Final

Long-Term Monitoring Optimization Guide

Version 1.2

HQ Air Force Center for Environmental Excellence
Environmental Restoration Division (AFCEE/TDE)
3300 Sidney Brooks
Brooks City-Base, TX 78235-5112

NOTICE

This final document reflects the current understanding of issues related to optimizing long-term monitoring programs. It is anticipated that the document may need to be periodically updated.

In no event shall the United States Government have any responsibility or liability for any consequences of any use, misuse, inability to use, or reliance upon the information contained herein, nor does either warrant or otherwise represent in any way the accuracy, adequacy, efficacy, or applicability of the contents hereof.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

APPENDICES

LIST OF ACRONYMS

AFBCA	Air Force Base Conversion Agency
AFCEE	Air Force Center for Environmental Excellence
ARAR	applicable or relevant and appropriate requirement
ASTM	American Society for Testing and Materials
BCP	BRAC Closure Plan
BCT	Base Realignment and Closure Cleanup Team
BRAC	Base Realignment and Closure
BTEX	benzene, toluene, ethylbenzene, and xylenes
CA	cost analysis
CAD	corrective action decision
CERCLA	Comprehensive Environmental Response, Compensation and Liability Act
CES	cost-effective sampling
CMI	corrective measures implementation
COC	chemical of concern
CSM	conceptual site model
DD	decision document
DoD	Department of Defense
DP	decision point
DQO	data quality objective
EE/CA	engineering evaluation/cost analysis
EPA	U.S. Environmental Protection Agency
ERC	Environmental Restoration Division, Consultant Operations Directorate
ERPIMS	Environmental Resources Program Information Management System
FFA	Federal Facility Agreement
GC	gas chromatography
GTS	Geostatistical Temporal/Spatial optimization algorithm
IRP	Installation Restoration Program
LLNL	Lawrence Livermore National Laboratory
LTM	long-term monitoring
LTMOR	Long-Term Monitoring Optimization Report
LTMOT	Long-Term Monitoring Optimization Team
LTMWP	Long-Term Monitoring Work Plan
MAP	Management Action Plan
MAROS	Monitoring and Remediation Optimization System

MCL	maximum contaminant level
MDL	method detection limit
MS	mass spectrometry
MW	monitoring well
NFRAP	no further response action planned
PAHs	polynuclear aromatic hydrocarbons
PA/SI	preliminary assessment/site inspection
PCBs	polychlorinated biphenyls
PW	production well
QA	quality assurance
QC	quality control
RA	remedial action
RAB	Restoration Advisory Board
RACER	Remedial Actions Cost Engineering and Requirements
RCRA	Resource Conservation and Recovery Act
RD	remedial design
RFA	RCRA facility assessment
RFI/CMS	RCRA facility investigation/corrective measures study
RI/FS	remedial investigation/feasibility study
ROD	record of decision
RPO	remedial process optimization
SDT	Standard Sampling Frequency Decision Tree
SFDT	sampling frequency decision tree
TCE	trichloroethene
UST	underground storage tank
VOC	volatile organic compound

PREFACE

This guide was prepared for the Air Force Center for Environmental Excellence (AFCEE) - Consultant Operations Division (ERC) in 1997. The development of this guide was funded by the Air Force Base Conversion Agency (AFBCA). The purpose of this guide is to assist Department of Defense (DoD) installation managers in the optimization of their long-term monitoring (LTM) programs by identifying and applying the appropriate strategies and optimization tools. These strategies and tools should assure compliance with data quality objectives (DQOs) and quality assurance (QA) requirements to improve overall effectiveness while minimizing cost.

The guide has been updated and revised by AFCEE/TDE in 2006. This update has been prompted primarily by the development of two LTM optimization tools-- Monitoring and Remediation Optimization System (MAROS) and Geostatistical Temporal/Spatial (GTS) optimization algorithm software packages. These computer-based programs are available at no cost and can be downloaded from the AFCEE website.

NO INFORMATION WRITTEN ON THIS PAGE.

PART 1. BACKGROUND INFORMATION

NO INFORMATION WRITTEN ON THIS PAGE.

1. INTRODUCTION

1.1 LTM BACKGROUND

Many Air Force Installation Restoration Program (IRP) projects require compliance monitoring of their active remedial systems and postclosure sites where ground-water contamination is still present. This type of monitoring, known as long-term monitoring (LTM), is dictated by the Resource Conservation and Recovery Act (RCRA); Comprehensive Environmental Response, Compensation and Liability Act (CERCLA); and Underground Storage Tank (UST) programs and is a costly necessity at most military installations. Consequently, improving the efficiency of these programs has the potential for substantial cost savings.

LTM programs are intended to track the occurrence of contaminant migration in various media including surface water, ground water, soil, and sediment, and they are an essential part of Remedial Design/Remedial Action (RD/RA). The programs are established to verify Remedial Investigation/Feasibility Study (RI/FS) conclusions once the final RA is in place as approved in a decision document (DD) such as a Record of Decision (ROD). These LTM programs, which can be viewed as an overall quality assurance (QA) of the cleanup process, are designed to meet one or more of the following goals:

1. To examine the accuracy of an RI/FS, ensuring that predictions are as expected.
2. To provide early warning that an additional RA may soon be necessary.
3. To audit contaminant concentration levels at a compliance location.
4. To audit the RA; i.e., evaluate the efficiency/effectiveness of the overall RA.
5. To improve remediation methodologies and the quality of subsequent RAs.

Figure 1 shows the position of LTM in the remediation process of CERCLA/*RCRA* sites.

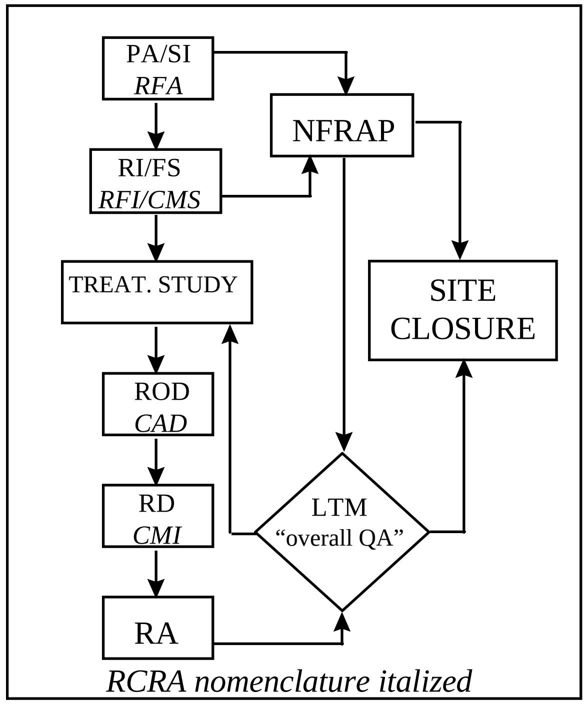

Figure 1. Flow Diagram of LTM in the Remediation Process of CERCLA/RCRA sites.

Optimizing an existing or planned LTM program involves reducing the cost of the program while maintaining or increasing the quality and effectiveness.

The procedures presented in this guide address the LTM optimization of ground water. This process focuses on collecting relevant data and optimizing the LTM process in order to efficiently achieve the closure endpoint or termination of the program. The closure endpoint is reached when the regulatory requirements are met and the LTM operations are completed. At some installations, the monitoring program has been “prematurely” committed or promulgated to LTM for several hundred analytes at hundreds of monitoring wells, regardless of the nature and extent of the contamination and the endpoint of the monitoring program. These programs require extensive data collection and analyses, some of which are often irrelevant to the objectives of the monitoring program. The costs for excessive data collection are compounded by the costs of processing, management, review, and preparation of the periodic LTM report. The objective of this guide is to help streamline and optimize existing or planned LTM processes while maintaining or increasing the program’s effectiveness.

1.2 PERIODIC REVIEW

To ensure optimum efficiency of an existing optimized LTM program, the optimization process should be reviewed and updated periodically using the LTM optimization guidance principles. At a minimum, during each review the following items should be reexamined:

- Existing LTM-related information and data quality objectives (DQOs).
- Recent sampling results.
- Reapplication of the optimization strategies.
- LTM/RA closure date, and/or phased closure projection.

The periodic ground-water monitoring reports (e.g. quarterly, semiannual, annual and/or multi-annual) submitted to the regulatory agencies should summarize and evaluate the status of the current ground-water monitoring system. For example, chemical of concern (COC) trends should be identified and depicted graphically. Tests for trend are available and can be used to determine if these trends are statistically significant. For key chemical constituents, tests for trend should be performed. In addition, these reports should document the results of the iterative optimization review process. Any changes (e.g., sampling frequency decision tree [SFDT], DQOs) that result from the optimization review process should also be presented.

NO INFORMATION WRITTEN ON THIS PAGE.

2. THE LTM OPTIMIZATION GUIDE

2.1 PURPOSE

The purpose of this guide is to provide instruction to project managers for the optimization of their LTM programs through the identification and application of appropriate strategies and optimization tools. These strategies and tools assure compliance with DQOs and QA requirements and improve overall effectiveness while minimizing cost.

This guide provides an approach for evaluating the major parameters that determine LTM costs and for reducing those costs without adversely affecting the quality of the program. Although this guide directly addresses existing LTM programs, the same principles can be applied to programs in the design phase. Consequently, implementing the LTM strategies presented in this guide can also produce significant cost savings in the RD phase. If a site is considering ground-water monitoring as part of a ROD, it is important to consult the LTM guide prior to the signing of the document to ensure the LTM program can be optimized in the future. Specifics of the optimization process should not be included in the ROD; however, supporting documents and this optimization guide may be referenced.

Every LTM program is unique in terms of schedule, regulatory requirements, political considerations, nature and levels of contamination, complexity of the hydrogeological settings, and other site-specific considerations. The approaches described in this guide are specific but are intended to be flexible to accommodate the complex nature of LTM programs. Each program should be carefully evaluated, and the optimization process must be tailored to the base's specific considerations and needs.

If the LTM evaluation team discovers during the optimization process that the LTM program is inadequately designed and inefficient in meeting program objectives, modifications may be required. Such modifications may have significant immediate costs, but they may avoid the potentially greater costs of collecting and processing irrelevant data.

The LTM optimization process described in this guide may provide the following benefits:

- A reduction in the scope and cost of an existing program while maintaining quality and effectiveness.
- LTM program closure projection.
- A validated program according to the optimized procedures.
- Guidance for optimizing a program that is in the planning stage.
- Standardized reporting procedures.

2.2 USING THIS GUIDE

The success of optimizing a long-term ground-water monitoring program depends on a common understanding and agreement among the decision makers on the objectives of the LTM program. These objectives may change over time and therefore require periodic review and updating.

An LTM optimization team (LTMOT) should be formed to provide input during the optimization process. Table 1 lists the members of an LTMOT. The core team includes technical experts such as hydrologists, chemists, engineers, and risk assessors and programmatic decision makers such as members or representatives of the Air Force cleanup team (including federal, state, tribal, local regulators), Base

Realignment and Closure (BRAC) Cleanup Team (BCT), Local Reuse Authority, Restoration Advisory Board (RAB) members, and citizenry groups. Additional experts (e.g., statisticians, public involvement specialists) may be required for site-specific needs. This guide encourages involving regulators and the community because they have significant roles and interest in ensuring that quality and effectiveness are maintained during optimization.

Table 1. LTM Optimization Team Members

	LTM Optimization Team Members
1.	Technical Experts (Air Force and Contractors)
2.	Air Force Program Managers
3.	Regulators
4.	Programmatic Decision Makers
5.	Citizenry Groups

Because the amount of information and conditions vary from site to site, a prescriptive guide to optimizing LTM programs would be difficult. This guide recommends generic approaches and criteria to guide the optimization process, but local circumstances will require site-specific selection and adaptation.

The IRP contractor should prepare and present an LTM Work Plan (LTMWP) to the LTMOT for approval. An LTMWP is necessary to describe the manner in which the program will be optimized and the tasks necessary to perform the optimization. An outline of the LTMWP is included in Part 1, section 3.1. To optimize LTM programs, sections 3 and 4 of the LTMWP outline should be included. If there is an existing LTMWP for the site or base, it should be modified to include the above-referenced sections.

The IRP contractor should also prepare and present an LTM Optimization Report (LTMOR) to the LTMOT for their review and approval. An LTMOR is a report that documents the optimization process and results. A suggested outline of the LTMOR is included in Part 1, section 3.2, of this guide. Part 2 of this guide describes in more detail the steps required and issues to consider when performing the LTM optimization and writing the LTMOR.

Following is a summary of the sections presented in part 2 of this guide.

COLLECTING DATA AND SCOPING THE LTM OPTIMIZATION STUDY: Describes a method for collecting and organizing information that will provide an overview of the site and set the boundaries and objectives for the optimization process.

DOCUMENTATION OF LTM PROGRAM: Describes a method for documenting the basis and details of the LTM program. The details included in this section are taken from the information gathered during the data-collection effort. Relevant information obtained during this process will be used to write the Executive Summary and Introduction sections of the LTMOR.

OPTIMIZATION PROCEDURES AND RESULTS: Describes the following four strategies and related considerations for optimizing LTM programs for cost-effectiveness while protecting program quality and presents guidelines for documenting the findings in the LTMOR:

1. Establish decision rules for wells and sampling frequency.
2. Refine field procedures.
3. Refine analytical protocols.

4. Streamline data management.

EVALUATION OF COST SAVINGS: Describes how to estimate and to document the potential cost savings of the optimized LTM program over the existing LTM program.

CONCLUSIONS AND RECOMMENDATIONS: Describes how to document the proposed recommendations for applying cost-saving optimization strategies based on the results of the preceding sections.

2.3 PILOT STUDY

The first draft of this guide, prepared in October 1996, was used to conduct an LTM optimization pilot study in Sacramento, California, in January 1997. The objectives of the pilot study were as follows:

- Test and validate the guidance and tools from the draft guidance document.
- Evaluate the LTM program.
- Incorporate lessons learned from the pilot study into this revised guidance document.

The pilot study generated several recommendations for the LTM program: (1) reduce the number of wells sampled; (2) reduce sampling frequency; and (3) simplify analytical protocols. Prior to this pilot study, the site had an advanced, progressive monitoring program that incorporated conscientious field practices, a continuously updated sampling decision tree, and the validated use of low-flow purging. However, by applying cost-reduction strategies to the process, the pilot study recommended eliminating sampling at nine monitoring wells and reducing the sampling frequency at 81 others. Annual costs of the recommended program were estimated at $147,000 less than the 1996 program estimated cost, a savings of more than 21% (Waste Policy Institute 1997).

2.4 USING INNOVATIVE TECHNOLOGIES

In recent years, innovative monitoring and sampling technologies have emerged to provide cost-effective, accurate, and timely results. Examples of these technologies include real-time field monitoring measurements using fiber-optic instruments and sensors with on-line analyzers. Advantages include eliminating waste generated during sampling, real-time sampling, and remote control operations. The application of some of these technologies is in the testing stage by industry and government research organizations. Therefore, the use of these technologies will depend on their ability to meet established QA requirements and regulatory approval. Whenever possible, cost-effective innovative technologies should be incorporated into LTM programs.

NO INFORMATION WRITTEN ON THIS PAGE.

3. LTM DOCUMENT FORMAT

3.1 OPTIMIZED LTM WORK PLAN OUTLINE

The purpose of the LTMWP is to describe the manner in which site-specific procedures will be optimized and implemented. The tasks needed to complete the optimization and subsequent report should be documented in the LTMWP. This information can be used for project scheduling and budget estimation purposes.

All LTMWPs prepared by contractors shall address the information contained in the following suggested format, and all applicable components of the outline shall be addressed.

REPORT COVER
TITLE PAGE
NOTICE
REPORT DOCUMENTATION PAGE (SF298)
PREFACE (optional)
TABLE OF CONTENTS
LIST OF FIGURES
LIST OF TABLES

1. **INTRODUCTION**
2. **SUMMARY OF EXISTING INFORMATION**
3. **LTMWP RATIONALE**
    - **DQOs**
    - **Optimization Strategy**
4. **LTM OPTIMIZATION TASKS**
5. **REPORTING REQUIREMENTS**
6. **PROGRAM SCHEDULE AND COST**
7. **PROGRAM MANAGEMENT**
    - **Organization**
    - **Responsibility**
    - **Schedule**
8. **REFERENCES**
9. **APPENDICES**

3.2 LTM OPTIMIZATION REPORT OUTLINE

The major purposes of the LTMOR follow:

- Document the status of the monitoring program and the COCs at the site.
- Present recommendations to optimize and conduct a subsequent refinement of the LTM program.
- Present a discussion on the manner in which the optimization of site specific procedures will be implemented.

The optimization and required corrective action information can be used for out-year project scheduling and budget estimation purposes.

Below is a suggested outline for all LTMORs prepared by contractors. All components of the outline shall be addressed, but specific information presented for each component will be dependant upon the LTM program being evaluated. Part 2 of this guide describes in detail issues to be considered when performing the evaluation and preparing the LTMOR.

REPORT COVER
TITLE PAGE
NOTICE
REPORT DOCUMENTATION PAGE (SF298)
PREFACE (optional)
TABLE OF CONTENTS
LIST OF FIGURES
LIST OF TABLES
LIST OF ACRONYMS
EXECUTIVE SUMMARY

1. **INTRODUCTION**
2. **DOCUMENTATION OF EXISTING LTM PROGRAM AND BASELINE MONITORING COSTS**
3. **OPTIMIZATION PROCEDURES AND RESULTS**
4. **EVALUATION OF COST SAVINGS**
5. **CONCLUSIONS AND RECOMMENDATIONS**
6. **REFERENCES**
7. **APPENDICES**

NO INFORMATION WRITTEN ON THIS PAGE

PART 2. PERFORMING THE OPTIMIZATION AND WRITING THE REPORT

NO INFORMATION WRITTEN ON THIS PAGE.

1. COLLECTING DATA AND SCOPING THE LTM OPTIMIZATION STUDY

1.1 COLLECTING DATA

Collect relevant documents and information prior to beginning the optimization process.

Sites that have already developed DQOs will find that this step is substantially complete, and the relevant information can be extracted and directly transferred to the appropriate sections in the report fairly easily. The following guidance for data gathering is based on *Data Quality Objectives Process for Superfund* (Environmental Protection Agency [EPA] 1993a), *Using the Data Quality Objectives Process in Risk Assessment* (U.S. Department of Energy 1994), and *Data Quality Objectives Process for Superfund, Interim Final Guidance* (EPA 1993b).

The following documents and information will be necessary and should be acquired if possible:

- Basewide well location maps (monitoring and water-supply wells)
- Sampling procedures for basewide ground-water monitoring and sampling
- Analytical protocols for basewide ground-water monitoring
- Analytical data (including most recent sampling events)
- Maps showing plumes, COCs, contaminant concentration and mass, and ground-water flow direction
- The most recent ground-water monitoring reports
- Monitoring reduction decision tree in print and electronic formats (see Part 2, section 3.1, and Appendix A)
- Well inventory in electronic format (spreadsheet or data management system)
- Ground-water modeling report(s)
- Applicable RODs
- Data management system specification documentation
- Conceptual site models (CSMs)
- Relevant sections of the RI/FS
    - Receptor/pathway information
    - Health and ecological risk information
- RD/RA documentation
- Engineering evaluation/cost analysis (EE/CA) documentation
- Management Action Plans (MAPs)
- BRAC Closure Plans (BCPs)
- Land-use plans
- Applicable RPO reports

Upon collection, the documents and information listed above may be categorized—as general information, ground-water contamination, regulatory authorities and stakeholders, LTM requirements, and existing LTM program—for incorporation into the LTMOR.

1.2 SCOPING THE LTM OPTIMIZATION STUDY

Scoping of an LTM optimization study entails preparation of the site overview and of the study objectives. This information should be included in the introduction of the LTMOR. Some scoping information may need to be drawn from the data-gathering process.

NO INFORMATION WRITTEN ON THIS PAGE.

2. DOCUMENTATION OF EXISTING LTM PROGRAM

Provide general information to document the quality and effectiveness of the existing program and political considerations.

General information helps describe the existing LTM program and provides information to evaluate its quality and effectiveness. This section should include inputs from stakeholders and decision makers and information from RODs, current land use, future land-use plans, and legal requirements. The regulatory basis and details of the existing LTM program should be documented.

General information also includes study boundaries; that is, information about the geographic, hydrogeologic, and geopolitical boundaries of the existing program. Study boundaries include plume margins, contaminants comprising the plume, well fields, sites, base boundaries, and municipality limits. For example, if the plume is located in two municipalities, additional considerations (i.e., multiple regulatory agency involvement, legal requirements) may be required for the existing LTM program.

2.1 SITE OVERVIEW

Describe the site by providing relevant information.

The site overview describes the site location and can be illustrated by one or more maps. An explanation of how the program is organized, such as describing operable units, is relevant. The geology and hydrology of the site should be characterized. Finally, the site's history and current status should be summarized.

2.2 REGULATORY AUTHORITIES AND STAKEHOLDERS

Identify the regulatory authorities' and stakeholders' input regarding the existing LTM program. Discuss any proposed or negotiated plan involving ground-water monitoring in this section.

2.3 OPTIMIZATION OBJECTIVES

Clearly state the objectives for the current optimization study and document any past optimization efforts.

The LTM elements (e.g., number of wells, number of analytes, frequency of sampling) should be enumerated. Objectives for the current optimization study should be clearly stated, with consideration for both quality and cost. In addition, any previous optimization effort conducted at the site should be identified. Cost savings from any previous optimization efforts should also be documented.

2.4 GROUND-WATER CONTAMINATION

Present a comprehensive discussion of the ground-water contamination at the site.

The information discussed in this section should include the hydrogeologic characteristics of the site and the site's known ground-water contamination plumes. The discussions should include the nature and extent of the contamination, the CSM, and the predictions of the fate and transport plume model if available and appropriate. In addition, identified COCs should be listed. Previous and ongoing remedial activities should be documented.

2.5 LONG-TERM MONITORING REQUIREMENTS

Document in detail all LTM requirements (i.e., sampling frequency, natural attenuation analytical parameters) arising from applicable authorities.

Requirements that should be documented in this section include sampling and analytical protocols; sampling frequency; and the duration, projected endpoints, and periodic review schedule of the LTM program. These are the requirements that form the basis of and the parameters for the LTM program, against which all considerations of quality and effectiveness must be measured. The ROD documents and the long-term ground-water monitoring plans usually contain these requirements. Mandated requirements, including monitoring requirements outside of base boundaries, and the objectives for these mandated requirements should also be discussed here.

2.6 EXISTING LONG-TERM MONITORING PROGRAM ELEMENTS

Document the elements of the existing LTM program as a basis for cleanup efficiency and future cost comparisons.

The following elements should be documented:

- Program objectives
- Decision rules for determining wells to be sampled and sampling frequency
- Well inventory, including identifiers, locations, and construction specifications
- Field procedures
- Analytical protocols
- Data management plan
- Program review plan

These elements will also be used in the optimization process. Therefore, the section should be organized in a systematic and comprehensive format. Tables and spreadsheets should be used to present this information.

NO INFORMATION WRITTEN ON THIS PAGE.

3. OPTIMIZATION PROCEDURES AND RESULTS

Describe the process and results of applying the selected optimization strategy(ies), including the current LTM status, objectives, strategies applied, all relevant findings, assumptions, and the decisions of the optimization process. Attach supporting documents.

The principal optimization strategies are listed below.

OPTIMIZATION STRATEGIES
1. Establish decision rules for well placement and sampling frequency.
2. Refine field procedures.
3. Refine analytical protocols.
4. Streamline data management.

All four strategies should be considered; however, all of them may not require further optimization. Each of the selected strategies should be described and documented in detail, including the rationale for selecting or rejecting each strategy.

The input of all team members is essential during the optimization process, and it is especially important for the regulatory agencies to be active members of this team. The LTMOT, and the agencies as members of the team, should participate in the process of clarifying the objectives and performing the optimization to avoid misunderstanding and disagreement and to obtain the early acceptance of the process. LTMOT members must use their technical knowledge, experience, and professional judgment to achieve a consensus evaluation.

The LTM optimization process can minimize costs while maintaining or improving program quality and effectiveness by ensuring the following:

1. Protecting human health.
2. Meeting stakeholder expectations.
3. Satisfying RODs and other regulatory requirements.
4. Applying decision rules.
5. Monitoring fate and transport of contaminants.
6. Applying computer-aided geostatistics and mathematical algorithms to simulate and predict present and future hydraulic conditions, plume movement, and attenuation.
7. Using computer software packages (e.g., MAROS, GTS) to optimize LTM networks based on geostatistical analysis.

Consideration of cost-saving measures must be confined to those strategies and limits that sustain and promote program quality and effectiveness by collecting and processing only relevant data.

AFCEE has developed two computer software packages that employ sophisticated geostatistical/statistical analysis algorithms to facilitate the optimization and termination of current LTM monitoring programs. Monitoring and Remediation Optimization System (MAROS) software (Aziz et al., 2006), designed for use by mid-level environmental professionals, is user-friendly and provides technically defensible recommendations for optimizing monitoring networks both spatially and temporally. Individual input data sets must characterize only one aquifer or hydrogeologic unit. Geostatistical Temporal/Spatial (GTS) optimization algorithm is a more robust and powerful computer application that is designed for use by mid-level geostatisticians. GTS software can optimize individual input data sets for LTM networks containing analytical data from more than one aquifer or hydrogeologic unit. For an LTMO case study that used GTS see Cameron and Hunter (2003). Additional technical information, user's manual and executable computer code for MAROS and GTS can be obtained from the AFCEE website.

3.1 DECISION RULES

Document the decision rule process used to select the strategies to optimize well placement, number of wells, number of analytes, and sampling frequency. Present discussion and results of the evaluation of each strategy.

A decision rule is expressed in the form of an if/then statement that specifies the conditions under which a specific action will be taken or a decision will be made. For example: "If the maximum concentration of a contaminant continuously declines below the cleanup level for five consecutive years, then the site warrants no further monitoring." Decision rules can be based on statistical parameters such as the mean, median, or 95 percent confidence level. Following are the two general types of decision rules:

(1) A decision rule written to justify terminating the entire LTM program.
(2) A decision rule written to justify removing a well from or adding a well to the LTM program, reducing the frequency of its sampling, or reducing the number of analytes monitored.

Decision rules may already exist in a ROD or other documentation. The entire team should be involved in developing or modifying decision rules and consequently amending the ROD appropriately. Decision rules are important in the optimization process because they can ensure consistent actions and earn acceptance for the program. The decision rules may involve considering human heath and ecological risks and other objectives of the LTM program. Therefore, it is important to establish the objectives and other major considerations prior to this step.

3.1.1 Program Elimination

Document any consideration of eliminating the entire LTM program. Discuss the LTM program elimination in accordance with the regulatory requirements. Document the rationale for this proposal if elimination of the LTM program is justifiable.

Ideally, the closure endpoint of an LTM program would be predictable so that the decision makers can strategically plan the site closure. To achieve site closure, the closure objectives should have been met and the continuation of LTM should no longer provide useful information.

The LTM program may be eliminated at some sites, whether they are under CERCLA, RCRA, UST, or other compliance programs, by progressively reducing the sampling frequencies and locations. Base officials should seek and hopefully obtain, in advance, applicable regulatory agency approval for this method of LTM termination.

3.1.2 Well Elimination or Abandonment/Destruction

Recommend and justify the elimination, abandonment, or destruction of monitoring wells that do not provide data that meets the LTM DQOs. Identify by map location and document those wells that can be eliminated, abandoned, or destroyed without reducing the quality and effectiveness of the LTM program.

The excessive number of sampling locations is a major Department of Defense (DoD)-wide problem. This problem can be corrected by eliminating many of these irrelevant and redundant wells using sound scientific methods. Eliminating or abandoning/destroying monitoring wells can be justified by determining that a monitoring well is redundant, unnecessary, or provides unreliable information.

Wells that duplicate information are redundant. For example, if two wells are located less than 50 feet apart within the same unconsolidated permeable aquifer and are screened over the same interval, then they are providing the same information.

Geostatistical procedures (e.g., Kriging algorithms, Neural Networking) are a key approach to identifying spatial redundancy of existing sampling networks. The selected algorithm should associate the error or uncertainty term with the contour data. Contours showing high error obviously indicate that more sampling locations are needed. Extremely low errors or uncertainty indicate spatial redundancy. A useful reference that discusses statistical evaluation of monitoring data is the *Statistical Analysis of Ground-Water Monitoring Data at RCRA Facilities, Interim Final Guidance* (EPA 1989).

Wells that are not needed to meet the objectives of the LTM program are unnecessary. For example, if the only objectives of the LTM program are to protect human health and the environment, then it is unnecessary to monitor wells located away from the receptor pathways, such as drinking water wells, wetlands, and surface waters, to meet those objectives. For strategies to eliminate unnecessary wells, a monitoring decision tree can be employed. Detailed discussion of the monitoring decision tree is presented in Part 2, section 3.1.4. Alternatively, a geostatistical software tool such as MAROS or GTS can be used to identify redundant wells.

Monitoring wells in poor physical condition, wells screened over multiple aquifers, wells that may serve as a contaminant conduit, wells that were installed for temporary use, and wells that are dry part of the year may provide unreliable information. Wells that provide unreliable data need to be further evaluated to determine whether they should be replaced or refurbished to meet DQOs or if they can be eliminated.

Legal (statutes or administrative rules and regulations) requirements are a driving force for properly abandoning/destroying a well. Some states require certain decommissioning procedures by law, and others only publish guidelines to be followed. Differing requirements and guidelines regarding proper well abandonment/destruction significantly dictate the cost of the process.

The abandonment/destruction technique used must be tailored to the surrounding geology. Localities may have specific procedures for certain situations, and the appropriate procedures should be followed. However, rules and statutes do not fit every circumstance, and selection of the proper and cost-effective procedure must be made through experience, with subsequent appeals made to the proper regulatory authority.

Grouping wells for abandonment/destruction reduces mobilization costs. Ideally, well abandonment/destruction should occur only once each time the optimization process is performed. State or local regulations may dictate how long an inactive well may be left unsealed. Well abandonment/destruction procedures are described in the *Manual of Water Well Construction Practices for EPA* (The National Water Well Association 1975) and the *Standard Guide for Decommissioning of Ground Water Wells, Vadose Zone Monitoring Devices, Boreholes, and Other Devices for Environmental Activities* (The American Society for Testing and Materials [ASTM] 1993).

3.1.3 Well Placement and Construction

Document the optimal placement and construction for new wells. Specify location of proposed wells, along with the design and rationale for these wells.

If optimal well placement is considered in the planning stages, the costs associated with installation, maintenance, and sampling can be reduced. The placement of the monitoring wells should be based on the objectives of the LTM program, potential influence of natural hazards, ease of access, and site-specific constraints. Site-specific conditions including ground-water flow velocity and plume migration need to be considered in current and future well locations. For example, if the water-table wells are located where water-level fluctuation is high or a significant trend exists, then the wells should be appropriately screened. Future projections involving the long-term development of the site and land use program may need to be considered.

If the objective of the LTM program is to evaluate the fate of fuel hydrocarbons in ground water, the *Technical Protocol for Implementing Intrinsic Remediation with Long-Term Monitoring for Natural Attenuation of Fuel Contamination Dissolved in Groundwater* (AFCEE 1995) should be consulted regarding well placement.

If the objective of the LTM program is to evaluate the fate of chlorinated solvents in ground water, the *Technical Protocol for Evaluating Natural Attenuation of Chlorinated Solvents in Groundwater Draft Revision 1* (AFCEE 1996) should be consulted.

Properly located, designed, and constructed LTM wells can be a significant cost savings. Many factors contribute to poorly designed and constructed monitoring wells and can necessitate replacement and rehabilitation of these wells. These factors include field conditions (e.g., subsurface material), technical difficulties (e.g., screen, packing material, poor drilling equipment), and other site-specific problems (Smith 1995). Consult the *Handbook of Suggested Practices for the Design and Installation of Ground-Water Monitoring Wells* (EPA 1991) and *Standard Practice for Monitoring Well Protection* (ASTM 1995) for proper well design and construction.

Construction and placement of new wells should include appropriate wellhead protection. Guidance on this subject can be obtained from *A Guide to Protection* (American Planning Association 1995) and *Why Do Wellhead Protection? Issues and Answers in Protecting Public Drinking Water Supply Systems Wellhead* (EPA 1995).

When a new well is installed, the well inventory should be updated. The well inventory includes a comprehensive well listing and dates when wells were installed and sampled, survey coordinates, condition of the wells, and well construction when installed. This well inventory is crucial in determining the wells' relevance to the objectives of the LTM program, well location, and construction integrity.

Technical analysis can determine the spatial distribution of the monitoring wells relative to the contaminant mass (plumes, contaminant source). Analytical graphical products that can be used to determine a well's relationship to a ground-water plume include the following:

- Modeling computer codes that are validated, documented, and accepted by the modeling community.
    - Ground-water flow models.
    - Contaminant fate and transport models.
- Contaminant distribution maps.
- CSMs.
- Water-table maps, geologic cross sections.
- Lithologic facies maps.

Any recent development at the site that impacts ground-water flow velocity should be documented. Examples of developments that alter well siting include the following:

- Installation or reactivation of nearby production wells.
- Changes in contaminant migration pathway.
- Water-level fluctuation and/or trends.

Professional judgment based on technical expertise and experience is required in this evaluation process.

3.1.4 Sampling Frequency

Determine the optimal sampling frequencies.

Monitoring wells are commonly sampled at the following frequencies: (1) biennial, (2) annual, (3) semiannual, and (4) quarterly. An LTM program may consist of wells that are sampled more frequently than necessary and wells that are sampled less frequently than necessary. Because the former usually outnumber the latter, sampling frequency optimization is usually accompanied by a reduction in LTM program sampling costs.

The tool most often used to optimize sampling frequency is a logic diagram known as the sample frequency decision tree (SFDT). By answering a series of questions, the user follows the SFDT logic which leads to a recommendation of the optimum sampling frequency for the target well. It is important to explain the rationale of a new, revised, or validated SFDT and to document the effects of applying this SFDT to each LTM well by including tables contrasting the proposed frequencies to those of the existing program.

SFDTs are discussed in Appendix A, and an example SFDT is presented in Figure A-1. Another example of an SFDT can be found in the *Long-term Ground Water Monitoring Program Guidance* (California Base Closure Environmental Committee 1994).

In developing an SFDT, all factors that affect a monitoring well's importance to the LTM program should be evaluated and incorporated into the logic structure. The main factors that should be considered include (1) direction of movement of the contaminant mass (i.e., plume), (2) location of a well with respect to the plume, (3) location of a well with respect to potential receptors, (4) site hydrogeology, (5) seasonal water-table fluctuations and/or trends, (6) quality of well construction, (7) COC detection history, (8) special ground-water uses, and (9) regulatory compliance. Detailed discussions of most of these factors are included in Appendix A.

A properly designed SFDT can be applied with confidence to each well in the monitoring well network. The SFDT should be applied to each well after each round of sampling in order to determine each well's optimal sampling frequency for subsequent sampling events. The SFDT should be revised periodically to reflect modifications to LTM objectives, recent contaminant detection, increased knowledge of the site, and regulatory changes. Some interpretation and professional judgment will likely be necessary when applying the SFDT.

Alternatively, sampling frequency can be reduced by using a statistical approach such as a protocol called cost-effective sampling (CES) developed by the Lawrence Livermore National Laboratory (LLNL) and the Savannah River Technology Center (Ridley 1995, Johnson et al. 1996). CES is a system for estimating the least frequent sampling schedule adequate for a given ground-water monitoring location. Each well is assigned the most frequent schedule recommended by the algorithm for any individual compound. The developers of this method recognized that a higher risk is associated with sampling wells located downgradient of the contaminant plume and close to residential areas. For this reason, these wells are sampled quarterly and are not eligible for reduction. The Modified CES method can be accessed through the MAROS software tool.

3.2 FIELD PROCEDURES

Document the selection of optimized field sampling procedures and the rationale for their selection.

Selecting efficient and cost-effective field procedures should not reduce the quality or effectiveness of the LTM program. Various field procedures have been evaluated recently. The following procedures taken from those studies are routine practices for monitoring projects. Some of these recommendations require execution at the early stage of LTM projects, but most can be instituted at any stage.

3.2.1 Well Development

Document the evaluation and verification of adequate well development. Document potential improvements of well development protocol.

Poorly developed wells can contain suspended solids that bias chemical analyses so that ground-water samples do not represent subsurface conditions. Well development must be completed on all newly installed wells and possibly on some existing wells at the site.

During well development, removal of fine materials and drilling fluid/mud is essential to ensure the following:

- Restore physical and hydraulic properties damaged during drilling operation.
- Alter the physical characteristics of the aquifer near the boreholes so that water can flow more freely to a well.
- Increase hydraulic communication between the formation and the well to maximize the value of data from aquifer tests.
- Ensure the representativeness of ground-water samples to be collected from the well.
- Minimize the potential for clogging and damaging pumping equipment during future pump tests and well purging.

Wells should be developed using procedures approved for the particular site. Examples of acceptable procedures include the *Handbook of Suggested Practices for the Design and Installation of Ground-Water Monitoring Wells* (EPA 1991), *RCRA Groundwater Monitoring: Draft Technical Guidance* (EPA 1992), and *Model Field Sampling Plan* (AFCEE 1997).

3.2.2 Well Maintenance and Problem Prevention

Document the evaluation of maintenance and problem prevention for existing LTM wells. Record any potential improvements to the procedures.

LTM wells are subject to deterioration because they are inactive over long periods of time. Therefore, during its lifetime, an LTM well can exhibit a variety of problems, including silting-in, poor yield, corrosion, construction deterioration/failure, and fouling due to iron/manganese/sulfur bacteria (Smith 1995). These problems affect not only the quality and effectiveness of the LTM program, but also the costs. Some of these conditions can be prevented by selecting the proper materials during the design phase and performing appropriate maintenance procedures periodically. Preventive treatments can be more cost-effective than rehabilitation or reconstruction of LTM wells. It is important to understand the cause of problems, document them, and learn from the experience to prevent future recurrences.

3.2.3 Low-Flow (Micro-) Purging and Sampling Techniques

Document the evaluation of low-flow purging and sampling techniques, including sampling equipment, for an LTM program. Provide the rationale for any proposed changes in technique, including results of pilot testing and cost analysis of the alternative. Evaluate the potential for corrosion or encrustation of dedicated well sampling equipment, and select appropriate corrective action.

Sampling techniques used in ground-water monitoring must provide data that accurately represent the water quality of the aquifer in the vicinity of the well. Prior to sampling, sufficient water must be removed (purged) from the well to ensure that stagnant water has been completely displaced by fresh aquifer water representative of the surrounding aquifer. Conventional ground-water monitoring practice calls for the removal of three to five well-casing volumes prior to sampling. The time required to accomplish the pumping and the disposal of potentially contaminated purge water are both cost factors.

There is debate about how to withdraw water from a well to obtain the most representative ground-water samples and what volume is sufficient. In general, two methods are used to withdraw water from a well: conventional and low-flow. Low-flow is generally less expensive. Many articles have been published regarding the techniques and advantages of using low-flow purging (see Appendix B). Table 2 compares the methods with respect to factors that affect cost and quality of ground-water samples.

Table 2. Comparison of Well-Sampling Methods

Non-Dedicated Conventional-Flow Purging Technique	Dedicated Low-Flow Micro-Purging Technique
Higher costs for disposal and staging of large volume of purge water	Lower costs for disposal of smaller volume of purge water
Unrepresentative results due to turbidity	Low turbidity
May represent a large volume or area of aquifer	Usually more representative because sample taken

	at the discrete zone of aquifer
Historic technology	Innovative technology
Long decontamination times	Short decontamination times

Regardless of the techniques used, dedicated equipment should be considered. Dedicated equipment can reduce the volume of water used for decontaminating sampling equipment, which is required for disposal, and the time required to decontaminate the sampling equipment. The potential for corrosion or encrustation of dedicated well sampling equipment should be evaluated, and appropriate corrective action should be selected. A cost analysis should be conducted to determine the benefit of dedicated equipment since high equipment investment may be required.

If low-flow purging is to replace conventional purging, a test should be conducted to demonstrate the comparability of the data collected using these two methods. In addition, the reliability, efficiency, and compatibility of the equipment with the site should be evaluated (i.e., pump performance efficiency, corrosion resistance, inertness). A group of wells should be sampled using both methods. The volumes purged, the time required to reach stabilization, and measurements of the stability parameters should be recorded for each method. This comparison should be documented and evaluated.

3.2.4 Purged-Water Disposal Practices

Discuss the consideration of practical and cost-effective purged-water disposal practices. Document any potential improvements to the practices.

Whether using conventional or low-flow (micro-) purging, disposal costs are often very significant. Purged water may be regulated by federal, state, and/or local regulatory agencies, and off-site disposal may be required. Practices that reduce disposal costs include (1) segregating contaminated purged water by contaminant type and concentrations; (2) using an experienced and reputable waste disposal company that is familiar with the regulatory requirements; and (3) evaluating on-site treatment of purged water for applicability and requirements, including discharge, sampling, and permit requirements at the facility.

3.3 ANALYTICAL PROTOCOLS

Present procedures to reduce analytical costs associated with LTM while still satisfying project-specific DQOs that facilitate decision making.

An LTM program spanning several decades produces large quantities of analytical data. Consequently, even minor changes in analytical protocols can significantly affect the associated lifetime costs.

3.3.1 Chemicals of Concern

Discuss the determination of the proper COCs to be sampled. Document the rationale of proposed changes.

The COCs can be found in documents related to the remediation effort, including ROD and RI/FS documentation. If analytes were misidentified as COCs or if they no longer exist as a component of a complete exposure pathway, the associated analytical method should be considered for omission from the analytical protocol. For example, if trichloroethylene (TCE) [where TCE is the main contaminant] is determined to no longer be a COC, then the method employed for TCE analysis (e.g., SW8260) should be eliminated from the analytical protocol.

3.3.2 Indicator Analyses

Discuss consideration of a practice known as indicator analysis, which yields significant cost savings. Document the rationale in this section if this approach is found to be appropriate.

Indicator analysis relies on the monitoring of only those analytes that are capable of indicating the status of other plume-related constituents. For example, if the objective of a particular LTM program is to monitor the boundary of a particular plume containing several types of compounds (e.g., benzene, toluene, ethylbenzene, and xylenes [BTEX]; polynuclear aromatic hydrocarbons [PAHs]; and polychlorinated biphenyls [PCBs]), the plume's position may be tracked adequately by analyzing for only the analyte type known to possess the fastest migration rate (e.g., the compound with the lowest K_{oc} value). This practice should be considered very carefully, however, because several scenarios can exist that would render this approach ineffective. For example, should the concentration of the indicator analytes drop below the method detection limit (MDL) of the analytical method prior to reaching the monitoring well, the position of the other plume constituents would be unknown.

3.3.3 Analytical Suites

Discuss the selection of the optimum analytical protocol that will produce data that meet the minimum QA requirements while eliminating unnecessary expenses. Document the results of the evaluation of the following three analytical factors: confidence level, detection limits, and analyte type.

Many different analytical methods possessing a wide range of specific characteristics are employed in EPA programs. Consequently, careful planning must go into the analytical protocol selection process to ensure that the proper method(s) for the project is (are) chosen.

The first step toward choosing the appropriate analytical method is to thoroughly review and understand the DQOs because they are the basis for making future decisions.

3.3.3.1 Confidence Level

The level of confidence needed in the data will affect which analytical method is selected. Generally speaking, methods can be broadly categorized as screening or definitive.

Screening methods tend to be the quickest and cheapest of the methods used to identify a COC and should be used if DQOs allow. However, most screening methods possess unacceptably high detection limits and are susceptible to interferences that can affect the accuracy of the results. Data obtained by these methods should be judged with low confidence and used only after the data have been closely scrutinized. If screening data are not acceptable, then a definitive method must be chosen.

Definitive methods can be divided into those with high confidence and lower confidence levels. Definitive methods with a high confidence level are capable of positively identifying an analyte. For example, mass spectrometry (MS) and gas chromatography (GC) with second-column confirmation are two ways of ensuring that analytes of interest are positively identified. While positive identification methods yield more information, they can also significantly increase the cost of analysis (e.g., $60 for SW8021 without second-column confirmation as opposed to $100 for SW8260, which employs MS). If an LTM program protocol required that 150 wells be sampled semiannually for 20 years, a savings of $240,000 could be realized by implementing a nonconfirmatory method (e.g., SW8021 without second-column confirmation) as compared to an MS method (e.g., SW8260). If this scenario were applied to 20 separate sites, the savings would approach $5 million.

LTM sites have typically been well characterized, and ample historical data often exist to support and confirm a positive detection. Therefore, high-confidence methods such as GC/MS or second-column confirmation are often unnecessary. In addition, because most analytes in LTM are often at or below their action levels and semi-volatile analytes by GC/MS generally have higher detection limits than other types of chromatographic detection systems, GC/MS is not recommended (e.g., PAH by 8310). Lower-confidence methods, which typically rely on retention-time matches for identification and do not positively identify the COC, generally meet the requirements for LTM.

While the potential exists to reduce long-term analytical costs, the exclusion of positive identification techniques from the analytical protocol should be carefully considered on a site-specific basis. For each site, it is necessary to ensure that (1) ample historical data exist to define the site chemistry and (2) the project-specific quality assurance project plan or other similar guidance document does not prohibit this practice.

Figure 2 is a flowchart to guide the decision maker in selecting the proper analytical protocol. Each decision must be based on the DQOs.

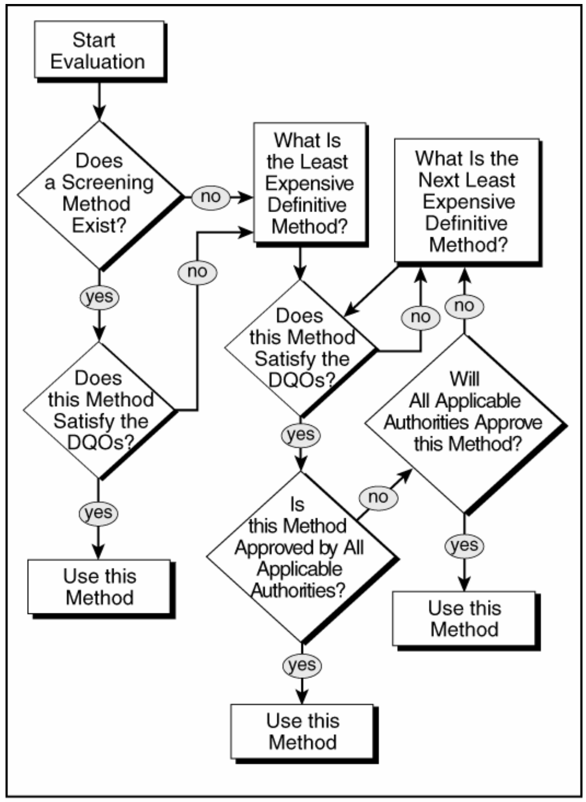

Figure 2. Flowchart for Determining a Cost-Effective Analytical Protocol

3.3.3.2 Concentration

Detections of past COC concentrations often dictate the detection limits necessary to satisfy the DQOs and consequently affect the selection of the analytical method. Therefore, it is important to consider the minimum concentration of the COC when selecting an analytical protocol. In general, the lower the detection limits for a particular method, the more expensive the instrument and analysis. While it is crucial that the detection limits for analysis be appropriate to achieve the project-specific DQOs, savings can be realized by ensuring that the method is not overselected. In other words, if the project objectives have been satisfied, additional costs to achieve a lower detection level are wasteful. For example, if the objective for monitoring wells downgradient of a plume is to protect human health and the objective for wells within the plume is to monitor the trend, the analytical method used to monitor downgradient wells may require a lower detection limit. Using the same, more expensive method for wells within the plume would not be cost-effective.

3.3.3.3 Analyte Type

Ground water may be contaminated with only one type of compound, or it may be contaminated with different types of compounds. For example, if analytes of interest constitute only one type of volatile organic compound (VOC)—such as BTEX—a comprehensive analysis of all types of VOCs (e.g., SW8240/8260) may be unnecessary and costly. SW8020 may prove more cost-effective.

If a particular LTM process requires that a host of aromatic and halogenated compounds be measured, then individual methods that detect these types of compounds separately (e.g., SW8020 and SW8010, respectively) may be less economical than using a comprehensive analysis (e.g., SW8021 or SW8260).
The duplication of analyses for a COC should be avoided. For example, if only the concentration of benzene is of interest, employing two separate methods such as the aromatic VOC method SW8020 and the halogenated VOC method SW8010 may be redundant and unnecessary.

3.3.4 Analysis for Quality Assurance

Discuss the consideration of appropriate and cost-effective QA for an LTM program. Present the rationale of any potential changes in QA procedures.

In general, LTM requires less stringent QA than other phases of the remediation effort because the site chemistry has been well defined. The purpose of LTM is often to demonstrate that the COC concentrations are below a particular action level. In fact, most data will be below the MDLs or site-specific action levels. Therefore, the number of quality control (QC) samples (e.g., field duplicates, matrix spike/matrix spike duplicates, field blanks) can be reduced without any detrimental effect on the quality or usability of the LTM data. As with other approaches to reducing LTM costs, if the project-specific guidance prohibits their implementation, this option is unavailable.

3.3.5 Competitive Laboratory Bids

Discuss procedures followed to obtain competitive laboratory bids. Document the potential cost savings and related data quality issues.

Laboratory prices can vary substantially depending on the laboratory type, availability, and location, as well as sample volume. Competitive bidding can produce cost savings, but it is important to use reputable and competent laboratories. Facility and procedural changes may affect the consistency of data quality, so transition should be carefully planned and executed.

3.4 DATA MANAGEMENT PLAN

Document the results of the evaluation of the data management system that supports the LTM program. Discuss the present or proposed system and any special considerations that affect the management of the LTM data, including such issues as regulatory requirements, legacy data *systems, or data transfer standards used by analytical laboratories.*

Long-term ground-water monitoring programs produce significant quantities of data describing water quality and site physical characteristics (e.g., contamination concentrations, well data, cultural data). These data must be organized in a manner that provides easy access for project team members and should be arranged in tabular and graphic formats that allow for evaluation of historical, current, and predicted site status. Data collection and management can therefore be a significant cost factor in the LTM program.

3.4.1 Collection and Format

Discuss how LTM programs can be improved to increase the efficiency and reduce the cost of data management. Document the results of assessing the following data management issues:

- DQOs should be evaluated to ensure that there is a specific need for the data in evaluating environmental site conditions or that there is a defined regulatory requirement.
- Data should be collected in a manner that allows for cost-effective conversion to an electronic format.
- Minimum legal reporting and presentation requirements for regulatory review of electronic and print versions of the data should be documented and arrangements made for meeting those requirements.
- QC data should be well documented and easily traceable.
- Off-the-shelf data management systems should be evaluated for cost-effectiveness and applicability to the needs of the program. The cost of the hardware and software, maintenance, and the required expertise of operational personnel should be evaluated.
- When possible, the LTM data report should be merged with the LTMOR.

LTM data management is summarized in Figure 3.

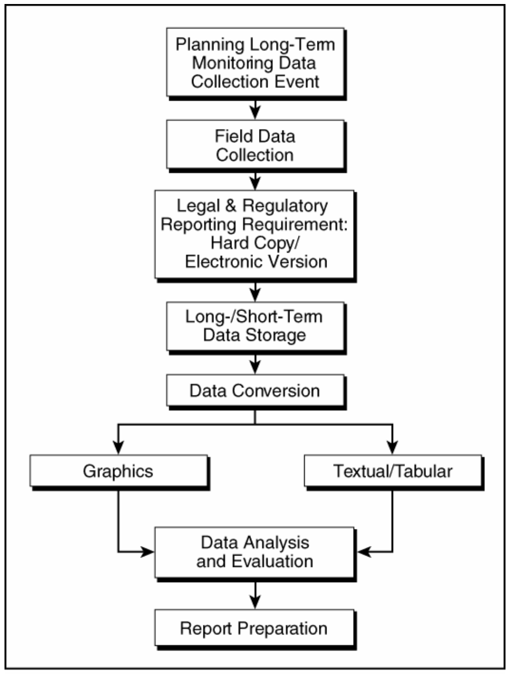

Figure 3. Overview of Determining Data Management Requirements

LTM data can be evaluated using either electronic or print format. Electronic manipulation of data reduces processing and document preparation time, but legal and regulatory reporting may require printed documentation. These issues should be addressed in the LTM planning process.

3.4.2 Data Evaluation

Document the methods and processes that can be used to evaluate the LTM data. Discuss each of the applicable issues presented below and how they will be addressed to provide efficient, comparable, and cost-effective evaluation of LTM data:

- Textual and tabular data should be converted into formats that allow for easy evaluation and that meet submission requirements of the appropriate regulatory entities. Data-presentation formats should allow comparison with data previously collected at the site and should be consistent throughout the project.
- Data should be converted into effective graphics, including annotated maps, contour maps, well and hydrogeologic cross sections, time concentration graphs, and any other format that effectively describes the data. The formats should be comparable and compatible in scale and projection to other data previously collected at the site and should be consistent throughout the project.
- Annual monitoring reports should be standardized to ensure the consistency of the reporting requirements and site evaluation process. Standardization also provides a consistent base for cost-estimation and project scheduling.

3.4.3 Data Storage

Discuss data storage issues. Present the plan for long-term storage of LTM data. Discuss each of the applicable issues presented below and document the strategies to implement the results:

- Data should be stored in a format that allows accessibility to the user community.
- Duration of the required data storage should be established.
- Plans and schedules for archive security and data backups must be developed.
- Data should be stored in a format that allows future accessibility. ASCII format should be used and meta-data describing file formats should accompany the data. Proprietary file formats specific to software applications should be avoided.
- Storage media should be selected that will ensure long-term accessibility. The media should be evaluated periodically to ensure electronic persistence and compatibility with current standards.
- A plan that considers legal requirements should be developed for the final disposition and disposal dates of the data.

Additional requirements may include loading collected environmental data into the Environmental Resources Program Information Management System (ERPIMS). The ERPIMS data-loading requirements and process are described in the *ERPIMS Data Loading Handbook*. ERPIMS documentation can be obtained from AFCEE or can be downloaded from the Internet at the AFCEE World Wide Web page at http://www.afcee.brooks.af.mil.

NO INFORMATION WRITTEN ON THIS PAGE.

4. EVALUATION OF COST SAVINGS

Document the estimated potential savings that could be realized by implementing the optimization strategies explored in the preceding section. Identify and compare cost estimates for the existing and proposed sampling and analysis programs. Attach detailed cost data to the LTMOR.

To evaluate the optimization process, the user must be able to estimate the cost of both the existing and optimized LTM programs. Costs of both programs can be calculated by using a cost-estimating tool. The same method should be used on both programs so that the comparison is based on the same information and assumptions. With these estimates, the savings resulting from optimization can be predicted.

The cost reduction resulting from optimizing an LTM program can be measured using Remedial Action Cost Engineering Requirements (RACER), a cost-estimating tool (Earth Tech, Inc. 2004). RACER was designed to measure RA costs, but it is capable of calculating costs associated with LTM programs as well.

RACER cost models are based on generic engineering solutions for environmental projects, technologies, and processes. These generic solutions were derived from historical project information, government laboratories, construction management agencies, vendors, contractors, and engineering analyses. During the creation of an estimate for an existing or optimized LTM program, the generic engineering solutions are tailored to reflect the specific conditions and requirements. To obtain the costs of existing and optimized LTM programs, the parameters for fixed and adjustable costs must be established.

The fixed-cost parameters have the same values for both existing and optimized LTM programs. They can be obtained from the existing LTM program. Examples of fixed-cost parameters follow:

- Site type
- Contaminant source
- Media
- Ground water
- Depth to ground water
- Sampling rounds
- Samples per round
- Mobilization distance

Adjustable cost parameters are input after fixed-cost parameters are established. The adjustable cost parameters can be obtained from the existing LTM program and the optimization results. Efforts should be made to ensure that the estimated costs are accurate. Examples of adjustable cost parameters follow:

- Sampling frequency
- Total samples collected per well
- Total number of COCs required per well
- Sampling crew
- Number of wells sampled per day
- Analytical methods
- Number of drums of purged water
- Disposal cost of sampling-derived waste

A total-cost estimate can be generated once the fixed and adjustable cost values have been entered into a RACER cost model. Comparing the cost estimates for the existing and optimized LTM programs reveals the cost reduction potential for the optimization.

NO INFORMATION WRITTEN ON THIS PAGE

5. CONCLUSIONS AND RECOMMENDATIONS

LTM as part of an RD/RA or no further response action planned (NFRAP) should be viewed as a strategic QA checkpoint. Identify and recommend those optimization strategies that the analysis indicates to be cost-effective. Recommendations should be categorized by optimization strategy:

OPTIMIZATION STRATEGIES

1. Establish decision rules for well placement and sampling frequency.
2. Refine field procedures.
3. Refine analytical protocols.
4. Streamline data management.

Each recommendation should reference rationales and relevant findings from the preceding analyses and attached supporting documents. It must be clear that the recommendations address the objectives of the LTM program and maintain or improve its quality and/or effectiveness.

All decision makers, including the Air Force, regulators, and the community, should review the report generated by the team prior to implementing any modifications to the existing program. If the optimization requires significant modifications to the existing program, DDs should be altered to document the modifications. If a DD (i.e., ROD, Federal Facility Agreement [FFA]) is already in place, an addendum to the ROD may be required. If a ROD has not been written but is developed later, it should allow for implementation of optimization.

NO INFORMATION WRITTEN ON THIS PAGE.

6. CONTRACTING CONSIDERATIONS

Most LTMO projects are suitable to the use of Firm-Fixed-Price contracts to obtain the lowest cost-benefit ratio and best value for the Air Force. More specifically, the use of performance-based contracts (PBCs) generally offers a more streamlined, cost-effective, and timely means of conducting these projects for the ultimate goal of reaching site closure. Most LTMO projects, with the exception of small ones (e.g., contract period of performance less than two years or cost less than approximately $100K), should be evaluated as potentially good candidates for PBC.

PBC contracting requires considerable communication between and level of effort for the AFCEE Contracting Officer (CO), Contracting Officer's Representative (COR), Base or MAJCOM environmental coordinator and appropriate state and federal regulators. Consequently, the CO or COR, along with the Base or MAJCOM environmental coordinator, should consider grouping LTMO projects into a single award across several sites or installations as a recommended way of making PBC a highly advantageous Air Force contract vehicle for both large and small LTMO projects.

For more detailed information pertaining to PBC, AFCEE recommends consulting *Environmental Restoration Performance Based Contracting (PBC) Concept of Operations*, November, 2005. This document is available for downloading from the AFCEE website: http://www.afcee.brooks.af.mil/products/pbc/meeting/. For information on performance-based management, AFCEE recommends *Performance-Based Management Master Guidance, November 2005*, available for downloading at http://www.afcee.brooks.af.mil/products/techtrans/pbm/PBMguidance.asp

NO INFORMATION WRITTEN ON THIS PAGE.

REFERENCES

Air Force Center for Environmental Excellence. 1995. Technical Protocol for Implementing Intrinsic Remediation with Long-Term Monitoring for Natural Attenuation of Fuel Contamination Dissolved in Groundwater. Version 0. Brooks Air Force Base, Tex.

Air Force Center for Environmental Excellence. 1997. Model Field Sampling Plan. Version 1.1. Brooks Air Force Base, Tex.

Air Force Center for Environmental Excellence. 1996. Technical Protocol for Evaluating Natural Attenuation of Chlorinated Solvents in Groundwater. Draft Revision 1. Brooks Air Force Base, Tex.

American Planning Association.1995. A Guide to Wellhead Protection. Planning Advisory Service Report Number 457/458.

American Society for Testing and Materials. 1993. Standard Guide for Decommissioning of Ground Water Wells, Vadose Zone Monitoring Devices, Boreholes, and Other Devices for Environmental Activities. D5299-92 in the ASTM 1993 Annual Book of Standards, Vol. 04.08.

American Society for Testing and Materials. 1995. Standard Practice for Monitoring Well Protection. ASTM D5787-95.

Aziz, J.J., M. Vanderford, C.J. Newell, M. Ling, H.S. Rifai, and J.R. Gonzales. 2006. Monitoring and Remediation Optimization System (MAROS) Software Version 2.2 User's Guide, Air Force Center for Environmental Excellence, Brooks City-Base, Tex.

California Base Closure Environmental Committee. 1994. Long-Term Ground Water Monitoring Program Guidance. State of California.

Cameron, K. and P. Hunter. 2003. Optimization of LTM Networks at AF Plant 6 using GTS. In V.S. Magar & M.E. Kelley (Eds.), *In-situ and On-site Bioremediation—2003*. Proceedings of the Seventh International In-situ and On-site Bioremediation Symposium (Orlando, Fl, June 2003).

Earth Tech, Inc. 2004. Remedial Action Cost Engineering Requirements System (RACER), RACER 2005. Englewood, CO.

Johnson, V., R. C. Tuckfield, M. N. Ridley, and R. A. Anderson. 1996. Reducing the Sampling Frequency of Groundwater Monitoring Wells. Environmental Science and Technology. v. 30, no. 1, pp. 355-358.

National Water Well Association. 1975. Manual of Water Well Construction Practices for EPA. EPA-570/9-75-001.

Ridley, M. 1995. Cost-Effective Sampling of Groundwater Monitoring Wells. The Regents of University of California/Lawrence Livermore

National Laboratory, Livermore, Calif.

Smith, S. S. 1995. Monitoring and Remediation Wells: Problem Prevention, Maintenance, and Rehabilitation. Lewis Publishers.

U.S. Department of Energy. 1994. Using the Data Quality Objectives Process in Risk Assessment. EH-231-023/0794.

U.S. Environmental Protection Agency. 1989. Statistical Analysis of Ground-Water Monitoring Data at RCRA Facilities, Interim Final Guidance. EPA 530-SW-89-026.

U.S. Environmental Protection Agency. 1991. Handbook of Suggested Practices for the Design and Installation of Ground-Water Monitoring Wells. EPA/600/4-89/034.

U.S. Environmental Protection Agency. 1992. RCRA Ground-Water Monitoring: Draft Technical Guidance. EPA/530-R-001.

U.S. Environmental Protection Agency. 1993a. Data Quality Objectives Process for Superfund. EPA/540-R-93-071 FS.

U.S. Environmental Protection Agency. 1993b. Data Quality Objectives Process for Superfund. Interim Final Guidance. EPA/540-R-93-071.

U.S. Environmental Protection Agency. 1995. Why Do Wellhead Protection? Issues and Answers in Protecting Public Drinking Water Supply Systems. EPA 813-K-95-001.

Waste Policy Institute. 1997. Cost-Effective Long-Term Monitoring Evaluation Report for Mather Air Force Base, Calif.

NO INFORMATION WRITTEN ON THIS PAGE.

GLOSSARY

Data Quality Objectives	Qualitative and quantitative statements that define the type, quality, and quantity of data necessary to support defensible environmental decision-making.
Decision Rules	A logical "if..then" statement that defines the conditions that would cause the decision maker to choose among alternative actions.
Contaminant Conduit	An open conduit to a local aquifer that is a potential pathway for contamination reaching the ground water.
Kriging	A statistical technique used to contour maps that has certain statistically optimal properties and provides measures of the error or uncertainty of the contoured surface.
Legacy Data Systems	The data systems that are presently being utilized.
Neural Networking	A class of artificial intelligence that has been identified as appropriate for pattern association tasks.
Well Decommissioning	Sealing of wells and boreholes to remove a threat to both physical safety and ground-water quality and to restore the hydrogeologic conditions.

NO INFORMATION WRITTEN ON THIS PAGE.

APPENDIX A. NARRATIVE DESCRIPTIONS OF DECISION POINTS AND RECOMMENDATIONS OF THE EXAMPLE STANDARD SAMPLING FREQUENCY DECISION TREE

A.1 INTRODUCTION

One of the most important tools required to optimize an LTM program is the sampling frequency decision tree. The example Standard Sampling Frequency Decision Tree (SDT) depicted in Figure A-1 is a logic flow diagram made up of a series of interconnected decision points (DPs). At each point, a “Yes” or “No” answer leads either to another decision point or to a recommendation relating to monitoring well sampling frequency.

The SDT is the result of an ongoing attempt to develop a widely applicable decision tree that can be used at any military installation with an LTM program. The SDT may be used as is, or it may be modified, if necessary, to conform to a specific set of conditions. Each DP in any sampling frequency decision tree should be reviewed by personnel who are qualified to assess its relevance to the conditions, and the well should also be evaluated within its historical analytical context. The tree should be approved by the appropriate regulators before it is applied.

A.1.1 Example Use of the SDT

The following example illustrates using the SDT to determine the recommended sampling frequency for the downgradient monitoring well (MW) MW-4 as shown in Figure A-2. Prior to using the SDT to determine a sampling frequency for a monitoring well, refer to the appropriate sections of this document to ensure that the data that will be used in the determination meets DQOs.

MW-4 is assumed to have the following characteristics:

- **Three years old.**
- **Downgradient from the contaminant plume.**
- **Screened at an elevation that will intersect with the plume (Figure A-3-A).**
- **Screened below the current water table.**
- **Located in an area in which the hydraulic gradient is typically horizontal, with negligible vertical components.**
- **Not located within the area of influence of an active production well.**
- **Located on a receptor pathway.**
- **Located within the base boundary.**
- **Not a RCRA or CERCLA well.**
- **No COCs detected in the most recent sampling round.**
- **Not a possible contaminant conduit.**

Step 1: **Evaluate DP-1. The investigation of MW-4 reveals that the well is not screened across an aquitard (Figure A-3-D) and does not have screens in an uncontaminated or contaminated aquifer. The investigation also determines that there is no residual dense non-aqueous phase liquid (DNAPL) contamination in the area and that the well’s surface seal is properly constructed. A review of the narrative description for DP-1 in section A.2.1 indicates that no evidence is available to support a decision that MW-4 is a possible contaminant conduit. Therefore, the answer to this DP is “No.” Proceed to DP-2.**

Step 2: **Evaluate DP-2. After reviewing the appropriate narrative description in section A.2.1, consider the various factors that can cause a well to go dry, such as: (1) installing the well screen at the wrong depth, (2) lowering of the regional water table due to aquifer depletion, (3) localized water-table drawdown due to a nearby pumping well, (4) naturally occurring seasonal fluctuations in the water-table elevation, and (5) lowering of the regional water table by drought. Because MW-4 is screened below the current water table and because a sample was obtained during the most recent sampling event, the answer to the question, “Is the well dry?” is “No.” Proceed to DP-3.**

Step 3: **Evaluate DP-3. After reviewing the narrative for DP-3 in section A.2.1, evaluate subsurface profiles indicating the elevations of the upper and lower boundaries of the contaminant plume. A determination is made that the plume is migrating primarily horizontally and that the vertical component of migration is negligible. Although MW-4 is not intended to capture floating contaminants (Figure A-3-C), it may have been installed at an inappropriate elevation to monitor dissolved contaminants (Figure A-3-B). However, an inspection of well-construction logs and review of the estimate of the plume’s vertical extent indicates that when the plume reaches MW-4, the well screen will encompass the upper and lower plume boundaries**

(Figure A-3-A). Therefore, the conclusion is made that MW-4 is screened at the appropriate elevation. The answer to the question, "Is well screened at appropriate elevation?" is "Yes." Proceed to DP-5.

Note: **A "Yes" answer at DP-1 or DP-2 or a "No" answer at DP-3 would have led to Recommendation 4, "Evaluate the well for abandonment." As indicated in the narrative for Recommendation 4 in section A.2.1, well abandonment consists of removing the well casing and grouting the borehole. State regulations should be consulted to determine the procedure to be followed when abandoning a monitoring well.**

Step 4: **Evaluate DP-5. The narrative description for DP-5 in section A.2.1 states that new monitoring wells should initially be sampled for a minimum of four quarterly sampling rounds in order to provide data to serve as a baseline for future comparisons. Review the well installation records and the historical analytical data for MW-4 to determine when it was installed and if four quarterly samples were obtained. The conclusion is made that the well is three years old and is currently on an annual sampling schedule, but the well was sampled in each of the first four quarters after its installation. Therefore, the answer to the question, "Was well initially sampled for four consecutive quarters?" is "Yes." Proceed to DP-7.**

Note: **A "No" answer at DP-5 would lead to Recommendation 6, which indicates that the well should be, or should continue to be, sampled quarterly.**

Step 5: **Evaluate DP-7. The DP-7 narrative in section A.2.1 states that off-base contingency wells are used for special purposes and are likely to have sampling frequencies that are set by the regulatory authorities. Refer to the well-location diagram and confirm that the well is an on-base well. The answer to the question, "Is the well an off-base contingency well?" is "No." Proceed to DP-8.**

Note: **If MW-4 was an off-base contingency well, a "Yes" answer to DP-7 would have led to Recommendation 9, "Negotiate with regulators to achieve lowest sampling frequency." Sampling frequencies that are set by regulatory authorities for a specific purpose unrelated to LTM may be higher than needed for LTM programs. By negotiating with the regulators, sampling frequencies may be lowered to mutually satisfactory levels.**

Step 6: **Evaluate DP-8. A review of the DP-8 narrative in section A.2.1 and the applicable or relevant and appropriate requirements (ARARs) indicates that MW-4 is not a background or point-of-compliance well (RCRA) and was not placed to monitor the progress of a remedial action (CERCLA). Therefore, the answer to DP-8, "Is well needed for RCRA or CERCLA compliance?" is "No." Proceed to DP-10.**

Note: **If MW-4 were needed for RCRA or CERCLA compliance, a "Yes" answer to DP-8 would have led to Recommendation 9, "Negotiate with regulators to achieve lowest sampling frequency." Sampling frequencies that are set by regulatory authorities for a specific purpose unrelated to LTM may be higher than needed for LTM programs. By negotiating with the regulators, sampling frequencies may be lowered to mutually satisfactory levels.**

Step 7: **Evaluate DP-10. Review the DP-10 narrative in section A-2 and then review well records and the well-location diagram to determine if there any active water-supply wells in the vicinity of MW-4. The active production well (PW) PW-1, as shown in Figure A-2, is determined to be near MW-4. An estimate of PW-1's area of influence provided by a hydrologist. does not include MW-4. Therefore, the answer to the question, "Is the well within the area of influence of an active production well?" is "No." Proceed to DP-12.**

Note: **If MW-4 had been found to be located within PW-1's area of influence, the answer to DP-10 would have been "Yes." This would have led to Recommendation 11, which calls for quarterly sampling.**

Step 8: **Evaluate DP-12. After reviewing the DP-12 narrative in section A-2.1, review the plume map, which depicts a plume boundary based on a concentration that is one-half of the maximum contaminant level (MCL) and the MDL. MW-4 is located outside of the plume boundary but near the plume (Figure A-2). Therefore, the question, "Is well located within plume boundary?" is answered with a "No." Proceed to DP-16.**

Step 9: **Evaluate DP-16. A review of the narratives for DP-16, DP-19, and Statement 21 indicates that (1) ground water moves along a hydraulic gradient from areas of higher head to areas of lower head and (2) as it moves, it continually dissolves contaminants from the upstream (upgradient) source of contamination and carries them downstream (downgradient) to form the plume. Hydraulic gradients are generally horizontal gradients, but that they may have vertical components. Upgradient wells are located above the plume on the hydraulic gradient "upstream" from the contaminant source; downgradient wells are located downstream in the path of the plume; and crossgradient wells are located beside the plume, perpendicular to the direction of ground-water movement. An evaluation of the plume map determines that MW-4 is located in the path of the plume and is therefore horizontally downgradient from the plume (Figure A-2). In addition, the evaluation**

determines that MW-4 is located "near" the plume (i.e., within the maximum distance that the plume could be expected to move in a year) and that MW-4 cannot be considered "remote" from the plume (Figure A-2). Therefore, the answer to the question "Is well horizontally or vertically upgradient or remote from contaminant plume?" is "No." Proceed to DP-19.

Step 10: **Evaluate DP-19. In Step 9, MW-4 is determined to not be a crossgradient well. Therefore, the answer to the question, "Is well crossgradient from contaminant plume?" is "No." Proceed to Statement 21.**

Step 11: **Evaluate Statement 21. In Steps 8, 9, and 10, the determination is made that MW-4 was not located (1) within the plume boundary, (2) horizontally or vertically upgradient or remote from the plume, or (3) crossgradient from the plume. This leaves only the choice described in Statement 21, "Well is horizontally or vertically downgradient from the contaminant plume," as shown in Figure A-2. Perform a final check to verify this and proceed to DP 22.**

Note: **If the check indicates that the well in question is not horizontally or vertically downgradient from the contaminant plume, an error has been made in (1) evaluating the well's location with respect to the plume or (2) using the SDT. Reevaluate the well's location and return to DP-1 of the SDT.**

Step 12: **Evaluate DP-22. A review the analytical results of the most recent sample obtained from MW-4 indicates that no COCs were detected. Therefore, the answer to the question, "Were COCs detected in most recent sample?" is "No." Proceed to DP-23.**

Note: **"Yes" answers at DPs 12, 16, and 19 would also have led to the question, "Were COCs detected in most recent sample?" at DPs 13, 17, and 20, respectively. Depending on the answers at those DPs, you would have reached Recommendation 14, "Sample annually"; Recommendation 15, "Evaluate abandonment or multi-year sampling intervals"; Recommendation 18, "Evaluate need for additional investigation"; or DP-23, "Is well on a receptor pathway?"**

Step 13: **Evaluate DP-23. A review of the ~~of the~~ narrative for DP-23 indicates that a receptor pathway is the subsurface route that contamination would travel from the plume to a receptor such as a production well. The actual route depends on local subsurface conditions and may not be straight. A review of the plume map/well location diagram determines that MW-4 is located between PW-1 and the apparent direction of approach of the contaminant plume (Figure A-2). A review of the geology in the area reveals uniform subsurface conditions that should not affect the direction of approach of the plume. Therefore, the answer to the question, "Is well on a receptor pathway?" is "Yes." This leads to Recommendation 25, "Sample semiannually." Thus, according to the SDT, MW-4 should be sampled semiannually.**

Note: **A "No" answer at DP-23 would have led to Recommendation 24, "Sample annually."**

A.2. INTRODUCTION

The purpose of the following narrative is to provide sufficient information to enable a non-technical person using the SDT to answer "Yes" or "No" to the question at each DP in the SDT. The data supporting the LTM program should be reviewed in total by the SDT evaluator to ensure the decisions are made within the proper context of the program.

A.2.1 NARRATIVE DESCRIPTIONS OF SDT DECISION POINTS, STATEMENTS AND RECOMMENDATIONS

Decision Point 1. Is the well a possible contaminant conduit?

Could the well serve as a conduit by which contaminated ground water could reach uncontaminated levels of the subsurface? For instance, if a well has screens in both the aquifer containing the plume and an uncontaminated aquifer or is screened across the separating aquitard (Figure A-3-D), contaminated ground water from the plume could move through the well to contaminate the previously uncontaminated aquifer. Other possibilities exist. A well constructed across a confining layer in an area of DNAPL contamination could allow DNAPL to contaminate a lower aquifer by gravity flow through the well's sand pack, or a poorly constructed well could allow contaminants from the surface to reach the ground water. Wells that could act as contaminant conduits should be evaluated for abandonment, as discussed under Recommendations 4 and 14 below.

Decision Point 2. Is the well dry?

Wells may be dry for a variety of reasons, including, but not limited to, (1) installing the well screen at the wrong depth, (2) lowering of the regional water table due to aquifer depletion, (3) localized water-table drawdown due to a nearby pumping well, (4) naturally occurring seasonal fluctuations in the water-table elevation, and (5) lowering of the regional water table by drought. Dry wells should be evaluated for abandonment or multi-year sample intervals if sufficient data is available to support the conclusion that they will be of no further value to the LTM program.

Decision Point 3. Is the well screened at an appropriate elevation?

If a well screen is not appropriately located, the well will not serve its intended purpose in the LTM program. For example, if a well is intended to sample the plume, the well screen must be situated at an elevation that allows it to intersect the mass of contaminated ground water (Figure A-3-A). If a well is located upgradient (DP-16 narrative and Figure A-2), crossgradient (DP-19 narrative and Figure A-2), or downgradient (Statement 21 narrative and Figure A-2) from a plume rather than within the plume itself (DP-12 narrative and Figure A-2), the well screen should still be located at an elevation that would allow the screen to intersect the plume if the plume were extended to the well. If a well is intended to monitor a particular aquifer, whether contaminated or not, the well screen must be located within the aquifer. In some cases, a well must be screened across the water table in order to sample floating contaminants such as petroleum products (Figure A-3-C), or the screen must extend deep enough to allow for seasonal water table fluctuations. Evaluating the appropriate well screen elevation, therefore, requires knowledge of the top and bottom elevations of the well screen and plume and aquifer, respectively, in addition to a knowledge of water table elevation and fluctuations, COCs, and the subsurface geology near the well.

Recommendation 4. Evaluate the well for abandonment.

Wells that are (1) possible contaminant conduits, (2) permanently dry, or (3) screened at elevations that make them unusable for the LTM program should be abandoned properly to reduce maintenance expenses and to eliminate the possibility that they could allow the introduction of contaminants to the aquifer by accident or vandalism.

Well abandonment, which generally consists of removing the well casing and grouting the borehole, is discussed in greater detail in Part 2, section 2.3.5. The appropriate regulations should be consulted to determine the procedure to be followed when abandoning a monitoring well.

Decision Point 5. Was well initially sampled for 4 consecutive quarters?

Every newly installed monitoring well should initially be sampled for a minimum of four quarterly sampling rounds in order to provide data to serve as a baseline for future comparisons.

Decision Point 7. Is the well an off-base contingency well?

Off-base contingency wells are used for special purposes. These wells are likely to have prescribed sampling frequencies. An off-base contingency well is generally sampled at the frequency required by regulatory authorities. (See Recommendation 9 regarding regulatory negotiations.)

Decision Point 8. Is well needed for RCRA or CERCLA compliance?

A monitoring well may be placed at a particular location in order to comply with RCRA (e.g., wells mandated for landfill points of compliance) or CERCLA (e.g., wells placed to monitor the progress of a ground-water remediation project) requirements. Such wells are generally sampled at the frequency required by regulatory authorities. (See Recommendation 9 regarding regulatory negotiations.)

Recommendation 9. Negotiate with regulators to achieve lowest sampling frequency.

Sampling frequencies that are set by regulatory authorities for a specific purpose unrelated to LTM may be higher than needed for LTM programs. By negotiating with the regulators, you may be able to lower sampling frequencies to mutually satisfactory levels.

Decision Point 10. Is the well within area of influence of an active production well?

The area of influence of an active production well is the area called "cone of depression" that is formed by the well's drawdown of the potentiometric surface. The perimeter of a well's area of influence may vary from nearly circular to highly irregular, depending on hydrogeological conditions in the vicinity of the well. Ground water and any dissolved contaminants within the area of influence potentially may be drawn into the well. Monitoring wells within the area of influence thus may provide advance warning of contaminated water being drawn toward the production well. The size and shape of a well's area of influence can be estimated with knowledge of the aquifer characteristics and the production well's pumping rate. Techniques ranging from simple calculations to computer modeling may be required, depending on the complexity of the subsurface conditions.

Decision Point 12. Is the well located within the plume boundary?

The delineation of plume boundaries is an important element in constructing a plume map for use with a decision tree. The basis for delineating plume boundaries should be negotiated with regulators prior to constructing a plume map. Plume maps based upon MCLs depict the horizontal extent of only those parts of the plume in which concentrations are above regulatory limits. The SDT is designed to be used with a plume map that depicts as nearly as possible the maximum measurable size of the entire contaminant plume. Plume map boundaries based on MCL concentrations may satisfy regulatory requirements, but because they depict only the central mass of the plume and omit the fringes, they do not give a true picture of the full size of the plume. Thus, a well that appears outside the plume on a map based on MCLs might appear within the plume if the boundary were based on the MDL.

The MDL is not ideally suited to represent the measurable plume boundary. This is due to variability in laboratory procedures, instruments, and samples. It is important that definitive criteria be established that allow the application of the SDT. While the cleanup boundary of the plume is represented by the MCL, a decision boundary should be established by extending the isoconcentration lines to a value that is one-half the MCL so the SDT can function effectively. This value would perform the protective functions designed into the SDT. The decision for establishment of the plume boundary for application of the SDT should be made with full regulatory approval.

Current plume maps being used for the LTM optimization should be checked against previous plume maps. Differences should be resolved before proceeding. Computer-generated contour maps should always be reviewed by a geologist or hydrologist.

Decision Points 13, 17, 20 and 22. Were COCs detected in the most recent sample?

A negative answer at any of these DPs alerts the SDT user to the possibility that, after due evaluation, the goal of optimizing the LTM program might be advanced by abandoning the target well or reducing its sampling frequency.

Factors to be evaluated for each monitoring well include historical detection of COCs, the well's location with respect to the plume, its proximity to other contaminant sources or plumes, and whether or not it could be considered redundant.

Recommendation 15. Evaluate abandonment or multi-year sampling intervals.

Abandonment should be considered as a possible alternative for wells that are within the contaminant plume or are upgradient or remote from the plume if no COCs were detected in the most recent sample. Abandoning a well (Recommendation 4 narrative) is the preferred alternative when it can be justified, because it eliminates the possibility that the well can become a contaminant conduit, and because it eliminates any further expense related to the well. However, if the need for continued data from the well location outweighs the perceived liabilities of maintaining the well, it may be beneficial to retain the well in the LTM program and sample it at longer intervals. Multi-year sampling intervals (e.g., 2-year, 3-year, 4-year, 5-year) still allow periodic assessments of the condition of the aquifer at the well, but associated sampling and analytical costs are reduced.

Decision Point 16. Is the well horizontally or vertically upgradient or remote from the contaminant plume?

The locations of monitoring wells outside the plume are defined in relation to ground-water movement. Ground water flows "downstream" along a **hydraulic gradient** from areas of higher head (i.e., upgradient areas) to areas of lower head (i.e., downgradient areas). Thus, the plume's leading edge, or "toe," is said to be downgradient from the source of contamination located at the upgradient end of the plume.

All plumes are three-dimensional and have both vertical and horizontal components to their migration. Decisions based on the relationship of a well screen to a plume's migration pathway must include consideration of the three-dimensional aspects of plume migration.

Upgradient wells are located "upstream" from the plume on the hydraulic gradient (MW-1,

Figure A-2). They provide background information on the composition of the ground water before it reaches the contaminant source.

Remote wells, for the purposes of the SDT, are defined as monitoring wells that are farther from the plume than the estimated maximum distance that the plume can travel in a year (MW-5, Figure A-2). The dividing line between near and remote wells should be based on site-specific aquifer and contaminant characteristics.

Upgradient wells and remote wells are unlikely to be affected by conditions within the plume. However, they may still be affected by other known contaminant plumes or by contaminants originating from unknown sources.

Recommendation 18. Evaluate the need for additional investigation.

The detection of COCs in an upgradient or crossgradient well or a well remote from the plume is a potential indication that an unknown source may be operating or that the well has been impacted by a second plume. The need for an investigation to determine the reason for the appearance of the COCs in the well should be evaluated.

Decision Point 19. Is the well crossgradient from the contaminant plume?

Crossgradient wells are located adjacent to the plume and perpendicular to its three-dimensional direction of migration (MW-3, Figure A-2). They may become contaminated if the plume branches or changes direction due to a shift in the direction of the hydraulic gradient. Such a directional shift can be caused by, for example, the startup of an adjacent pumping well.

Statement 21. The well is horizontally or vertically downgradient from the contaminant plume.

Downgradient wells are located “downstream” from the plume on the three-dimensional hydraulic gradient (MW-4, Figure A-2). They are in the path of the plume as it migrates downgradient and will become contaminated when/if the plume reaches them. Downgradient wells on receptor pathways (DP-23 narrative) can give advance notice when the target plume approaches an active production well and can also be affected by unknown sources. However, it is generally assumed that the detection of COCs in a previously uncontaminated downgradient well indicates that the leading edge of the target plume has reached the well location to be confirmed in future sampling events.

Decision Point 23. Is the well on a receptor pathway?

A receptor pathway is defined as the subsurface route that contamination would potentially travel from a plume or contaminant source to a receptor (e.g., an active production well). The receptor pathway may not lead in a straight line from the plume to the receptor. The actual contaminant pathway is dependent on subsurface geology and localized head conditions. Aquifer testing is recommended to determine if a well is on a receptor pathway.

If the receptor is an active production well, the receptor pathway extends from the plume to the edge of the well's area of influence. The area of influence of a production well is discussed in the narrative for DP-10.

NO INFORMATION WRITTEN ON THIS PAGE.

APPENDIX B. RECOMMENDED READING

Ahlfeld, D. P., and E. H. Hill. 1996. The sensitivity of remedial strategies to design criteria. Ground Water. v. 34, no. 2, pp. 341-348.

Ahlfeld, D. P., and M. Heidari. 1994. Applications of optimal hydraulic control to ground-water systems. Journal of Water Resources Planning and Management. v. 20, pp. 350-365.

Ahlfeld, D. P., and C. S. Sawyer. 1990. Well location in capture zone design using simulation and optimization techniques. Ground Water. v. 28, no. 4, pp. 507-512.

Ahlfeld, D. P., J. M. Mulvey, and G. F. Pinder. 1988. Contaminated groundwater remediation design using simulation, optimization, and sensitivity theory 1. Model development. Water Resources Research. v. 24, no. 3, pp. 431-441.

Ahlfeld, D. P., J. M. Mulvey, and G. F. Pinder. 1988. Contaminated groundwater remediation design using simulation, optimization, and sensitivity theory 2. Analysis of a field site. Water Resources Research. v. 24, no. 3, pp. 443-452.

Ahlfeld, D.P., R. H. Page, and G. F. Pinder. 1995. Optimal ground-water remediation methods applied to a Superfund site: from formulation to implementation. Ground Water. v. 33, no. 1, pp. 58-70.

Air Force Center for Environmental Excellence. March, 1996. Model Field Sampling Plan. Version 1.0.

Backus, D. A., J. N. Ryan, D. M. Groher, J. K. MacFarlane, and P. M. Gschwend. 1993. Sampling colloids and colloid-associated contaminants in ground water. Ground Water. v. 31, pp. 466-479.

Bangsund, W. J., Peng, C. G., and Mattsfield, W. R. Investigation of contaminant migration by low-flow rate sampling techniques. pp. 311-321.

Barcelona, M. J., H. A. Wehrman, M. R. Schock, M. E. Sievers, and J. R. Karny. Sampling frequency for ground-water quality monitoring. EPA/600/4-89/032.

Cameron, K. and P. Hunter. 2002. Using Spatial Models and Kriging Techniques to Optimize Long-Term Groundwater Monitoring Networks: A Case Study. *Environmetrics.* v.13, pp. 629-656.

Culver, T., and C. D. Shoremaker. 1992. Dynamic optimal control for groundwater remediation with flexible management periods. Water Resources Research. v. 24, no. 3, pp. 629-641.

Dielman, S., Y. M. Sternberg, and C. F. McLane. 1993. Design and evaluation of a ground water monitoring well network. Superfund XIV Conference and Exhibition Proceedings. v. 1, pp. 316-322.

Driscoll, F. G. 1986. Groundwater and Wells. Johnson Division. 1089 p.

GeoTrans, Inc. MODMAN facts sheet.

Gibbons, R. D. 1991. Some additional nonparametric prediction limits for groundwater detection monitoring at waste disposal facilities. Ground Water. v. 29, no. 5, pp. 729-736.

Gorelick, S., C. I. Voss, P. E. Gill, W. Murray, M. A. Saunders, and M. H. Wright. 1984. Aquifer reclamation design: the use of contaminant transport simulation combined with nonlinear programming. Water Resources Research. v. 20, no. 4, pp. 415-427.

Greacen, J., and K. A. Silvia. A comparison of low flow vs. high flow sampling methodologies on groundwater metals concentrations. pp. 345-353.

International groundwater modeling center. Groundwater Software Catalog. 1995.

Javandel, I., and C. Tsang. Capture-Zone Type Curves: A tool for aquifer cleanup. Ground Water. v. 24, no. 5, pp. 616-625.

Johnson V., R. C. Tuckfield, M. N. Ridley, and R. A. Anderson. 1996. Reducing the sampling frequency of groundwater monitoring wells. Environmental Science & Technology. v. 30, no. 1, pp. 355-358.

Johnson, V., and L. Rogers. 1995. Location analysis in ground-water remediation using neural networks. Ground Water. v. 33, no. 5, pp. 749-758.

Kearl, P. M., N. E. Korte, and T. Cronk. Spring 1992. Suggested modifications to ground water sampling procedures based on observations from the colloidal boroscope. Ground Water Monitoring and Remediation. pp. 155-161.

Kearl, P. M., N. E. Korte, M. Stites, and J. Baker. Fall 1994. Field comparison micropurging vs. traditional groundwater sampling. Ground Water Monitoring and Remediation. pp. 183-190.

LINDO System, Inc. LINDO facts sheet.

Loaciga, H. A., R. J. Carbeneau, L. G. Everett, G. E. Fogg, B. F. Hobbs, and S. Rouhani. 1992. Review of ground-water quality monitoring network design. Journal of Hydraulic Engineering. v. 118, no. 1.

Marryott, R., D. Dougherty, and R. Stollar. Optimal groundwater management. Application of simulated annealing to a field-scale contamination site. Water Resources Research. v. 29, no. 4, pp. 847-860.

McKinney, D., and M. Lin. 1995. Approximate mixed-integer nonlinear programming methods for optimal aquifer remediation design. Water Resources Research. v. 31, no. 3, pp. 731-740.

McKinney, D., and M. Lin. 1996. Pump-and-treat ground-water remediation system optimization, Journal of Water Resources Planning and Management. v. 122, no. 2, pp. 128-136.

Medina, M. A., T. Jacobs, W. Lin, and K. Lin. 1996. Ground water solute transport, optimal remediation planning, and decision making under uncertainty. Water Resources Bulletin. v. 32, no. 1.

Meyer, P. D., and E. D. Brill. 1988. A method for locating wells in a groundwater monitoring network under conditions of uncertainty. Water Resources Research. v. 24, no. 8, pp. 1277-1282.

Nielsen, D. M. 1991. Practical Handbook of Ground-Water Monitoring. 717.

Powell, R. M., and R. W. Puls. 1993. Passive sampling of groundwater monitoring wells without purging: multilevel well chemistry and tracer disappearance. Journal of Contaminant Hydrology. v. 12, pp. 51-77.

Puls, R. W., and C. J. Paul. Winter 1995. Low-flow purging and sampling of groundwater monitoring wells with dedicated systems. Ground Water Monitoring and Remediation. pp. 116-123.

Puls, R. W., and R. M. Powell. 1992. Acquisition of representative ground water quality samples for metals. Groundwater Monitoring Review. v. 12, no. 3, pp. 167-176.

Ridley, M. 1995. Cost-effective sampling of groundwater monitoring wells. The Regents of UC/LLNL. pp. 1-10.

Rogers, L. L., F. U. Dowla, and V. M. Johnson. 1995. Optimal field-scale groundwater networks and the genetic algorithm. Environmental Science Technology. v. 29, pp. 1145-1155.

Sanders, T. G., R. C. Ward, J. C. Loftis, T. D. Steele, D. Adrian, and V. Yevjevich. 1987. Design of Networks for monitoring water quality. Water Resources Publications.

Smith, S. S., with Wisconsin Water Well Association. 1994. Well & Borehole Sealing: Importance, Materials, Methods, and Recommendations for Decommissioning, Ground Water Publishing Co.

Tiedeman, C., and S. Gorelick. 1993. Analysis of uncertainty in optimal groundwater contaminant capture design. Water Resources Research. v. 29, no. 7, pp. 2139-2153.

Tuckfield, R. C. 1994. Estimating an appropriate sampling frequency for monitoring groundwater well contamination. Nuclear Material Management. v. 232, pp. 80-85.

United States Environmental Protection Agency. Evaluation of sampling and field-filtration methods for the analysis of trace metals in ground water. EPA/600/R-94/119.

United States Environmental Protection Agency. Methods for monitoring pump-and-treat performance. EPA/600/R-94/123, pp. 102.

United States Environmental Protection Agency. 1994. Methods of monitoring pump-and-treat performance. EPA/600/R-94/123.

United States Environmental Protection Agency. RCRA ground-water monitoring: Draft technical guidance. EPA/530-R-001.

Ward, R. C., J. C. Loftis, K. S. Nielsen, and R.D. Anderson. 1979. Statistical evaluation of sampling frequencies in monitoring networks. Journal of Water Pollution Federation. v. 51, pp. 2292-2300.

Wilson, C. R., C. M. Einberger, R. L. Jackson, and R. B. Mercer.1992. Design of groundwater monitoring networks using the monitoring efficiency model (MEMO). Ground Water. v. 30, no. 6, pp. 965-970.

Wilson, C. R., C. M. Einberger, R. L. Jackson, and R. B. Mercer. 1992. Efficiency-based groundwater design using the monitoring efficiency model (MENO). Groundwater Monitoring Design. pp. 915-917.

Xiang, Y., J. F. Sykes, and N. R. Thomson. 1995. Alternative formulations for optimal ground-water remediation design. Journal of Water Resources Planning and Management. v. 121, no. 2, pp. 171-181.