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Site Specific Report

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NAVAL AIR STATION PATUXENT RIVER LONG-TERM MONITORING OPTIMIZATION CASE STUDY

August 1999

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

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FINAL

NAVAL AIR STATION PATUXENT RIVER LONG-TERM MONITORING OPTIMIZATION CASE STUDY

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LIST OF ACRONYMS

bgl	below ground level
BTEX	benzene, toluene, ethylbenzene, xylenes
CERCLA	Comprehensive Environmental Response, Compensation, and Liability Act
EPA	Environmental Protection Agency
ERM	Environmental Resources Management
GIS	geographic information system
HDPE	high-density polyethylene
IRA	interim remedial action
LTM	long-term monitoring
MCL	Maximum Contaminant Level
MDE	Maryland Department of the Environment
msl	mean sea level
NAS	Naval Air Station
NOV	Notice of Violation
NPL	National Priorities List
PCBs	polychlorinated biphenyls
QA/QC	Quality Assurance/Quality Control
RCRA	Resource Conservation and Recovery Act
ROD	Record of Decision
SVOCs	semivolatile organic compounds
TAL	Total Analyte List
TCE	trichloroethene
TCL	Total Compound List
TPH	total petroleum hydrocarbons
UST	underground storage tank
VOCs	volatile organic compounds

EXECUTIVE SUMMARY

ES.1 Purpose of the Plan

The purpose of this case study is to evaluate the long-term monitoring (LTM) programs for two sites at Naval Air Station (NAS) Patuxent River, Maryland. Specific recommendations to streamline LTM and avoid some of the costs associated with LTM at the Former and Current Landfills and the Fuel Farm are included in this case study. A discussion of closeout strategy for these sites is also presented. In addition, best practices that have been implemented at the landfills and the fuel farm and may be incorporated into the strategy of other facilities are documented in this plan.

ES.2 Optimization Approach

The approach used to evaluate and optimize the LTM programs at NAS Patuxent River includes an assessment of five basic areas:

- The number of monitoring points;
- The efficiency of current field procedures;
- The duration and frequency of monitoring;
- The analyte list and analytical methods; and
- Reporting and data management protocols.

ES.3 Former and Current Landfills

The Former Landfill is located adjacent to and upgradient from the Current Landfill (Figure 3-1). The Former and Current Landfills are being monitored as one site, and for the purpose of this document will be referred to as "the landfill."

The landfill occupies approximately 16.5 acres in the southern portion of the Base. Disposal operations began at the site in 1974 and continued for approximately 20 years. Contamination of groundwater by organic and inorganic compounds has resulted from site operations. A landfill cap was installed as an interim remedial action (IRA) in 1996-1997 to officially close the site. An adjacent site, Site 34, has evidence of contamination due to drum disposal but has not yet been fully investigated.

The landfill is a Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) National Priorities List (NPL) site. An LTM program is being conducted at this site to assess the effectiveness of the landfill cap. This monitoring program includes groundwater, surface water, sediment, leachate, and landfill gas. This case study focuses on the most costly aspect of this program, the groundwater monitoring.

There have been several commendable examples of program streamlining in the landfill IRA, LTM, and performance monitoring programs. These include:

- Using on-site borrow to reduce the construction costs of the landfill cap;
- Negotiating quarterly monitoring instead of the State-proposed monthly monitoring; and
- Exploring contracting options and mechanisms to identify potential cost savings.

ES.3.1 Recommendations

Following an assessment of the landfill and associated documents, recommendations regarding site closeout, LTM strategy, and landfill cap performance monitoring were formulated.

Site Closeout—In preparation for the 5-year review of the LTM program, several things should be considered:

- In anticipation of the final Record of Decision (ROD) for the site, the Base should identify decision criteria for determining when monitoring at the site, or for a specific monitoring point, may be stopped.
- Several rounds of natural attenuation data may be instrumental in convincing regulators that no active remediation is necessary at the landfill or Site 34. A program to collect such data should be considered.
- Combined monitoring of groundwater at the landfill and Site 34 should be investigated, in case the State requires an LTM program at Site 34. Combining these sites is likely to reduce the overall number of monitoring wells in the program.
- Cost and performance data for the flare system should be tracked to continually assess site progress and prepare for the 5-year review.
- Contaminant trends in groundwater should be tracked to continually assess site progress and prepare for the 5-year review.

Long-Term Monitoring— Following is a summary of specific recommendations made for the LTM program at the landfill:

- Consider eliminating two or three wells from the LTM program this year. Conduct a statistical analysis next year to determine if additional wells may be eliminated.
- Pursue a reduction to semiannual monitoring with regulators following the reporting of four quarters of data.
- Investigate the potential for using micropurging techniques by determining if well recharge is adequate. If so, consider installation of a dedicated sampling system to save labor, eliminate equipment blanks, and improve sample quality.
- Reduce the analyte list by eliminating compounds not detected in the first year of sampling. Also, consider eliminating dissolved metals and decreasing QA/QC sample rates.
- Take advantage of the service contract in place to provide geographic information system (GIS) and electronic data handling support. With this support, use data analysis tools to enhance decision-making.
- Streamline the reporting effort by focusing on graphic and tabular data presentations and consolidating all reports for a year in one binder.

Performance Monitoring— Although an in-depth assessment of landfill cap performance monitoring was not made, there is one recommendation for improving the efficiency of weekly landfill gas monitoring. By modifying the sampling ports so that they can be accessed from the surface, rather than by entering the vaults in which they are currently housed, sampling time can be decreased. In addition, the safety of the operation will be increased.

ES.3.2 Benefits

The benefits of applying the above recommendations include a potential LTM program cost savings of over 25% of the current budget, prior to reducing sampling frequency from quarterly to semiannually. In addition to the cost savings, adopting these recommendations has the potential to improve data and report quality as well as sampling personnel safety.

ES.4 The Fuel Farm

The fuel farm occupies more than 12 acres in the northwest portion of the Base. Fuel handling operations began at the site in the early 1940s but are inactive today. Possible leaks from tanks and pipelines have resulted in the contamination of soil, groundwater, and surface water. Several investigations and technology demonstrations have taken place at the site from the late 70s to the present.

The fuel farm is an underground storage tank (UST) site and falls under State of Maryland UST regulations. Groundwater sampling has been conducted in some or all of the site's 90 wells nine times since 1984. A tank and soil removal action took place early in calendar year 1999 and a formal LTM program has been started at the fuel farm.

NAS Patuxent River has been proactive in assessing innovative remedial actions for the fuel farm. As a result of these assessments, viable remedial alternatives, such as mobile bioslurping and a pump and treat system, have been implemented. In addition, a significant amount of data that could be used to support a natural attenuation remedy have been collected.

ES.4.1 Recommendations

Following an assessment of the fuel farm and associated documents, recommendations regarding site closeout, LTM program design, and system performance monitoring were formulated.

Site Closeout—Several strategies for negotiating eventual site closeout should be considered now that the removal action and first round of monitoring has been completed:

- Several bioremediation studies have been conducted at the site, with promising results. Additional natural attenuation data should be collected to support decisions to shut down active treatment systems when appropriate.
- Decision criteria should be formulated now so that decisions regarding shutting down remedial systems, stopping monitoring, and closing out the site can be made when appropriate.
- Collection of cost and performance data for the treatment system and contaminant trends in groundwater should be tracked to continually assess site progress and support a possible natural attenuation remedy.

Long-Term Monitoring— Following is a summary of specific recommendations made for the upcoming LTM program at the fuel farm:

- Eliminate 60% of the site wells from the fuel farm LTM program. Continue to assess the potential for eliminating additional wells on an annual basis.
- Investigate the potential for using micropurging techniques by determining if well recharge is adequate. If so, consider installation of a dedicated sampling system to save labor, eliminate equipment blanks, and improve sample quality.
- Pursue an appropriate sampling frequency for wells remaining in the LTM program to limit costs and facilitate trend analysis.
- Pursue an appropriate analyte list for site contaminants, focusing on specific analytes of regulatory significance.
- Take advantage of the service contract in place to provide GIS and electronic data handling support. With this support, use data analysis tools to enhance decision-making.

- Streamline the reporting effort by focusing on graphic and tabular data presentations and consolidating all reports for a year in one binder.

Performance Monitoring— Although an in-depth assessment of system performance monitoring was not made, there are a few recommendations for improving this task. These are to:

- Track contaminant mass removal and cost per pound data to support decisions regarding future shutdown of active remedial systems;
- Conduct bail-down tests so that true product thickness can be determined; and
- Better define the potentiometric surface at the site.

ES.4.2 Benefits

Eliminating over 60% of the wells at the site from the LTM program design will decrease the LTM budget by approximately the same percentage without compromising the quality of the program. Other benefits of the suggestions cited for the fuel farm include the potential for earlier shutdown of active remedial systems, via a natural attenuation alternative, and improved data and report quality.

1.0 INTRODUCTION

The following sections explain the purpose, approach, and content of the case study.

1.1 Purpose and Objectives

The primary purpose of this case study is to assess the long-term monitoring (LTM) strategy and progress for the Former and Current Landfills and the Fuel Farm at Naval Air Station (NAS) Patuxent River, Maryland. Included in this approach are recommendations to optimize any LTM programs that must continue, along with a discussion of site closeout decisions supported by LTM data. The objectives of this report are to:

- Evaluate ongoing LTM programs and make recommendations if cost reductions can be implemented without a loss of quality;
- Assess the site closeout strategy and decision making related to the LTM programs for the landfill and fuel farm sites, and provide recommendations that would help to optimize this strategy; and
- Document best practices that have been implemented at the Base and may be incorporated into the strategy of other bases.

1.2 Document Organization

The remainder of Section 1 outlines the approach that is followed to formulate optimization recommendations for the LTM program. The rest of the document is organized as follows:

Section 2.0, Location and Physical Setting of NAS Patuxent River— This section gives the general location of the installation, as well as a description of the local geology, hydrology, and geography.

Section 3.0, Former (Site 11) and Current Landfills—This section describes the status and regulatory framework of active monitoring at the landfill, as well as best practices that have already been implemented for this program. On the basis of site information, LTM and performance monitoring optimization recommendations, including an estimate of potential cost avoidance and effects on data quality, are provided.

Section 4.0, Fuel Farm (Site UST 1)—This section follows the same format as Section 3.0, but presents recommendations for the design of the upcoming LTM program at the fuel farm.

Section 5.0, References—This section provides a list of the documents cited in the report.

1.3 Optimization Approach

This case study focuses on ways to reduce the resources expended on sites with ongoing LTM of groundwater without sacrificing program quality or protectiveness. There are five general optimization strategies that may be used to increase cost effectiveness of LTM programs. They include:

- Reducing the number of monitoring points;
- Assuring efficient field procedures;
- Reducing monitoring duration and/or frequency;
- Simplifying analytical protocols; and
- Streamlining data management and reporting.

Figure 1-1 shows a graphic representation of the above process. In addition, Table 1-1 includes more detailed rationale for each of these strategies.

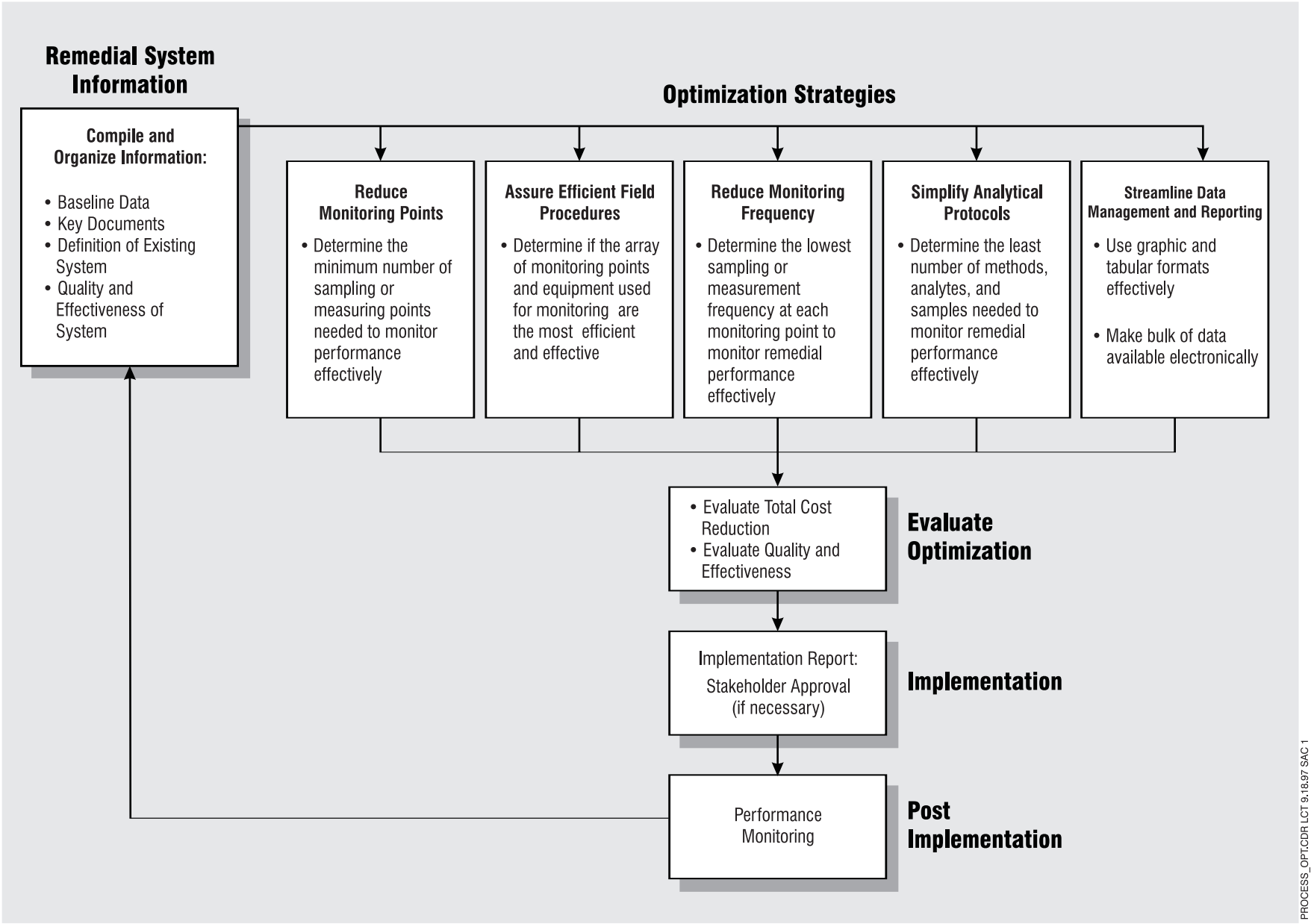

Figure 1-1. LTM Program Optimization Process

Table 1-1
Application of the LTM Program Optimization Strategies to NAS Patuxent River

Optimization Strategy	Example Data for NAS Patuxent River	Example Optimization Rationale
Reduce the number of monitoring points	Constituent concentrations collected at a specific monitoring point (e.g., contaminant concentrations in a particular groundwater monitoring well)	• If points were not sampled, the same decisions about contaminant extent or remedial performance can be made with data from other points in the monitoring system. • The contamination has been drawn away from the monitoring point by the remedial action. • Concentrations obtained at other monitoring points are more representative and reliable than at this monitoring point. • The potential for lateral or vertical migration to this monitoring point has been eliminated or decreased; therefore, monitoring the point is unnecessary. • Concentrations at this monitoring point have reached and consistently remained below the cleanup goal; continued sampling is not necessary. • The concentrations obtained from this point have historically been redundant with adjacent points (i.e., identical or similar results).
	Nonchemical data measured at a monitoring point (e.g., water level measurements)	• The measurements from this location have stabilized (leveled off in four or five most recent events); therefore, additional measurements from the point are unnecessary. • Measurements obtained from this point have historically been redundant with adjacent points. • The same decision about contaminant extent or remedial performance could have been made with data from the remaining monitoring points if this point was not measured.
	Sampling or measuring point depth	• Sampling or measurements are no longer required at a specific depth because vertical migration is observed not to be occurring or cleanup at that particular depth is complete
Reduce measurement frequency	Contaminant concentrations in samples	• The data collected from one season, or one time of day, are more representative of conditions than other times; therefore, sample/measure at the most representative time only. • Concentrations or measurements have stabilized or reached an asymptotic level; changes can be monitored with sampling at a lesser frequency.
	Velocity of contaminant migration in soil gas or percolating water (from permeability and gradient data)	• The monitoring frequency can be decreased such that time between sample collections is more than the minimum time interval necessary for the contaminant to migrate between monitoring points.

Table 1-1
(Continued)

Optimization Strategy	Example Data for for NAS Patuxent River	Example Optimization Rationale
Simplify analytical protocols	Constituent concentration data collected at a particular monitoring point	• Sampling for methods currently being performed can be deleted if the method is not needed to demonstrate cleanup progress, remedial performance, or natural attenuation. • The total time interval of sampling for undetected, "potential" analytes should be limited; delete analyses for potential contaminants if they have not been detected in the first year of samples (not to include degradation products). • Analyses should be performed only with the method(s) appropriate for indicator compounds or elements that are most indicative of contaminant extent.
	Historical quality control assessments	• Precision, accuracy, representativeness, and completeness of methods have been historically demonstrated; QC sampling and analyses can be reduced with no loss of quality.
Ensure efficient field procedures	Data acquisition methods	• Measuring points that are not open (for example, screened) at the proper depth or horizontal location to provide accurate measurements should not be monitored. • Purging and sampling methods should be the most cost effective methods available without compromising sample quality. • An automated recording device/data logger/telephonic transmitter may be added to critical locations to improve the timing of measurements and save labor costs over the time interval of monitoring.

2.0 LOCATION AND PHYSICAL SETTING OF NAS PATUXENT RIVER

2.1 Location of NAS Patuxent River and Case Study Sites

NAS Patuxent River is a 6,800-acre naval installation that has been in operation since 1942. Located 68 miles south of Washington D.C. in St. Mary's County, Maryland, the installation is situated at the confluence of the Patuxent River and Chesapeake Bay. Figure 2-1 shows the general location of the Base.

The Former (Site 11) and Current Landfills are located near the southern border of the NAS, approximately 1.5 miles southeast of the main gate. This site consists of two sanitary landfills, the 6.5-acre Former Landfill that was operated as the station landfill from 1974 to 1980, and the 10-acre Current Landfill, which was active until 1994. This site will be referred to as "the landfill" for the purpose of this case study.

The Fuel Farm (Site UST 1) is located in the central portion of the installation. This site consists of several aboveground and underground storage tanks and is one of the two primary fuel storage sites at NAS Patuxent River. This site originated in the 1940s and is inactive today. Several interim remedial actions have taken place at the site, including installation of fuel recovery trenches and an associated pump and treat system.

2.2 Physical Setting

This section describes the geology, hydrogeology, and geography at NAS Patuxent River. The information in this section is summarized from the *Hydrogeologic Study of the Former and Current Sanitary Landfills* (CH2M HILL, 1990) and the draft unpublished *Remedial Investigation for Sites 11, 28, and 34* (CH2M HILL, undated).

2.2.1 Geology

NAS Patuxent River is located in the Atlantic Coastal Plain geologic province. The Atlantic Coastal Plain consists of unconsolidated sediments ranging in size from clay to gravel. These sediments were eroded from the Appalachian and Piedmont geologic provinces to the west. They were transported by fluvial processes and deposited in alluvial fans and as tidal marine muds during advance and retreat of the ocean. Approximately 2000 feet of these sediments overlie the Precambrian igneous and metamorphic bedrock in this area.

2.2.2 Hydrogeology

Surface water—Bordered by the Patuxent River and Chesapeake Bay, over 25 miles of shoreline ranging from sandy beaches to tidal marshes line three sides of the installation. Other important aquatic features at NAS Patuxent River include three seaplane basins, six man-made freshwater ponds, and three tidal creeks.

Groundwater—Surficial deposits of the Atlantic Coastal Plain, which are recharged by precipitation, make up the shallowest aquifer underlying NAS Patuxent River. This aquifer discharges to the surface water on Base. The surficial aquifer is separated from two deeper aquifers, the Nanjemoy and Piney Point aquifers, by the clays and silts of the Choptank and Calvert Confining Beds. These deeper aquifers occur between 250 and 400 feet below mean sea level (msl).

The aquifer used for domestic water supply for NAS Patuxent River and nearby residents is the Aquia Formation. This aquifer occurs at approximately 400 to 600 feet below msl. Several other aquifers, separated by confining layers, occur between the Aquia Formation and the Precambrian bedrock. All of the aquifers beneath the surficial aquifer are recharged to the west where these formations outcrop.

2.2.3 Geography

Approximately 17,500 military, civilian, and contract personnel work at NAS Patuxent River. The nearest community to the installation is Lexington Park, Maryland, with a population of approximately 10,000.

Land use around NAS Patuxent River includes residential, park, industrial, and commercial properties. On Base, natural areas such as wetlands and wooded areas are interspersed with developed land that houses administrative and mission related buildings and airfield facilities. It is not anticipated that land use, either on- or off-Base, will change significantly in the foreseeable future.

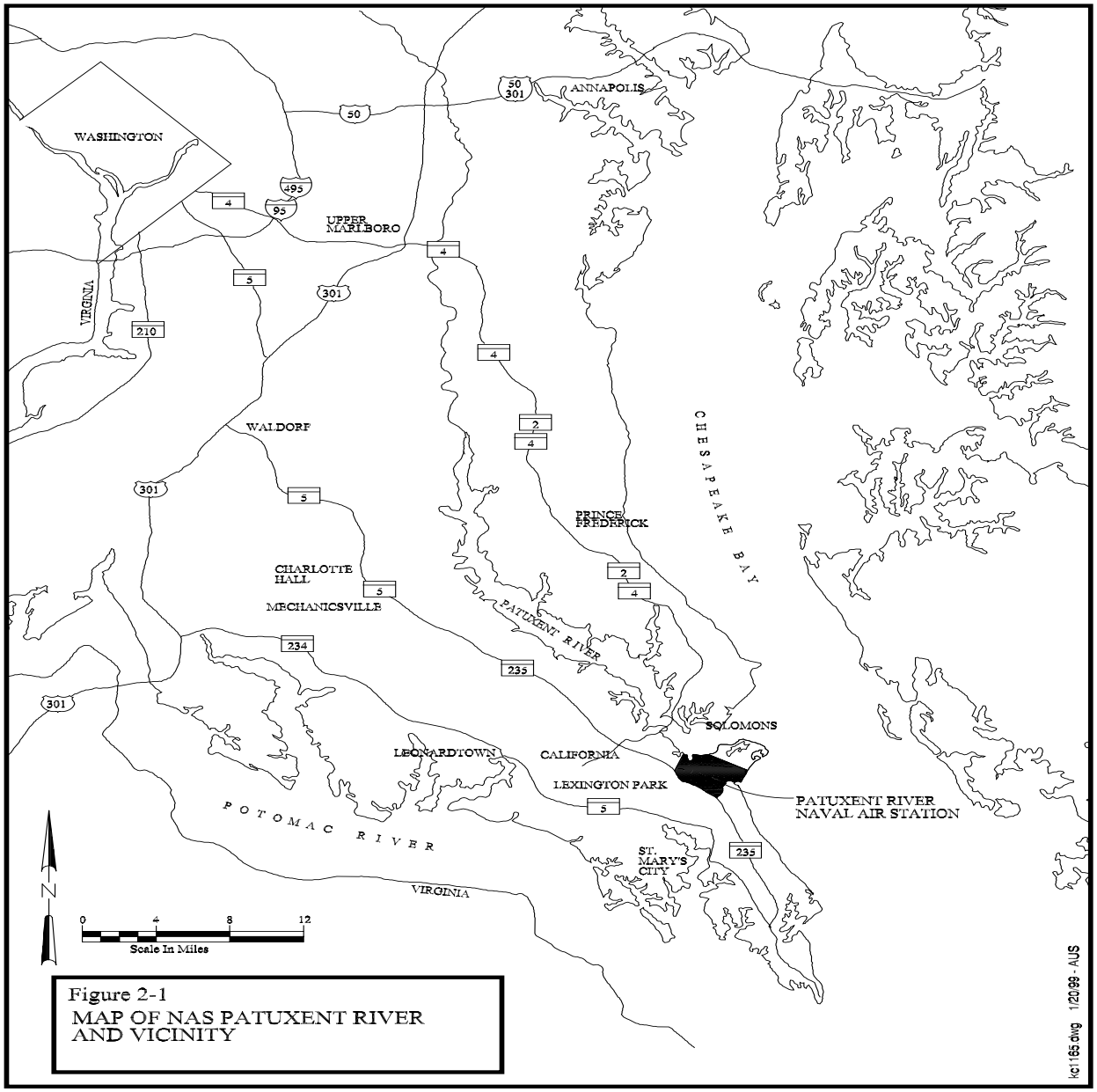

Figure 2-1
MAP OF NAS PATUXENT RIVER AND VICINITY

3.0 FORMER (SITE 11) AND CURRENT LANDFILLS

The following section outlines the background information for the landfill and presents the recommendations for LTM optimization at the site.

3.1 Site Background

The information in this section is taken primarily from the Operation and Maintenance Plan for the site (NAS Patuxent River, Maryland, September 1998) and the Record of Decision (ROD) that was put in place in July 1996 (Department of the Navy Environmental Program, July 1996).

3.1.1 Physical Setting

The landfill occupies approximately 16.5 acres in the southern portion of the installation. A predominantly coniferous forest surrounds the site on all sides, and intermittent streams border the site to the east and the west. Surface elevations at the site range from approximately 60 to 110 feet above msl. Figure 3-1 shows the layout of the site.

Groundwater elevation at the site ranges from 50 to 80 feet above msl. Depth to water in the site monitoring wells is typically 15 to 20 feet below ground level (bgl), with the exception of one well located along the southeast boundary of the landfill where groundwater is only 3 to 5 feet bgl. Groundwater flow is generally north-northeast at the site. The rate of groundwater flow is estimated at 0.2 to 100 feet per year. This variability is due to the three order-of-magnitude range of hydraulic conductivities on site.

Surface water at the site flows north into a small pond, which in turn flows into another drainage to the east that leads to Chesapeake Bay.

The soils at the site consist of unconsolidated coastal plain sediments, including sands, silts, clays, and gravels.

3.1.2 Site History

Disposal operations at the Former Landfill began in the spring of 1974 and ended in 1980. This unlined landfill is estimated to have received 22,500 tons of paper and plastic trash and 43 tons of oil-contaminated solid and liquid wastes, including petroleum, oils, lubricants, solvents, thinners, paints, and small amounts of pesticides and photographic wastes. Liquid wastes occurred primarily as residues left in cans and on rags and absorbents. Soils to cover the wastes were taken from an adjacent borrow pit.

Disposal operations began at the Current Landfill in 1980, when the Former Landfill was closed. The Current Landfill, which is regulated under Resource Conservation and Recovery Act (RCRA) Subtitle D, is on the site of the borrow pit that was located adjacent to the Former Landfill. A liner and leachate collection system were installed during the construction of this landfill, which is estimated to have received 145,000 tons of municipal waste. From November 1991 to its closure in September 1994, the Current Landfill accepted rubble fill and clean fill only.

The Former and Current Landfills were closed in 1997. Construction of a RCRA Subtitle D cap over both landfills was begun in June 1996 and completed in February 1997. From the waste up, cap construction includes 24 inches of compacted soil, a 40-mil high-density polyethylene (HDPE) geomembrane, a geocomposite drainage layer, 18 inches of cover soil, and 6 inches of top soil covered with high-quality vegetation. In addition, a landfill gas collection system was installed at the time of closure.

3.2 Site Activity Status

A monitoring program is being conducted at the landfill to determine the

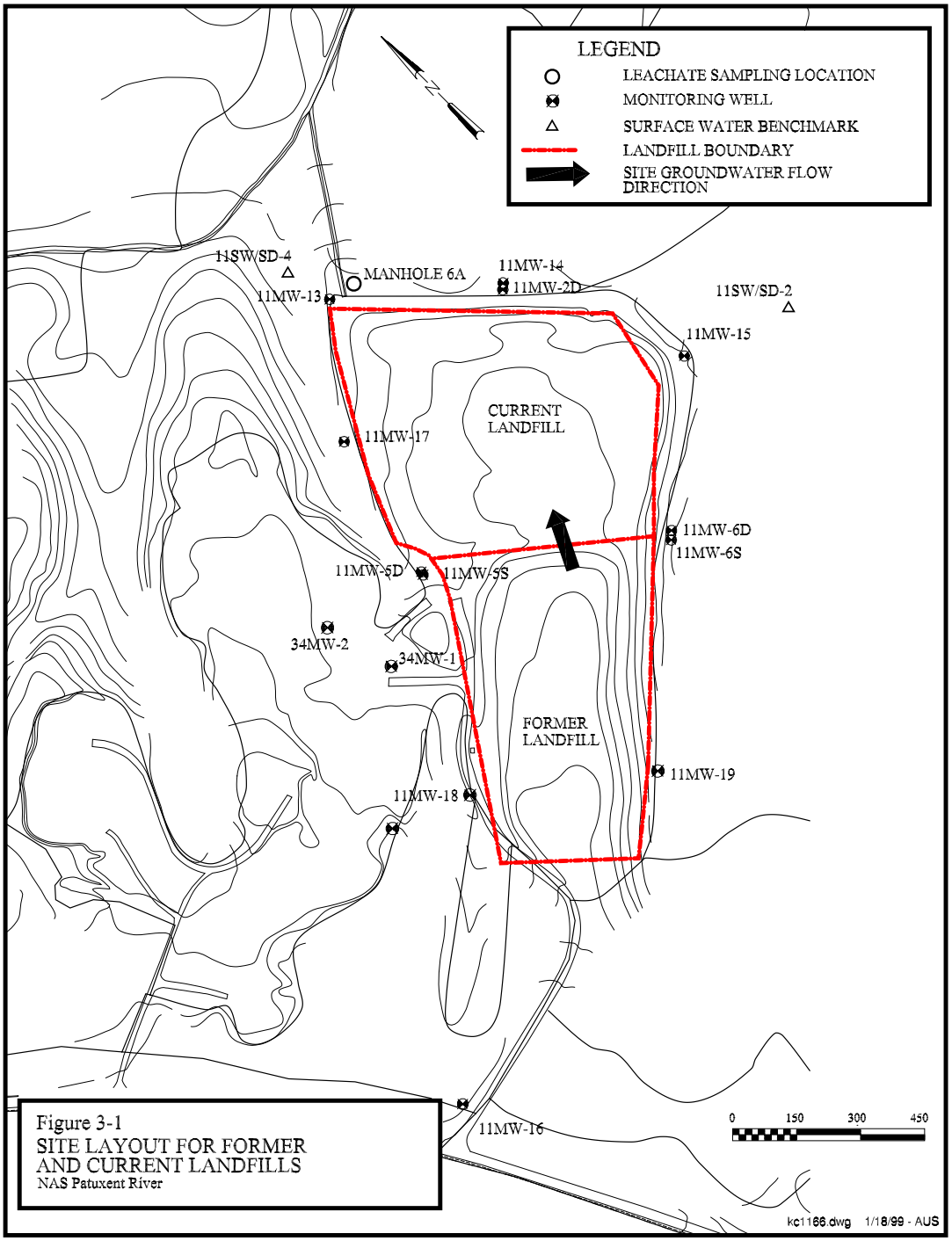

Figure 3-1
SITE LAYOUT FOR FORMER AND CURRENT LANDFILLS
NAS Patuxent River

effectiveness of the landfill cap. The monitoring program at the site includes groundwater, surface water, sediment, landfill gas, and leachate.

The groundwater LTM program at the landfill includes quarterly monitoring at 12 wells. Eleven of these wells are located around the perimeter of the site, with a twelfth well located upgradient. Figure 3-1 shows the site and the monitoring well network. Samples collected from these wells are analyzed for Total Analyte List (TAL) metals (total and dissolved) and Total Compound List (TCL) organics. A complete analyte list is included in Appendix A. Water level measurements are also collected at each well on a quarterly basis.

In addition to groundwater monitoring at the site, two surface water and sediment samples are also collected quarterly and analyzed for TAL metals (total only) and TCL organics. One leachate sample is collected from a sanitary sewer manhole for these same analytes. Six landfill gas monitoring probes are monitored quarterly for percent lower explosive limit and methane.

Four quarters of monitoring have been conducted since cap completion—in March, May, August, and December of 1998. The results of these sampling events have been submitted in quarterly reports (CH2M HILL, June 1998, August 1998, November 1998, and February 1999). The data for the final quarter of sampling has not yet been reported.

3.3 Regulatory Framework

Past disposal operations at the landfill have resulted in contamination to soil, groundwater, surface water, and sediment. The site is now a Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) National Priorities List (NPL) site.

The State of Maryland Department of the Environment (MDE) issued a Notice of Violation (NOV) in 1987 for the Current Landfill. The NOV stated that the landfill did not comply with the terms and conditions of the permit, and as a result stricter monitoring controls were enforced. The NOV required:

- Modification of the existing landfill to control leachate migration, management, and disposal;
- Preparation of a Groundwater Monitoring Plan with a discussion of the underlying groundwater quality and fluctuations;
- Submission of a monthly leachate monitoring report;
- Submission of a deed amendment; and
- Performance of monthly monitoring of well water elevations for submission with the landfill utilization annual report.

The Navy formally responded to the NOV with information documenting their compliance with the permit. Some additional measures were taken in 1995 to monitor and improve performance of the landfill. A flow meter was installed to keep a constant record of leachate volumes being collected and sent to the county for treatment. In addition, sediment and erosion control structures were repaired, the Current Landfill was graded to improve drainage, and slopes were stabilized.

NAS Patuxent River was put on the NPL in 1994, and an interim ROD for the site was signed in 1996. The interim ROD specified an interim remedial action (IRA) at the site, which included a landfill cap and associated landfill gas collection system. The interim ROD does not address the underlying groundwater. The final ROD for this site will be completed in approximately 2003, to coincide with the 5-year review period, and will include groundwater monitoring.

3.4 Best Practices Already in Place

There are several examples of best practices that NAS Patuxent River has already put in place to reduce operation and maintenance programs at the landfill. The following items may be evaluated by other installations seeking to reduce costs:

- Negotiated quarterly monitoring with the State, rather than the monthly monitoring initially proposed;
- Negotiated a less stringent and less costly Subtitle D landfill cap, versus a Subtitle C cap, thereby lowering potential operation and maintenance costs.
- Used an on-site borrow pit for landfill soil cover to significantly reduce cap construction costs;
- Evaluated innovative techniques, including vegetative cover and gas-to-energy studies, to assess potential cost savings;
- Used drought tolerant vegetation for cap cover;
- Used other government agencies, such as the U.S. Geological Survey, Fish and Wildlife, and the U.S. Army Corps of Engineers to assist them, where beneficial; and
- Investigated other contractor/contracting options to be sure they were using the most cost-effective approach.

3.5 Site Closeout Considerations

Although the landfill is in the early stages of LTM, it is important to consider site closeout strategies from the beginning. These strategies may include formulating decision criteria for eliminating wells and analytes, as well as ceasing monitoring altogether; assessing the role of natural attenuation at the site; and combining groundwater monitoring at adjacent sites to decrease the overall number of wells. Also, in preparation for the 5-year review and final ROD planned for 2003, it is advantageous to track certain types of data. These data include cost and performance tracking, contaminant trends, and natural attenuation data.

Decision Criteria—Following are recommended decision criteria that may be used to determine when monitoring at the site may be reduced or halted:

- Following four quarters of monitoring, the sampling frequency will be reduced to semiannual, unless site data indicate rapid changes to contaminant concentrations.
- Following four rounds of non-detect data, a specific compound will be removed from the site analyte list.
- Following three consecutive rounds of all analytes of concern detected at less than the maximum contaminant levels (MCLs), monitoring at the site will be stopped, provided the State-mandated 5-year monitoring period has been met or a variance obtained.

These decision criteria provide a measurable basis for reducing or terminating an LTM program.

Natural Attenuation Data—Collection of several rounds of natural attenuation data prior to the 5-year review may be instrumental in promoting a natural attenuation remedy as part of the final ROD. Natural attenuation indicator constituents, such as dissolved oxygen and total organic carbon, should be monitored quarterly for a year. Annual (or semiannual if significant seasonal variation is expected) monitoring can then be conducted until enough data have been collected to support the occurrence of natural attenuation. Several guidance documents are available for use in developing and implementing a natural attenuation program. Recommended guidance documents include:

- *Technical Guidelines for Evaluating Monitored Natural Attenuation at Naval and Marine Corps Facilities, Draft* (Department of the Navy, March 1998);
- *Technical Protocol for Evaluating Natural Attenuation of Chlorinated Solvents in Groundwater* (U.S. Environmental Protection Agency Office of Research and Development, 1998);
- *Guidance Handbook on Natural Attenuation of Chlorinated Solvents* (Remedial Technologies Development Forum, September 1996); and
- The U.S. Environmental Protection Agency's *Monitored Natural Attenuation Policy* (OSWER, 1997).

Combined Monitoring—One strategy that NAS Patuxent River may wish to consider for the landfill is the incorporation of groundwater from the adjacent drum dump, Site 34, into the final ROD for the landfill. Combining the two sites should result in fewer overall wells to be monitored, if further action is deemed necessary at Site 34.

Data Evaluation and Trend Analysis—In addition to natural attenuation data, there are several other types of data that should be tracked prior to the 5-year review. All program costs, as well as performance data, should be tracked over time. For the LTM program, contaminant trends (i.e., concentrations over time and concentrations over area) should be tracked in order to present an accurate picture of contaminant behavior. A spatial data analysis tool, such as a geographic information system (GIS), is particularly effective in presenting this information to regulators in a clear and concise way. More information regarding data analysis tools is presented in Section 3.6.6, and examples are given in Appendix B.

3.6 Recommended Optimization of Groundwater Monitoring

The following subsections outline suggestions for making the LTM program at the landfill more cost effective without compromising quality. These suggestions are based on the optimization strategy summarized in Section 1.3 of this case study. A summary of the site-specific recommendations is given in Table 3-1. It is important to note that, in evaluating these suggestions, regulator and community approval must also be considered.

3.6.1 Monitoring Point Reduction

One of the most effective ways to reduce LTM costs is to reduce the number of wells or other points sampled. This not only saves labor in the field, it reduces analytical, data management, and reporting costs. Although there is not a great number of wells being sampled as part of the LTM program at the landfill, there may be a few wells that can be eliminated without compromising quality. Typically,

> "monitoring points…placed during remedial investigation or pilot testing are more than the number needed for long term monitoring of a remedial system."

(Radian, 1997). The elimination of three monitoring wells from the LTM program would save approximately 25% in analytical and validation costs, and slightly less than 25% in sampling and reporting labor.

The groundwater LTM program at the landfill includes 12 monitoring wells. One of these is a background well. Three of the wells are deeper wells co-located with shallower wells to assess the potential for vertical migration of contaminants. To date, no contaminants have been detected in the deeper wells at concentrations above those seen in blanks.

One approach to determining if a well can be eliminated from an LTM program is to conduct a statistical analysis of concentrations in a well to determine if

Table 3-1. Summary of Recommendations for the Former and Current Landfills at NAS Patuxent River

Strategy	Site-Specific Recommendation(s)	Potential Cost Savings[1]/Benefits
Monitoring Point Reduction	1. Eliminate sampling 2 of the 3 deep wells (11MW-2D and -5D) until contaminants are detected in the co-located shallow wells (11MW-14 and -5S, respectively). 2. Eliminate sampling of 11MW-16 unless it can be shown that contaminants are coming from the landfill. Sample 11MW-19, which is already included in the LTM program, as the background well. 3. Following four quarters of data reporting, conduct a statistical analysis of the analytical data to determine if additional wells may be eliminated from the program. 4. Determine whether any wells are providing redundant data and eliminant the redundant well(s).	Eliminating 25% (3 out of 12) of the wells sampled each quarter would cut analytical and validation costs by 25%, or nearly $24,000 annually. Sampling and reporting labor will probably not be cut by an entire 25%, but there should be additional savings in these areas.
Duration and Frequency Reduction	1. Continue quarterly sampling until one full year of data are reported. Then pursue a reduction to semiannual monitoring. 2. Consider sampling upgradient or background wells annually 3. If deep wells cannot be eliminated from the program until contaminants are detected in the co-located shallow wells, decrease monitoring to annual.	Reducing sampling frequency to semiannual will reduce virtually all costs associated with the LTM program by 50%, or over $70,000 annually.
Field Procedures and Equipment Efficiency Improvements	Investigate the potential for using micropurging techniques to reduce labor, eliminate equipment blanks, and improve sample quality.	Implementing a dedicated bladder pump system would cost approximately $10,000 to $13,000. Cost savings after implementing micropurging could exceed $20,000/year in quarterly labor and analytical costs.
Reducing the Number of Analytes	1. Once the first full year of data have been analyzed, consider eliminating any analyte that has not been detected above the reporting limit. 2. Consider eliminating “dissolved” metals data. 3. Decrease QA/QC sample collection rate by 50% and consolidate shipping to decrease trip blanks.	1. Eliminating unnecessary analytes may not save a great deal in sampling or analytical costs. However, significant savings should be realized in data validation, management, and reporting costs. 2. Eliminating analysis of dissolved metals should save approximately $9000/year in analytical and validation costs for quarterly monitoring. This does not include filters and labor for filtering samples. 3. Decreasing QA/QC samples by 50% will eliminate at least one equipment blank and one field duplicate for groundwater each quarter, for a cost savings of nearly $8000/yr.

Table 3-1
(Continued)

Strategy	Site-Specific Recommendation(s)	Potential Cost Savings[1]/Benefits
Data Analysis Tools	1. Take advantage of the service contract in place to provide GIS and electronic data handling support. 2. Use data analysis tools such as concentration vs. time graphs and plume contouring maps to track contaminant behavior, enhance presentations to regulators, and support site closeout decisions.	Taking advantage of the service contractor will not cost the program any additional funds. Benefits of this approach may include expedited regulator buy-in and, potentially, expedited site closeout.
Report Streamlining	1. Provide a tabbed binder and submit one draft of the monitoring reports on a quarterly or semiannual basis for insertion into the binder. 2. Eliminate "general" information in monitoring reports and provide more background and discussion in an annual summary report. 3. Focus on graphical and tabular formats; highlight important data in tables and combine site maps to the extent possible.	Streamlining the reporting procedure will save labor costs for both reporting and reviewing documents. Copying and material costs will also be reduced. In addition, the clarity of site data should be enhanced.

[1]Estimated cost savings are based on the LTM contractor's current budget. Actual LTM program costs will not be known until after the program is a full year old.

there is a significant upward or downward trend. The Mann-Kendall nonparametric trend test is an example of a statistical method commonly used for this approach. The Mann-Kendall test is best applied to at least four rounds of data. More details regarding the statistical analysis of LTM data are given in Appendix C.

There are other approaches that can be taken to determine if and when a well can be eliminated from the monitoring program. One such approach is to determine if a well is serving its intended purpose. For example, monitoring well 11MW-16 is supposed to be the background well for the site. However, this well has had significant hits, including one for trichloroethene (TCE) above the MCL of 5 µg/L, which are apparently coming from an upgradient source. Unless it is determined that the contamination in this well is coming from the landfill, it should be eliminated from the LTM program for this site. It may be maintained for the purpose of determining water levels, or perhaps will be needed to determine the other source of contamination. This well may also need to be sampled in the future if contamination begins to appear in landfill wells, to eliminate the possibility of an upgradient source. For current monitoring purposes, however, 11MW-19 may be a more appropriate well to determine background contaminant concentrations for the landfill, as it does not appear to have been affected by contamination from this or any other source.

Although they should not be abandoned, it may be acceptable to eliminate sampling in some of the deeper wells until significant contamination is detected in the co-located shallow well. Shallow monitoring well 11MW-6S has had significant detections, including one for benzene above the MCL of 5 µg/L. Therefore, the co-located deep well (11MW-6D) should be sampled regularly. In addition, well pair 11MW-6S and 6D is the only location where a significant downward gradient has been noted at the site (CH2M HILL, 1990).

Shallow monitoring wells 11MW-14 and 11MW-5S have not had significant detections of contaminants to date, and therefore the co-located deep wells (11MW-2D and –5D, respectively) may be eliminated from the program until contaminants are detected in the corresponding shallow wells. Alternatively, the deeper wells could be sampled less frequently, such as annually (see Section 3.6.2).

One last approach that may be used to eliminate some of the wells from the LTM program at the landfill is to assess whether data provided by a well either are redundant with that provided by another well, or do not add anything to the current knowledge of contaminant extent. Following four rounds of data reporting, it should be assessed whether 11MW-13 and -14, both relatively clean downgradient wells completed in the same unit, are providing redundant information. If so, one of these wells may be eliminated without compromising the quality of the LTM program at the landfill.

Currently, none of the wells at the landfill should be considered for abandonment. These wells aid in determining groundwater flow rate and direction and should continue to be monitored for water level whenever sampling is conducted.

In addition to the groundwater monitoring points, there are two sediment/surface water, one leachate, and six gas sampling locations. The surface water/sediment sample pairs are located in two separate drainages receiving runoff from different portions of the landfill. Both of these locations should continue to be sampled. Likewise, no reductions to the

leachate or landfill gas collection locations are currently recommended.

3.6.2 Duration and Frequency Reduction

Another important approach to decreasing LTM program costs is decreasing the number of samples through reductions in sampling duration and/or frequency.

Duration Reduction—The current duration of the monitoring program at the landfill is set to coincide with the 5-year review. If, at that time, it appears that additional monitoring is needed, an annual review period and decision criteria for stopping monitoring should be specified in the ROD so that NAS Patuxent River is not locked into 5 more years of monitoring. Maryland regulations state that:

> "Landfills in Maryland shall be subject to post-closure monitoring and maintenance by the permittee… for a period of time not less than 5 years after the complete installation of the landfill cap. This time period may be extended by the Department if significant maintenance situations occur at the landfill during the 5-year period after closure."

On the basis of current site data, however, it does not appear that there is a large contaminant problem at the site. If amenable to State regulators, it is recommended that the Base work toward continual reduction of the LTM program, via the strategies outlined in this section, between now and the 5-year review.

Frequency Reduction—All of the wells included in the LTM program for the landfill, as well as all of the other media sampled, are monitored on a quarterly basis. Quarterly sampling has been conducted for one full year. At this time, an assessment should be made to determine if it is reasonable to reduce monitoring to semiannual, or even annual, at some or all of the landfill monitoring points. Clearly, reducing monitoring frequency by 50% or more will decrease sampling labor, analysis, validation, and reporting costs by a like percentage.

If, by applying a statistical analysis such as that recommended in Section 3.6.1 (or some other type of trend analysis), the data indicate that concentration trends in target analytes are not changing rapidly, monitoring may be decreased to semiannually. Following a year of semiannual data collection, a similar analysis should be made to see if a reduction to annual monitoring might be implemented. Sampling frequency of groundwater, surface water, and sediment may all be similarly reduced. It is likely that leachate will continue to require quarterly sampling to ensure compliance with county pretreatment standards. Landfill gas may also continue to require quarterly collection to satisfy landfill performance assessment needs. However, regular coordination between the LTM contractor and the operation and maintenance contractor will allow for timely and appropriate reductions to landfill gas sampling frequency.

The purpose of a well should also be taken into account when determining the frequency it needs to be sampled. Downgradient, plume edge wells usually require more frequent sampling than an upgradient or background well. It may be possible to decrease sampling frequency at the background well (either 11MW-16 or 11MW-19) to annually immediately following the first year of data collection.

As indicated in Section 3.6.1, there are two deep wells that have co-located shallow wells with no evidence of significant contamination. If it is determined that these wells cannot be eliminated from the sampling program until their respective shallow wells indicate contamination, the frequency should be decreased to annually. An analysis of the vertical flow gradients at

both of these well clusters indicate that there is not a significant upward or downward gradient at these locations (CH2M HILL, 1990).

3.6.3 Field Procedures and Equipment Efficiency Improvements

Although a round of groundwater monitoring at the site currently takes only two-and-a-half days for two personnel, it may be possible to improve the efficiency of some of the field procedures in order to save money on sampling labor. If a day per round could be eliminated, the field labor costs could be decreased by 40%.

The LTM contractor currently applies low-flow purging (approximately 1 gal/min) techniques using nondedicated pumps. However, a full three well casing volumes are removed prior to sampling. This is an unnecessarily conservative approach, as there is no volume-related criteria when using the low-flow purging technique (Puls and Barcelona, 1995). An effort should be made to determine if this site is appropriate for true low-flow (or "micropurging") techniques. The primary question is whether all of the wells that are essential to the LTM program at the site have adequate recharge rates to support true low-flow purging. *The following discussion on micropurging has relevance to all other current and future groundwater monitoring programs at the Base, and is therefore presented in significant detail.*

The goal of this technique is to eliminate vertical movement of groundwater within the well casing during purging. In doing this, the well may be purged from one small section of the screened interval, without the mixing of stagnant casing water and fresh formation water. Therefore, purge times and volumes are significantly decreased. Wells are purged only until water quality parameters such as pH, conductivity, temperature, and dissolved oxygen, have stabilized. This is typically accomplished after just a few liters.

To determine if the wells being sampled are candidates for low-flow purging, a pump capable of rates less than 0.5 L/min should be used. Pumps should be lowered gently into the well to approximately the middle of the screened interval, and the water column should be allowed to stabilize prior to the start of purging. During purging, water levels should be monitored and the pump rate adjusted so that drawdown does not exceed 0.3 feet. If it is not possible to accomplish this at rates of between 0.5 and 0.1 L/min, the well is probably not a candidate for low-flow purging.

Although dedicated bladder pumps are the preferred equipment for successfully applying low-flow purging (Puls and Barcelona, 1995), the appropriateness of this technique for this site should be determined prior to considering an investment in dedicated equipment. The cost of installing such a system is approximately $1000/well, plus $1000 for a pump controller that can be moved from well to well. Assuming that some of the wells can be eliminated from the LTM program, a dedicated sampling system may be acquired for approximately $10,000. If sampling labor can be decreased by 40% each round, an annual savings of $3200 may be realized, based on five 8-hour person-days per quarter at $50/hour. These savings may be partially offset by costs for maintenance of the pumps. The elimination of two equipment blanks per quarter, at approximately $1000 per sample in analytical costs, would save another $8000 annually.

Another potential cost avoidance and sample quality benefit that may result from low-flow purging is the decrease in metal concentrations that usually results from this technique. Metal concentrations may be decreased by two orders of magnitude by decreasing turbidity associated with

traditional purging methods. The need to analyze dissolved metals may be eliminated, saving another $9000 in analytical and data validation costs per year.

At this rate, a dedicated pump system should pay for itself in 1 year of quarterly sampling. This conservative estimate does not include cost savings associated with data management, purge water handling (not a significant cost at the landfill), travel, reporting, etc. When LTM has been terminated, the dedicated pumps can be decontaminated and reinstalled in other wells or at other sites in order to increase the economy of the program.

If a dedicated system is not deemed feasible, but the micropurging technique is appropriate for the site, renting two nondedicated pumps should be considered. With two pumps, one can be placed in a well and allowed to stabilize while purging, sampling, and decontamination of another well is taking place.

3.6.4 Simplification of Analyses

Since analytical costs make up a significant portion of LTM program expenses, streamlining the analytical approach is a viable way to cut overall LTM program costs. Reducing the number of analytes at a site, eliminating overlapping analytical methods, and reducing Quality Assurance/Quality Control (QA/QC) samples to the minimum required are examples of ways to streamline the LTM analyses.

Reducing the Number of Analytes—Reducing the number of analytes reported for a site not only reduces analytical costs, it reduces data management, validation, interpretation, and reporting costs. Even if receiving data for the total analyte list of a given method is no more costly than receiving data for certain analytes, it is beneficial to eliminate the extra analytes. Eliminating these unnecessary analytes results in clearer, more concise reports.

Currently, the landfill groundwater LTM program includes numerous analytes, most of which have not been detected in samples from the site. A total of 41 volatile organic compounds (VOCs), 59 semivolatile compounds (SVOCs), 28 pesticides, 23 metals (for both dissolved and total analyses), and cyanide are currently included in the analyte list for the landfill.

Any of the parameters that have not been detected above the reporting limit (i.e., has had all results “U” or “B” flagged) in the first four quarters of sampling should be eliminated from the program. This is likely to eliminate most of the pesticide and SVOC analyses and limit the analytical list to primarily VOC and metal analytes.

In addition, the usefulness of collecting both “dissolved” and “total” metals data should be assessed. Dissolved metals are generally measured on samples that have been filtered to 0.45 microns, which is the operable definition of dissolved. This is an arbitrary cutoff and does not necessarily represent the chemical conditions of the aquifer. A total metals analysis on a high quality (low turbidity) sample is more likely to represent true aquifer conditions. The current dissolved metals results appear to be within the same order of magnitude as the total results, and adoption of micropurging techniques may further reduce the difference and increase sample representativeness, as suggested in Section 3.6.3.

Eliminating Overlapping Methods—Eliminating overlapping methods saves money and simplifies data interpretation. However, with the exception of the metals issue noted above, there were no cases of method overlap in the NAS Patuxent River landfill LTM program.

Decreasing QA/QC Samples—An evaluation of the types

and numbers of the QA/QC samples collected for the landfill LTM program indicated that some cost savings could be realized without negatively affecting the quality of the program. Data reproducibility and potential interferences, such as matrix effects, tend to be very well characterized after a few sampling rounds. Therefore, it is generally acceptable to reduce the rate of QA/QC sample collection and analysis.

Trip blanks, which are submitted with each shipment containing samples for volatile parameters, may be decreased by decreasing the number of coolers packed with these types of samples (e.g., shipping every other day, putting all VOC samples together in one cooler, etc.). Also, if a day of sampling is eliminated by improving field procedure efficiency (see Section 3.6.3), a trip blank may be eliminated.

Table 3-2 illustrates the recommended reductions in QA/QC samples. These recommendations pertain only to groundwater samples. For other media, only one field duplicate per analytical method is currently being collected and no reductions are recommended.

3.6.5 Report Streamlining

Report streamlining is also a way to significantly cut LTM costs, especially in a program with quarterly monitoring. The quarterly monitoring reports for the landfill LTM program were assessed to see if further cost avoidance is possible.

An increasingly common approach is to have the LTM contractor submit a ring binder to the Base each year. This "living" document is tabbed to provide space for quarterly and semiannual monitoring results once the data are available. Then, on a yearly basis, a more formal annual monitoring report is submitted and inserted in the front of the document. While the annual reports are submitted in draft and final versions, quarterly or semiannual reports may be submitted only once, or the draft may be submitted electronically.

This approach allows for several other efficiency improvements. First of all, all general information in the quarterly reports can be eliminated, minimizing the amount of text that must be produced. If only data are submitted, comments are unlikely and the need for a draft is eliminated. If changes are necessary due to a data reporting error, replacement pages may be submitted.

Data tables within the report body currently present only analytes that have been detected in at least one well. This is an excellent approach. Readability of the tables may be improved by shading or otherwise delineating hits, either above the detection limit or some standard such as an MCL. Appendix B gives an example. Raw data may be held and submitted as one appendix on an annual basis or inserted into a separate appendix tab on a quarterly basis.

Table 3-2 Recommended Groundwater QA/QC Sample Reductions

Analyte	Number of Samples	Field Duplicates	Equipment Blanks	Trip Blanks[a]	Total Samples
TCL Organics	12	2 → 1	2 → 1	2 → 1	18 → 15
TAL Metals	12	2 → 1	2 → 1	N/A	16 → 14

[a]VOCs only
→ denotes the recommended reduction.

Sample location maps currently included in the quarterly reports may be consolidated by showing groundwater sampling locations along with the quarterly potentiometric surface on one map, and all other monitoring points on another. Quarterly potentiometric surface maps are more useful than including this information in tabular format, as they can show seasonal fluctuations and other subtle differences in groundwater flow.

3.6.6 Data Analysis Tools

There are several data analysis tools that may make interpreting and tracking the behavior of contaminants at the landfill easier over the 5-year review period. Use of these tools, such as GIS and custom databases, increases the efficiency of handling large amounts of data. NAS Patuxent River already has a support contract in place with Eagan, McAllister Associates, Inc. for assistance with GIS and electronic data handling. Based on conversations with this support contractor, GIS spatial displays (e.g., water level contours and plume maps) can be provided on request once the appropriate data have been entered into the system. A strategy for integrating environmental data into the existing NAS Patuxent River GIS is being prepared under a separate task.

A customized database that allows commonly executed data queries (such as hit lists) to be generated with the click of a button can be designed relatively easily. Data from this type of database can be linked to graphing packages to track contaminant trends. Concentration versus time graphs are very useful, if any wells consistently exhibit measurable concentrations of an analyte. These can be tracked on a quarterly basis, with a new point added each quarter, and used to justify discontinued monitoring.

The NAS Patuxent River central GIS can be used to display data spatially and can also be used to construct plume or other types of “concentration over area” maps. Presentations to State regulators and the community can be greatly enhanced by using such a system. Regulator buy-in may be obtained during a data visualization meeting, rather than awaiting comments on bulky documents. These applications can usually be linked directly to a database, such as the one described above, to further streamline data handling and errors associated with redundancy. Appendix B gives some examples of the applicability of GIS to LTM programs.

3.7 Recommended Optimization of Landfill Cap Performance Monitoring

Landfill cap performance monitoring is achieved, in part, via sampling of landfill gas on a weekly basis. Weekly monitoring is necessary to track flare system performance, especially during the early years of operation, and to safeguard against conditions that may lead to a landfill gas fire (Personal Communication, Byran L. Cummings, Safety and Environmental Manager, Johnson Controls, Inc., 11 January 1999).

A team of two samplers access seven well vaults to conduct an on-site analysis of landfill gas concentrations and temperature. These vaults, which constitute confined spaces, are covered with a heavy metal lid that must be opened by two people. The vaults are entered using a boat ladder that is hooked over the concrete wall of the vault. The vaults are shallower than the height of the average adult, and there is the potential for the metal lid to fall, causing injury to sampling personnel.

If the ports for sampling gas and temperature could be run from within the vault to the ground surface, both sampling efficiency and safety could be drastically increased. This could be achieved by running plastic tubing from the sampling

port through a hole drilled in the lid of the vault. A clamp placed on the end of the tubing would keep it from slipping back into the vault and contain gases between sampling rounds. Likewise, a thermocouple probe and wire could be run from the temperature measurement port to the surface for weekly reading with an electronic temperature meter. The cost of materials for the above modification would cost approximately $70 per vault, or approximately $500, plus $100 for the meter, depending on supplier and grade of materials.

The installation costs for the above modifications are insignificant, and it is conservatively estimated that sampling time could be cut in half. More importantly, confined space entry and other safety hazards are significantly decreased. Inspections of the interior of the vault are still possible, and adjustments can be made by entering the vault whenever necessary.

3.8 Evaluation of Optimization

Evaluation of the optimization suggestions includes two aspects: 1) the estimate of total cost reduction, and 2) the potential effects on data quality.

3.8.1 Impact on Data Quality

The general strategies of LTM optimization discussed in this section must be applied in such a way that LTM data quality is not compromised. If only sampling points that do not contribute to the LTM goal or that already have well-defined trends are eliminated or their monitoring frequency reduced, the LTM program quality will not be adversely affected. Likewise, QA/QC reductions must be implemented only when data sufficient to define sample variability and potential interferences have been gathered.

Implementing the recommendation to install a dedicated bladder pump system for micropurging should actually improve data quality, via lower turbidity levels and lower likelihood of cross contamination. Likewise, implementing the suggestions to streamline reporting and data management may improve the clarity and readability of LTM reports and data presentations.

The suggestion to modify weekly soil gas sampling to eliminate regular confined space entry is also a process improvement, by significantly reducing risk to the sampling personnel.

3.8.2 Estimate of Total Cost Reduction

Annual LTM costs have been estimated on the basis of the LTM contractor's annual budget. Quarterly costs will fluctuate depending upon weather, equipment malfunction, and many other factors. Therefore, only an estimate of the total potential savings resulting from the implementation of the suggestions outlined in Section 3.6 is currently available. Table 3-1 summarizes some of the cost savings and other benefits that may be realized through implementation of the LTM optimization recommendations. If these suggestions are implemented, it is estimated that nearly $40,000, or over 25% of the cost currently budgeted for this year's monitoring, can be eliminated. This does not include the suggestion to decrease sampling to semiannually, which would cut the remaining budget in half. It also takes into account that there is overlap in some of the suggestions (e.g., eliminating dissolved metals analyses is a potential benefit of both the field procedures and analytical suggestions).

Implementing the suggestion to convert landfill gas sampling to an aboveground procedure will also result in cost savings of approximately 50%, resulting from decreased labor, with minimal (approximately $600) capital costs.

4.0 FUEL FARM (SITE UST 1)

The following section outlines the background information for the Fuel Farm (Site UST 1), and presents the recommendations for LTM optimization at the site.

4.1 Site Background

The following subsections summarize the site geology and hydrogeology, as well as the site history. Much of this information comes from the *Site Characterization Summary Report for the Fuel Farm at the Patuxent River Naval Air Station* (Dames and Moore, October 1996).

4.1.1 Physical Setting

The fuel farm occupies more than 12 acres in the northwest portion of the installation, near the south bank of the Patuxent River. Although the main area of the fuel farm where the tanks are located is open, the northern portion of the site is heavily vegetated. A stream that flows into a small wetland area with a pond borders the site to the north. Figure 4-1 shows the layout of the site.

Groundwater ranges from 5 to 20 feet below ground level (bgl) in site monitoring wells, and discharges to the stream and pond to the north. In general, groundwater at the fuel farm flows steeply to the north and discharges into the stream and wetland area. However, it appears on some quarterly potentiometric maps as if a potentiometric high occurs in the main portion of the fuel farm, with groundwater flowing in a radial pattern from the site. Groundwater in the southeastern portion of the site appears to flow steeply to the southeast, although site topography appears relatively flat in this area. It is possible that groundwater mounding occurs in the area of the fuel farm, perhaps due to subsurface inhomogeneities such as the presence of fill material. It is also possible that some water level measurements are in error.

A large portion of the original sediments at the site was replaced with fill material during construction of the fuel farm. This fill may extend to 35 feet bgl, and makes up a high, flat area in the vicinity of the underground tanks. The undisturbed sediments at the site consist primarily of iron-rich sands and gravels overlying a thick clay layer. Some peat layers were also encountered during drilling operations.

The thickness of the clay layer is unknown, as no wells installed at the fuel farm have penetrated beneath it. The clay acts as a confining layer, preventing the vertical movement of both groundwater and site contaminants into deeper aquifers.

4.1.2 Site History

Fuel farm operations began in 1943, during the commissioning of NAS Patuxent River. Five 100,000-gallon underground reinforced concrete tanks installed at the site in the 1940s were since removed. In addition, there are two 560,000-gallon aboveground tanks that were installed in the 1970s, and various other small tanks and pipelines. Jet fuels, heating oils, and automobile and aviation gasolines have been stored at the site over time.

Leakage from both the tanks and associated pipelines may have been the source of petroleum product contamination of the soil and groundwater. Dry wells used from the 1940s through the 1970s to dispose of condensate water drained from tank bottoms may have also contributed, to a large extent, to site contamination. In addition, a sludge pit is reported to be located somewhere along the northern edge of the area where the 100,000-gallon tanks were located.

Based on the 1996 sampling event, two distinct plumes defined by benzene at concentrations greater than 100 ug/L have

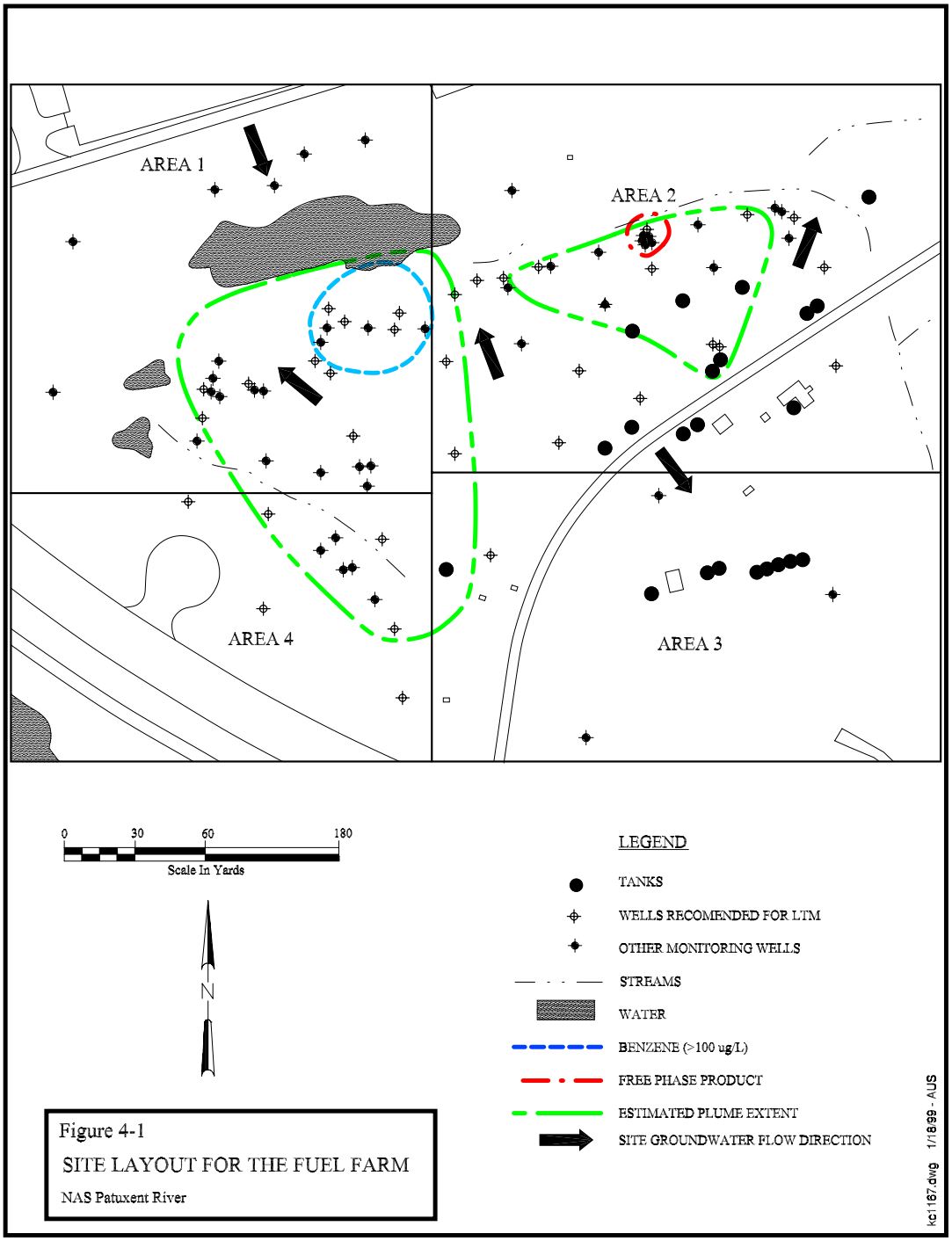

Figure 4-1
SITE LAYOUT FOR THE FUEL FARM
NAS Patuxent River

been identified at the site. These plumes are shown in Figure 4-1.

The five 100,000-gallon tanks were removed in February 1999, following cleanout late in 1998. During this removal action, the tanks and some of the contaminated soil were removed. Following excavation, the site was regraded, and a groundwater sampling event was conducted in late 1998.

4.2 Site Activity Status

From the late 1970s to the present, several investigations and evaluations of various technologies have taken place at the fuel farm. Ninety monitoring wells have been installed on the site as a result of the investigations and technology demonstrations. Technology demonstrations to date include seven bioremediation studies, a product recovery trench and associated treatment system, and a mobile bioslurping system.

A pump and treat system has been in operation at the fuel farm since October 1993. This system includes three interceptor trenches and seven recovery wells situated in a topographic low to the south (just upgradient) of the stream and pond. This groundwater recovery system acts as a hydraulic barrier to prevent contaminants from flowing into the surface water body. Free-phase hydrocarbons are recovered in an oil/water separator and contaminated groundwater is pumped to an air stripping system. Following treatment, the water is discharged to the stream (Dames and Moore, 1996).

Prior to the most recent sampling event, the last groundwater sampling event was a baseline study conducted in 1996. At that time, approximately 90 wells were sampled for fuel constituents. (Dames and Moore, 1996). Recommendations in this report are based in part upon the findings of that study.

Although eight groundwater sampling events have taken place between 1984 and 1996, only one sampling event, in the fourth quarter of 1998, has been conducted in the past 2 years. A contract for the LTM program is now in place and 25% of the wells are scheduled to be sampled each quarter.

Monitoring has also been conducted at the site to track the performance of the pump and treat system installed in 1993. Monitoring of this system involves monthly effluent sampling for benzene, toluene, ethylbenzene, xylenes (BTEX), and naphthalene, as well as monthly groundwater level measurements for the site.

4.3 Regulatory Framework

The fuel farm falls under the State of Maryland UST regulations. In October 1990, NAS Patuxent River received an NOV from the State. The NOV was based on an inspection conducted by the State in August of 1990 that identified free product in observation wells, as well as oil leaking out of the banks of the stream located to the north of the site. These findings constituted a violation of Maryland law, as well as the Environmental Corrective Agreement between the State and NAS Patuxent River. As a result of the NOV, the Base was required to sample all 31 of the observation wells located within the fuel farm at that time, as well as surface water from the stream. These samples were analyzed for BTEX, naphthalene, and total petroleum hydrocarbons (TPH).

4.4 Best Practices Already in Place

Although a consistent monitoring program has not been active for the past 2 years, NAS Patuxent River has been aggressive in pursuing innovative remedial alternatives for the fuel farm. By allowing various vendors and consultants to demonstrate their technology at the site, the Base has been able to assess the effectiveness of several different

technologies that may have applicability at this or other fuel contaminated sites at the installation. These technologies include:

- **April 1988—**Laboratory investigation of in situ biorestoration (University of Nevada, Reno).
- **September 1988—**Nutrient evaluation for stimulating biodegradation in fuel-contaminated soils (Batelle).
- **December 1988—**Bioreclamation study of subsurface hydrocarbon contamination (Groundwater Technology).
- **December 1988—**Removal of aqueous phase petroleum products in groundwater by aeration (Battelle).
- **February 1989—**Evaluation and verification of biodegradation of petroleum hydrocarbons by the use of radiolabeled hydrocarbons (Skidaway Institute of Oceanography).
- **August 1989—**Evaluation of innovative approaches to stimulate degradation of jet fuels in subsoils and groundwater (Battelle).
- **October 1990—**Biodegradation of hydrocarbon contaminants by native soil microbial communities (University of North Carolina).
- **1992—**Remedial design study for groundwater recovery and treatment system (CH2M HILL).
- **1996—**Mobile bioslurping pilot test (Environmental Resources Management [ERM]).

It appears that the mobile bioslurping technology may be a successful remedial alternative for the fuel farm (Dames and Moore, 1996).

4.5 Site Closeout Considerations

Because NAS Patuxent River is preparing to enter into a formal LTM program with the State, strategies for negotiating eventual site closeout need to be considered now. These strategies may include assessing the role of natural attenuation at the site and formulating decision criteria for shutting down the active pump and treat system and reducing or eliminating the LTM program. It is also advantageous to begin tracking certain types of data early in the program to support site closeout decisions at a later date. These data include cost and performance tracking, contaminant trends, and natural attenuation indicators.

Natural Attenuation Data—Natural attenuation can play a critical role in the treatment of fuel-contaminated sites. Seven bioremediation studies were conducted at the fuel farm between the late 1980s and early 1990s. Although the findings of these studies were somewhat variable, the overall conclusions were that:

1. There is a substantial native community of hydrocarbon degrading microbes at the site;
2. Oxygen may be a limiting factor in the success of the biodegradation of fuels;
3. Biodegradation is not nutrient limited at the site; and
4. Biodegradation of fuels was more successful in sand layers than in peat layers.

Given the conclusions presented above, a few more rounds of high quality natural attenuation data could be instrumental in supporting decisions to shut down any active treatment systems that are no longer cost effective or efficient at removing site contaminants. After completion of the removal action, natural attenuation indicator constituents should be monitored quarterly for a year. Annual (or semiannual if significant seasonal variation is expected) monitoring can then be conducted until enough data have been

collected to support the occurrence of natural attenuation. Section 3.5 gives references for several natural attenuation guidance documents.

Decision Criteria—Since no groundwater monitoring program has been formalized at the site, an opportunity exists to define the decision criteria that will allow for regular adjustments to the program. Following are recommended decision criteria that may be used to determine when monitoring or treatment at the site may be reduced or halted:

- If natural attenuation data and contaminant concentration trends indicate that site contaminants will be remediated below action levels within 5 years, active remediation at the site will be stopped.
- If quarterly monitoring is implemented, the sampling frequency will be reduced to semiannual or annual after four quarters of monitoring, unless site data indicate rapid changes in contaminant concentrations.
- If concentrations at a monitoring point remain below the cleanup goal for three sampling rounds, the monitoring point may be eliminated or, if appropriate, become an upgradient point allowing a former upgradient point to be eliminated.

If buy-in is obtained in advance from the State, and the proper data are tracked, these criteria provide a measurable basis for streamlining or eliminating treatment or monitoring at the fuel farm.

Data Trend Analysis—In addition to natural attenuation data, there are several other types of data that should be tracked in support of eventual site closeout. Cost and performance data should be tracked at least quarterly for the pump and treat system. Figure 4-2 shows examples of common cost and performance evaluation plots.

For the LTM program, contaminant trends (i.e., concentrations over time and concentrations over area) should be tracked in order to present an accurate picture of contaminant behavior, and further support a natural attenuation remedy. A spatial data analysis tool, such as a geographic information system (GIS), is particularly effective in presenting this information to regulators in a clear and concise way. More information regarding data analysis tools are presented in Section 4.6.6, and examples are given in Appendix B.

4.6 Recommended Strategies for Groundwater Monitoring

The following subsections outline the elements of designing and implementing a cost-effective monitoring program. In addition, strategies are given for making reductions to the LTM program as more data are collected. These suggestions are based on the optimization strategy summarized in Section 1.3 of this case study. A summary of the site-specific recommendations is given in Table 4-1. It is important to note that, in evaluating these suggestions, regulator and community approval must also be considered.

4.6.1 Identify Appropriate Monitoring Points

One of the most effective ways to minimize LTM costs is to identify and sample only those points that are necessary to track contaminant movement at the site. This not only saves labor in the field, it reduces analytical, data management, and reporting costs. This strategy is the most important one that can be applied to the upcoming LTM program at the fuel farm. In the first year of an LTM program, it is more valuable to have quarterly data from a smaller number of carefully chosen wells than to have data from less frequent sampling of a large number of wells.

The 1996 sampling event at the fuel farm included approximately 90 wells. This is far more than the number necessary to

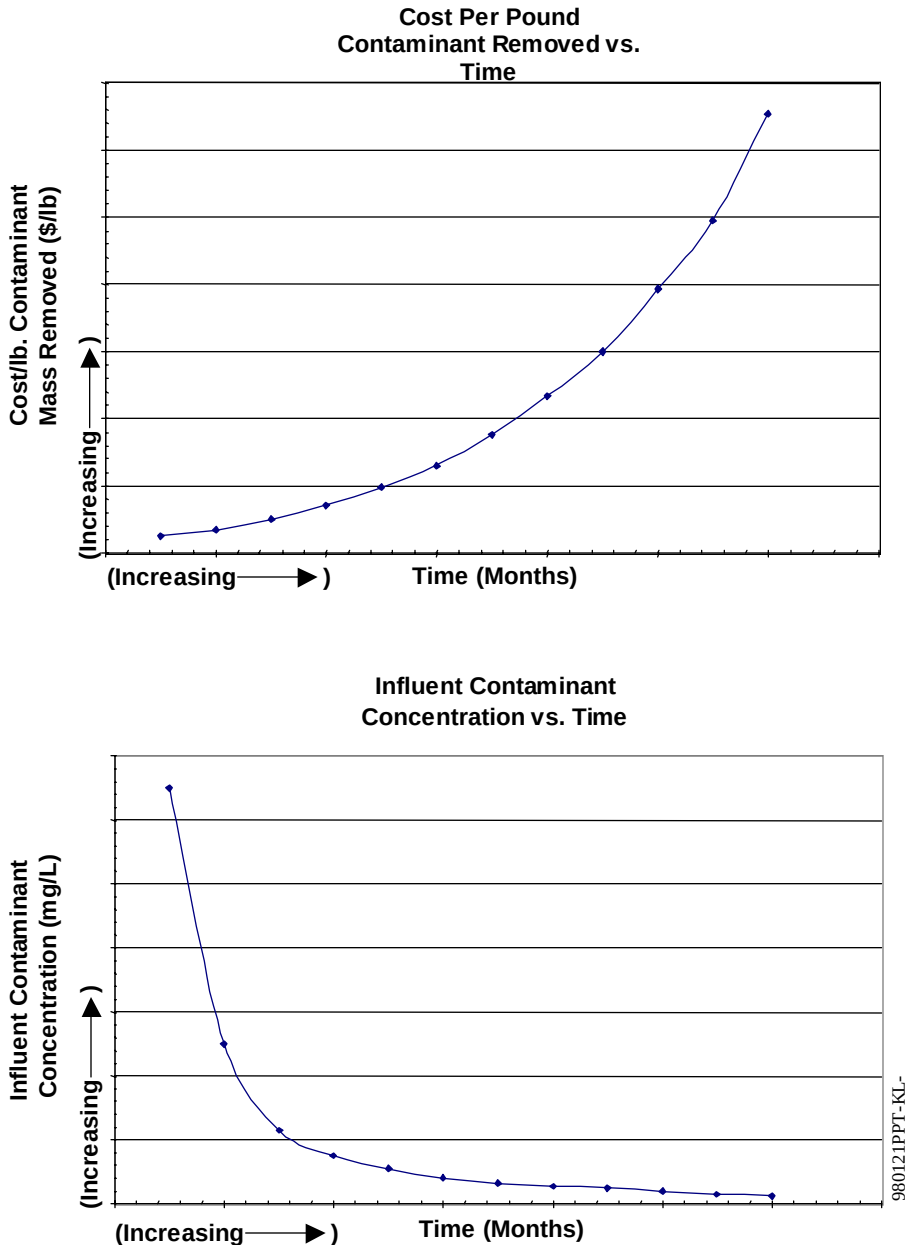

Figure 4-2. Common Cost and Performance Evaluation Plots

Table 4-1. Summary of Recommendations for the Fuel Farm (Site UST 1)

Strategy	Site-Specific Recommendation(s)	Potential Cost Savings/Benefits
Monitoring Point Reduction	1. Eliminate from the LTM program wells that are not necessary to achieve the goals of tracking system performance and defining plume shape and size changes over time. Retain a good distribution of plume edge wells, in-plume wells, extraction wells, downgradient wells, and background wells. 2. Eliminate from the LTM program the wells that are on the opposite side of the pond from the fuel farm. Discharge of groundwater from the fuel farm into the pond prohibits migration of contaminants to these wells. 3. Eliminate from the LTM program wells that are damaged or that contain free product. Properly abandon damaged wells. Monitor product thickness in wells that contain free product.	Decreasing the number of wells to be sampled from 90 to 34, a little more than a 60% decrease, represents a significant cost savings for the LTM program. Costs associated with analytical, sampling, data management and interpretation, and reporting can all be reduced significantly by applying this strategy.
Duration and Frequency Reduction	1. Put decision criteria and annual review periods in place so that the LTM program can be continuously reviewed and halted when appropriate. 2. Conduct quarterly sampling until one full year of data are gathered. Then pursue a reduction to semiannual or annual monitoring. 3. Sample upgradient or background wells annually.	Initial quarterly sampling of a representative subset of wells will provide better definition of temporal and spatial trends in contaminant distribution than sampling 25% of the wells each quarter, although first year costs will be slightly higher.
Field Procedures and Equipment Efficiency Improvements	Investigate the potential for using micropurging techniques to reduce labor, eliminate equipment blanks, and improve sample quality.	Installing a dedicated bladder pump system at the fuel farm would cost approximately $35,000. However, in a large program that is just starting out, the capital costs should be easily recouped. Besides decreased labor costs and the elimination of equipment blanks, this sampling approach results in higher quality samples with generally lower analyte concentrations.
Reducing the Number of Analytes	1. Measure only analytes that are present at significant concentrations and that can be linked to specific regulatory endpoints. 2. Collect QA/QC samples at a rate of 5% for field duplicates and matrix spike/matrix spike duplicates, one per week for equipment blanks. 3. Consolidate coolers and ship every other day, if possible, to minimize trip blanks.	Indicators such as TPH are inexpensive to measure but may be difficult to link to specfic risk-based decision criteria. Reducing the QA/QC sample rate will save approximately 50% of the QA/QC analytical budget, or approximately 5% of the overall analytical budget.
Data Analysis Tools	1. Take advantage of the service contract in place to provide GIS and electronic data handling support. 2. Use data analysis tools such as concentration vs. time graphs and plume contouring maps to track contaminant behavior, enhance presentations to regulators, and support site closeout decisions.	Taking advantage of the service contractor will not cost the program any additional funds. Benefits of this approach may include expedited regulator buy-in and, potentially, expedited site closeout.

Table 4-1
(Continued)

Strategy	Site-Specific Recommendation(s)	Potential Cost Savings/Benefits
Report Streamlining	1. Provide a tabbed binder and submit one draft of the monitoring reports on a quarterly or semiannual basis for insertion into the binder. 2. Eliminate "general" information in monitoring reports, and provide more background and discussion in an annual summary report. 3. Focus on graphical and tabular formats; highlight important data in tables.	Streamlining the reporting procedure will save labor costs for both reporting and reviewing documents. Copying and material costs will also be reduced. In addition, the clarity of site data should be enhanced.

implement a successful LTM program. The purpose of LTM at the fuel farm is to monitor the effects of the remedial systems and to track changes in contaminant concentrations, and therefore plume shape and size, over time.

The following paragraphs describe strategies for identifying specific wells that may be excluded from the LTM program. Using these strategies, a total of 56 wells were identified that may be eliminated from the LTM program. Figure 4-1 shows the spatial distribution of the wells that are suggested for inclusion in the LTM program. Table 4-2 gives the identification numbers for these wells, and the justification for including them in the program.

It is important to include a good distribution of wells within and downgradient from treatment systems in order to track influent concentrations and system effectiveness. However, the fuel farm has several recovery wells located within the treatment trenches, and it is probably not necessary to sample all of them. Those wells that have the highest concentrations and provide a good distribution of analytical data are the best candidates for the LTM program.

There are several wells located to the north of the pond and stream that have been monitored as part of this site in the past. Although groundwater flows north from the most contaminated portions of the site, groundwater discharges into the small stream and pond preventing it from reaching the wells further to the north. Historical data also indicate that these wells have not been affected by fuel farm contamination. None of these wells should be included in the LTM program for the fuel farm.

There are many monitoring wells located within the two main plumes at the fuel farm. Only the number of wells necessary for defining the plume shape and tracking plume concentration trends should be sampled. Therefore, a good distribution of wells that are located near the plume edge, either within or outside of the plume, should be sampled.

There are several instances where two or more monitoring wells are close together (less than 50 yards), screened at very similar intervals, and within the same location relative to the plume (i.e., within the plume, upgradient of the plume, etc.). In general, all but one of the wells within the area can be eliminated from the sampling program. For instance, wells CP-1 through CP-6 are all located within the plume and are less than 50 yards away from each other. All are screened from 10 to 20 feet bgl. Likewise, wells MW-22, -24, -25, and -33 and EP-1 and EP-2 are also located in this area and screened in the same interval. One of the wells in this cluster may be chosen as part of the LTM program, and the others eliminated. Typically, the well with the highest contaminant concentrations is chosen.

Some wells, such as 6MW-1, -2 and -3, are located too far from the plume edge to provide information about the site. In fact, any constituents detected in these wells may be coming from another source and may serve to confuse the understanding of site contaminant distribution. These wells should be used to clarify groundwater flow direction in the area, but should not be sampled as part of the fuel farm LTM program unless the plume expands toward this area.

Other wells that should be excluded from the LTM program include any wells that are not in working condition and wells that contain free product. Wells such as CH2M-MW-7 and CP-4, which are noted to be obstructed, dry, or damaged, can be eliminated from the program and in general there is at least one well close by that will provide comparable data. An inspection of all wells should be made prior to defining the monitoring network. A damaged well

Table 4-2. Wells Suggested for Inclusion in the Fuel Farm LTM Program

Well ID	Justification
Area 1—10 wells	
MW-20	In-plume well
MW-114	Extraction trench well
OLDPZ-4	Downgradient of extraction trench
OLDPZ-5	Downgradient of extraction trench
PZ18N60	In-plume well
PZ-8	Extraction trench well
PZ-10	In-plume well
RW-1	Recovery well
RW-4	Recovery well
RW-6	Recovery well
Area 2—17 wells	
MW-8	Upgradient well
MW-9	Plume definition well—outside plume
MW-11	In-plume well
MW-13	Plume definition well—outside plume
MW-14	Plume definition well—outside plume
MW-16	Plume definition well—inside plume
MW-17	Plume definition well—inside plume
MW-101	Extraction trench well
MW-107	Extraction trench and plume definition well—outside plume
MW-108	Extraction trench and plume definition well—inside plume
MW-111	Extraction trench well
MW-112	Extraction trench well
NEWPZ-5	Extraction trench and plume definition well—outside plume
NEWPZ-6	Extraction trench and plume definition well—outside plume
CH2M-MW-2S	Part of clustered well pair completed at two different depths
CH2M-MW-2D	Part of clustered well pair completed at two different depths
CH2M-MW-5	Plume definition well—outside plume
Area 3—1 well	
6MW-4	Plume definition well—outside plume
Area 4—6 wells	
MW-22	In-plume well
MW-23	Plume definition well—outside plume
MW-24	Plume definition well—inside plume
MW-27	Plume definition well—outside plume
MW-28	Plume definition well—inside plume
MW-29	Plume definition well—outside plume

should be properly abandoned. If its location is crucial to the LTM program, it should be replaced.

Wells with free product should be monitored for product thickness, but should not be sampled for analytical data. During the 1996 sampling event, PZ-3, NEWPZ-4, and PZ-11 were found to contain measurable free product.

Wells that should not be excluded from the monitoring program, at least initially, include well clusters completed at two different depths. Although these clusters, such as CH2M-MW-2S and 2D are located very close horizontally, they may provide valuable data on the migration of contaminants to deeper portions of the aquifer.

Following collection of four rounds of data, there are other strategies that can be used to eliminate additional wells from the LTM program. One such approach is to conduct a statistical analysis of concentrations in a well to determine if there is a significant upward or downward trend. The Mann-Kendall nonparametric trend test is an example of a statistical method commonly used for this approach. A discussion of the application of statistics to LTM programs is given in Appendix C.

When a network of monitoring wells that meets the goals of the LTM program has been defined, consideration should be given to abandoning those wells that do not contribute to the program. This will eliminate the need to maintain nearly 100 wells at the site. However, it will probably be necessary to keep more than the number of wells monitored to allow for proper definition of the potentiometric surface and continued tracking of the plume as it changes shape and size. Wells that are damaged or located very close to other wells screened within similar intervals should be considered for abandonment first.

4.6.2 Determine Monitoring Duration and Frequency

Another important approach to minimizing LTM program costs is to identify a reasonable sampling duration and frequency.

Duration—There is currently no duration defined for the monitoring program at the fuel farm. Rather than setting a duration for the monitoring program, an annual review period and decision criteria for stopping monitoring should be specified in negotiations with the State.

Frequency—It is generally accepted practice to conduct quarterly sampling for the first year. Although the State of Maryland has agreed to annual monitoring of all 90 wells on site, this arrangement may not be optimal for monitoring remedial performance or controlling long-term cost. If, by applying a statistical analysis such as that recommended in Section 4.6.1 (or some other type of trend analysis), the initial quarterly data indicate that concentration trends in target analytes are not rapidly changing, monitoring may be decreased to semiannual or annual without loss of data and without extraneous measurements from wells not suitably located for the LTM program.

The purpose of a well should also be taken into account when determining the frequency it needs to be sampled. Downgradient, plume edge wells probably require more frequent sampling than an upgradient or background well. However, it will be necessary to get a better picture of groundwater flow at the site before an appropriate background well or wells can be identified. Once background wells have been chosen, the potential for sampling them on an annual basis should be considered.

4.6.3 Ensure Efficient Field Procedures

As was suggested for the landfill, low-flow, or micropurging, techniques

should be investigated as an approach to saving labor costs and maximizing sample quality. For a full discussion of this approach, see Section 3.6.3.

4.6.4 Identify Representative Analytical Methods

Since analytical costs make up a significant portion of LTM program expenses, streamlining the analytical approach is a viable way to cut overall LTM program costs. Minimizing the number of analytes at a site, eliminating overlapping analytical methods, and reducing QA/QC samples to the minimum required are examples of ways to streamline the LTM analyses.

Minimizing the Number of Analytes—Minimizing the number of analytes reported for a site to those necessary for characterizing plume movement not only reduces analytical costs, it reduces data management, validation, interpretation, and reporting costs. Eliminating unnecessary analytes results in clearer, more concise reports.

During the 1996 sampling event at the fuel farm, only BTEX, naphthalene, and TPH were analyzed. The State of Maryland has agreed to further reduce this list to include only TPH. This may be reducing the number of analytes too much. TPH data are often difficult to interpret in terms of risk and progress in cleaning up VOCs. Comparatively more information is gained from compound-specific analytes, such as BTEX and naphthalene. The extra cost of compound-specific analyses is small relative to the overall cost of the LTM program; it is worth an additional $100 per sample to collect meaningful data.

Eliminating Overlapping Methods—Eliminating overlapping methods saves money and simplifies data interpretation. However, it is not an issue with the small number of target analytes for the fuel farm.

Decreasing QA/QC Samples—The current recommended rate of QA/QC sample collection is half or less than that traditionally used for monitoring programs. Field duplicates and matrix spike/matrix spike duplicate samples are currently recommended at a rate of 5%. Equipment blanks should be collected at a rate of one per week.

Trip blanks, which are submitted with each shipment containing samples for volatile parameters, may be decreased by decreasing the number of coolers packed with these types of samples. This may be accomplished by consolidating VOC samples in one cooler and shipping every other day of the sampling round, provided analytical hold times are not approached.

4.6.5 Create a Streamlined Report Layout

Report streamlining is also a way to significantly cut LTM costs, especially in a program with quarterly monitoring. An increasingly common approach is to have the LTM contractor submit a ring binder to the Base each year. This “living” document is tabbed to provide space for quarterly and semiannual monitoring results once the data are available. Then, on a yearly basis, a more formal annual monitoring report is submitted and inserted in the front of the document. While the annual reports are submitted in draft and final versions, quarterly or semiannual reports may be submitted only once, or the draft may be submitted electronically.

This approach allows for several other efficiency improvements. First of all, all general “cut and paste” information in the quarterly reports can be eliminated, minimizing the amount of text that must be produced. If only data are submitted, comments are unlikely and the need for a draft is eliminated. If changes are necessary due to a data reporting error, replacement pages may be submitted. Raw data, purging

logs, etc., should be submitted as an appendix, either on a quarterly or annual basis.

Focusing on tabular and graphic presentation styles also helps in cutting down on review time. Presenting a summary table of the data, using shading or some other method for highlighting detections that exceed some standard, increases the readability of the information. Appendix B gives examples of tabular and graphic data formats.

4.6.6 Use Data Analysis Tools

There are several data analysis tools that may make interpreting and tracking the behavior of contaminants at the fuel farm easier and allow for more efficient communications with State regulators.

The management of large amounts of data can be done most effectively in electronic format. Base personnel already have numerous resources in this area. Some of the historic data from the site are already available electronically. In addition, NAS Patuxent River already has a contract in place for assistance with GIS and electronic data handling. Since the LTM program has not been contracted yet, the Base should be sure to include a provision in the scope of work that requires all analytical data to be provided electronically. This will decrease clerical labor and the potential for data entry errors.

Types of data analysis tools that are useful for LTM programs include concentration versus time graphs. These can be tracked on a quarterly basis, with a new point added each quarter, and used to justify discontinuing active treatment and/or monitoring. An example of this type of graph is shown in Appendix B.

A GIS package will help display data spatially and can also be used to construct plume or other types of “concentration over area” maps. Presentations to State regulators and the community can be greatly enhanced by using such a system. Regulator buy-in may be obtained during a data visualization meeting, rather than awaiting comments on bulky documents. These applications can usually be linked directly to a database to further streamline data handling and reduce errors associated with redundancy. Appendix B gives examples of the applicability of GIS to LTM programs.

4.6.7 Evaluation of Program Design

Evaluation of the monitoring program design includes two aspects: 1) the estimate of total cost avoidance, and 2) the potential effects on data quality. Following is a brief discussion of each aspect.

Impact on Data Quality—The general strategies of LTM design discussed in this section must be applied in such a way that LTM data quality is not compromised. Although only a few streamlining measures can be taken early in the program, many more can be implemented following collection of the first year’s data. As long as these measures are implemented following the guidelines presented in this case study, no negative effect on data quality should be expected.

Estimate of Total Cost Reduction—Because the LTM program at the fuel farm has just begun, costs for the program are unknown. However, by starting with a well thought-out program and continually reviewing the data and goals in order to optimize LTM, the program will be conducted in a cost-effective manner. The elimination of over 60% of the fuel farm wells from the LTM program, as suggested in Section 4.6.1, will save 60% of the initial analytical budget as well as significant sampling and reporting labor costs. Table 4-1 summarizes some of the relative cost savings and other benefits that may be realized through implementation of the LTM program design strategies outlined in this case study.

4.7 Recommended Optimization of Remediation System Monitoring

Although an in-depth assessment of the remediation system monitoring was not performed, a few suggestions for improving efficiency and quality are:

- Track mass removal and cost per pound data in preparation for future shut down of active remedial systems.
- Conduct bail-down tests to get a measure of true product thickness for more information on contaminant mass in the groundwater.
- Better define the potentiometric surface of the site through a more in-depth analysis of water level data so that better predictions of contaminant movement can be made.

5.0 LIST OF REFERENCES

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Appendix A

Current Analyte List for the Landfill Long-Term Monitoring Program

Target Compound List (TCL) Volatile Compounds

Chloromethane
Bromomethane
Vinyl Chloride
Chloroethane
Methylene Chloride
Acetone
Carbon Disulfide
1,1-Dichloroethene
1,1-Dichloroethane
1,2-Dichloroethene (total)
cis-1,2-Dichloroethene
trans -1,2-Dichloroethene
Chloroform
1,2-Dichloroethane
2-Butanone
Bromochloromethane
1,1,1-Trichloroethane
Carbon Tetrachloride
Bromodichloromethane
1,2-Dichloropropane
cis-1,3-Dichloropropene
Dibromochloromethane
1,1,2-Trichloroethane
Benzene
trans-1,3-Dichloropropene
Bromoform
4-Methyl-2-pentanone
2-Hexanone
Tetrachloroethene
1,2-Dibromoethane
Toluene
1,1,2,2-Tetrachloroethane
Chlorobenzene
Ethylbenzene
Styrene
Xylenes (Total)
1,2-Dibromo-3-chloropropane
1,3-Dichlorobenzene
1,4-Dichlorobenzene
1,2-Dichlorobenzene
1,2,4-Trichlorobenzene

Target Compound List (TCL) Pesticides/Aroclors (PCBs)

alpha-BHC
beta-BHC
delta-BHC
gamma-BHC
(Lindane)
Heptachlor
Aldrin
Heptachlor epoxide
Endosulfan I
Dieldrin
4,4'-DDE
Endrin
Endosulfan II
4,4'-DDD
Endosulfan sulfate
4,4'-DDT
Methoxychlor
Endrin ketone
Endrin aldehyde
alpha-Chlordane
gamma-Chlordane
Toxaphene
Aroclor-1016
Aroclor-1221
Aroclor-1232
Aroclor-1242
Aroclor-1248
Aroclor-1254
Aroclor-1260

Target Compound List (TCL) Semivolatiles

Phenol
bis(2-Chloroethyl) ether
2-Chlorophenol
1,3-Dichlorobenzene
1,4-Dichlorobenzene
1,2-Dichlorobenzene
2-Methylphenol
2,2'-oxybis (1 Chloropropane)
4 Methylphenol
N-Nitroso-di-n-propylamine
Hexachloroethane
Nitrobenzene
Isophorone
2-Nitrophenol
2,4-Dimethylphenol
bis(2-Chloroethoxy) methane
2,4-Dichloropenol
1,2,4-Trichlorobenzene
Naphthalene
4-Chloroaniline
Hexachlorobutadiene
4-Chloro-3-methylphenol
2-Methylnaphthalene
Hexachlorocyclopentadiene
2,4,6-Trichlorophenol
2,4,5-Trichlorophenol
2-Chloronapthalene
2-Nitroaniline
Dimethylphthlate
Acenaphthylene
2,6-Dinitrotoluene
3-Nitroaniline
Acenaphthene
2,4-Dinitrophenol
4-Nitrophenol
Dibenzofuran
2,4-Dinitrotoluene
Diethylphthalate
4-Chlorophenyl-phenyl ether
Fluorene
4-Nitroaniline
4,6-Dinitro-2-methylphenol
N-Nitrosodiphenylamine
4-Bromophenyl-phenyl ether
Hexachlorobenzene
Pentachlorophenol
Phenanthrene
Anthracene
Carbazole
Di-n-butylphthalate
Flouranthene
Pyrene
Butylbenzylphthalate
3,3'-Dichlorobenzidine
Benzo(a)anthracene
Chrysene
bis-(2-Ethylhexy1)phthalate
Di-n-octylphthalate
Benzo(b)fluoranthene
Benzo(k)fluoranthene
Benzo(a)pyrene
Indeno(1,2,3-cd)pyrene
Dibenz(a,h)anthracene
Benzo(g,h,i)perylene

Target Analyte List (TAL) Metals/Cyanide

Aluminum
Antimony
Arsenic
Barium
Berylium
Cadmium
Calcium
Chromium
Cobalt
Copper
Iron
Lead
Magnesium
Manganese
Mercury
Nickel
Potassium
Selenium
Silver
Sodium
Thallium
Vanadium
Zinc
Cyanide

Appendix B

Examples of Tabular and Graphic Format

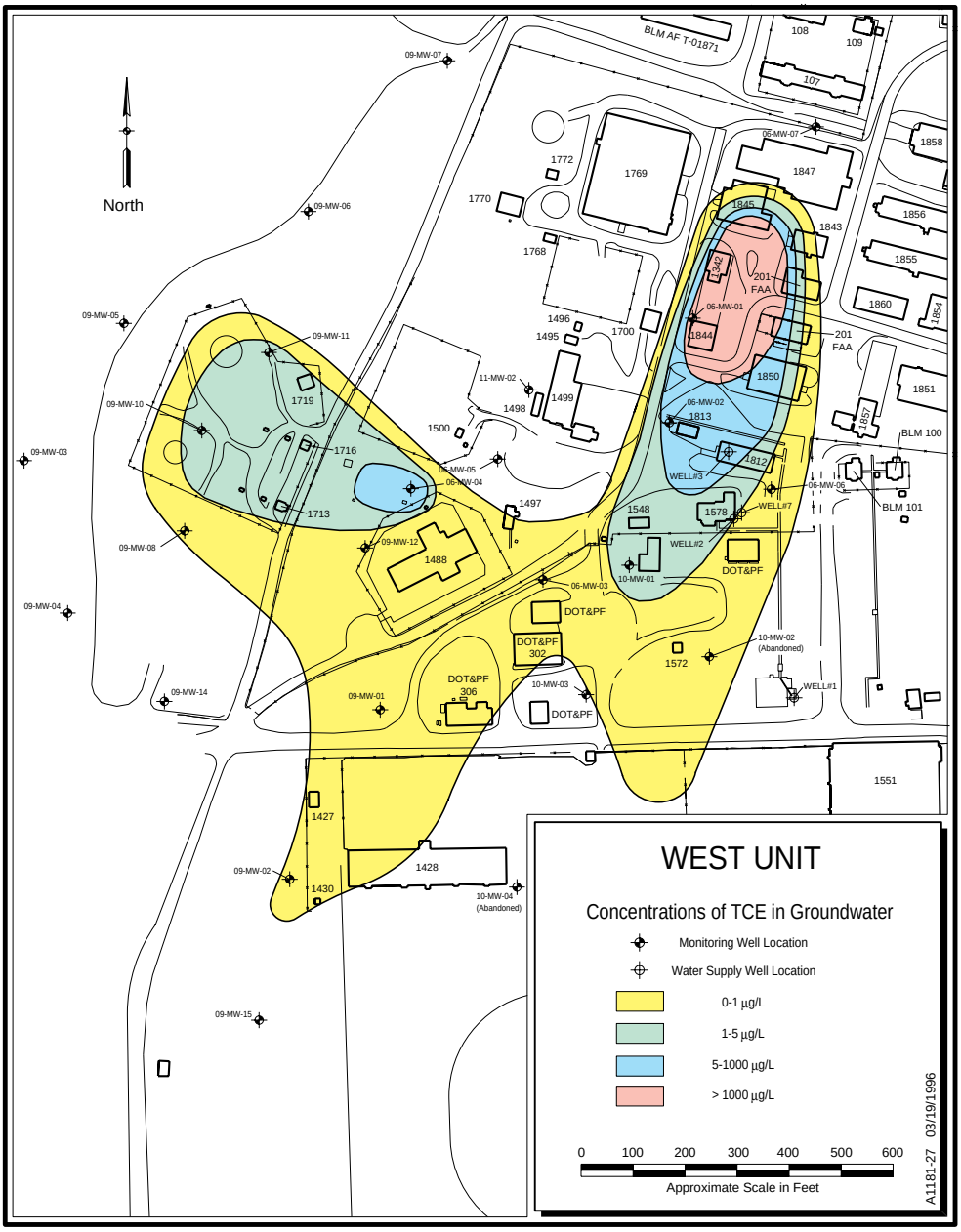
Tank Farm Groundwater Data—Round 3

Analyte	Method (units)	Screening Criteria	Location ID						
			05-MW-02	05-MW-03	05-MW-04	05-MW-05	05-MW-06	05-MW-07	05-MW-11
Gasoline Range Organics	AK101 (ug/L)	NA	ND (50)[a]	17,000 (50)	110,000 (50)	130,000 (50)	ND (50)	97,000 (50)	1,200 (50)
Diesel Range Organics	AK102 (ug/L)	NA	40 J (100)	2,100 (100)	13,000 (100)	6,900 (100)	53 J (100)	8,700 (100)	1,200 (100)
Acetone	SW8260 (ug/L)	3,700 RN	5.01 B (2.09)	14.4 (2.09)	745 (522)	54.2 (31.4)	2.49 B (2.09)	56.4 (31.4)	7.94 (2.09)
Benzene		5 M	0.0300 BJ (0.0307)	4,530[b] (3.07)	27,200 (30.7)	41,000 (30.7)	0.0700 B (0.0307)	24,400 (15.4)	10.4 (0.0307)
Chloromethane		1.4 RC	0.240 B (0.155)	ND (0.155)	222 (38.8)	2.85 (2.32)	ND (0.155)	ND (2.32)	ND (0.155)
Dibromochloromethane		0.13 RC	ND (0.0283)	ND (0.0283)	ND (7.08)	ND (0.424)	ND (0.0283)	ND (0.424)	ND (0.0283)
1,2-Dichloroethane		5 M	0.710 (0.0791)	0.840 (0.0791)	ND (19.8)	35.1 (1.19)	ND (0.0791)	59.2 (1.19)	0.450 (0.0791)
1,1-Dichloroethene		7 M	ND (0.0806)	ND (0.0806)	17.5 J (20.2)	ND (1.21)	ND (0.0806)	ND (1.21)	ND (0.0806)
Trans-1,3-Dichloropropene		0.077 RC	ND (0.0829)	ND (0.0829)	ND (20.7)	ND (1.24)	ND (0.0829)	ND (1.24)	ND (0.0829)
Ethylbenzene		700 M	ND (0.110)	330 (3.30)	810 (27.5)	741 (1.65)	ND (0.110)	649 (1.65)	0.0900 J (0.110)
Methylene chloride		5 M	0.210 B (0.151)	0.930 B (0.151)	398 (37.8)	20.2 (2.26)	0.160 B (0.151)	3.60 (2.26)	0.130 BJ (0.151)
4-Methyl-2-Pentanone (MIBK)		2,900 RN	ND (0.501)	2.81 (0.501)	ND (125)	46.2 (7.52)	ND (0.501)	ND (7.52)	2.21 (0.501)
1,1,2,2-Tetrachloroethane		0.052 RC	ND (0.170)	ND (0.170)	ND (42.5)	ND (2.55)	ND (0.170)	ND (2.55)	ND (0.170)
Toluene		1,000 M	ND (0.0336)	2,200 (3.36)	13,400 (33.6)	19,100 (33.6)	0.0500 (0.0336)	20,200 (16.8)	2.64 (0.0336)
Trichloroethene		5 M	ND (0.0439)	ND (0.0439)	ND (11.0)	4.50 (0.658)	ND (0.0439)	ND (0.658)	ND (0.0439)
Total Xylenes		10,000 M	ND (0.489)	1,100 (14.7)	2,250 (122)	2,560 (93.1)	ND (0.489)	3,090 (93.0)	0.610 (0.489)

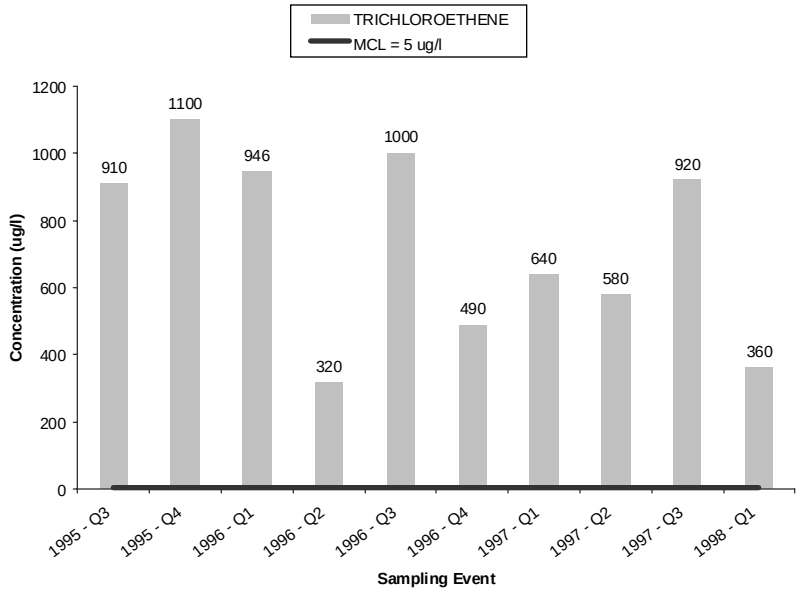
[a]Numbers in parentheses are sample-specific quantitation limits.
[b]Shaded results exceed the screening criteria.

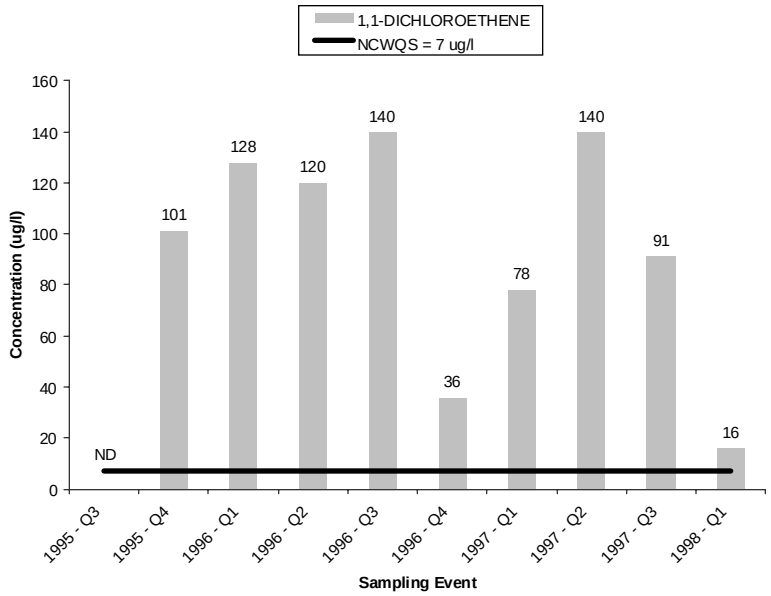
M = Maximum Contaminant Level (MCL).
RC = EPA Region III risk-based criteria, carcinogenic level.
RN = EPA Region III risk-based criteria, non-carcinogenic level.
ND = Not detected at the specified quantitation limit.
J = Detected at a concentration less than the specified detection limit.
B = Detected at concentrations indistinguishable from those detected in laboratory blanks.

Example 1. Tabular Format with Highlighted Results
(NOTE: these are sample data and do not reflect site conditions at any NAS Patuxent River site)



Example 2. Graphic Format with Contaminant Plume Contouring
(NOTE: these are sample data and do not reflect site conditions at any NAS Patuxent River site)





Example 3. Concentration Tracking Graphs
(NOTE: these are sample data and do not reflect site conditions at any NAS Patuxent River site)

B.0 GIS NOTES

Example GIS Application Features

The following two pages illustrate screen shots of a GIS application that allows the user to generate plume maps using data from a monitoring program. By selecting an Operable Unit, a contaminant of concern, and a sampling round, a custom query is generated. The concentration data from the query are subsequently contoured and displayed on the screen. A table containing the query data is also displayed.

By clicking on a well, building, source area, or other feature in the GIS display, the user can bring up specific data describing the chosen feature. For example, clicking on a specific well may enable the user to bring up well construction, water level, or contaminant concentration data. Clicking on a site or Operable Unit may bring up pertinent information such as contaminants of concern, site activities, and dates of operation.

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

Example GIS Applications to LTM Programs

These types of applications have many uses within an LTM program. By being able to continuously track a plume's size and shape, decisions regarding which wells to sample and when to shut down active remediation systems can be made. For instance;

- If a plume is determined to be shrinking, wells once within the plume may become downgradient wells. Further downgradient wells may be eliminated from monitoring.
- If changes to plume size and contaminant concentrations become insignificant over time, consideration may be given to shutting down active remediation and allowing natural attenuation to take place.
- If a plume appears to be growing, additional wells may need to be identified or installed to track the plume edge. In addition, changes may need to be made to the remediation system to prevent offsite migration of contaminants.

Additional uses of this type of system involve tracking of individual monitoring points over time. By querying out several rounds of data for a single monitoring point, either in tabular or graphic format, decisions can be made regarding that monitoring point:

- If contaminant concentrations appear to be decreasing, the well may be eliminated from the program, depending upon its location, or monitored less frequently.
- If contaminant concentrations have leveled off, the well may be proposed for less frequent monitoring.
- If contaminant concentrations appear to be increasing, the well should be kept in the LTM program and monitored at the current frequency.

By querying several rounds of analytical data for an entire site, decisions regarding analytical methods may be made. If a given analyte has not been detected in four sampling rounds, it should be proposed for elimination from the LTM program for that site. If no analytes of concern have been detected at concentrations above action levels for two or more rounds, it may be reasonable to propose the entire site for closeout.

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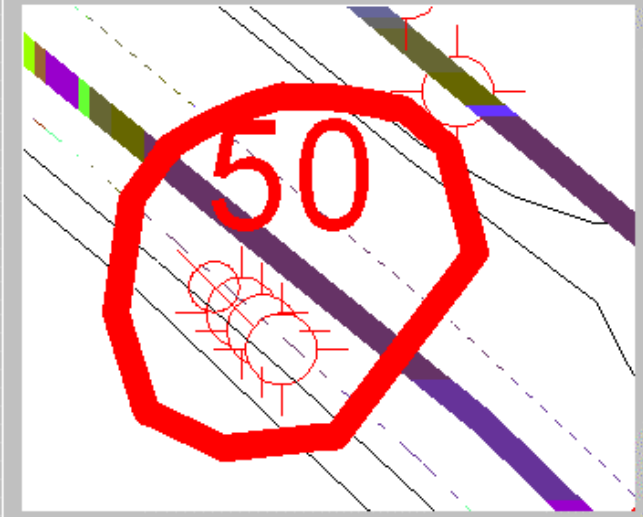
Magnifier



Close

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Map for 2Q97 and AU Groundwater Zone and PCE

List Well Data

Pan Left | Pan Up | Zoom In | Zoom Out | Pan Down | Pan Right

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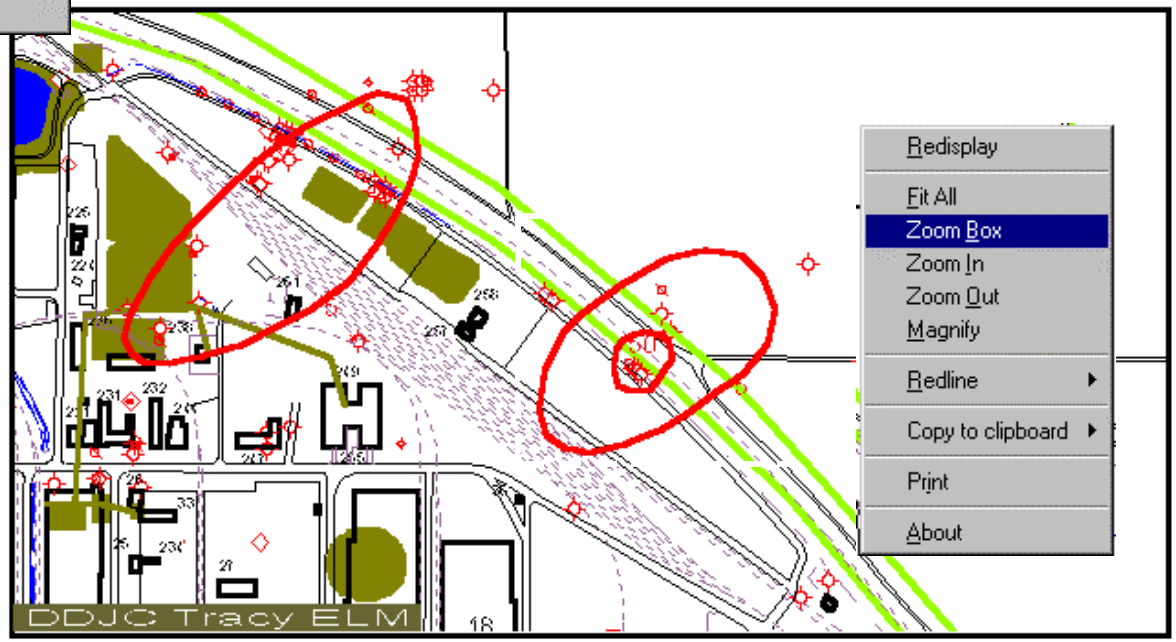
Well	Result	Units	Sampling Event	GW Zone
LM025AUA	0	ug/L	2Q97	AU
LM030AUA	38.6	ug/L	2Q97	AU
LM032AU	151	ug/L	2Q97	AU
LM035AU	9.65	ug/L	2Q97	AU
LM058AU	15.9	ug/L	2Q97	AU
LM093AU	0	ug/L	2Q97	AU
LM115AU	0	ug/L	2Q97	AU
LM143AU	7.18	ug/L	2Q97	AU
LM144AU	3.69	ug/L	2Q97	AU
LM145AU	0	ug/L	2Q97	AU



Redisplay
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Zoom Out
Magnify
Redline
Copy to clipboard
Print
About

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File Edit View Go Communicator Help

Query...

ELM Help

ELM Home

SWMUs

Well Inventory

Groundwater Elevations

Contaminant Concentrations

Underground Storage Tanks

TCE Comparison Map (1995-96)

Select...

Draw Map for 2Q97 and AU Groundwater Zone and PCE

List Well Data

View...

Groundwater Contamination Inventory (PCE)

Well	Result	Units	Sampling Event	GW Zone
LM025AUA	0	ug/L	2Q97	AU
LM030AUA	38.6	ug/L	2Q97	AU
LM032AU	151	ug/L	2Q97	AU
LM035AU	9.65	ug/L	2Q97	AU
LM058AU	15.9	ug/L	2Q97	AU
LM093AU	0	ug/L	2Q97	AU
LM115AU	0	ug/L	2Q97	AU
LM143AU	7.18	ug/L	2Q97	AU
LM144AU	3.69	ug/L	2Q97	AU
LM145AU	0	ug/L	2Q97	AU

Pan Left | Pan Up | Zoom In | Zoom Out | Pan Down | Pan Right

Document: Done

Appendix C

Statistical Applications to Long-Term Monitoring Program

Statistical analysis of spatial and temporal trends in groundwater monitoring data typically starts with visual inspection of graphical plots of the results for a well or group of wells over time or as a function of distance from the source. Visual examination of such data is a highly sensitive means of detecting trends or potential trends in the data. Statistical tests can then be used to verify the significance of any observable trends by calculating the liklihood that the trend might have resulted purely from random variability.

A useful tool for assessing the significance of trends noted in visual examination of concentration versus time plots is the Mann-Kendall test. The Mann-Kendall test can be interpreted as a nonparametric test for an increasing or decreasing slope for the line describing concentration as a function of time. The Mann-Kendall test is described in detail in R. O. Gilbert, *Statistical Methods for Environmental Pollution Monitoring* (1987) and is also discussed in the EPA guidance document, *Guidance for Data Quality Assessment, Practical Methods for Data Analysis* (1998, Office of Research and Development, EPA/600/R-96/084). This test is useful because it does not require that data be collected at equally-spaced time intervals and it is non-parametric (a *nonparametric* test does not require that the data conform to any particular statistical distribution such as normality or log-normality). It also can accommodate non-detected results since only the relative magnitudes of the results rather than the actual observed values are used.

Specifically, for a given well, the Mann-Kendall trend statistic *S* for a single location is calculated as:

$$S = \sum_{k=1}^{n-1} \sum_{j=k+1}^{n} sign(X_j - X_k),$$

where
$$sign(X_j - X_k) = 1 \quad \text{if } (X_j - X_k) > 0$$
$$sign(X_j - X_k) = 0 \quad \text{if } (X_j - X_k) = 0$$
$$sign(X_j - X_k) = -1 \quad \text{if } (X_j - X_k) < 0$$

In the equations, X_i represents the concentration at time *i*, and *n* is the total number of observations.

A Mann-Kendall trend statistic, *S*, of zero indicates that there is neither an increasing nor a decreasing trend. A positive *S* indicates an increasing trend. A negative *S* indicates that the trend is decreasing. As an example, suppose three measurements were taken at times 1, 2 and 3 and that concentrations of 5, 10 and 15 were observed, respectively, at these times. This corresponds to an *S* of +3, which indicates an increasing trend.

However, even if no true trend is present, it is possible to obtain a positive or negative *S*, just due to random variability. A test of statistical significance is a method for assessing whether an observed trend can be attributed to random variability and involves computing a p-value, which represents the probability that a result as extreme as the observed *S* (an *S* as high in the positive direction or as low in the negative direction) could have occurred just by random chance. If the p-value is small (typically, less than 0.05, although this varies from one project to another), the trend is said to be statistically significant.

For the Mann-Kendall statistic, the details of the significance test depend on the sample size. For small sample sizes (less than 10), an exact test is applied. This exact test is described in Gilbert (1987) and is based on computing all the possible orderings of results that could have occurred, if there were no true trend.

Using the previous example, if there is no true trend, then the three observed results could have occurred in any order, and each possible ordering would have been equally likely. The six possible orderings are: (5,10,15), (5,15,10), (10,5,15), (10,15,5), (15,5,10), and (15,10,5). These six orderings correspond to *S* trend statistics of -3, -1, -1, +1, +1, +3, respectively, and each is equally likely if there is no true trend. Thus, the chances of obtaining an observed S as high as that obtained in the example above, just due to random chance, is 1/6 or a 16.67% chance. The p-value corresponding to the observed S=+3 is 0.1667. Thus, in this example, even though a positive test statistic was obtained (in fact the highest possible test statistic), the result would be concluded to be not statistically significant, using 0.05 as the cutoff between statistical significance and non-significance. For this reason, tests for trend typically are not performed on samples of size three or smaller. When four samples are available, the number of possible orderings increases to 24, and it is possible to obtain statistics that are significant at the 0.05 significance level.

Clearly, as the sample size increases, the number of possible orderings increases, and the computation of p-values can become time- or computer-intensive. Gilbert (1987) provides a table for sample sizes up to 10. If more than 10 samples are available, then an approximate method, which does not require large tables or intensive calculations, can be used to compute the p-value. The approximation is calculated by first computing the standard error (a measure of uncertainty) associated with *S*:

$$Var(S) = \frac{1}{18}\left[n(n-1)(2n+5) - \sum_{p=1}^{g} t_p (t_p - 1)(2t_p + 5) \right]$$

Then a standard normal Z statistic is calculated as

$$Z = \frac{S-1}{\sqrt{Var(S)}} \quad \text{if } S > 0$$

$$Z = 0 \quad \text{if } S = 0$$

$$Z = \frac{S+1}{\sqrt{Var(S)}} \quad \text{if } S < 0.$$

Finally, a p-value is calculated for the Z statistic based on percentiles from a standard normal distribution.

The Mann-Kendall trend test is an attractive option for assessing the statistical significance of an observed increasing or decreasing trend. Its strengths lie in the fact that few statistical assumptions (such as normality or log-normality) are required, it is robust against one or two anomalous data values, it can easily accommodate non-detected results, and is easy to interpret. However, one of its strengths is also a potential weakness. That is, the actual concentrations themselves are not taken into account. For example, a series of results such as (1,2,3,4,5) is as significant as (1,10,20,100,200). Practically, however, the second scenario is more likely to reflect a true trend than the first. For this reason, the Mann-Kendall trend test is always accompanied by graphical presentations of the data.

Other possible methods for testing for trend include modifications to the Mann-Kendall test for trend to accommodate multiple measurements per well per sampling event or to correct for seasonal effects, as well as a parametric tests for trend based on regression. These modifications to the Mann-Kendall test would be appropriate if pronounced seasonal variation were noted in monitoring data or if duplicate samples were to be included in the analysis. One

drawback to correction for seasonal effects is that a longer time series of data is needed before statistical analysis can be usefully implemented.

A regression approach to testing for trend involves constructing a model to predict concentration as a function of time (typically assuming linearity). If the model provides a good fit to the data and there is a predicted increase (or decrease) in concentration as a function of time, then the trend can be said to be significant. Computing p-values to objectively assess the goodness of the model fit is discussed in the EPA guidance document, *Guidance for Data Quality Assessment, Practical Methods for Data Analysis* (1998, Office of Research and Development, EPA/600/R-96/084), as well as in many standard statistical textbooks such as Mason, et al. (1989), *Statistical Design and Analysis of Experiments*.

Regression analysis can be more strongly biased by outliers such as anomolously high results and requires that non-detects be assigned numerical values. Also, purely linear models may not accurately represent trends in contaminant concentrations, which are often log-normally distributed. While these limitations can be addressed, additional level of effort is required to assess the statistical properties of the data and properly format all results for the analysis. It is recommended that the Mann-Kendall be applied as the first step in assessing trends. Regression analysis may be appropriate for assigning numerical values to trends identified as significant, as in calculating natural attenuation rates, contaminant mass removal, or rates of plume advance or retreat.

Other relevant statistical tools that do not specifically assess trend but that can be incorporated in the LTM optimization include spatial statistical analysis, statistical tests for outliers, statistical comparisons of populations (e.g., downgradient to upgradient well comparisons), statistical estimation of average or extreme concentrations (for purposes of comparing to regulatory criteria), and multivariate statistical approaches to evaluate concentrations for multiple compounds simultaneously. Many of these tools are discussed in more detail in *Guidance for Data Quality Assessment, Practical Methods for Data Analysis* (1998, Office of Research and Development, EPA/600/R-96/084).

While many of these tests are more appropriate for site assessment and remedial investigation phases of effort, rather than long-term monitoring, they may find application in specific instances. For example, statistical analysis of upgradient and downgradient populations may be useful if site closure is sought despite not having attained MCLs in downgradient wells. If upgradient populations have statistically similar contaminant concentrations, closure may be justified by arguing that no contaminant source remains at the site. Multivariate statistical analysis may be useful in instances where it is suspected that concentrations or trends in concentrations of one or more contaminants are related in some way, for example as in the degradation of TCE and the production of daughter products such as cis-1,2 dichloroethene. Statistical verification of such trends can have important implications for remedial design and operation as well as regulatory approvals.

References:

Gilbert, R.O., 1987, *Statistical Methods for Environmental Pollution Monitoring*, New York: Van Nostrand Reinhold.

Mason, R.L., Gunst, R.F., Hess, J.L., 1989, *Statistical Design and Analysis of Experiments*, New York: John Wiley and Sons.

EPA, Office of Research and Development 1998, *Guidance for Data Quality Assessment, Practical Methods for Data Analysis*, EPA/600/R-96/084.