure pathway. Depending upon the initial interpretation of indoor air data, it may or may not be necessary to collect simultaneous outdoor and sub-slab samples when collecting indoor air samples for LTM. Collecting background data in association with LTM may be required if the initial evaluations indicated that outdoor air contained COCs or if properly functioning mitigation systems fail to reduce the COC concentrations below acceptable levels. If VI background samples are necessary during LTM, then outdoor air samples should not be used *alone* as an estimate of indoor background, since concentrations of many compounds emitted from common indoor sources are higher in indoor air than in outdoor air. A building survey should be performed to identify potential indoor sources in a particular building (e.g., solvents, paints, VOC-containing cleaning supplies). Data from published studies on indoor air background concentrations can be used for comparison as part of the weight-of-evidence evaluation. Another method being evaluated for separating indoor and/or outdoor sources from VI sources is pressure cycling (DON, 2009). In this method, indoor air samples are collected once when the building is under an induced positive pressure relative to the subsurface, and again when the building is under negative pressure (or vacuum) relative to the subsurface and the relative contribution from the subsurface is assessed. Under the negative pressure, vapors from the subsurface will flow into the building; under positive pressure, these vapors will be blocked from entering the building. Thus, if the contaminants are present under the positive pressure conditions but not the negative pressure conditions, the source can be attributed to indoor or outdoor air sources and vice versa.

It is important to understand background contributions to VI because the DON's Background Policy (DON, 2000) stipulates that cleanup efforts at Navy sites should address only those risks associated with chemical concentrations elevated as a result of a site-related release. DON is developing a new document entitled *Guidance for Environmental Background Analysis, Volume IV: Vapor Intrusion Pathway* that will provide guidance on assessing background concentrations for VI. This document is currently in preparation, with anticipated release in late 2010.

14.2.1 Selection and Distribution of VI Monitoring Locations. For selection and distribution of monitoring locations, it is important to understand the CSM so that the most representative locations are chosen. Generally, sampling locations for LTM should be similar to those that provided the best information during the initial VI evaluation. However, these may need to be adjusted to include additional buildings where mitigation systems have been installed. Often, the results from the first round of sampling can be used to optimize later rounds.

For indoor air sampling, two issues to be considered are which buildings to sample and where within a building to sample. Initially, indoor air sampling may be appropriate in buildings with a mitigation system to confirm that the system is effectively reducing indoor air concentrations of VI COCs. Air samples (both indoor and outdoor) generally should be collected from the breathing zone (several feet off the ground). Indoor air samples should be collected from the basement (if present) or first floor. Outdoor air samples should be collected at locations upwind from the buildings where indoor air samples are collected.

Once performance has been established, it may be acceptable to monitor only the operational performance of the mitigation system, with limited or no indoor air sampling. Also, for the indoor air sampling, it may be acceptable to sample a subset of representative buildings. Requirements for monitoring mitigation systems may vary with location.

14.2.2 Sampling Frequency and Monitoring Duration. The concepts discussed in Chapter 4 also apply to VI monitoring and the frequency and duration will be site specific. Typically, the sampling frequency will be greater during the first year of monitoring, particularly where mitigation systems are installed to ensure that the system is functioning as intended. Sampling is often performed quarterly for the first year, with decreasing frequency after that. The frequency schedule and criteria for changing the frequency should be negotiated with regulatory partners and documented in the LTM plan. Some state guidance documents provide recommendations for the monitoring schedule. For example, Colorado's Indoor Air Guidance (Colorado Department of Public Health and Environment, 2004) includes a table of recommended monitoring frequencies for existing buildings with installed indoor air remediation systems. In this case, indoor air monitoring is recommended quarterly the first year, semiannually the second year, and annually the third year and beyond.

Over time, some monitoring points may be eliminated. As samples are collected, certain monitoring points are likely to be identified that are more critical to the evaluation than others; thus, it may be allowable to eliminate the points that are not critical. For example, if certain parts of the building or soil vapor locations always have much greater concentrations than others, it may be possible to limit monitoring to the points with the higher concentrations. Also, if there are soil vapor points that are low and decrease over time, it may be acceptable to completely eliminate these points. In cases where mitigation systems are in place and the effectiveness and reliability of the systems have been established, it may be acceptable to eliminate contaminant monitoring and rely on performance checks of system operations. Once remediation is completed and it can be demonstrated that the risk is within acceptable levels, monitoring can be stopped and close-out achieved (see Section 14.3.3).

14.2.3 Sample Collection and Analytical Methods. Information on sample collection methods and analytical methods for VI is provided in the *DoD Vapor Intrusion Handbook* (DoD, 2009). The two analytical methods most commonly used to measure VOCs in indoor air and soil gas are USEPA's toxic organic TO14 (and TO14-A) and TO15 (and TO15 Supplemental) methods. The same analytical methods are used for soil-gas, sub-slab, indoor air, and outdoor air samples.

Time-integrated sampling of 8 to 24 hours can account for short-term variability to better represent exposure concentrations in indoor air and is thus preferred over shorter duration grab samples. The duration of the sampling event should reflect the site-specific exposure scenario being evaluated. Generally, for residential dwellings, 24-hour samples are recommended; 8-hour samples are recommended for buildings with occupation exposures. Active air sampling is most commonly used for VI monitoring. Collection methods are similar to those for soil gas (i.e., pre-evacuated canisters or adsorbent-filled traps for VOCs).

In addition to the commonly used active methods, passive sampling techniques are available and can potentially offer more cost-effective methods for LTM of VI, although most regulators are not familiar with these methods and thus may not find them acceptable (DON, 2009). Passive techniques can be either qualitative or quantitative. Qualitative passive methods can be used to collect information on relative proportions of chemicals, which may be useful in determining whether the source of contaminants is from subsurface or indoor/outdoor air; however, qualitative methods generally are not used to determine if VI is below acceptable risk levels. Quantitative passive methods may be useful to determine if concentrations are below acceptable risk levels and offer the option to collect samples over a longer period (14 days or possibly more), rather than the usual 24-hour period (or less) for the current active methods. The longer sampling period may provide more representative data for long-term average exposure levels, since indoor air concentrations are easily influenced by transient activities in the building. Research is being performed to establish the effectiveness of these methods for use in VI studies compared to the conventional active sampling methods. Passive samplers come in a variety of shapes and adsorbent materials. Several samplers being evaluated in an ESTCP study include the SKC Ultra II Badge, the automated thermal desorption tube-style sampler, the polydimethylsiloxane sampler, and the Radiello sampler. RPMs should check for updated information on the reliability of passive sampling methods; if appropriate, they may want to consider these options for optimizing LTM at their sites.

14.3 Site Scenarios for LTM Related to Vapor Intrusion

Scenarios for VI LTM are summarized in Table 14-1 and include sites with and without mitigation systems (active or passive). As noted earlier, the optimization strategy for LTM related to VI will depend on the site-specific scenario and the type of mitigation or remediation selected for the site. The types of mitigation systems implemented for a site may be influenced, in part, by local regulatory guidance. For example, in New Jersey, only active systems are considered acceptable for mitigating VI in existing buildings (New Jersey Department of Environmental Protection [NJDEP], 2005). In addition to the *DoD Vapor Intrusion Handbook* (2009), general information on types of available mitigation systems can be found in several references, including:

- USEPA’s Engineering Issue on Indoor Air Vapor Intrusion Mitigation Approaches (April 2008)
- California DTSC’s Vapor Intrusion Mitigation Advisory (April 2009)
- ITRC‘s Vapor Intrusion Pathway: A Practical Guideline (Chapter 4; January 2007).

The first two documents also include useful information on LTM for mitigation systems. Because State VI guidance can vary widely, the RPM should consult State-specific VI mitigation requirements for the site.

Table 14-1. Site Scenarios for VI Monitoring

I. Sites with VI Mitigation Systems Installed
A. Active Mitigation Systems
Sub-Slab Depressurization (SSD) (and variations on SSD such as block/sump/foundation drain depressurization systems)
Sub-Membrane Depressurization
Sub-Slab Venting
Sub-Slab Pressurization
Building Pressurization
Indoor Air Treatment
B. Passive Mitigation Systems
Vapor Barrier
Passive Sub-Slab Venting
II. Sites Without VI Mitigation Systems
A. Sites with Potential for Plume Migration beneath Existing Buildings (contaminant plume is not currently posing an unacceptable VI risk, but has potential to migrate beneath buildings or increase in concentration)
B. Sites with Potential Future Buildings above a Plume

14.3.1 Sites with VI Mitigation Systems Installed. At sites where VI poses unacceptable human health risk, mitigation systems can be installed to reduce COC concentrations to acceptable levels. The mitigation measures can be active systems requiring electrical power to operate, or they can be passive systems that operate by creating a barrier to vapor movement or inducing natural ventilation processes. Regardless of the type of system employed, a site-specific O&M plan should be developed for the mitigation system. The objectives of LTM at sites with mitigation systems are to determine that the system is functioning as designed and to monitor the progress of any remedial actions to eliminate the source of contamination responsible for VI concerns. Once a mitigation system has been turned off, the objective of LTM is to ensure that COCs in indoor air remain at or below acceptable concentrations.

14.3.1.1 Active Mitigation Systems. Active mitigation systems include SSD, sub-membrane depressurization (SMD), sub-slab venting (SSV), sub-slab pressurization, building pressurization, and indoor air treatment systems. A brief description of each type is presented in Table 14-2 and monitoring considerations for these systems are discussed below.

SSD systems are the most commonly used type of VI mitigation system in existing buildings. These systems function by continuously creating a lower pressure directly underneath a building floor relative to the pressure within the building. The resulting sub-slab negative pressure prevents soil gases from flowing into the building, thus reducing entry of volatile chemicals into the building (USEPA, 2008; Cal DTSC, 2009). SMD systems are similar to SSD but depressurize the area below a membrane installed to block vapor movement into the building.

Table 14-2. Types of Mitigation Systems

Active Mitigation Systems
SSD entails drilling or cutting one or more holes in the existing slab, removing soil from beneath the slab to create an open hole or suction pit, and placing vertical suction pipes into the holes. The suction pipes are routed to a blower and collect soil gas from just beneath the slab. Soil gas from beneath the slab is vented to the atmosphere at a height well above the outdoor breathing zone and away from air intakes and windows (Cal DTSC, 2009). Figure 14-2 shows the typical setup of an SSD system. These systems can be installed in existing buildings. For proper function, it is important that openings in the slab and foundation are adequately sealed to prevent air-conditioned indoor air from being pulled into the mitigation system (USEPA, 2008). SSD systems are reliable, cost-effective, and efficient technologies for controlling VI in the majority of cases and generally can reduce concentrations in the range of 90 to 99% (ITRC, 2007). SSD systems may not be appropriate for sites having a very shallow water table. Several variations on this system include: • Block-wall suction systems to remove vapors that accumulate in basement walls constructed of hollow blocks • Drain-tile suction systems, where suction is applied to existing water drainage systems that circle a building • Sump-hole suction, where suction is applied to the sump. Because SSD has been used extensively for radon mitigation, there is substantial information available on operating these systems.
SMD is similar to SSD; however, it is applied to crawl spaces and basements with earthen floors. In SMD, an impermeable membrane is applied to cover and seal the exposed dirt surface, and the suction is applied beneath the membrane to depressurize the area below the membrane (Figure 14-3). The collection system is similar to that used for the SSD.

Table 14-2. Types of Mitigation Systems (Continued)

SSV functions by venting sub-slab soil gases or providing a pathway that allows soil gas to migrate to the building's exterior, rather than entering the building. Active SSV systems use a fan to blow ambient air into the venting layer below the building, which dilutes and reduces the volatile concentrations. Vapors are directed to the edge of the foundation by perforated collection pipes that are installed in the venting layer. Collection pipes are connected to a main header point that runs up through or along the inner or outer wall and exhausts above the roofline. Because of extensive foundation work, SSV systems are generally easier to install in new construction than in existing buildings (Cal DTSC, 2009). Diagnostic criteria for adequate performance of an SSV system are more difficult to specify than criteria for SSD systems because the flows required for dilution are difficult to specify (USEPA, 2008). Cal DTSC (2009) recommends including a sampling port within the vertical collection pipe or horizontal vent pipes below the floor as part of the SSV design to allow sampling of COC concentrations. Low concentrations indicate that the system is preventing accumulation of contaminants below the building and thus reducing entry of the vapors into the building. ***Sub-slab pressurization systems*** are similar to SSD systems, except that blowers are used to push air into the soil or venting layer below the slab instead of pulling the air out. This technology is intended to increase the sub-slab air pressure above ambient levels, forcing vapors from the subsurface to the sides of the building. This technology is particularly effective in higher-permeability soils, where it may be difficult to pull enough air to depressurize the sub-slab region by SSD (ITRC, 2007). Because indoor air is typically used to force air below the slab, fans should be equipped with a filter to prevent buildup of debris in the vent system (ITRC, 2007).
Building pressurization/HVAC optimization involves adjusting the building heating, ventilating and cooling (HVAC) system or installing a new system to maintain a positive indoor pressure relative to the sub-slab area. This approach is more commonly used in commercial buildings and can be cost-effective if the existing HVAC already maintains a positive pressure (Cal DTSC, 2009). It is also used in buildings such as daycare facilities where no amount of VI is deemed acceptable (ITRC, 2007). Increasing the pressure will result in higher energy costs, particularly if significant heating or cooling is required. Typically, only small increases in building pressure (less than 0.001 inch H_2O) are required to prevent VI; however, this method is appropriate only for buildings that are relatively tight, with few doors or other openings (ITRC, 2007). Cal DTSC (2009) does not consider this an appropriate mitigation approach for residential structures. The technology requires regular maintenance and air balancing of the system to be effective. Appropriate pressure tests and monitoring should be incorporated into the design of HVAC remedies in order for VI to ensure that sufficient positive pressures are maintained throughout the areas of the building that might be subject to VI (ITRC, 2007). If the HVAC system is shut off during the night and weekends, VI can occur while the system is off. The impact on indoor air quality during the downtime and the time it persists after the HVAC is turned back on should be evaluated in determining the system's operating requirements and effectiveness.
Indoor air treatment functions by directing air within the building through air pollution control equipment to remove toxic air contaminants from the building interior, rather than by preventing their entry into the building. Types of air pollution control equipment include zeolite or carbon sorption filters or photocatalytic oxidation units. Systems can be either in-duct models or portable air cleaners. In most cases, this is not the preferred mitigation method because it encourages the collection of contaminant vapors within the structure and is dependent on the treatment system's uninterrupted performance to protect receptors. However, it may be useful in cases where other methods, such as SSD, do not work or as a temporary solution until another mitigation system can be installed and effectively adjusted. It can also be applied in combination with other methods or for treatment of a particular problem room within a building. These systems require periodic maintenance, such as changing the filter cartridges, with frequency depending on the concentrations encountered and on the manufacturer's recommendations. Indoor air monitoring will most likely be required to determine that the system is achieving acceptable indoor air concentrations and could be more frequent than with other systems.

Table 14-2. Types of Mitigation Systems (Continued)

Passive Mitigation Systems
Vapor barriers are used to block migration of vapors from the subsurface into a building. Barriers are most appropriate for new construction, where they can be installed between the building foundation and sub-foundation material or soil to block migration of vapors into an enclosed space (Figure 14-4). However, they can also be placed over earthen floors in crawl spaces or basements. Passive barriers are intended to divert vapors laterally beyond the building footprint by diffusion gradients. Most passive barriers consist of an essentially impermeable high density polyethylene sheet or a rubberized asphalt emulsion applied as a liquid that hardens to form a barrier. Vapors can also be physically blocked by sealing or repairing cracks in the foundation or elimination of preferential pathways.
Passive venting involves placing a layer of permeable material, such as sand or pea gravel, below the floor to encourage vapors to move laterally beyond the building footprint under natural diffusion gradients or pressure gradients (ITRC, 2007). Passive venting is generally only feasible in new construction, except in crawl spaces, and, although it can be used alone, it is often combined with vapor barriers for more effective prevention of VI. These systems rely on natural thermal and wind effects to withdraw soil gases from the sub-slab venting layer. Thus, they are influenced by seasonal variations.

The LTM program should demonstrate that the system is meeting the performance goals to reduce COC concentrations and should include baseline measurements of airflow and differential pressure readings, sub-slab soil gas and indoor air. When collecting indoor air samples, the same considerations for teasing out background contributions during VI assessment applies to LTM. As previously noted, LTM air sampling should be limited to the COCs identified during the VI assessment.

Confirmation that a negative pressure is being attained across the slab can be determined by using a micromanometer. The confirmation locations should ensure that negative pressure is being achieved beneath all portions of the slab being affected by VI (generally the entire slab for residential buildings) Generally, the same sub-slab measurement probes used for design diagnostics can be used for performance testing (USEPA, 2008). Smoke tubes can be used to test for leaks at cracks and joints in the concrete slab, as well as at the suction point in sealed SSD systems and at potential leakage points through floors above sealed crawlspace systems. However, smoke testing has limitations and may not detect leaks that are too small for visual detection. A U-tube manometer is often used to measure pressure. Visible or audible alarms can be installed with the SSD system to indicate a loss of system pressure. These alarms should be installed in locations that are frequented by the building occupants to ensure that malfunction of the mitigation system is detected in at timely manner.

Regulatory stakeholder requirements and the CSM will determine when to initiate post-mitigation monitoring, which could include soil gas, SSD stack, indoor air sampling and outdoor air sampling. The manufacturer’s SSD system specifications may recommend a schedule for inspection/maintenance. The NYSDOH (2006) recommends air monitoring at least 30 days following installation of an SSD system. At Hill Air Force Base (AFB), Utah, initial monitoring following installation of mitigation systems consisted of indoor air sampling approximately three weeks after SSD system installation (U.S. Air Force, 2004). Developing a schedule for subsequent LTM should consider the following:

- Regulatory requirements
- Seasonal variation (heating season is generally considered representative of worse case)
- Exposure levels and efficacy of risk reduction
- System design and manufacturer’s specifications, and indoor air monitoring during the heating season.

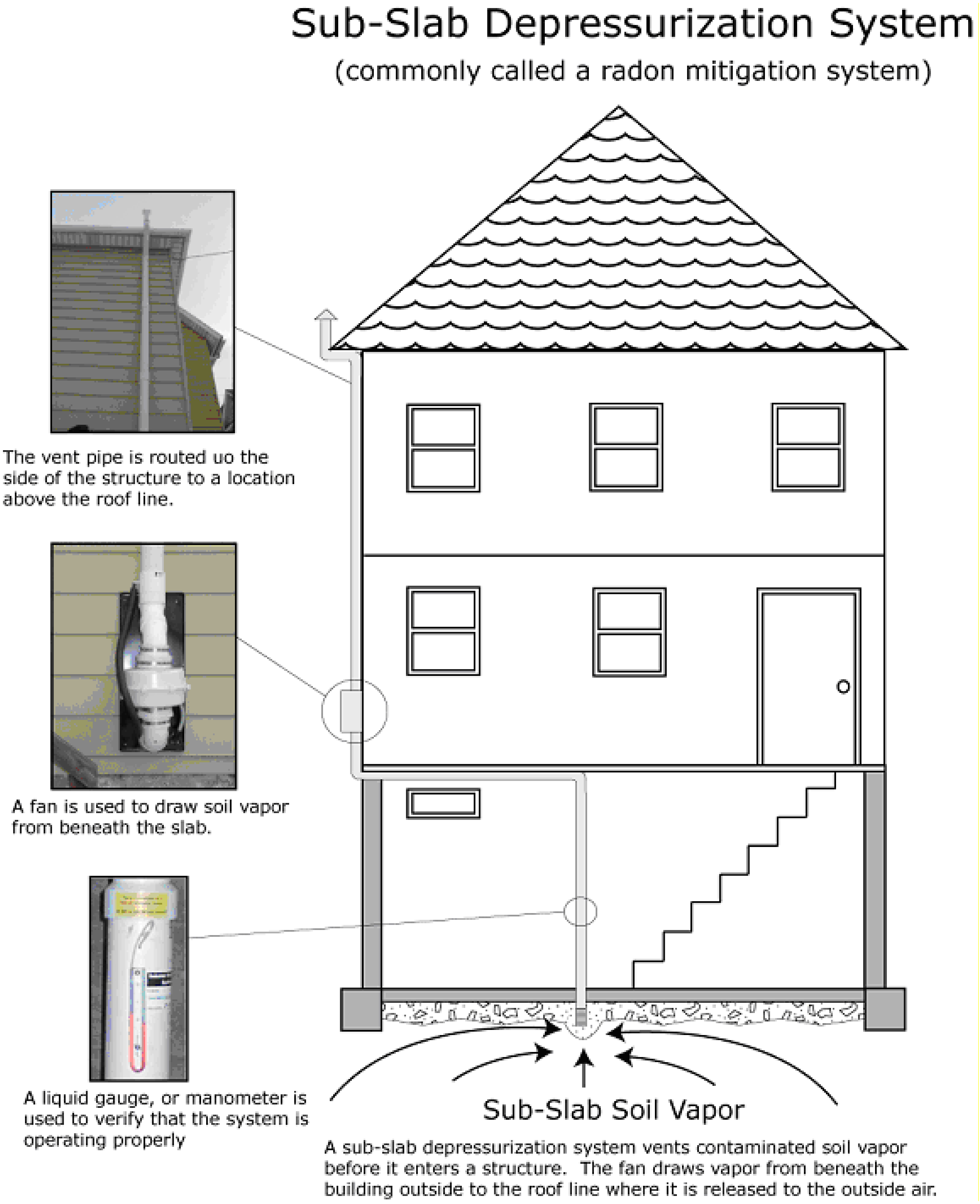

Figure 14-2. Schematic of a Typical SSD and Component Photos (Source: NYSDOH, 2006)

At Hill AFB, when contaminants are detected in the initial air samples or follow-up samples at concentrations below established criteria, quarterly sampling is recommended for one year and the results evaluated to determine the need for additional monitoring or mitigation. For SSD systems, New Jersey guidance (NJDEP, 2005) recommends that the pressure gauge (typically a U-tube manometer) be monitored quarterly to determine if the system is operating efficiently. In addition, semi-annual inspections are required to determine if any new or existing areas need to be sealed, caulked, and/or covered. Inspection frequency can be reduced after one year of efficient system operation. Also, it may be possible to set up remote monitors and/or the alarms for system performance. If feasible, this may provide an opportunity for optimizing LTM by reducing the need to gain access to each building to determine that the mitigation system is functioning properly.

For SSV systems that use a fan to draw outside air into the sub-slab venting layer, it can be difficult to specify the pressure/rate of ventilation and indoor air monitoring should be weighted heavily in the effectiveness evaluation (USEPA, 2008). Cal DTSC (2009) recommends that a sampling port within the vertical collection pipe or horizontal vent pipes below the floor be included in the design to allow sampling of COC concentrations. These measurements will verify that the system is providing adequate dilution or removal of the COCs. Generally, the goal is for the COC concentrations in sub-slab soil gas to be less than 100 times the acceptable concentration for indoor air (based on an attenuation factor of 0.01 between sub-slab soil gas and indoor air in an unmitigated building) (Cal DTSC, 2009).

For mitigation measures that rely on adjusting the building HVAC systems to maintain positive indoor pressure relative to the sub-slab, frequent pressure monitoring (monthly to quarterly) should be considered to ensure positive pressure is maintained. Mitigation measures that rely on indoor air purifying units (zeolite or carbon sorption filters or photocatalytic oxidation units that are either in-duct models or portable room units) would rely on indoor air monitoring to ensure acceptable exposure levels and would require routine inspection and filter cartridge replacement.

Once the effectiveness of the mitigation system has been demonstrated, the need for, or continued frequency of, sub-slab and/or indoor/outdoor air monitoring should be re-examined. An exit strategy for air monitoring should be implemented when it can be shown that, with routine inspection and maintenance, the mitigation system is functioning as intended and COC concentrations are reduced to acceptable risk levels.

Figure 14-3. Crawl Space Mitigation Using SMD
(Source: ITRC, 2007; Courtesy of Kansas Department of Health and Environment)

14.3.1.2 Passive Mitigation Systems. Passive systems operate by natural forces without a supplemental energy source. The two major types are vapor barriers and passive venting systems (see Table 14-2 for descriptions). Passive systems are not acceptable to all regulators, and they tend to be used more frequently in new construction than in existing buildings. Also, passive methods can be combined with active methods to provide added protection.

As with active mitigation systems, the LTM program for passive mitigation systems should demonstrate that the passive system is meeting the performance goals to reduce COC concentrations. When collecting indoor air samples, the same considerations for teasing out background contributions during VI assessment applies to LTM and air sampling should be limited to the COCs identified during the VI assessment. Frequency and duration of monitoring should be defined in the SAP along with an exit strategy for discontinuing LTM.

Figure 14-4. Passive Vapor Barrier Installation
(Source: DON, 2010)

Vapor barriers use an impermeable barrier layer to block migration of vapors from the subsurface into a building. Initial post-installation inspection is required to ensure that the barrier was properly installed and proper sealing has been achieved. LTM will include inspecting the building to ensure that no modifications to the structure have occurred and that the integrity of the barrier has not been compromised. Indoor air monitoring may be required initially and periodically thereafter to ensure that the indoor air is below the acceptable concentration thresholds.

Passive venting systems have a porous venting layer such as sand or pea gravel beneath the building with piping to collect vapors and vent them to the outside via natural thermal and wind ventilation effects. Post-installation inspection should be performed to ensure that the venting system is functioning effectively and performance goals are being met. Adjustments could be required, including installation of an active system, if the passive system cannot achieve the required performance goals. Indoor air monitoring is required to determine that acceptable concentrations are being achieved. Sampling events for passive venting systems should be timed to include seasonal variations, particularly seasons where venting may be less efficient. Also, as noted above, Cal DTSC (2009) recommends that a sampling port within the vertical collection pipe or horizontal vent pipes below the floor be included in the design to allow sampling of COC concentrations to verify that the system is providing adequate dilution or removal of the COCs. Generally, the goal is for the COC concentrations in sub-slab soil gas to be less than 100 times the acceptable concentration for indoor air (based on an attenuation factor of 0.01 between sub-slab soil gas and indoor air in an unmitigated building) (Cal DTSC, 2009).

14.3.2 Sites Without Mitigation Systems. VI monitoring may be appropriate even for sites where mitigation systems are not needed to ensure protection of human health. This could include sites where VI monitoring is conducted as a sentinel measure when VI is occurring but not at levels that pose unacceptable risk and there is potential for groundwater or vapor plumes to increase in concentration or migrate to areas that could pose an unacceptable VI risk in current or future buildings.

14.3.2.1 Sites with Potential Plume Migration. Sites having volatile contaminants in groundwater or soil gas, where these contaminants are not currently causing unacceptable VI risk but have the potential to pose an unacceptable VI risk in the future, may require periodic sentinel monitoring. This monitoring could be conducted for a known subsurface source to demonstrate that VI is not occurring at levels that pose unacceptable risk, or by monitoring groundwater or soil gas for potential migration of the plume toward target buildings. To monitor for potential migration toward a target building, sentinel monitoring points should be established downgradient from the plume in locations between the plume and buildings to provide advance warning of the approaching plume. In these cases, the frequency of monitoring should be determined based on the rate at which the plume is migrating, as well as on the COC concentrations and potential unacceptable risks. Source remediation, if under way, may also affect the frequency of monitoring. Monitoring could include soil-gas and/or groundwater sampling, depending on the site-specific conditions and on which of these media pose the greatest concern. Methods for monitoring these media are the same as those for routine environmental investigations. These are described in Chapter 11 for monitoring soil gas in the vadose zone and in Chapter 7 for groundwater monitoring.

Where a plume is present underneath an occupied building but VI is below the threshold risk levels, periodic monitoring may be appropriate if there is potential for concentrations to increase. It may be acceptable to monitor soil gas or groundwater at locations near the building, so that further actions can be taken if concentrations increase. The frequency of sampling and sampling locations should be evaluated based on a trend analysis of COC concentrations in a manner similar to that discussed in Chapter 4. Also, periodic monitoring of indoor air and or sub-slab soil gas may be required as part of the LTM plan. If indoor air is monitored, it is important to assess potential indoor sources and to collect outdoor air samples and possibly sub-slab soil gas concurrently.

14.3.2.2 Sites with Future Buildings. Monitoring strategies for sites where VI is a concern for future buildings is similar to monitoring soil gas or groundwater at other sites. At those sites, the media driving the VI risk should be monitored. Chapter 11 discusses monitoring of soil gas in the vadose zone, and Chapter 7 discusses groundwater monitoring and sampling.

14.3.3 Termination of Mitigation Systems and Building Controls. At most sites, remediation efforts will eventually reduce source concentrations in soil, soil gas, and/or groundwater to acceptable levels that no longer pose a VI hazard. When source remediation is complete, the VI mitigation systems should be shut down and/or removed with regulatory/stakeholder concurrence and any ICs revised accordingly. Before turning off a mitigation system, it is important to understand the regulatory requirements for the particular location. Some states, such as New York (NYSDOH, 2006) and New Jersey (NJDEP, 2005), require that a proposal be submitted and approved before the mitigation system can be turned off.

Once the mitigation system has been turned off, sampling of indoor air and/or sub-slab soil gas is required to demonstrate that indoor air concentrations continue to be below the target risk levels with the mitigation system turned off. As with all indoor air sampling, concurrent outdoor air sampling and/or sub-slab soil-gas sampling and evaluation of indoor air background sources are recommended. States may have requirements for this sampling. For example, New Jersey (NJDEP, 2005) requires sampling of indoor air and sub-slab soil gas, and requires that this sampling be conducted during winter or late spring (defined as November through March). States also may have requirements for the length of time and frequency for confirmation monitoring. The criteria for when confirmation sampling can be terminated should be specified in the SAP prior to remediation and mitigation.

14.4 Lessons Learned in VI Monitoring

VI is an evolving science and many of the common pitfalls associated with VI monitoring are related to lack of understanding of vapor movement in the subsurface. Most Navy sites are in the initial characterization phase and thus do not have substantial experience with LTM at this time. Therefore, suggestions for optimization of VI monitoring are taken largely from the experience at other federal sites such as Hill AFB or privately-owned sites such as the Endicott, NY site and the Redfield site in Colorado. Lessons learned from current VI projects that should be considered by RPMs who plan and carry out LTM are provided in Table 14-3.

Table 14-3. Common Pitfalls Associated with VI Monitoring and Suggested Avoidance Methods

VI Monitoring Pitfalls	Avoidance Methods
High temporal variability in sample concentrations within a particular area	• Understand the CSM and use multiple lines of evidence to establish the VI relationship. Also, include sampling at different seasons and weather conditions to ensure that worst-case conditions are covered.
Variation among locations within the building	• Select sample locations to best represent the highest exposure and the most frequently occupied areas. For indoor air at residences, these will typically include the basement and the first floor.
Indoor air sampling indicates concentrations exceeding risk thresholds when VI is not a likely source.	• When sampling indoor air, include concurrent sampling of outdoor air and sub-slab soil gas, as well as a building survey to identify any potential indoor sources. The supporting information will provide multiple lines of evidence for evaluating VI.
High variability of sample concentrations in close proximity to each other at a particular site	• Spatial variability may indicate complex geologic conditions at the site that may increase the difficulty of determining whether and where VI is resulting in concentrations that exceed acceptable levels. Understand the CSM and use multiple lines of evidence to establish the VI relationship.
Sample representativeness when a residence gets a non-detect and then refuses further sampling	• Develop a plan for communication with the community and residents. Continue efforts to offer additional sampling (e.g., annually) as appropriate for the site and as documented in the SAP.
Intrusive nature of VI investigation	• Develop a plan for working with the residents to minimize the disruptions caused by sampling.
Changing standards (toxicity values) for contaminants	• Work with regulators and other stakeholders to develop concurrence on an approach to revising the action levels when toxicity values are revised.

VI LTM Case Study: Optimization of the VI Sampling Program at Hill AFB, Utah

Project Summary

At Hill AFB, several plumes of groundwater contaminated with VOCs have migrated from on-base sources to off-base areas beneath surrounding residential communities. The VOCs (primarily chlorinated solvents) are present in shallow aquifers resulting in the potential for VI into the overlying residences. Hill AFB has undertaken an extensive program to define the plumes, test indoor air, install vapor mitigation systems, and perform LTM. This program has been optimized by the development of specific methodologies for the various stages of sampling, mitigation and monitoring and by applying an iterative approach to mitigation beginning with simpler, less costly methods and progressing to more sophisticated measures as necessary. It has also been optimized by the careful investigation and identification of indoor air sources that interfere with testing the effectiveness of the VI mitigation systems.

Optimization Strategy Employed

Hill AFB's basewide indoor air sampling program was initiated in 2003 and procedures for this program are defined in the Final Basewide Sampling and Analysis Plan for Indoor Residential Air Sampling (United States Air Force, 2004). This plan provides the general organization for indoor air quality programs, including lines of communication, key personnel, and authority to initiate and approve any sampling and necessary corrective actions. It includes procedures for contacting residents, sample collection scheduling, sample equipment, sample collection procedures, sample shipping and handling procedures, quality control sample requirements, types and frequencies of air sampling tests, and documentation procedures.

The VOC contamination near the residences is in shallow groundwater found from ground surface (seeps and springs) to approximately 80 ft bgs. The groundwater plume boundaries are defined by the federal drinking water MCLs for each COC (e.g., 5 µg/l for TCE). The primary candidates to be evaluated for VI are identified as those residences overlying the plume or within 100 ft laterally from the plume boundary, although any request to participate in the program is reviewed. The residents living over and within 100-ft of the plume boundary are contacted by mail and offered annual indoor air sampling.

As part of the Basewide SAP, mitigation action levels (MALs) were defined for indoor air concentrations of each VOC identified as a COC. The MALs for the target compounds follow the USEPA generic screening levels, based on a cancer risk of 1×10^{-5} and a Hazard Index of 1.

Indoor air sampling is performed at all residences that accept the offer. Sampling is limited to the contaminants identified below or near that residence. If contaminants are not detected, follow-up sampling is offered on an annual basis, preferably during the following winter. If contaminants are detected, an indoor source investigation is suggested. Source investigations are generally prioritized by contaminant, relative concentration, and homeowner receptiveness. For residences where an indoor source cannot be identified and concentrations exceed the MALs, a mitigation system is recommended. If contaminants are detected below the MALs and an indoor source is not identified, quarterly indoor air sampling is recommended for one year and results are evaluated to determine the need for additional sampling or mitigation. However, if requested by the homeowner, Hill AFB will install a mitigation system in any home where COCs are detected and an indoor source has not been identified.

VI LTM Case Study: Optimization of the VI Sampling Program at Hill AFB, Utah

Hill AFB applies an iterative approach to mitigation whereby simpler, less costly means of mitigation are employed first, followed by more sophisticated measures as needed after initial performance indoor air testing. Active sub-slab depressurization systems have been identified as the most efficient cost-effective mitigation method and achieve very high rates of reduction in most cases. To date, these are the most common type installed, followed to a much lesser extent by crawl-space sub-membrane depressurization and sump/foundation drain depressurization systems. In some cases, augmentation is needed to reduce concentrations to below the MAL.

Indoor air testing is generally performed within 14 days after installation of the mitigation system and periodically thereafter to assess performance. If contaminants are detected above MALs, the system is adjusted or a new mitigation system is employed and the process is repeated until testing indicates that mitigation is effective. When the mitigation system has been finalized, indoor air sampling is performed quarterly for one year, semi-annually the following year and annually thereafter for a minimum of two years.

Between 2001 and 2008, 1500 of 2900 homes agreed to sampling. TCE was detected in 235 (16%) of homes sampled and was above the MAL in 123 homes. Of the 123 homes, 35 were known or suspected to have indoor sources. The installation of the VI systems has shown a high degree of success with 88% of the residences showing successful mitigation on the first installation and success at the remaining systems following modification.

One of the biggest challenges for Hill AFB has been separating indoor air sources from VI. For example, 1,2-DCA was initially identified as a COC, but was later found to be attributable to indoor sources. Early in the program (FY 2004), there were very few detections of 1,2-DCA in indoor air; however, detections steadily increased through FY 2008. Also, the mitigation systems did not reduce the concentrations of 1,2-DCA and some detections were found in homes outside the plume boundaries. These factors seemed to indicate an indoor source, although there were no known products containing this substance. Finally, after an extensive investigation of indoor sources, it was determined that molded plastic decorations were the source of 1,2-DCA. Review of the data and other lines of evidence led to the conclusion that VI was not the source of 1,2-DCA and this compound was removed from the COC list.

In summary, Hill AFB chose to perform indoor air sampling at all potentially affected residences for VI characterization and to install mitigation systems at residences exceeding the selected MALs. They have established a clear and consistent program for initial sampling, installation, and monitoring. They use an iterative approach to mitigation installations, using simple, cost-effective and reliable systems first with more sophisticated modifications provided as necessary to reduce contaminants below the action levels. Due to the interferences they have encountered from indoor sources, they plan to take a more “top down” approach to sampling in the future to carefully identify potential indoor sources during characterization.

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VI LTM Program Development Checklist

Identify LTM Objectives

- ☐ Detect any potentially harmful intrusion of vapors into a building.
- ☐ Track contaminant concentration changes in soil vapor, sub-slab vapor and indoor air.
- ☐ Confirm performance and effectiveness of VI mitigation system.
- ☐ Confirm that remediation has been completed.
- ☐ Confirm that inhalation risk levels for building occupants are below the target thresholds, and/or
- ☐ Determine whether a migrating contaminant plume with potential for VI is approaching an occupied building or is increasing in concentration to levels causing concern for receptors.

Selection and Distribution of Monitoring Locations

- ☐ For LTM, consider sampling locations that provided the most compelling information on VI during characterization.
- ☐ Conduct sub-slab and outdoor sampling in conjunction with indoor air sampling to help distinguish VOCs originating from subsurface sources versus indoor air background sources.
- ☐ If conditions preclude sub-slab sampling, collect samples just outside the building (i.e., near-slab samples).
- ☐ Sample indoor air in areas where occupants are most likely to be exposed and from areas more immediately influenced by VI such as basements or identified cracks in a foundation (identify potential indoor sources of contaminants prior to conducting indoor air sampling).
- ☐ Understand the CSM, including locations of utility connections that could be preferential pathways into the building and collect samples near these features.
- ☐ Collect outdoor air samples from locations that are generally upwind from the building(s) being sampled, several feet off the ground, and away from wind breaks and known building exhausts.

Determine Monitoring Frequency and Duration

- ☐ Indoor air sampling performed over several seasons is ideal, but at a minimum, should include the heating season in areas with seasonal variability.
- ☐ For indoor air, understand building operation factors that affect VI, such as weather and HVAC operation, and sample for a worst-case condition.
- ☐ For indoor air, 24-hour time-integrated samples for residential dwellings and 8-hour samples for occupational buildings are recommended.
- ☐ The number of outdoor and sub-slab air sampling events will be dictated by the sampling requirements for indoor air.

VI LTM Program Development Checklist

- ☐ Sampling duration of outdoor air should match the sampling duration for the indoor-air (e.g., 24-hour time-integrated samples).
- ☐ Reduction in sampling frequency for each monitoring point and possible elimination of monitoring points should be evaluated based on COC trends and risk to receptors.

Identify Analytes for Initial Monitoring

- ☐ LTM samples should be analyzed only for those VOCs and their degradation products that have been detected in soil, soil gas, or groundwater, and identified as COCs for VI.

Determine Monitoring Technique

- ☐ Active sampling is most widely accepted. (Passive sampling methods are currently being tested for reliable application in VI sampling and may become more accepted in the future.)

- ☐ Consistent analytical methods should be used for soil-gas, sub-slab, indoor air, and outdoor air samples.

Mitigation Monitoring

- ☐ Mitigation systems should be inspected and tested following installation to ensure they were properly installed and are functioning as intended; baseline monitoring should be performed to evaluate their effectiveness.
- ☐ SSD systems and their variations should be tested to ensure that the depressurization extends to the edges of the slab and ensure that a sufficient pressure differential exists.
- ☐ Indoor air sampling may be required initially to determine whether acceptable risk levels have been met. Outdoor air and sub-slab soil gas should be collected concurrently with indoor air sampling. It may be possible to eliminate air sampling from the LTM program once the mitigation system is shown to be effective; however, this will depend on the level of risk involved and acceptance by the regulators.

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Chapter 15.0: Resources

15.1 Useful Websites

15.1.1 State Environmental Agencies

Alabama www.adem.state.al.us
Alaska www.state.ak.us
Arizona www.adeq.state.az.us
Arkansas www.adeq.state.ar.us
California www.state.ca.us
Colorado www.state.co.us
Connecticut www.state.ct.us
Delaware www.dnrec.state.de.us
Florida www.state.fl.us
Georgia www.dnr.state.ga.us
Hawaii www.state.hi.us
Idaho www.state.id.us
Illinois www.ipcb.state.il.us
Indiana http://www.state.in.us/idem
Iowa http://www.iowa.gov/
Kansas www.state.ks.us
Kentucky www.state.ky.us
Louisiana www.deq.state.la.us
Maine www.state.me.us
Maryland www.mde.state.md.us
Massachusetts www.state.ma.us
Michigan www.michigan.gov/deq
Minnesota www.pca.state.mn.us
Mississippi www.deq.state.ms.us
Missouri www.state.mo.us
Montana www.deq.state.mt.us
Nebraska www.deq.state.ne.us
Nevada www.state.nv.us
New Hampshire www.state.nh.us/des
New Jersey www.state.nj.us/dep
New Mexico www.state.nm.us
New York www.dec.state.ny.us
North Carolina http://www.enr.state.nc.us/
North Dakota www.ehs.health.state.nd.us
Ohio http://www.epa.state.oh.us/
Oklahoma www.deq.state.ok.us
Oregon www.deq.state.or.us
Pennsylvania www.dep.state.pa.us
Rhode Island http://www.dem.ri.gov/
South Carolina http://www.sc.gov/
South Dakota www.state.sd.us/denr
Tennessee www.state.tn.us
Texas www.tnrcc.state.tx.us
Utah www.deq.state.ut.us
Vermont www.anr.state.vt.us
Virginia www.deq.state.va.us
Washington www.access.wa.gov
West Virginia www.state.wv.us
Wisconsin www.wisconsin.gov/state/home
Wyoming http://www.state.wy.us

15.1.2 Other Useful Websites

Navy

Department of the Navy Environmental Restoration Optimization Web Site
https://portal.navfac.navy.mil/portal/page?_pageid=181,5346904&_dad=portal&_schema=PORTAL#slide_show_end

Air Force

AFCEE Remedial Process Optimization Website
http://www.afcee.brooks.af.mil/products/rpo/default.asp

AFCEE LTM Optimization Guide
http://www.afcee.brooks.af.mil/products/rpo/docs/LTM06Guidance1212.pdf

Army

Army Corps of Engineers (USACE) Remediation System Evaluation (RSE) Checklists
http://www.environmental.usace.army.mil/library/guide/rsechk/rsechk.html

DoD

Defense Environmental Network and Information Exchange (DENIX)
https://www.denix.osd.mil/denix/denix.html

ESTCP
http://www.estcp.org/

Strategic Environmental Research and Development Program
http://www.serdp.org/

US EPA

U.S. Environmental Protection Agency (Cleanup)
http://www.epa.gov/ebtpages/cleanup.html
Federal Facilities Restoration and Reuse Office
http://www.epa.gov/swerffrr

DQOs

Department of Navy DQO Training:
http://www.navylabs.navy.mil/ManualsDocs.htm

Department Of Energy DQO Training:
http://www.qe3c.com/dqo/training/cover.html

Miscellaneous

Interstate Technology and Regulatory Council (ITRC) RPO Team
http://www.itrcweb.org/teampublic_RPO.asp

Federal Remediation Technologies Roundtable (FRTR) (Monitoring Optimization Website)
http://www.frtr.gov/optimization/monitoring.htm

EPA Hazardous Waste Clean-up Information (CLU-IN) Website
http://www.clu-in.org

15.2 Useful Documents

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United States Department of the Navy. 1998. *Technical Guidelines for Evaluating Monitored Natural*

Attenuation of Petroleum Hydrocarbons and Chlorinated Solvents in Groundwater at Naval and Marine Corps Facilities. September.

USEPA, see United States Environmental Protection Agency.

United States Environmental Protection Agency. 1989. *Guidance on Preparing Superfund Decision Documents, Interim Final*. EPA/540/G-89/007. July.

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United States Environmental Protection Agency. 1998. *Technical Protocol for Evaluating Natural Attenuation of Chlorinated Solvents in Ground Water.* September.

United States Environmental Protection Agency. 2000. *Guidance for the Data Quality Objectives Process - QA/G-4.* EPA/600/R-96/055, Office of Environmental Information, U.S. Environmental Protection Agency, Washington, D.C.

United States Environmental Protection Agency. 2006. *Guidance on Systematic Planning Using the Data Quality Objectives Process*. Quality Assurance Management Staff. Office of Research and Development. EPA QA/G-4. February.

Chapter 16.0: References

The following are references that were used to develop Part I, Chapters 1-6 of this guide. References for Part II of this document are provided at the end of each chapter.

Air Force Center for Environmental Excellence (AFCEE). 1997. *Long-Term Monitoring Optimization Guide*.

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APPENDIX A

Summary of Optimization Case Studies

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FINAL

NAVAL WEAPONS INDUSTRIAL RESERVE PLANT DALLAS LONG-TERM MONITORING DEVELOPMENT CASE STUDY

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EXECUTIVE SUMMARY

ES.1 Purpose of the Case Study

The main purpose of this case study is to provide: (1) specific guidance and direction to the Naval Weapons Industrial Reserve Plant (NWIRP) in Dallas, Texas, regarding the required elements of a groundwater compliance plan, and (2) recommendations for continual streamlining of a monitoring program. A discussion of closeout strategy for the installation is also presented. In addition, best practices that have been implemented at NWIRP Dallas and may be incorporated into the strategy of other facilities are documented in this case study.

ES.2 Optimization Approach

This case study focuses on ways to reduce the resources expended at NWIRP Dallas for groundwater monitoring without compromising program and data quality. This evaluation includes an assessment of five basic areas:

- The number of monitoring points;
- The efficiency of current field procedures;
- The duration and frequency of monitoring;
- The analyte list and analytical methods; and
- Reporting and data management protocols.

ES.3 Installation and Program Background

NWIRP Dallas is a government owned, contractor-operated (GOCO) facility located in Grand Prairie, Texas, between Dallas and Fort Worth. It covers 314 acres on the shoreline of Mountain Creek Lake and is adjacent to Naval Air Station (NAS) Dallas, which is now closed. The primary mission of the installation, which was built in 1941, has been military aircraft manufacturing. The installation is currently operated by Northrop Grumman. Environmental work began at NWIRP Dallas in the 1980s. During a Resource Conservation and Recovery Act (RCRA) Facility Assessment (RFA) conducted in the early 1990s, 16 solid waste management units (SWMUs) and 6 areas of concern (AOCs) were identified. The RFA determined that contamination to the groundwater has resulted from activities at these SWMUs and AOCs, which include wastewater treatment, waste and hazardous material storage, waste disposal and incineration, and manufacturing.

An RCRA Facility Investigation (RFI) was conducted from 1993 to 1994. The investigation results indicated that there is one large plume of groundwater contamination by chlorinated solvents and other volatile organic compounds (VOCs) covering 80% of the installation. Consequently, the installation has been treated as one site. An RCRA Part B permit was issued by the Texas Natural Resource Conservation Commission (TNRCC) to NWIRP Dallas in April 1994. The Part B permit specified that stabilization measures be implemented to stop further off-site migration of the contaminated plume.

ES.4 Best Practices Already in Place

There are several examples of practices that NWIRP Dallas has already put in place to optimize their periodic groundwater monitoring program. The following items may be evaluated by other installations seeking to reduce costs associated with their own long term monitoring (LTM) or periodic monitoring programs:

- NWIRP Dallas has implemented micropurging to increase sample quality and, in many cases, eliminate metals as chemicals of concern (COCs).
- The installation has analyzed groundwater monitoring data from sampling events, performed trend analysis, and contoured the data to make recommendations for program improvements.
- NWIRP Dallas used geostatistics to demonstrate that 58 monitoring wells could be removed from the program without compromising program quality.
- The installation currently handles all of its data electronically to facilitate data management and visualization.
- NWIRP Dallas proactively initiated a site-wide background study for metals.
- The installation has employed the help of outside government agencies to assist in evaluation and treatment of the contaminated groundwater plume.

ES.5 Site Closeout Strategy

Several strategies for negotiating eventual site closeout should be considered now, as the monitoring program is about to start. These include the following:

- Continue to aggressively pursue the application of monitored natural attenuation (MNA) for the contaminated plume.
- Initiate discussions with TNRCC to establish alternate concentration limits (ACLs) for the groundwater plume, with Mountain Creek Lake as the point of compliance.
- Consider expanding the Stabilization System Performance Evaluation Reports to include graphical presentation of additional cost and performance metrics.
- Initiate discussions with the regulatory agencies to establish measurable decision criteria defining the meaning of technical and/or cost impracticability for NWIRP Dallas.
- Continue to evaluate innovative in situ groundwater treatment remedies as possible cost-effective alternatives to conventional pump and treat for source removal.

ES.6 Monitoring Program Design

On the basis of the optimization strategy summarized in Section ES.2, several suggestions for the design of the monitoring program at NWIRP Dallas are offered:

- Exclude approximately 80% of the installation monitoring points from the monitoring program, using TNRCC guidance to identify those points that should be included.
- Following a year of quarterly sampling, pursue a reduction of sampling frequency to semiannually for point-of-compliance (POC) and corrective action observation wells, and annually for upgradient and background wells.
- Continue using micropurging techniques, but refine the placement of dedicated tubing intakes to ensure purging from the most productive zones, thus eliminating vertical flow within the wells.
- Decrease the analyte list to VOCs and metals of concern, including hexavalent chromium.
- Pursue coordination of the monitoring database with a geographic information system (GIS) application.
- Focus on graphical and tabular reporting formats and minimize the amount of text submitted in quarterly reports.

TNRCC regulations require that requests for modifications to an issued groundwater compliance plan be submitted following a specific format. These requests must be accompanied by a fee, the amount of which depends on the extent of the proposed modifications. Therefore, it is important to have a thorough periodic evaluation of the monitoring program so that modification requests can be minimized to the extent possible.

ES.7 Benefits

The benefits of applying the above recommendations include a potential cost savings of almost $130,000 per sampling round, as compared with the cost of sampling all monitoring points for target compound list (TCL) organics and target analyte list (TAL) metals. During the second year of sampling, additional cost savings, estimated at $65,000 per year, may be realized by decreasing monitoring frequency. The cost associated with requesting a compliance plan modification, including labor, should be substantially less than the amount saved. These estimated savings do not consider additional savings associated with data validation, management, and reporting.

FINAL

MARINE CORPS BASE CAMP LEJEUNE LONG-TERM MONITORING OPTIMIZATION CASE STUDY

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EXECUTIVE SUMMARY

ES.1 Purpose of the Plan

The purpose of this case study is to evaluate the monitoring programs for six Operable Units (OUs) at Marine Corps Base (MCB) Camp Lejeune, North Carolina. Specific recommendations to streamline LTM and avoid some of the costs associated with monitoring at the OUs are included in this case study. A discussion of site closeout strategy is also presented. In addition, best practices that have been implemented at the installation and may be incorporated into the strategy of other facilities are documented in this plan. This case study was conducted for the Naval Facilities Engineering Service Center (NFESC) under a Broad Agency Announcement contract.

NFESC is assisting a Department of the Navy working group that will develop 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, Naval Facilities Engineering Command, and Chief of Naval Operations. The working group selected six OUs at MCB Camp Lejeune for this case study. Similar case studies are also underway at two other Navy facilities. The "lessons learned" and findings from these case studies will be used to develop the guidance document.

ES.2 Optimization Approach

The approach used to evaluate and optimize the LTM programs at MCB Camp Lejeune includes an assessment of five basic areas:

- The number of monitoring points;
- The duration and frequency of monitoring;
- The efficiency of current field procedures;
- The analyte list and analytical methods; and
- Reporting and data management protocols.

Section ES.6 summarizes the recommendations for each of these areas.

ES.3 LTM Program at Camp Lejeune

The LTM program at MCB Camp Lejeune currently includes six OUs. There are a total of 13 sites at these six OUs. Nine are included in the LTM program, two required no further action, and one was closed out following a removal action. Another site was removed from the LTM program following several rounds of non-detect (ND) data. By the end of calendar year 1999, it is anticipated that an additional three sites will have been eliminated from the LTM program. It is also anticipated that Records of Decision (RODs) will be put in place during 1999 for two more OUs that will be added to the LTM program.

ES.4 Best Practices Already in Place

There have been several commendable examples of program streamlining in the MCB Camp Lejeune LTM program. These include:

- Use of decision criteria to remove sites from the LTM program;
- Detailed work plans for the entire LTM program;
- Trend analysis and plume contour maps to make recommendations for program improvements;
- Inspection and abandonment of deteriorating wells;

- Semiannual or annual monitoring for the entire LTM program;
- A “team approach” with regulators and the community;
- A streamlined reporting process; and
- Electronic data handling.

ES.5 Site Strategy Considerations

In preparation for the 5-year review, scheduled for calendar year 1999, there are several site strategies to consider. These include:

- Assessing the role of natural attenuation at the LTM sites;
- Tracking cost and performance data for the pump and treat systems at OU Nos. 1 and 2; and
- Pursuing a potential technical impracticability waiver for the pump and treat system at OU No. 2.

ES.6 Recommended Optimization of LTM

Following is a summary of specific recommendations made for the LTM program at MCB Camp Lejeune, based on the optimization approach outlined in Section ES.2.

Monitoring Point Reduction— Although the LTM program for Camp Lejeune includes a reasonable number of wells at each site to achieve program objectives, there are a few wells that may be eliminated from the program without compromising quality. The elimination of five groundwater monitoring wells at OU No. 2 and two surface water and sediment sample locations at OU No. 4 from the LTM program is recommended. In addition, the current policy of regularly inspecting wells and abandoning those found to be in deteriorating condition should be continued as a way to further reduce the number of monitoring points.

Duration and Frequency Reduction—Several of the semiannual monitoring reports discuss the natural occurrence of high levels of metals in groundwater at Camp Lejeune. A small base-wide background metals study is recommended as a potential tool for decreasing the duration of monitoring at sites where metals are contaminants of concern. This strategy may not be necessary for Site 28 (OU No. 7), which may be closed out during calendar year 1999, but may be very helpful in eventually closing out Site 41 (OU No. 4). Several of the deep wells at OU No. 2 have already been reduced to annual monitoring. Two deep wells at OU No. 1 and one at OU No. 12 may also be reduced to annual monitoring. Reducing the sampling frequency of upgradient or background wells to annual monitoring is another recommended approach for achieving frequency reduction.

Field Procedure Efficiency Improvements—Low-flow purging, or “micropurging”, using the stabilization of water quality parameters as the purge criteria, is recommended. Consideration should be given to the installation of a dedicated sampling system to save labor, eliminate the need for equipment blanks, and improve sample quality.

Simplification of Analyses— The analyte list may be significantly simplified by eliminating compounds not detected in four rounds of sampling. In addition, Contract Laboratory Protocol (CLP) metals are being recommended for elimination from the OU No. 2 LTM program by the LTM contractor. A background metals study, recommended as a tool to help close metal-contaminated sites, may also help to eliminate metals from the analyte list at some sites.

Report Streamlining—Camp Lejeune has already made considerable efforts in streamlining the semiannual reporting process. Further streamlining of the reporting effort by decreasing text discussion and consolidating graphic and tabular data is recommended.

Data Analysis—There are currently plans to incorporate the electronic data from the LTM program into the active Geographic Information System (GIS) application for Camp Lejeune. The Base should complete this task as soon as possible so that spatial and other data analysis tools are available for LTM and site closeout decision making. In addition, having a GIS application for the LTM program will significantly improve the quality of presentations to regulators and the public.

ES.7 Benefits

The benefits of applying the above recommendations include a potential annual LTM program cost savings of approximately 18% of the analytical budget, or $6000, and approximately 50% of the field labor budget, or $30,000. These figures do not include all of the possible savings, such as for reporting and data management, and it is estimated that it may take two years to recoup some recommended capital expenditures. There are additional potential benefits of implementing the suggestions summarized above and detailed within this case study. It is anticipated that data, report, and presentation quality may be improved as a result of some of the recommended monitoring program changes.

FINAL

NAVAL AIR STATION PATUXENT RIVER LONG-TERM MONITORING OPTIMIZATION CASE STUDY

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EXECUTIVE SUMMARY

ES.1 Purpose of the Plan

The purpose of this case study is to evaluate the LTM programs for two sites at Naval Air Station (NAS) Patuxent River, Maryland. Specific recommendations to streamline LTM and avoid some of the costs associated with LTM at the Former and Current Landfills and the Fuel Farm are included in this case study. A discussion of closeout strategy for these sites is also presented. In addition, best practices that have been implemented at the landfills and the fuel farm and may be incorporated into the strategy of other facilities are documented in this plan.

ES.2 Optimization Approach

The approach used to evaluate and optimize the LTM programs at NAS Patuxent River includes an assessment of five basic areas:

- The number of monitoring points;
- The efficiency of current field procedures;
- The duration and frequency of monitoring;
- The analyte list and analytical methods; and
- Reporting and data management protocols.

ES.3 Former and Current Landfills

The Former Landfill is located adjacent to and upgradient from the Current Landfill (Figure 3-1). The Former and Current Landfills are being monitored as one site, and for the purpose of this document will be referred to as “the landfill.” The landfill occupies approximately 16.5 acres in the southern portion of the Base. Disposal operations began at the site in 1974 and continued for approximately 20 years. Contamination of groundwater by organic and inorganic compounds has resulted from site operations. A landfill cap was installed as an interim remedial action (IRA) in 1996-1997 to officially close the site. An adjacent site, Site 34, has evidence of contamination due to drum disposal but has not yet been fully investigated.

The landfill is a Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) National Priorities List (NPL) site. An LTM program is being conducted at this site to assess the effectiveness of the landfill cap. This monitoring program includes groundwater, surface water, sediment, leachate, and landfill gas. This case study focuses on the most costly aspect of this program, the groundwater monitoring.

There have been several commendable examples of program streamlining in the landfill IRA, LTM, and performance monitoring programs. These include:

- Using on-site borrow to reduce the construction costs of the landfill cap;
- Negotiating quarterly monitoring instead of the State-proposed monthly monitoring; and
- Exploring contracting options and mechanisms to identify potential cost savings.

ES.3.1 Recommendations

Following an assessment of the landfill and associated documents, recommendations regarding site closeout, LTM strategy, and landfill cap performance monitoring were formulated.

Site Closeout—In preparation for the 5-year review of the LTM program, several things should be considered:

- In anticipation of the final Record of Decision (ROD) for the site, the Base should identify decision criteria for determining when monitoring at the site, or for a specific monitoring point, may be stopped.
- Several rounds of natural attenuation data may be instrumental in convincing regulators that no active remediation is necessary at the landfill or Site 34. A program to collect such data should be considered.
- Combined monitoring of groundwater at the landfill and Site 34 should be investigated, in case the State requires an LTM program at Site 34. Combining these sites is likely to reduce the overall number of monitoring wells in the program.
- Cost and performance data for the flare system should be tracked to continually assess site progress and prepare for the 5-year review.
- Contaminant trends in groundwater should be tracked to continually assess site progress and prepare for the 5-year review.

LTM—

Following is a summary of specific recommendations made for the LTM program at the landfill:

- Consider eliminating two or three wells from the LTM program this year. Conduct a statistical analysis next year to determine if additional wells may be eliminated.
- Pursue a reduction to semiannual monitoring with regulators following the reporting of four quarters of data.
- Investigate the potential for using micropurging techniques by determining if well recharge is adequate. If so, consider installation of a dedicated sampling system to save labor, eliminate equipment blanks, and improve sample quality.
- Reduce the analyte list by eliminating compounds not detected in the first year of sampling. Also, consider eliminating dissolved metals and decreasing QA/QC sample rates.
- Take advantage of the service contract in place to provide geographic information system (GIS) and electronic data handling support. With this support, use data analysis tools to enhance decision-making.
- Streamline the reporting effort by focusing on graphic and tabular data presentations and consolidating all reports for a year in one binder.

Performance Monitoring—

Although an in-depth assessment of landfill cap performance monitoring was not made, there is one recommendation for improving the efficiency of weekly landfill gas monitoring. By modifying the sampling ports so that they can be accessed from the surface, rather than by entering the vaults in which they are currently housed, sampling time can be decreased. In addition, the safety of the operation will be increased.

ES.3.2 Benefits

The benefits of applying the above recommendations include a potential LTM program cost savings of over 25% of the current budget, prior to reducing sampling frequency from quarterly to semiannually. In addition to the cost savings, adopting these recommendations has the potential to improve data and report quality as well as sampling personnel safety.

ES.4 The Fuel Farm

The fuel farm occupies more than 12 acres in the northwest portion of the Base. Fuel handling operations began at the site in the early 1940s but are inactive today. Possible leaks from tanks and pipelines have resulted in the contamination of soil, groundwater, and surface water. Several investigations and technology demonstrations have taken place at the site from the late 70s to the present.

The fuel farm is an underground storage tank (UST) site and falls under State of Maryland UST regulations. Groundwater sampling has been conducted in some or all of the site's 90 wells nine times since 1984. A tank and soil removal action took place early in calendar year 1999 and a formal LTM program has been started at the fuel farm.

NAS Patuxent River has been proactive in assessing innovative remedial actions for the fuel farm. As a result of these assessments, viable remedial alternatives, such as mobile bioslurping and a pump and treat system, have been implemented. In addition, a significant amount of data that could be used to support a natural attenuation remedy have been collected.

ES.4.1 Recommendations

Following an assessment of the fuel farm and associated documents, recommendations regarding site closeout, LTM program design, and system performance monitoring were formulated.

Site Closeout—Several strategies for negotiating eventual site closeout should be considered now that the removal action and first round of monitoring has been completed:

- Several bioremediation studies have been conducted at the site, with promising results. Additional natural attenuation data should be collected to support decisions to shut down active treatment systems when appropriate.
- Decision criteria should be formulated now so that decisions regarding shutting down remedial systems, stopping monitoring, and closing out the site can be made when appropriate.
- Collection of cost and performance data for the treatment system and contaminant trends in groundwater should be tracked to continually assess site progress and support a possible natural attenuation remedy.

LTM—
Following is a summary of specific recommendations made for the upcoming
LTM program at the fuel farm:

- Eliminate 60% of the site wells from the fuel farm LTM program. Continue to assess the potential for eliminating additional wells on an annual basis.
- Investigate the potential for using micropurging techniques by determining if well recharge is adequate. If so, consider installation of a dedicated sampling system to save labor, eliminate equipment blanks, and improve sample quality.
- Pursue an appropriate sampling frequency for wells remaining in the LTM program to limit costs and facilitate trend analysis.
- Pursue an appropriate analyte list for site contaminants, focusing on specific analytes of regulatory significance.
- Take advantage of the service contract in place to provide GIS and electronic data handling support. With this support, use data analysis tools to enhance decision-making.

- Streamline the reporting effort by focusing on graphic and tabular data presentations and consolidating all reports for a year in one binder.

Performance Monitoring— Although an in-depth assessment of system performance monitoring was not made, there are a few recommendations for improving this task. These are to:

- Track contaminant mass removal and cost per pound data to support decisions regarding future shutdown of active remedial systems;
- Conduct bail-down tests so that true product thickness can be determined; and
- Better define the potentiometric surface at the site.

ES.4.2 Benefits

Eliminating over 60% of the wells at the site from the LTM program design will decrease the LTM budget by approximately the same percentage without compromising the quality of the program. Other benefits of the suggestions cited for the fuel farm include the potential for earlier shutdown of active remedial systems, via a natural attenuation alternative, and improved data and report quality.

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APPENDIX B

Statistical Methods

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Throughout all phases of a groundwater monitoring program (including the establishment of DQOs, the preparation for the initial sampling event, and the continual reassessments while the program progresses), data are evaluated to answer the objectives of the investigation. Techniques used to evaluate groundwater monitoring results require groundwater data to accurately characterize site conditions and require data evaluations to justifiably answer project objectives.

To obtain the most accurate evaluations, data must portray site conditions as closely as possible; otherwise, evaluations are not informative (if you put "garbage data" into the analysis, then you get "garbage answers" out of the analysis). One way to minimize decision errors is to ensure that precision, accuracy, representativeness, completeness, and comparability (PARCC) criteria are met with respect to the analytical data.

Statistical methods are recommended in all phases of the program as a means for evaluating data. These methods are recommended because they provide accurate and defensible characterizations of groundwater conditions and can answer objectives of a monitoring program. Chapter 6 presents a number of statistical techniques to use when answering monitoring objectives. Because decision rules are specialized for each monitoring program, this section focuses on the tools useful for answering the most typical objectives of a monitoring program.

B.1 What Type of Data Do I Have Available? Does It Represent Site Conditions?

Before data evaluations can be performed investigators must:

- Identify the type of groundwater data available—is it censored or uncensored; and
- Determine how to best represent site conditions with respect to handling non-detected results (NDs).

For accurate data evaluations that best represent site conditions, uncensored data should be used and proxy concentrations should be estimated. Details about identifying the type of data available and defining proxy concentrations are discussed below.

Identifying the type of groundwater data available. Laboratories can report analytical data in two ways, as censored or uncensored. Censored data are data reported numerically if the concentration is above a censoring limit (typically, the sample-specific quantitation limit, SQL), or reported as "not detected" (ND), or "less than" a censoring limit if the concentration is below the censoring limit. Uncensored data include all instrument responses both above and below the censoring limit. If there is no instrument response (as may occur for low-level organic analytes) the result is reported as ND.

With censored data, no quantitative information is available about a ND result (except that the result is less than the censoring limit) because no estimate is provided to quantify how much smaller the result is from the censoring limit. Although useful for data reporting and presentation, censored data complicate statistical analyses and data interpretation because a qualitative result ("ND") can not be used in calculations. Quantitative results are required; statistical analyses require the use of numbers, not attributes. Therefore, when data are censored, the censored values must either be ignored or proxy values must be assigned for NDs so that numerical values are available for computations (see next subsection about how to estimate proxy values). Assigning proxies requires assumptions about the distribution of NDs (e.g., all NDs are equal or NDs vary in a manner similar to results above the censoring limit). The assumption that all NDs are equal (which allows one to substitute ½ the censoring limit) can bias the estimated standard deviation for the data set, particularly when a substantial number of results are "ND" (see ASTM D-4210-89 for further discussion of this topic). Biasing such summary statistics will bias conclusions to statistical methods, which in turn may lead to incorrectly answering project objectives.

Using uncensored data for statistical computations (not necessarily for data reporting) prevents the need to assign proxy concentrations based on arbitrary algorithms (USEPA, 1992 and Gilbert, 1987). While measurements below the censoring limit may not indicate the presence of target analytes as reliably as measurements above the limit, uncensored measurements are better estimates of concentrations than any proxy concentration and allow for better characterization of site conditions by data users and decision makers. Censored data are still relevant for determining the presence or absence of a contaminant at a site.

Although it is appropriate to flag results that are below censoring limits, statistical literature, federal standards, and EPA guidance all advocate the use of actual uncensored measured concentrations rather than proxy values in statistical calculations. Uncensored data provide more accurate estimates of mean and standard error, thus allowing more accurate data interpretation and more accurate answers to project objectives. Despite these advantages in some cases, requesting uncensored data may increase the laboratory expense and require additional time and effort for data interpretation. Uncensored data are usually not available, or difficult to retrieve, for historical sampling events. Listed below are references associated with the use of uncensored data:

- American Society for Testing and Materials (ASTM) D-44210-89. Gilbert, Richard 0., *Statistical Methods for Environmental Pollution Monitoring*, Van Nostrand Reinhold, New York, 1987.
- USEPA, Office of Research and Development, *Guidance for Data Quality Assessment, Practical Methods for Data Analysis,* EPA QA/G-9, EPA/600/R-96/084, January 1998.
- USEPA, Office of Emergency and Remedial Response, *Guidance for Data Usability and Risk Assessment, Part A Final,* 9285.7-09A, April 1992.

Defining proxy concentrations for NDs. Before statistical analyses and other data evaluations can be performed, proxy values must be defined for all NDs associated with censored data and for all “no response” results associated with uncensored data (see previous subsection about use of uncensored data). A frequently used method for estimating proxy concentrations (assigning ½ the censoring limit) may bias calculations such as the standard error. Alternative statistical methods are available and can provide more accurate estimates of summary statistics.

- A relatively simple method defines proxies as random uniform numbers between 0 and the censoring limit. The benefit of this approach is that the proxy concentrations will closely follow the distribution of measurements that could have been made by the analytical instrument.
- Other methods account for the data’s distribution and assume that all data, above and below the censoring limit, follow the same distribution. Examples of such methods are the “maximum likelihood estimation procedure” and the “probability plotting method.” Approaches that require distributional assumptions are accurate only when such assumptions are appropriate and valid.
- Another alternative method, called Cohen’s adjustment, adjusts estimates of the average and standard deviation for the NDs instead of estimating proxy values for each ND result. A rule of thumb for applying Cohen’s adjustment is that it handles cases with between 15% and 50% NDs. However, some practical difficulties may be encountered that produce elevated estimates of the average and standard error. A statistician should be consulted for additional guidance.

Sometimes no censoring limit is provided with data. An alternative “censoring limit” for uncensored data is to define censoring levels for each chemical as the minimum detected result, or as the smaller of the sample-specific method detection limit (MDL) and the minimum detected result. For censored data sets where only project-specific reporting limits are available, the minimum of the J-flagged result for the given analysis can be used. In each case, proxy values can be assigned using the methods described above. For censored data, however, the distribution of J-flagged values should be examined for unusually low J-flagged results that may set proxies at inappropriately low levels (especially if the minimum J-flagged result is used as a proxy value). Listed below are references associated with the various techniques for defining proxy concentrations:

- Gilbert, Richard 0, *Statistical Methods for Environmental Pollution Monitoring*, Van Nostrand Reinhold, New York, 1987.
- (For a discussion of Cohen's adjustment): USEPA, Office of Research and Development, *Guidance for Data Quality Assessment, Practical Methods for Data Analysis*, EPA QA/G-9, EPA/600/R- 96/084, January 1998.
- Helsel, Dennis R, *Less than Obvious: Statistical treatment of data below the detection limit*, Environ. Sci. Technol., Vol. 24.
- Helsel, Dennis R. and Cohn, Timothy A., *Estimation of Descriptive Statistics for Multiply Censored Water Quality Data*, Water Resources Research, Vol. 24, No. 12, pp.1997-2004, December 1998.
- Rao, S. Trivikram; et al., *Analysis of Toxic Air Contaminant Data Containing Concentrations below the Limit of Detection*, J. Air Waste Manage. Assoc., Vol. 2, pp. 442-448, 1991.

B.2 What Statistical Techniques Should I Use to Achieve Program Objectives?

This section provides a number of statistical methods that can be used to answer typical groundwater monitoring program objectives. This section is set up in terms of potential objectives, and presents the statistical methods most appropriate for answering each objective.

Scenario 1: How can I visualize data in order to evaluate and report results?

There are a number of methods of plotting data, including:

- Box plots of groundwater concentrations;
- Spatial maps of groundwater concentrations; and
- Time or trend plots of concentrations.

These plots can illustrate an enormous amount of information including, but not limited to, what is the range of concentrations, where are extreme concentrations located, how have plumes been identified, what potential trends exist, and how different are upgradient and downgradient concentrations. The plots are simple to create and evaluate and are extremely useful for summarizing information and conclusions associated with evaluating groundwater monitoring data. These plots are discussed in more detail in Chapter 6.

Scenario 2: How can I identify well concentrations that exceed regulatory limits?

Groundwater monitoring programs are generally designed to determine when groundwater concentrations of certain constituents are above regulatory limits (such as risk-based concentrations, state or federal standards, maximum concentration limits, water quality criteria, etc.). There are several methods for comparing concentrations to these levels, depending on the project objectives. If the objective is to simply identify chemicals with detected result(s) that exceed the regulatory limit, it may be enough to compare each detected result to the regulatory limit. This method is simple. With minimal effort, summaries can be produced showing how many detected results exceed the criteria. However, this technique is unforgiving when it comes to infrequent anomalous, high values.

If the objective is to identify chemicals that have some percentile of concentrations (say, at the 90th percentile) that exceed the regulatory limit, then an upper tolerance limit (UTL) is more appropriate. An

UTL estimates the upper bound of a specified percentile of a data set (such as the 90th percentile) with a given level of confidence. An upper tolerance limit calculation is based on the distribution of the groundwater data. If this UTL does not exceed the regulatory limit, then this limit provides a high level of certainty that the specified percentile of the groundwater data does not exceed the regulatory limit.

If the objective is to identify chemicals that have concentrations typically (on average) greater than the regulatory limit, then a one-sample means comparison should be used. A one-sample means comparison determines if concentrations are, on average, greater than regulatory criteria. Appropriate one-sample means comparisons are statistical tests such as the one-sample t-test and the signed-rank test. The type of one-sample means comparison performed depends on the distribution of the groundwater data. If the result of a one-sample means comparison is that the average concentration does not exceed the regulatory limit, then the comparison provides a level of certainty, given a desired level of confidence, that the average does not exceed the regulatory limit.

Listed below is a general reference text that contains details for calculating UTLs and for performing one sample means comparison tests:

- Mason, Robert L., et al., *Statistical Design & Analysis of Experiments, with Applications to Engineering and Science*, John Wiley and Sons, New York, 1989.

Scenario 3: How can I identify outliers or extreme concentrations?

Statistical methods that identify outliers are useful for classifying extreme concentrations— results that are extremely small or large compared to the rest of the data. Statistical outliers can be identified using a box plot or an outlier test. Box plots are graphical tools for displaying extreme concentrations as well as the central tendency and variability of the data. Using a box plot, investigators can identify more than one result as an outlier; and, outliers can be present at both ends of the concentration range. Figure 6-2 provides an example of a box plot and its outliers. An outlier test is provided by EPA*(Statistical Analysis of Ground-water Monitoring Data at RCRA Facilities*, April 1989, and *Statistical Analysis of Groundwater Monitoring Data at RCRA Facilities: Addendum to Interim Final Guidance*, June 1992). Unlike box plots, this test is limited to identifying one point as an outlier. This outlier test can identify an outlier under one of two scenarios— the maximum concentration is an outlier, or the minimum concentration is an outlier.

Once outliers are identified, the project team should review outliers and determine why such unusual concentrations have been detected. Statistical outliers should not be removed from any data evaluations unless a specific reason for the abnormal measurements can be determined. For example, valid reasons for removing statistical outliers include evidence that they are the result of contaminated sampling equipment, laboratory errors or transcription errors. If a plausible reason can not be found for removing a statistical outlier, the result should be treated as a true, but extreme value. Although the value should not be excluded from further data evaluations, the additional evaluations should account for these extreme values so that they do not unduly influence statistics such as the mean.

Listed below are references associated with identifying outliers:

- Devore, Jay L, *Probability and Statistics for Engineering and the Sciences*, Brooks/Cole Publishing Company, 1987.
- USEPA, Office of Solid Waste Management Division, *Statistical Analysis of Ground-Water Monitoring Data at RCRA Facilities*, PB89-151047, EPA/530-SW-89-026, April 1989.

- USEPA, Office of Solid Waste Management Division, *Statistical Analysis of Ground-Water Monitoring Data at RCRA Facilities: Addendum to Interim Final Guidance*, EPA 86-W0-0025, June 1992.

Scenario 4: How can I identify differences in concentrations between downgradient and upgradient wells, or differences in concentrations between current and baseline data?

Generally, when two sets of data are compared, several statistical comparisons can be performed—two sample means comparisons, individual comparisons, and quantile tests. Depending on how the DQOs are stated, either all, some, or just one of these comparisons should be performed.

If the objective of the program is to identify any chemical with an average downgradient concentration that exceeds the average upgradient concentration, then a two-sample means comparison is appropriate. Two-sample means comparisons determine if downgradient concentrations are, on average, greater than upgradient concentrations. They are performed using tests such as the two-sample t-test and wilcoxon rank-sum test, depending on the downgradient and upgradient data distributions. Analytes that show downgradient concentrations do exceed, on average, upgradient concentrations, or analytes that have low power for this comparison should continue to be monitored. Only those chemicals that have high power associated with the comparisons and that show average downgradient concentrations do not exceed average upgradient concentrations should be considered for removal from the analyte list.

If the objective of the program is to identify cases when *any* downgradient concentrations differs from concentrations seen in upgradient wells, then an individual comparison or a quantile test is more appropriate. Individual comparisons determine if individual downgradient results indicate the presence of a "hot spot" relative to upgradient concentrations, and are performed by comparing every downgradient result to an upper tolerance limit (UTL) calculated from upgradient data. An UTL estimates the upper bound of a specified percentile of the data set (such as the 95th percentile), with a given level of confidence, and is based on the distribution of the groundwater data. This individual comparison is preferable to the quantile test when an investigator wishes to identify concentrations from specific well locations exceeding upgradient concentrations. A quantile test provides a way to identify if proportions of downgradient concentrations have shifted above upgradient concentrations. This test can detect shifts in own gradient concentrations that may not be extreme enough to cause the two-sample means comparison to show a statistically significant difference between downgradient and upgradient concentrations. The quantile test compares the upper percentiles of downgradient concentrations to the upper percentiles of upgradient concentrations, to test whether specified proportions of the downgradient concentrations are significantly larger than the upgradient concentrations.

Each of these comparisons is useful and provides different information about the data. Two-sample means comparisons provide an overall picture of the differences between downgradient and upgradient data ranges. Individual comparisons provide information about "hot spots" for specific well locations and chemicals. Quantile tests view downgradient results as a whole, rather than as individual results. Only the means comparisons and individual comparisons, though, provide a systematic way of quantifying decision uncertainty.

If baseline data are available, then similar comparisons can be performed between current groundwater concentrations and baseline concentrations. These comparisons to baseline should be used to understand how groundwater concentrations have changed since the last time baseline concentrations were taken.

Listed below are references for the two-sample means comparison, the UTL, and the quantile test:

- Mason, Robert L; et al., *Statistical Design & Analysis of Experiments, with Applications to Engineering and Science*, John Wiley and Sons, New York, 1989.
- USEPA, Office of Research and Development, *Guidance for Data Quality Assessment, Practical Methods for Data Analysis*, EPA QA/G-9, EPA/600/R-96/084, January 1998.
- NUREG-1505, Nuclear Regulatory Commission (NRC), 1997a, *A Nonparametric Statistical Methodology for the Design and Analysis of Final Status Decommissioning Surveys*, Washington D.C.: Nuclear Regulatory Commission, 1997.

Scenario 5: How can I identify differences in chemical concentrations among wells or identify differences in concentrations among multiple chemicals?

When more than two sets of data are compared, the appropriate statistical method to use is an Analysis of Variance (ANOVA) in conjunction with multiple comparison tests or contrast tests. An ANOVA is similar to a two-sample means comparison (as described in Scenario 4) except that averages for several different groups can be evaluated simultaneously. The concept behind an ANOVA is to list all possible contributors to variability (e.g., well to well differences, gradient to gradient differences, chemical to chemical differences) and then test which sources contribute most to the overall variability in the concentrations. If a given source of variability contributes more than could be expected due to chance alone, it is concluded to be statistically significant. For example, if the variability in concentrations from one well to the next is large relative to the overall variability, then the well-to-well differences are said to be statistically significant. The specific type of ANOVA performed depends on the most appropriate statistical distribution assumption and on the different sources of variability that are included in the ANOVA. If results from an ANOVA show that significant differences exist (such as significant well-towell differences), then a multiple comparison test can be performed to identify which wells, on average, differ and which wells, on average, are similar. There are a number of multiple comparison tests. Some of the more frequently used tests are the Duncan's multiple range test, Tukey's significant-difference test (SDT), and Fisher's least significant-difference test (LSD). Contrast tests are similar to multiple comparison tests, but they can be developed to compare a combination of results to another combination of results. Contrasts are particularly useful when investigators want to identify if concentrations from one downgradient well exceeds concentrations associated with all, combined, upgradient wells.

An ANOVA may be useful in instances where it is suspected that concentrations or trends in concentration of one or more contaminants are related in some way, for example as in the degradation of TCE and the production of daughter products such as cis-1,2 dichloroethene. Statistical verification of such trends can have important implications for remedial design and operation as well as regulatory approvals.

Listed below are references for the ANOVA, multiple comparisons tests, and contrasts:

- Mason, Robert L.; et al., *Statistical Design & Analysis of Experiments, with Applications to Engineering and Science*, John Wiley and Sons, New York, 1989.
- Snedecor, and Cochran, *Statistical Methods,* Iowa State University Press, Ames, IA, 1989.

Scenario 6: How can I test for a trend?

Recommended statistical approaches for assessing trends are the Mann-Kendall test and regression analyses, combined with visual inspections of graphical plots. Typically, spatial and temporal trend analyses start by visually inspecting plots of the results for a well or group of wells over time or as a function of distance from the source. Statistical tests such as the Mann-Kendall test or regression analysis can then be used to verify the significance of any observable trends.

The Mann-Kendall test can be interpreted as a test for an increasing or decreasing trend of concentrations as a function of time. This test is useful because it does not require that data be collected at equally spaced time intervals. This test has few statistical assumptions (such as an assumption of normality), is robust against one or two anomalous data values, can easily accommodate non-detected results, and is easy to interpret. However, one of its strengths is also a potential weakness. That is, the actual concentrations themselves are not taken into account. For this reason, the Mann-Kendall trend test is always accompanied by graphical presentations of the data. Also, this test for trend is typically not performed on a small number of concentrations; a rule of thumb is to perform trend analyses at least 4 samples.

Modifications to the Mann-Kendall test can be made to accommodate multiple measurements per well per sampling event or to correct for seasonal effects. The nonparametric approach suggested by Mann and Kendall (Mann, 1945; Kendall, 1938) can be used to test for a temporal trend at individual monitoring points. Although the Mann-Kendall test can detect the presence of a trend, it gives no estimate of its magnitude. Sen (1968) has developed a nonparametric method for estimating a trend that is used here in conjunction with the Mann-Kendall result. These modifications to the Mann-Kendall test would be appropriate if pronounced seasonal variation were noted in monitoring data or if duplicate samples were to be included in the analysis. One drawback to correct for seasonal effects is that a longer time series of data is needed before statistical analysis can be usefully implemented.

Regression analyses can also identify trends. Such an approach involves constructing a model to predict concentration as a function of time. Linear regression analysis can be as simple as estimating the slope and coefficient of determination from a linear trendline, or application of a more complex method such as that proposed by Buscheck and Alcantar (1995). If the model provides a good fit to the data and there is a predicted increase (or decrease) in concentration as a function of time, then the trend can be said to be significant. Regression analysis can be biased by outliers, such as anomalously high results. Also, purely linear models may not accurately represent trends in contaminant concentrations, which are often log-normally distributed. While these limitations can be addressed, an additional level of effort is required to assess the statistical properties of the data and properly format all results for the analysis.

The results for the linear regression method include the regression coefficient (an estimate of the change in concentration per year) and a p value; results for the Mann-Kendall method include the Mann-Kendall statistic and a p value; and results for the Sen test include the Sen nonparametric estimate of trend. The sign of the regression coefficient, Mann Kendall statistic, and the Sen estimate of trend indicate whether the trend is increasing (positive) or decreasing (negative). For the linear regression method and the Mann-Kendall test, a trend is considered significant at a 95% confidence if the associated p-value is <0.05. The Sen test does not provide an indication of the statistical significance of a trend; instead, it provides an estimate of the direction of the trend (i.e., increasing or decreasing) and the magnitude of the trend. Therefore, the significance of the trend is determined based on the results (i.e., p value) of the linear regression method and the Mann-Kendall Test; whereas, the magnitude of the trend is indicated by the linear regression method and the Sen test. Other results from these analyses can include the percentage decrease, as calculated from the linear regression method and the Sen estimate of trend. Also, because nonparametric procedures typically have less power than parametric methods, the Mann-Kendall method (nonparametric) reveals fewer significant trends.

There are also many other statistical methods that can be used for identifying trends at monitoring points and identifying uncertainty, including the iteratively reweighted least squares (IRLS) robust regression method used in combination with nonparametric Bootstrap method, as described in Ling et al (2003). It should be noted that typically, a minimum of four time-series data points are required to perform a trend analysis, and that confidence in trend analysis results increases with the number of data points.

Trend analyses also can be performed using data for several monitoring point groupings in order to attempt to better elucidate trends for specific areas of a site. In analyzing trends for selected areas of the site (i.e., using data from multiple points), the parametric approach proposed by Naber et al. (1997) can be used. This method fits a common slope over the region of interest while allowing for different initial values for each point within the region.

The Mann-Kendall test should be applied as the first step in assessing trends. Regression analysis may be appropriate for assigning numerical values to trends identified as significant, as in calculating natural attenuation rates, contaminant mass removal, or rates of plume advance or retreat.

Listed below are references for the Mann-Kendall trend test and regression analysis:

- Gilbert, Richard 0., *Statistical Methods for Environmental Pollution Monitoring*, Van Nostrand Reinhold, New York, 1987.
- USEPA, Office of Research and Development, *Guidance for Data Quality Assessment, Practical Methods for Data Analysis*, EPA QA/G-9, EPA/600/R-96/084, January 1998.
- Mason, Robert L.; et al., *Statistical Design & Analysis of Experiments, with Applications to Engineering and Science*, John Wiley and Sons, New York, 1989.
- Buscheck, T.E., and Alcantar, C.M. 1995. "Regression Techniques and Analytical Solutions to Demonstrate Intrinsic Bioremediation." In *Proceedings of the 1995 Battelle International Conference on In Situ and On-Site Bioreclamation*.
- Kendall, M.G. 1938. "A New Measure of Rank Correlation," *Biometrika* **30**: 81-93.
- Ling, M., H.S. Rifai, C. J. Newell, J. J. Aziz, and J. R. Gonzales. 2003. "Groundwater monitoring plans at small-scale sites – an innovative spatial and temporal methodology". In *Journal of Environmental Monitoring*, Volume 5, pp. 126-134.
- Mann, H.B. 1945. "Nonparametric Tests Against Trend," *Econometrica* **13**: 245-259.
- Naber, S.J., Buxton, B., McMillan-Darby, N., and Soares, A. 1997. "Statistical Methods for Assessing the Effectiveness of Intrinsic Remediation." In *Proceedings of the Fourth International In Situ and On-Site Bioremediation Symposium: Volume 5*. B.C. Alleman and A. Leeson (eds.). pp. 349-354. Battelle Press, Columbus, Ohio.

Scenario 7: How can I evaluate data spatially and what can I gain from such an analysis?

Spatial statistical methods, or geostatistics, can be applied to groundwater monitoring data to help in:

- Defining plume(s); and
- Providing a basis for not continuing to monitor a well and/or a chemical.

Two related statistical tools are useful in spatial evaluations: semivariograms and kriging. Semivariograms are plots that provide information about the spatial correlation across a region. That spatial information is used by kriging to estimate concentrations at unsampled locations. Kriging maps can be evaluated to obtain a better understanding of the spatial pattern of contamination across a region that may not be apparent just by mapping individual concentrations.

Defining plume(s). Semivariograms can help define plume(s) by quantifying relationships between samples taken at different well locations. Strong spatial patterns that can be interpreted based on site knowledge may suggest groundwater regions should be considered as separate statistical populations. Separating wells into various regions or plumes can decrease the variability of concentrations and can allow for more accurate statistical tests and decision-making. This also provides valuable information for effective remedial design by distinguishing areas that require remediation from those that do not.

Providing a basis for not continuing to monitor a well and/or a chemical. Kriging maps can be used to delineate areas of contamination and to develop decisions about further sampling. These kriging maps can provide a powerful visual argument that the current delineation is either adequate or not; this can be useful in discussions with regulators. Uncertainty maps (maps of uncertainties associated with kriging predictions) can indicate whether additional sampling is useful. Also, if estimated chemical concentrations are substantially lower than comparison values (regulatory limits, upgradient UTLs, etc.), even after accounting for uncertainty, then it may not be necessary to collect additional samples even when sampling is sparse across that area or well.

Listed below are references for these spatial analyses:

- Clark, I., *Practical Geostatistics,* Applied Science Publishers, London, 1979.
- Gilbert, Richard O. and Simpson, J. C., *Kriging from Estimating Spatial Pattern of Contaminants: Potential and Problems,* Environmental Monitoring Assessment, Vol. 5, pp.113-115, 1985.
- Journel, A. G., and Huijbregts, C. H. J., *Mining Geostatistics,* Academic Press, New York, 1978.

Scenario 8: How can I obtain the power achieved by a statistical method?

Power can be estimated only when statistical methods are performed. Before discussing power much further, the fundamentals of statistical tests are presented. This provides a basis for the explanation of power. A statistical test requires a null hypothesis and alternative hypothesis. Generally, a null hypothesis is a hypothesis of no change and an alternative hypothesis is a hypothesis of change (Mason, Gunst, and Hess, 1987). There are two possible ways to have an incorrect answer:

- Rejecting the null hypothesis when the null hypothesis is true (i.e., stating that there is a change, when no change has truly occurred). This type of error is called a Type I error.
- Accepting the null hypothesis when the null hypothesis is not true (i.e., stating that there is no change, when a change has truly occurred). This type of error is called a Type II error.

Statistical tests can not control these two types of errors. So, a test is set up in a manner that Type I errors are considered the more serious error and are controlled by the test. Statistical tests limit the frequency of Type I errors by setting a level of confidence, such as a 95% level of confidence. This level of confidence means that we want to be 95% certain that we correctly accepting the null hypothesis when the null hypothesis is true. Statistical tests are set up so a Type II error is not as serious an error, so Type II errors are not controlled. However, after a test is performed, an estimate can be computed to represent the frequency of Type II errors by calculating the power of a test. The power of a test describes the certainty associated with correctly rejecting the null hypothesis when the null hypothesis is not true. The table below illustrates the types of errors and correct decisions associated with statistical tests:

Conclusions associated with Statistical Tests

		True Hypothesis (what has truly occurred)	
		Null Hypothesis True	**Alternative Hypothesis True**
Test Decision	**Do Not Reject Null Hypothesis**	Correct Decision (level of confidence)	Type II error
	Reject Null Hypothesis	Type I error	Correct Decision (power)

Power of a test is calculated by estimating the probability of rejecting the null hypothesis when the null hypothesis is not true. The method for calculating power is specialized for each statistical test. For further information about estimating power, refer to the general reference text listed below:

- Mason, Robert L.; et al., *Statistical Design & Analysis of Experiments, with Applications to Engineering and Science*, John Wiley and Sons, New York, 1989.

The importance of estimating power is its relationship with sample size. As the number of samples increase, the power of a statistical test increases (assuming other factors remain constant). In fact, power formulas can be used to identify the number of samples necessary to achieve a specified amount of power for a given statistical test. For all phases of groundwater monitoring, we highly recommend determining the number of samples needed to achieve a certain level of power. This will ensure that data evaluations provide the most informative and accurate results as possible.