Technical Report EL-99-7
March 1999

US Army Corps of Engineers
Waterways Experiment Station

Monitored Natural Attenuation of Explosives in Groundwater – Environmental Security Technology Certification Program Completion Report

by Judith C. Pennington, Mansour Zakikhani, Danny W. Harrelson

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19991019 054

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Prepared for Environmental Security Technology Certification Program Office

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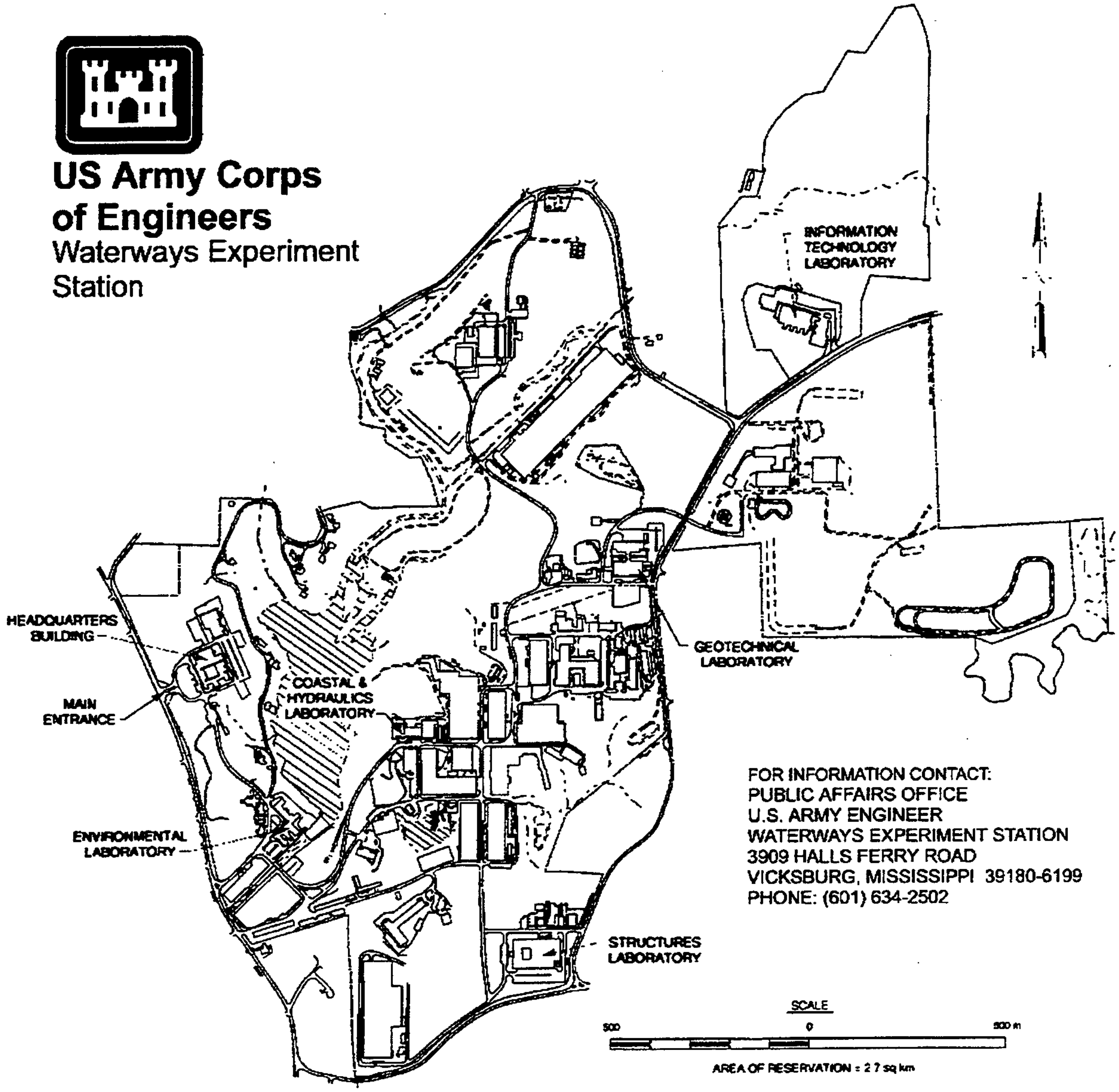

FOR INFORMATION CONTACT:
PUBLIC AFFAIRS OFFICE
U.S. ARMY ENGINEER
WATERWAYS EXPERIMENT STATION
3909 HALLS FERRY ROAD
VICKSBURG, MISSISSIPPI 39180-6199
PHONE: (601) 634-2502

Waterways Experiment Station Cataloging-in-Publication Data
Pennington, Judith C.

Monitored natural attenuation of explosives in groundwater - Environmental Security Technology Certification Program / by Judith C. Pennington, Mansour Zakikhani, Danny W. Harrelson ; prepared for Environmental Security Technology Certification Program Office.

230 p. : ill. ; 28 cm. — (Technical report ; EL-99-7)

Includes bibliographic references.

1. Hazardous wastes — Natural attenuation. 2. Hazardous wastes — Purification. 3. Groundwater — Environmental aspects — Mathematical models. I. Pennington, Judith C. II. Zakikhani, Mansour, 1954- III. Harrelson, Danny W. IV. United States. Army. Corps of Engineers. V. U.S. Army Engineer Waterways Experiment Station. VI. Environmental Laboratory (U.S. Army Engineer Waterways Experiment Station) VII. Environmental Security Technology Certification Program Office. VIII. Title. IX. Series: Technical report (U.S. Army Engineer Waterways Experiment Station) ; EL-99-7.

TA7 W34 no.EL-99-7

Monitored Natural Attenuation of Explosives in Groundwater - ESTCP Completion Report

U.S. Army Engineer Waterways Experiment Station

DEPARTMENT OF DEFENSE
UNITED STATES OF AMERICA

ESTCP
ENVIRONMENTAL SECURITY TECHNOLOGY CERTIFICATION PROGRAM

April 1999

Contents

Preface

This report was prepared by the Environmental Laboratory (EL) of the U.S. Army Engineer Waterways Experiment Station (WES), Vicksburg, MS. The demonstration was sponsored by the Environmental Security Technology Certification Program, Arlington, VA, Mr. Jeffrey Marqusee, Program Manager, Project Number 9518, and the Strategic Environmental Research and Development Program, Arlington, VA, Dr. John Harrison and Mr. Bradley P. Smith, Executive Directors, Project Number 1043. The U.S. Army Industrial Operations Command, Rock Island, IL, Mr. Cyril Onewokae, Environmental Quality Directorate, funded monitoring at the validation site. The Principal Investigator was Dr. Judith C. Pennington, EL.

The authors of this report, Dr. Pennington, Dr. Mansour Zakikhani, EL, and Mr. Danny W. Harrelson, Geotechnical Laboratory, WES, acknowledge the cooperation and site support received from Mr. Ira May, Mrs. Laurie Haines, and others, Army Environmental Center, Aberdeen Proving Ground, MD; Mr. Doyle Williams, Environmental Officer, Louisiana Army Ammunition Plant, Minden, LA; and Mr. Art Holz, Environmental Coordinator, Joliet Army Ammunition Plant, Wilmington, IL.

This report was reviewed by Drs. James M. Brannon and William B. Davis, EL. The study was conducted under the direct supervision of Dr. Richard E. Price, Chief, Environmental Processes and Effects Division, EL, and Dr. John Harrison (retired), Director, EL.

At the time of publication of this report, Acting Director of WES was COL Robin R. Cababa, EN.

This report should be cited as follows:

> Pennington, J. C., Zakikhani, M., and Harrelson, D. W. (1999). "Monitored natural attenuation of explosives in groundwater - Environmental Security Technology Certification Program completion report," Technical Report EL-99-7, U.S. Army Engineer Waterways Experiment Station, Vicksburg, MS.

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U.S. Army Engineer Waterways Experiment Station

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1. Introduction

1.1 Background Information

The Army has an estimated 1,300 installations worldwide containing approximately 5,500 individual sites contaminated with various compounds that will require some form of remedial actions (Environmental Quality Technology Program 1998). A significant portion of this contamination is due to past practices for disposal of explosives, especially 2,4,6-trinitrotoluene (TNT) and 1,3,5-trinitro-1,3,5-hexahydrotriazine (RDX). Congress has mandated that the Army and other services comply with all applicable environmental laws and regulations at these contaminated sites to ensure protection of human health and the environment. The estimated cost of the Army's Restoration Program is currently estimated to range between 7 and 10 billion dollars (Environmental Quality Technology Program 1998).

Monitored natural attenuation may be a sensible alternative to existing remediation techniques for explosives-contaminated sites that meet well-defined selection criteria and acceptable risk levels and that satisfy specific regulatory concerns. A recent study verified a regulatory attitude of potential acceptance of monitored natural attenuation for explosives-contaminated sites (Balasco et al. 1996). This study confirmed that most regulatory agencies would accept monitored natural attenuation given appropriate scientific, engineering, and risk-assessment data.

Natural attenuation is defined as reduction of contaminant concentrations to environmentally benign levels through natural processes. Monitored natural attenuation may be justified at sites where contaminant concentration is so low that other remedial actions are not viable or cost effective, contaminants are readily biodegradable under existing site conditions, contaminants are immobilized via natural processes, disturbance of structures or sensitive habitat is undesirable, and/or immediate engineered remedial action is not required or not feasible. In the context of this demonstration, monitored natural attenuation excludes enhancement efforts, but is not a "no action" remedial alternative. Monitored natural attenuation may require more extensive site characterization than other remedial alternatives, extended (long-term) monitoring of groundwater contamination and of attenuation processes, and modeling to anticipate future transport of contamination toward receptors of concern. However, the potential for significant cost savings over engineered remedial alternatives makes monitored natural attenuation a viable consideration. Estimates of savings of 10 times the costs of other alternatives are not unreasonable. Development of natural attenuation of explosives in soils and groundwater as a remediation technology will provide the Department of Defense (DoD) with an effective, low-cost alternative for explosives-contaminated sites.

1.2 Official DoD Requirement Statement(s)

The following is a list of high-priority DoD user requirements related to this demonstration at its inception (listed in order of priority) (Table 1). The project contributed to each of these requirements. By the end of the demonstration, these requirements had changed as indicated by the current requirement rank.

Table 1
DoD User Requirements Related to This Demonstration Project

Original Requirement	Current Requirement Rank	Project Contribution
1.2.a Explosives in Groundwater	4	An effective, low-cost remedial alternative
		Characterization of explosives contamination in groundwater
		Models for conceptualization and prediction of migration of explosives in groundwater
1.3.a Remediation of Explosives in Soil	8	Biomarker techniques for assessing rate and extent of microbial degradation processes in soils
		Methods for determining site capacity and partitioning properties
		Techniques for use of cone penetrometry for lithological, microbiological, and chemical (geochemical and contaminant) characterization
		Validation of onsite field assays for explosives
1.2.f Alternatives to Pump and Treat	None	Nonintrusive, in situ remediation alternative
		An effective, low-cost remedial alternative

(Continued)

Table 1. (Concluded)

Original Requirement	Current Requirement Rank	Project Contribution
1.5.g Hazard/Risk Assessment of Military-Unique Compounds	9	Methods for predicting migration and degradation rate and extent
		Identification of potential receptors
1.5.c Hazardous and Explosive Waste Fate/Transport Predictions	12	Methods for predicting migration and degradation rate and extent
		Methods for determining site capacity and partitioning properties
		Models for conceptualization and prediction of migration of groundwater contamination
1.1.k Alternative Techniques for Subsurface Characterization	17	Refined techniques for reducing artifacts in groundwater sampling data
		Techniques for use of cone penetrometry for lithological, microbiological, and chemical (geochemical and contaminant) characterization
		Validation of onsite field assays for explosives
		Biomarker techniques for assessing rate and extent of microbial degradation processes in soils
1.3.m Soil Bioremediation	None	Biomarker techniques for assessing rate and extent of microbial degradation processes in soils
1.1.a Develop/ Improve Field Analytical Techniques	None	Validation of onsite field assays for explosives
		Refined techniques for reducing artifacts in groundwater-sampling data
1.3.i Soil Treatment Under Structures	18	Nonintrusive, in situ remediation alternative
1.1.f Non-invasive Field Techniques	None	Nonintrusive, in situ remediation alternative
1.3.h Determine Natural Attenuation Rates of Army-Unique Compounds	3	An effective, low-cost remedial alternative
		Models for conceptualization and prediction of migration of explosives in groundwater
		Biomarker techniques for assessing rate and extent of microbial degradation processes in soils
		Methods for determining site capacity and partitioning properties
1.1.i Develop Standard Analytical Methods and Field Analytical Techniques for Army-Unique Compounds	14	Characterization of explosives contamination in groundwater
		Biomarker techniques for assessing rate and extent of microbial degradation processes in soils
		Methods for determining site capacity and partitioning properties
1.1.h Determine Defensible Sampling Strategies	None	Techniques for use of cone penetrometry for lithological, microbiological, and chemical (geochemical and contaminant) characterization
		Refined techniques for reducing artifacts in groundwater sampling data
		Validation of onsite field assays for explosives

1.3 Objectives of the Demonstration

The broad project objective was to demonstrate monitored natural attenuation of explosives at an Army site and to develop guidance for evaluating, selecting, and implementing monitored natural attenuation of explosives. The demonstration required refinements in existing technologies and adaptations of several developmental technologies. Specific objectives included the following:

a. Refine groundwater-monitoring techniques to optimize detection of trends in explosives concentrations over time.

b. Adapt microbial molecular genetics techniques (biomarkers) for application as monitoring tools for natural attenuation of explosives as a remedial alternative.

c. Determine the significance of soil sorption and site-capacity determination on transport and degradation rate at the demonstration site.

d. Examine the feasibility of using stable isotope ratios to track attenuation of explosives.

e. Adapt conceptual and numerical models to be used in site conceptualization and predictions of the long-term fate of contaminants at the site, respectively.

f. Develop a protocol for the evaluation, selection, and implementation of monitored natural attenuation of explosives.

A demonstration of monitored natural attenuation of explosives in groundwater provides the DoD with a low-cost alternative for sites where natural processes are adequate to protect human health and the environment.

The primary site for demonstration of monitored natural attenuation of explosives was Area P at the Louisiana Army Ammunition Plant (LAAP), Minden, LA (Figure 1). A second site at Joliet Army Ammunition Plant (JAAP), Joliet, IL (Figure 2), provided verification of the approaches developed at LAAP. Objectives of the monitoring were to determine trends in groundwater concentrations over time and provide data to support conceptual and predictive modeling for each site. Objectives of the cone penetrometry sampling were to refine conceptualization of site lithology and contaminant distribution in the subsurface and to provide site material for development of biomarkers as monitoring tools for natural attenuation of explosives. Points of contact for the demonstration project are listed in Appendix A. Sources for the archived data and the demonstration plan are given in Appendix B.

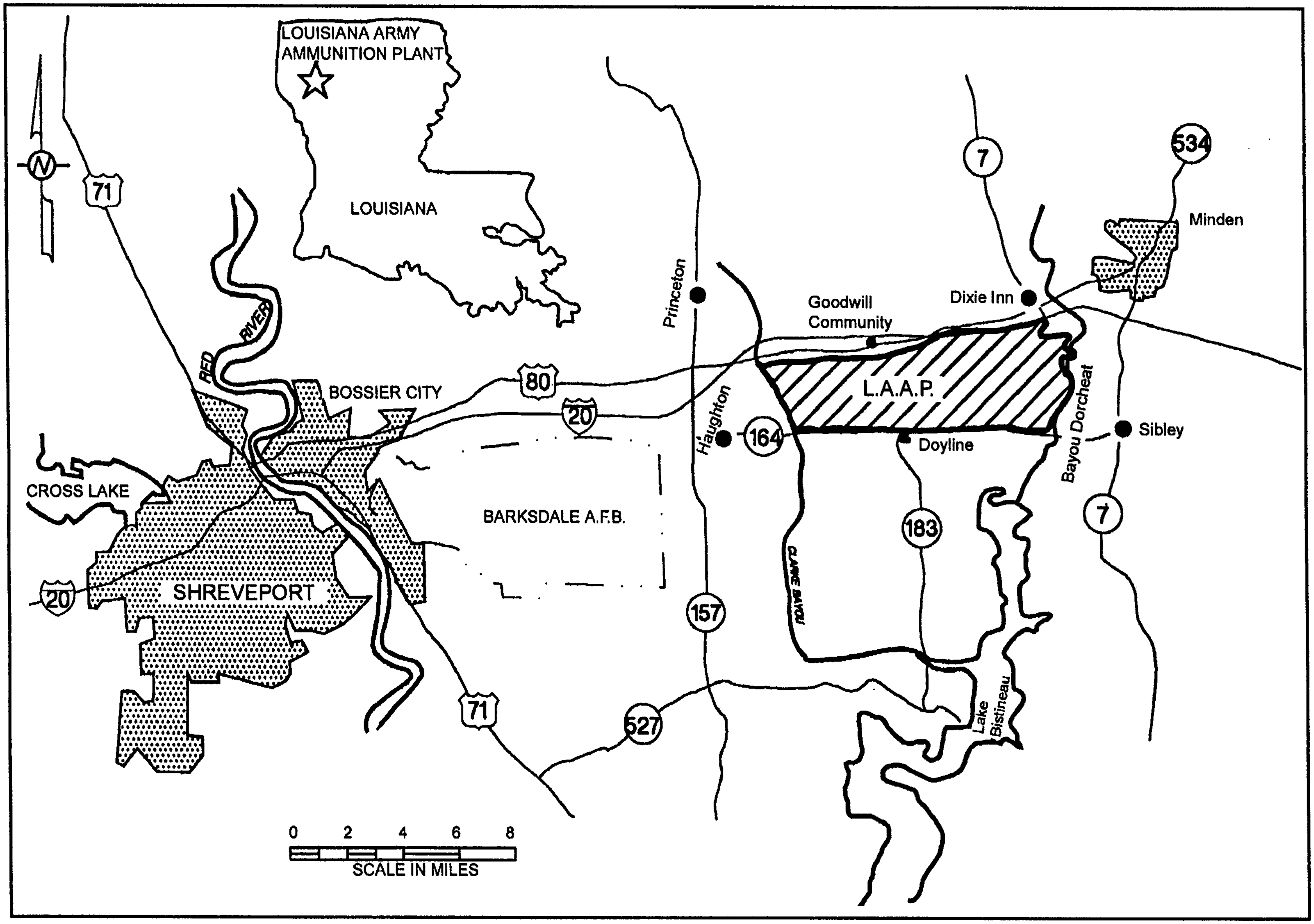

Figure 1. Location of Louisiana Army Ammunition Plant, Minden, LA

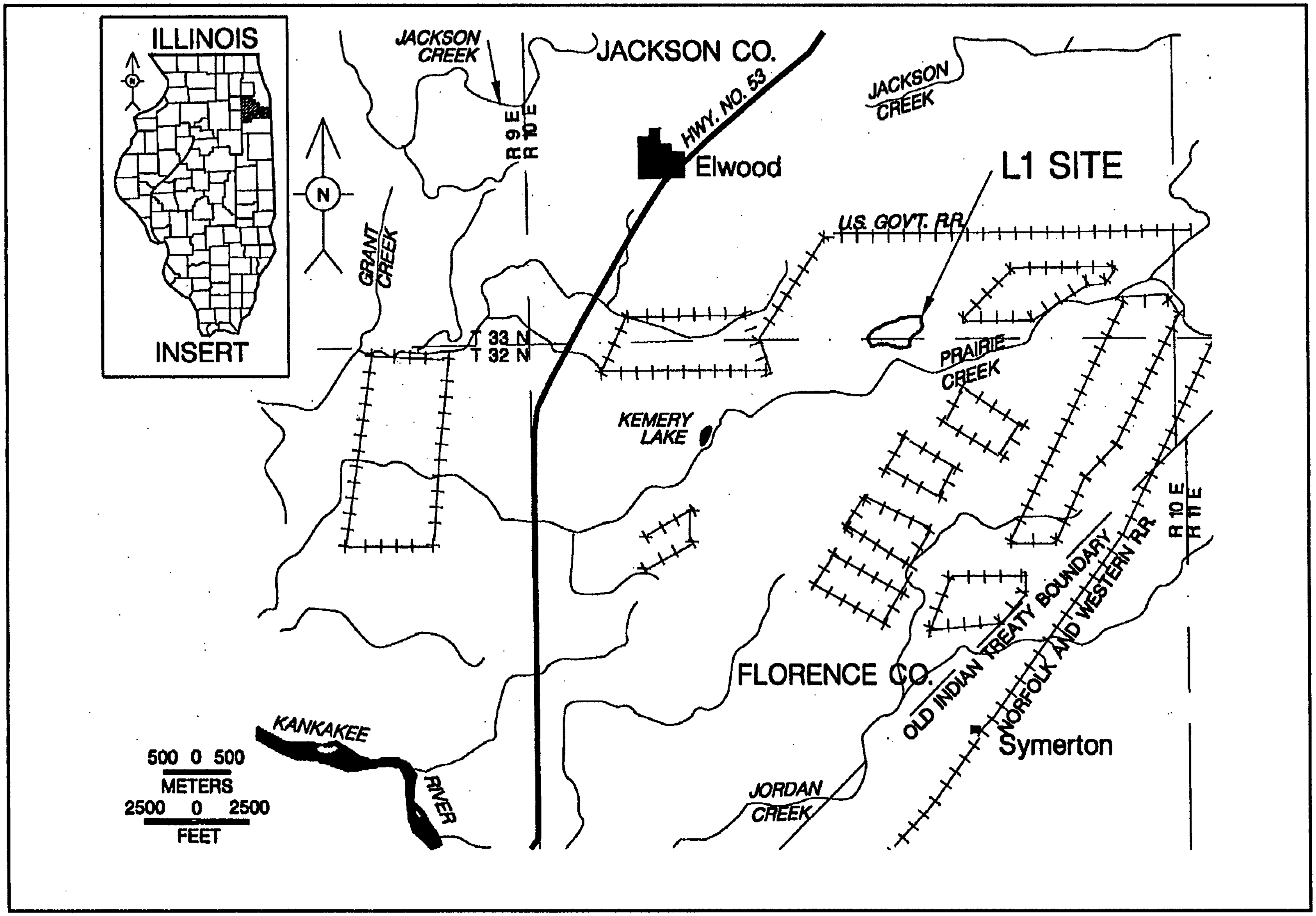

Figure 2. Location of Joliet Army Ammunition Plant, Joliet, IL

1.4 Regulatory Issues

Because of concern for adoption of responsible monitored natural attenuation practices, the U.S. Environmental Protection Agency (EPA) Office of Solid Waste and Emergency Response (OSWER) issued a draft policy directive (OSWER Directive Number 9200.4-17) to clarify EPA policy regarding the use of "monitored natural attenuation" at sites regulated by their office (EPA 1997). These sites include Superfund, Resource Conservation and Recovery Act (RCRA) Corrective Action, and Underground Storage Tanks sites. The directive emphasizes source control, monitoring, and use of "three lines of evidence" as follows:

a. Historical groundwater and/or soil-chemistry data that demonstrate a clear, meaningful trend of declining contaminant mass and/or concentrations at appropriate monitoring or sampling points.

b. Hydrogeologic or geochemical data that can be used to indirectly demonstrate the type(s) of natural attenuation processes active at the site and the rate at which such processes will reduce contaminant concentrations to required levels.

c. Data from field or microcosm studies (conducted in or with actual contaminated site media) that directly demonstrate the occurrence of a particular natural attenuation process at the site and its ability to degrade the contaminants of concern (typically used to demonstrate biological degradation processes only).

The directive includes various "physical, chemical, or biological processes that, under favorable conditions, act without human intervention to reduce the mass, toxicity, mobility, volume, or concentration of contaminants in soil or groundwater." The directive is risk based, recommends that source control be a high priority, and requires planning of "contingency remedies" should monitored natural attenuation prove less effective than anticipated.

Regional EPA offices and State regulatory agencies may have distinctly different additional requirements and must be involved in selection and implementation of any remedial alternative. The "Draft Protocol for Evaluating, Selecting, and Implementing Monitored Natural Attenuation at Explosives-Contaminated Sites" provides guidance for involving these and other interested parties (Pennington et al., in preparation).

1.5 Previous Testing of the Technology

A significant precedent for monitored natural attenuation of environmental contaminants has been set by the widely implemented protocol for monitored natural attenuation of fuels developed by the Air Force Center for Environmental Excellence (AFCEE) (Wiedemeier et al.

1995a,b). The protocol has been implemented at more than 60 sites nationwide. The protocol espouses development of the following three lines of evidence for monitored natural attenuation: (a) documented loss of contaminants at the field scale, (b) use of chemical analytical data in mass balance calculations, and (c) laboratory microcosm studies using aquifer samples collected from the site. To that end, the following eight steps are recommended:

a. Review existing site data.

b. Develop preliminary conceptual model for the site and assess potential significance of natural attenuation processes.

c. Perform site characterization in support of monitored natural attenuation.

d. Refine conceptual model based on site-characterization data, complete premodeling calculations and document indicators of natural attenuation processes.

e. Model natural attenuation using numerical fate and transport models that allow incorporation of a biodegradation term (e.g., Bioplume II or Bioplume III).

f. Conduct an exposure assessment.

g. Prepare long-term monitoring plan.

h. Present findings to regulatory agencies and obtain approval for the monitored natural attenuation with long-term monitoring option.

The protocol relies appropriately upon indicators of microbiological degradation processes, which are the most significant degradation processes for fuels. The AFCEE has developed another protocol for chlorinated solvents that is being equally well received (Wiedemeier et al. 1996).

The Army has also circulated an interim policy statement on monitored natural attenuation (*Federal Register* 1990). This statement mandates that monitored natural attenuation be at least considered for all Army sites when developing remediation plans.

2. Technology Description

2.1 Description

The site description reported in terminology consistent with "Guide to Documenting Cost and Performance for Remediation Projects" (Member Agencies of the Federal Remediation Technologies Roundtable 1995) can be summarized as in Table 2.

Table 2
Site Description

Site Background:
Historical Activity that Generated Contamination
SIC Code: 2892 (Chemical and Allied Products, Explosives)

Management Practices that Contributed to Contamination
Liquid Waste Disposal in Unlined Lagoons (Load, Assemble, and Package of Munitions)

Site Characteristics:
Media Treated
Groundwater (in situ)

Contaminants Treated
Explosives (including the following constituents:
TNT, RDX, TNB, and related degradation products)

Treatment System:
Primary Treatment Technology
Monitored Natural Attenuation

Supplemental Treatment Technology
Investigation Derived Waste (Groundwater) - Carbon Adsorption

No design criteria are associated with monitored natural attenuation. However, criteria for site characterization, monitoring, and modeling are described in the "Draft Protocol for Evaluating, Selecting, and Implementing Monitored Natural Attenuation at Explosives-Contaminated Sites" (Pennington et al., in preparation).

2.1.1. Groundwater Monitoring. Declining concentrations of explosives in groundwater over time may be evident from site historical data. If adequate, these historical records provide the first line of evidence under the EPA policy directive, "Historical groundwater and/or soil chemistry data that demonstrate ... declining contaminant mass and/or concentrations...." The first exercise was to evaluate the extensive historical data at LAAP for trends in explosives concentration. Since long-term monitoring is required to verify any observed trends, development of a monitoring plan was the next exercise. To optimize the validity of trends in new data, attention was focused on the quality of the data generated by the groundwater-monitoring plan. Special emphasis was placed on development of techniques for ensuring quality data. Efforts included techniques for minimizing the influence of oxygen at the well head on explosives concentrations, sample preservation, precision, accuracy and representativeness of the data, data comparability, field quality control, and confirmation of analytical chemistry. For monitoring data to support the second line of evidence, "Hydrogeologic or geochemical data that can be used to indirectly demonstrate the type(s) [and rate] of natural attenuation processes active at the site..," collection of data that was not collected during predemonstration monitoring was required. Therefore, an extensive list of explosives-transformation products and geochemical parameters were included in the analyses (See Section 4.4).

The number and locations of monitoring wells will be based upon what is known about the distribution of the contamination and the location(s) of potential receptors (Figure 3). However, definition of plume extent in the four cardinal directions and with depth should be considered minimal. A typical remedial monitoring scheme may require one upgradient well, three down-gradient wells, and at least one well close to the contamination source. Wells may also be needed along the center of the contaminated plume and around the outer boundary of the plume (Figure 3). Sentinel well(s) will also be needed between the plume and the potential receptor(s).

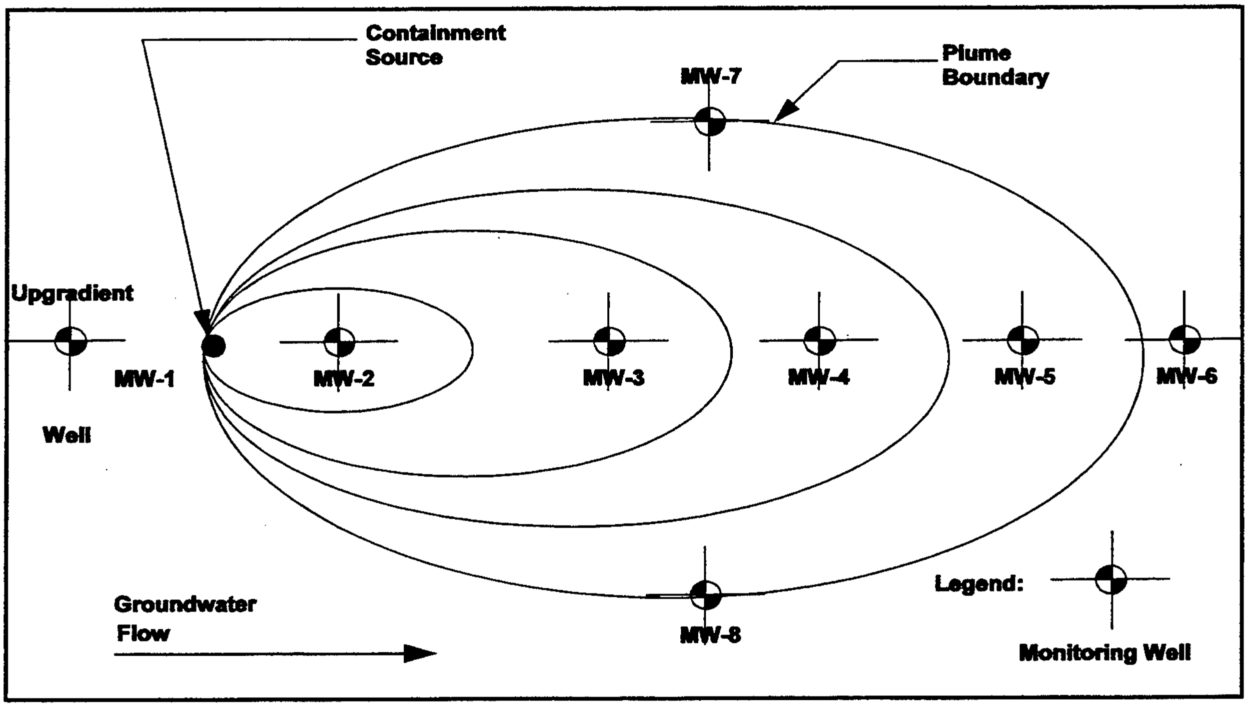

Figure 3. Recommended groundwater well network for demonstrating monitored natural attenuation (EPA 1994a)

2.1.2. Site Capacity. Site capacity for attenuation of explosives is a function of soil sorption, biodegradation, transformation, and chemical interactions with soil organic matter and clay. All of these processes are not well defined for explosives. Nonetheless, site capacity can be measured by simple batch-shake and column tests that quantify contaminant half-life and adsorption coefficients. These capacity measurements can be used to refine predictive capabilities of numerical models for the site. Both batch-shake and column tests were performed on soils from the LAAP aquifer to quantify sorption coefficients and disappearance rates for explosives. These data can support the second line of evidence by providing attenuation-rate measurements. Methods for executing these tests are described in 40 CFR§796.2750 (1989).

2.1.3. Biomarkers. Biomarker techniques have been used to detect the involvement of microorganisms as biocatalysts for the transformation and/or degradation of contaminants. The techniques have been used extensively to measure changes in microbial community structure and microbial response to contaminants.

Radiorespirometry provides direct evidence that transformation and/or complete mineralization can occur in site soils by challenging the indigenous microflora with radiolabeled TNT and/or RDX. Mineralization is evidenced by evolution of radiolabeled carbon dioxide. Methods for executing these tests are described in Pennington et al. ("Monitored Natural Attenuation of Explosives in Soil and Water Systems at Department of Defense Sites: Interim Report"). Analyses of bacterial polar lipids provide information on microbial community biomass and composition and the changes resulting from anthropogenic chemical perturbations. Analysis of nucleic acids provides a mechanism to detect the presence of genes-encoding enzymes required for explosive degradation in situ. The radioassay results can be correlated with results from the two biomarkers and site geochemical data to build a case for monitored natural attenuation onsite. Biomarkers demonstrate (a) whether a viable biomass is present, active, and capable of metabolizing RDX and TNT, (b) the presence of catabolic genes necessary for in situ degradation, and (c) whether significant positive correlations to explosive concentrations, geochemistry, and mineralization properties exist.

The third line of evidence "Data from field or microcosm studies ... which directly demonstrate the occurrence of a particular natural attenuation process ... to degrade the contaminants of concern..." generally requires laboratory testing of field samples (groundwater and/or aquifer material). Therefore, samples of aquifer soils collected by cone penetrometry were subjected to biomarker analyses in laboratory microcosms. Soils from LAAP were used for development and refinement of techniques, while soils from JAAP were used to validate procedures. The two biomarker techniques, phospholipid fatty acid analysis and microbial DNA analysis were coupled with radiorespirometry in microcosm studies.

2.1.4. Stable Isotopes. Stable isotopes ratios of both carbon and nitrogen were evaluated as indicators of attenuation processes. An objective of the work was to develop a preparation technique for isolation and analysis of the ratios without creating an artifact of isotopic fractionation. This objective was met by development of a soxhlet/ultrasonic extraction procedure for soils and a solid-phase extraction procedure for groundwater. Carbon ratios did not change with explosives concentration in groundwater. Results to date suggest a trend in nitrogen ratios that is related to concentration. Soil samples contained insufficient explosives concentrations to effectively evaluate techniques in soil at LAAP. However, additional studies are in progress on groundwater samples.

2.1.5. Modeling. Modeling is essential for (a) conceptualization of the contamination at the site so that proximity to receptors can best be determined, (b) evaluation of factors dominating natural attenuation processes at the site, and (c) prediction of long-term contaminant migration and/or attenuation. A numerical model was applied to the LAAP site using results from the other focus areas, i.e., groundwater monitoring, site-capacity determinations, and biomarkers, in addition to local weather data and other published information. A comprehensive computer graphical and integral modeling system, the Department of Defense Groundwater Modeling System (GMS) (1996), was used. The GMS contains tools to facilitate site conceptualization, geostatistical computations, and postprocessing. The GMS links transport and water quality models to predict the fate and transport of contaminants. Sensitivity of the model simulations and predictions to input parameters was coupled with the desired level of accuracy to determine the level of detail required for field and laboratory measurements. Contaminant mass over time was also calculated using the measured and predicted explosives concentrations. A more detailed description of the GMS is given by Pennington et al. ("Draft Protocol for Evaluating, Selecting, and Implementing Monitored Natural Attenuation at Explosives-Contaminated Sites" and "Monitored Natural Attenuation of Explosives in Soil and Water Systems at Department of Defense Sites: Interim Report"). Additional models are described in Pennington et al. ("Monitored Natural Attenuation of Explosives in Soil and Water Systems at Department of Defense Sites: Interim Report").

2.2 Strengths, Advantages, and Weaknesses

The greatest practical advantage of monitored natural attenuation over other remedial alternatives is cost savings. The estimated cost to pump-and-treat a similar volume of groundwater for 30 years at the LAAP is six to eight million dollars (Pennington et al. 1996). The estimated cost for monitored natural attenuation at LAAP, including site characterization, modeling, and monitoring for 30 years, is three million dollars. Monitored natural attenuation is also relatively noninvasive. Therefore, surface disturbance is minimal once monitoring and compliance wells are in place. Sites containing low-level residual contamination after engineered remediation may also be candidates for monitored natural attenuation.

The greatest disadvantage of monitored natural attenuation is the long time frame likely to be required to achieve remediation goals. This requirement may restrict use of the site until remediation goals are achieved. Extensive site characterization and modeling are required as are relatively innovative methods for demonstrating attenuation processes and rates. Some of these services require highly skilled professionals.

2.3 Factors Influencing Cost and Performance

Selected parameters suggested for documentation of full-scale technology applications (Member Agencies of the Federal Remediation Roundtable 1995) are presented below (Table 3).

Table 3
Selected Parameters Suggested for Documentation of Full-Scale Technology Applications (Member Agencies of the Federal Remediation Roundtable 1995)

Matrix Characteristics: Soil Type Soil classification Clay content and/or particle size Distribution	**Nonmatrix Characteristics:** Contaminant type Contaminant concentration Environmental setting Geology Stratigraphy Hydrogeology Quantity of material treated Cleanup goals/requirements Cleanup schedule
Matrix Characteristics: Aggregate Soil Properties Hydraulic conductivity/water permeability pH Transmissivity	
Matrix Characteristics: Organics Total organic carbon Nonaqueous phase liquids	
Operating Parameters: System Parameters Extent and frequency of monitoring Need for well installation	**Operating Parameters: Biological Activity** Biomass/microbial activity assessment

For implementation of monitored natural attenuation for explosives-contaminated sites, the following factors exert the most significant effects on cost and performance:

a. Size of the contaminated site. Characterization of large sites is likely to require greater effort (more monitoring wells, more extensive cone penetrometry, more analytical chemistry) than smaller sites.

b. Contaminant concentration. Sites where contamination is high will likely require longer for attenuation to achieve remedial goals than sites where contamination is low. This extended time translates into longer monitoring. However, once rates of attenuation are determined, longer time periods between monitoring events may be appropriate. This may reduce the total number of monitoring events to acceptable and cost-effective limits.

c. Location of potential receptors of concern relative to contamination. Performance will depend upon the relationship between groundwater hydrology, attenuation rate, and proximity of the contamination to potential receptors of concern. Groundwater flow must be sufficiently slow to allow natural attenuation processes to reduce contamination before it reaches receptors.

d. Geological heterogeneity. Where subsurface heterogeneity is extreme, plume definition and potential migration rates may be complex and difficult to define. Therefore, site characterization costs are potentially higher, and performance may be difficult to predict and measure.

Specific treatment cost elements for monitored natural attenuation of explosives are given in Section 6.1.

3. Site/Facility Description

3.1 Background

The primary site for demonstration of monitored natural attenuation of explosives was Area P at LAAP (Figure 4). This site was selected because the source of contamination had been removed, extensive historical contaminant and geological data were available, and more than 50 groundwater monitoring wells were in place. A second site at JAAP provided verification of the approaches developed at LAAP[1] (Figure 5). Objectives of the monitoring were to determine trends in groundwater concentrations over time and provide data to support conceptual and predictive modeling for each site.

The primary mission of the LAAP was to load, assemble, and package explosives into shell casings, manufacture ammunition metal parts, and provide associated support functions for ammunition production. Eight ammunition lines and one ammunition nitrate-graining plant were constructed by the Silas Mason Company between July 1941 and May 1942. Production ceased in August 1945 at the conclusion of World War II. The plant was placed on standby status in September 1945, and contract operations were terminated in November 1945.

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[1] Funds for groundwater monitoring at this site were provided by the Industrial Operations Command, Rock Island, IL, Mr. Cyril Onewokae, Environmental Quality Directorate. Site description and results of site monitoring are presented in Pennington et al. (1998).

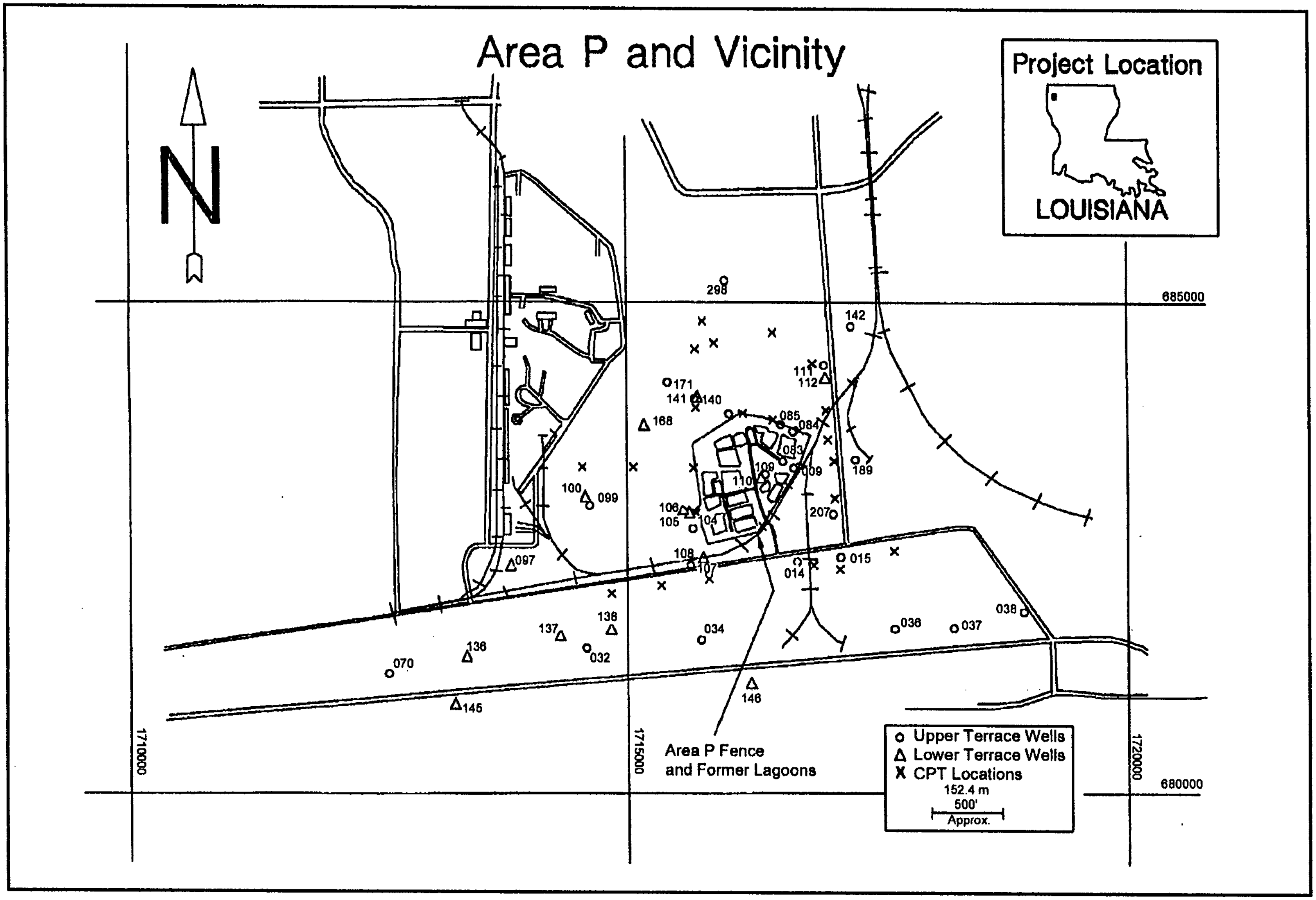

Figure 4. Locations of groundwater monitoring wells and cone penetrometry sampling points around former lagoons, Area P

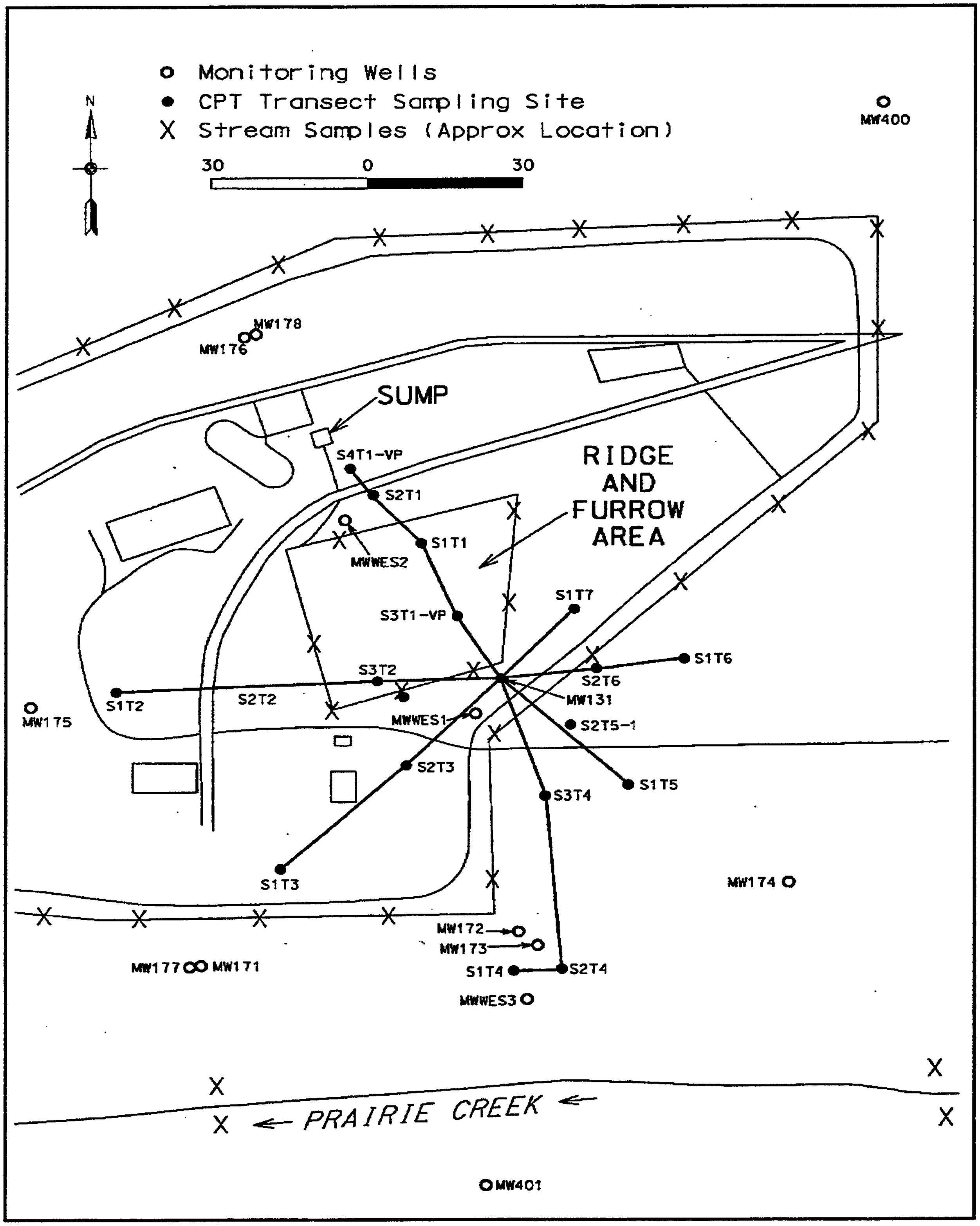

Figure 5. Locations of groundwater monitoring wells and cone penetrometry sampling points at JAAP

In February 1951, with the outbreak of the Korean Conflict, Remington Rand reactivated the plant under contractual agreement with the Federal government. Ammunition production was suspended in October 1957, and again the facility was placed on standby status. The Federal government again reactivated the facility in September 1962 and contracted with Sperry Rand Corporation to operate munitions production in support of the Vietnam Conflict. In 1974, Thiokol Corporation took over the facility operations when Sperry Rand Corporation relinquished its contract. Thiokol Corporation maintained the facility until the summer of 1996 when most operations at the plant ceased. As of August 1997, five contractors were bidding to resume very limited production of "black powder" at a single load line (Y line).

The LAAP was placed on the National Priorities List in March 1989 because of contamination caused by past disposal of explosives-laden wastewater in 16 unlined surface impoundments located in Area P. An interim remedial action was initiated in 1988 because investigations indicated that the lagoons were contributing explosives to the groundwater. The lagoons were remediated by draining and treating wastewater and incinerating soils. The lagoons were excavated until a total field-determined explosive concentration of less than 100 mg explosives kg^{-1} soil was reached. The incineration of 92,468,429 kg or 9.2×10^7 kg (101,929 tons) of soils and the treatment of 2.03×10^8 L or 2.03×10^5 kL (53,604,490 gal) of wastewater and rainwater collected within the 16 lagoons were completed in 1990. The area was then backfilled with the incinerated soil, capped, and vegetated. The 105,219-m^2 (26-acre) site was covered with a minimum 0.61-m- (2-ft-) thick compacted cap of uncontaminated clay soil from Area P and a nearby borrow pit located north of the lagoons. This clay cap covered all of the original Area P including the former lagoons and was compacted to at least 90 percent of the standard proctor density for the clay used. The cap was covered with 10 cm (4 in.) of topsoil with a slope of at least 1 percent to facilitate drainage.

The predominant contaminants at LAAP were TNT and RDX. Previous studies conducted in conjunction with remedial action on the lagoons had defined two subsurface geological terraces. A conceptualization of the contaminant plume and general groundwater hydrology and site geology had been made (Science Applications International Corporation (SAIC) 1994). Therefore, extensive historical contaminant and site-characterization data existed for Area P. These data provided a springboard for development of the groundwater monitoring plan.

3.2 Site/Facility Characteristics

3.2.1. Site Description. The LAAP is a Government-owned, contractor-operated facility located 35 km (22 miles) east of Shreveport, LA (Figure 1). The LAAP is bound to the north by Interstate 20 and U.S. Highway 80, to the south by State Route 164, to the east by Dorcheat Bayou, and to the west by Clarke Bayou. Two streams, Boone Creek and Caney Creek, flow north to south across the site. The facility lies within the Bossier and Webster parishes. The 60,597,876 m^2 (14,974 acres) within LAAP are predominantly woodlands (80 percent);

approximately 20 percent of the area is occupied by former production lines and mission support facilities. The LAAP lies within the Western Gulf Coastal Plain physiographic province. Two major landforms, dissected uplands and rolling prairie, are found within LAAP. Minor landforms include abandoned channels, typically filled with clay that was deposited by ancient courses of the ancestral Red River. Relief at LAAP is moderate with elevations varying from about 40 m (130 ft) above mean sea level (msl) near Dorcheat Bayou to 24 m (80 ft) above msl at Clarke Bayou. Regionally, LAAP lies within a subsurface structural feature known as the North Louisiana Syncline. This syncline lies on the eastern limb of the much larger Sabine Uplift. The uplift was formed by deformation of sediments during tectonic activity that began approximately 225 million years ago (Paleozoic Era). The North Louisiana Syncline and the LAAP region is bounded to the south and east by the Monroe Uplift, and to the west and north by the Sabine Uplift. Smaller local uplifts exist in the area and can significantly modify the local structural geology (i.e., formation dip) and groundwater flow regimes.

The surface at Area P consists of Pleistocene Age terrace deposits unconformably overlying the Eocene Age Cane River Formation. Collectively, the Pleistocene Age units are a fining upwards sequence deposited in a fluvial environment. The terrace deposits in Area P can be further subdivided into the Lower Terrace consisting of fine sands and a trace of gravel and the Upper Terrace consisting of very fine silt, clays, and silty clays. An intermediate clay unit is present at some locations, but is totally absent at many locations. Where present, this layer can serve as a limited aquitard. The Eocene Age, Cane River Formation directly underlies all terrace deposits and consists of clay or clay sufficiently indurated to be classified as claystone. The Cane River is not an aquifer beneath Area P, and is, therefore, considered the confining layer for modeling the site. Earlier geological descriptions of LAAP including Area P were reviewed prior to initiation of groundwater monitoring (Louisiana Department of Conservation 1954; U.S. Geological Survey 1983; U.S. Army Corps of Engineers 1984 and 1987; Engineering Technologies Associates 1991; SAIC 1994; and International Technologies Corporation 1997).

3.2.2. Hydrology. Groundwater in the Upper Terrace aquifer generally exists under water table (unconfined) conditions at depths varying from approximately 1.5 to 7.6 m (5 to 25 ft) below ground level (BGL). The Lower Terrace aquifer, while not present in all areas, typically occurs from 7.6 m (25 ft BGL) to the top of the Cane River, which is about 15.2 m (50 ft) BGL. The Lower Terrace aquifer also tends to produce more water than the Upper Terrace deposits. Although none of the terrace deposits supply water to production wells on the installation, some domestic wells in Haughton, Princeton, Dixie Inn, Minden, Sibley, and Doyline are completed in the terrace deposits. Groundwater quality modeling conducted for Area P indicated that contaminant (explosives) migration in the Upper Terrace generally traveled downwards with little horizontal spreading (Engineering Technologies Associates 1991). Furthermore, the modeling and water-level measurements indicated that the regional groundwater flow in the Upper Terrace aquifer was southwest.

3.2.3. Historical Contaminant Data. SAIC (1994) under contract to the U.S. Army Environmental Center (USAEC) conducted a 5-year review to assess the effectiveness of the interim remedial action at Area P. The review was conducted in accordance with the Comprehensive Environmental Response, Compensation, and Liability Act, or Superfund (CERCLA) laws of 1980. The final report was submitted to USAEC in August of 1994. A statistical regression analysis approach was used to identify groundwater trends. Groundwater-sampling data were evaluated from 1980 through 1994. Quadratic and linear analyses were conducted for 108 data sets. Trend categories were assigned to each of the data sets based on improving, deteriorating, and stable groundwater quality with regards to explosives. In these data sets, no specific trends were identified, but the general conclusion was that the overall quality of water in the Upper and Lower Terrace aquifers at Area P was improving.

4. Demonstration Approach

4.1 Performance Objectives

The primary technical performance criteria were described in the project demonstration plan (Pennington et al. 1996) and included the following:

a. Decreases in concentrations of TNT and RDX below concentrations predicted from the site geology and hydrology. These results will suggest that the explosives are attenuated in the subsurface by degradation, transformation, and/or immobilization processes.

b. Increases in concentrations of transformation/degradation products of TNT and RDX. These results will demonstrate formation of known transformation and/or degradation products. Spatial distribution of these products relative to parent compounds and uncontaminated area can be used to assess the progression of degradation mechanisms. Some intermediates are considered environmentally undesirable; therefore, these intermediates must be tracked as carefully as the parent compounds. The amino-substituted transformation products of TNT are much more subject to immobilization processes than the parent compound; therefore, their appearance and disappearance are also important to track.

c. Predictions by the model that potential receptors will be protected because of documented site geological and hydrological characteristics. The groundwater flow rate and subsurface permeability may be so low that receptors are protected for a significantly long period of time. Site data together with application of the model will reveal the potential for acceptable risk.

4.2 Physical Setup and Operation

Physical and operational requirements for implementation of monitored natural attenuation can be described in the following three categories: (a) site characterization, (b) monitoring, and (c) modeling.

4.2.1. Site Characterization. Site characterization is needed before any remedial alternative can be chosen for the site. All alternatives will require definition of the contamination, including contaminant identity, mass, and distribution, and some definition of groundwater hydrogeology. Characterization of subsurface processes provide data to support the EPA second and third "lines of evidence" and may require testing of aquifer soils as well as groundwater. The most efficient method to obtain samples for these tests is cone penetrometry (CPT). Therefore, the services of a CPT truck and all associated piping, grouting, decontamination, and sample-processing equipment may be needed. On a typical day, barring complications, eight penetrations to a depth of 15 to 40 m can be achieved. A four-man crew is typically required to operate the truck and decontaminate equipment between penetrations, while an additional three-man crew processes samples for microbial and chemical analyses.

4.2.2. Monitoring. Selection of monitoring points and frequency depends upon the conceptualization of contaminant distribution, groundwater geological and hydrological regimes, and locations of existing monitoring wells. Monitoring points should transect the plume with points of compliance established between the existing known extent of the plume and all potential receptors, but particularly receptors downflow of the contamination. Frequency of monitoring should be determined on the basis of what is known about groundwater hydrology (flow rate) and natural attenuation rate. At LAAP, 30 existing wells (Figure 4) were monitored quarterly for the 2-year demonstration. Use of two, two-man crews operating in "leap frog" fashion compresses the well-sampling time required. Using this technique, three or four wells could be sampled per day for all the analytes included in the demonstration.

4.2.3. Modeling. Developing a conceptual and numerical model for the site requires approximately 1.5 man-years. Computational requirements for modeling vary with the model adopted and are rapidly evolving. Approximately 0.5 man-years are need to update the model annually with new data as monitoring progresses.

4.3 Sampling Procedures

4.3.1. Groundwater Sampling. The wells at LAAP were sampled by micropurge (low-flow) techniques (Gass et al. 1991). A 5-cm-diam low-flow pump was used for sampling wells having a diameter as small as 10 cm. Field parameters were measured with an in-line continuously monitoring unit (Yellow Springs Instruments, Yellow Springs, MO) with data transmitted directly to a laptop computer. Ecowatch software (Yellow Springs Instruments, Yellow Springs, MO) was used to visualize the parameters in real-time. These parameters included pH, conductivity, dissolved oxygen (DO), temperature, redox, turbidity, and salinity. Field data were recorded with time until formation water was obtained. Discharge was matched to recharge using the low-flow pump until a stable DO reading was obtained. Initially, sampling procedures defined stability as achievement of three consecutive DO readings that were within 10 percent of each other. Once this was achieved, the groundwater was sampled. After two sampling events in which the time required to achieve a stable DO was consistent for each well, a minimum pumping time was established. On subsequent sampling rounds, the DO was monitored for the minimum pumping time to confirm this correlation between time and DO stabilization. An exception to this protocol was adopted for MW109U because recharge was too slow to use the micropurge technique. This well was evacuated and allowed to recharge for 10 min three consecutive times and then sampled.

Groundwater was pumped through the monitoring unit and discharged via Teflon tubing until time for sampling. Before sampling, the water flow was redirected through a 0.45-µm filter. The whole sample was collected in a 4-L brown glass bottle that had been certified precleaned. After thorough mixing, the sample was divided into separate bottles already containing appropriate preservatives for the specific analyses (see analytical chemistry below). The collection bottle was rinsed three times with deionized water between wells. Three subsamples of groundwater were distributed as follows: a 1-L sample for explosives, a 500-ml sample for nitrate/nitrite, total organic carbon, total iron, calcium, magnesium, and manganese, and a 100-ml sample for sulfate and chloride. During Month 3 (Round 3, April 1996), a sample from each well was assayed for picric acid. Iron speciation, Fe^{+2} and Fe^{+3}, and methane were assayed in Month 10 (Round 7, November 1996) and in Month 12 (Round 24, February 1998) in selected wells (MW012U, MW014U, MW085U, MW099U, MW100L, MW104U, MW107L, MW108U, MW109U, MW110L, MW140U, and MW141L). Samples were collected by bailing after samples for explosives and other geochemical parameters had been collected by pumping. Samples were transferred from the bottom of the bailer into volatile organic analysis (VOA) tubes with silicon Teflon-faced septa using a volatile organic contaminants removal device to reduce contact between the sample and air. All samples were stored on ice or under refrigeration until analyzed and were transferred under documented chain-of-custody. All monitoring wells, physical boundaries and features, and subsequent CPT and surface soil sampling locations were surveyed using a global positioning system. Detailed sampling procedures are presented in Pennington et al. ("Monitored Natural Attenuation of Explosives in Soil and Water Systems at Department of Defense Sites: Interim Report"). A set of standard operational procedures are appended (Appendix C).

4.3.2. Cone Penetrometry Sampling. Soil samples were collected from 24 locations along eight transects at LAAP using CPT (Figure 4). Depths of penetration were through both Upper and Lower Terraces. Generally, the penetrations were about 15 m (50 ft) deep and reached total depth in the Cane River Formation (the confining layer). Locations were determined to meet the following sampling objectives: (a) to ensure sampling from highest concentrations to zero concentration in all four cardinal directions from the source (original lagoons) and through the vertical extent of the plume at each location, (b) to provide samples for biomarker development along the leading edge of the contaminant plume, and (c) to refine the vertical and lateral definition of the contamination. Penetration of the Area P cap was not permitted because of concern that the integrity of the cap would be compromised. Unpublished CPT data collected during a 1994 study at LAAP were used to stratify the various lithologies and to locate new CPT sites. TNT and RDX concentrations from groundwater sampling to the date of the event were contoured to identify "hot spots" prior to establishing transects. The first punch on a given transect was used to stratify the site by measuring resistivity to penetration. The strata were defined in terms of lithology and substrate conducive to microbial processes. Subsequent punches were used to collect soil samples with a split-spoon sampler (45.7 cm, or 18 in.) that had been sterilized to minimize contamination. Typically, at least three depths, surface, middepth, and just above bedrock, were sampled. Sampling along each transect was restricted to one or two locations before proceeding to the next transect. This was done to allow time to send the samples to the laboratory and obtain explosives-concentration data upon which to base selection of the next location along that transect. Vertical profiles of soil samples were collected at five locations. Depending upon the depth of the CPT hole, from 6 to 14 samples were collected for each vertical profile. Up to 400 g of soils were collected by the split-spoon sampler.

A thin vertical slice of the soil in the split spoon was removed by opening the sampler slightly and inserting a sterile spatula into one end of the core to a depth of approximately 1 cm and running the spatula along the length of the core. This subsample was mixed and analyzed for TNT and RDX using a field-test kit (Ensys, Inc., Research Triangle Park, NC) (Jenkins 1990; Walsh and Jenkins 1991). The remainder of the core sample was removed by fully opening the sampler and sliding the contents into 1-L Ziploc bags (DowBrands L.P., Indianapolis, IN). The bags were sealed immediately, labeled as to exact location and depth, and stored on ice. Between uses, the sampler was scrubbed and sterilized for 10 min in a solution containing 20-percent household bleach and 0.01-percent detergent, followed by rinsing with a steam sprayer. Explosives and geochemical parameters, including permeability, were measured on these samples after subsamples for biomarker research were removed. Hydraulic conductivity was based on results of standard sieve analysis. Soils were classified by the U.S. Army Corps of Engineers unified soil classification system (U.S. Army Corps of Engineers 1960).

4.4 Analytical Procedures

4.4.1. Geochemical Parameters. A list of geochemical parameters for groundwater samples is provided in Table 4. Laboratory analyses included total iron, calcium, magnesium, and manganese (Method 6010, EPA 1988), total organic carbon (Method 505C, American Public Health Association 1985), nitrate-nitrite nitrogen (Method 353.2, EPA 1982), sulfate (Method 375.2, EPA 1982), and chloride (Method 325.2, EPA 1979). Samples for total iron, calcium, magnesium, and manganese, total organic carbon, and nitrate-nitrite nitrogen were preserved with 0.4 g $NaHSO_4$ to 250 ml of water. Samples for sulfate and chloride were not preserved. Iron speciation was achieved by ion chromatographic separation (Dionex Corporation, Sunnyvale, CA) of samples preserved with 1 percent HCl followed by analysis according to Method 6020 (EPA 1988) on a Perkin Elmer (Norwalk, CT) inductively coupled plasma mass spectrometer.

For methane analyses, 20-ml aliquots of well water were transferred by gas-tight syringe to 40-ml VOA tubes. The samples were allowed to equilibrate with the headspace. A standard curve was developed by adding four concentrations of standard (100-percent pure) nitrogen gas to similar 40-ml VOA tubes containing 20 ml of distilled water. Headspace of standards and samples were quantified on a Model 8610 gas chromatograph (SRI Instruments, Las Vegas, NE).

Soil samples collected by CPT were analyzed for pH (Mehlich 1984), nitrate nitrogen, nitrite nitrogen, total Kjeldahl nitrogen, phosphorus, sulfate, and total organic carbon (American Public Health Association 1985). Hydraulic conductivity was measured by standard sieve methods, and soils were classified according to the U.S. Army Corps of Engineers unified soil classification system (U.S. Army Corps of Engineers 1960). Particle size distribution in the <2-mm fraction was determined by the methods of Day (1956) as modified by Patrick (1958).

Table 4
Geochemical Parameters Monitored in Groundwater at LAAP and JAAP

	Assayed in the Laboratory	
Monitored in the Field	**Aerobic Collection**	**Anaerobic Collection**
pH Conductivity Dissolved oxygen Temperature Redox potential Turbidity Salinity	Total organic carbon Total iron Calcium Magnesium Manganese Nitrate/nitrite nitrogen Sulfate Chloride	Reduced iron Methane

4.4.2. Explosives Analyses. Judging from detections reported in the historical data for wells sampled at LAAP Area P, the most significant explosives on the site were TNT, TNB, and RDX (SAIC 1994). Other detections included HMX, tetryl, 2,6-dinitrotoluene (2,6DNT), 2,4-dinitrotoluene (2,4DNT), 1,3-dinitrobenzene (DNB), and nitrobenzene (NB). However, the presence of additional transformation products of TNT provides evidence for initial subsurface processes that may prove relevant to natural attenuation mechanisms. Therefore, the list of explosives analytes was expanded (Table 5).

Table 5
Explosives and Related Analytes Monitored in Groundwater at LAAP and JAAP

Chemical Name	Acronym
2,4,6-Trinitrotoluene	TNT
1,3,5-Trinitro-1,3,5-hexahydrotriazine	RDX
Octahydro-1,3,5,7-tetranitro-1,3,5,7-tetrazocine	HMX
N,2,4,6-Tetranitro-N-methylaniline	Tetryl
1,3,5-Trinitrobenzene	TNB
2,6-Dinitrotoluene	2,6DNT
2,4-Dinitrotoluene	2,4DNT
1,3-Dinitrobenzene	1,3DNB
Nitrobenzene	NB
4-Amino-2,6-dinitrotoluene	4ADNT
2-Amino-4,6-dinitrotoluene	2ADNT
3,5-Dinitroanaline	35DNA
2,4-Diamino-6-nitrotoluene	24DANT
2,6-Diamino-4-nitrotoluene	26DANT
2,2',4,4'-Tetranitro-6,6'-azoxytoluene	66'AZOXY
4,4',6,6'-Tetranitro-2,2'-azoxytoluene	22'AZOXY
2,2',6,6'-Tetranitro-4,4'-azoxytoluene	44'AZOXY
Hexahydro-1-nitroso-3,5-dinitro-1,3,5-triazine	MNX
Hexahydro-1,3-dinitroso-5-dinitro-1,3,5-triazine	DNX
Hexahydro-1,3,5-trinitroso-1,3,5-triazine	TNX
Mononitroso-octahydro-1,3,5,7-tetranitro-1,3,5,7-tetrazocine	MN-HMX
Picric acid	

The target analytes for EPA SW846 Method 8330 (EPA 1994b) include the following: HMX, RDX, TNB , DNB , tetryl, TNT, NB, 4-amino-2,6-dinitrotoluene (4ADNT), 2-amino-4,6-dinitrotoluene (2ADNT), 2,4-DNT, 2,6-DNT, o-nitrotoluene (2NT), m-nitrotoluene (3NT), and p-nitrotoluene (4NT). All of these analytes except for the mononitrotoluenes (2NT, 3NT, and 4NT) were assayed in LAAP groundwater samples. In addition to these analytes, several other compounds have been identified as potential environmental transformation products of TNT, RDX, and TNB. Those from TNT and TNB include 3,5-dinitroanaline (DNA), 2,4-diamino-6-nitrotoluene (2,4DANT), and 2,6-diamino-4-nitrotoluene (2,6DANT) and three isomeric azoxy compounds. All of these analytes were assayed except for the 2,2',4,4'-tetranitro-6,6'-azoxytoluene (66'AZOXY). Standards were available for unresolved 2,2',6,6'-tetranitro-4,4'-azoxytoluene (44'AZOXY) and 4,4',6,6'-tetranitro-2,2'-azoxytoluene (22'AZOXY) during the first 2 months of sampling. The resolved isomers, 22'AZOXY and the 44'AZOXY, were each available for samples from Months 3 through 5; and only the 44'AZOXY isomer was available for Months 6 through 12.

Samples were analyzed with and without a preconcentration step to broaden the range of detection from very low micrograms-per-liter to high milligrams-per-liter concentrations. Preconcentration was achieved by solid-phase extraction. The High-Performance Liquid Chromatography

(HPLC) (Waters Corporation, Milford, MA) used an LC-18 reverse-phase column and an LC-CN reverse-phase confirmatory column having a slightly different retention time. Elution was with methanol/water (50/50 v/v). Analyte detection was achieved with a photodiode array at 254 nm used for detecting AZOXY transformation products of TNT (EPA 1994b).

Three nitroso derivatives of RDX have been observed as microbial transformation products (McCormick, Cornell, and Kaplan 1981). They are hexahydro-1-nitroso-3,5-dinitro-1,3,5-triazine (MNX), hexahydro-1,3-dinitroso-5-nitro-1,3,5-triazine (DNX), and hexahydro-1,3,5-trinitroso-1,3,5-triazine (TNX). All three of these analytes were assayed. Standards for MNX and TNX were available after Round 6; the standard for DNX was available after Round 8. Most of these compounds cannot be determined using Method 8330 as written. Therefore, a gradient elution RP-HPLC method was used. This method was designed to allow determination of compounds much more polar and much less polar than those on the Method 8330 target list. The standard for the mononitroso transformation product of HMX (MN-HMX) was also available after Round 11.

Some explosives-contaminated sites contain picric acid, which was used during World War II in armor-piercing shells, bombs, and rocket warheads. During one round of sampling at LAAP (Round 1, May 1997), visual observation of water (a fluorescent yellow-green coloration) from MW171U suggested the presence of picric acid. Analytical results indicated the presence of picric acid; therefore, groundwater from all other wells was analyzed for picric acid in Round 3, July 1997. Sample preparation for picric acid analysis was the same as for Method 8330. However, HPLC analysis used a mobile phase consisting of 40 percent methanol and 60 percent 0.5 M KH_2PO_4 buffer (pH adjusted to 3.5 with concentrated acetic acid). Elution was at 1.5 ml min^{-1} for 10 min. The Waters 586 Tunable Absorbance Detector (Waters Corporation, Milford, MA) was set at 265 nm, which is maximum absorbance for picric acid.

Soil samples collected by CPT were analyzed for explosives and transformation products of explosives by Method 8330 (EPA 1994b). The difference between the procedure for soils and for groundwater was the requirement for extracting the soil prior to injection into the HPLC. Soils were extracted with acetonitrile using sonication. Analytical standards and analytes were the same as for analysis of groundwater samples.

The same procedures used at LAAP were employed at JAAP. Specific sampling sites are described in Pennington et al. ("Draft Protocol for Evaluating, Selecting, and Implementing Monitored Natural Attenuation at Explosives-Contaminated Sites" and "Monitored Natural Attenuation of Explosives in Soil and Water Systems at Department of Defense Sites: Interim Report").

5. Performance Assessment

5.1 Performance Data

Declining concentrations of explosives over the 2-year monitoring period were documented at LAAP (Figure 6) (Pennington et al., "Monitored Natural Attenuation of Explosives in Soil and Water Systems at Department of Defense Sites: Interim Report"). Results support the first line of evidence required under EPA guidance for verification of monitored natural attenuation, i.e., declining contaminant mass. Methods were developed to optimize accuracy and minimize variability between sampling events, so that trends in concentration over time were readily demonstrated and reliable. None of the geochemical characteristics of the site correlated with explosives concentrations. Therefore, monitoring geochemical parameters provides limited evidence of natural attenuation processes. Sampling methods developed at LAAP were verified by application at JAAP. Although the sampling period at JAAP was limited to 9 months, about 20 percent of the wells exhibiting concentrations of explosives above detection limits showed significant declines (Figure 7). Geochemical parameters were unrelated to explosives concentrations as observed at LAAP.

The definition of the contaminant plume was refined by CPT sampling at both sites (Figures 8 and 9). By coupling rapid laboratory "turnaround" with placement of the CPT, efficiency was optimized while minimizing analysis of uncontaminated samples beyond the plume. Lithology and contaminant data were used in the site conceptual and numerical models. The CPT also provided samples for development of biomarkers.

Batch-shake test results were demonstrated to adequately describe sorption and disappearance rate constants in the LAAP soils (Figure 10). Sorption of explosives compounds by the aquifer soils was limited, with all constituents showing K_D values below 1 L kg^{-1} for all soils. These results indicated that a single, average sorption coefficient for each compound in the LAAP soils adequately described sorption for numerical modeling. Disappearance rate constants were low in comparison with those typically observed in surface soils. Use of the disappearance rate coefficients in modeling was complicated by the proximity of the coefficients to zero and the uncertainty that this created about applying results from short-term bench-scale testing to field scale. Use of the disappearance rate coefficients in groundwater models may require adjustment to accurately depict measured groundwater concentrations that reflect field conditions and a longer time frame than is possible with bench-scale batch and column studies. These results suggest that mass-transport limitations rather than site capacity restrict transport at LAAP.

Integration of results from radiorespirometry, nucleic acid, and lipid biomarker techniques was used to evaluate the ability of indigenous microorganisms to degrade explosives. For the two sites, LAAP and JAAP, lipid biomarker technologies provided estimates of viable cell abundance. By identifying the amount and nature of the in situ viable microflora in relation to

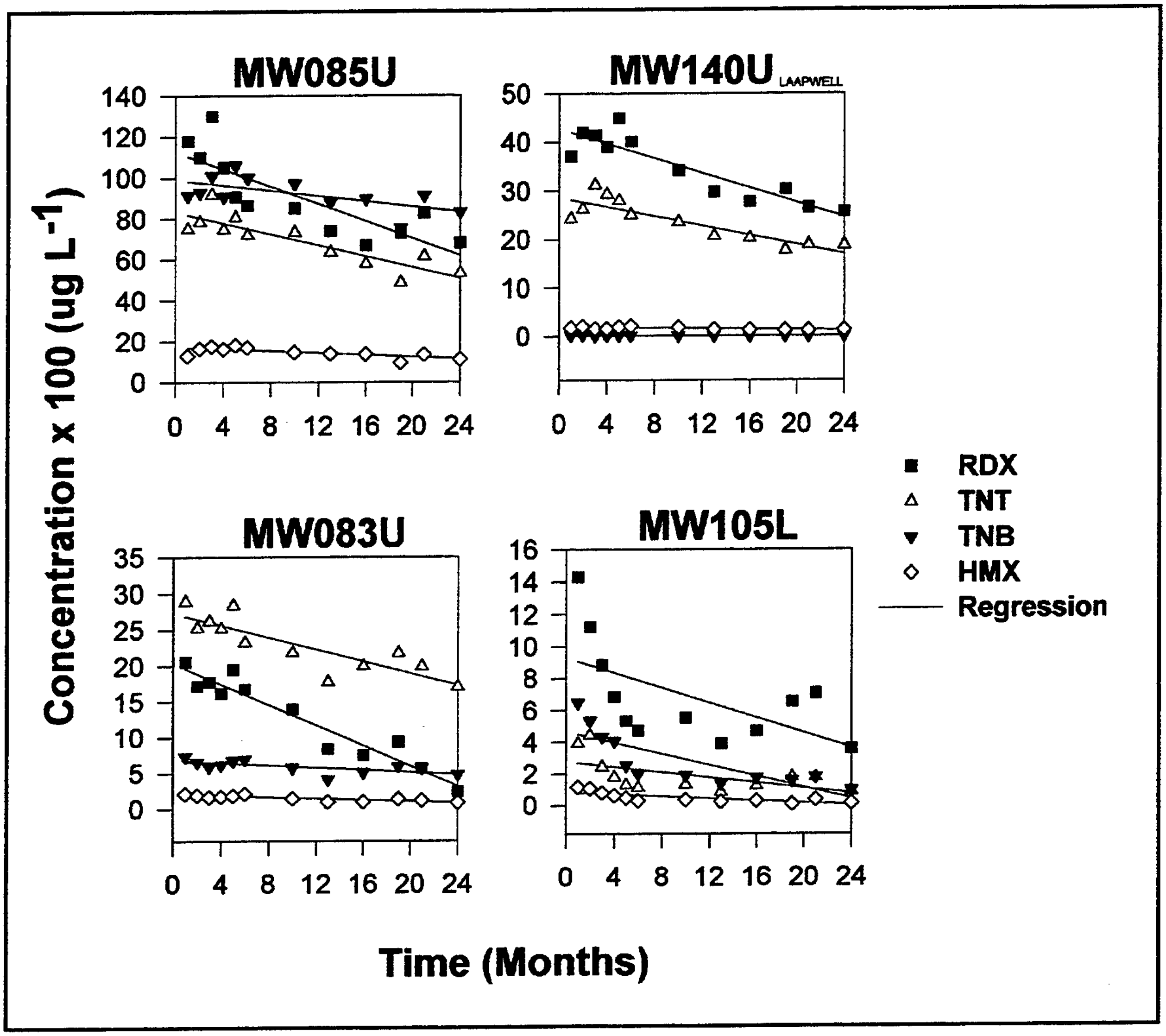

Figure 6. Concentration of explosives in selected LAAP monitoring wells over 2 years of quarterly sampling

nitroaromatic contamination, a direct link was established between the rates of contaminant mineralization observed in the radiorespirometry flasks and the indigenous microbial populations. The nucleic acid biomarkers provided the necessary evidence of a genetic capability for natural attenuation processes at each site. Biomarkers at both sites provided positive evidence that microbial transformation/mineralization processes play a substantial role in explosives attenuation at these sites.

Rates of TNT and RDX mineralization were very low in LAAP soils, and few significant correlations with geochemical parameters and biomarkers were found. At JAAP, mineralization rates were considerably higher (Figure 11). Furthermore, several nucleic acid probes correlated

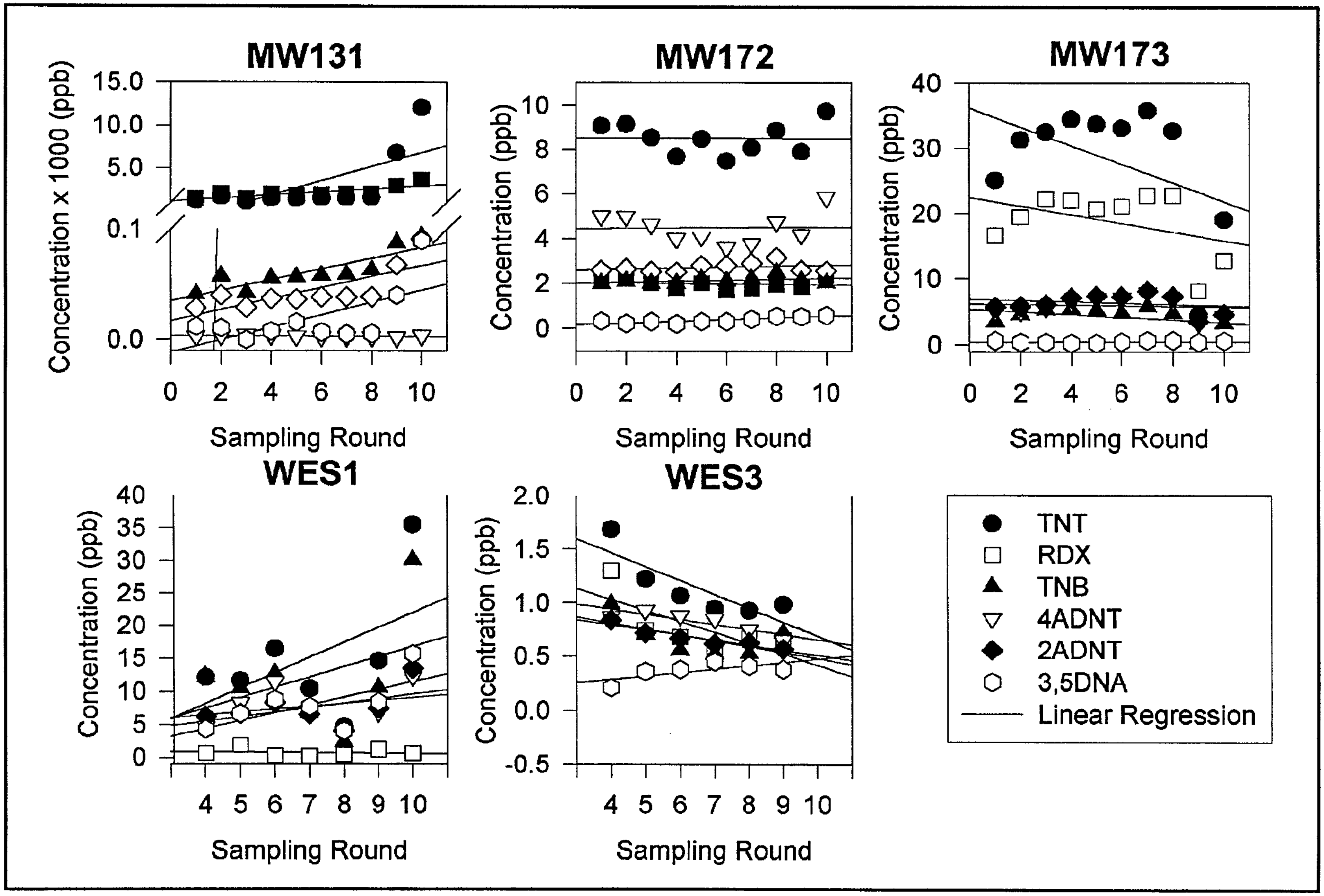

Figure 7. Concentrations of explosives in selected JAAP monitoring wells over the 11 months of sampling (Monitoring Wells WES1 and WES3 were installed in the fourth sampling month)

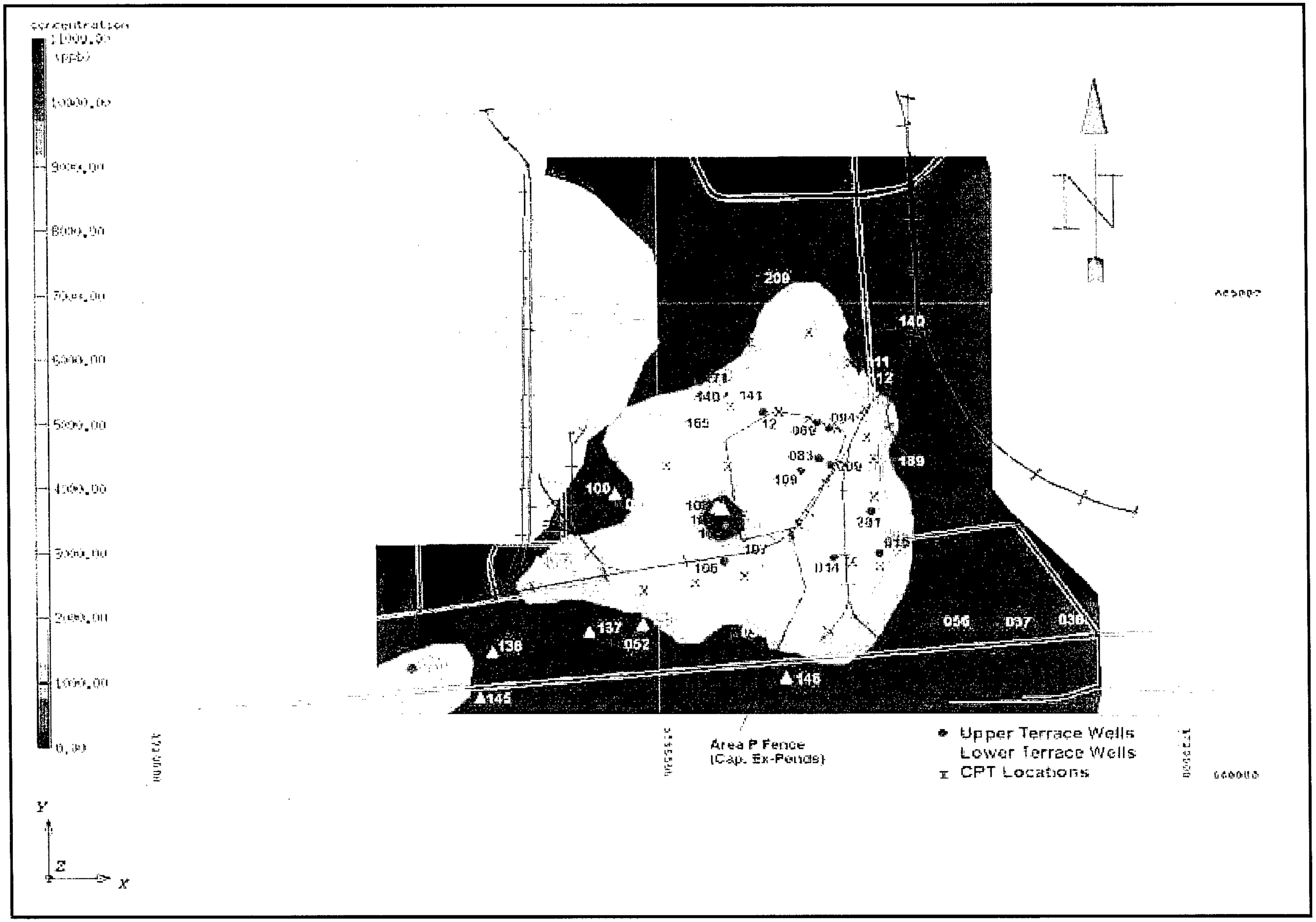

Figure 8. Initial (February 1996) distribution of TNT in Upper Terrace at LAAP

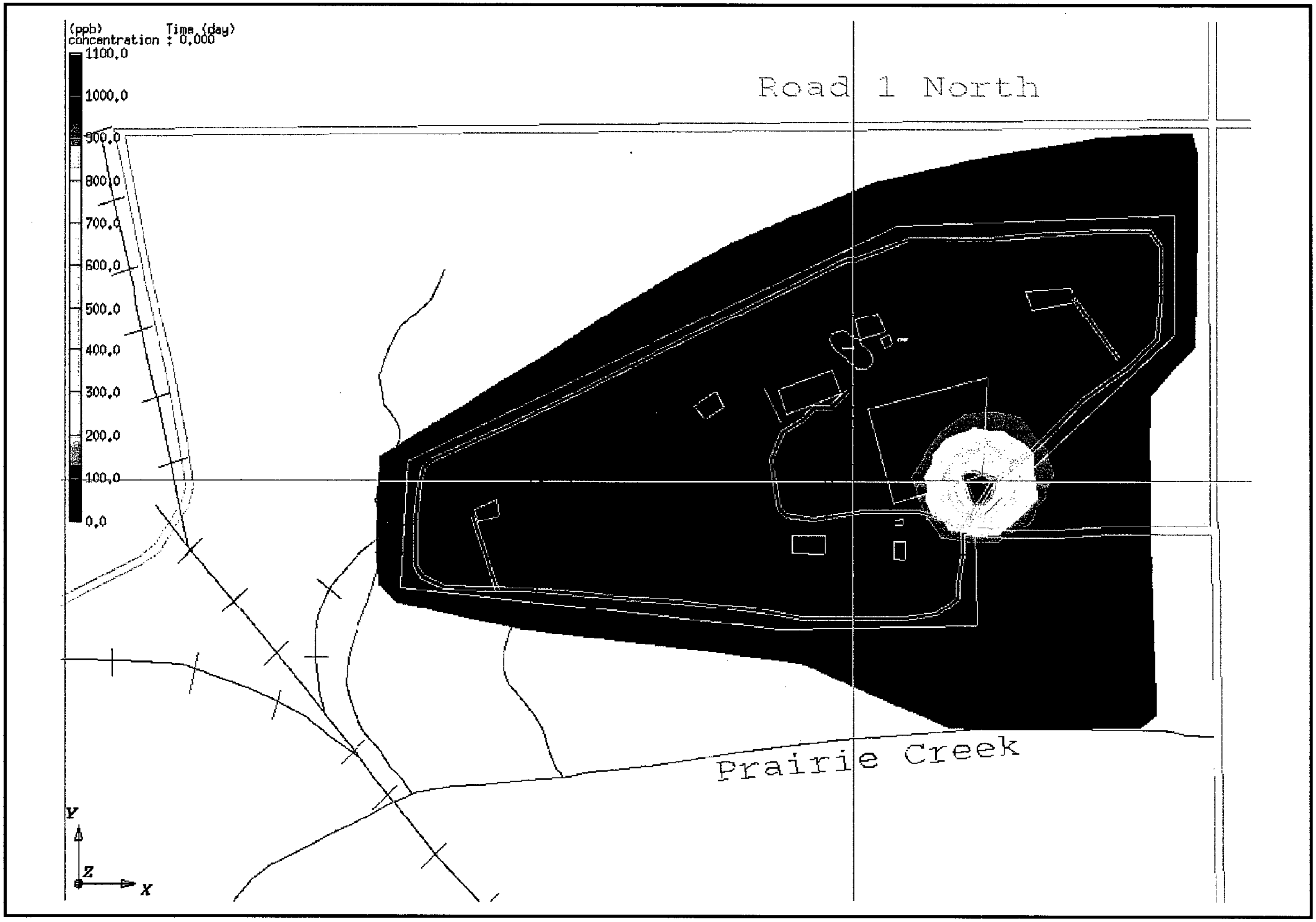

Figure 9. Initial (April 1997) distribution of TNT at JAAP

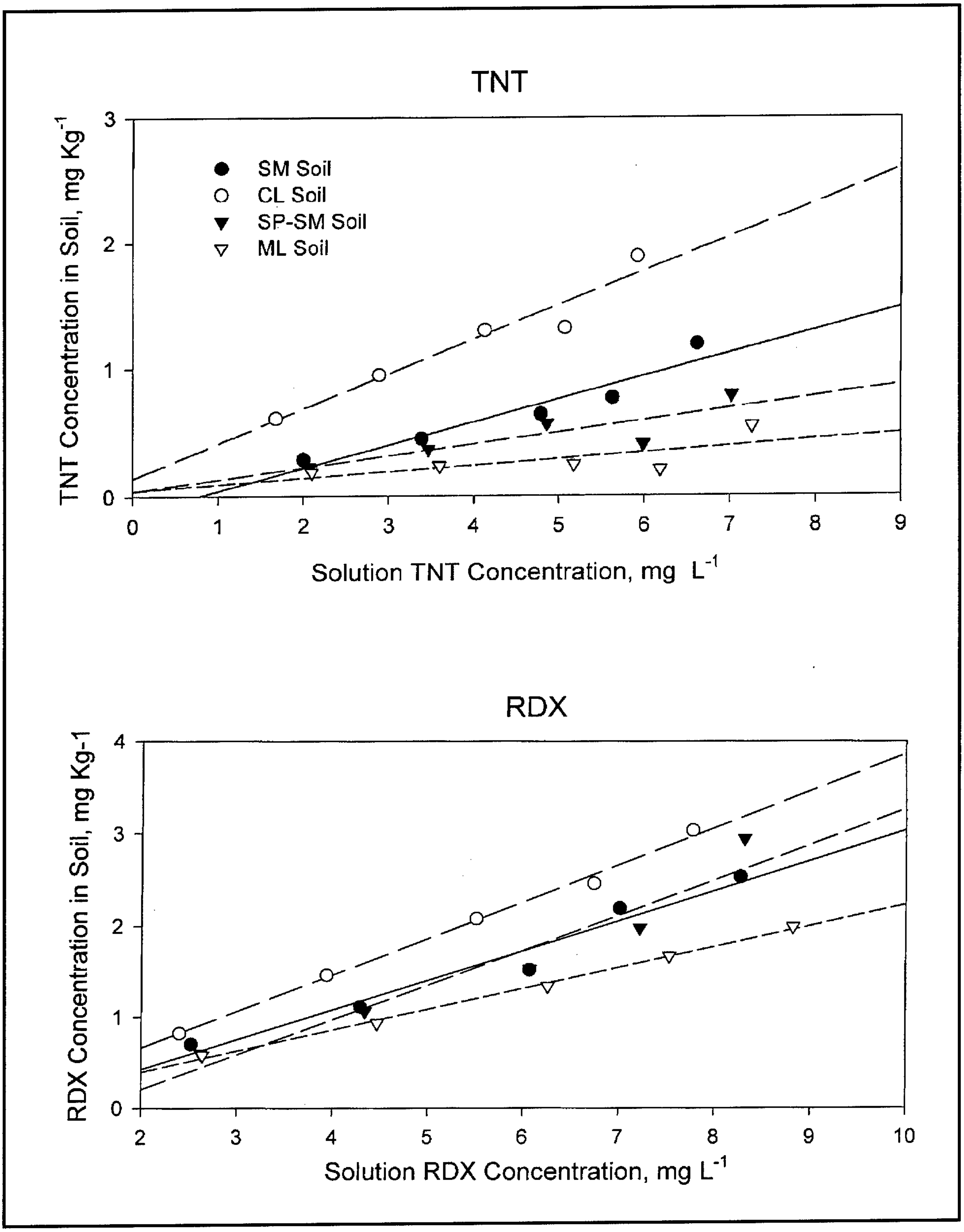

Figure 10. Site capacity isotherms for LAAP

positively with mineralization rate as did the following parameters determined by lipid biomarkers: biomass, abundance of gram-negative, sulfate-reducing, and iron-reducing bacteria, and a sulfite reductase (Table 6). Aerobic degradation of TNT in LAAP soils was indicated by the presence of two catechol oxygenase gene probes. Therefore, the microbial population contained genes for explosives mineralization. At JAAP, presence of a gene for a denitrification enzyme suggested the mechanism for microbial reduction of TNT. Other observed genes supported potential for both anaerobic and aerobic metabolism of the TNT ring. Details of these studies and results are presented in Pennington et al. ("Monitored Natural Attenuation of Explosives in Soil and Water Systems at Department of Defense Sites: Interim Report").

Biomarker techniques provided an effective tool for demonstrating microbial destruction potential in field samples. The rate and extent of degradation and transformation were also estimated. The effectiveness of microbially mediated natural attenuation processes depends upon site characteristics, the composition and abundance of the viable biomass, and the genetic capabilities of the site microflora. Biomarkers were effective in measuring each of these at LAAP and JAAP.

The GMS provided efficient numerical tools to integrate and translate the complex field data into simple graphic forms that could be used to determine fate and transport of the contaminant plumes. The measured and simulated flow data indicated slow subsurface flow at the LAAP site because of the low-permeability media and low-hydraulic gradients. The TNT and RDX plumes were virtually static. The simulated flow directions were consistent with the direction of explosives plume propagation. The simulated results indicated that explosives at LAAP may be reduced naturally without posing any threat to offsite receptors (Figure 12). Even though, the reduction process is very slow, the plume is confined to a limited area and is not moving significantly. The results of contaminant-mass calculations indicated that the initial mass of TNT and RDX was reduced significantly during 20 years of simulation. The sensitivity analysis suggested that the important model-input parameters are the adsorption coefficient rates and the bio-decay rates. Results of the 20-year simulations at JAAP also indicated declining mass over time, but also predicted limited migration of the plume (Figure 13). The predicted results for both sites should be adjusted and the calibration processes repeated as new data become available. Details of modeling are presented in Pennington et al. ("Monitored Natural Attenuation of Explosives in Soil and Water Systems at Department of Defense Sites: Interim Report").

5.2 Data Assessment

The data allowed a realistic assessment of the demonstration objectives for LAAP. The quarterly sampling using the refinements in sampling techniques indicated declining concentrations in most wells. The CPT sampling improved site conceptualization while providing adequate sample material for biomarker assessment.

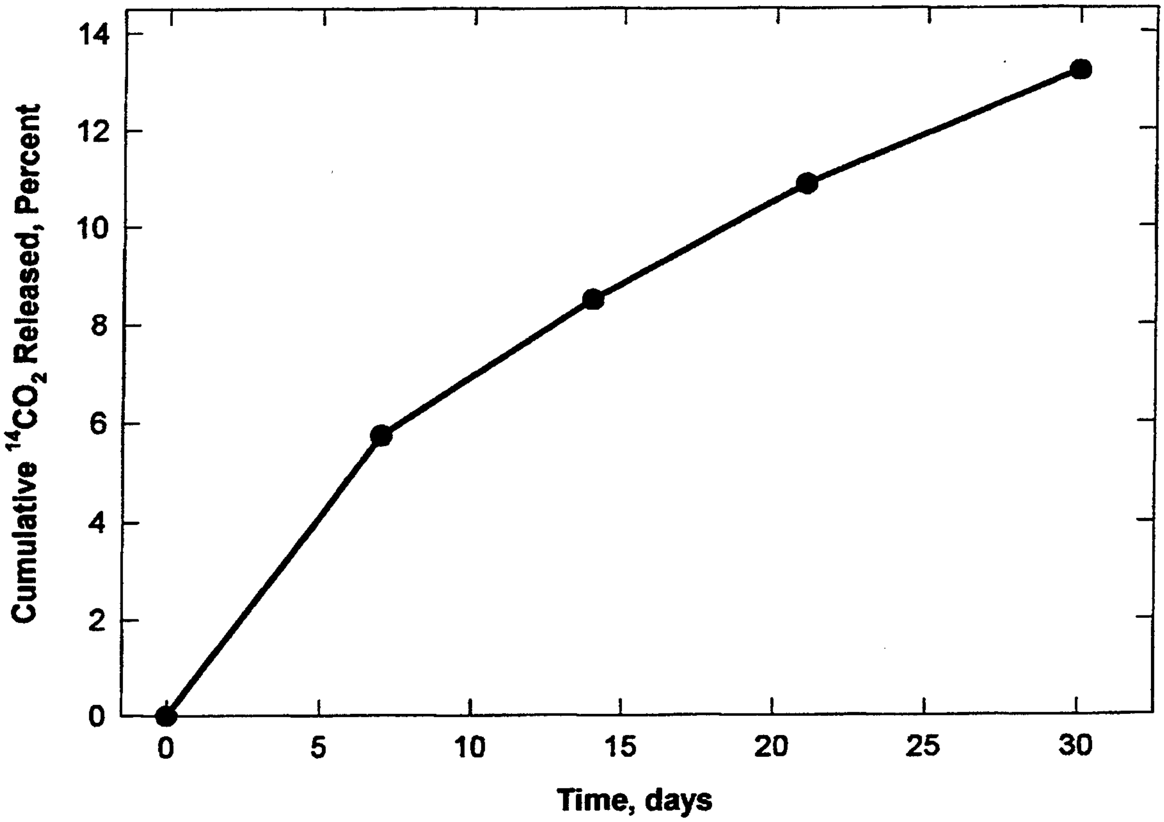

Figure 11. Microbial mineralization rate of TNT in JAAP soil

5.3 Technology Comparison

EPA and the U.S. Air Force jointly have produced a summary of the strengths and limitations of innovative and conventional technologies for remediation of soils, sediments, sludges, groundwater, and air emissions (U.S. Environmental Protection Agency and U.S. Air Force Environics Directorate 1993). The guide includes 13 screening factors for evaluating the various technologies (Table 7). Monitored natural attenuation is one of the technologies included in the guide; however, monitored natural attenuation in groundwater is restricted to nonhalogenated volatile, and semivolatile organic and fuel hydrocarbons, halogenated volatiles and semivolatiles, and pesticides. Most of the screening factors apply equally well to monitored natural attenuation of explosives. Monitored natural attenuation is generally as good as or better than carbon adsorption and bioreactor remediation of contaminated groundwater. The greatest limitations pointed out by the matrix are as follows:

Table 6
Summary of Spearman Correlations Comparing Microbial Mineralization at LAAP and JAAP with Explosive Concentrations, Geochemistry, and Biomarkers

Variable	Mineralization Rates					
	LAAP			JAAP		
	Acetate	TNT	RDX	Acetate	TNT	RDX
Explosive Concentrations						
TNT		X[1]				
TNB		X				
2ADNT						X
RDX		X				
HMX		X				
Geochemistry						
pH					X(-) [2]	
%Silt		X(-)			X	
TOC					X(-)	
Genetic Biomarkers						
NAD(P)H flavin Nitroreductase	X(-)				X	
Catechol-2,3-dioxygenase	X(-)	X		X	X	
Catechol 2,3-dioxygenase 125bp					X	
Membrane Lipid Biomarkers						
Viable biomass			X(-)		X	
Gram-positive				X		
Obligate anaerobe					X	
Actinomycete	X				X	
Long-term stress					X	
Short-term stress	X					

[1] X indicates significant positive correlation ($p < 0.05$).
[2] X(-) indicates significant negative correlation ($p < 0.05$).

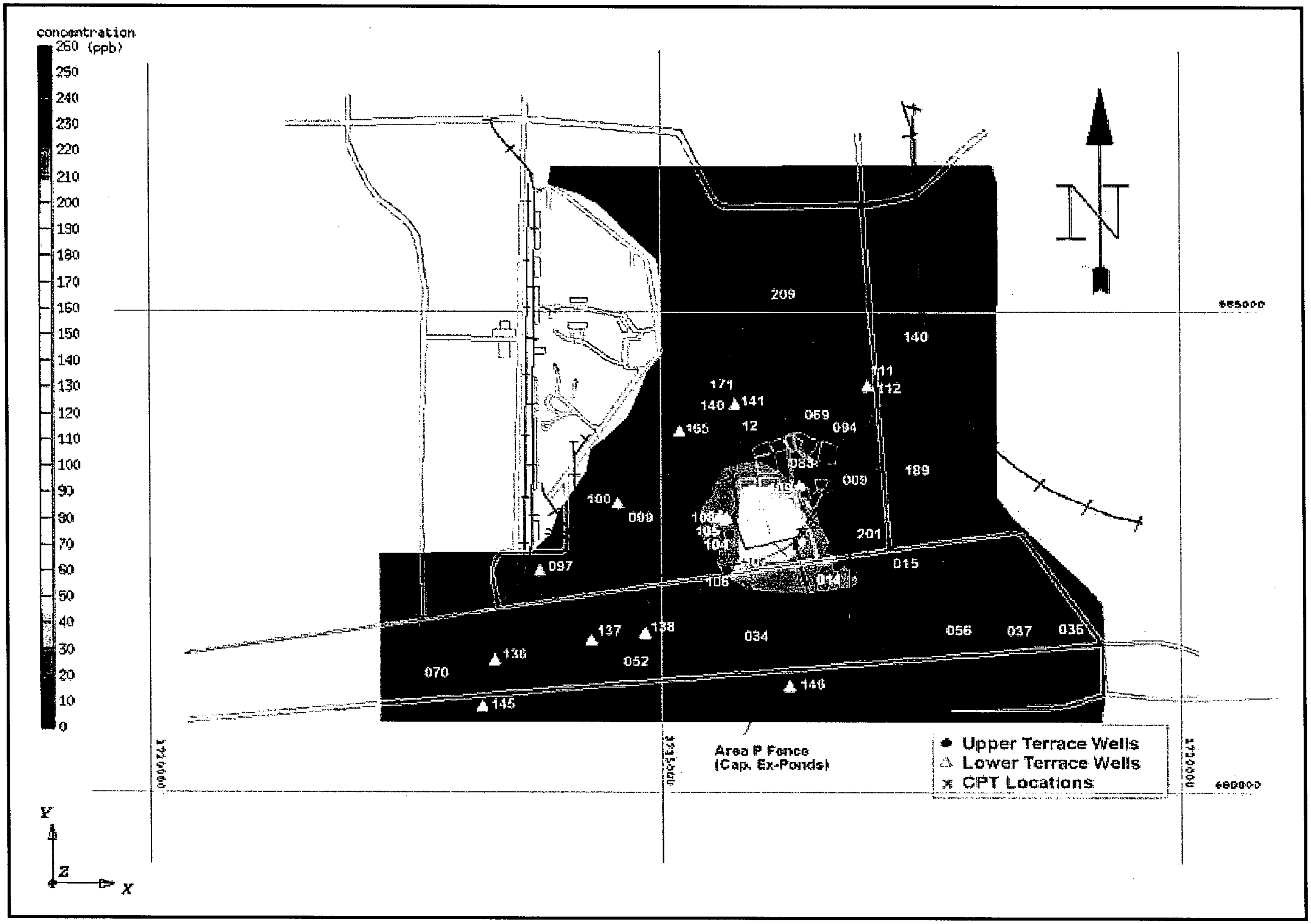

Figure 12. Predicted TNT contaminant plume (model) at LAAP after 20 years

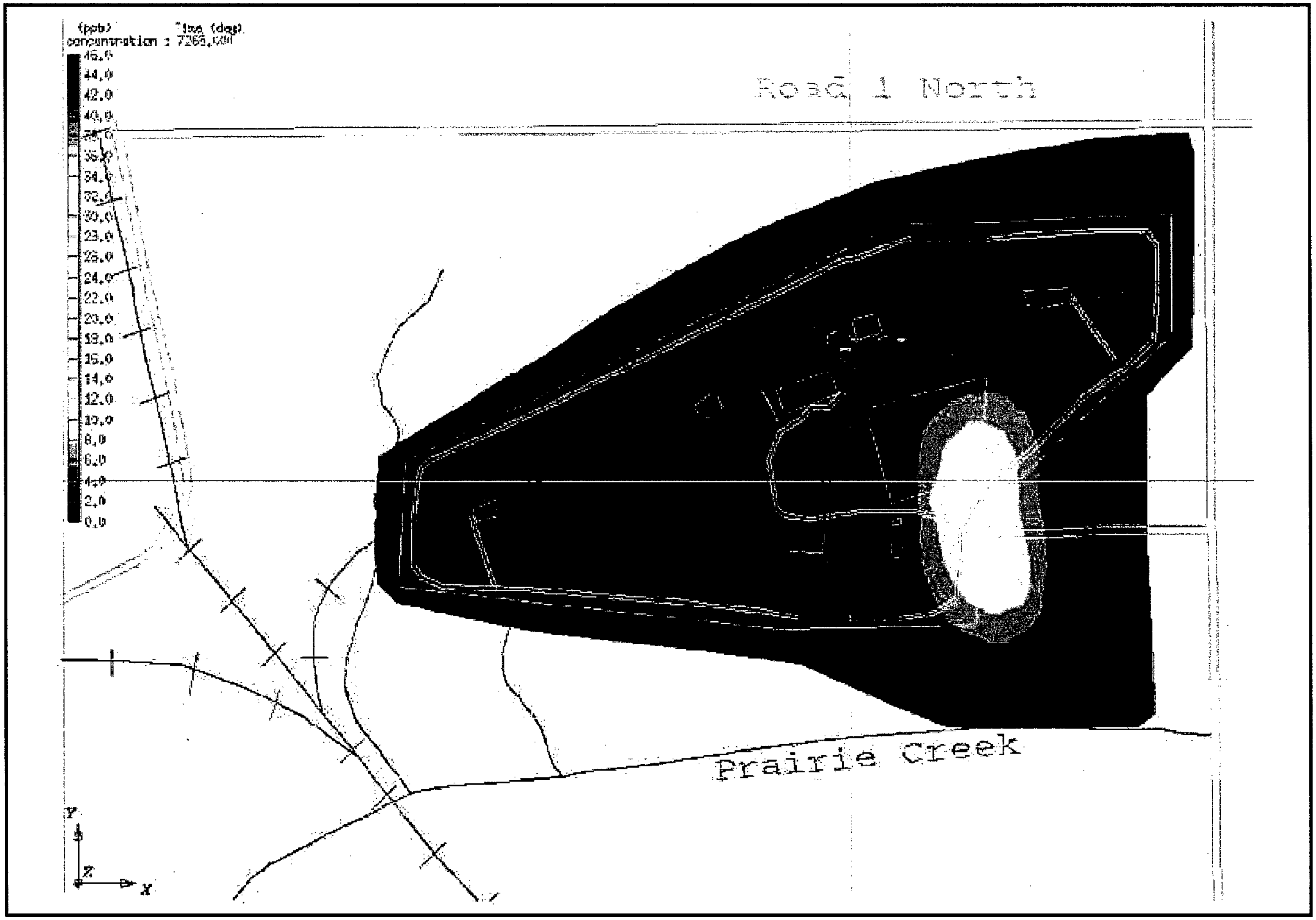

Figure 13. Predicted TNT contaminant plume (model) at JAAP after 20 years

Table 7
Remediation Technologies Screening Matrix for Monitored Natural Attenuation and Two Other Technologies[1]

Criterion	Monitored Natural Attenuation[2]	Carbon Adsorption[3]	In Situ Biological Processes[4]			
			O_2[5]	Cometabolite[6]	NO_3[7]	Air Sparge[8]
Overall cost	Better[9]	Worse[10]	Average[11]	Average	Better	Better
Capital or O&M intensive?	Neither	O&M	O&M	O&M	Neither	Neither
Commercial availability	Better[12]	Better	Better	Worse[13]	Worse	Better
Typically part of a treatment train?	No	No	No	No	No	No
Residuals produced?	None	Solid	None	None	None	None

[1] From U.S. Environmental Protection Agency and U.S. Air Force Environics Directorate 1993.
[2] Based upon monitored natural attenuation of nonhalogenated volatile and semivolatile organic and fuel hydrocarbons, halogenated volatiles and semivolatiles, and pesticides in groundwat
[3] Based upon groundwater being pumped through a series of canisters containing activated carbon to which dissolved organic contaminants adsorb; requires periodic replacement or regeneration of saturated carbon. Targets included halogenated and nonhalogenated semivolatile organic compounds, halogenated volatile organic compounds, fuel hydrocarbons, pesticides and inorganics.
[4] Based upon introduction of amendments to groundwater to promote microbial degradation of contaminants.
[5] A dilute solution of hydrogen peroxide is circulated throughout the contaminated groundwater zone.
[6] Water containing dissolved methane and oxygen is injected into groundwater.
[7] Solubilized nitrate is circulated throughout the groundwater-contaminated zone.
[8] Air is injected under pressure below the water table.
[9] Less than $3.00 per 1,000 gal, or $0.79 per 1,000 L.
[10] More than $10.00 per 1,000 gal, or $2.64 per 1,000 L.
[11] $3.00 to $10.00 per 1,000 gal, or $0.79 to $2.64 per 1,000 L.
[12] More than four vendors.
[13] Less than two vendors.
[14] Less than 5 g/L.
[15] More than 10 years.
[16] 3 to 10 years.
[17] High reliability and low maintenance.
[18] Low reliability and high maintenance.
[19] Average reliability and average maintenance.
[20] Moderately known; some information available in the technical literature.
[21] Generally known; information readily available in the technical literature.
[22] Generally unknown; little information available in technical literature.
[23] Below average.
[24] Above average.
[25] Serious public involvement is likely, and the outcome is uncertain.
[26] Minimal opposition from the community is likely.
[27] Public involvement usually occurs, but the technology is generally accepted.

Table 7. (Concluded)

Criterion	Monitored Natural Attenuation[2]	Carbon Adsorption[3]	In Situ Biological Processes[4]			
			O_2[5]	Cometabolite[6]	NO_3[7]	Air Sparge[8]
Minimum contaminant concentration achievable?	Inadequate information	Better[14]	Better	Better	Better	Better
Addresses toxicity, mobility, or volume?	Toxicity	Volume	Toxicity	Toxicity	Toxicity	Toxicity
Long-term effectiveness/permanence?	Yes	Yes	Yes	Yes	Yes	Yes
Time to complete cleanup	Worse[15]	Not applicable	Average[16]	Average	Average	Average
System reliability/maintainability	Better[17]	Better	Worse[18]	Worse	Average[19]	Better
Awareness of the remediation consulting community	Average[20]	Better[21]	Better	Worse[22]	Worse	Average
Regulatory/permitting acceptability	Worse[23]	Better[24]	Average	Inadequate information	Worse	Average
Community acceptability	Worse[25]	Better[26]	Better	Inadequate information	Average[27]	Better

a. Time to complete cleanup (more than 10 years).

b. Regulatory/permitting acceptability (below average).

c. Community acceptability (serious public involvement is likely and the outcome is uncertain).

While "time to clean up" will be influenced by many site-specific variables such as degradation rate and cleanup goals, greater time than required for many engineered technologies is likely. However, no rating is given for carbon adsorption nor for bioreactors. Since both of these technologies depend upon pumping of water and contaminants from the ground before treatment, both may require extensive time frames (comparable with monitored natural attenuation) to achieve remedial goal.

Although monitored natural attenuation is a relative new technology, the EPA has recognized "monitored natural attenuation" as a potentially viable alternative for remediation of contaminated groundwater. Therefore, regulatory acceptability may improve as more demonstrations of efficacy are implemented. As the regulatory and commercial communities gain experience with monitored natural attenuation, the public will also gain an understanding of the advantages and limitation of monitored natural attenuation as a remedial alternative. They will recognize that monitored natural attenuation is not a "no action" alternative selected for the convenience of remediators, but can be a low-cost and suitable remedial alternative.

6. Cost Assessment

6.1 Cost Performance

An assessment of the expected operational costs associated with implementation of monitored natural attenuation of explosives (Table 8) was based upon the following general assumptions:

a. Remedial investigation/feasibility study (RI/FS) or equivalent has been conducted to determine the character and extent of contamination.

b. Potential receptor(s) has been identified relative to the contamination.

c. Source of contamination has been removed.

d. Coordination with the regulatory community and other interested parties has been initiated.

Table 8
Expected Operational Costs Associated with Natural Attenuation[1]

	Cost Element	Unit Cost, $	No. of Units	Cost, $
Before-Treatment Costs[2]	**Mobilization and Preparatory Work (WBS 33 1 01)**[3] - Site reconnaissance and review of existing data[4]	25,000	Lump sum	25,000
	- Site modeling[5]	100,000	Lump sum	100,000
	- Development of plan for additional data collection[4]	30,000	Lump sum	30,000

(Sheet 1 of 3)

[1] Assuming a 101,172-m^2 (25-acre) site with 10 existing monitoring wells, installation of 10 new monitoring wells, and quarterly sampling for the first 2 and biannually for the remainder of 20 years. Costs estimated do not take into account contaminant levels, treatment goals, or time to achieve site closure.

[2] "Before-Treatment Costs" are those costs associated with site characterization in addition to existing data such as typically found in Remedial Investigation/Feasibility Studies.

[3] Cost elements to the second level were based upon Hazardous, Toxic, and Radioactive Waste (HTRW) Remedial Action (RA)-Work Breakdown Structure (WBS) (U.S. Army Corps of Engineers 1996).

[4] Assuming a site with 5 years of historical contaminant and hydrogeological data.

[5] Site modeling includes data analysis, conceptual site-model development, sensitivity analysis, and model prediction.

[6] Includes the following: lease of rig and crew for 4 days (mobilization only) at $2,400/day, Level D personal protective equipment. Distance from job site may add additional cost (ECHOS 1998b, page 3-156).

[7] Assuming one CPT truck with a two-man crew drilling multiple holes to various depths. Warranted to refine understanding of hydrogeology, to further characterize contaminant plume, and/or to obtain site material for biomarkers and site-capacity determinations; typically 15 CPT punches can be achieved each day; assuming grouting of each hole after sampling and decontamination between punches.

[8] See description of tests in Section 2.1; assuming that tests are conducted on three representative soils from the site.

[9] Based upon sampling an average of three wells per day, approximately 3 days for mobilization/demobilization, and sampling of all 20 wells.

[10] See list of analytes in Section 4.4; assuming one sample analyzed from each well.

[11] Assuming a single completion well, 10 cm (4-in.) in diameter drilled by hollow-steam-auger methods, 15.2 m (50 ft) deep. Warranted if existing site wells are inadequate because of depth, location, or other sampling restrictions, e.g., small diameter, or if existing wells insufficient in number.

[12] Assuming 2 days to develop each well. (ECHOS 1998b, page 3-158).

[13] Assuming clearing of medium brush, average grubbing, and clearing of some trees from 2,023 m^2 (0.5 acres) around each well (ECHOS 1998b, page 4-1.)

[14] Assuming 10 wells and five sampling depths using separate field-test kits for TNT and RDX (ENSYS, Inc., Research Triangle Park, NC).

[15] Assuming nonhazardous material disposed onsite by the spread and seed method. Hazardous materials may require additional costs.

[16] Costs are based upon treatment by passage through granular-activated carbon and returning to waste-treatment system onsite.

[17] "Treatment Costs" are costs associated with long-term monitoring of groundwater and periodic refinements in models.

[18] Assumes monitoring is quarterly for the first 2 and biannually for the remainder of 20 years.

[19] Assuming that the model is refined every 5 years, or four times in 20 years.

[20] Assuming a three-man crew working in Level C or D personal protective equipment.

[21] Based on U.S. Army Corps of Engineers, Vicksburg District, cost of $3,000 per day (three-man crew) and 2 days to rip casing and grout wells; local and State regulations should be consulted.

[22] If removal of wells significantly disturbs the surface, revegetation may be warranted; costs are based upon 2,023 m^2 (0.5 acre) disturbed area around each well (Czerwonka 1996).

Table 8. (Continued)

	Cost Element	Unit Cost, $	No. of Units	Cost, $
Before-Treatment Costs[2]	- Mobilization of drill rig and crew[6]	2,400/day	4	9,600
	Monitoring, Sampling, Testing and Analysis (WBS 33 1 02) - Cone penetrometry sampling[7]	2,000/day	10	20,000
	- Biomarker characterization[8]	3,000/sample	150	450,000
	- Site-capacity determinations[8]	8,000/sample	3	24,000
	- Baseline (initial) well sampling[9]	3,000/day	20	60,000
	- Sample analysis for explosives in baseline well samples[10]	500/well	20	10,000
	- Sample analysis for geochemical parameter in baseline well samples[10]	100/well	20	2,000
	Site Work (WBS 33 1 03) - Installation of additional monitoring wells[11]	15,000/well	10	150,000
	- Development of additional monitoring wells[12]	88/day	20	1,760
	- Field labor for additional monitoring well installation[11]	60/ft	500	30,000
	- Clearing and grubbing around monitoring wells[13]	550/acre	10	5,500
	Solids Collection and Containment (WBS 33 1 08) - Sampling and analysis of drill cuttings from new wells[14]	900/well	10	9,000
	- Treatment and disposal of drill cuttings from new wells[15]	3,000	Lump sum	3,000
	Liquids Collection and Containment (WBS 33 1 09) - Treatment and disposal of well development water[16]	3,000	Lump sum	3,000
	- Treatment and disposal of well purge water from initial sampling[16]	200/well	20	4,000
Treatment Costs[17]	**Monitored Natural Attenuation** - Groundwater monitoring[18]	35,000/event	44	1,540,000
	- Refinements of models[19]	70,000/refinement	4	280,000

(Sheet 2 of 3)

Table 8. (Concluded)

	Cost Element	Unit Cost, $	No. of Units	Cost, $
Treatment Costs[17]	- Treatment and disposal of well purge water[18]	4,000/event	80	320,000
	- Disposal of personal protective equipment[20]	100/event	80	8,000
After-Treatment Costs	**Demobilization (WBS 33 1 21)** - Well closings[21]	6,000/well	20	120,000
	Site Restoration (WBS 33 1 20) - Revegetation of disturbed areas[22]	4000/acre	10	40,000

(Sheet 3 of 3)

Assumptions specific to individual costs and a general summary of expected costs are described in Table 8. Cost elements to the second level are based upon *Hazardous, Toxic and Radioactive Waste (HTRW) Remedial Action (RA)-Work Breakdown Structure (WBS)* (U.S. Army Corps of Engineers 1996).

6.2 Cost Comparisons to Conventional and Other Technologies

Costs associated with monitored natural attenuation of explosives are compared with those associated with two other treatment technologies: in situ biodegradation in the saturated zone, an innovative technology (U.S. Environmental Protection Agency and U.S. Air Force Environics Directorate 1993) for which costs are summarized in Table 9, and pump-and-treat followed by carbon adsorption, a conventional technology (U.S. Environmental Protection Agency and U.S. Air Force Environics Directorate 1993) for which costs are summarized in Table 10. In situ biodegradation typically consists of the following treatment train: treatment and disposal of drill cuttings, professional field labor, and sampling and analysis (Environmental Cost Handling Options and Solutions (ECHOS) 1998a). Cost components may include the following: mobilization of the drill rig and crew, drilling, decontamination of equipment, well materials and installation, pumps, nutrients and microorganisms, holding tanks, piping, operations and maintenance, clearing and grubbing, fencing, and electrical distribution (ECHOS 1998a). Carbon adsorption remediation typically consists of the following treatment train: groundwater recovery, sedimentation, filtration, metals removal, oil removal, air stripping, pH adjustment, and sampling and analysis (ECHOS 1998a). Cost components may include the following: piping for influent and effluent waters, adsorbers, pumps, structural slab, saturation indicator, electrical usage, operations and maintenance, electrical distribution, and fencing (ECHOS 1998a).

To make adequate cost comparisons, the following assumptions were followed:

a. The site is the same for each technology and consists of 101,172 m^2 (25 acres) containing an explosives-contaminated groundwater plume. The assumption is that the site is suitable for implementation of any of the three technologies.

b. Treatment time is 20 years. The assumption is that the cleanup goal can be reached by any of the three technologies in this time period.

No site is likely to be suitable for all three technologies because of limitations such as permeability of the subsurface. Neither is a fixed time likely to be appropriate for all three technologies simultaneously. In fact, the time variable is likely to differ significantly among these technologies. The ultimate effectiveness, or lack of effectiveness, of each technology is likely to differ; therefore, effectiveness has not entered into the cost estimates. Table 11 summarizes the costs estimates for all three technologies under the above assumptions.

Table 9
Expected Operational Costs for In Situ Bioremediation[1]

	Cost Element	Unit Cost, $	No. of Units	Cost, $
Before-Treatment Costs[2]	**Mobilization and Preparatory Work (WBS 33 1 01)** - Site reconnaissance and review of existing data[3]	25,000	Lump sum	25,000
	- Mobilization of drill rig and crew[4]	2,400/day	4	9,600
	Monitoring, Sampling, Testing and Analysis (WBS 33 1 02) - Baseline (initial) well sampling[5]	3,000/day	10	30,000
	- Sample analysis for explosives in baseline well samples[6]	500/well	10	5,000

(Continued)

[1] Assuming a 101,172-m^2 (25-acre) site with 10 existing wells suitable to serve as extraction wells and injection of nutrients, microorganisms, and oxygen (hydrogen peroxide). Cost estimates do not take into account contaminant levels, treatment goals, or time to achieve site closure.

[2] "Before-Treatment Costs" include any costs associated with site characterization in addition to existing data such as typically found in Remedial Investigation/Feasibility Studies.

[3] Assuming a site of approximately 101,172 m^2 (25 acres), 10 or more existing wells (used as extraction wells), and 5 years of historical contaminant and hydrogeological data.

[4] Includes the following: lease of rig and crew for 4 days (mobilization only) at $2,400/day, Level D personal protective equipment. Distance from job site may add additional cost (ECHOS 1998b, page 3-156).

[5] Based upon sampling an average of three wells per day, approximately 3 days for mobilization/demobilization, and sampling of 10 wells.

[6] See list of analytes in Section 4.4; assuming one sample analyzed from each extraction well.

[7] Assuming medium brush, average grubbing, and clearing of some trees (ECHOS 1998b, page 4-1).

[8] Assuming 2-m (7-ft) galvanized chain-link fence around 101,172 m (25 acres) (ECHOS 1998b, page 5-15).

[9] Assuming one transformer, 10 light poles, and 2,438 m (8,000 ft) wire (ECHOS 1998b, page 7-1).

[10] Assuming 10, 5-cm (2-in.) injection wells and 2 days to drill and complete each well (ECHOS 1998b, page 3-161).

[11] Assuming adjustable flow 95 L (25 gal) per minute pump with motor (Source: ECHOS 1998, page 3-161).

[12] Assuming 2 days to develop each well (ECHOS 1998b, page 3-158).

[13] Assuming 10 wells, 10 cm (4 in.) in diameter and 15.2 m (50 ft) deep (ECHOS 1998b, page 8-207).

[14] Assuming 10 wells and five sampling depths using separate field-test kits for TNT and RDX (ENSYS, Inc., Research Triangle Park, NC).

[15] Assuming nonhazardous material disposed onsite by the spread and seed method. Hazardous material may require additional cost.

[16] Based upon treatment by passage through granular-activated carbon and returning to waste-treatment system onsite.

[17] Assuming one hydrogen peroxide feed tank, regulator, injector, and control panel per well (ECHOS 1998b, page 3-161).

[18] Assuming 45.4 kg (100 lb) microorganisms degraders once a month into each of 10 injection wells for 20 years (ECHOS 1988b, page 3-156).

[19] Assuming 22.7 kg (50 lb) of nutrients per well, once a month for 20 years (ECHOS 1998b, page 3-157).

[20] Assuming 5,200 days of operation over 20 years and 1,080 days downtime for maintenance and equipment replacement; assuming regulatory permission for reinjection of treated effluent (ECHOS 1998b, page 7-1).

[21] Assuming 10 samples per month, a single analyte (TNT or RDX) using a field-test kit, and 20 years of monitoring.

[22] Based upon removal of miscellaneous large fixed equipment (ECHOS 1998b, page 3-22).

[23] Based upon U.S. Army Corps of Engineers, Vicksburg District, cost of $3,000 per day (three-man crew) and 2 days to rip casing and grout 20 wells. Federal and State regulations should be consulted concerning issues related to well removal.

[24] Based upon 2,023 m^2 (0.5 acre) disturbed area around each well (Czerwonka 1996).

Table 9. (Concluded)

	Cost Element	Unit Cost, $	No. of Units	Cost, $
Before-Treatment Costs[2]	- Sample analysis for geochemical parameters in baseline well samples[6]	100/well	10	1,000
	Site Work (WBS 33 1 03) - Clearing and grubbing[7]	550/acre	25	13,750
	- Fencing[8]	26/ft	4,000	108,530
	- Electrical distribution[9]	27,850	Lump sum	27,850
	- Injection well installation (drilling)[10]	6,000/well	10	60,000
	- Injection pumps[11]	1,550/well	10	15,500
	- Development of injection wells[12]	88/day	20	1,760
	- Field labor for injection well installation (completion)[13]	60/ft	500	30,000
	Solids Collection and Containment (WBS 33 1 08) - Sampling and analysis of drill cuttings[14]	900/well	10	9,000
	- Treatment and disposal of drill cuttings[15]	3,000	Lump sum	3,000
	Liquid Collection and Containment (WBS 33 1 09) - Treatment and disposal of well development water[16]	3,000	Lump sum	3,000
	- Treatment and disposal of well purge water from initial sampling[16]	200/well	10	2,000
Treatment Costs	**Biological Treatment (WBS 33 1 11)** - Hydrogen peroxide feed tank[17]	2,715/well	10	27,150
	- Microorganisms degraders[18]	40,000/year	20	800,000
	- Nutrients[19]	7,200/year	20	144,000
	- Operation and maintenance (electrical systems)[20]	130,000/year	20	2,600,000
	- Periodic monitoring of treatment effluent[21]	45/test	2,400	108,000
After-Treatment Costs	**Demobilization (WBS 33 1 21)** - Removal of surface equipment[22]	1,280/day	20	25,600
	- Removal of extraction and injection wells[23]	6,000/well	20	120,000
	Site Restoration (WBS 33 1 20) - Revegetation of disturbed area[24]	4,000/acre	10	40,000

Table 10
Expected Operational Cost for Activated Carbon Adsorption Treatment of Groundwater[1]

	Cost Element	Unit Cost, $	No. of Units	Cost, $
Before-Treatment Costs[2]	**Mobility and Preparatory Work (WBS 33 1 01)** - Site reconnaissance and review of existing data[3]	25,000	Lump sum	25,000
	- Mobilization of drill rig and crew[4]	2,400/day	4	9,600
	Monitoring, Sampling, Testing and Analysis (WBS 33 1 02) - Baseline (initial) well sampling[5]	3,000/day	10	30,000

(Sheet 1 of 3)

[1] Assuming a 101,172-m^2 (25-acre) site with 10 existing wells suitable for use as extraction wells, installation of 10 new injection wells, pumping and treating of groundwater with activated-carbon treatment systems and reinjection of treated effluent.

[2] "Before-Treatment Costs" include any costs associated with site characterization in addition to existing data such as typically found in Remedial Investigation/Feasibility Studies.

[3] Assuming a site of approximately 101,172 m^2 (25 acres), 10 or more existing wells (used as extraction wells), and 5 years of historical contaminant and hydrogeological data.

[4] Includes the following: lease of rig and crew for 4 days (mobilization only) at $2,400/day, Level D personal protective equipment. Distance from job site may add additional cost (ECHOS 1998b, page 3-156).

[5] Based upon sampling an average of three wells per day, approximately 3 days for mobilization/demobilization, and sampling of 10 wells.

[6] See list of analytes in Section 4.4; assuming one sample analyzed from each extraction well.

[7] Assuming medium brush, average grubbing, and clearing of some trees (ECHOS 1998b, page 4-1).

[8] Assuming 2-m (7-ft) galvanized chain-link fence around 101,172 m^2 (25 acres) (ECHOS 1998b, page 5-15).

[9] Assuming one transformer, 10 light poles, and 2,438 m (8,000 ft) of wire (ECHOS 1998b, page 7-1).

[10] Assuming 10, 5-cm (2-in.) injection wells and 2 days to drill and complete each well (ECHOS 1998b, page 3-161).

[11] Assuming 95 L (25 gal) per minute, 1-hp, transfer pump with motor valves, piping, and saturation indicator per well (ECHOS 1998b, page 3-50 and 3-51).

[12] Assuming 2 days to develop each well (ECHOS 1998b, page 3-158).

[13] Assuming 10 wells 15.2 m (50 ft) deep (ECHOS 1998b, page 8-207).

[14] Assuming a 30.5-cm (12-in.) thick structural slab on grade, $7.50 per square feet, and 9.3 m^2 (100 sq ft) per well (ECHOS 1998b, page 3-50).

[15] Based upon a 3.7-m (12 -ft) wide, 914.4-m (3,000-ft) length and 40.6-cm (16-in.) depth of gravel (ECHOS 1998b, page 5-1).

[16] Assuming 10 wells and five sampling depths using separate field-test kits for TNT and RDX (ENSYS, Inc., Research Triangle Park, NC).

[17] Assuming nonhazardous material disposed onsite by the spread and seed method. Hazardous material may require additional cost.

[18] Costs are based upon treatment by passage through granular-activated carbon and returning to waste treatment system onsite.

[19] Assuming 95-L (25-gal) per minute, 149.7-kg (330-lb) filled, 316-L stainless steel, permanent adsorber (ECHOS 1998b, page 3-50).

[20] Assuming 5,200 days of operation over 20 years and 1,080 days downtime for maintenance and equipment replacement (ECHOS 1998b, page 7-1).

[21] Assuming replacement of carbon from adsorption vessels four times a year in all 10 wells for 20 years (ECHOS 1998b, page 3-51).

[22] Assuming pump and motor maintenance and repair for all 10 wells annually for 20 years (ECHOS 1998b, page 3-53).

[23] Assuming all 10 pumps will be replaced three times over 20-year period (ECHOS 1998b, page 3-53).

[24] Assuming 10 samples per month, a single analyte (TNT or RDX) using a field-test kit, and 20 years of monitoring.

[25] Based upon removal of miscellaneous large fixed equipment (ECHOS 1998b, page 3-22).

[26] Based upon U.S. Army Corps of Engineers, Vicksburg District, cost of $3,000 per day (three-man crew) and 2 days to rip casing and grout wells. Federal and State regulations should be consulted concerning issues related to well removal.

[27] Based upon on 2,023 m^2 (0.5 acre) disturbed area around each well (Czerwonka 1996).

Table 10. (Continued)

	Cost Element	Unit Cost, $	No. of Units	Cost, $
Before-Treatment Costs[2]	- Sample analysis for explosives in baseline well samples[6]	500/well	10	5,000
	- Sample analysis for geochemical parameters in baseline well samples[6]	100/well	10	1,000
	Site Work (WBS 33 1 03) - Clearing and grubbing[7]	550/acre	25	13,750
	- Fencing[8]	4,000/acre	25	100,000
	- Electrical distribution[9]	27,850	Lump sum	27,850
	- Injection well installation[10]	6,000/well	10	60,000
	- Transfer pumps and saturation meter[11]	1,650/well	10	16,500
	- Development of injection wells[12]	88/day	20	1,760
	- Field labor for injection well installation[13]	60/ft	500 (10 wells)	30,000
	- Structural slab[14]	750/well	10	7,500
	- Access road[15]	40,000	Lump sum	40,000
	Solids Collection and Containment (WBS 33 1 08) - Sampling and analysis of drill cuttings[16]	900/well	10	9,000
	- Treatment and disposal of drill cuttings[17]	3,000	Lump sum	3,000
	Liquid Collection and Containment (WBS 33 1 09) - Treatment and disposal of well development water[18]	3,000	Lump sum	3,000
	- Treatment and disposal of well purge water from initial sampling[18]	200/well	10	2,000
Treatment Costs	**Physical Treatment (WBS 33 1 13)** - Adsorbers[19]	3,200/each	10	32,000
	- Operation and maintenance (electrical systems)[20]	260,000/year	20	5,200,000
	- Removal and replacement of carbon from adsorbers[21]	2,800/year	20	56,000
	- Pump and motor maintenance and repair[22]	4,000/year	20	80,000

(Sheet 2 of 3)

Table 10. (Concluded)

	Cost Element	Unit Cost, $	No. of Units	Cost, $
Treatment Costs	- Road maintenance	1,000/year	20	20,000
	- Replacement of transfer pumps[23]	15,500/replacement	3	46,500
	- Periodic monitoring of treatment effluent[24]	45/test	2,400	108,000
After-Treatment Costs	**Demobilization (WBS 33 1 21)** - Removal of surface equipment[25]	1,280/day	20	25,600
	- Removal of extraction and injection wells[26]	6,000/well	20	120,000
	Site Restoration (WBS 33 1 20) - Revegetation of disturbed areas[27]	4,000/acre	10	40,000

(Sheet 3 of 3)

Table 11
Cost Comparison of Selected Remedial Alternatives with Natural Attenuation[1]

		Natural Attenuation, $	In Situ Bioremediation, $	Activated-Carbon Adsorption (Pump and Treat), $
Before-Treatment Cost	**Mobilization and Preparatory Work (WBS 33 1 01)**	164,600	34,600	34,600
	Monitoring, Sampling, Testing and Analysis (WBS 33 1 02)	566,000	36,000	36,000
	Site Work (WBS 33 1 03)	187,260	257,390	309,360
	Solids Collection and Containment (WBS 33 1 08)	12,000	12,000	12,000
	Liquids Collection and Containment (WBS 33 1 09)	7,000	5,000	5,000
Treatment Costs	**Monitored Natural Attenuation**	2,148,000	-	-
	Biological Treatment (WBS 33 1 11)	-	3,679,150	-
	Physical Treatment (WBS 33 1 13)	-	-	5,542,500
After-Treatment Costs	**Demobilization (WBS 33 1 21)**	120,000	145,600	145,600
	Site Restoration (WBS 33 1 20)	40,000	40,000	40,000
Total		3,244,860	4,209,740	6,125,060

[1] Cost estimates were generated from values in Tables 8, 9, and 10. All estimates assume a 101,172-m^2 (25-acre) site equally suitable for application of any of the three technologies and 20 years for achievement of cleanup goals.

7. Regulatory Issues

7.1 Approach to Regulatory Compliance and Acceptance

Site representatives of Region VI, EPA, Dallas, TX, the Louisiana Department of Environmental Quality, Abandoned Sites Division, Baton Rouge, LA, and other interested parties were briefed at LAAP Technical Review Committee meetings early in the project and several times during the project including one briefing at Region VI headquarters in Dallas, TX. Several phone discussions were held with personnel at EPA Headquarters in Washington, DC. The project Principal Investigator was given the opportunity to provide comments on an early draft of the Monitored Natural Attenuation Policy Memorandum issued by EPA in December 1997. A representative from the EPA Federal Facilities Reuse Office in Washington served as an ad hoc member of the monitored natural attenuation Technical Review Committee during initial stages of the project.

8. Technology Implementation

8.1 DoD Need

The Army has an estimated 1,300 installations worldwide containing approximately 5,500 individual sites contaminated with various compounds that will require some form of remedial actions (Environmental Quality Technology Program 1998).

8.2 Transition

The next step for monitored natural attenuation of explosives transition to users is a successful Record of Decision (ROD) at LAAP and at JAAP. The Industrial Operations Command (IOC) in concert with site personnel and other interested parties including Corps of Engineers Districts, State and Federal regulators, final recipients of the properties in question, and local interested parties are actively negotiating RODs including monitored natural attenuation for both study sites.

Additional demonstrations are not needed, but data from additional sites would increase the credibility of the approach, especially for the biomarkers, which are relatively new technologies. EPA will require strong evidence and justification of monitored natural attenuation for any contaminants. Protection of potential receptors will be an important issue for each site.

Additional funding for development will not be necessary. However, funding to consolidate case histories as sites implement monitored natural attenuation would be an asset to the technology. Industrial partners will be needed for site characterization, monitoring, and modeling.

The IOC and each of the demonstration sites, LAAP and JAAP, are now negotiating RODs including monitored natural attenuation. Each site will have specific issues to resolve concerning protection of receptors and regulatory concerns. These issues will have to be resolved by consensus of all interested parties at each site.

The Protocol (Pennington et al., "Draft Protocol for Evaluating, Selecting, and Implementing Monitored Natural Attenuation at Explosives-Contaminated Sites") provides guidance for evaluating the appropriateness of selecting monitored natural attenuation for a site. If the results of working through the Protocol suggest that monitored natural attenuation is appropriate, either as a primary remedy or as a secondary remedy after engineered remediation of source contamination, implementation can proceed. Implementation will require site characterization, monitoring, and modeling, all of which can be secured by contract with the private sector.

Industry was involved in formulation of the Protocol (Arthur D. Little, Inc., Cambridge, MA), in site characterization and monitoring (AScI Corporation, McLean, VA, DynTel Corporation, Vicksburg, MS, Applied Research Associates, Vicksburg, MS, and Engineering Technologies Associates, Ellicott City, MD), and in waste disposal (Engineering Technologies Associates, Ellicott City, MD). Industry will be interested in providing all of these functions as well as groundwater modeling for monitored natural attenuation of explosives.

Site Environmental Officers and the IOC will contract with industry for site characterization, monitoring, and modeling. The timetable will be relative to the level of existing site-characterization data and existing monitoring capabilities, e.g., presence of appropriate monitoring wells, and will be site specific. Guidance provided in the Protocol can be used to evaluate steps and time frame.

9. Lessons Learned

9.1 Lessons Learned

9.1.1. Data Quality. To have confidence in observed trends in contaminant concentration data, care must be exercised in collection, handling, and analyzing of groundwater samples. Data-quality objectives include the following:

a. Ensure data comparability. Consistent implementation of good sampling practices are essential to achievement of quality data. To that end, all parties involved in sampling, handling, and analysis should follow a consistent plan. Deviations from established protocols can greatly impact the observation of small trends over short-observation periods.

b. Prevent cross-contamination of samples well to well. To ensure that highly contaminated well water cannot cross-contaminate less contaminated water, three techniques should be adopted. First, after concentrations in all monitoring wells have been measured, all subsequent sampling should progress from low- to high-concentration wells. Second, when micropurge techniques are employed, sample tubing should be dedicated to each well. Third, all sampling apparatus that comes into contact with the groundwater should be decontaminated between wells. To ensure that the decontamination procedure is effective, random samples of rinsate from decontamination should be submitted for explosives analyses. At LAAP, one such sample was analyzed for each sampling day.

c. Remove the influence of the well head from the sample. Results of experiments conducted at the LAAP demonstrated that explosives concentrations varied inversely with dissolved oxygen as water was removed from the well head (Pennington et al. 1998b). Oxygenation of the water, which had been in contact with air in the well before pumping was initiated, caused a decrease in explosives concentrations. Therefore, removal of this oxygenated water, which can introduce an artifact into the explosives concentration data, is essential. Additional studies showed that explosives concentrations stabilized when DO reading stabilized as water was pumped from the well using a micropurge technique. This technique was adopted for LAAP well sampling. However, micropurge techniques cannot be used under conditions of low-well volume. Therefore, the number of well volumes that had been removed when explosives concentrations and DO stabilized were calculated. For LAAP removal of three well volumes by bailing was roughly equivalent to stabilization of DO and explosives concentrations.

d. Adequately preserve the analytes. Experiments were conducted at LAAP to determine the best sample preservative for the explosives analytes (Pennington et al., "Monitored Natural Attenuation of Explosives in Soil and Water Systems at Department of Defense Sites: Interim Report"). Results indicated that acidification to pH 2 with 1.5 g sodium bisulfate per liter of groundwater was effective. Therefore, all groundwater samples for explosives analyses were so preserved.

e. Ensure precision, accuracy, and representativeness in sampling. Precision is estimated from the agreement among replicate measurements. At least 1 of every 10 samples should be collected and analyzed in duplicate. Precision estimated from these samples include contributions from the entire measurement process including collection, storage, preconcentration, and determination. Accuracy is determined from spiked samples, which are subsequently subjected to the entire analytical process. At least two spiked blanks (distilled or reverse osmosis water) and three spiked groundwater samples should be analyzed for each sampling event. Spikes should represent both low- and high-analyte concentrations. For example, at LAAP, spikes into low-concentration samples were made at 1.0 $\mu g\ L^{-1}$, while spikes into high-concentration samples were made at 250 $\mu g\ L^{-1}$. Blank samples (distilled or reverse osmosis water without spikes) should also be analyzed to ensure that no positive interference occurred in any of the methods. Representativeness is the degree to which the data portray the quality of the water in the aquifer with respect to time and location. Temporal representativeness can be obtained by sampling with sufficient frequency to observe seasonal trends that may affect overall explosives-concentration trends. At LAAP, sampling was quarterly for 2 years. Spatial representativeness can be obtained by sampling from representative locations throughout the groundwater plume. At LAAP, 30 aerially distributed wells were sampled, including wells at different depths.

9.1.2. Sampling Efficiency. At LAAP, the field crew was split into two, two-man crews. While one crew sampled a well, the second crew mobilized to the next well and set up equipment for sampling. When the first well had been sampled, the first crew demobilized and moved to the second well. The second crew took the first set of equipment to the third well for set up. Using this “leap frog” technique greatly reduced field-sampling time.

9.1.3. Biomarkers. Biomarkers are an effective means of determining the potential rate and extent of explosives degradation in the aquifer. Successful measurement of biomarkers requires access to site material. Insufficient biomass was present in groundwater at LAAP to obtain adequate biomarker data. The groundwater and aquifer soil at LAAP are particularly low in organic carbon. However, biomarker data were successfully obtained from aquifer soil samples collected by CPT in spite of low-organic carbon in the soil. Therefore, before adopting biomarker techniques for a site, consideration should be given to the level of organic material available to provide microbial biomass and to the feasibility of obtaining CPT samples from the site subsurface. Unless organic carbon is high in groundwater, aquifer soil will be required. However, some sites are located on rocky substrates that are not amenable to CPT. Cone penetrometry can be an effective tool for refinements in site geological characterization, contaminant-distribution characterization, biomarker, and modeling support at sites where the substrate permits its use.

9.1.4. Site Capacity. Site capacity for adsorption and transformation of explosives can be measured by simple partitioning tests (Pennington et al., "Draft Protocol for Evaluating, Selecting, and Implementing Monitored Natural Attenuation at Explosives-Contaminated Sites," and "Monitored Natural Attenuation of Explosives in Soil and Water Systems at Department of Defense Sites: Interim Report"). However, if aquifer soils are very low in organic carbon (<0.1 percent) and high in sand (>90 percent), partitioning coefficients can be assumed to be zero for model input. Otherwise, partitioning tests should be conducted with aquifer material collected from the site.

9.1.5. Modeling. Simple models are likely to be adequate for initial conceptualization of the site; however, more complex numerical models will be required to predict long-term fate of the contaminants. Models should be sufficiently sophisticated to include measured contaminant half-life as well as hydrogeology.

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Appendix A
Points of Contact

Dr. Judith C. Pennington
Principal Investigator
U.S. Army Engineer Waterways
Experiment Station
3909 Halls Ferry Road
Vicksburg, MS 39180-6199
Ph: 601-634-2802
FAX: 601-634-3410
E-mail: *penninj@ex1.wes.army.mil*

Mr. Danny W. Harrelson
Principal Project Geologist
U.S. Army Engineer Waterways
Experiment Station
3909 Halls Ferry Road
Vicksburg, MS 39180-6199
Ph: 601-634-2685
FAX: 601-634-3153
E-mail: *harreld@ex1.wes.army.mil*

Dr. Mansour Zakikhani
Principal Project Groundwater Modeler
U.S. Army Engineer Waterways
Experiment Station
3909 Halls Ferry Road
Vicksburg, MS 39180-6199
Ph: 601-634-3806
FAX: 601-634-3129
E-mail: *zakikhm@ex1.wes.army.mil*

Dr. Joan U. Clarke
Project Statistician
U.S. Army Engineer Waterways
Experiment Station
3909 Halls Ferry Road
Vicksburg, MS 39180-6199
Ph: 601-634-2954
FAX: 601-634-3120
E-mail: *clarkej@ex1.wes.army.mil*

Dr. Douglas Gunnison
Principal Project Microbiologist
U.S. Army Engineer Waterways
Experiment Station
3909 Halls Ferry Road
Vicksburg, MS 39180-6199
Ph: 601-634-3873
FAX: 601-634-4017
E-mail: *gunnisd@ex1.wes.army.mil*

Dr. James M. Brannon
Principal Project Geochemist
U.S. Army Engineer Waterways
Experiment Station
3909 Halls Ferry Road
Vicksburg, MS 39180-6199
Ph: 601-634-3873
FAX: 601-634-4017
E-mail: *brannoj@ex1.wes.army.mil*

Dr. Thomas F. Jenkins
Principal Project Analytical Chemist
U.S. Army Cold Regions Research
and Engineering Laboratory
72 Lyme Road
Hanover, NH 03755-1290
Ph: 603-646-4385
FAX: 603-646-4785
Email:*jenkins@crrel41.crrel.usace.army.mil*

Drs. Mike Reynolds and Paul Miyares
Stable Isotopes
U.S. Army Cold Regions Research
and Engineering Laboratory
72 Lyme Road
Hanover, NH 03755-1290
Ph: 603-646-4394; 603-646-4394
FAX: 603-646-4785
Email:*jenkins@crrel41.crrel.usace.army.mil*

Ms. Laurie Haines
LAAP Site Geologist
U. S. Army Environmental Center
ATTN: SFIM-AEC-IR-G
BLDG E4435
Aberdeen Proving Ground, MD 21010-5401
Ph: 410-671-1512
FAX: 410-671-1548
E-mail: *lbhaines@aec.apgea.army.mil*

Mr. Cyril Onewokae
Validation Site Sponsor
Environmental Quality Directorate
Headquarter, Industrial Operations Command
BLDG 390
Rock Island, IL 61299-6000
Ph: 309-782-1350
FAX: 309-782-1457
E-mail: *conewoka@ria-emh2.army.mil*

Ms. Diana Mally
U.S. Environmental Protection Agency,
Region V
ATTN: SRF-5J
77 West Jackson Blvd.
Chicago, IL 60604-7275
Ph: 312-886-7275

Mr. Doyle Williams
Environmental Officer
Louisiana Army Ammunition Plant
Hwy 80
Minden, LA 71055
Ph: 318-459-5108
FAX: 318-459-5114

Mr. Art Holz
Environmental Coordinator
Joliet Army Ammunition Plant
29401 South, Route 53
Wilmington, IL 60481-8879
Ph: 815-423-2877
E-mail: *aholz@ria-emh2.army.mil*

Ms. Caroline Ziegler
1445 Ross Ave., Suite 1200
U.S. Environmental Protection Agency
Region VI
Dallas, TX 75202
Ph: 214-665-2178

Appendix B
Data Archiving and Demonstration Plan Availability

Requests concerning data from the Louisiana Army Ammunition Plant should be addressed to

Dr. Judith C. Pennington
CEWES-ES-P
U.S. Army Engineer Waterways Experiment Station
3909 Halls Ferry Road
Vicksburg, MS 39180-6199
Ph: 601-634-2802
penninj@ex1.wes.army.mil

Requests concerning the project demonstration plan and standard operational procedures for the field efforts should be addressed to

Mr. Danny Harrelson
CEWES-GG-YG
U.S. ARMY Engineer Waterways Experiment Station
3909 Halls Ferry Road
Vicksburg, MS 39180-6199
Ph: 601-634-2685
harrelsa@ex1.wes.army.mil

Request concerning groundwater modeling should be addressed to

Dr. Mansour Zakikhani
CEWES-ES-Q
U.S. ARMY Engineer Waterways Experiment Station
3909 Halls Ferry Road
Vicksburg, MS 39180-6199
Ph: 601-634-3806
zakikhm@ex1.wes.army.mil

The following technical reports concerning the project are available by e-mail request from any of the above contacts or from Ms. Betty Walker at *walker@ex1.wes.army.mil*:

Pennington, J. C., Harrelson, D. W., Zakikhani, M., Gunnison, D., Hayes, C. A., Clarke, J. U., Perkins, E., Ringelberg, D., McGrath, C. J., Fredrickson, H., and May, J. H. (1998). "Feasibility of using monitored natural attenuation as a remedial alternative for explosives-contaminated groundwater at Site L1, Joliet Army ammunition Plant, Joliet, Illinois," Technical Report EL-98-8, U.S. Army Engineer Waterways Experiment Station, Vicksburg, MS.

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Appendix C
Index of Standard Operating Procedures for the Natural Attenuation Study at Louisiana Army Ammunition Plant

001	Sample Labels
002	Chain of Custody Form
003	Field Logbook
004	Sample Packing and Shipping
005	Decontamination
006	Use of the IRDMS Network
007	Surface Water Sampling Procedures
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012	Specific Conductance Measurements
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015	Document Control System
016	Surface Water, Ground Water, and Soil/Sediment Field Logbooks
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018	Organic Vapor Analyzer (Foxboro 128 GC)
019	Photoionization Detector (Microtip HL-200)

020	Soil Sampling
021	Sample Container Cleaning
022	Aquifer (Hydraulic) Testing
023	Turbidity Measurements
024	Dissolved Oxygen Measurements
025	Redox Potential Measurements
026	Sample Preservation
027	Disposal of Investigation Derived Materials (IDM)
028	Hydrolab Multiparameter Water Quality Monitoring Instrument

STANDARD OPERATING PROCEDURE 001
SAMPLE LABELS

1.0 Scope and Application

The purpose of this standard operating procedure is to delineate protocols for the use of sample labels. Every sample will have a sample label uniquely identifying the sampling point and analysis parameters. An example label is included as Figure 001-1. Other formats with similar levels of detail are acceptable.

2.0 Material

a. Sample Label
b. Indelible lab marker

3.0 Procedure

The following steps describe how to use the sample labelling system:

3.1 As each sample is collected/selected, fill out a sample label. Enter the following information on each label:

a. Project Name

b. Project Number

c. Location/Site I.D. - enter the well # or surface water sampling #, and other pertinent information concerning where the sample was taken.

d. Date of Sample Collection

e. Time of Sample Collection

f. Analyses to be Performed (Note: due to number of analytes, details of analysis should be arranged with lab *a priori.)*

g. Whether Filtered or Unfiltered (water samples only)

h. Preservatives (water samples only)

i. The Number of Containers for the Sample (*e.g.* 1 of 2, 2 of 2)

3.2 Double-check the label information to make sure it is correct. Detach the label, remove the backing and apply the label to the sample container. Cover the label with clear tape, ensuring that the tape completely encircles the container.

3.3 Record the Sample Number and designated sampling point in the field logbook, along with the following sample information:

a. Time of sample collection (each logbook page should be dated)

b. The location of the sample

c. Organic vapor meter or photoionization meter readings for the sample (when appropriate)

d. Any unusual or pertinent observations (oily sheen on groundwater sample, incidental odors, soil color, grain size, plasticity, etc.)

e. Number of containers required for each sample

f. Whether the sample is a QA sample (split, duplicate or blank)

3.3.1 A typical logbook entry might look like this:

> 7:35 AM Sample No. MW-3. PID = 35 PPM
> Petroleum odor present. Sample designated MW-3-001.

Note: Duplicate samples will be given a non-existent well number rather than simply using the actual well number with an added prefix or suffix. This will prevent any indication to the lab that this is a duplicate sample. This fictitious well number will be listed in the logbook along with the actual location of the sample.

3.4 Place the sample upright in the designated sample cooler. Make sure there is plenty of ice in the cooler at all times.

4.0 Maintenance

Not Applicable.

5.0 Precautions

5.1 Note that although incidental odors should be noted in the logbook, it is unwise from a health and safety standpoint to routinely "sniff test" samples for contaminants.

5.2 No indication of which samples are duplicates is to be provided to the lab.

6.0 References

U.S. EPA. 1980, Interim Guidelines and Specifications for Preparing Quality Assurance Project Plans, QAMS-005/80

FIGURE 001-1
SAMPLE LABEL

PROJECT NAME ____________ PROJECT NUM. __________

SAMPLE LOCATION/SITE ID _________________________

DATE: ___/___/___ TIME: ____:____

ANALYTES: METALS VOC EXPLOSIVES ORGANICS OTHER

FILTERED: [NO] [YES]

PRESERVATIVE: [NONE] [HNO_3] [OTHER _____]

SAMPLER: ___________________

STANDARD OPERATING PROCEDURE 002
CHAIN-OF-CUSTODY FORM

1.0 Scope and Application

The purpose of this standard operating procedure is to delineate protocols for use of the Chain-of-Custody (COC) Form. An example is provided as part of this SOP. Other formats with similar levels of detail are acceptable.

2.0 Material

a. Chain-of-Custody Form
b. Indelible ink pen

3.0 Procedure

3.1 Give the site name and project name/number.

3.2 Enter the sample identification code.

3.3 Indicate the sampling dates for all samples.

3.4 List the sampling times (military format) for all samples.

3.5 Indicate "grab" or "composite" sample with an "X."

3.6 Specify the sample location.

3.7 Enter the total number of containers per cooler.

3.8 List the analyses/container volume.

3.9 Obtain the signature of sample team leader.

3.10 State the carrier service and airbill number, analytical laboratory, and custody seal numbers.

3.11 Sign, date, and time the "relinquished by" section.

3.12 Upon completion of the form, retain the shipper copy, and affix the other copies to the inside of the sample cooler, in a zip seal bag to protect from moisture, to be sent to the designated laboratory.

4.0 Maintenance

Not Applicable.

5.0 Precautions

None.

6.0 References

U.S. EPA. 1990. Sampler's Guide to the Contract Laboratory Program. EPA/540/P-90/006, Directive 9240.0-06, Office of Emergency and Remedial Response, Washington, D.C., December 1990.

U.S. EPA. 1991. User's Guide to the Contract Laboratory Program. EPA/540/O-91/002, Directive 9240.0-01D, Office of Emergency and Remedial Response, January 1991.

U.S. EPA. 1980, Interim Guidelines and Specifications for Preparing Quality Assurance Project Plans, QAMS-005/80

Proj. no.	Site Name				Num. of Containers										LAB :
															AIRBILL No:
Samplers:															Courier:
Date	Time	Comp	Grab	Field Sample No.											REMARKS
				TOTAL											

Relinquished by:	Date/ time	Received by:	Relinquished by:	Date/ Time	Received by:
Relinquished by:	Date/ time	Received by: (for lab)	Date/Time	Remarks	

FIGURE 002-1
EXAMPLE CHAIN-OF-CUSTODY FORM

STANDARD OPERATING PROCEDURE 003
FIELD LOGBOOK

1.0 Scope and Application

The purpose of this standard operating procedure is to delineate protocols for recording field survey and sampling information in the Field Logbook.

2.0 Material

a. Field Logbook (Teledyne 415 Level Book, or equivalent)[1]
b. Indelible ink pen

3.0 Procedure

All information pertinent to a field survey or sampling effort will be recorded in a bound logbook. Each page/form will be consecutively numbered, dated, and signed. All entries will be made in indelible ink and all corrections will consist of line-out deletions that are initialed and dated. The person making the correction will provide a brief explanation for the change. There should be no blank lines on a page. A single blank line or a partial blank line (such as at the end of a paragraph) should be lined to the end of the page. If only part of a page is used, the remainder of the page should have an "X" drawn across it. At a minimum, entries in the logbook will include but not be limited to the following:

a. Project number.

b. Unique, sequential field sample number.

c. Purpose of sampling.

d. Location, description, and log of photographs of each sampling point.

e. Details of the sample site (for example, the elevation of the casing, casing diameter and depth, integrity of the casing, etc.)

f. Name and address of field contact.

g. Documentation of procedures for preparation of reagents or supplies which become an integral part of the sample (e.g., filters and absorbing reagents).

---

[1] Pre-printed, bound forms are approved as well. See SOP 016 for recommended content and format.

h. Identification of sample crew members.

i. Type of sample (for example, groundwater or surface water).

j. Suspected waste composition.

k. Number and volume of sample taken.

l. Sampling methodology, including distinction between grab and composite sample.

m. Sample preservation.

n. Date and time of collection.

o. Collector's sample identification number(s).

p. Sample shipment (for example, name of the laboratory and cartage agent: Federal Express, United Parcel Service, etc.)

q. References such as maps of the sampling site.

r. Field observations (*e.g.* oily sheen on groundwater sample, incidental odors, soil color, grain size, plasticity, moisture content, layering, U.S.C.S. classification, etc.)

s. Any field measurements made (for example, pH, conductivity, explosivity, water depth, OVA readings, etc.)

t. Signature and date by the personnel responsible for observations.

u. Decontamination procedures.

Sampling situations vary widely. No general rules can specify the extent of information that must be entered in a logbook. However, records should contain sufficient information so that someone can reconstruct the sampling activity without relying on the collector's memory. The Project Manager will keep a master list of all field logbooks assigned to the Sampling Team Leaders. One logbook kept by the Project Manager will be a master site log of daily activities and will contain the list of field logbooks assigned to Sampling Team Leaders.

4.0 Maintenance

Not Applicable.

5.0 Precautions

None.

6.0 References

U.S. EPA. 1990. Sampler's Guide to the Contract Laboratory Program. EPA/540/P-90/006, Directive 9240.0-06, Office of Emergency and Remedial Response, Washington, D.C., December 1990.

U.S. EPA. 1991. User's Guide to the Contract Laboratory Program. EPA/540/O-91/002, Directive 9240.0-01D, Office of Emergency and Remedial Response, January 1991.

U.S. EPA. 1980, Interim Guidelines and Specifications for Preparing Quality Assurance Project Plans, QAMS-005/80

STANDARD OPERATING PROCEDURE 004
SAMPLE PACKING AND SHIPPING

1.0 Scope and Application

The purpose of this Standard Operating Procedure (SOP) is to delineate protocols for the packing and shipping of samples to the laboratory for analysis.

2.0 Material

a. Waterproof coolers (hard plastic or metal)
b. Metal cans with friction-seal lids (*e.g.* paint cans)
c. Custody seals
d. Packing material [1]
e. Sample Documentation
f. Ice
g. Plastic Garbage Bags
h. Clear Tape
i. Zip seal plastic bags

3.0 Procedure

3.1 Check cap tightness and verify that clear tape covers label and encircles container.

3.2 Wrap sample container in bubble wrap or closed cell foam sheets.

3.3 Enclose each sample in a clear zip-seal plastic bag.

3.4 Place several layers of bubble wrap, or at least 1" of vermiculite on the bottom of the cooler. Line cooler with open garbage bag, place all the samples upright inside a garbage bag and tie the bag.

3.5 Double bag and seal loose ice to prevent melting ice from soaking the packing material. Place the ice outside the garbage bags containing the samples.

3.6 Pack shipping containers with packing material (closed-cell foam, vermiculite, or bubble wrap). Place this packing material around the sample bottles or metal cans to avoid breakage during shipment.

---

[1] Permissible packing materials are: a) (non-absorbent) bubble wrap or closed cell foam packing sheets; b) (absorbent) vermiculite. Organic materials such as paper, wood shavings (excelsior), and cornstarch packing "peanuts" will not be used.

3.7 Enclose all sample documentation (i.e., Field Parameter Forms, COCs) in a waterproof plastic bag and tape the bag to the underside of the cooler lid. If more than one cooler is being used, each cooler will have its own documentation.

3.8 Seal the coolers with signed and dated custody seals so that if the cooler were opened, the custody seal would be broken. Place clear tape over the custody seal to prevent damage to the seal.

3.8.1 Refer to SOPs 001, 002, 003, 016 and 39.

3.9 Tape the cooler shut with packing tape over the hinges and place tape over the cooler drain.

3.10 Ship all samples via overnight delivery on the same day they are collected if possible.

4.0 Maintenance

Not Applicable.

5.0 Precautions

5.1 Any samples suspected to be of medium/high contaminant concentration or containing dioxin must be enclosed in a metal can with a clipped or sealable lid (e.g., paint cans). Label the outer metal container with the sample number of the sample inside.

5.2 If the sample is suspected of being contaminated with chemical agent, DO NOT use this SOP for packing and shipping methods USE ONLY the packing and shipping methods prescribed in SOP035.

6.0 References

U.S. EPA. 1990. Sampler's Guide to the Contract Laboratory Program. EPA/540/P-90/006, Directive 9240.0-06, Office of Emergency and Remedial Response, Washington, D.C., December 1990.

U.S. EPA. 1991. User's Guide to the Contract Laboratory Program. EPA/540/O-91/002, Directive 9240.0-01D, Office of Emergency and Remedial Response, January 1991.

U.S. EPA. 1980, Interim Guidelines and Specifications for Preparing Quality Assurance Project Plans, QAMS-005/80

STANDARD OPERATING PROCEDURE 005
DECONTAMINATION

1.0 Scope and Application

All personnel or equipment involved in intrusive sampling, or which enter a hazardous waste site during intrusive sampling must be thoroughly decontaminated prior to leaving the site to minimize the spread of contamination and prevent adverse health effects. This procedure describes the normal decontamination of sampling equipment and site personnel.

2.0 Material

a. Plastic sheeting, buckets, etc. to collect wash water and rinsates.
b. Approved water.
c. HPLC-grade water.[1]
d. 0.10N Nitric Acid.
e. Non-phosphate laboratory detergent.
f. Reagent grade alcohol [2]
g. Aluminum foil or clean plastic sheeting.
h. Pressure sprayer, rinse bottles, brushes.
i. Plastic garbage bags.
j. 0.01N HCl

3.0 Procedure

3.1 Sample Bottles

At the completion of each sampling activity the exterior surfaces of the sample bottles must be decontaminated as follows:

3.1.1 Be sure that the bottle lids are on tight.

3.1.2 Wipe the outside of the bottle with a paper towel to remove gross contamination.

---

[1] For the purposes of this SOP, HPLC-grade water is considered equivalent to "Deionized ultra filtered water", "Reagent-grade distilled water", and "Deionized organic-free water". The end product being water which is pure with no spurious ions or organics to contaminate the sample. The method of generation is left to the individual contractor.

[2] For the purposes of this SOP, the term "reagent grade alcohol" refers to either pesticide grade isopropanol or reagent grade methanol.

3.2 Personnel Decontamination

Review the project Health and Safety Plan for the appropriate decontamination procedures.

3.3 Equipment Decontamination

3.3.1 Water Samplers

3.3.1.1 Bailers.

After each use, Polytetrafluoroethelyne (PTFE) double check valve bailers used for groundwater sampling will be decontaminated as follows:

a. Discard all ropes used in sampling in properly marked sealable container, or as directed by the health and safety plan. Note: no tubing is to be used in conjunction with a bailer in collecting samples.

b. Scrub the bailer to remove gross(visible) contamination, using appropriate brush(es), approved water, and non-phosphate detergent.

c. Rinse off detergent with approved water.

d. Rinse bailer with reagent grade alcohol.

e. Rinse bailer with HPLC-grade water.

f. Rinse bailer with 0.10N Nitric Acid solution.

g. Rinse bailer with HPLC-grade water.

h. Allow bailer to air dry.[3]

i. Wrap bailer in aluminum foil or clean plastic sheeting, or store in a clean, dedicated PVC or PTFE storage container.

j. Dispose of used decon solutions with drummed purge water.

k. Rinse bailer with HPLC-grade water immediately prior to re-use.

---

[3] If the bailer has just been used for purging and is being decontaminated prior to sampling do not air dry. Double rinse with HPLC-grade water and proceed to collect samples.

3.3.1.2 Pumps

Submersible pumps will be decontaminated as follows:

a. Scrub the exterior of the pump to remove gross (visible) contamination, using appropriate brush(es) , approved water, and non-phosphate detergent. (Steam cleaning may be substituted for detergent scrub).

b. Calculate the volume of pump plus any tubing which is not disposable and not dedicated to a single well. Pump 3 volumes of non-phosphate laboratory detergent solution to purge and clean the interior of the pump.

c. Rinse by pumping no less than 9 volumes of approved water to rinse.

d. Rinse pump exterior with reagent grade alcohol.

e. Rinse pump exterior with HPLC-grade water.

f. Allow pump to air dry.

g. Wrap pump in aluminum foil or clean plastic sheeting, or store in a clean, dedicated PVC or PTFE storage container.

h. Prior to reusing pump rinse exterior again with HPLC-grade water. (Double rinse in step "e" above may be substituted for this step).

3.3.1.3 Dip samplers

All dip samplers, whether bucket, long-handled, or short-handled (see SOP-007 "Surface Water Sampling") will be decontaminated in the same manner as given in section 3.3.1.1 "bailers" above.

3.3.1.4 Labware

Labware such as beakers which are used to hold samples for field measurements, water chemistry, etc. will be decontaminated according to the procedures in 3.3.1.1 "bailers" above.

3.3.1.5 Water level indicators

Electric water level indicators, weighted measuring tapes, or piezometers used in the determination of water levels, well depths, and/or NAPL levels will be decontaminated in accordance with section 3.3.1.1 "bailers" above. Clean laboratory wipes may be substituted for brushes. Tapes, probes, and piezometers should be wiped dry with clean laboratory wipes, and coiled on spools or clean plastic sheeting rather than allowed to air dry.

3.3.2 Solid materials samplers

Solid materials samplers include soil sampling probes, augers, trowels, shovels, sludge samplers, and sediment samplers. All will be decontaminated as follows:

a. Scrub the sampler to remove gross(visible) contamination, using appropriate brush(es), approved water, and non-phosphate laboratory detergent.

b. Rinse off detergent with approved water.

c. Rinse sampler with reagent grade alcohol.

d. Rinse sampler with HPLC-grade water.

e. (Non-metallic samplers only) Rinse sampler with 0.10N Nitric Acid solution.

f. (Non-metallic samplers only) Rinse sampler with HPLC-grade water.

g. Allow sampler to air dry.

h. Wrap sampler in aluminum foil clean plastic sheeting, or store in a new zip-seal bag (size permitting) or clean, dedicated PVC or PTFE storage container.

i. Dispose used decon solutions properly according to the site health and safety plan.

j. Rinse sampler with HPLC-grade water immediately prior to re-use.

3.3.3 Other sampling and measurement probes

3.3.3.1 Soil gas sampling probes will be decontaminated as solids sampling devices.

3.3.3.2 Temperature, pH, conductivity, Redox, and dissolved oxygen probes will be decontaminated according to manufacturer's specifications. If no such soecifications exist, remove gross contaminant and triple rinse probe with HPLC-grade water. A summary of the decontamination procedures to be used must be included in the instrument-specific SOP.

3.3.3.3 Measuring tapes which become contaminated through contact with soil during field use will be decontaminated as follows:

a. Wipe tape with a clean cloth or laboratory wipe which has been soaked with non-phosphate laboratory detergent solution to remove gross contamination. Rinse cloth in the solution and continue wiping until tape is clean.

b. Wipe tape with a second clean, wet cloth (or lab wipe) to remove soap residues.

c. Dry tape with a third cloth (or lab wipe) and rewind into case, or re-coil tape.

3.3.4 Drilling Rigs

All drilling rigs and associated equipment such as augers, drill casing, rods, samplers, tools, recirculation tank, and water tank (inside and out) will be decontaminated prior to site entry after over-the-road mobilization and immediately upon departure from a site after drilling a hole. Supplementary cleaning will be performed prior to site entry there is a likelihood that contamination has accumulated on tires and as spatter or dust enroute from one site to the next (see also Field Investigation Plan, § 6.3.7).

a. Place contaminated equipment in an enclosure designed to contain all decontamination residues (water, sludge, etc.).

b. Steam clean equipment until all dirt, mud, grease, asphaltic, bituminous, or other encrusting coating materials (with the exception of manufacturer-applied paint) have been removed.

c. Water used will be taken from an approved source.

d. Containerize, sample, characterize, and dispose of all decontamination residues properly.

3.3.5 HPLC-grade water Storage

Dedicated glass storage containers will be used solely for dispensing HPLC-grade water. New HPLC-grade water containers will be decontaminated as follows:

a. Clean with hot tapwater from approved source and non-phosphate laboratory detergent while scrubbing the exterior and interior of the container with a stiff-bristled brush.

b. Rinse thoroughly with approved water.

c. Rinse with 0.01N Nitric acid.

d. Rinse with approved water.

e. Rinse thoroughly with HPLC-grade water.

f. Fill clean container with HPLC-grade water. Cap with one layer of PTFE-lined paper and one layer of aluminum foil. Secure cap with rubber band and date the container.

Used HPLC-grade water containers will be decontaminated as follows:

a. Clean the exterior with hot tapwater from an approved source, non-phosphate laboratory detergent, and a stiff-bristled brush.

b. Rinse the exterior thoroughly with HPLC-grade water

c. Rinse the interior twice with pesticide-grade isopropanol.

d. Rinse interior thoroughly with HPLC-grade water.

e. Fill clean container with HPLC-grade water. Cap with one layer of PTFE-lined paper and one layer of aluminum foil. Secure cap with rubber band and date the container.

4.0 Maintenance

4.1 HPLC-grade water will be stored only in decontaminated glass containers with aluminum foil lids as stipulated above. The water may not be stored for more than, nor used more than three days after manufacture.

4.2 HPLC-grade water will be manufactured on-site. An approved tap water source will be used as the influent to the system. Procedures for system set-up, operation and maintenance will conform to manufacturer's specifications.

5.0 Precautions

5.1 Dispose of all wash water, rinse water, rinsates, and other sampling wastes (tubing, plastic sheeting, etc.) in properly marked, sealable containers, or as directed by the health and safety plan.

5.2 Once a piece of equipment has been decontaminated, be careful to keep it in such condition until needed.

5.3 Do not eat, smoke or drink on site.

6.0 References

Site-specific health and safety plan.

STANDARD OPERATING PROCEDURES 006
USE OF THE IRDMS NETWORK

1.0 LOGIN/LOGOUT OF THE IRDMS (PRI) NETWORK

1.1 Files may be transferred to, or copied from, the PRI LAN through remote terminals. The connection requires a Hayes-compatible modem operating at 1200 baud, and 3COM network software. The contractor will purchase the 3COM 3+ Remote package, and PRI will supply a "Remote Login Disk" which contains DOS startup files (AUTOEXEC.BAT, COMMAND.COM, IBMBIO.COM, IBMDOS.COM, etc.) and 3COM network programs for startup, remote dialing, etc.

1.2 To connect to the PRI LAN, the PC must be rebooted from the Remote Login Disk #1. After the standard DOS startup routines are completed, you will get the A> prompt. Change to the drive containing the IRDMS files (C or D).

```
Type      D: <CR>
Get       D>
```

Next, you will start the 3COM linking program.

Type: 3COM XXX (include the space) (where XXX is the contractor i.d.) <CR> Get (after pauses - you will hear the phone ring and data transmission):

```
Login 1.1 - Copyright (etc.) 3COM
XXX:PRI:IRDMS logged in
D> 3f link e:
E: Linked to \\XXX:PRI:IRDMS
D>
```

(NOTE: The Remote Login Disk may now be removed from the A: drive)

You are now linked to the E: drive on the PRI LAN, which can be treated as any other drive. For example, you can switch to the E: drive by typing E: <CR>. After a pause (sometimes several seconds), you should get the E> prompt.

Under E: is a subdirectory \TRANSFER where all files are sent (*.TRN) to be transferred. To copy a file SEMAP.TRN from drive D and directory DATA to the network,

```
Type      E: <CR>
Get       E>
Type      CD\TRANSFER <CR>
Get       E>  (The subdirectories do not show on the prompt)
Type      copy D:\DATA\SEMAP.TRN <CR>
```

(NOTE: any valid DOS COPY format can be used)

After a while, you may get a message saying that the network is still trying, and allows you to do an abort. Eventually, you should get a file(s) copied message:

Get	1 file(s) copied

To verify that the file was transmitted, you can print the directory listings.
If you are not on the E> (actually E\TRANSFER) prompt, type E: <CR>, then

CD\TRANSFER <CR>, then

Type	DIR <CR>
Get	(a listing of the \TRANSFER directory contents. SEMAP.TRN should be in the listing.)

To log out after all files have been transmitted:

Type	D; <CR>
Get	D>
Type	LOGOUT <CR>
Get	a "logged out" message

You can now (a) do other things with the IRDMS programs, or (b) reboot the machine with the Remote Login Disk removed, to return the PC to local control.

AFTER EVERY TRANSFER OF DATA TO THE PRI LAN, call PRI at (410) 679-3030 (ask for the contact for the specific installation) and give them the installation and file type (e.g., SL map file data) and the DOS name of the file that was transmitted. The contractor should receive by Fax a confirmation that the data was received; if not, call PRI and ask for it.

STANDARD OPERATING PROCEDURE 007
SURFACE WATER SAMPLING

1.0 Scope and Application

The purpose of this standard operating procedure is to delineate protocols for sampling surface water. This procedure can be applied to the collection of surface water samples from streams, rivers, ditches, lakes, ponds and lagoons. Surface water samples provide an indication of the amount of contaminant in the surface water. It is therefore important to collect a representative sample.

2.0 Material

a. Sample bottles
b. Stainless steel or PTFE-lined bucket
c. Long-handled dip sampler (PTFE or stainless steel)
d. Short-handled dip sampler (PTFE or stainless steel)
e. Peristaltic pump with 0.45μM filters and disposable tygon tubing
f. 0.45µ disposable filters
g. Cooler with ice

3.0 Procedure

3.1 For all surface water samples, mark the sampling locations on a site map. Photograph and describe each location, and place a numbered stake above the visible high water mark on the bank closest to the sampling location, and/or mark adjacent trees with surveyor's flagging. The photographs and descriptions must be adequate to allow the sampling station to be relocated at some future date by someone other than the original sampling crew. Use the long handled dip sampler where access is poor or non-contact with water is suggested in the health and safety plan.

3.2 Sampling should performed deliberately and methodically to minimize disturbance of bottom sediments, yet as quickly as possible to ensure a representative sample. To prevent contamination of the exterior of the sample container, and/or potential contamination of the surface water sample by laboratory contaminants on the exterior of the bottle, the sample container should never be dipped into the water, rather a decontaminated, long-handled or measuring cup-type PTFE or stainless steel sampler, or a sampling bucket should be used to collect unfiltered samples.

3.3 **Sampling with the PTFE or stainless steel sampler** (long-handled or measuring cup-type):

3.3.1 Remove the cap from the sample bottle.

3.3.2 Dip a sample of surface water using the sampler.

3.3.3 Tilt sample bottle and gently pour sample from sampler into the bottle. Allow the sample to trickle down the side of the bottle. Avoid aerating the sample.

3.3.4 Add preservative as required by SOP039. Replace cap, and place in cooler immediately.

3.4 Sampling with stainless steel or PTFE-lined bucket:

3.4.1 Remove cap from sample bottle.

3.4.2 Gently dip collection bucket in the water. Fill bucket and carefully lift from water body.

3.4.3 Tilt sample bottle and gently pour sample from sampler into the bottle. Allow the sample to trickle down the side of the bottle. Avoid aerating the sample.

3.4.4 Add preservative as required by SOP039. Replace cap, and place in cooler immediately.

– OR –

3.4.5 Use smaller sampling cup to transfer sample from bucket to sample bottle as in section 3.3 above.

3.5 Both filtered and unfiltered samples will be taken for metals analyses. Bulk samples for filtration will be collected using the stainless steel or PTFE-lined bucket method described in section 3.4 above. Sample filtration must be performed immediately upon retrieval of the bulk sample as follows:

3.6 Filtration will be performed immediately after collecting sample. Set up filtration equipment prior to collecting sample. Filtration may be accomplished by gravity (see 3.7), or if necessary, due to slow filtering, a peristaltic pump will be used to pressure filter the sample (see 3.8). Vacuum filtration will not be used due to the possibility of analyte volatilization.

3.7 Gravity filtration will be accomplished as follows:

3.7.1 Using decontaminated forceps, place a $0.45\mu M$ membrane in a decontaminated filter funnel.

3.7.2 Slowly pour sample into the funnel and collect filtrate directly into appropriate sample container(s).

3.7.3 Add preservative(s) as required by SOP039. Immediately cap container and place in cooler.

3.7.3 Dispose of filter membrane.

3.8 Pressure filtration will be accomplished as follows:

- **3.8.1** Using previously assembled disposable tubing, 45µ in-line filter, and peristaltic pump, filter sample from collection bucket into appropriate container.
- **3.8.2** Adjust pump rate to avoid aeration of sample.
- **3.8.3** Fill container, preserve as indicated in SOP0039, immediately cap container and place in cooler.
- **3.8.4** Dispose of filter and tubing.

3.9 Refer to SOP 1-5, 16, and 39.

4.0 Maintenance

Refer to manufacturer's specifications for maintenance procedures on generators and pumps.

5.0 Precautions

5.1 Avoid disturbing bottom sediments.

5.2 Consult the health and safety plan (HASP) prior to collecting any samples for PPE such as dermal and respiratory protection and personal flotation devices when sampling in or near deep water or from boats.

5.3 Always decontaminate the sampling and filtration equipment, and change gloves between sampling locations to minimize the risk of cross contamination.

5.4 Always set up generators downwind of working area. Never service generators onsite.

6.0 References

None.

STANDARD OPERATING PROCEDURE 008
pH MEASUREMENT USING BECKMAN Φ™ 12 pH/ISE METER

1.0 Scope and Application

The purpose of this standard operating procedure is to delineate protocols for measuring the pH of all types of aqueous solutions, including drinking water, saline water, industrial and domestic wastes. pH is a measure of the hydrogen ion content of a solution, and thus gives a general indication of the acidity or alkalinity of a water sample.

Use of brand names in this SOP is in nowise intended as endorsement or mandate that a given brand be used. Alternate equivalent brands of detectors, sensors, meters, etc. are acceptable. If alternate equipment is to be used, the contractor shall provide applicable and comparable SOPs for the maintenance and calibration of same.

2.0 Material

a. Φ 12 pH Meter
b. Combination (pH) electrode
c. Automatic temperature compensator (ATC) probe
d. Commercial Buffer solutions (standards) of pH 4.00, 7.00, and 10.00
e. HPLC-grade water
f. Beakers
g. Wash bottle
h. Laboratory wipes for blotting electrodes

3.0 Procedure

3.1 **Calibration check**. Calibration of the pH meter will be checked on a daily basis. A two point calibration should be used as follows:

3.1.1 Prepare beakers of buffer solutions of pH 4.00, 7.00, and 10.00.

3.1.2 Calibration should closely bracket the expected pH range of the samples to be taken.

3.1.3 Turn on instrument, clear instrument

3.1.4 Rinse the electrode with distilled water and blot excess.

3.1.5 Immerse probes in beaker of pH 4.00 or 7.00 standard, swirl gently.

3.1.6 Press pH key, then STD key.

3.1.7 Keep the probes in the sample until the reading stabilizes. The reading should be the pH of the standard.

3.1.8 Rinse the electrode with distilled water and blot excess.

3.1.9 Repeat the procedure with pH 7.00 and 10.00 standards

3.1.10 Record the initial readings.

3.1.11 If the measured values vary from the expected value by greater than 0.2 pH units, recalibrate the instrument with fresh aliquots of buffer solution. If the discrepancy persists, alert the Field Operations Leader, who has the option of trying to fix the meter or obtaining a second pH meter.

3.1.12 Record all measurements in the field logbook.

3.1.13 Verify calibration by reading the pH of the third buffer solution.

3.1.14 Refer to SOP 003 and 016.

3.2 **pH measurements** will be taken using the two-point standardization method as follows:

3.2.1 Connect the ATC and pH electrodes to the appropriate inputs.

3.2.2 Turn on instrument, clear instrument.

3.2.3 Prepare two small beakers of standard buffer solutions. Ideally the pH values of these standards will "bracket" the expected pH value of the sample and be as close as possible to the pH of the sample.

3.2.4 Rinse a small beaker with distilled water, then sample water. Fill the beaker with sample water.

3.2.5 Rinse the probes with distilled water. Blot excess.

3.2.6 Immerse electrode and ATC in first standard. Swirl gently. Press pH key and STD key. Wait for display to stop flashing.

3.2.7 Rinse the probes with distilled water. Blot excess.

3.2.8 Immerse electrode and ATC in second standard. Swirl gently. Press STD key. Wait for display to stop flashing.

3.2.9 Rinse the probes with distilled water. Blot excess.

3.2.10 Immerse the probes in the sample and swirl gently, keeping the probes in the sample until the display stops flashing.

3.2.11 Record the sample pH and temperature after stabilization. Note any problems such as meter drift.

3.2.12 Rinse the probes with distilled water. Blot excess.

3.2.13 Repeat steps 3.2.9 through 3.2.12 for additional samples.

3.3 **Decontaminate probe** according to manufacturer's specifications.

3.4 **Decontaminate beakers** according to SOP005, section 3.3.1.4 "labware".

4.0 Maintenance

The following steps will be taken to maintain the pH meter.

4.1 Check the batteries each time the meter is used.

4.2 Keep the probe stored in a 0.1 M KCl solution adjusted to pH 4 when the meter is not in use. Alternatively, the electrode may be rinsed with deionized water and the protective cap put on, trapping any residual water inside it (do not blot the electrode dry prior to putting the cap on).

5.0 Precautions

5.1 Remove coatings of oil material or particulate matter that can impair electrode response by gentle wiping or detergent washing, followed by distilled water rinsing.

5.2 As noted in Section 1 (above), these procedures may not apply to alternate manufacturers' equipment.

5.3 Calibration is always performed using the pH 7.00 and one end point (pH4.00 or 11.00) standard <u>never</u> calibrate the instrument using two end points only.

6.0 References

Beckman Instruments, Inc., Users Manual for Φ™ 10 pH Meter, Φ™ 11 pH meter, and Φ™ 12 pH/ISE Meter

US EPA. 1983. <u>Methods for Chemical Analysis of Water and Wastes</u>, March, 1983.

Franston, Mary Ann H., et al. (eds), Standard Methods for the Examination of Water and Wastewater, 15th Edition, American Public Health Assn., American Water Works Assn., and Water Pollution Control Federation, 1981

STANDARD OPERATING PROCEDURE 009
TEMPERATURE MEASUREMENTS

1.0 Scope and Application

The purpose of this standard operating procedure is to delineate protocols for measuring the temperature of a solid or liquid sample, in particular, for measuring water temperature. Groundwater temperature does not vary dramatically over the course of a year. Therefore, groundwater temperature can be used to help identify an aquifer, identify stream reaches where groundwater inflow is occurring, identify thermal gradients in lakes or ponds, and also indicate when sufficient water has been removed from a well during purging.

2.0 Material

Digital reading, thermocouple thermometer in combination meter or in a stick. Accuracy= +/- 0.5°C

3.0 Procedure

3.1 Rinse the probe with distilled water.

3.2 Insert the probe into the sample, and leave it in the sample until the temperature stabilizes.

3.3 Record the temperature reading, being sure to indicate °C or °F.

3.4 Decontaminate the probe according to SOP005 "Decontamination" section 3.3.1.4 "Labware."

3.5 Refer to SOP 003, 005, and 016.

NOTE: $°C = (°F - 32)(5/9)$
$°F = ((9/5)C°) + 32$

4.0 Maintenance

Not Applicable.

5.0 Precautions

None

6.0 References

Methods for Chemical Analysis of Water and Wastes, U.S. EPA, March, 1983.

STANDARD OPERATING PROCEDURE 010
WATER LEVEL AND WELL-DEPTH MEASUREMENTS

1.0 Scope and Application

The purpose of this standard operating procedure is to delineate protocols for measuring water level and well-depth. This procedure is applicable to the sampling of monitoring wells and must be performed prior to any activities which may disturb the water level, such as purging or aquifer testing.

2.0 Material

a. Electric Water Level Indicator (dipmeter) with cable measured at 0.01 foot increments.

-or-

Weighted Steel Tape and chalk.

-or-

Transducer and datalogger.

b. Oil-water interface probe
c. Plastic Sheeting
d. Photoionization detector (PID) or intrinsically safe flame ionization detector (FID)

3.0 Procedure

3.1 Preliminary Steps

3.1.1 Locate the well and verify its position on the site map. Record whether positive identification was obtained, including the well number and any identifying marks or codes contained on the well casing or protective casing. Gain access to the top of the well casing.

3.1.2 Locate the permanent reference mark at the top of the casing. This reference point will be scribed, notched or otherwise noted on the top of the casing. If no such marks are present, measure to the top of the highest point of the well casing and so note this fact in field logbook. Determine from the records and record in the notebook the elevation of this point.

3.1.3 Record any observations and remarks regarding the completion characteristics and well condition, such as evidence of cracked casing or surface seals, security of the well (locked cap), and evidence of tampering.

3.1.4 Keep all equipment and supplies protected from gross contamination; use clean plastic sheeting. Keep the water level indicator probe in its protective case when not in use.

3.2 Operation

3.2.1 Sample the air in the well head for gross organic vapors by lifting the well cap only high enough for an organic vapor meter (PID or FID) probe to be entered into the well casing. This will indicate the presence of gross volatile contaminants as well as indicating potential sampler exposure.

Remove cap. Allow well to vent for 60 to 90 seconds. Resample headspace. Record both readings. If the second reading is lower than the first, use the second reading to determining whether respiratory protection will be required during subsequent water level and well depth determinations, and sampling.

Note that all headspace sampling must be performed at arm's length and from the upwind side of the well if possible.

3.2.1.1 Refer to SOP 011, 023, or 024 as appropriate.

3.2.2 If non-aqueous phase liquid (NAPL) contamination is suspected [1], use an interface probe to determine the existence and thickness of NAPLs.

3.2.2.1 Open the probe housing, turn the probe on, and test the alarm. Slowly lower the probe into the well until the alarm sounds. A continuous alarm indicates a NAPL while an intermittent alarm indicates water. If a NAPL is detected, record the initial level (first alarm). Mark the spot by grasping the cable with the thumb and forefingers at the top of the casing. If a mark is present on the casing, use the mark as the reference point. If no mark is present, use the highest point on the casing as the reference point. Withdraw the cable sufficiently to record the depth.

3.2.2.2 Continue to slowly lower the probe until it passes into the water phase. Slowly retract the probe until the NAPL alarm sounds and record that level in the manner as described above.

3.2.2.3 Record the thickness of the LNAPL (see section 3.3.1).

3.2.2.4 Continue to slowly lower the interface probe through the water column to check for the presence of DNAPL.

3.2.2.5 Measure and record the thickness of the DNAPL layer (if any) as described above.

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[1] Interface probes will be used in all wells for first round sampling, regardless of site history. If no NAPLs are detected during the first round of sampling, this step may be omitted during subsequent sampling events **unless** conditions such as site history or headspace vapors would indicate otherwise.

3.2.2.6 Slowly raise the interface probe, recording the depth to each interface as the probe is withdrawn. If there is a discrepancy in depths, clean the probe sensors and re-check the depths.

3.2.2.7 NOTE: Air/liquid interface depth is more reliable if probe is lowered into liquid. NAPL/water drepths are more accurate if probe is moved from water into NAPL.

3.2.2.8 Always lower and raise interface probe slowly to prevent undue mixing of media.

3.2.2.9 Always perform NAPL check in wells installed in areas with suspected NAPL contamination. Always perform NAPL check if headspace test reveals presence of volatiles. Always perform NAPL check the first time a well is sampled. **If** a well has been sampled previously **and** no NAPLs were present **and** none of the preceeding conditions are met, the NAPL check may be omitted.

3.2.3 If no NAPL is present use an electronic water level detector as follows.

3.2.3.1 Remove the water level indicator probe from the case, turn on the sounder, and test check the battery and sensitivity scale by pushing the red button. Adjust the sensitivity scale until you can hear the buzzer.

3.2.3.2 Slowly lower the probe and cable into the well, allowing the cable reel to unwind. Continue lowering until the meter buzzes. Very slowly, raise and lower the probe until the point is reached where the meter <u>just</u> buzzes. Marking the spot by grasping the cable with the thumb and forefingers at the top of the casing. If a mark is present on the casing, use the mark as the reference point. If no mark is present, use the highest point on the casing as the reference point. Withdraw the cable and record the depth.

3.2.4 Alternatively use a steel tape with an attached weight if aquifer gradients are lower than 0.05 ft/ft. Due to the possibility of adding unknown contaminants from chalk colorants, only white chalk is permitted.

3.2.4.1 Rub chalk onto the first 1 foot of the steel tape and slowly lower the chalked end into the well until the weighted end is below the water surface. (A small splash can be heard when the weighted end hits the water surface.)

3.2.4.2 Using the method described above read and record the length from the steel tape.

3.2.4.3 Remove the steel tape. The chalk will be wet or absent where the tape was below the water surface. Locate, read, and record this length. Subtract wetted length from total length and record the difference. This is the depth to water table.

3.2.5 Transducers and dataloggers will be used where water level fluctuations over time are to be measured, such as tidal fluctuation studies (SOP043) and slug tests (SOP033). Note that transducers are inappropriate for measuring well depth.

3.2.5.1 Slowly lower the transducer into the well until it is below the lowest possible piezometric level (typically 2-3 ft below the water table).

3.2.5.2 Tape the umbilical to the protective casing to prevent the transducer from falling further.

3.2.5.3 Attach the umbilical leads to the datalogger.

3.2.5.4 Turn datalogger on.

3.2.6 To measure the well depth, lower electric water level indicator probe or tape until slack is noted. Very slowly raise and lower the cable until the exact bottom of the well is "felt." Measure (cable) or read the length :(tape) and record the depth.
Note that if the electric water level indicator is used to determine depth of well, the offset distance between the tip of the probe and the electrode must be added to the reading to determine actual depth.

3.2.7 Withdraw the probe or tape.

3.2.8 Decontaminate the probe(s) and cable(s).

3.3 Data Recording and Manipulation

3.3.1 Record the following computations:

date and time
weather
method of measurement
casing elevation
NAPL surface elevation = casing elevation - depth to NAPL
NAPL thickness = depth to bottom of NAPL - depth to top of NAPL
water level elevation = casing elevation - depth to water
well bottom elevation = casing elevation - depth to bottom (or read directly from tape)

3.4 Refer to SOPs 3, 5, and 16.

4.0 Calibration

No calibration is needed.

5.0 Precautions

5.1 Depending upon the device used, correction factors may be required for some measurements.

5.2 Check instrument batteries prior to each use.

5.3 Exercise care not to break the seals at the top of the electric water level indicator probe.

6.0 References

M^{c}Alary, T. A., and Barker, J. F., 1987. "Volitalization Losses of Organics During Ground Water Sampling from Low Permeability Materials" in Ground Water Monitoring Review, Fall,1987

Thornhill, Jerry T., 1989. Accuracy of Depth to Groundwater Measurements; In "EPA Superfund Ground Water Issue" EPA/540/4-89/002

STANDARD OPERATING PROCEDURE 011
PHOTOIONIZATION DETECTOR (HNu Model PI-101 and HW-101)

1.0 Scope and Application

The purpose of this standard operating procedure is to delineate protocols for field operations with a photoionization detector (HNu Systems Model PI-101 or HW-101). The photoionization detector (PID) detects total ionizables, hence it is used to monitor both organic and inorganic vapors and gases to determine relative concentrations of air contaminants. This information is used to establish level of protection and other control measures such as action levels. The PID cannot effectively detect compounds having ionization potentials above the photon energy level of the lamp used; therefore, methane, which has an ionization potential of 12.98 eV, is undetectable by PIDs, whose lamps are capable of producing 9.5, 10.2, or 11.7 eV.

Use of brand names in this SOP is in nowise intended as endorsement or mandate that a given brand be used. Alternate equivalent brands of detectors, sensors, meters, etc. are acceptable. If alternate equipment is to be used, the contractor shall provide applicable and comparable SOPs for the maintenance and calibration of same.

2.0 Material

a. HNu Systems Model PI-101 or HW-101 survey probe with 9.5, 10.2, or 11.7 eV lamp.
b. Lead-acid gel-cell battery
c. Calibration Gas (*e.g.* isobutylene - 101 ppm) w/regulator
d. Tygon tubing
e. Tedlar bag (optional)
f. Instrument logbook

3.0 Procedure

These procedures are to be followed when using the HNu in the field.

3.1 Start Up Procedures

3.1.1 Before attaching the probe, check the function switch on the control panel to ensure that it is in the off position. Attach the probe by plugging it into the interface on the top of the readout module.

3.1.2 Turn the function switch to the battery check position. The needle on the meter should read within or above the green battery arc on the scale. If not, recharge the battery. If the red indicator light comes on, the battery needs recharging or service may be indicated.

3.1.3 Turn the function switch to any range setting. Listen for the hum of the fan motor. Check meter function by holding a solvent based marker pen near the sample intake. If there is no needle deflection, look briefly into the end of the probe (no more than one or two seconds) to see if the lamp is on. If it is on, it will give a purple glow. Do not stare into the probe any longer than two seconds. Long term exposure to UV light can damage the eyes. (See also note 5.4)

3.1.4 To ZERO the instrument, turn the function switch to the standby position and rotate the zero adjustment until the meter reads zero. A calibration gas is not needed since this is an electronic zero adjustment. If the span adjustment setting is changed after the zero is set, the zero should be rechecked and adjusted, if necessary. Allow the instrument to warm up for 3-5 minutes to ensure that the zero reading is stable. If necessary, readjust the zero.

3.2 Operational Check

3.2.1 Follow the start up procedure in section 3.1

3.2.2 With the instrument set on the 0-20 range, hold a solvent-based magic marker near the probe tip. If the meter deflects upscale, the instrument is working.

3.3 Field Calibration Procedure

3.3.1 Follow the start-up procedures in section 3.1 and the operational check in section 3.2.

3.3.2 Set the function switch to the range setting for the concentration of the calibration gas.

3.3.3 Attach a regulator HNu P/N 101-351 or equivalent (flow = 200 to 300 ml/min) to a disposable cylinder of isobutylene (HNu 101-351 or equivalent). Connect the regulator to the probe of the HNu with a piece of clean Tygon tubing. Turn on the valve of the regulator.

3.3.4 After five seconds, adjust the span dial until the meter reading equals the benzene concentration of the calibration gas used, corrected to its equivalence which should be marked on the canister (Isobutylene ~0.7X benzene).

3.3.5 Record in the field log: the instrument ID No.; serial number; the initial and final span settings; the date; time; location; concentration and type of calibration gas used; and the signature of the person who calibrated the instrument.

3.3.6 If the HNu does not function, check-out, or calibrate properly, the project equipment manager is to be notified as soon as possible. Under no circumstances is work requiring monitoring with a PI-101 or HW-101 to be done with a malfunctioning instrument.

3.4 Calibration to a Gas Other Than Isobutylene

The HNu may be calibrated to any certified calibration gas. However, after calibration all subsequent instrument readings will be relative to the calibration gas used.

3.4.1 Calibrate according to procedure 3.3

3.4.2 Partially fill and flush to two times a gas bag (Tedlar recommended) with the certified National Institute of Standards and Technology (NIST) (formerly NBS) traceable calibration gas. Then fill the bag with one to three liters of the calibration gas. If the gas is toxic, this must be done in a fume hood.

3.4.3 Feed the calibration gas into the probe with the range set for the value of the gas. After five seconds, adjust the span control until the meter reads the value of the calibration gas.

3.4.4 Record the results of the calibration on the calibration/maintenance log and attach a new calibration sticker (if available) or correct the existing sticker to reflect the new calibration data. All subsequent readings will be relative to the new calibration gas.

3.5 Operation

3.5.1 Follow the start up procedure, operational check and calibration check (refer to 3.1).

3.5.2 Set the function switch to the appropriate range. If the concentration of gases of vapors is unknown, set the function switch to 0-20 ppm range. Adjust if necessary.

3.5.3 While taking care not to permit the HNu to be exposed to excessive moisture, dirt, or contaminants, monitor the work activity as specified in the Site Health and Safety Plan.

3.5.4 When the activity is completed or at the end of the day, carefully clean the outside of the HNu with a damp disposable towel to remove all visible dirt. Return the HNu to a secure area and place on charge. Place the instrument on charge after each use; the lead acid batteries cannot be ruined by over charging.

3.5.5 With the exception of the probe's inlet and exhaust, the HNu can be wrapped in clear plastic to prevent it from becoming contaminated and to prevent water from getting inside in the event of precipitation. If the instrument becomes contaminated, make sure to take necessary steps to decontaminate it. Call the Equipment Administrator if necessary; under no circumstances should and instrument be returned from the field in a contaminated condition.

3.6 Refer to SOP 3 and 16.

4.0 Maintenance

The following sections cover basic maintenance and servicing procedures; they are to be performed only by persons who have been specifically trained in the procedures. In general, disassembly procedures not covered in this text are to be left to trained service personnel, including the contractor's equipment administrator or equipment managers as appropriate.

The appropriate calibration/maintenance logs are to be filled in completely whenever a PI-101 or HW-101 receives servicing. This is true of both contractor-owned and rental instruments.

The equipment manager should be called to arrange for a fresh instrument when necessary. The contractor's equipment facility is responsible for arranging all repairs which cannot be performed by the project equipment manager.

4.1 Routine Service

The PID's performance is affected by a number of factors. These include but are not limited to the decay of the UV lamp output over time and the accumulation of dust and other particulate material and contaminates on the lamp and in the ion chamber. Because of these factors, the PID should not be left in the field for a period of more than two weeks before being replaced with a fresh instrument. If a site is going to be inactive for a period of more than a week, all monitoring instruments are to be returned to the project equipment manager or his trained designee for servicing and/or reassignment. The following procedures are to be performed at the designated intervals for routine service.

Procedure	Frequency
Operational Check	Prior to use and at instrument return
Field Calibration	Prior to use and at instrument return
Full Calibration	Bi-weekly (return instrument to equipment manager for replacement with a fresh unit)
Clean UV Lamp and Ion Chamber	Bi-weekly or as needed
Replace UV Lamp	As needed

4.1.1 UV Lamp and Ion Chamber Cleaning

During periods of analyzer operation, dust and other foreign materials are drawn into the probe forming deposits on the surface of the UV lamp and in the ion chamber. This condition is indicated by meter readings that are low, erratic, unstable, non-repeatable, drifting, and which show apparent moisture sensitivity. These deposits interfere with the ionization process and cause erroneous readings. Check for this condition regularly to insure that the HNu is functioning properly. If the instrument is malfunctioning, call your respective equipment manager to arrange to have a fresh replacement.

4.1.2 Lamp eV Change

If different applications for the analyzer would require different eV lamps, separate probes, each with its own eV lamp, must be used. A single readout assembly will serve for any of the probes (9.5, 10.2 and 11.7 eV). A change in probe will require resetting of the zero control and recalibrating the instrument. The 11.7 eV lamp will detect more compounds than either of the two lower eV lamps. However, the 11.7 eV probe needs more frequent calibration, it burns out much faster than the lower eV lamps.

5.0 Precautions

5.1 The HNu PI-101 and HW-101 are designed to sample air or vapors only. DO NOT allow any liquids or low boiling vapors to get into the probe or meter assembly.

5.2 High concentrations of any gas can cause erroneous readings. High humidity can also cause the instrument readings to vary significantly from the actual concentration of gases or vapors present. This is true even through the HNu cannot react to water vapor.

5.3 High humidity, dust, and exposure to concentrations of low boiling vapors will contaminate the ion chamber, causing a steady decrease in sensitivity.

5.4 Continued exposure to ultraviolet light generated by the light source can be harmful to eyesight. If a visual check of the UV lamp is performed: Do not look at the light source from a distance closer than 6 inches with unprotected eyes. Use eye protection (UV-blocking sunglasses or safety glasses). Only look briefly - never more than about 2 seconds.

5.5 Place the instrument on charge after each use; the lead batteries cannot be ruined by over charging.

5.6 If at any time the instrument does not check out or calibrate properly in the field, the equipment manager is to be notified immediately and a replacement provided for the malfunctioning instrument. Under no circumstances should field work requiring continuous air monitoring for organic vapors and/or gases be done with a malfunctioning HNu, without a HNu or an approved comparable instrument.

6.0 References

Manufacturer's Equipment Manual(s).

STANDARD OPERATING PROCEDURE 012
SPECIFIC CONDUCTANCE MEASUREMENTS

1.0 Scope and Application

The purpose of this standard operating procedure is to delineate protocols for measuring the specific conductance of any aqueous solution, including drinking water, saline water, industrial and domestic wastes. Conductivity is the ability of an aqueous solution to pass an electrical current. The current is primarily carried by dissolved inorganic ions such as chlorides, nitrates, sulfates, along with cations such as sodium, calcium, magnesium and others. Organic compounds do not carry current and therefore have almost no conductivity.

2.0 Material

a. Conductivity meter with integral temperature compensation - Accuracy = ± 2% at 25°C (77°F)
b. Conductivity cell
c. Appropriate conductivity reference solution
d. HPLC-grade water (see SOP005 footnote 2)
e. Thermometer (optional, see 5.2)

3.0 Procedure

3.1 Calibration

The specific conductivity meter should be calibrated at the beginning of each day[1] as follows:

3.1.1 Thoroughly rinse the probe with Appropriate conductivity reference solution

3.1.2 Zero meter if appropriate.

3.1.3 Measure the specific conductance of fresh Appropriate conductivity reference solution record it in the field notebook, and adjust the calibration knob until the meter reads properly.

3.1.4 Rinse probe with HPLC-grade water.

3.1.5 Measure the specific conductance of HPLC-grade water and record in the field logbook. If Specific conductivity of HPLC-grade water is not 0 (±2%) recalibrate instrument.

3.2 Operation

The specific conductivity meter will be operated as follows:

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[1] The meter should be recalibrated any time the readings are suspect (*e.g.* out of expected range)

3.2.1 Thoroughly rinse the probe and sample beaker with sample water.

3.2.2 Measure the temperature of the sample water. Convert Fahrenheit temperature readings to Celsius using C = 5/9 (F - 32) if Celsius temperature is not obtained directly.

3.2.3 Place the probe in the sample beaker with sufficient sample to completely submerge the probe. Swirl the probe to remove any air bubbles trapped in the probe.

3.2.4 Select the highest multiplier scale on the meter and turn the instrument on. Progressively use lower multiplier scales until a mid-scale deflection is obtained.

3.2.5 If appropriate, check probe accuracy by pressing cell test button. If value change is > 10% check probe.

3.2.6 Record the temperature and conductivity values.

3.2.7 Specific conductivity values are corrected for temperature using:

$$^{K}25\,^{\circ}\mathrm{C} = \frac{K \ \text{measured}}{1 + 0.0191\ (t-25)}$$

where:

K = conductivity in μmhos
t = temperature, °C

3.2.8 Decontaminate the probe. (See SOP005 § 3.3.3.2)

3.3 Refer to SOPs 003, 005, and 016.

4.0 Maintenance

The following steps will be taken to properly maintain the conductivity meter:

4.1 Check the batteries each time the instrument is used.

4.2 Inspect the probe on a daily basis for damage or loss of platinum black plating from the electrode. If the platinum is damaged, alert the Field Team Leader and arrange to get a new cell.

4.3 Follow manufacturers specifications regarding storage of probe between uses.

5.0 Precautions

5.1 Be certain there is no air in the cell before taking a reading.

5.2 If conductivity meter does not have integral temperature compensation, use a thermometer to determine temperature of the sample.

6.0 References

USEPA, 1983. Methods for Chemical Analysis of Water and Wastes, March, 1983.

Manufacturer's Manual

STANDARD OPERATING PROCEDURE 013
COLLECTION OF MONITORING WELL SAMPLES

1.0 Scope and Application

The purpose of this standard operating procedure is to delineate protocols for the collection of groundwater samples from monitoring wells.

2.0 Material

a. Conductivity meter
b. Thermometer (optional)[1]
c. pH meter with ORD probe
d. Turbidity meter
e. Dissolved Oxygen meter
f. Water-level indicator
g. Transparent bailer with a double check valve
h. PVC bailer (for purging only)
i. Stainless steel bailer (for purging and sampling)
j. Polytetrafluoroethelyne (PTFE) bailer with PTFE-coated stainless steel cable, double check valve top and controlled flow bottom discharge attachment[2] for VOC sampling (40-mL vials), and top discharge attachment for collecting larger samples (1-L bottles) (for purging and sampling)
k. Polypropylene rope
l. Submersible pump and hose (for purging only)
m. Peristaltic pump with tubing for filtering samples
n. Variable speed, low flow submersible pump (*e.g.* Grundfos MP1 ground-water sampling pump) (for purging and sampling)
o. Bladder pump (dedicated to one well only)
p. 0.45μM filters
q. Sample bottles and labels
r. Logbook or book of field parameter forms
s. Generator
t. Tygon tubing
u. Plastic sheeting
v. Photoionization Detector (PID) Organic Vapor Analyzer

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[1] Temperature compensation and measurement capabilities are generally available as integral functions of pH meters and conductivity meters. If this is the case, a separate thermometer is not required.

[2] Although use of a controlled flow bottom discharge valve is historically preferred, use of such a device can cause aeration of the sample.

3.0 Procedure

3.1 General: Ground-water sampling will follow these general steps:

- Arrive on site
- Set up apparatus (generators, pumps, etc.)
- Glove
- Perform all steps of SOP 010 - organic vapor check, water level and well depth measurements
- Sample NAPLs (as required)
- Begin purge procedure
  - If using bailer to purge and sample see § 3.6.
  - If using pump to purge and bailer to sample see § 3.7.
  - If using bladder or low-flow pump to purge and sample see § 3.8.
- Decon/reglove
- Take samples
  - If with bailer see § 3.6.5
  - If with bladder or low flow pumps see §3.8
- Decon/dispose of wastes, move equipment to next site.

3.2 General Rules for Groundwater Field Parameter Logbook (see SOP 016 for further procedures):

3.2.1 Only one site or installation per logbook, and only one sampling location per page or form (if using pre-printed forms). The same book maybe used for more than one sampling event.

3.2.2 First five pages will be reserved for index, general notes, etc. Sign and date each entry.

3.2.3 Last five pages will be reserved for recording calibration data for the pH, temperature, turbidity, ORD, DO, and conductivity meters. Use the page number or a separately recorded "Cal Reference Number" to refer to each calibration.

3.2.4 (As appropriate). Insert the cardboard flap under the form being filled out, so that writing does not go through to the pages below.

3.2.5 (As appropriate). Fill in the forms from front to back of the logbook, tearing out the white copy for each sample when the sample has been collected. This copy goes in the cooler with the sample, directly to the laboratory. The original copy must be torn out before you write on the back of the duplicate form.

3.2.6 (As appropriate). Duplicate copies, index pages, and calibration sheets remain intact.

3.3 Groundwater Sampling General Rules

3.3.1 Refer to SOPs 001-005, 008-012, 036, 037, and 039

3.3.2 Groundwater samples will be collected from the least contaminated wells first, progressing to the most contaminated [3].

3.3.3 Upon arrival at the well site, immediately set up and organize the purging, sampling, and filtration equipment. If needed, due to muddy or contaminated ground, remoteness from sampling vehicle, and\or for placement of hose(s) and\or power cord if a pump is used, place clean plastic sheeting at, or around the well, to serve as a clean staging area for purging and sampling equipment, as conditions warrant. Care must be exercised not to step on plastic sheeting.

3.3.4 If the well is remote from the sampling vehicle set up the filtration equipment and place rope, wrapped bailer, and pre-labeled sample containers on the plastic sheet, uphill from the well.

3.3.5 When a pump is to be used situate the portable generator on level ground approximately 15 feet away from and downwind from the well. All generator maintenance (oil and fueling) is to be performed off site. If the hose(s) and/or power cord of the pump are not on a reel, place the pump with its hose and power cord on the plastic sheeting downhill from the well.

3.3.6 Glove. Check well headspace for organic vapor which may pose a health and safety hazard and indicate the presence of NAPL. Measure depth(s) to and thickness(es) of NAPL(s) as appropriate. Measure the depth to water and depth of well. From the water depth, well diameter, sand pack length, etc., calculate the equivalent volume (1 EV) of water in the well.

1 EV = volume in casing + volume in saturated sand pack. Therefore; if the **water table lies below the top of the sandpack**, use the following equation:

$$\mathbf{1\ EV = (\pi R_w{}^2 h_w) + (0.30\pi(R_s{}^2 - R_w{}^2)h_w) * (0.0043)}$$

If the **water table lies above the top of the sandpack** use this equation:

$$\mathbf{1\ EV = [(\pi R_w{}^2 h_w) + (0.30\pi(R_s{}^2 - R_w{}^2)h_s)] * (0.0043)}$$

where: R_s = radius of sandpack in inches
R_w = radius of well casing in inches
h_s = height of sandpack in inches
h_w = water depth in inches

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[3] First round samples are to be collected from upgradient wells first, moving to downgradient wells under the assumption that upgradient wells will be less contaminated than downgradient wells. Results of first round analysis may mandate a change in sampling sequence.

0.0043 gal/in^3
Assumed filter pack porosity = 30%

Tables and graphs showing equivalent volumes for typical well constructions are available.

Alternate equations for calculating EV are acceptable, two alternates are given in SOP 010

3.3.7 Samples will always be collected in order of decreasing volatility (*i.e.*, the samples to be analyzed for the volatile constituents should be collected first.) Deliver the VOC sample to the vial by allowing the water to trickle down the inside wall of the vial at a rate no greater than approximately 100 ml/min. Other samples may be delivered at a faster rate. Sampling rates will at no time exceed 1 L/min. Procedures for each class of samples are contained in Appendix A of the GWP, the QAPP, and SOP 039.

3.3.8 When collecting samples for volatile analysis care should be taken to prevent analyte loss by volatilization. The following procedures should be adhered to when collecting these samples [4]:

3.3.8.1 Avoid excessive aeration and agitation of sample.

3.3.8.2 Fill vial so that a reverse meniscus is present by adjusting the flow rate from the sampling device.

3.3.8.3 Place septum on vial so that the PTFE side is in contact with the sample. After the cap is on the bottle, check for air bubbles in the sample. If air bubbles are present, properly dispose of that sample and recollect the sample in the same vial.

3.3.8.4 Make sure vial is labeled and immediately transfer the vial to the cooler with ice.

3.3.9 Filtered and unfiltered samples will be taken for inorganics (metals) analyses. The samples will be filtered through an in-line 0.45μM filter (preferred method), or by gravity through a 0.45μM membrane placed in a filter funnel. Use forceps to place the membrane into the funnel and pour sample through funnel until appropriate volumes have been filtered.

If necessary, due to slow filtering, a peristaltic pump may be used to filter the sample through an in-line filter. Connect the pump to the generator, attach tygon tubing to the bottom discharge valve on the bailer. Start pump and collect sample from the end of the in-line filter directly into the proper container, preserved (as required by SOP 039), and placed in the cooler. Filtered samples will be preserved in the field with acid to a pH of less

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[4] Although EPA Region III policy is to preserve VOA samples by acidifying to pH < 2, the possibility of generating mustard agent by reverse hydrolyzation of thyodiglycol mandates that at the Edgewood Area, APG this not be done. Instead, the holding time on all VOA samples **shall not** exceed 7 days.

than 2. Make sure sample bottle is labeled and the cap is on tightly. Then place in cooler with ice immediately.

– OR –

If a low flow pump is used collect the samples, filtered samples will be taken by installing a 0.45μM filter in-line and pumping the water through the filter. Collect sample from the end of the in-line filter directly into the proper container, preserved (as required by SOP 039), and placed in the cooler. Filtered samples will be preserved in the field with acid to a pH of less than 2. Make sure sample bottle is labeled and the cap is on tightly. Then place in cooler with ice immediately.

3.3.10 Unfiltered samples will be collected by slowly pouring the sample water into the appropriate sample container, being careful not to agitate or cause bubbles to form. Do not overfill bottles. Make sure sample bottle is labeled and the cap is on tightly. Then place the sample in cooler with ice immediately.

3.3.11 All samples will be delivered to the laboratory as soon as possible. If possible, samples will be shipped on the same day as they are collected. If samples must be retained due to weekend sampling (Friday through Sunday), the lab shall be notified as to the time sensitive nature of the samples.

3.3.12 Refer to SOP 1-5, 16, 31, and 39 .

3.4 Sampling of Non-Aqueous Phase Liquids

3.4.1 If NAPLs are detected in the well, a sample from all layers must be collected prior to any purging activities. Non-aqueous phase liquids (NAPLs) may be indicated by the presence of volatiles in the well headspace, and confirmed by the oil/water interface probe (see SOP 10 § 3.2 - 3.2.2.3).

3.4.1.1 Collecting LNAPLs will be accomplished using a transparent bailer with a double check valve. This bailer will be slowly lowered until the bottom of the bailer is 1-2 in. below the LNAPL-water interface, as determined in SOP 010 then slowly withdrawn. Verify that the interface was sampled by visual inspection of the bailer contents through the side of the bailer. Measure the thickness of the LNAPL in the bailer and note in the Field Notebook. Sample for laboratory analysis. An additional field verification may be performed by decanting the remainder of the contents of the bailer into a glass jar, adding a hydrophobic dye such as Sudan IV, or Redoil, shaking the sample and looking for coloration of NAPL. Alternate field tests are: examine the sample under ultra violet light (many fluoresce), or allow the sample to stand overnight, and examine for interface and/or volatiles in the headspace the following day. Refer to following sections on purging and sample collection for set up and general operation.

3.4.1.2 Collecting dense non-aqueous phase liquids (DNAPLs) will be accomplished using a transparent bailer with a double check valve. The bailer must be lowered very slowly to the bottom of the well and raised slowly out of the well in a controlled fashion. Sample for analysis as above. The same field check described above may be employed for DNAPL. Refer to following sections on purging and sample collection for set up, and general operation.

3.4.1.3 If NAPLs are present in the well, **and** a low-flow pump is to be used for purging and sampling, the well will be allowed to re-equilibrate prior to purging and sampling. This will be accomplished by allowing the well to stand undisturbed for at least 8 hours prior to purging and sample collection.

3.5 Well Purging - General Rules

Water within the casing of a well will stagnate, degas, lose volatiles, possibly precipitate metals due to changes in redox potential, and may react with the screen and/or casing material. It is therefore necessary to purge a sufficient volume of this stagnant water from the well and/or casing to ensure that a representative sample of formation water can be obtained. Traditionally, the volume of water to be purged was arbitrarily set at 3 to 5 equivalent volumes. Recent advances in sampling technologies have caused a re-thinking of such arbitrary purge volumes. It is for this reason that Monitoring of select chemical and physical properties of the sample medium will be used instead of strict volumes to determine when a representative sample may be taken from a well.

3.5.1 Acceptable purge/sampling devices include: bailers, high-discharge submersible pumps (purge only), and variable speed, low-flow pumps which include both submersible pumps (purge and sample), and dedicated bladder pumps (purge and sampling). It is recommended to purge and sample at similar rates with one type device per well. An acceptable exception to this general rule is to use a high-discharge submersible pump to purge a deep, fast-recharging well, and a bailer to sample the same well.

3.5.2 Peristaltic, gas-lift, and centrifugal pumps can cause volatilization, produce high pressure differentials, and can result in variability in the analysis of some analytes of interest. These types of pumps shall not be used to purge or sample wells.

3.5.3 To prevent ground-water from cascading down the sides of the screen in to an open hole, thereby aerating the sample, purge rates will closely match recharge rates. If the static water level is within the casing, the initial purge rates may be set high enough to lower the water level to the top of the screen, then reduced to maintain that level.

3.5.4 Purging will be accomplished with either a submersible pump, a low-flow (submersible or bladder) pump, or bailer. The choice of bailer or pump will be based on depth to water table, volume to be purged, and permeability of the aquifer. If the well recharges rapidly and/or has greater than 20 gallons (estimated EV) to be purged, water may be removed with a submersible pump or a low-flow pump. If the well recharges slowly and/or has less than 20 gallons to be purged, water will be removed with a bailer or a low-flow pump.

3.5.5 Purging will be accomplished with as minimal disturbance to the surrounding formation as possible.

3.5.6 Purge water will be containerized[5] on site until analysis of samples is completed. At that time, if the samples are non-hazardous, the water may be disposed of through the waste water treatment plant on-post. If the purge water is found to be hazardous, it will be disposed of as hazardous waste in a licensed TSDF.

3.5.7 If the water level is within the screened interval and the well recharge rate is less than 0.1 L/min purge the well using a low-flow pump as follows:

3.5.7.1 Draw the water down to within 1 foot of the top of the pump.

3.5.7.2 Allow the well to recover.

3.5.7.3 Check and record field parameters (§ 3.7.3).

3.5.7.4 Repeat steps 3.5.7.1 through 3.5.7.3 then collect samples for metals analysis only [6].

3.5.7.5 Note the event in the field log book, and report the problem to the APG project manager. If this extremely low recharge problem consistently occurs in a given well, the well may be considered for re-development and/or replacement.

3.5.7.6 If adjacent wells have elevated VOC levels, additional soil gas surveys will be considered in the vicinity of the low recharge well to help determine the need for replacement.

3.6 Purging and Sampling With Bailers

3.6.1 Bailers may be used for both purging and sampling wells if: a) the well recharge rate is less than 4 L/min, b) depth to the water table is less than 50 ft, and c) less then 20 gal are to be

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[5] If, after two rounds of quarterly samples, the water has proven to be uncontaminated, and the purge volume does not exceed 10,000 Gal/day, the purge water may be discharged on the surface, at least 50 ft downhill from the well. If the water is contaminated but does not exceed 100 ppm total VOC, **and** other contaminants are non toxic to aquatic life as defined in COMAR 26.08.02.03-2, Table 1, MDE may be petitioned on a case-by case basis for a waiver for surface discharge. This letter will be drafted by the contractor for DSHE signature.

[6] Analyte losses due to volatilization in a drained well are too high for valid VOC sampling (M^{c}Alary and Barker, 1987).

purged (5 EV < 20 gal)[7].

3.6.2 When purging with a bailer, either a PVC, PTFE, or stainless steel bailer may be used. The bailer will be attached to either a spool of PTFE-coated stainless steel cable or polypropylene rope. If using cable, attach it to the bailer using stainless steel cable clamps. Thoroughly decon the cable after each use, prior to rewinding cable onto spool. Cable clamps and raw cable ends may serve to trap contamination. Exercise particular caution in deconning these areas. If using rope, attach the rope to the bailer using a bowline knot, dispense the needed length (a few feet more than the well depth) and cut the remainder away, then, at the end opposite the bailer, make a slip knot and place it around the well casing or protective posts to prevent losing the bailer and rope down the well. The polypropylene rope will be not reused, it will be properly disposed of. Either type of bailer will be repeatedly lowered gently into the well until it fills with water, removed, and the water will be discharged into an appropriate container until purging is complete. Care must be taken not to unduly agitate the water, as this tends to aerate the sample, increase turbidity, makes stabilization of required parameters (3.6.3) difficult to achieve, and generally prolongs purging.

3.6.3 After purging 2 EV, obtain a sample of groundwater and measure the following stabilization parameters: temperature (SOP 009), conductivity (SOP 012), pH (SOP 008), turbidity (SOP 036), redox potential (Eh) (SOP 038), and dissolved oxygen level (SOP 037) at each successive half-well volume. When three of these stabilization parameters are in agreement within approximately 10% in three consecutive half-well volume samples, sufficient water has been purged from the well. The results of these tests should be recorded in the sampling logbook. Should these parameters not reach agreement, no more than five well volumes will be purged.

3.6.4 Immediately upon completion of purging, collect samples for laboratory analysis using a PTFE bailer on a PTFE-coated stainless steel cable. The bailer will be equipped with double check valve top and controlled flow bottom discharge attachments for VOC sampling (40-mL vials), and top discharge attachment for collecting larger samples (1-L bottles).

3.6.5 Slowly, so as not to agitate the water, lower the bailer into the well, using a spool of PTFE-coated cable. Allow bailer to fill, withdraw smoothly. Refill bailer as needed.

3.6.5.1 Please see footnote 2. If the controlled flow bottom discharge attachment is used

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[7] These numbers are based on the following assumptions: 1) In purging, it is preferable to remove water at approximately the recharge rate. 2) Four L/min is estimated as the approximate maximum rate at which water can be removed with a bailer from depths of 20-50 feet. 3) Twenty gallons is estimated to be at the limit of the sampler's endurance, at which point fatigue and sloppiness of technique begin.

for VOC sampling, attach it to the bottom of the bailer. Using the stopcock valve on the bailer to control the flow, fill sample vials as described above in § 3.3.8.

3.6.5.2 Remove check valve top and pour unfiltered sample into inorganics sample bottles.

3.6.5.3 Collect filtered samples as described in § 3.3.9 (above).

3.6.6 Decon bailer and cable in accordance with SOP 005 § 3.3.1.1

3.7 Purging With Pump, Sampling With Bailer

3.7.1 If the recharge rate of the well is greater than 30 L/min, or the water level is deeper than 50 ft, or more than 20 gal or purge water will be generated (5 EV > 20 gal), then purging and sampling may be accomplished using a submersible pump / bailer combination.

3.7.2 When purging with a pump, gradually lower the intake until it is submerged within the screened interval. Lower an electronic water level probe to the top of the screen (as determined from completion records) to the monitor water level, start pump, and slowly lower the pump as the water level continues to fall. Care should be exercised to lower the water column to the top of the screened interval (water level probe will stop beeping) but not below the top of the screen if possible. This will ensure that the stagnant layer has been removed, but should minimize the detrimental effects of over pumping the well. Secure hose(s) and/or power cord to casing and place discharge hose into the proper container, downhill and as far away from the well as possible. Determine and record the discharge rate.

Discharge rate = volume of container/time to fill container

The discharge rate will be established at approximately equal to or just greater than the well's recharge rate (determined from well development). If well development records are incomplete, recharge rate can be determined by monitoring the rise/fall of the water level within the casing as one purges the well. If the water level is static at a given pumping rate, but fluctuates up or down as pumping rate is decreased or increased, the pumping rate at which the water level is static is the recharge rate.

3.7.3 After purging 2 EV, obtain a sample of groundwater and measure the following stabilization parameters: temperature, conductivity, pH, turbidity, redox potential (Eh), and dissolved oxygen level at each successive half-well volume. When three of these stabilization parameters are in agreement within approximately 10% in three consecutive half-well volume samples, sufficient water has been purged from the well. The results of these tests should be recorded in the sampling logbook. Should these parameters not reach agreement, no more than five well volumes will be purged.

3.7.4 Immediately upon completion of purging, collect samples for laboratory analysis using a PTFE bailer on a PTFE-coated stainless steel cable. The bailer will be equipped with double check valve top and controlled flow bottom discharge attachments for VOC sampling (40-mL vials), and top discharge attachment for collecting larger samples (1-L bottles). Filtration of metals samples will be accomplished using either an in-line filter attached to the bottom of the bailer, or a funnel and appropriate filter (see § 3.3.9 above).

3.7.5 Slowly, so as not to agitate the water, lower the bailer into the well, using a spool of PTFE-coated cable. Allow bailer to fill, withdraw smoothly, fill sample containers as described above in § 3.6.5

3.7.6 Decon bailer and cable in accordance with SOP 005 § 3.3.1.1. Decon pump in accordance with SOP 005 § 3.3.1.2.

3.8 Purging and Sampling With Low-Flow Pump

To obtain representative samples, subsurface disturbances should be kept to a minimum, thereby preventing sample alteration due to sampling actions. The reasoning behind the use of low-flow pumps to purge and sample monitoring wells is that these pumps minimize physical disturbance (turbulence) at the sampling point and chemical changes (aeration) in the medium. For these reasons, the low-flow pump is the preferred method for both purging and sampling in most cases. For the purposes of this SOP, "low-flow pumps" are defined as either dedicated bladder pumps or variable speed submersible pumps. Practical operational flow rates for these sampling devices range from 0.1 L/min to 30 L/min.

3.8.1 Low-flow pumps may be used for purging and sampling any well having recharge greater than 0.1 L/min, which is the practical lower limit of pump performance. Below that pumping rate, pump inefficiencies and/or overheating may alter the physical and chemical properties of the sample. If the pump is continuously operated at sampling rates higher than the well recharge rate, the water level will be lowered in the well, possibly allowing aeration of the sample which is unacceptable sampling procedure. Low-flow pumps are suitable for sampling wells with recharge rates lower than 0.1 L/min if precautions are taken to avoid aeration of the sample.

3.8.2 Low flow submersible pumps will be used as follows:

3.8.2.1 Lower the pump into the well, slowly so as not to agitate the water, until the pump is at the mid-point of the screened interval or the mid-point of the water column if the static water table lies below the top of the screen [8]

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[8] This assumes a 10-ft. screened interval. If the screened interval is greater than 10-ft., multiple samples should be taken as follows:

- If the screen is 10 - 12 ft., sample the canter of the water column, as outlined above.

3.8.2.2 Attach the pump's umbilical cord (which will consist of power cord and sampling tubing) to the protective casing, or lock the cord spool so that the pump cannot move vertically in the well during sampling.

3.8.2.3 Lower the water level probe into the well behind the pump until it just touches water. This will allow the sampler to monitor the water level while purging and sampling, and prevent the inadvertent drying of the well.

3.8.2.4 Begin purging at the pump's lowest setting, then gradually increase rate[9] until the pumping rate matches the aquifer recharge rate. **If the water level is above the top of the screen**, the pumping rate may be allowed to slightly exceed recharge rate, lowering the water level to no less than 1 foot above the screen, then reduced until it matches recharge rate and purging continued. **If the water level is below the top of the screen**, always keep the purge rate lower than well's recharge rate.

3.8.2.5 Monitor stabilization parameters listed in § 3.6.3 beginning immediately, using an in-line monitoring system. Record parameters regularly, at a rate of one set of parameters per each 1-3 liters of water removed from the well. When these parameters stabilize to within 10% over 3 consecutive readings, reduce[10] flow rate to 0.1 L/min (if needed) and begin collecting VOC samples directly from the discharge line.

3.8.2.6 If the well recharges at a rate less than 0.1 L/min, purge until the water level is even with the top of the screen, allow the well to recover and sample immediately.

3.8.2.7 Remove and decon water level probe (SOP 005 § 3.3.1.5) and pump (SOP 005 § 3.3.1.2).

- If the screen is longer than 12-ft., and the water column is 10-ft or less, sample the center of the water column.

- If the screen is longer than 12-ft., and the water column fills the screen, or extends above the screen, sample at 1/3 and 2/3 the height of the water column, or about every 6-ft.

[9] Some sources indicate that the pumping rate should not exceed 1 L/min, with 0.5 L/min being preferable. The optimal purge rate is highly aquifer dependent, and may range from less than 0.5 L/min to greater than 10 L/min. The purge rate for a given well will; therefore, be a field decision, based on well development, purge, and sampling records rather than SOP mandate.

[10] Sampling should occur at the same rate as purging as long as aeration of sample does not occur.

3.8.3 The length of tubing used in conjunction with the low-flow pump will be appropriate to the depth of the well (*i.e.* A 100 ft roll of tubing may not be used in sampling a 30 ft well. A 50 ft roll would be used instead, thereby generating less decon solution, and providing less opportunity for physical and chemical changes in the sample due to contact with the spooled tubing (see § 3.8.4)). This means that the contractor will have on hand: a) spools of varying length (*e.g.* 25, 50, 75, and 100 ft spools) or b) several short *e.g.* 10 ft lengths of tubing with a secure means of connecting them end-to-end.

3.8.4 When a sampling event occurs during summer months, in full sun, shade will be provided for the spooled tubing. Otherwise the tubing will be an effective water heater, warming the ground-water sample, creating the potential for volatilization of organics.

3.8.5 Spooled tubing will be monitored to ensure that no air bubbles are trapped at the top of a coil. Trapped air bubbles can enhance volatilization of organics.

3.8.6 If a dedicated bladder pump is used, follow steps 3.8.2.3 through 3.8.2.5. for purging and sampling.

4.0 Maintenance

Refer to manufacturer's requirements for maintenance of pumps and generators.

5.0 Precautions

Refer to the HASP for appropriate PPE.

6.0 References

Gass, Taylor E.; Barker, James F.; Dickhout, R.; Fyfe, J. S.; 1991, Test Results of the Grundfos Ground-water Sampling Pump, From: "Proceedings of the Fifth National Symposium on Aquifer Restoration and Ground Water Monitoring"

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USATHAMA. 1990. Installation Restoration Quality Assurance Program, December 1985, 1st edition, March 1987, 2nd edition).

STANDARD OPERATING PROCEDURE 014
COLLECTION OF PRODUCTION WELL SAMPLES

1.0 Scope and Application

The purpose of this standard operating procedure is to delineate protocols for the collection of groundwater samples from production wells. This protocol will allow for collection of samples from both active production wells (§ 3.4) and inactive production wells (§ 3.10).

2.0 Material

- a. Conductivity meter
- b. Temperature meter
- c. pH meter
- d. Turbidity meter
- e. ORD probe
- f. Dissolved oxygen meter
- g. Sample bottles and labels
- h. Logbook or field parameter form

3.0 Procedure

3.1 Upon arrival at the well site, immediately set up and organize the sampling and ancillary equipment. If needed, due to muddy or contaminated ground and/or remoteness from sampling vehicle place plastic sheeting at, or around the sampling location as conditions warrant. Exercise caution not to step on and contaminate the sheeting.

3.2 If the well is remote from the sampling vehicle set up the filtration equipment and place sample containers on the plastic sheet, uphill of the sampling location.

3.3 If a pump is to be used for filtration, situate the portable generator on level ground approximately 15 feet away from and downwind from the sampling location. All generator maintenance (oil and fueling) is to be preformed off site.

3.4 If the well is currently in use. As close as possible to the well, open a tap to a high flow rate and allow the well to purge.

3.5 Obtain a sample of groundwater for temperature, conductivity, ORD, DO, turbidity, and pH measurements. Record values in sampling logbook.

3.6 Take samples for physical stabilization (water quality) parameters every 5 minutes during the well purging process.

3.7 Allow the well to purge until the water quality parameters of pH, temperature, conductivity, turbidity, oxidation-reduction potential, and dissolved oxygen measurements stabilize within 10% in three consecutive 5-minute sampling periods, purging will be considered complete and sampling may proceed.

3.8 Slow water flow rate to a trickle.

3.9 For procedures for collecting samples, with the exception of the sample source being a bailer: Refer to SOP 013 3.2.1; 3.5.1 and 3.5.3 through 3.5.8.

3.10 If the well is not currently in use. Use a pump and bailer, or low-flow pump for sampling. Refer to SOP 013 for purging and sampling protocol.

3.11 decontaminate equipment

3.12 Refer to SOP 1-5, 13, and 16.

4.0 Maintenance

Not applicable.

5.0 Precautions

Not applicable.

6.0 References

USATHAMA. 1990. Installation Restoration Quality Assurance Program, December 1985, 1st edition, March 1987, 2nd edition).

STANDARD OPERATING PROCEDURE 015
DOCUMENT CONTROL SYSTEM

1.0 Scope and Application

The purpose of this standard operating procedure is to delineate protocols for identifying and storing a complete set of documents relating to project tasks. Each document will receive a unique identification number made up of elements describing the document.

2.0 Materials

Not applicable.

3.0 Procedure

3.1 Each project-related document will be given to the Document Control Officer.

3.2 The Document Control Officer will record information for each document on a Document Control Sheet which will be retained as a backup record.

3.3 The information from each Document Control Sheet will be maintained in a computer database.

3.4 The individual Document Control Number will be entered on the Document Log Sheet and will be written on the document.

3.5 The storage location for each document will be recorded on the Document Control Logsheet and the documents will be stored in the recorded location.

3.6 The database file will be backed up on a regular basis to prevent accidental loss of the data.

4.0 Maintenance

Not Applicable.

5.0 Precautions

None.

6.0 References

None.

STANDARD OPERATING PROCEDURE 016
SURFACE WATER, GROUNDWATER, AND SOIL/SEDIMENT FIELD LOGBOOKS

1.0 SCOPE AND APPLICATION

The purpose of this standard operating procedure is to delineate protocols for recording surface water, groundwater, soil/sediment sampling information, as well as instrument calibration data in the Field Logbooks. Example forms are given. Alternate, equivalent forms are acceptable.

2.0 MATERIAL

a. Applicable Field Logbook
b. Indelible ink pen

3.0 PROCEDURE

All information pertinent to soil/sediment, groundwater, or surface water sampling will be recorded in the appropriate logbook. Each page/form of the logbook is consecutively numbered. All entries will be made with an indelible ink pen. All corrections will consist of line-out deletions that are initialed and dated.

A. Soil/Sediment Logbook

1. Field Parameters (refer to forms 16-a and b)

a. If using carbon paper or self-duplicating forms, before entering data in logbook, insert a sheet protector between form sets to isolate first blank form from remaining forms.

b. HIGH CONCENTRATION EXPECTED?: answer "Yes" or "No."

c. HIGH HAZARD?: answer "Yes" or "No."

d. INSTALLATION/SITE: record the complete name of the installation or site.

e. AREA: record the area designation of the sample site.

f. INST CODE: record the 2 letter installation code appropriate for the installation or site. Correct abbreviations can be found on pages 3-6 of the IRDMS User's Guide for chemical data entry.

g. FILE NAME: record "CSO" for a soil sample or "CSE" for a sediment sample.

h. SITE TYPE: record the abbreviation appropriate for where the sample was taken. Correct abbreviations can be found on pages 18-21 of the IRDMS User's Guide for chemical data entry. This entry must match the Site Type on the map file form.

i. SITE ID: record a code up to 10 characters or numbers which is unique to the site.

j. FIELD SAMPLE NUMBER: record a code specific for the sample.

k. DATE: enter the date the sample was taken.

l. TIME: enter the time (12 hour or 24 hour clock acceptable as long as internally consistent) the sample was taken.

m. AM PM: circle "AM" or "PM" to designate morning or afternoon (12 hour clock).

n. SAMPLE PROG: record "GQA" (Groundwater Quality Assessment) or other appropriate sample program.

o. DEPTH (TOP): record the total depth sampled.

p. DEPTH INTERVAL: record the intervals at which the plug will be sampled.

q. UNITS: record the units of depth (feet, meters)

r. SAMPLE MEASUREMENTS: check the appropriate sampling method.

s. CHK: check off each container released to a laboratory.

t. ANALYSIS: record the type of analysis to be performed on each sample container.

u. SAMPLE CONTAINER: record the sample container type and size.

v. NO.: record the number of containers.

w. REMARKS: record any remarks about the sample

x. TOTAL NUMBER OF CONTAINERS FOR SAMPLE: record the total number of containers.

y. SITE DESCRIPTION: describe the location where the sample was collected.

z. SAMPLE FORM: record the form of the sample (i.e., clay, loam, etc.) using The Unified Soil Classification System (USCS).

aa. COLOR: record the color of the sample as determined from standard Munsell Color Charts.

bb. ODOR: record the odor of the sample or "none". See SOP 001 § 5.0 "Precautions".

cc. PID (HNu): record the measured PID(HNu) values.

dd. UNUSUAL FEATURES: record anything unusual about the site or sample.

ee. WEATHER/TEMPERATURE: record the weather and temperature.

ff. SAMPLER: record your name.

2. Map File Form (refer to form 16-c)

   a. The mapfile logbook form will be located on the reverse of the field parameter logbook form, or on an adjoining page of the field logbook (if level book is used)

   b. SITE ID: record the Site ID from the field parameter form.

   c. POINTER: record the field sample number for the sample being pointed to.

   d. DESCRIPTION/MEASUREMENTS: describe the location where the sample was taken, along with distances to landmarks.

   e. SKETCH/DIMENSIONS: diagram the surroundings and record the distances to landmarks.

   f. MAP REFERENCE: record which U.S.G.S. Quad Map references the site.

   g. COORDINATE DEFINITION: write the compass directions the X- and Y-Coordinates of the map run.

   h. COORDINATE SYSTEM: write "UTM" (Universal Transverse Mercator).

   i. SOURCE: record the 1 digit code representing the Map Reference.

   j. ACCURACY: give units (*e.g.* write "1-M" for 1 meter).

   k. X-COORDINATE: record the X-Coordinate of the sample site location.

   l. Y-COORDINATE: record the Y-Coordinate of the sample site location.

   m. UNITS: record the units map sections are measured in.

   n. ELEVATION REFERENCE: record whether topography was determined from a map or a topographical survey.

- o. ELEVATION SOURCE: record the 1 digit code representing the elevation reference.
- p. ACCURACY: record the accuracy of the map or survey providing the topographical information.
- q. ELEVATION: record the elevation of the sampling site.
- r. UNITS: write the units in which the elevation is recorded.
- s. SAMPLER: write your name.

B. Surface Water Logbook (refer to form 16-b and c)

1. Field Parameter Logbook
    - a. CAL REF: record the calibration reference for the pH meter.
    - b. pH: record the pH of the sample.
    - c. TEMP: record the temperature of the sample in degrees Celsius.
    - d. COND: record the conductivity of the water.
    - e. For all other sections, see 3.B.1.
2. Map File Form - See 3.A.2.

C. Groundwater Logbook (refer to form 16-b and d)

1. Field Parameter form - See 3.B.1.
2. Map File form (refer to form 16-c)
    - a. WELL NO. OR ID: record the abbreviation appropriate for where the sample was taken. Correct abbreviations can be found on pages 18-21 of the IRDMS User's Guide for chemical data entry.
    - b. SAMPLE NO.: record the reference number of the sample.
    - c. WELL/SITE DESCRIPTION: describe the location where the sample was taken, along with distances to landmarks.
    - d. X-COORD and Y-COORD: record the survey coordinates for the sampling site.
    - e. ELEV: record the elevation where the sample was taken.

f. UNITS: record the units the elevation was recorded in.

g. DATE: record the date in the form MM/DD/YY.

h. TIME: record the time, including a designation of AM or PM.

i. AIR TEMP.: record the air temperature, including a designation of C or F (Celsius or Fahrenheit).

j. WELL DEPTH: record the depth of the well in feet and inches.

k. CASING HT.: record the height of the casing in feet and inches.

l. WATER DEPTH: record the depth (underground) of the water in feet and inches.

m. WELL DIAMETER: record the diameter of the well in inches.

n. WATER COLUMN HEIGHT: record the height of the water column in feet and inches.

o. SANDPACK DIAM.: record the diameter of the sandpack. Generally, this will be the same as the bore diameter.

p. EQUIVALENT VOLUME OF STANDING WATER: use one of the following equations, to determine one equivalent volume (EV):

1 EV = volume in casing + volume in saturated sand pack. Or to restate:

$$1\ \text{EV} = (\pi R_w^2 h_w + 0.30\pi(R_s^2 - R_w^2)h_s) * (0.0043)$$

where: R_s = radius of sandpack in inches
R_w = radius of well casing in inches
h_s = height of sandpack in inches
h_w = water depth in inches

$0.0043 = \text{gal/in}^3$
and filter pack porosity is assumed as 30%

– OR –

$$\text{Volume in casing} = (0.0043\ \text{gal/in}^3)(\pi)(12\ \text{in/ft})(R_c^2)(W_h)$$

where R_c = radius of casing in inches, and
W_h = water column height in feet

$$\text{Vol. in sandpack} = (0.0043\ \text{gal/in}^3)(\pi)(12\ \text{in/ft})(R_b^2 - R_c^2)(W_h)(0.30)$$

(if W_h is less than the length of the sandpack),

– PLUS –

$$\text{Vol. in sandpack} = (0.0043\ \text{gal/in}^3)(\pi)(12\ \text{in/ft})(R_b^2 - R_c^2)(S_h)(0.30)$$

(if W_h is greater than the length of the sandpack).

where R_b = radius of the borehole, and
S_h = length of the sandpack.

Show this calculation in the comments section.

q. VOLUME OF BAILER OR PUMP RATE: record bailer volume or pump rate.

r. TOTAL NUMBER OF BAILERS OR PUMP TIME: record the number of bailers required to remove 3 equivalent volumes (EV) of water from the well or the total purge time and volume as applicable.

s. WELL WENT DRY? write "YES" OR "NO."

t. NUMBER OF BAILERS OR PUMP TIME: record the number of bailers or pump time which made the well go dry.

u. VOLUME REMOVED: record the volume of water (gal) removed before the well went dry.

v. RECOVERY TIME: record the time required for the well to refill.

w. PURGE AGAIN?: answer "YES" or "NO."

x. TOTAL VOL. REMOVED: record the total volume of water (in gallons) removed from the well.

y. CAL REF.: record the calibration reference for the pH meter.

z. TIME: record time started (INITIAL T(0)), 2 times DURING the sampling and the time sampling ended (FINAL).

aa. pH: record the pH at start of sampling (INITIAL), twice DURING the sampling and at the end of sampling (FINAL).

bb. TEMP: record the water temperature (Celsius) at the start of sampling, twice DURING the sampling and at the end of sampling (FINAL).

cc. COND: record the conductivity of the water at the start of sampling, twice DURING the sampling and at the end of sampling (FINAL).

dd. D.O.: record the dissolved oxygen level in the water at the start of sampling, twice DURING the sampling and at the end of sampling (FINAL).

ee. TURBIDITY: record the readings from the turbidity meter (nephelometer) and units at the start of sampling, twice DURING the sampling and at the end of sampling (FINAL).

ff. ORD: record the oxidation/reduction(RedOx) potential of the water sample at the start of sampling, twice DURING the sampling and at the end of sampling (FINAL).

gg. HEAD SPACE: record any positive readings from organic vapor meter reading taken in well headspace prior to sampling.

hh. NAPL: Record the presence and thickness of any non aqueous phase liquids (LNAPL and DNAPL)

ii. COMMENTS: record any pertinent information not already covered in the form.

jj. SIGNATURE: sign the form.

D. Field Calibration Forms (refer to form 16-e)

a. Record time and date of calibration.

b. Record calibration standard reference number.

c. Record meter I.D. number

d. Record initial instrument reading, recalibration reading (if necessary), and final calibration reading on appropriate line.

e. Record value of reference standard (as required).

f. COMMENTS: Record any pertinent information not already covered on form.

g. SIGNATURE: sign form.

4.0 MAINTENANCE

Not Applicable.

5.0 PRECAUTIONS

None.

6.0 REFERENCES

User's Guide to the Contract Laboratory Program, USEPA, July, 1984.

FIELD PARAMETER/LOGBOOK FORM 16-a
SOIL AND SEDIMENT SAMPLES

HIGH CONCENTRATION EXPECTED? ____________________ HIGH HAZARD?

INSTALLATION/SITE ____________________ AREA __________

INST CODE __________ FILE NAME ____________________

SITE TYPE __________ SITE ID ____________________

FIELD SAMPLE NUMBER ____________________

DATE (MM/DD/YY) ___/___/___ TIME __________ AM PM SAMPLE PROG. ______

DEPTH (TOP) __________ DEPTH INTERVAL ____________________ UNIT ______

SAMPLING METHOD:

SPLIT SPOON ____ AUGER ____ SHELBY TUBE ____ SCOOP ____ OTHER __________

CHK	ANALYSIS	SAMPLE CONTAINER	NO.	REMARKS

TOTAL NUMBER OF CONTAINERS FOR SAMPLE __________

DESCRIPTION OF SITE AND SAMPLE CONDITIONS

SITE DESCRIPTION : ____________________

SAMPLE FORM ____________________ COLOR __________ ODOR __________

PID (HNu) ____________________ UNUSUAL FEATURES __________

WEATHER/TEMPERATURE ____________________

SAMPLER ____________________

FIELD PARAMETER/LOGBOOK FORM 16-b
GROUNDWATER AND SURFACE WATER SAMPLES

HIGH CONCENTRATION EXPECTED? ____________________ HIGH HAZARD? __________

INSTALLATION/SITE ____________________ AREA __________

INST CODE __________ FILE NAME ____________________ SITE TYPE __________

SITE ID ____________________ FIELD SAMPLE NUMBER __________

DATE (MM/DD/YY) ___/___/___ TIME __________ AM PM SAMPLE PROG. ______

DEPTH (TOP) __________ DEPTH INTERVAL __________ UNITS ______

SAMPLING MEASUREMENTS

CAL REF. ______ pH ______ TEMPERATURE °C ______ CONDUCTIVITY ______ OTHER __________

CHK	ANALYSIS	SAMPLE CONTAINER	NO.	REMARKS

TOTAL NUMBER OF CONTAINERS FOR SAMPLE __________

DESCRIPTION OF SITE AND SAMPLE CONDITIONS

SITE DESCRIPTION ____

____

____

SAMPLING METHOD ____

SAMPLE FORM ____________________ COLOR __________ ODOR __________

PID (HNu) ____

UNUSUAL FEATURES ____

WEATHER/TEMPERATURE ____________________ SAMPLER __________

MAP FILE LOGBOOK FORM 16-c
SURFACE WATER, SOIL, AND SEDIMENT SAMPLES

SITE ID ______________________ POINTER ____________

DESCRIPTION/MEASUREMENTS ______________________

____

____

____

SKETCH/DIMENSIONS :

MAP REFERENCE ______________________

COORDINATE DEFINITION (X is ____________ Y is ____________)

COORDINATE SYSTEM ____________ SOURCE ____________

ACCURACY ____________

X-COORDINATE ____________ Y-COORDINATE ____________ UNITS ________

ELEVATION REFERENCE ______________________

ELEVATION SOURCE ____________ ACCURACY ____________

ELEVATION ____________ UNITS ____________

SAMPLER ______________________

MAP FILE AND PURGING LOGBOOK FORM 16-d
GROUNDWATER SAMPLES

WELL COORD. OR ID ____________________ SAMPLE NO. __________

WELL/SITE DESCRIPTION ____________________

X-COORD. __________ Y-COORD. __________ ELEV. __________ UNITS ______

DATE ___/___/___ TIME __________ AIR TEMP. __________

WELL DEPTH ________ FT. ________ IN. CASING HT. ________ FT. ________ IN.

WATER DEPTH ________ FT. ________ IN. WELL DIAMETER ________ IN.

WATER COLUMN HEIGHT ________ FT. ________ IN. SANDPACK DIAM. ________ IN.

EQUIVALENT VOLUME OF STANDING WATER ____________ (GAL) (L)

VOLUME OF BAILER ________ (GAL) (L) or PUMP RATE ________ (GPM) (LPM)

TOTAL NO. OF BAILERS (5 EV) ________ or PUMP TIME ________ MIN.

WELL WENT DRY? [Yes] [No] NUM. OF BAILERS ________ or PUMP TIME ________

VOL. REMOVED ____________ (GAL) (L) RECOVERY TIME ________

PURGE AGAIN? [Yes] [No] TOTAL VOL. REMOVED ____________ (GAL) (L)

DATE & TIME	QUANTITY REMOVED	TIME REQ'D	pH	Cond	Temp	ORD	Turb	DO	Character of water (color / clarity / odor / partic.)
(before)									
(during)									
(during)									
(during									
(after)									

COMMENTS ____________________

SIGNATURE ____________________

EXAMPLE
FIELD CALIBRATION FORM 16-e
FOR
pH, CONDUCTIVITY, TEMPERATURE, TURBIDITY, ORD, AND DISSOLVED OXYGEN METERS

INITIAL CALIBRATION	FINAL CALIBRATION
DATE:	DATE:
TIME:	TIME:

pH METER CALIBRATION

CALIBRATION STANDARD REFERENCE NO: ____________

METER ID

pH STANDARD	INITIAL READING	RECALIB. READING	FINAL READING
7.0			
10.0			
4.0			

CONDUCTIVITY METER CALIBRATION

CALIBRATION STANDARD REFERENCE NO: ____________

METER ID

COND. STANDARD	INITIAL READING	RECALIB. READING	FINAL READING

TEMPERATURE METER CALIBRATION

METER ID

TEMP. STANDARD	INITIAL READING	RECALIB. READING	FINAL READING
ICE WATER			
BOILING WATER			
OTHER			

EXAMPLE
FIELD CALIBRATION FORM 16-e
FOR
pH, CONDUCTIVITY, TEMPERATURE, TURBIDITY, ORP, AND DISSOLVED OXYGEN METERS

TURBIDITY METER CALIBRATION

CALIBRATION STANDARD REFERENCE NO: ______________

METER ID

STANDARD	INITIAL READING	RECALIB. READING	FINAL READING

ORP METER CALIBRATION

CALIBRATION STANDARD REFERENCE NO: ______________

METER ID

STANDARD	INITIAL READING	RECALIB. READING	FINAL READING

DISSOLVED OXYGEN METER CALIBRATION

CALIBRATION STANDARD REFERENCE NO: ______________

METER ID

STANDARD	INITIAL READING	RECALIB. READING	FINAL READING

COMMENTS ____

____

____

____

SIGNATURE ______________________________

STANDARD OPERATING PROCEDURE 017
MONITORING WELL INSTALLATION

1.0 Scope and Application

The installation of monitoring wells is contingent upon the existing conditions at the project site. The purpose of this Standard Operating Procedure is to delineate the quality control measures required to ensure the accurate installation of monitoring wells. The applicable Cluster Work Plan or site Sampling Design Plan should be consulted for specific installation instructions. The term "monitoring wells", as used herein is defined to denote any environmental sampling well. Subsections 6.7 *et seq.* and 6.8 *et seq.* of the Field Investigation Plan, as well as sections 1, 2, 3, and 6 of the Field Sampling Plan (Appendix A) are included by reference. Example well log forms are given at the end of this SOP. Alternate, equivalent forms are acceptable.

2.0 Material

2.1 Drilling Equipment

a. Appropriately sized drill adequately equipped with augers, bits, drill stem, etc.
b. Steam cleaner and water obtained from approved source for decontaminating drilling equipment.
c. PID: Microtip HL-200 (or equivalent)
d. Water level indicator
e. Weighted Steel tape measure
f. LEL-Oxygen monitor
g. Steel drums for intrusion derived wastes (drill cuttings, contaminated PPE, decon solutions, etc.)
h. Source of approved water
i. Heavy plastic sheeting
j. Sorbent pads and/or log

2.2 Well Installation Materials [1]

a. Well screen : [2]

PVC: JOHNSON (or equivalent); PVC Vee Wire Continuous slot, wire wrapped screen;

---

[1] Technical information on all installed materials (screens, riser pipe, filter pack, bentonite, cement, etc.) and representative samples of the proposed filter pack, bentonite powder, and bentonite pellets will be supplied to the Contracting Officer's Representative (COR).

[2] Well screen slot size and filter pack gradation will be determined from sieve analysis of aquifer materials. Screen and casing material type will be determined based on field tests of groundwater chemistry and contaminants.

4-inch diam.; SCH 40; flush-threaded (leak-proof) joints; PVC complies with ASTM D2665, ASTM D1784, and ASTM F480; free of ink markings; cleaned and prepackaged by manufacturer

Stainless Steel: JOHNSON (or equivalent); Stainless steel Vee-Wire Continuous slot, wire wrapped screen; 304 stainless steel [3]; ASTM F480 flush threads; cleaned, wrapped, and heat sealed by manufacturer.

b. Riser pipe:

PVC: JOHNSON (or equivalent); STD. PVC; 4-inch diam.; SCH 40; flush-threaded (leak-proof) joints; PVC complies with ASTM D2665, ASTM D1784, and ASTM F480; free of ink markings; cleaned and prepackaged by manufacturer

Stainless Steel: JOHNSON (or equivalent); SCH 5; 304 stainless steel; ASTM type A312 material; 4-inch diam.; cleaned, wrapped and heat sealed by manufacturer.

c. Plugs/Caps: JOHNSON (or equivalent); standard PVC or stainless steel
d. Filter pack: MORIE, 100 well gravel (or equivalent) Note: final gradation may vary as a function of the gradation of the formation (see footnote 2)
e. Fine Ottawa sand
f. Bentonite seal: BAROID, bentonite pellets (3/8-inch diam.)
g. Cement: Type II Portland Cement (see table 19-1)
h. Bentonite powder: BAROID, Aquagel Gold Seal
i. Steel Protective Casing: BRAINARD-KILMAN (or equivalent) zinc-plated steel, lockable, painted.[4]
j. Geotextile: MIRAFI (or equivalent); GTF 130; non-woven; 4 oz.
k. Coarse (blanket) gravel: Crushed stone aggregate
l. Containers for purged water, as required.
m. Submersible pump or bailer of appropriate capacity, and surge block sized to fit well
n. Hach DREL 2000 portable laboratory (or equivalent)
o. Conductivity, pH, ORD, turbidity, dissolved oxygen, and temperature meters
p. Electric well sounder and measuring tape.
q. Portland Type II cement (see table 19-1)
r. Steel Posts (pickets), Painted (see footnote)

2.3 Documentation

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[3] Unless the sum of Cl^-, F^-, and Br^- is >1000ppm, in which case type 316 should be used (see also "Field Investigation Plan" Section 6.8.6 and Appendix A, "Field Sampling Plan" § 3.3.2.)

[4] All painted components (protector casing, steel pickets) will be painted high-visibility orange and allowed to dry completely prior to being brought onsite.

a. Copy of appropriate Cluster Work Plan
b. Copy of Section 6 "Field Investigation Plan'
c. Copy of Appendix A 'Field Sampling Plan"
d. Copy of approved Health And Safety Plan
e. Copies of well and excavation permits
f. Copies of SOPs 003, 005, 008-012, 019(this SOP), 023, 024, and 028
g. Boring log forms
h. Well completion diagram form
i. Well development form

2.4 Geologist's personal equipment

a. 1OX handlens
b. Unified Soil classification System chart
c. Munsell color chart
d. Sieve set (Keck model SS-81 or equivalent)
e. PPE as required by HASP

3.0 Procedure

3.1 Materials Approval

3.1.1 Water sources for drilling, grouting, sealing, filter placement, well installation, and equipment decontamination must be approved by the COR prior to arrival of the drilling equipment. Information required for the water source includes: water source, manufacturer/owner, address and telephone number, type of treatment and filtration prior to tap, time of access, Cost per gallon (if applicable), dates and results associated with all available chemical analyses over the past two years, and the name and address of the analytical laboratory (if applicable).

3.1.2 Pure sodium bentonite with no additives (bentonite) will be the only drilling fluid additive allowed, and its use must be approved by the COR prior to the arrival of the drilling equipment. The information required for evaluation includes: brand name, manufacturer, manufacturer's address and telephone number, product description, and intended use for the product.

3.1.3 Granular Filter Pack material must be approved by the COR prior to drilling. A one-pint representative sample must be supplied to the COR. Information required includes: lithology, grain size distribution, brand name, source, processing method, and slot size of intended screen.

3.1.4 Portland Type II cement will be used for grout (see table 19-1).

3.2 Drilling

3.2.1 The objective of the selected drilling technique is To ensure that the drilling method provides representative data while minimizing subsurface contamination, cross contamination of aquifers, and drilling costs. The preferred drilling method is with hollow stem auger. Other drilling methods [5] are approved as conditions warrant, and will not require variances be issued by EPA and MDE. The method used at a specific site will be proposed in the work plan and evaluated by the COR. Any drilling method not listed herein will require approval on a case by case basis by MDE and EPA.

3.2.2 A Site Geologist will be present during all well drilling and installation activities and will fully characterize all tasks performed in support of these activities into the monitoring well logbook. The Site Geologist will be responsible at only one operating rig for the logging of samples, monitoring of drilling operations, recording of water losses/gains and groundwater data, preparing the boring logs and well diagrams, and recording the well installation procedures of the rig. The Site Geologist will have onsite sufficient equipment in operable condition to perform efficiently his/her duties as outlined in the Field Investigation Plan (Section 6), and the Field Sampling Plan (Appendix A), and other contractual documents. Items in the possession of each Site Geologist will include, copies of Section 6, Appendix A, the approved HASP, this SOP, a hand lens (10X), a standard color chart, grain-size chart, and a weighted (with steel or iron) steel tape long enough to measure the deepest well, heavy enough to reach that depth, and small enough to fit readily within the annulus between the well and drill casing. The Site Geologist will also have onsite, a water level measuring device, preferably electrical.

3.2.3 Only solid vegetable shortening (*e.g.* Crisco®) without flavoring or additives may be used on downhole drilling equipment. Additives containing either lead or copper will not be allowed. In addition, polychlorinated biphenyls will not be permitted in hydraulic fluids or other fluids used in the drilling rig, pumps, or other field equipment and vehicles.

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[5] If the design depth of the well is < 100 ft., open, hollow stem augers will be used to drill the well unless "running sands" preclude the use of open augers. In that case, an inert "knockout" plug may be used in the bottom of the auger string. This plug will be driven out of the augers and left at the bottom of the hole when the well is installed.

If the design depth of the well is > 100 ft., rotary drilling methods may be used to install wells. The following drill fluids and methods are approved in the order listed: 1) Rotary drilling with water from an approved source as drilling fluid. Clays from the formations will tend thicken the fluid and coat the walls of the borehole and this is acceptable. 2) Rotary drilling with water as a fluid, advancing a temporary casing with the bit to maintain an open hole. 3) Mud rotary using water with additives as drill fluid. Due to the potential for aquifer contamination and plugging, mud rotary drilling is not recommended for monitoring wells. If; however, "running sands" are encountered and the aquifer is expected to have a relatively high flow rate, then mud rotary is considered an approved method. Pure sodium bentonite is the only approved additive. Mud rotary drilling must be halted at the last aquitard above the target aquifer. Casing must be set, all bentonite-bearing fluids flushed from the hole and drill rig, and drilling may be resumed using water only as the drill fluid until the target depth is reached.

3.2.4 Surface runoff or other fluids will not be allowed to enter any boring or well during or after drilling/construction.

3.2.5 Antifreeze used to keep equipment from freezing will not contain rust inhibitors and sealants. Antifreeze is prohibited in an areas in contact with drilling fluid. The ground surface at the well site will be protected from possible coolant, fuel, and hydraulic fluid spills and/or leakage by placement of plastic sheeting with raised edges, draining into a lined catch basin large enough to contain spills and/or leakage from motors, radiators, or vehicle tanks. Sorbent pillows will be placed to catch obvious leaks from the drill rig. Sorbent logs may be used instead of, or in conjunction with a lined catch basin to contain spills.

3.2.6 An accurate measurement of the water level will be made upon encountering water in the borehole and later upon stabilization. Levels will be periodically checked throughout the course of drilling. Any unusual change in the water level in the hole such as a sudden rise of a few inches may indicate artesian pressure in a confined aquifer will be the basis for cessation of drilling. The geologist will immediately contact his/her supervisor [6]. Particular attention for such water-level changes will be given after penetrating any clay or silt bed, regardless of thickness, which has the potential to act as a confining layer.

Anticipated depths of wells are given in well specific work plans (*e.g.* Appendix I). In case the previously defined criteria have not been met before the depth range for a given hole is reached, the geologist will stop the drilling and confer with her/his supervisor. The current boring conditions (depth, nature of the stratigraphic unit, and water-table depth) will be compared to those of other wells nearby to decide to continue drilling or to terminate and complete the well.

3.2.7 **<u>If the well is to be installed in the surficial aquifer:</u>** Drilling will be terminated before penetrating the basal aquitard. The basal aquitard is defined as the first 2 foot-thick clay below the water table, or below 5 feet in the case of a shallow aquifer (Field Investigation Plan, § 6.7.3)

3.2.8 **<u>If the well is to be installed in a lower, confined aquifer:</u>**

3.2.8.1 Penetrations of aquifers located lower than the water table aquifer will be limited to avoid cross-contamination.

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[6] The USACE Waterways Experiment Station (WES) may also be contacted for guidance. The WES project manager is Dr. James May (601) 634-3395. He also exercises direct technical oversight of the Lauderick Creek Study Area. Mr. Danny Harrelson (601) 634-2685 has technical oversight of the Westwood Study Area. Dr. Robert Larson (601) 634-3201 has technical oversight of the Bush River Study Area.

3.2.8.2 Placement of new upper confined aquifer wells will be initially limited to those areas where contamination has been confirmed.

3.2.8.3 The location of upper confined aquifer wells will be based upon the findings of the water-table aquifer investigation. Areas of known contamination will be targeted for installing upper confined aquifer wells for the purposes of delineating vertical contamination.

3.2.8.4 Where possible, upper-confined aquifer wells will be located such that they afford triangulation with other wells within the same aquifer to allow for a determination of ground-water flow direction.

3.2.8.5 Some upper-confined aquifer wells will be installed approximately 10-15 ft from water-table wells to enable the accurate assessment of vertical hydraulic gradients. If the direction of ground-water flow is known, wells within a group will be located sidegradient of each other.

3.2.8.6 The boring will be advanced until the base of the surficial aquifer is reached (see § 3.2.7).

3.2.8.7 An outer, surface casing will be set 2 to 5 ft into the confining layer to minimize the potential for cross-contamination from the unconfined aquifer during drilling activities.

3.2.8.8 The surface casing will be driven into the confining bed and grouted into place. A grout plug at least 2 feet thick will be tremied into the bottom of the surface casing. The grout will be permitted to cure for 24 hours. All drilling fluids within the surface calling will then be removed, and the casing will be flushed with clean potable water.

3.2.8.9 The drilling equipment will be decontaminated, a smaller bit or auger selected, and the hole will be continued through the grout plug into the confined aquifer.

3.2.8.10 If deeper aquifers are to be screened, repeat preceding steps until total depth is reached.

3.2.9 **<u>If DNAPL contamination is detected during drilling</u>**, the well will be terminated and completed at the base of the aquifer. Drilling will not continue through the confining unit.

3.2.9.1 Stainless steel screens will be used in DNAPL wells. Screen size selection will be according to criteria set forth in § 3.4.3.2 (below). The formation grain size will be multiplied by the higher factor (6) to determine filterpack grain size.

This will ensure that the filterpack is sufficiently coarse to permit DNAPL to pass freely from the formation into the coarser filterpack, then into the open well (Cohen and Mercer, 1993).

3.2.9.2 DNAPL sampling cups are prohibited. The well screen will be capped, and set 0.3 ft (0.5 ft max.) into the top of the confining bed and rest on the bottom of the hole or bentonite backfill (if used). No sand will be placed below the screen.

3.2.9.3 The remainder of the well installation and completion will be accomplished according to section 3.4.

3.3 Logging

3.3.1 All borings for monitoring wells will be logged by a geologist. Logs will be recorded in a field logbook and/or a boring log. If the information is recorded in a logbook, it will be transferred to Boring Log Forms on a daily basis. Field notes are to include, as a minimum:

a. Boring Number
b. Material Description (as discussed below)
c. Weather conditions
d. Evidence of Contamination
e. Water Conditions (including measured water levels)
f. Daily Drilling Footage and Quantities (for billing purposes)
g. Notations on Man-Placed Materials
h. Drilling Method and Bore Hole Diameter
i. Any Deviations from Established Field Plans
i. Blow Counts for Standard Penetration Tests
k. Core and Split-Spoon Recoveries

3.3.2 Material description for soil samples must include:

a. Classification
b. Unified Soil Classification Symbol
c. Secondary Components and Estimated Percentages
d. Color
e. Plasticity
f. Consistency
g. Density
h. Moisture Content
i. Texture/Fabric/Bedding and Orientation
j. Grain Angularity
k. Depositional Environment and Formation
l. Incidental odors
m. OVA reading(s)

n. Staining

3.3.3 Material description for rock samples must include:

a. Classification
b. Lithologic Characteristics
c. Bedding/Banding Characteristics
d. Color
e. Hardness
f. Degree of Cementation
g. Texture
h. Structure and Orientation
i. Degree of Weathering
i. Solution or Void Conditions
k. Primary and Secondary Permeability
l. Sample Recovery
m. Incidental odors
n. OVA reading(s)
o. Staining

See also SOP003 and SOP016 for details on logbook entries.

3.4 Well Construction and Installation

After the hole is drilled and logged, backfill hole as required for proper screen placement. The integrity of the aquitard will be restored by placing a bentonite plug of an appropriate thickness, either to the top of the aquitard (normal well installation) or to within 0.3 ft of the top of the aqitard (DNAPL well). Aquifer fill will be clean filter pack.

Normal screen placement for the water table (surficial) aquifer will be with 2 ft of the screen extending above the static water level. The bottom of the screen will rest no more than 6 in. from the bottom of the hole or backfill material, whichever is applicable.

Note: the end cap in DNAPL wells will rest on the bottom of the bottom of the hole, or bentonite backfill if applicable. (see § 3.2.9.2 above)

Screen placement for a confined aquifer well will normally be at the top of the confined aquifer.

3.4.1 Screen lengths will not normally exceed 10 feet. If it appears advantageous in a given situation (e.a. to screen an entire aquifer which is thicker than 10 feet, approval must be sought on a case-by-case basis from MDE and EPA. Otherwise, wells will be screened as follows:

Thickness of Aquifer:	Action:
< 10'	Screen entire aquifer
> 10' < 30'	screen top 10' consider vertically nested well cluster
> 30'	install vertically nested well cluster

3.4.2 The installation of monitoring wells in uncased or partially cased holes will begin within 12 hours of completion of drilling, or if the hole is to be logged, within 12 hours of well logging, and within 48 hours for holes fully cased with temporary drill casings. once installation hall begun, work will continue until the well has been grouted and the drill casing has been removed. Exceptions MUST be requested in writing by the contractor to the Contracting officer's Representative prior to drilling. Unscheduled delays attributable to unforeseeable site occurrences will not require advance approval.

3.4.3 Well screens, casings, and fittings will conform to National Sanitation Foundation Standard 14 or American Society for Testing and Materials (ASTM) equivalent for potable water usage. These materials will bear the appropriate rating logo. If the logos are not present, a written statement from the manufacturer/supplier stating that the materials contain the appropriate rating must be obtained. Material used will be new and essentially chemically inert to the site environment.

3.4.3.1 Well screen and casing should be inert with respect to the ground water; therefore, the selection of screen and casing material will be based on select field tests of aquifer chemistry and potential contaminants as delineated in Appendix A, Table A.3.1. The screen will be capped without sediment trap or DNAPL sampling cup, and lowered into the hole. The well casing will be precut to extend 2 to 2.5 ft above the ground surface. Prior to placement of the last piece of well casing, a notch or other permanent reference point will be cut, filed, or scribed into the top edge of the casing.

3.4.3.2 Screen slot size will be appropriately sized to retain 90 to 100% of the filter pack material, the size of which will be determined by sieve analysis of formational material (See § 3.4.3.2).

3.4.3.3 The tops of all well casing will be capped with covers composed of materials compatible with the products used in the well installation. Caps may either be vented, or a telescopic fit, constructed to preclude binding to the well casing caused by tightness of fit, unclean surfaces, or weather conditions. In either case it should be secure enough to preclude the introduction of foreign material into the well, yet allow pressure equalization between the well and the atmosphere.

3.4.4 Filter pack material will be placed, lightly tamped and leveled. Filter pack will extend from the bottom of the hole to a height of 1-2 ft above the top of the screen. The filter pack will be capped with a minimum of 1 ft of fine (Ottawa) sand to prevent the bentonite seal from infiltrating the filter pack. If the bentonite seal is placed as a slurry, a minimum of 2 ft of fine sand will be required.

If the hole is less than 20 ft deep, the filter pack may be poured into the annulus directly. If the hole is deeper than 20 ft, the filter pack must be tremied into place.

3.4.4.1 Granular filter packs will be chemically and texturally clean, inert, and siliceous.

3.4.4.2 Filter pack grain size will be based on formation grain-size analysis. The D30 (70% retained) sieve size multiplied by a factor of not less than 3 nor greater than 6 will be used to determine the appropriate grain size.

3.4.4.3 Calculations regarding filter pack volumes will be entered into the Field Logbook along with any discrepancies between calculated and actual volumes used. If a discrepancy of greater than 10% exists between calculated and actual volumes exists, an explanation for the discrepancy will also be entered in the Logbook.

3.4.5 Bentonite seals will be no less than two feet nor more than five feet thick as measured immediately after placement. The normal installation will include a five foot seal. Thinner seals may be used in special cases as defined in Section 3.12 of Appendix A. The final depth to the top of the bentonite seal will be measured and recorded.

3.4.6 GROUT

Grout used in construction will be composed by weight of:

- 20 parts cement (Portland cement, type II)(see table 19-1)
- 0.4 to 1 part (max.)(2-5%) bentonite
- 8-gallons (max.) approved water per 94-lb bag of cement.

Neither additives nor borehole cuttings will be mixed with the grout. Bentonite will be added after the required amount of cement is mixed with the water.

3.4.6.1 All grout material will be combined in an above-ground container and mechanically blended to produce a thick, lump-free mixture. The mixed grout will be recirculated through the grout pump prior to placement.

3.4.6.2 Grout placement will be performed using a commercially available grout pump and a rigid, side discharge tremie pipe.

3.4.6.3 The following will be noted in the Field Logbook: 1) calculations of predicted grout volumes, 2) exact amounts of cement, bentonite, and water used in mixing grout, c) actual volume of grout placed in the hole, d) any discrepancies between calculated and actual volumes used. If a discrepancy of greater than 10% exists between calculated and actual volumes exists, an explanation for the discrepancy will also be entered in the Logbook.

3.4.7 Well protective casings will be installed around all monitoring wells on the same day as the initial grout placement around the well. Any annulus formed between the outside of the protective casing and the borehole will be filled to ground surface with cement.

3.4.8 The construction of each well will be depicted as built in a well construction diagram. The diagram will be attached to the boring log and will graphically denote:

a. Screen location, length
b. Joint location
c. Granular filter pack
d. Seal
e. Grout
f. Cave-in
g. Centralizers
h. Height of riser
i. Protective casing detail

3.5 Monitoring well completion

3.5.1 Assemble appropriate decontaminated lengths of pipe and screen. Make sure these are clean and free of grease, soil, and residue.

3.5.2 Lower each section of pipe and screen into the borehole, one at a time, screwing each section securely into the section below it. No grease, lubricant, polytetrafluoroethelyne (PTFE) tape or glue, may be used in joining the pipe and screen sections.

3.5.3 If a well extends below 50 ft, centralizers will be installed at 50 ft and every 50 ft thereafter except within screened interval and bentonite seal. Centralizer material will be PVC, PTFE, or stainless steel. Determination of centralizer material will be based on the same criteria as screen and calling selection (see Field Investigation Plan, Section 6.8)

3.5.4 Cut the riser with a pipe cutter approximately 2-2.5 ft above grade. All pipe cuts MUST be square to ensure that the elevation between the highest and lowest point of the well casing is less than or equal to 0.02 ft Notch, file, or otherwise permanently scribe a permanent reference point on the top of the casing.

Torches and saws may not be used to cut the riser. Care must be taken that all filings or trimmings cut from the reference point fall outside the riser rather than into the well. Under no circumstances will a permanent marker or paint pencil be used to mark the reference point.

In some locations, range safety requirements may mandate that a well be flush-mounted with no stick-up. If a flush-mounted well is required at a given location, an internal pressure cap must be used instead of a vented cap to ensure that rainwater cannot pool around the wellhead and enter the well through the cap.

3.5.5 When the well is set to the bottom of the hole, temporarily place a cap on top of the pipe to keep the well interior clean.

3.5.6 Place the appropriate filter pack (§ 3.4.4). Monitor the rise annulus with a weighted tape to assure that bridging is not occurring.

3.5.7 After the pack is in place, wait three to five minutes for the material to settle, tamp and level a capped PVC pipe, and check its depth weighted steel tape.

3.5.8 Add a 1-2 foot cap of fine-grained (Ottawa) sand to prevent infiltration of the filterpack by overlying bentonite seal. See §3.4.4 for guidance on appropriate thickness of fine sand layer.

3.5.9 Install the bentonite seal (2 ft to 5 ft thick) by dropping bentonite pellets into the hole gradually. If the well is deeper than 30 feet, a tremie pipe will be used to place either bentonite pellets or slurry. Tamp and level pellets. If the well is ≤ 30 ft, tamp with a capped PVC pipe, if > 30 ft, tamping bay be accomplished with the weighted end of the tape. In either case, check the depth to the top of the seal with a weighted tape as above.

If the bentonite pellets are of poor quality, they may have a tendency to hydrate and swell inside the tremie pipe and bridge. This situation may be solved by the following procedure:

a. Use a different brand of pellets. Different brands may have longer hydration times.

b. Freeze the pellets[7]. Note that this will require a longer wait-time to allow proper hydration after the pellets thaw.

c. Place the bentonite seal as a slurry using a side-discharge tremie pipe as though installing grout. Note (§ 3.4.4) this will require that a minimum of 2 ft fine sand be placed as a cap on top of the filter pack material.

---

[7] Bentonite pellets may be "flash-frozen" by brief immersion in liquid nitrogen (LN2). This can be accomplished by pouring LN2 over a small quantity (¼ to ½ bucket) of pellets, allowing the LN2 to boil off, then pouring the pellets into the tremie pipe. **NOTE:** use of LN2 is an additional jobsite hazard and must be addressed in the contractor's HASP. This contingency must be covered before drilling starts in order to avoid delays in well installation.

3.5.10 Wait a for the pellets to hydrate and swell. Hydration times will be determined by field test or by manufacturer's instructions. Normally this will be 30 to 60 minutes. Document the hydration time in the field notebook. If the pellets are above the water level in the hole, add several buckets of clean water to the boring. Document the amount of water added to the hole.

3.5.11 Mix an appropriate cement-bentonite slurry (§ 3.4.6). Be sure the mixture is thoroughly mixed and as thick as is practicable.

3.5.12 Lower a side discharge tremie pipe into the annulus to the level of the pellet seal.

3.5.13 Pump the grout slurry into the annulus while withdrawing the tremie pipe and temporary casing.

3.5.14 Stop the grout fill at 5 feet below the ground surface. Allow to cure for not less than 12 hours. If grout settles more than 6-in., add grout to bring level back up to within 5-ft. of ground surface. Place approximately 2 ft of bentonite pellets (minimum 0.5 ft) in annulus. Seat the protective casing in the bentonite seal, allowing no more than 0.2 ft between the top of the well casing and the bottom of the protective casing cap. Fill inner annulus (between well casing and protective casing) with bentonite pellets to the level of the ground surface. Cover bentonite pellets with 1 ft of clean granular material (coarse sand or pea gravel filter pack). Fill the outer annulus (between the protective casing and the borehole) with neat cement. Allow the cement to mound above ground level and finish to slope away from the casing. Lock the cap.

-or-

3.5.15 Continue the grout fill to the ground surface. Seat the protective casing in the grout, allowing no more than 0.2 - ft between the top of the well casing and the bottom of the protective casing cap. Lock the cap.

-and-

3.5.16 Allow the grout slurry to set overnight.

3.5.17 Fill the outer annulus (between the casing and the borehole) with neat cement. Allow the cement to mound above ground level and finish to slope away from the casing.

3.5.18 Slope the ground surface away from the casing for a distance of two feet, at a rate of no less than 1 inch in two feet. Surface this sloping pad with a geotextile mat covered by 3 in. of coarse gravel.

-or-

3.5.19 Frame and pour a 4 ft square by 6 in thick (4' X 4' X 6") concrete pad centered around the protective casing.

-and-

3.5.20 Set pre-painted protective steel pickets (3 or 4) evenly around and 4 feet out from well. These pickets will be set into 2 ft-deep holes, the holes will then be filled with concrete, and if the pickets are not capped, they will be filled with concrete also.

3.6 Well Development

3.6.1 Well development is the process by which drilling fluids, solids, and other mobile particulates within the vicinity of the newly installed monitoring well have been removed while restoring the aquifer hydraulic conductivity. Development corrects any damage to or clogging of the aquifer caused by drilling, increases the porosity of the aquifer in the vicinity of the well, and stabilizes the formation and filter pack sands around the well screen.

3.6.2 Well development will be initiated after 48 consecutive hours but no longer than 7 calendar days following grouting and.or placement Of surface protection. The record of well development will be submitted to the Contracting Officer's Representative within three working days after well development is completed.

3.6.3 Two well development techniques - over pumping and surging will be employed in tandem. over pumping is simply pumping the well at a rate higher than recharge. Surging is the operation of a plunger up and down within the well casing similar to a piston in a cylinder.

3.6.4 Materials Required

a. Well Development Form
b. Boring Log and Well Completion Diagram for the well
c. Submersible pump or bailer of appropriate capacity, and surge block
d. Conductivity, pH, ORD, turbidity, dissolved oxygen, and temperature meters
e. Electric well sounder and measuring tape.
f. Containers for purged water, if required.

3.6.5 Summary of Procedures and Data Requirements.

3.6.5.1 Pump or bail the well to ensure that water flows into it, and to remove some of the fine materials from the well. Removal of a minimum of one equivalent volume (EV) is recommended at this point. The rate of removal should be high enough to stress the well by lowering the water level to approximately 1/2 its original level. If well recharge exceeds 15gpm, the requirement to lower the head will be waived.

3.6.5.2 Slowly lower a close-fitting surge block into the well until it rests below the static water level, but above the screened interval. (Note: this latter is not required in the case of an LNAPL well.)

3.6.5.3 Begin a gentle surging motion which will allow any material blocking the screen to break up, go into suspension, and move into the well. Continue surging for 5-10 minutes, remove surge block, and pump or bail the well, rapidly removing at least one EV.

3.6.5.4 Repeat previous step at successively lower levels within the well screen until the bottom of the well is reached. Note that development should always begin above, or at the top of, the screen and move progressively downward to prevent the surge block from becoming sand locked in the well casing. As development progresses, successive surging can be more vigorous and of longer duration as long as the amount of sediment in the screen is kept to a minimum.

3.6.5.5 Development is expected to take at least 2 hours in a small well installed in a clean sand, and may last several days in large wells, or in wells set in silts with low permeabilities.

3.6.5.6 Development will continue until little or no sediment can be pulled into the well, and target values for parameters listed in 3.6.4.9 (e.) (below) are met.

3.6.5.7 At a minimum, development will remove 3 to 5 development volumes (DV) of water. One DV is defined as (1) EV (see sop013 for calculation), plus (1) the amount of fluid lost during drilling, plus (1) the volume of water used in filter pack placement.

- **a.** Monitor water quality parameters (3.6.5.9 d) before beginning development procedures, and after removing 2, 2½, and 3 DV of water.
- **b.** If these parameters have stabilized over the three readings, the well will be considered developed.
- **c.** If the parameters have not stabilized after these three readings, continue pumping the well to develop, but stop surging. Monitor the stabilization parameters every ½ DV.
- **d.** When the parameters have stabilized over three consecutive readings at ½DV intervals, the well will be considered developed.

3.6.5.8 All water removed must be disposed of as directed by the Sampling Design Plan.

3.6.5.9 Record all data as required on a Well Development Record Form (see example), which is made a part of the complete Well Record. These data include:

a. Depths and dimensions of the well, the casing, and the screen, obtained from the Well Diagram.

b. Water losses and uses during drilling, obtained from the boring log for the well.

c. Water contained in the well, obtained from calculations found in SOP013, § 3.3.6

d. Measurements of the following indicator parameters: turbidity, pH, conductivity, oxidation-reduction (ORD, Redox) potential, dissolved oxygen, and temperature.

e. Target values for the indicator parameters listed above are as follows: pH - stabilize, conductivity - stabilize, ORD - stabilize, DO stabilize, temperature - stabilize, turbidity NTU 5 or stabilize. A value is considered to have stabilized then 3 consecutive readings taken at ½ DV intervals are within 10% of each other.

f. Notes on characteristics of the development water.

g. Data on the equipment and technique Used for development.

h. Estimated recharge rate and rate/quantity of water removal during development. (See SOP 013 section 3.2.)

3.7 Refer to SOP003 (Field Logbook), 005 (Decontamination), 008 - 012 and 036 038 (Instrumentation for Groundwater Parameters).

4.0 Maintenance

Not Applicable.

5.0 Precautions

Refer to the site-specific Health and Safety Plan for discussion of hazards and preventive measures during well development activities.

6.0 References

Aller, Linda, *et al.*, 1989. Handbook of Suggested Practices for the Design and Installation of Ground-Water Monitoring Wells, National Water Well Association

Cohen, Robert M., and Mercer, James W. 1993. DNAPL Site Evaluation, CRC Press, Inc.

COMAR 26.04.04 Well Construction

EPA Groundwater Handbook 1989

Nielsen, David M., 1993. Correct Well Design Improves Monitoring, in "Environmental Protection", Vol.4, No.7, July, 1993.

USATHAMA. 1987. Geotechnical Requirements for Drilling, Monitoring Wells, Data Acquisition, and Reports, March 1987.

ASTM D 2487-92 Standard Classification of Soils for Engineering Purposes (Unified Soil Classification System)

ASTM D 5092-90 Standard Practice for Design and Installation of Ground Water Monitoring Wells in Aquifers

Cement Type	Special Characteristics	Recommended Usage
I	No special properties.	General use as grout mix or cement plug (if sulfates <250 ppm), surface pad.
IA	Air-entraining Type I. (Note that air entrainment properties can be achieved by chemical admixtures.)	Air entrainment gives cement greater freeze-thaw resistance. Recommended for surface pads.
II	Moderate sulfate resistance, low heat of hydration.	General use as grout mix or cement plug where ground water sulfate >250 ppm and <1500 ppm, surface pad.
IIA	Air-entraining Type II	See type IA.
III	High early strength, high heat of hydration.	Elevated temperature can damage well casing and fracture grout/cement plugs. NOT RECOMMENDED.
IIIA	Air-entraining Type III	NOT RECOMMENDED.
IV	Low heat of hydration.	General use as grout mix or cement plug preferred type for well abandonment to ensure intact grout/cement plug.
V	High Sulfate resistance.	Use when ground water sulfate levels >1500 ppm.

Table 19-1 Portland Cement Types and Recommended Applications

WELL DESIGNATION: ____________________ DATE(S) OF INSTALLATION: ____/____/____

SITE GEOLOGIST: __________________________ DEVELOPMENT DATE(S): ____/____/____

STATIC WATER LEVELS BEFORE AND AFTER DEVELOPMENT *:

BEFORE ____________ DATE __________ 24 HR. AFTER __________ DATE __________

DEPTH TO SEDIMENT BEFORE AND AFTER DEVELOPMENT *:

BEFORE ____________ DATE __________ 24 HR. AFTER __________ DATE __________

DEPTH TO WELL BOTTOM *: ________________ SCREEN LENGTH ______________

HEIGHT OF WELL CASING ABOVE GROUND SURFACE: __________________

QUANTITY OF MUD/WATER:

LOST DURING DRILLING	(+)____________________	gallons
REMOVED PRIOR TO WELL INSERTION	(-)____________________	gallons
LOST DURING THICK FLUID DISPLACEMENT	(+)____________________	gallons
ADDED DURING FILTER PACK PLACEMENT	(+)____________________	gallons
TOTAL LOSSES	____________________	gallons

(a) Water column ht. (ft.) ____________ (b) Well radius (in.) ____________

(c) Screen length (ft.) ____________ (d) Borehole radius (in.) ____________

(e) QUANTITY OF FLUID STANDING IN WELL $(12*a*\pi*b^2*0.0043)=$ __________ gallons

(Show Calculation)

(f) QUANTITY OF FLUID IN ANNULUS $[12*c*\pi 8(d^2-b^2)*0.0043*0.30]$ __________ gallons

(Show Calculation)

DEVELOPMENT VOLUME = (5 * TOTAL LOSSES) + [5 * (e + f)] = ____________ gallons

(Show Calculation)

*** ALL DEPTHS MEASURED FROM TOP OF WELL CASING**

EXAMPLE WELL DEVELOPMENT RECORD
(PAGE 2 OF 2)

WELL DESIGNATION ____________ DATE(S) OF DEVELOPMENT: ____/____/____

TYPE AND SIZE OF PUMP: ____

TYPE AND SIZE OF BAILER: ____

DESCRIPTION OF SURGE TECHNIQUE: ____
____

RECORD OF DEVELOPMENT

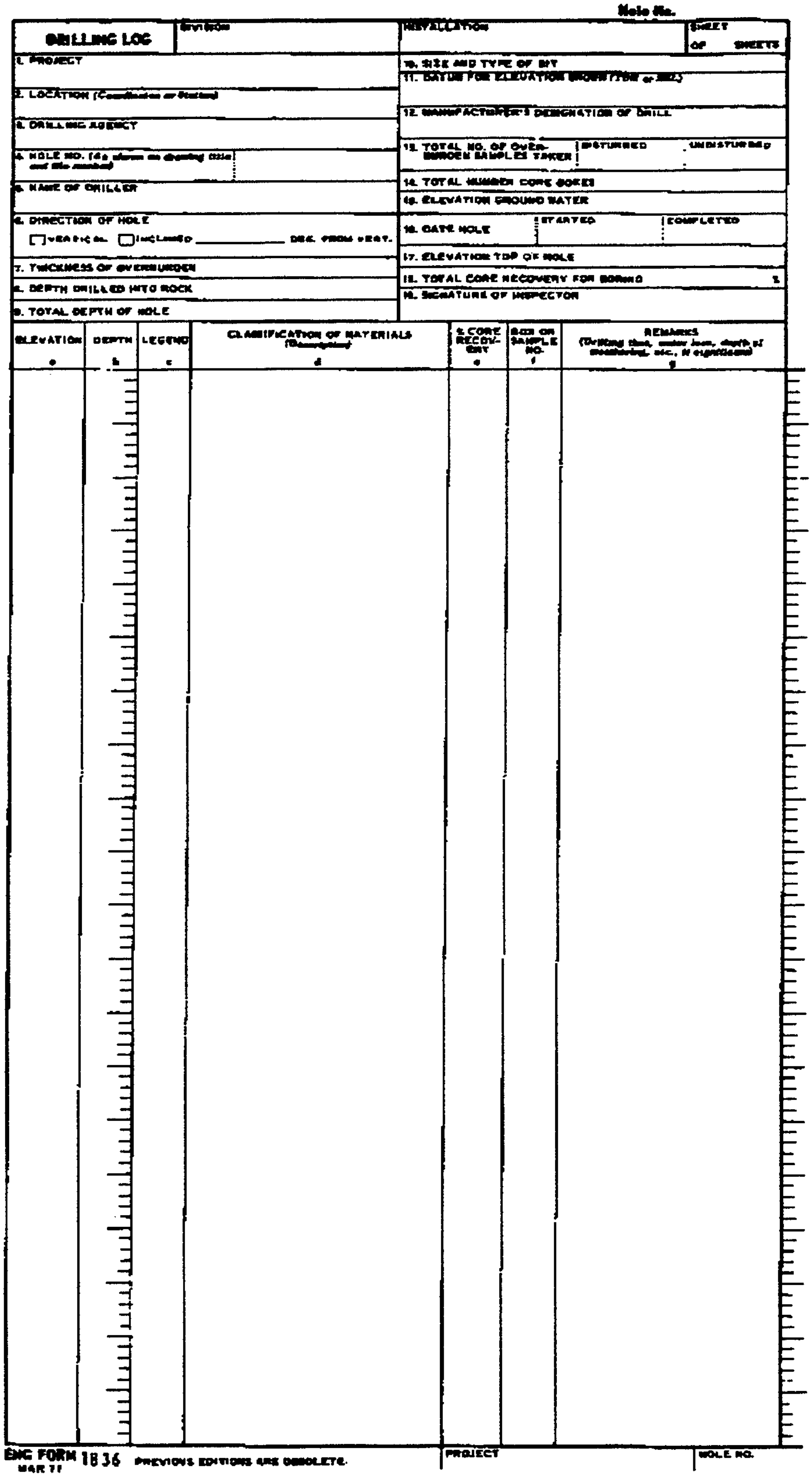
DATE & TIME	QUANTITY REMOVED	TIME REQ'D	pH	Cond	Temp	ORD	Turb	DO	Character of water (color / clarity / odor / partic.)
(before)									
(during)									
(during)									
(during									
(after)									

TYPICAL PUMPING RATE ________ GAL./HR. EST. RECHARGE RATE ______________

TOTAL QUANTITY OF WATER REMOVED ____________ TIME REQUIRED ______________

REMARKS ____
____
____

SIGNATURE OF SITE GEOLOGIST ______________________________



Hole No.

DRILLING LOG

DIVISION

INSTALLATION

SHEET
OF SHEETS

1. PROJECT

2. LOCATION (Coordinates or Station)

3. DRILLING AGENCY

4. HOLE NO. (As shown on drawing title and file number)

5. NAME OF DRILLER

6. DIRECTION OF HOLE

☐ VERTICAL ☐ INCLINED ______ DEG. FROM VERT.

7. THICKNESS OF OVERBURDEN

8. DEPTH DRILLED INTO ROCK

9. TOTAL DEPTH OF HOLE

10. SIZE AND TYPE OF BIT

11. DATUM FOR ELEVATION SHOWN (TBM or MSL)

12. MANUFACTURER'S DESIGNATION OF DRILL

13. TOTAL NO. OF OVERBURDEN SAMPLES TAKEN | DISTURBED | UNDISTURBED

14. TOTAL NUMBER CORE BOXES

15. ELEVATION GROUND WATER

16. DATE HOLE | STARTED | COMPLETED

17. ELEVATION TOP OF HOLE

18. TOTAL CORE RECOVERY FOR BORING %

19. SIGNATURE OF INSPECTOR

ELEVATION a	DEPTH b	LEGEND c	CLASSIFICATION OF MATERIALS (Description) d	% CORE RECOVERY e	BOX OR SAMPLE NO. f	REMARKS (Drilling time, water loss, depth of weathering, etc., if significant) g

ENG FORM 1836 PREVIOUS EDITIONS ARE OBSOLETE.
MAR 71

PROJECT

HOLE NO.

Figure 19.1. Example of well log form.

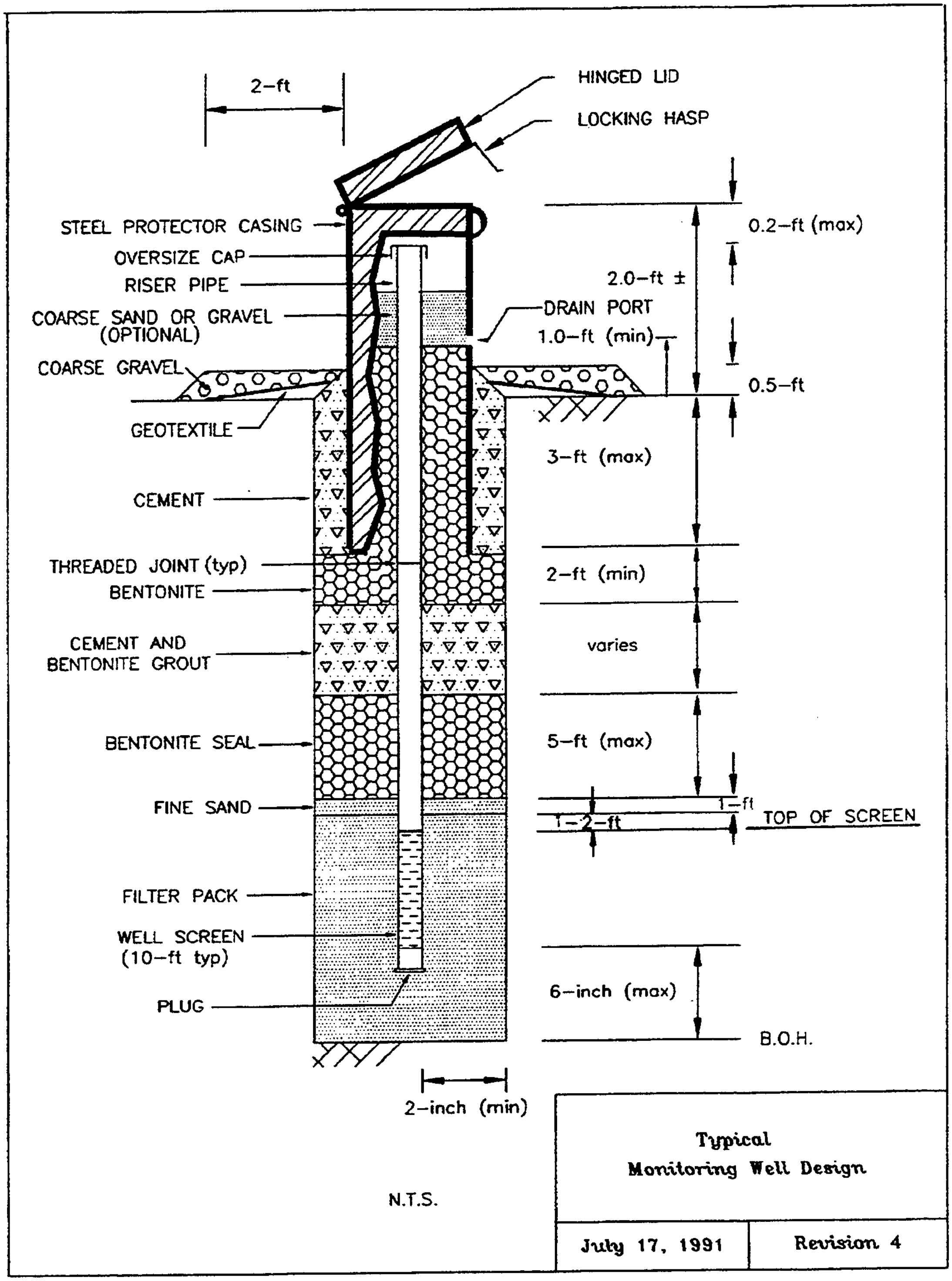


Figure 19.2. Typical shallow sampling well construction.

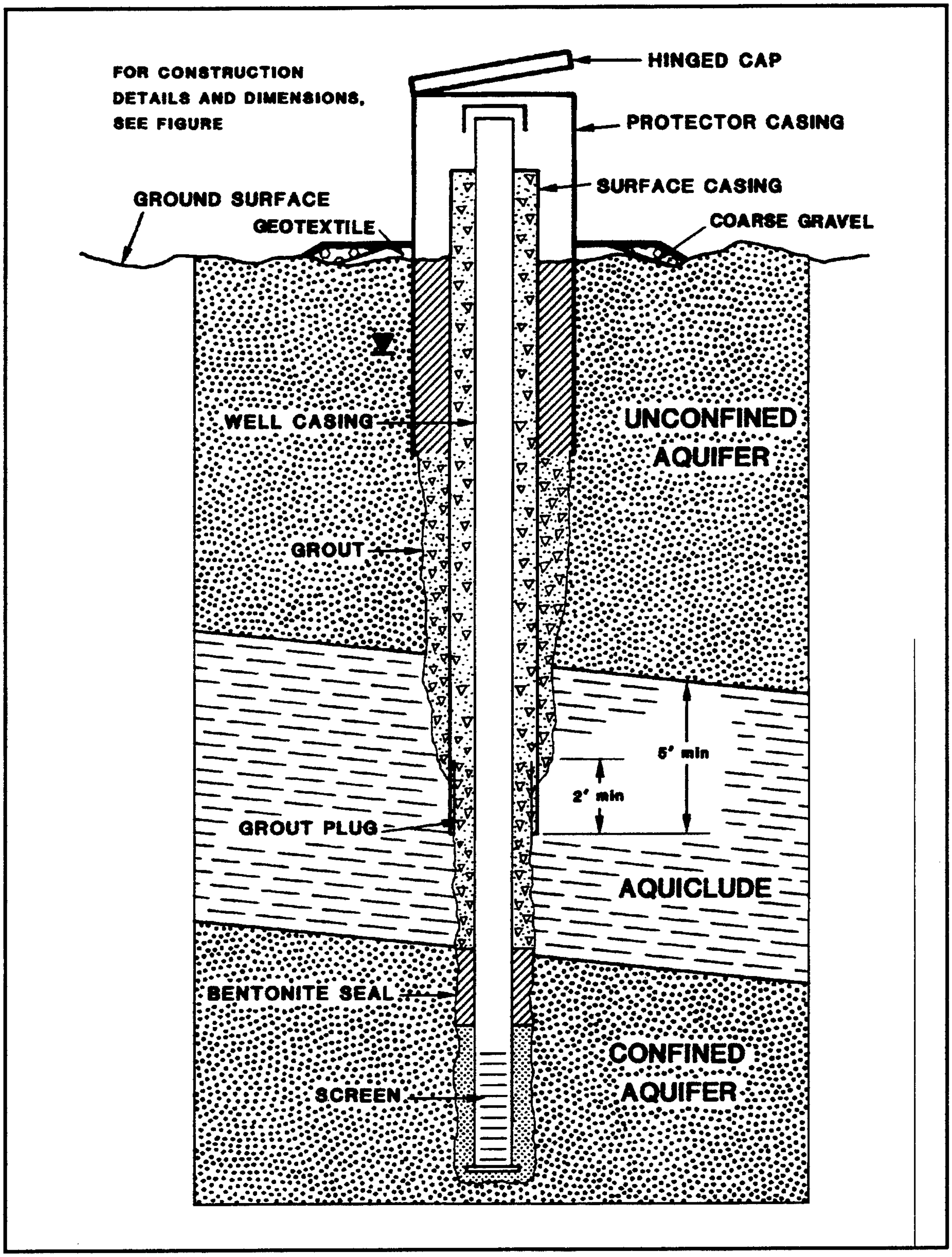


Figure 19.3. Typical well installation, confined aquifer.

STANDARD OPERATING PROCEDURE 018
ORGANIC VAPOR ANALYZER (FOXBORO 128 GC)

1.0 Scope and Application

The purpose of this standard operating procedure is to delineate protocols for field operations with the organic vapor analyzer (Foxboro Model 128 GC). The organic vapor analyzer (OVA) is an intrinsically safe, flame ionization detector designed to detect and measure organic vapor concentrations by producing a response to an unknown sample, which can be related to a gas of known composition to which the instrument has previously been calibrated. This information is used to determine control measures such as protection and action levels.

Use of brand names in this SOP is in nowise intended as endorsement or mandate that a given brand be used. Alternate equivalent brands of detectors, sensors, meters, etc. are acceptable. If alternate equipment is to be used, the contractor shall provide applicable and comparable SOPs for the maintenance and calibration of same.

2.0 Material

a. probe/readout assembly
b. sidepack assembly
c. tedlar bag
d. calibration gas (*e.g.* methane 90 - 100ppm)
e. fuel (zero grade hydrogen - 99.999%)
f. tygon tubing
g. regulator

3.0 Startup Procedure

3.1 Connect the Probe/Readout Assembly to the Sidepack Assembly by attaching the sample line and the electronic jack to their respective receptacles located on the side of the Sidepack.

3.2 Check the battery condition by moving the INSTRUMENT toggle switch to the "BATT." position and ensure that the meter needle is beyond the white BATTERY OK line.

3.3 Move the INSTRUMENT toggle switch to the ON position, and allow a 5 minute warm-up.

3.4 Adjust the CALIBRATION ADJUST knob to set the meter needle to the level desired for activating the audible alarm. If the alarm level is other than zero, the CALIBRATION range toggle switch must be set to the appropriate range (i.e., X1, X10, or X100).

3.5 Turn the ALARM VOLUME knob fully clockwise.

3.6 Using the ALARM LEVEL ADJUST knob (located on the back of the Probe/Readout Assembly), turn the knob until the audible alarm is activated.

3.7 Move the CALIBRATION range toggle switch to the X1 position and adjust the meter reading to zero using the CALIBRATION ADJUST knob.

3.8 Turn the PUMP toggle switch ON. Place the instrument in the vertical position. Observe the SAMPLE FLOW RATE tube. Ensure flow rate is between 1-1/2 - 2-1/2 units.

3.9 Open the H_2 TANK valve and the H_2 SUPPLY valve, wait one minute for hydrogen to purge the system.

3.10 Press the red IGNITER BUTTON (located on the side of the Sidepack Assembly) until the alarm sounds and the needle on the Probe/Readout Assembly jumps upscale. CAUTION: THE IGNITER BUTTON SHOULD NOT BE DEPRESSED FOR MORE THAN 8 SECONDS. IF FLAME DOES NOT LIGHT WITHIN 8 SECONDS, WAIT 1 MINUTE AND TRY AGAIN.

3.11 The instrument is ready for use. Use the CALIBRATION ADJUST knob to zero out ambient background organics.

4.0 SHUT DOWN PROCEDURE

4.1 Close H_2 TANK VALVE

4.2 Close H_2 SUPPLY VALVE

4.3 Move "INSTRUMENT" BATT./OFF/ON toggle switch to OFF.

4.4 Wait 5 seconds and move the "PUMP" toggle switch to OFF.

5.0 FUEL REFILLING

WARNING: THERE SHOULD BE NO POTENTIAL IGNITERS OR FLAMES IN THE AREA.

5.1 The instrument and the charger should be completely shut down prior to hydrogen tank refilling operations. Refilling should be done in a well ventilated non-hazardous area.

5.2 If this is the first filling of the instrument or if the filling hose has been allowed to fill with air, the filling hose should be purged with hydrogen prior to filling the instrument tank.

5.3 The filling hose should be left attached to the hydrogen supply tank when possible. Ensure that the FILL/BLEED valve on the instrument end of the hose is in the OFF position. Connect the hose to the refill connection on the Sidepack Assembly.

5.4 Open the hydrogen supply bottle valve slightly. Open the H_2 REFILL VALVE and the H_2 TANK VALVE on the instrument and place the FILL/BLEED valve on the filling hose assembly to the FILL position.

5.5 After the fuel tank is filled, close the H_2 REFILL VALVE on the instrument, close the FILL/BLEED valve on the refill hose, and close the valve on the hydrogen supply bottle.

5.6 The hydrogen trapped in the refill hose must now be bled off. CAUTION: THE REFILL HOSE WILL CONTAIN A SIGNIFICANT AMOUNT OF HYDROGEN AT HIGH PRESSURE. Turn the FILL/BLEED valve on the filling hose to the BLEED position. After the hose is bled down to atmospheric pressure, the FILL/BLEED valve should be turned to the FILL position to allow the hydrogen trapped in the connector fittings to move into the hose assembly. Turn the FILL/BLEED valve to the BLEED position and exhaust the trapped hydrogen. Then turn the FILL/BLEED valve to the OFF position to keep the remaining hydrogen in the hose at one atmosphere to ensure no air will be trapped in the hose for the next filling.

5.7 Close the H_2 TANK VALVE.

5.8 Observe the H_2 TANK PRESSURE meter and ensure that the pressure reading does not decrease rapidly.

6.0 CALIBRATION

Field calibration is accomplished using a single known sample of methane in air in the range of 90ppm to 100ppm. This may not provide the accuracy stated under specifications but is adequate for field survey work.

6.1 Place instrument in normal operation with the CALIBRATION range toggle switch set to X10 and the GAS SELECT KNOB SET TO 300.

6.2 Use the "CALIBRATION" ADJUST knob to adjust the meter reading to zero.

6.3 Fill a tedlar bag with methane sample of known concentration (between 90ppm and 100ppm) and connect to the OVA sample probe.

6.4 Adjust the CALIBRATION GAS SELECT KNOB until the meter reading is equivalent to the value of the gas standard.

6.5 Record in a field log book: date, time, location, instrument ID number, calibration gas and concentration, final GAS SELECT setting, and the name of the person calibrating the instrument.

7.0 BATTERY CHARGING

WARNING: NEVER CHARGE BATTERY IN A HAZARDOUS ENVIRONMENT

7.1 Insert battery charger cable into the battery pack RECHARGER receptacle. Plug battery charger into 115 VAC outlet.

7.2 Turn battery charger on.

7.3 Approximately one hour of charging is required for each hour of use. However, an overnight charge is recommended. The charger can be left on indefinitely without damage to the batteries. When finished, turn the charger off and disconnect the charger from the battery.

8.0 PRECAUTIONS

8.1 Keep battery on charger when not in use, and recharge battery as soon as possible after use.

8.2 Avoid intake of boiling vapors and liquids.

8.3 Avoid over-tightening of valves.

8.4 Use zero grade H_2 (99.999%, certified total hydrocarbons as methane < 0.5 ppm recommended).
8.5 Calibration gas mixture must be balanced in air.

8.6 Do not over tighten valves.

9.0 REFERENCES

Foxboro OVA 128 Reference Manual, December, 1985.
ICF Field Equipment Manual, November, 1988.

STANDARD OPERATING PROCEDURE 019
PHOTOIONIZATION DETECTOR (MICROTIP HL-200)

1.0 Scope and Application

The purpose of this standard operating procedure is to delineate protocols for field operations with the photoionization detector (Microtip HL-200). The photoionization detector (PID) uses an ultraviolet emitting lamp designed to detect, measure and display the total concentration of airborne ionizable gases and vapors. This information is used to determine control measures such as protection and action levels.

Use of brand names in this SOP is in no wise intended as endorsement or mandate that a given brand be used. Alternate equivalent brands of detectors, sensors, meters, etc. are acceptable. If alternate equipment is to be used, the contractor shall provide applicable and comparable SOPs for the maintenance and calibration of same.

2.0 Material

a. Microtip
b. Battery Pack
c. Calibration Gas (100ppm Isobutylene)
d. Tedlar Bag
e. Tygon Tubing
f. Regulator

3.0 Startup/Calibration Procedure

3.1 Turn the instrument on by pressing the back of the power switch located on the handle of the Microtip.

3.2 The message "Warming up now, please wait" will be displayed for up to three minutes. After normal display appears, the Microtip is ready for calibration.

3.3 Fill a tedlar bag with the desired calibration gas (usually 100ppm Isobutylene).

3.4 Press SETUP button and select the desired Cal Memory using the arrow keys (normally set to 200ppm). Press EXIT button to leave setup function.

3.5 Press CAL button and expose Microtip to Zero Gas. (Usually clean outdoor air will be suitable. If any doubt exists as to the cleanliness of the background air a commercial source of zero gas should be used.).

3.6 The Microtip then asks for the Span Gas concentration. Enter the known span gas concentration and then connect the tedlar bag containing the Span Gas.

NOTE: THE SPAN GAS CONCENTRATION IS DEPENDENT UPON BOTH THE

CONCENTRATION OF THE SPAN GAS USED AND THE RATING OF THE UV LAMP IN THE MICROTIP AT TIME OF CALIBRATION. IF USING 100ppm ISOBUTYLENE AND THE STANDARD 10.6 eV LAMP, THE SPAN GAS CONCENTRATION WILL BE 56ppm.

3.7 Press enter and the Microtip sets its sensitivity. Once the display reverts to normal the Microtip is calibrated and ready for use. Remove the Span Gas from the inlet probe. The instrument should be calibrated at least once a day.

4.0 Battery charging

4.1 Ensure Microtip is off.

4.2 Set the voltage selector switch on the bottom of the battery charger to the appropriate AC line voltage.

4.3 Press the release button on the bottom of the Microtip and remove the battery pack by sliding it backwards.

4.4 Plug charger into the battery pack and then into an AC outlet and allow the battery to charge for at least 8 hours.

4.5 After charging, remove the charger, first from the outlet then from the battery pack, and slide the battery pack back onto the Microtip.

5.0 Precautions

5.1 Microtip does not carry an Intrinsic Safety Rating and must not be used in a hazardous location where flammable concentrations of gases or vapors are constantly present.

5.2 All calibration, maintenance and servicing of this device, including battery charging, must be performed in a safe area away from hazardous locations.

5.3 Do not open or mutilate battery cells

5.4 Do not defeat proper polarity orientation between the battery pack and battery charger.

5.5 Substitution of components may affect safety rating.

6.0 References

Microtip HL-200 User's Manual, February, 1990.

STANDARD OPERATING PROCEDURE 020
SOIL SAMPLING

1.0 Scope and Application

The purpose of this standard operating procedure is to delineate protocols for sampling surface and subsurface soils. Soil samples give an indication of the area and depth of site contamination, so a representative sample is very important.

2.0 Materials

a. Stainless steel spoon, trowel, knife, spatula, (as needed)
b. Split-spoon, Shelby tube, or core barrel sampler
c. Bucket auger or push tube sampler
d. Drill rig and associated equipment
e. Stainless steel bowl
f. PPE as required by the HASP

3.0 Procedure

3.1 Subsurface Samples

3.1.1 Don PPE. Collect split-spoon, core barrel, or Shelby Tube samples during drilling.

3.1.2 Upon opening sampler, or extruding sample, immediately screen soil for volatile organic compounds using either a PID or FID. If sampling for VOCs, determing the area of highest concentration, use a stainless steel knife, trowel or lab spatula to peel and sample this area.

3.1.3 Log the sample in field notebook in accordance with SOP 003, while it is still in the sampler.

3.1.4 Peel and transfer the remaining sample in a decontaminated stainless steel bowl. Mix thoroughly with a decontaminated stainless steel spoon or trowel.

3.1.5 Place the sample into the required number of sample jars.

3.1.6 Preserve samples as required in SOP 026.

3.1.7 Discard any remaining sample into the drums being used for collection of cuttings.

3.1.8 Decon sampling implements according to SOP 005 § 3.3.2.

3.1.9 All borings will be abandoned according to state of Louisiana and LAAP procedures.

NOTES: If sample recoveries are poor, it may be necessary to composite samples before placing them in jars. In this case, the procedure will be the same, except that two split-spoon samples will be mixed together. The field logbook should clearly state that the samples have been composited, which samples were composited, and why the compositing was done.

Samples taken for geotechnical analysis will be undisturbed samples, collected using a thin-walled (shelby tube) sampler.

3.2 Surficial Soil Samples

3.2.1 Don PPE. Remove vegetative mat. Collect a sample from under the vegetative mat with a stainless steel trowel, push tube sampler, or bucket auger.

3.2.2 If a representative sample is desired over the depth of a shallow hole or if several shallow samples are to be taken to represent an area, composite as follows:

3.2.2.1 As each sample is collected, place a standard volume in a stainless steel bowl.

3.2.2.2 After all samples from each hole or area are in the bucket, homogenize the sample thoroughly with a decontaminated stainless steel spoon, trowel or spatula.

3.2.3 If no compositing is to occur place sample directly into the sample jars.

3.2.4 Place the leftover soil in the auger borings and holes left by sampling. If necessary, add clean sand to bring the subsampling areas back to original grade. Replace the vegetative mat over the disturbed areas.

3.2.5 Samples for VOCs will not be composited. A separate sample will be taken from a central location of the area being composited and transferred directly from the sampler to the sample container.

3.2.6 Preserve samples as required in SOP 026.

3.2.7 Decon sampling implements according to SOP 005 § 3.3.2

3.3 Refer to SOP 1-5, and 16.

4.0 Maintenance

Not Applicable.

5.0 Precautions

5.1 Refer to the Health and Safety Plan.

5.2 Soil samples will not include vegetative matter, rocks, or pebbles, unless the latter are part of the overall soil matrix.

6.0 References

ASTM Method D1586-84, Penetration Test and Split-Barrel Sampling of Soils.

ASTM Method D1587-83, Thin Walled Sampling of Soils.

Department of the Army, Office of the Chief of Engineers, Engineer Manual 1110-2-1907 Soil Sampling, 31 March 1972

STANDARD OPERATING PROCEDURE 021
SAMPLE CONTAINER CLEANING

1.0 Scope and Application

The purpose of this standard operating procedure is to define laboratory protocols to be used in cleaning and preparing containers used to collect environmental samples.[1]

2.0 Materials

a. Polyethylene bottles
b. Amber glass bottles
c. 40 ml vials
d. Bottle caps
e. Polytetrafluoroethelyne (PTFE) liners
f. 5% NaOH
g. 5% Ultrex HNO_3
h. Deionized water
i. Alconox detergent
j. Hexane (Nanograde or equivalent)
k. Acetone
l. Methelyne Chloride

3.0 Procedures

3.1 Polyethylene bottles

3.1.1 Rinse bottles and lids sequentially with 5% NaOH, with deionized water, with 5% Ultrex nitric acid, and with deionized water.

3.1.2 Drain and allow to air dry.

3.2 Amber glass bottles and 40 ml vials

3.2.1 Wash bottles in detergent and rinse with copious amounts of distilled water.

3.2.2 Rinse with acetone

3.2.3 Rinse with methelyne chloride

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[1] This SOP is included for completeness only. It is anticipated that sample containers will either be provided by the laboratory, or that the sampling contractor will purchase new, certified clean sample containers.

3.2.4 Rinse with hexane

3.2.5 Allow bottles to air dry.

3.2.6 Place bottles in a drying oven and heat to 200°C.

3.2.7 Allow bottles to cool prior to sealing with clean caps and PTFE liners.

3.3 Bottle Caps

3.3.1 If applicable, remove paper liners from caps.

3.3.2 Wash caps with detergent, followed by a distilled water rinse.

3.3.3 Dry caps in drying oven at 40°C.

3.4 PTFE liners

3.4.1 Always handle liners with forceps or tweezers, never use fingers.

3.4.2 Wash liners with detergent, followed by distilled water rinse.

3.4.3 Rinse the liners with acetone, followed by hexane (Nanograde or equivalent).

3.4.4 Allow liners to air dry prior to placing in clean caps, then heat liner and caps in drying oven at 40°C for 2 hours.

3.4.5 Allow caps and liners to cool prior to placing on clean bottles.

3.5 A statistically representative number of randomly selected clean sample containers shall be analyzed for TAL/TCL analytes (GWP Tables 8.2 - 8.5). Results of these analyses shall be provided to the contracting officer's representative (COR).

4.0 Maintenance

Not Applicable.

5.0 Precautions

None.

6.0 References

None

STANDARD OPERATING PROCEDURE 022
AQUIFER (HYDRAULIC) TESTING

1.0 Scope and Application

The purpose of this standard operating procedure is to define various hydraulic test methods which may be used at APG, to specify how these tests are to be performed, and to provide appropriate methodologies for data reduction and interpretation. This SOP assumes a high degree of technical competency on the part of the investigator, in that certain assumptions and interpretations must be made in the selection of the test and data analysis to achieve valid results.

Aquifer testing is a process performed on selected wells to characterize the **Hydraulic Conductivity**, **Transmissivity**, and **Storativity** of the aquifer into which those wells are installed. Aquifer tests fall into two broad categories — pumping tests and slug tests. Pump tests and slug tests are relatively inexpensive when compared to the RI budget as a whole, but it should be noted that, as with many *in situ* tests, aquifer tests may yield non-unique solutions.

Pumping tests are typically performed on wells installed in highly permeable materials, confined aquifers, and in areas of little or no suspected contamination in the ground-water. The principle of pumping tests is to remove water from the aquifer at a sufficient rate and for a sufficiently long period of time to stress the aquifer and cause measurable drawdown in the pumped well and adjacent observation well(s). The aquifer characteristics can then be calculated by substituting inter-well distances, drawdown and well discharge data into appropriate equations, employing curve matching techniques, or using computer programs to reduce the data.

- Advantages of performing pumping tests are: 1) they encompass large areas, 2) test results are more accurate, 3) they can resolve complex aquifer conditions (*e.g.* boundaries) 4) time periods and pump rates can be varied, 5) pump tests represent remedial actions.

- Disadvantages of pumping tests are: 1) large quantities of potentially contaminated water are generated, 2) the contaminant plume may be moved by the test, 3) they are very costly, 4) the data produced are averages over large areas

Slug tests are conducted to determine the characteristics of an aquifer in materials whose conductivity is too low to perform a pumping test, or in aquifers which are highly contaminated. Slug tests consist of inserting and/or removing either a slug of inert material of known volume, or a "slug" of water of known volume. Either method will cause an instantaneous rise or fall and subsequent recovery of the water table within the aquifer.

- Advantages of slug tests are: 1) they provide location-specific data, 2) they are small-scale, and unlikely to move the contaminant plume, 3) no contaminated water (other than decon solutions) is generated, 4) they are low cost, therefore 5) high data density is feasible, 6) they can be used as an aid in selecting an appropriate area to perform pump test(s)

- Disadvantages of performing slug tests are: 1) they provide less precise estimates of parameters, 2) they may not yield values for storativity, 3) they cannot resolve complex geometries, 4) since they are short-term tests, they cannot resolve long-term events.

2.0 Materials

Pump Tests:

a. Pump
b. Transducer or other water level indicator [1]
c. Logbook
d. Semilogarithmic paper-arithmetic vertical scale and logarithmic horizontal scale, or log-log paper
e. Type curves for curve-matching analyses
f. Flowmeter or stopwatch and bucket, graduated cylinder, or rain gauge

Slug Tests:

Test Conducted with Inert Cylinder
a. Transducer (see footnote 1)
b. Logbook
c. Semilogarithmic paper-arithmetic vertical scale and logarithmic horizontal scale
d. Inert, negatively buoyant cylinder of known volume
e. Type curves for curve-matching analyses

Test Conducted with Input/Output of Water
a. Teflon bailer with teflon-coated stainless steel leader and rope or pump.
b. Logbook
c. Semilogarithmic paper
d. Transducer or other water level indicator (see footnote 1)
e. Type curves for curve-matching analyses
f. Approved water and/or containers for removed water.

Note: All well intrusive equipment must be decontaminated prior to and after use, as is indicated in SOP

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[1] Although removal (or insertion) of larger volumes of water may increase the recovery time(s) of the aquifer to the point that use of electrical water level meters or steel tapes is feasible, piezometers and data loggers are preferred because they tend to provide more complete records with less maintenance and operator error.

005.

3.0 Procedure

3.1 Selection of Test Method

Before beginning any aquifer test, the investigator should have a good conceptual model of the site's hydrogeologic condition. This is essential because of the assumptions made in each analysis method. If the site conditions do not correspond with the assumptions in a given model, the analysis will be invalid. The conceptual understanding of the hydrogeology of the site can be developed from driller's logs and/or borehole geophysical logs of the wells to be tested, or from previous reports on the hydrogeology of the area. Table 1 is a decision tree which can be used with this conceptual model to determine the appropriate test/analysis method(s) which may be used at a given site.

3.2 Pump Tests

Pump tests can be divided into two broad categories: those in which the pumping (discharge) rate is kept constant, and 2) those in which the pumping rate varies over time. All water removed from pumping wells must be disposed of appropriately (SOP042).

3.2.1 Constant Discharge

These methods require that the discharge or injection rate in the pumping well be kept constant. Of these, the Theis method is the most widely referenced and applied, and serves as the basis for the solution of other, more complex boundary condition problems. Both the Cooper & Jacob and the Jacob modifications to the Theis method recognize that if pumping times are long and/or the distances to control wells are small, the Theis solution will yield a straight line plot on semilogarithmic paper, thereby simplifying the Theis equation. The Thiem method, unlike the Theis / Modified Theis methods assumes that steady-state (equilibrium) conditions can be achieved in a confined aquifer.

The Theis method is detailed in § 5.1.1 and ASTM D-4106; the modified Theis method, in § 5.1.2 and ASTM D-4105; and the Thiem method is described in § 5.1.3.

The preceding methods all assume that the aquifer being tested is confined. If the aquifer is unconfined or semi-confined (leaky), the preceding methods are invalid. DeGlee developed an equation which assumes that the tested aquifer is either overlain or underlain by a continuous, leaky confining layer which has uniform properties, and that leakage from the aquitard is proportional to the hydraulic gradient across the aquitard. Hantush and Jacob derived the same equation. Hantush later observed that a simpler, approximation is possible if the ratio of the distance to monitoring well/leakage across the aquitard is < 0.05. As in all preceding cases, radial flow is assumed. The Hantush-Jacob method assumes that no storage occurs in the aquitard. The DeGlee equation and Hantush approximation is given in § 5.3.1.

Neuman and Witherspoon, and Hantush both have proposed methods which take into account storage in the aquitard. The Neuman/Witherspoon method is given in § 5.3.2

3.2.2 Variable Discharge

Variable discharge methods have been presented by numerous researchers. These methods are performed as a series of constant-rate, stepped changes in discharge rate. These changes in discharge rate may be linear or exponential. Type curves are derived for control wells. These methods can be applied in extensive leaky aquifers, but are generally used in confined aquifers. The only requirement is that the response to a unit stress be known. Variable discharge methods are included herein for the sake of completeness. They are not widely used outside the research environment. No further details on variable pump rate tests are provided in this SOP.

3.3 Slug Tests

Slug tests involve the use of a single well, and evaluating its response to an instantaneous raising and/or lowering of the water level within the casing. If the well is poorly designed or poorly developed, the test may end up evaluating the performance of the well screen and/or filter pack rather than the aquifer.

Slug tests are usually of short duration — usually less than 5 minutes. The first 30 seconds are the most important in respect to data collected. Piezometers and digital data loggers are; therefore, a must.

4.0 Field Data Records

4.1 Logbook

4.1.1 Only one site or installation per logbook, and only one slug test per data table (see below).

4.1.2 The first page must include the well number, location, date of test, persons conducting the test, and reference plane for drawdown measurements.

4.1.3 Next page(s) must be table format with the columns designating time/date, water volume withdrawn/added or displaced by inert cylinder, water levels, etc.

4.1.4 Test data must be entered in a table as data are acquired. Data must include sufficient information to indicate that the water level was stable before the test, during equilibrium and after the test(s).

4.1.5 Further information on the logbook can be obtained from SOP 003.

5.0 Interpretation of Data

5.1 Confined Aquifer Methods

5.1.1 Theis Method

The Theis test method involves pumping a well (pumped well, PW) at a constant rate (Q) and measuring drawdown (s) in an adjacent observation well (OW). Theis assumed that groundwater flow in an aquifer is analogous to heat flow in a solid and derived the following equation:

$$s=\frac{Q}{4\pi T}\int_{r^{1}\frac{s}{4\pi T}}^{\infty}\left(\frac{e^{u}}{u}\right)du$$

Equation 1

Where:

s = drawdown
r = radial distance to observation well
Q = pumping (discharge) rate
T = transmissivity (K x aquifer thickness)
S = storativity
t = time

$$u=\frac{r^{s}S}{4T}$$

and Equation 2

If the integral is expressed as the well function W(u), then we can rewrite the equation as:

$$s=\frac{Q}{4\pi T}W(u)$$

Equation 3

Which can be also written as:

$$T=\frac{Q}{4\pi s}W(u)$$

Equation 4 **or:**

$$S=\frac{4Tt}{r^{2}}u$$

Equation 5

5.1.1.1 Assumptions

To permit an analytical solution for non-steady, radial flow into the well, the Theis method makes the following assumptions. Most of these assumptions are incorporated in the other analysis methods detailed herein. Only exceptions or additions to these assumptions will be noted in each method.

- The aquifer has seemingly infinite areal extent compared to the well, whose diameter is assumed infinitesimally small
- The aquifer is homogeneous, isotropic, of uniform thickness, and horizontal.
- The head is uniform and constant prior to the test
- Darcy's law is valid
- The well is pumped at a constant rate
- Water is discharged from storage instantaneously
- The well screen fully penetrates the aquifer
- Flow within the aquifer is radial to the well and strictly horizontal.
- Drawdown data are taken from an adjacent observation well

One additional assumption is made in this SOP, which was not made by Theis: The PW has been previously sampled and analysis of the ground-water at that site is not grossly contaminated (*e.g.* no NAPLs).

5.1.1.2 **Procedure** (see also ASTM D 4106-91)

Field Operations

a. Perform all steps of SOP010 — organic vapor check, water level determination, depth of well — except NAPL checks.
b. Suspend pump at midpoint of PW screen
c. Record water level
d. Select an appropriate transducer for the range of water level change anticipated during the test.
e. Submerge the transducer in the well to a sufficient depth to provide effective performance. Well bottom sediment plugging of the transducer must be avoided.
f. Record water level
g. Start data logger
h. Start pump
i. Monitor and record flow rate using flowmeter or stopwatch and bucket (rain gauge, graduated cylinder, etc.)

Data Plots

a. Prepare a type curve of W(u) over 1/u on log-log paper (Figure 1) data for these plots may be found in ASTM D 4106-91, ASTM D 5270-92, or in most hydrology texts such as Fetter or Dominico [2]. It is recommended that this plot be copied onto tracing paper, drafting film, or an overhead viewer film copy be made to facilitate later steps. Note: W(u) over u can be plotted if preferred, but will require additional computational steps if used.

b. Plot drawdown over time for each observation well on log-log paper which has the same scale as the type curve (above).

c. Superimpose the type curve and the plot of observation well data. **Keeping both the X and Y axis of each plot parallel**, position the two curves to obtain the best match when overlain. Note: if paper copies of both plots are all that is available, a light table or brightly lit window will be required for this step.

d. Select a match point on the overlapping portion of the two graph papers such that the values for that point simplify the calculations (*e.g.* even log cycles of [W(u), 1/u] — [1,1]; [1,10] *etc.*)

e. Read coordinates for W(u), 1/u, s, and t.

f. Substitute the match point values for the appropriate variable in equations 3, 4, and 5.

g. Repeat for each observation well.

5.1.2 Modified Theis (Cooper & Jacob; Jacob) Method (see also ASTM D 4105-91)

5.1.2.1 General From equation 1 we have:

$$\int_{u}^{\infty}\left(\frac{e^{u}}{u}\right)du = W(u) = -0.577216 - \log_{e}u + u - \frac{u^{2}}{2!2} + \frac{u^{3}}{3!3} - \frac{u^{4}}{4!4} + \ldots$$

Equation 6.

Jacob noted that as values of u become small, the value of the series to the right of $\log_e$u becomes insignificant. That is the series becomes equal to or less than 0.01. The value of u decreases as the value of t (time) increases, and as the value of r (radial distance to OW) decreases. Therefore, for long pumping times and/or observation wells reasonably close to the pumping well, the Theis equation can be stated as:

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[2] See section 6.0 for complete citations of these references.

$$s=\frac{Q}{4\pi T}[-0.577216-\ln(r^2\frac{S}{4Tt})]$$

Equation 7.

Lohman was then able to show the following relationships:

$$T=\frac{2.3Q}{4\pi\Delta s/\Delta\log_{10}t}$$

Equation 8 and

$$T=\frac{2.3Q}{4\pi\Delta s/\Delta\log_{10}r}$$

Equation 9

Where:

$\Delta s/\Delta\log_{10}t$ = the drawdown (measured or projected) over one log cycle of time

$\Delta s/\Delta\log_{10}r$ = the drawdown (measured or projected over one log cycle of radial distance from the control well

5.1.2.2 Procedure

Field operations (see Field Operations under 5.1.1.2)

Data Plots

a. Plot drawdown over time (log scale) on semilog paper.
b. Draw a best fit straight line through the later portion of the data and project it back to s=0.
c. Read t_0 as the time corresponding to the s=0 point.
d. Solve for T using:

$$T=\frac{2.3Q}{4\pi\Delta s}$$

Equation 10

e. Solve for s using:

$$s=\frac{2.25Tt}{r^2}$$

Equation 11

f. Solve for K (K = T/aquifer thickness). Aquifer thickness = screened interval (see assumptions in 5.1.1.1).
g. Repeat for each monitoring well.

5.1.3 <u>Theim (Steady State Flow) Method</u>

5.1.3.1 Assumptions

All the Theis assumptions hold except that equilibrium has been reached between discharge and drawdown. Note that this condition is theoretically impossible in a confined aquifer where all discharge is derived from storage.

5.1.3.2 Equation

When these assumptions are met, the following equation expresses groundwater flow in the aquifer:

$$Q=\frac{2\pi T(s_1-s_2)}{\ln(\frac{r_2}{r_1})}$$

Equation 12

Where:
Q = Well discharge
T = Aquifer transmissivity
r_1 and r_2 are respective distances of OW-1 and OW-2 from the PW
s_1 and s_2 are respective steady-state drawdowns in the OWs

Note that the Thiem equation is designed to solve for transmissivity only, and cannot be used to solve for storativity.

5.1.3.3 Procedure

Field Operations

a. Follow steps a - i in 5.1.1.2 (above)

b. Continue pumping until steady-state conditions are reached. This equilibrium is defined as the time when variations of drawdown with respect to time are negligible. Note that this may require considerably more time than with either the Theis or Modified Theis methods described above.

Data Plots Method 1:

a. Substitute the steady-state drawdown of the two OWs into equation 12 along with the values of r and Q. Solve for T.

b. Repeat with all possible combinations of OWs to obtain the mean transmissivity of the aquifer.

Data Plots Method 2:

a. Plot the observed steady-state drawdown of each OW over distance (log scale) to the PW.

b. Construct a best-fit straight line through the plotted points.

c. Determine the maximum drawdown per log cycle.

d. Substitute this value of $(s_1 - s_2)$ in equation 12 along with Q and solve. Note that the term $\ln(r_2 - r_1)$ is taken to $\ln(10)$ equal to 2.30.

5.2 Bounded, Non-leaky, Confined Aquifer

The test methods described in this section are essentially duplicates of the Theis and Modified Theis methods which are detailed above. The principal differences are that, by definition, a bounded aquifer is limited in its areal extent by a fully-penetrating linear boundary, which is either a constant head (*e.g.* stream or lake) or a no-flow boundary (*e.g.* impermeable, or significantly less permeable geologic formation). These conditions are illustrated in Figure 2.

As stated, the equations used to evaluate data derived from bounded wells are modifications to the basic Theis equations. Drawdown (S) at any point in the aquifer is defined as the sum of the drawdown due to the real ($_r$) and image ($_i$) wells such that:

$$S_0 = S_r \pm S_i$$

Equation 13

$$s = \frac{Q}{4\pi T}[W(u_r) \pm W(u_i)] = \frac{Q}{4\pi T}\sum W(u)$$

so that Equation 1 can be rewritten as:
Equation 14

$$u_i = \frac{r_r^2 S}{4Tt}$$

where: Equation 15 and

$$u_i = \frac{r_i^2 S}{4Tt}$$

Equation 16

$$u_i = (\frac{r_i}{r_r})^2 u_r$$

so that: Equation 17 or

$$u_i = k_l^2 u_r$$

Equation 18

$$K_l = \frac{r_i}{r_r}$$

where: Equation 19.

Note that K_l is a constant of proportionality, and should not be confused with the hydraulic conductivity.

5.2.1.1 Assumptions

All assumptions listed under the Theis method apply with these exceptions:

- The nonleaky aquifer is of infinite areal extent except where limited by linear boundaries.
- The boundaries are vertical planes of infinite length, which fully

penetrate the aquifer.

- The hydraulic boundaries are perfect. Impermeable boundaries yield no water to the aquifer, recharge boundaries are in perfect hydraulic connection with the aquifer.

5.2.1.2 **Procedure** (see also ASTM D 5270-92)

Field Operations (see Field operations under § 5.1.1.2)

Data Plots

a. Generate a family of type curves for the solution of the modified Theis formula (K_1). This family of curves should include curves for both discharging and recharging image wells. Plot the coordinates of $\Sigma W(u)$ on the vertical axis and $1/u$ (Figure 3). It is recommended that this plot be copied onto tracing paper, drafting film, or an overhead viewer film copy be made to facilitate later steps.

b. Plot drawdown (s) over t/r^2 for each observation well on log-log paper which has the same scale as the type curve (above). Note: t=time, r=radial distance from PW.

c. Superimpose the type curves and the plot of observation well data. **Keeping both the X and Y axis of each plot parallel**, position the two curves to obtain the best match when overlain. Note: if paper copies of both plots is all that is available, a light table or brightly lit window will be required for this step.

d. Select a match point on the overlapping portion of the two graph papers such that the values for that point simplify the calculations (*e.g.* even log cycles of [$\Sigma W(u)$, $1/u_p$] — [1,1]; [1,10] *etc.*)

e. Read coordinates for $\Sigma W(u)$, $1/u_p$, s, and t/r^2.

f. Substitute the match point values for the appropriate variable in the equations below:

Transmissivity =
$$T=\frac{Q}{4\pi s}\sum W(u)$$
Equation 20

Storativity =
$$S=4T\left(\frac{t}{r^2}\right)u$$
Equation 21

g. For each OW, determine the distance from the image well (r_i) using the following:

$$r_i = K_I r_r \qquad \text{Equation 22}$$

h. Repeat for each observation well.

5.2.2 Modified Theis Nonequilibrium Method

As in the case of a non-bounded aquifer, the hydraulic parameters can also be determined using a Modified Theis equation and a straight line (semi-log) plot of s and $\log_{10}t$.

5.2.2.1 Procedure

a. Refer to § 5.1.2 (above) and ASTM D 4105-91 for details on plotting the data and the equations to be used in calculating transmissivity and storativity using this method. Note that the data will define <u>two</u> rather than one straight line portions. This is due to the image well effect of the boundary conditions.

b. Select a convenient value of s within the initial straight-line part of the plot. Drawdown represented by this portion of the curve has not been affected by the boundary. Therefore, $s=s_r$ and the corresponding value of t_r corresponds to s_r.

c. Graphically extend the initial straight-line part of the curve to the right. The departure of the measured drawdown from the extended line represents the drawdown due to the presence of the boundary. This effect is also referred to as the image well drawdown, s_i.

d. Select a point on the second straight-line such that $s_i=s_r$. Note the value of time t_i which corresponds to s_i.

e. Since t_r and t_i are selected such that $s_i=s_r$, then $u_r=u_i$ and

$$\frac{r_r^2 S}{4Tt_r} = \frac{r_i^2 S}{4Tt_i} \qquad \text{(Equation 23)}$$

so that:

$$K_I = \frac{r_i}{r_r} = \sqrt{\frac{t_i}{t_r}} \qquad \text{(Equation 24)}$$

f. Determine the distance to the image well using Equation 22.

g. Repeat this calculation for each OW.

Determine the location of the boundary as follows:

a. Accurately plot the locations of the control and observation wells on a map.

b. With a compass, using each OW as the center point, draft a circle which has a radius equal to the distance from that well to the boundary.

c. The image well is located at the intersection of these circles. If the circles do not intersect exactly, the probable well location is at the centroid of the intersections, or the polygonal area bounded by the circles in the case of no overlap.

d. Draw a straight line from the PW to the image well. The boundary is defined as the perpendicular bisector to this line at the image well.

5.2.3 Limitations

The following caveats apply to either of the above two methods:

a. In cases where this test method is employed to locate an unknown boundary, a minimum of three OWs are required to accurately locate the image well which is the boundary. Two OWs will yield two possible locations for the image well. One OW will indicate the presence of a boundary, and the distance (radius) from the OW, but the image well will be located somewhere on that surface.

b. The effects of a constant head (recharging) boundary are indistinguishable from those of a leaky aquifer. It is; therefore, imperative that care be taken in developing the conceptual model of the geohydrologic system being studied prior to testing.

5.3 Semi-confined (Leaky) Aquifer

In some instances, the confining beds either above or below the aquifer will not be completely impermeable. In these cases, the aquifer is said to be "leaky". This condition can be readily determined from the Theis s over t plot on log-log paper. In the initial phase of pumping, the plot will look like the Theis "type" curve. As pumping continues and the aquifer is depressurized (piezometric head decreases), a gradient within the overlying and/or underlying aquitard(s) is induced. Instead if the expected type curve, the plot will be somewhat flattened, and values for s may actually decrease over time if the vertical component of groundwater flow through the aquitard(s) is sufficiently high. The log-log plot will yield a considerably flattened curve. This is one of the reasons it is recommended that these log-log plots be done in the field, so that such conditions can be detected early, and steps be taken to minimize any adverse environmental impact of aquifer cross contamination.

5.3.1 Neuman and Witherspoon Method

The Neuman and Whitherspoon approach to solving the problem of evaluating a leaky aquifer is two-fold. First, they assumed that if the distance between OW and PW is minimized, the area of aquitard subjected to stress and possible leakage is minimized, and the Theis method could be employed. Next, they assumed that if only early time drawdown data were used, the effects of leakage could be further reduced. This is accomplished by closely monitoring the response curve(s) for transducers both in the aquifer and in the aquitard(s) themselves. When the s over t curve begins to flatten, indicating leakage, this is defined as the end of valid aquifer data. Data acquired beyond that point contains components of horizontal (aquifer) flow, and vertical (aquitard) flow. In order to accurately calculate the aquitard parameters, an undisturbed sample of the aquitard must be taken (ASTM D 1587-83). The laboratory tests will provide values for storage of the aquitard(s). Conductivity within the aquitard(s) is provided from the s over t plots for transducers located within the aquitard.

5.3.1.1 Assumptions

The same assumptions as in the Theis method hold with the following differences:

- The aquifer is leaky
- The aquifer and aquitard both have a seemingly infinite areal extent
- Flow in the aquitard is vertical
- Drawdown is negligible in both aquifer and aquitard
- The aquitard has storage
- The overlying and/or underlying aquifer(s) is capable of releasing water to the pumped aquifer through a decline in head.

5.3.1.2 Procedure

Field Operations

a. See field operations in 5.1.1.2 (above)

b. In addition, set piezometers within the aquitard at 0.25 and 0.50 aquitard thickness. These should be set at essentially the same location as the OW, either in the OW or in a sperate borehole adjacent to the OW, and the same radial distance from the PW.

Data Plots

a. Prepare log-log plots of s over t for the OW and transducers placed in the aquitard

b. Use the valid early-time data and the Theis method to calculate the pumped aquifer parameters

c. Calculate several s'/s ratios for the early time period used in b above

d. Calculate the parameter t_D using the following equation:

$$t_D = \frac{Kt}{Sr^2}$$

Equation 23

Where:
t = time
r = radial distance to observation well (and transducers)
K = pumped aquifer hydraulic conductivity
S = pumped aquifer storage

e. Using the value t_D calculated in d (above), and s'/s, determine a value for t'_D using Figure 4.

5.3.2 DeGlee Method and Hantush Approximation

DeGlee developed the following equation for steady-state drawdown within an aquifer with leakage from an aquitard proportional to the hydraulic gradient across the aquitard:

$$s = \frac{Q}{s\pi T}(K_0)\frac{r}{L}$$

Equation 24

Where:
T = transmissivity
s = steady-state drawdown in OW at distance r from PW
Q = discharge rate of PW
L = $\sqrt{Tc}$ = leakage factor
c = D'/K = hydraulic resistance of the aquitard
D'= saturated thickness of the aquitard
K'= Hydraulic conductivity of the aquitard for vertical flow
$K_0(x)$ = Modified bessel function of the second kind and of zero order (Hankel function)

Hantush observed that if r/L is small (≤ 0.05) equation 14 can be estimated by:

$$s = 2.30\frac{Q}{2\pi T}(\log 1.12\frac{L}{r})$$

Equation 25

5.3.2.1 Assumptions

See 5.3.1.1 (above)

- Flow to the PW is in steady state

- L is greater than 3D, where D is the saturated thickness of the aquifer

5.3.2.2 Procedure

Field Operations
Field methods are identical to the Thiem method in 5.1.3 (above).

Data Plots

a. Plot s over r (log scale) on semi-log paper Where r/L is small, the points fall in a straight line plot. Where r/L is large, the curve approaches the zero-drawdown axis asymptotically.

5.3.3 Other methods for calculating leaky aquifer parameters include:

The Neuman and Witherspoon Unsteady-state flow method, the Hantush Curve-Fitting Method, the Hantush Inflection Point Method, and the Walton Method. As before, these are included for the sake of completeness, but not detailed herein.

5.4 Unconfined Aquifers

Flow to a pumping well in an unconfined (phreatic or water table) aquifer occurs in three phases. In the first phase, pumping has just begun, and the aquifer acts like a confined aquifer. Water is derived from storage (expansion of the water, compression of the aquifer). The time over drawdown plot for this phase closely mimics the Theis type curve. During the second phase, delayed yield occurs. This phenomenon results as water remaining in the pores is drained by gravity (specific yield), replenishing the portion of the aquifer supplying water to the well during the first phase, and results in a reduction in rate of drawdown over the first phase, and a flattening of the time-drawdown plot. The third phase brings equilibration in the rate of drawdown and the time-drawdown plot again looks like the Theis curve.

The duration of the first two phases is a function of the ratio of storage (S) to specific yield (S_y). If the ratio is in the range of 10^{-1} to 10^{-2}, S is relatively large and the first phase drawdown should be significant. This condition is typical of saturated fine-grained sediments such as silts, clays and fine-grained sands. If the ratio S/S_y is in the range of 10^{-4} to 10^{-6}, S_y is relatively large, the second phase phenomenon is expected to be dominant, and coarser-grained sediments (sands and gravels) are indicated.

In addition to S/S_y, the distance between PW and OW also affects the time-drawdown plot. As the distance to the OW increases, the effects of S decrease.

5.4.1 Neuman Method

5.4.1.1 Assumptions

- The same assumptions as listed in 5.1.1.1
- At least one OW located at $r/b \leq 1$
- Drawdown in the observation well $s \leq 0.25b$

5.4.1.2 Procedure

Field Operations

a. See 5.1.1.2 (above)

Data Plots

a. Prepare A and B curves (Figure 5) tables of these values can be found in many hydrology texts such as Fetter

b. Plot s over t on log-log paper at the same scale as the type A and B curves

c. Superimpose the late-time drawdown data over the B curves. Note the value for the curve which best matches the field data.

d. Select a match point which has a value of 1 for as many of the variables as possible.

e. At the selected match point read values for s, t, $W(u_B,\beta)$ and $1/u_B$

f. Repeat steps a-e, superimposing the early time data over the A curve which has the same β value as the B curve.

g. Read values for s, t, $W(u_A,\beta)$ and $1/u_A$

f. Substitute these values in the following equations:

$$T_B=\frac{Q}{4\pi s}(W(u_B^{\prime}\beta))$$

Equation 26. Transmissivity B curve.

$$T_A=\frac{Q}{4\pi s}(W(u_B^{\prime}\beta))$$

Equation 27. Transmissivity A curve.

$$S_y=\frac{4T_B t u_B}{r^2}$$

Equation 28. Specific Yield.

$$S=\frac{4T_A t u_A}{r^2}$$

Equation 29. Storage.

$$S_s=\frac{S}{B}$$

Equation 30. Specific Storage.

$$K_h=\frac{T}{b}$$

Equation 31. Horizontal Conductivity.

$$K_D=\frac{\beta b^2}{r^2}$$

Equation 32. Anisotropy.

$$K_v=K_D*K_h$$

Equation 33. Vertical Conductivity.

Note: transmissivities should be within ± 10% of each other. If they are, their average should be used in the remaining equations, otherwise use the T value from the B curve.

5.5 Slug Tests

5.5.1 Option 1 - Inert Object Insertion

5.5.1.1 Select an appropriate transducer for the range of water level change anticipated in the slug test.

5.5.1.2 Perform all steps of SOP010 — organic vapor check, water level determination, depth of well — except NAPL checks.

5.5.1.3 Submerge the transducer in the well to a sufficient depth to provide effective performance. The range of the transducer must be considered in the determination of the submersion depth. Well bottom sediment plugging of the transducer must be avoided as well as transducer interference by the inert object.

5.5.1.4 Monitor water level until it returns to original level as measured in 5.5.2. before initiating the test.

5.5.1.5 Lower an inert object into the well to displace the water and thereby raise the water level. The inert object may be a retrievable sealed PVC cylinder filled with sand or similar material. All intrusive equipment must be decontaminated as is described in SOP 005.

5.5.1.6 Record the water level response during cylinder emplacement and record the water level response (falling) with the cylinder in place. This is called the falling head slug test.

5.5.1.7 Once the water level has stabilized, the cylinder is removed and the rising head slug test is conducted by measuring the response of the water level to the removal of the cylinder.

5.5.2 OPTION 2 - ADDING OR REMOVING WATER

5.5.2.1 Select an appropriate transducer for the range of water level change anticipated in the slug test.

5.5.2.2 Submerge the transducer in the well to a sufficient depth to provide effective performance. The range of the transducer must be considered in selection of the submersion depth. Well bottom sediment plugging of the transducer must be avoided.

5.5.2.3 Monitor water level until it returns to original level as measured in 3.1.2. before initiating the water addition/extraction test.

5.5.2.4 Water levels and water volumes extracted/added are recorded during the entire test.

5.5.2.5 Water addition/extraction is continued until a condition of water table level equilibrium is reached. At equilibrium the rate of addition/extraction equals the well recharge rate and the recharge/drawdown remains constant.

5.5.2.6 Water addition/withdrawal is then stopped and the response of the water level is continuously monitored and readings recorded.

NOTE: If removing water from a well, the water must be containerized for testing and if necessary, properly disposed of. If adding water to the well, the water should be from a non-chlorinated approved water source.

5.5.3 Data Plots

5.5.3.1 Record the water level in the well immediately after the inert object emplacement/withdrawal (option 1) or at the equilibrium of the water table (option 2). This is the initial water level reading.

5.5.3.2 Following the initial water level reading, the water level in the well is continuously recorded along with the time of the level measurement.

5.5.3.3 The ratio of the initial water level to the change in head are plotted with respect to time.

5.5.3.4 The ratio is plotted on the arithmetic scale and time is plotted along the logarithmic scale.

5.5.3.5 The relationships of the initial water level to changes in the water level are a function of parameters shown in Figure 6 and the formation transmissivity. The values of the function relationship are plotted for a series of transmissivities and are depicted in Figure 5.

5.5.3.6 The resulting field data plot (curve) is compared to a series of type curves (Figure 5). The field-data curve is placed over the type curves with the arithmetic axis coincident. The field data curve is matched to the type curve that has the same curvature.

5.5.3.7 The formation transmissivity is determined.

5.5.3.8 The value of storativity is calculated.

6.0 Maintenance

6.1 The transducers must be kept clean, operable, and thoroughly tested before emplacement in the well. A plugged or malfunctioning piezometer will give erroneous responses or fail to give any response.

7.0 Precautions

7.1 In the case of slug tests, care should be exercised to maximize the efficiency of the well. If there is a great disparity between the conductivity of the aquifer and that of the well screen / filter pack, one may find that the slug test has accurately measured the conductivity of the well screen / filter pack rather than the aquifer.

7.2 Transducers should be double checked to ensure that they are calibrated in the correct water level range. Water level and well depth should be checked with an electronic water level meter or steel tape before and after placing the transducers.

7.3 Be sure that the wells used are well developed.

7.4 If the water removed is contaminated and cannot be discharged at the surface, a tank of sufficient size to hold the effluent of the pump test must be available.

8.0 References

ASTM D 4043-91 Guide for Selection of Aquifer-Test Method in Determining Hydraulic Properties by Well Techniques

ASTM D 4044-91 Test Method for (Field Procedure) for Instantaneous Change in Head (Slug Tests) for Determining Hydraulic Properties of Aquifers

ASTM D 4050-91 Test Method (Field Procedure) for Withdrawal and Injection Well Tests for Determining Hydraulic Properties of Aquifer Systems

ASTM D 4104-91 Test Method (Analytical Procedure) for Determining Transmissivity of Nonleaky Confined Aquifers by Over-Damped Well Response to Instantaneous Change in Head (Slug Test)

ASTM D 4105-91 Test Method (Analytical Procedure) for Determining Transmissivity and Storage Coefficient of Nonleaky Confined Aquifers by the Modified Theis Nonequilibrium Method.

ASTM D 4106-91 Test Method (Analytical Procedure) for Determining Transmissivity and Storage Coefficient of Nonleaky Confined Aquifers by the Theis Nonequilibrium Method.

ASTM D 4630-86 (1991) Test Method for Determining Transmissivity and Storativity of Low-Permeability Rocks by In Situ Measurements using the Constant Head Injection Test

ASTM D 4631-86 (1991) Test Method for Determining Transmissivity and Storativity of Low-Permeability Rocks by In Situ Measurements using the Pressure Pulse Technique

ASTM D 5269-92 Test Method for Determining Transmissivity of Nonleaky Confined Aquifers by the Theis Recovery Method

ASTM D 5270-92 Test Method for Determining Transmissivity and Storage Coefficient of Bounded, Nonleaky, Confined Aquifers

Cooper, H. H., Jr., Bredehoeft, J. D., and Papadopulos, I. S., 1967. Response of a Finite Diameter Well to an Instantaneous Charge of Water, Water Resources Research, 3, pages 263-269.

Dominico, Patrick A. and Schwartz, Franklin W., 1990 Physical and Chemical Hydrogeology John Wiley & Sons, Inc., 824p.

Driscoll, F. G., 1986. Groundwater and Wells, Johnson Division, St. Paul, Minnesota 55112.

Fetter, C. W. Jr. 1980. Applied Hydrogeology, C. E. Merrill Publishing Company, Columbus, OH

43216., 488p.

Reynolds, Stephen D., 1993. Design and Analysis of Aquifer Tests, Association of Engineering Geologists short course, San Antonio, 1993

Fractured Aquifer	═ Yes >	Fractured Aquifer Gringarten & Ramey Barenblaatt *et al.* Boulton & Stretsova Moench
No V		
Single Aquifer	═ No >	Multiple Aquifers Bennett & Patten Hantush Neuman & Witherspoon Javendel & Witherspoon
Yes V		
Isotropic Aquifer	═ No >	Radial-Vertical Anisotropy Hantush Weeks Horizontal Anisotropy Papadopulous
Yes V		
Lateral Boundary	═ Yes >	Bounded Aquifer Ferris *et al.* Stallman
Yes V		
Confined Aquifer	═ No >	Unconfined Aquifer: Constant Discharge Boulton Neuman Slug Test Bouwer & Rice Bouwer
Yes V		
Leaky Aquifer	═ No >	Confined Aquifer: Constant Discharge Theis Cooper & Jacob Jacob Thiem Variable Discharge Stallman Hantush Abu-Zeid & Scott Aron & Scott Lai *et al.* Moench Constant Drawdown Jacob & Lohman Hantush Rushton & Rathod Slug Test Hvorslev Cooper *et al.*
Yes		
Storage in Confining Bed	═ No >	Without Storage Hantush & Jacob
Yes ─ >	══════════>	With Storage Hantush Neuman & Witherspoon

Table 1. Decision Tree for Selection of Aquifer Test Method (after ASTM D 4043-91)

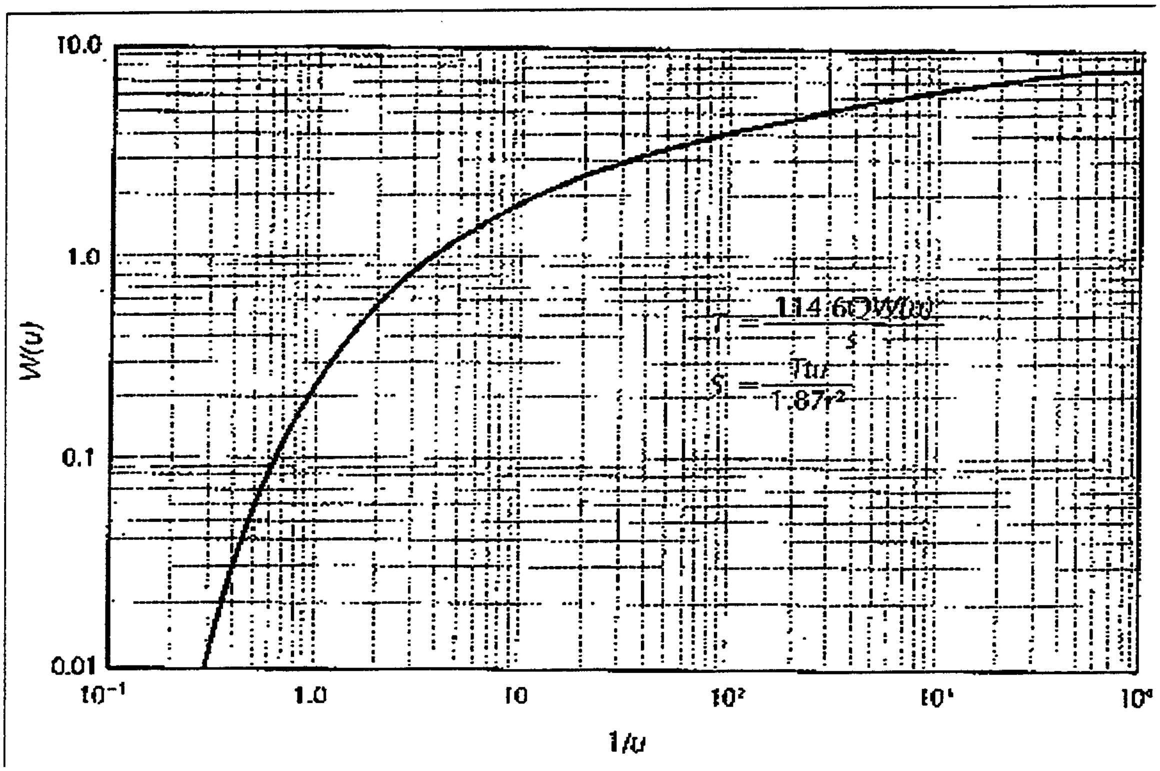
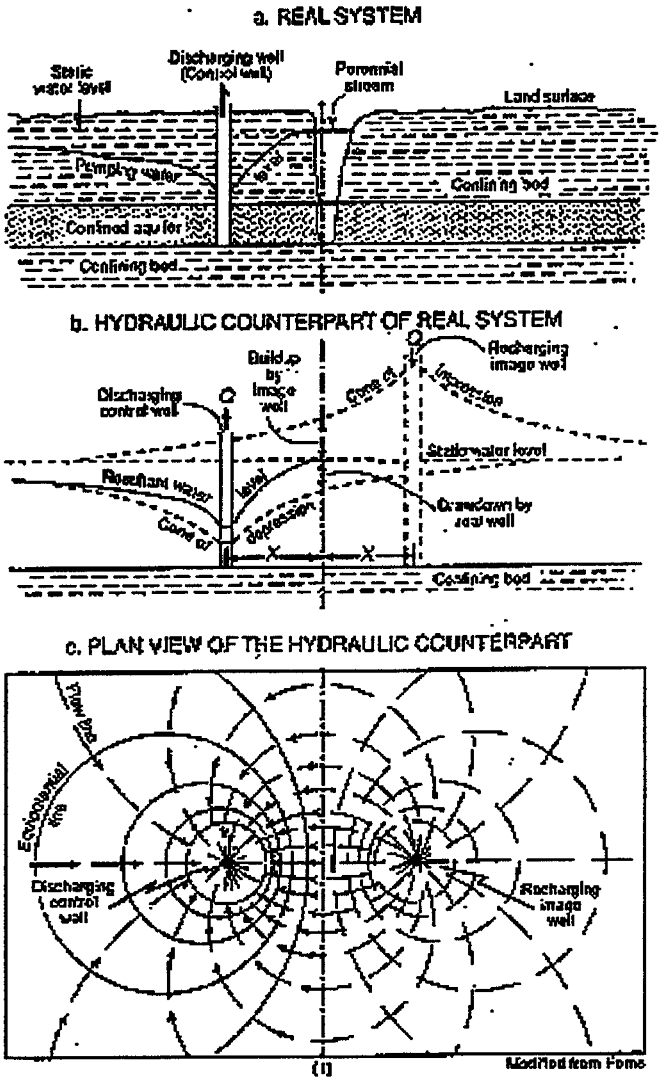
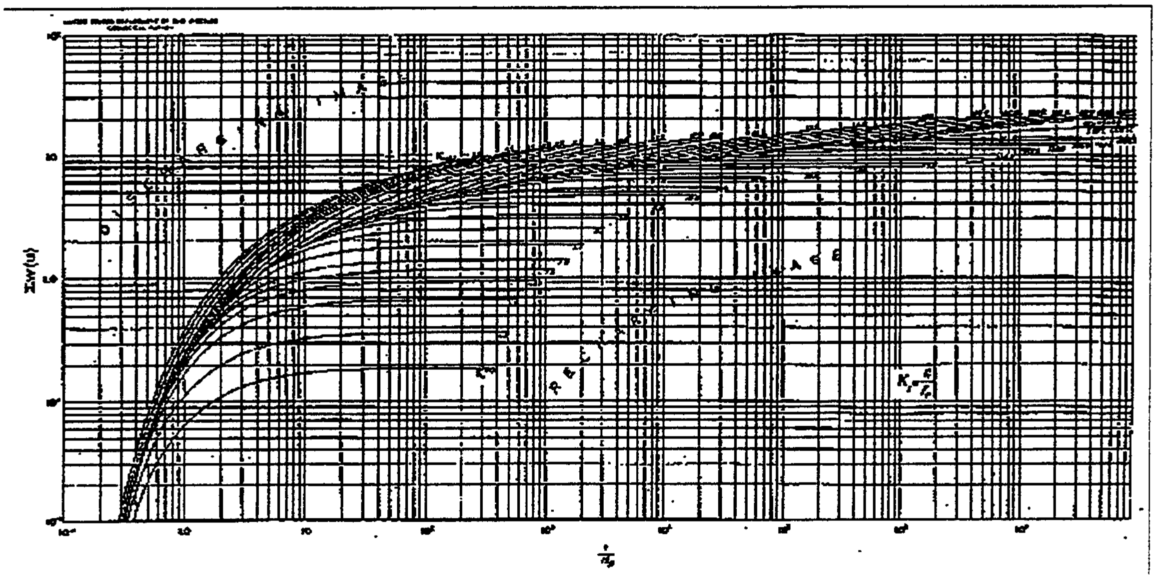


Figure 1. Theis Type Curve (after Fetter)



Note—Modified from Ferris and others (6) and Heath (7).

Figure 2. Illustration of Boundary Conditions (after ASTM D 5270-92)



Note—From Stallman (2).

Figure 3. Family of Type Curves for the Solution of the Modified Theis Formula (after ASTM D 5270-92)

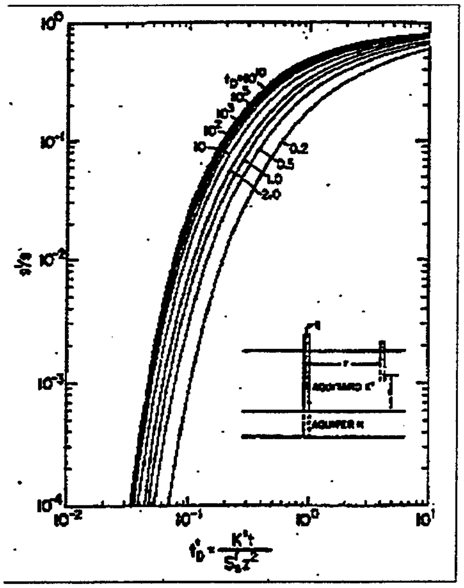


Figure 4. Variation of s'/s With t'_d for a Semi-Infinite Aquitard (after Reynolds)

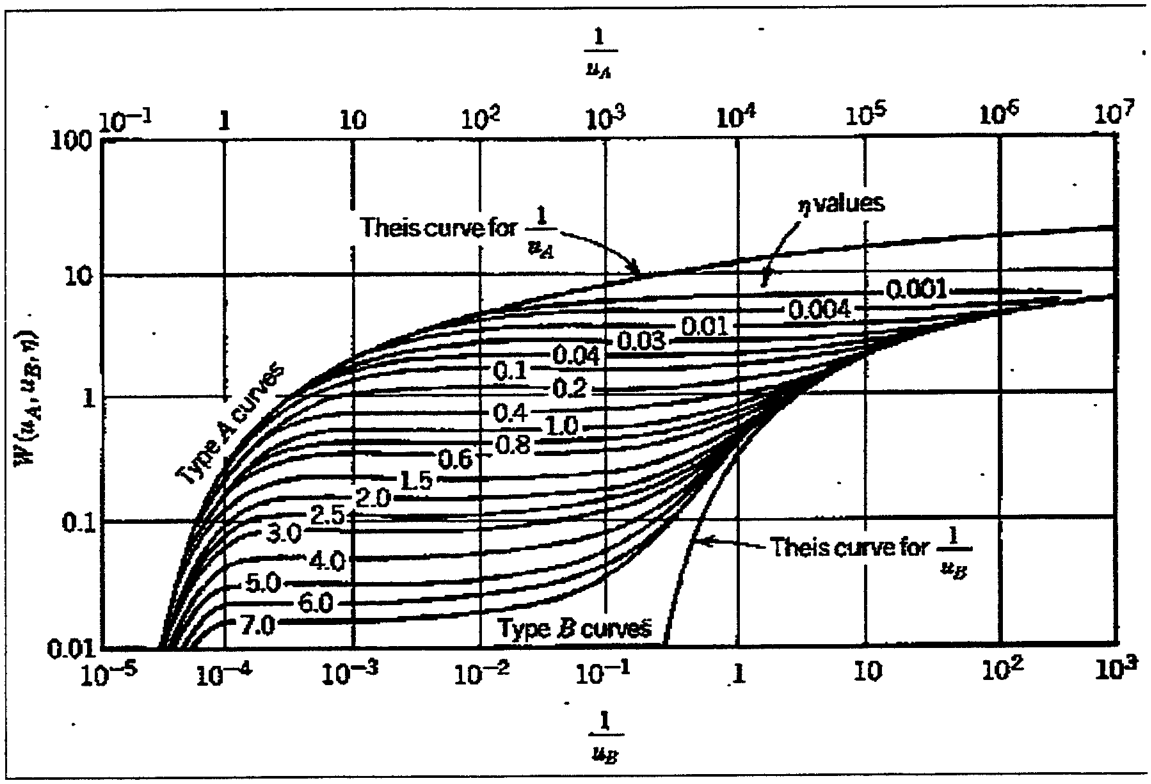


Figure 5. A and B Type Curves (after Dominico)

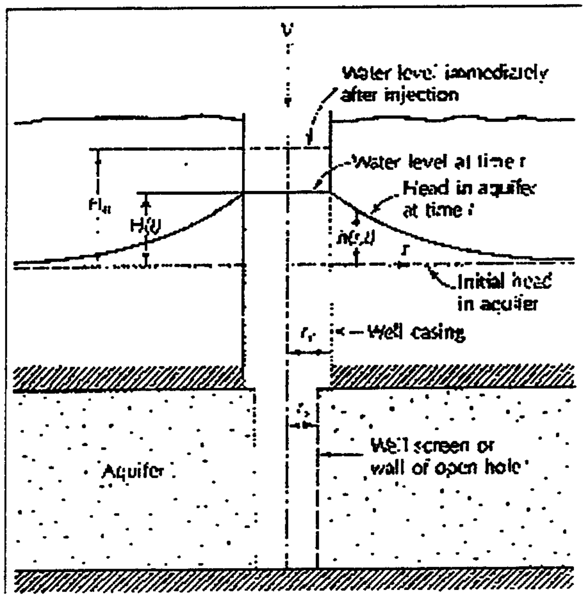


Figure 6. Well Parameters — Slug Tests (after Fetter)

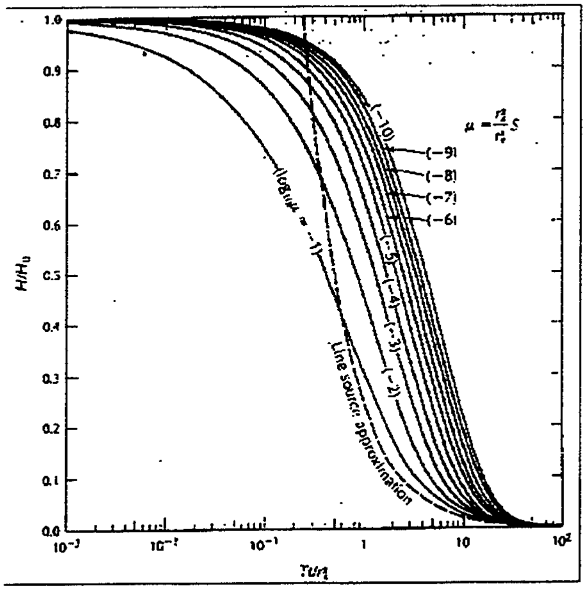


Figure 7. Transmissivity / Time Function Curves (after Fetter)

STANDARD OPERATING PROCEDURE 023
TURBIDITY MEASUREMENTS (DRT 100)

1.0 SCOPE AND APPLICATION

The purpose of this standard operating procedure is to delineate protocols for measuring the turbidity of all types of aqueous solutions, including drinking water, saline water, and industrial and domestic wastes. Turbidity is an indication of the optical properties that cause light to be scattered or absorbed through an aqueous sample. Turbidity is largely a function of the refractive index and the size and shape of the particles suspended or dissolved in the solution. Turbidity meters do not produce an "absolute" measurement, but one that is "relative" to the optical nature of the solids in solution.

Use of brand names in this SOP is in nowise intended as endorsement or mandate that a given brand be used. Alternate equivalent brands of detectors, sensors, meters, etc. are acceptable. If alternate equipment is to be used, the contractor shall provide applicable and comparable SOPs for the maintenance and calibration of same.

2.0 MATERIAL

a. Turbidity meter (DRT 100 or equivalent)
b. Lint free laboratory wipes (Kimwipes or equivalent)
c. Formazin standards (from manufacturer)
d. Sample bottle
e. Cuvettes

3.0 PROCEDURE

3.1 Calibration of the turbidity meter will be checked on a daily basis as follows.

3.1.1 Set the range switch to 1000 range before turning the turbidity meter on and whenever the light shield is not in place over the sample well.

3.1.2 Allow the turbidity meter 15 to 60 minutes to warm-up.

3.1.3 Clean the reference standard with kimwipes.

3.1.4 Place the formazin suspension or reference standard in the turbidity meter sample well.

3.1.5 Place the light shield over the reference standard.

3.1.6 Rotate the front panel range switch counterclockwise to the appropriate NTU range.

3.1.7 Adjust the reference adjust knob counterclockwise to read the same value as the reference standard value. This value is stamped on top of the reference standard.

3.1.8 The turbidity meter is now standardized on all ranges to the factory formazin calibration and unknown samples may be read directly in NTU, FTU, or JTU.

3.1.9 Rotate the range switch clockwise to the 1000 range before removing the reference standard.

3.1.10 Record reading in Field Logbook. (Refer to SOPs 003, and 016.)

3.1.11 Do not leave the reference standard in the sample well for long periods.

3.2 Turbidity will be measured as follows.

3.2.1 Pour aqueous sample into a new cuvette assuring no air bubbles.

3.2.2 Place the cuvette into the sample well.

3.2.3 Place the light shield over the sample.

3.2.4 Rotate the range switch counterclockwise to the range which provides best readability and sensitivity for the sample being measured.

3.2.5 Allow the turbidity meter to stabilize before recording the NTU value.

3.2.6 Turn the range switch clockwise to the 1000 range and then remove the sample.

3.2.7 Do not leave the filled cuvette in the sample well for long periods.

3.2.8 Repeat steps 3.2.1 - 3.2.7 for additional samples.

3.3 Cuvette cleaning procedure is as follows.

3.3.1 Cuvette must be clean and free of rubs or scratches.

3.3.2 Wash the cuvette in a detergent solution.

3.3.3 Rinse thoroughly 8-10 times, preferably with distilled water to remove all streaks.

3.3.4 Polish with kimwipes.

3.3.5 Cuvettes must be stored in a clean dust-free environment.

4.0 MAINTENANCE

4.1 Source Lamp may be replaced as follows.

4.1.1 Remove the instrument case per manufacturer instruction.

4.1.2 Remove the bulb by loosening a screw and removing the electrical leads.

4.1.3 Insert the new bulb and reconnect the electrical leads.

4.1.4 Before tightening the screw, be sure to position the filament so that it will be parallel to the axis of the sample well.

4.1.5 Insert the lamp alignment tool in the sample well to focus the new bulb.

4.1.6 Move the lamp bracket assembly in or out until a focused image of the filament is within the rectangular box on the lamp alignment tool.

4.1.7 Once the filament image has been aligned and focused within the rectangular box on the lamp adjustment tool, tighten all screws snugly.

4.1.8 Replace the instrument case

5.0 PRECAUTION

5.1 Handle the reference standard or sample cuvettes by the top to prevent surface scratches or finger smudges which will cause analysis errors.

5.2 Check the mechanical meter zero when the instrument is in a vertical position and the power switch is off. Adjust to zero only if necessary by means of the black screw on the meter face.

5.3 The turbidity meter should be left on for the entire work shift to minimize warm-up and recalibration delays.

5.4 Do not leave the reference standard or filled cuvette in the sample well for long periods.

5.5 Leave the light shield in place on the instrument when it is not in use in order to protect the sample well for long periods.

5.6 Always set the range switch to 1000 range before turning the instrument on and whenever the light shield is not in place over the well.

6.0 REFERENCES

Manufacturer's Manual

STANDARD OPERATING PROCEDURE 024
DISSOLVED OXYGEN MEASUREMENTS (YSI Model 57)

1.0 Scope and Application

The purpose of this standard operating procedure is to delineate protocols for measuring the dissolved oxygen (DO) of all types of aqueous solutions, including drinking water, saline water, and industrial and domestic wastes. DO is a measurement of the amount of soluble oxygen in an aqueous solution. It is a general indication of an aerobic/anaerobic condition of a water sample.

Use of brand names in this SOP is in nowise intended as endorsement or mandate that a given brand be used. Alternate equivalent brands of detectors, sensors, meters, etc. are acceptable. If alternate equipment is to be used, the contractor shall provide applicable and comparable SOPs for the maintenance and calibration of same.

2.0 Material

a. DO meter (YSI model 57 or equivalent)
b. Self-stirring BOD bottle probe
c. Membrane standards
d. BOD bottle

3.0 Procedure

3.1 Setup

It is important that before the meter is prepared for use and calibrated, it should be placed in the intended operating position, i.e., vertical, tilted, or horizonal. The instrument may need readjustment if the operating position is altered. The setup procedures should be as follows:

3.1.1 With the switch set to **OFF**, adjust the meter pointer to zero with the screw in the center of the meter panel.

3.1.2 Switch to **RED LINE** and adjust the **RED LINE** knob until the meter needle aligns with the red mark if necessary.

3.1.3 Switch to **ZERO** and adjust to 0 mg/L scale with the **ZERO** control knob.

3.1.4 Attach the prepared probe to the **PROBE** connector of the instrument and adjust the retaining ring finger tight.

3.1.5 Before calibrating, allow 15 minutes for optimum probe stabilization. Repolarize whenever the instrument has been **OFF** or the probe has been disconnected.

3.2 Calibration

Calibration is accomplished by exposing the probe to a known oxygen concentration, such as water-saturated air (%), or water of a known oxygen content (mg/L), and then adjusting the calibration controls so the display shows a reading matching the oxygen concentration of the known sample. Calibration can be disturbed by physical shock, touching the membrane, and fouling of the membrane or drying out of the electrolyte. Calibration will be checked after each series of measurements. Calibration of the DO meter will be performed on a daily basis as follows.

3.2.1 Place the probe in moist air. BOD probes can be placed in partially filled (50 ml) BOD bottles. Wait 10 minutes for temperature stabilize ± 2°C.

3.2.2 Switch to **TEMPERATURE** and read. Refer to Table 1 for solubility of oxygen in fresh water (calibration value).

3.2.3 Determine altitude or atmospheric correction factor from Table 2.

3.2.4 Multiply the calibration value from Table 1 by the correction factor from Table 2 to obtain the correct calibration value.

EXAMPLE: Assume a temperature of 20°C and an altitude of 1100 ft. From Table 1, the calibration value of 20°C is 9.09 mg/L. From Table 2, the correction factor for 1100 ft is 0.96. Therefore, the corrected calibration value is 9.09 mg/L x 0.96 = 8.73 mg/L.

3.2.5 Switch to the appropriate mg/L range, set the **SALINITY** knob to zero and adjust the **CALIBRATE** knob until the meter reads the calibration value from Step 4. Wait two minutes to verify calibration stability. Readjust if necessary.

3.3 DO Measurement

3.3.1 With the instrument prepared for use and the probe calibrated, place the probe in the sample.

3.3.2 Turn the **STIRRER** knob **ON.**

3.3.3 Adjust the **SALINITY** knob to the salinity of the sample if appropriate.

3.3.4 Allow sufficient time for the probe to equilibrate to the sample temperature and dissolved oxygen.

3.3.5 Read dissolved oxygen on appropriate scale.

3.3.6 Before measuring the DO of the next sample, rinse probe and sample bottle with distilled water and then with next water sample.

3.3.7 Follow steps 3.3.1 - 3.3.6 for the next sample(s).

3.3.8 The DO meter should normally be left on during the working day to avoid the delay of waiting for probe repolarization.

4.0 MAINTENANCE

The following steps will be taken to maintain the DO meter.

4.1 Replace the batteries when the **RED LINE** knob is at its extreme adjustment or at least annually.

4.2 In the **BATT CHECK** position on the **STIRRER** knob, the voltage of the stirrer batteries is displayed on the red **0-10** scale. Do not permit them to discharge below 6 volts.

4.3 Replace membrane every 2 to 4 weeks depending on application. Probes will be stored in a humid environment to prevent drying out.

5.0 PRECAUTION

The DO meter case is water resistant when properly closed. As a precaution against damaged gaskets or loose fittings, the instrument case will be opened and inspected for moisture whenever the instrument has been subjected to immersion or heavy spray. The case is opened by removing the screws on the rear cover an lifting the cover off.

6.0 REFERENCES

Manufacturer's handbook.

TABLE 1. SOLUBILITY OF OXYGEN IN WATER EXPOSED TO WATER SATURATED AIR AT 760 mm Hg PRESSURE

Temp. °C	Solubility mg/L	Temp. °C	Solubility mg/L	Temp. °C	Solubility mg/L
0	14.62	17	9.67	34	7.07
1	14.22	18	9.47	35	7.95
2	13.83	19	9.28	36	7.84
3	13.46	20	9.09	37	6.73
4	13.11	21	8.92	38	6.62
5	12.77	22	8.74	39	6.52
6	12.45	23	8.58	40	6.41
7	12.14	24	8.42	41	6.31
8	11.84	25	8.26	42	6.21
9	11.56	26	8.11	43	6.12
10	11.29	27	7.97	44	6.02
11	11.03	28	7.83	45	5.95
12	10.78	29	7.69	46	5.84
13	10.54	30	7.56	47	5.74
14	10.31	31	7.43	48	5.65
15	10.08	32	7.31	49	5.56
16	9.87	33	7.18	50	5.47

Derived from 17th Edition, Standard Methods for the Examination of Water and Wastewater.

TABLE 2. CALIBRATION VALUES FOR VARIOUS ATMOSPHERIC PRESSURES AND ALTITUDES

Pressure			Altitude in		Calibration
inches Hg	mm Hg	kPa	feet	meter	Value(%)
30.23	768	102.3	-276	-84	101
29.92	760	101.3	0	0	100
29.61	752	100.3	278	85	99
29.33	745	99.3	558	170	98
29.02	737	98.3	841	256	97
28.74	730	97.3	1126	343	96
28.43	722	96.3	1413	431	95
28.11	714	95.3	1703	519	94
27.83	707	94.2	1995	608	93
27.52	699	93.2	2290	698	92
27.24	692	92.2	2587	789	91
26.93	684	91.2	2887	880	90
26.61	676	90.2	3190	972	89
26.34	669	89.2	3496	1066	88
26.02	661	88.2	3804	1160	87
25.75	654	87.1	4115	1254	86
25.43	646	86.1	4430	1350	85
25.12	638	85.1	4747	1447	84
24.84	631	84.1	5067	1544	83
24.53	623	83.1	5391	1643	82
24.25	616	82.1	5717	1743	81
23.94	608	81.1	6047	1843	80
23.62	600	80.0	6381	1945	79
23.35	593	79.0	6717	2047	78
23.03	585	78.0	7058	2151	77
22.76	578	77.0	7401	2256	76
22.44	570	76.0	7749	2362	75
22.13	562	75.0	8100	2469	74
21.85	555	74.0	8455	2577	73
21.54	547	73.0	8815	2687	72
21.26	540	71.9	9178	2797	71
20.94	532	70.9	9545	2909	70
20.63	524	69.9	9917	3023	69
20.35	517	68.9	10293	3137	68
20.04	509	67.9	10673	3253	67
19.76	502	66.9	11058	3371	66

Derived from 17th Edition, Standard Methods for the Examination of Water and Wastewater.

STANDARD OPERATING PROCEDURE 025
REDOX POTENTIAL MEASUREMENTS

1.0 Scope And Application

The purpose of this standard operating procedure is to delineate protocols for measuring the redox of flooded sediment and soil. Redox is an indication of the reduction of oxidation intensity of an anaerobic system. Redox will be expressed in mV. A complete anaerobic system redox potential is -150 Mv. A positive value indicates an aerobic system.

Redox measurement in a natural system is difficult to obtain due to the absence of true equilibria, heterogeneity of media, and pH effects deprived redox measurements in natural media of precise thermodynamic significance (Ponnamperuma 1972). Despite the difficulties involved in the redox measurements in natural media, it is widely accepted that redox readings in natural anaerobic systems can provide valuable environmental information. Whitfield found redox useful as a semiquantative indicator of the degree of stagnation of a particular aquatic environment as did Ponnamperuma for flooded soils and sediments. The redox measurements of natural waters are not representative of that median, since natural waters are in a highly dynamic state rather than in or near equilibrium, according to Stumm and Morgan. It is generally recognized that redox measurements in oxygenated natural waters are invalid.

2.0 Material

a. pH Meter
b. Combination pH electrode
c. Lint free laboratory wipes (Kimwipes, or equivalent)
d. Distilled water
e. Sample bottle
f. Standard solution (pH 4 and 7 buffers saturated with quinhydrone).
g. Wash bottle

3.0 Procedure

3.1 Calibration of the pH meter will be calibrated on a daily basis as follows.

3.1.1 Prepare beaker of standard solution with known voltage(s).

3.1.2 Connect electrodes to instrument.

3.1.3 Turn on and clear

3.1.4 Rinse electrode with distilled water blot excess with laboratory wipes.

3.1.5 Immerse probe in beaker of standard solution.

3.1.6 Press mV key.

3.1.7 After the reading stabilizes, the absolute mV of solution is displayed.

3.1.8 Rinse electrode and blot excess.

3.2 Redox will be measured after calibration as follows.

3.2.1 Prepare sample in a beaker.

3.2.2 Rinse electrode and blot excess water.

3.2.3 Immerse electrode in sample and stir briefly.

3.2.4 Press mV switch.

3.2.5 Record the reading after it stabilizes.

3.2.6 For next sample(s), follow step 3.2.1 - 3.2.5.

4.0 Maintenance

4.1 Check the batteries each time the meter is used.

4.2 Keep the probe stored in a 0.1 M KCL solution when not in use. Alternatively, the electrode may be rinsed with deionized water and trapping any residual water inside the protective cap.

5.0 Precaution

5.1 Remove coatings of oil material or particulate matter that can impair electrode response by gentle wiping or detergent washing, followed by distilled water rinsing.

6.0 References

Beckman Instruments, Inc., User Manual for Φ 10, 11, and 12 pH/ISE meter.

Ponnamperuma, F. N., "The Chemistry of Submerged Soils," Advances in Agronomy, Vol 24, 1972.

Stumm, W. and Morgan, J. J., Aquatic Chemistry, Wiley, New York, 1970.

Whitfield, M., "Eh as an Operational Parameter in Estuarine Studies," Limnol. Oceanogr., Vol 14, 1969.

STANDARD OPERATING PROCEDURE 026
SAMPLE PRESERVATION AND CONTAINER REQUIREMENTS

1.0 Purpose and Scope

The purpose of this standard operating procedure is to define the preservatives and techniques to be employed in preserving environmental samples between collection and analysis.

2.0 Material

a. Containers (see § 3.0 below for description)
b. HNO_3
c. H_2SO_4
d. NaOH
f. Ice chests
g. Ice

3.0 Definition of Container Types

Type A **Container**: 80 oz amber glass, ring handle bottle/jug, 38-mm neck finish.
Closure: White polypropylene or black phenolic, baked polyethylene cap, 38-430 size, 0.015-mm Polytetrafluoroethelyne (PTFE) liner.

Type B **Container**: 40-mL glass vial, 24 mm neck finish
Closure: White polypropylene or black phenolic, open top, screw cap, 15-mm opening, 24-400 size.
Septum: 24-mm disc of 0.005-in PTFE bonded to 0.120-in silicon for total thickness of 0.125-in.

Type C **Container**: 1-L high density polyethylene, cylinder-round bottle, 28-mm neck finish.
Closure: White polyethylene cap, white ribbed, 28-410 size; F217 polyethylene liner.

Type D **Container**: 120-mL wide mouth glass vial, 48-mm neck finish.
Closure: White polyethylene cap, 40-480 size; 0.015-mm PTFE liner.

Type E **Container**: 250-mL boston round glass bottle
Closure: White polypropylene or black phenolic, open top, screw cap.
Septum: Disc of 0.005-in PTFE bonded to 0.120-in silicon for total thickness of 0.125-in.

Type F **Container**: 8-oz short, wide mouth, straight -sided, flint glass jar, 70-mm neck finish.
Closure: White polypropylene or black phenolic, baked polyethylene cap, 48-400 size; 0.030-mm PTFE liner.

Type G **Container**: 4-oz tall, wide mouth, straight -sided, flint glass jar, 48-mm neck finish.
Closure: White polypropylene or black phenolic, baked polyethylene cap, 48-400 size; 0.015-mm PTFE liner.

Type H **Container**: 1-L amber, Boston round, glass bottle, 33-mm pour-out neck finish.
Closure: White polypropylene or black phenolic, baked polyethylene cap, 33-430 size; 0.015-mm PTFE liner.

Type K **Container**: 4-L amber glass ring handle bottle/jug, 38-mm neck finish.
Closure: White polypropylene or black phenolic, baked polyethylene cap, 38-430 size; 0.015-mm PTFE liner.

Type L **Container**: 500-mL high-density polyethylene, cylinder bottle, 28-mm neck finish.
Closure: White polypropylene, white ribbed, 28-410 size; F217 polyethylene liner.

4.0 Procedure

4.1 All containers must be certified clean, with copies of laboratory certification furnished to the contracting officer's representative (COR).

4.2 Water samples will be collected according to procedures detailed in SOPs 007, 013, and 014 into containers appropriate to the intended analyte as given in Table 039-1.

4.2.1 Samples taken for metals analysis will be acidified in the field to a $pH < 2$ by the addition of HNO_3. Filtered samples will be acidified after filtration. After acidifying the sample, the container should be lightly capped, then swirled to thoroughly mix the sample. The cap will then be loosened to release any excess pressure this operation may have generated.

4.2.2 Samples taken for total phosphorous content will be acidified in the field to a $pH < 2$ by the addition of H_2SO_4. After acidifying the sample, the container should be lightly capped and swirled to thoroughly mix the sample. The cap will then be loosened to release any excess pressure this operation may have generated.

4.2.3 Samples taken for cyanide will be alkalized to a $pH > 12$ by the addition of NaOH.

4.2.4 No preservatives will be added to any other water samples. These samples will be immediately placed on ice and cooled to 4°C.

4.3 Soil, sediment, and sludge samples will be collected according to procedures detailed in SOPs 021, 025, and 041 into containers appropriate to the intended analyte as given in Table 039-2.

4.3.1 Samples taken for metals analysis will be tightly capped, placed on ice, and maintained at a temperature of 4°C.

4.3.2 Samples taken for total phosphorous content will be tightly capped, placed on ice, and maintained at a temperature of 4°C.

4.3.3 Samples taken for cyanide will be alkalized to a pH > 12 by the addition of NaOH.

4.3.4 No preservatives will be added to any other soil samples. These samples will be immediately placed on ice and cooled to 4°C.

4.3.5 Where field screening indicates the presence of mustard, methylene chloride or chloroform will be added to the sample container to cover and preserve the sample. ** awaiting confirmation of this procedure from CRDEC **

5.0 Maintenance

Not Applicable.

6.0 Precautions

HCl shall not be used to acidify samples. HCl will react with thiodiglycol to produce mustard agent by reverse hydrolysis.

Note that acidifying a sample containing cyanide may liberate HCN gas.

- Avoid breathing any fumes emanating from acidified samples.
- Acidify samples only in the open, rather than in closed spaces such as a vehicle.
- Hold suspected HCN - generating sample away from body and downwind while manipulating it.
- See the HASP for other safety measures

7.0 References

Test Methods for Evaluating Solid Waste, SW-845, (EPA 1986)
A Compendium of Superfund Field Operations Methods, EPA 540-P87-001
A Compendium of ERT Soil Sampling and Surface Geophysics Procedures, (EPA 1991)

Table 039-1
Preservation Requirements for Water Samples

Analyte	**Bottle Requirement, Volume**	**Required Headspace**	**Preservative**	**Holding Time**
Volatile Organic Compounds	(2)Type B, 80-mL total	0%	Cool to 4°C	7 days
Semivolatile Organic Compounds	Type A, K, or (2)H, 2-L total	10%	Cool to 4°C	7 days to extraction, 40 days after extraction
Pesticides/ Arochlors	Type A, K, or (2)H, 2-L total	10%	Cool to 4°C	7 days to extraction, 40 days after extraction
Total Metals	Type C, H, or (2)L, 1-L total	10%	HNO_3 to pH < 2 Cool to 4°C	6 months except Mercury (28 days)
Dissolved Metals	Type C, H, or (2)L, 1-L total	10%	HNO_3 to pH < 2 Cool to 4°C	6 months except Mercury (28 days)
Cyanide	Type C, H, or (2)L, 1-L total	10%	NAOH to pH > 12 Cool to 4°C	14 days
Total Phosphorous	(1) Type C, 1-L	10%	H_2SO_4 to pH < 2 Cool to 4°C	28 days
Explosives	(2) Type H, 1-L ea.	10%	Cool to 4°C	7 days to extraction, 40 days after extraction
Thyodiglycol	(2) Type H, 1-L ea.	10%	Cool to 4°C	7 days to extraction, 40 days after extraction
Dioxins/ Furans	(2) Type H, 1-L ea.	10%	Cool to 4°C	30 days to extraction (45 days to analysis)
Org-P and Org-s Compounds	(2) Type H, 1-L ea.	10%	Cool to 4°C	7 days to extraction, 40 days after extraction
IMPA and MPA	(1) Type E, 250-mL	0%	Cool to 4°C	40 days
Herbicides	(2) Type H, 1-L ea.	10%	Cool to 4°C	7 days to extraction, 40 days after extraction

Table 039-2
Preservation Requirements for Soil and Sediment Samples

Analyte	**Bottle Requirement, Volume**	**Required Headspace**	**Preservative**	**Holding Time**
Volatile Organic Compounds	(2) Type D, 240-mL total	0%	Cool to 4°C	14 days
Semivolatile Organic Compounds	Type F or G, 3 oz.	10%	Cool to 4°C	7 days to extraction, 40 days after extraction
Pesticides/ Arochlors	Type F or G, 3 oz.	10%	Cool to 4°C	7 days to extraction, 40 days after extraction
Total Metals	Type F or G, 3 oz.	10%	Cool to 4°C	6 months except Mercury (28 days)
Cyanide	Type I, 1-L	10%	Cool to 4°C	14 days
Total Phosphorous	1 1-L Polyethylene bottle	10%	Cool to 4°C	28 days
Explosives	(2) 1-L amber glass bottles	10%	Cool to 4°C	7 days to extraction, 40 days after extraction
Thyodiglycol	(2) 1-L amber glass bottles	10%	Cool to 4°C	7 days to extraction, 40 days after extraction
Dioxins/ Furans	(2) 1-L amber glass bottles	10%	Cool to 4°C	30 days to extraction (45 days to analysis)
Org-P and Org-s Compounds	(2) 1-L amber glass bottles	10%	Cool to 4°C	7 days to extraction, 40 days after extraction
IMPA and MPA	1 250-mL glass bottle, septum top	0%	Cool to 4°C	40 days
Herbicides	(2) 1-L amber glass bottles	10%	Cool to 4°C	7 days to extraction, 40 days after extraction

STANDARD OPERATING PROCEDURE 027
DISPOSAL OF INVESTIGATION DERIVED MATERIALS (IDM)

1.0 SCOPE AND APPLICATION

The purpose of this standard operating procedure is to define the required steps for disposing of Investigation Derived Materials (IDM) generated during field activities supporting the Natural Attenuation Study at Louisiana Army Ammunition Plant (LAAP).

IDM, as used herein, include soil cuttings, drilling muds, purged groundwater, decontamination fluids, and disposable personal protective equipment (PPE). For the sake of clarity and ease in use, this SOP is subdivided into procedures for disposal of Liquid IDM and Solid IDM as follows:

<u>Liquid IDM</u> **(See Section 3.2)** includes the following materials.

a. Water from initial development of new wells and the redevelopment of existing wells.

b. Purge water from groundwater sampling.

c. Decontamination fluids. **(see section 3.4.1)**

<u>Solid IDM</u> **(See Section 3.3)** consists of the following materials.

a. Drill cuttings from monitoring well installation

b. Grout, a mixture of cement and bentonite, generated during installation of monitoring wells

c. Disposable Personal Protective Equipment (PPE) **(see section 3.4.2)**

2.0 MATERIALS

a. DOT 17C spec. metal containers
b. Waste identification labels
c. Hazardous waste labels
d. Barcodes
e. Chain-of-Custody and RCRA Manifest forms
f. Permanent marker
g. Site logbook (bound)
h. Any additional equipment that may be dictated by project or site-specific plans.

3.0 PROCEDURE

3.1 General

3.1.1 No container shall be labeled as a "Hazardous Waste" unless the contents are in fact known to be hazardous as defined by 40 CFR 261.

3.1.2 IDM may be disposed onsite if it is: **1)** Initially screened, or evaluated to determine whether it is contaminated, **2)** Not abandoned in an environmentally unsound manner and, **3)** Not inherently waste-like.

3.1.3 IDM are to be considered contaminated if they: **1)** Are visually or grossly contaminated, **2)** Have activated any field monitoring device which indicates exceedance of standard levels [1], **3)** Have previously been found to exhibit levels of contamination above environmental quality standards, **4)** The responsible party and/or appropriate regulator deem(s) that records of historical uses indicate that additional testing of the IDM is needed, or additional caution is warranted handling IDM from a given site.

3.2 Procedures for Liquid IDM Disposal

3.2.1 All water from initial development of new wells, and purge water generated during the first round of groundwater sampling will be containerized in DOT approved 55-gallon drums. Decon fluids may be bulk-containerized until completion of field task.

3.2.2 Label all containers as to type of media, the date the container was sealed, the point of generation, and the points of contact (both APG and contractor). The well number and container number will be identified on the container.

3.2.3 The contractor/support personnel will log all media generated on-site into a bound site logbook. Media information should include the following: the date of generation; contents of containers; the number of containers with the same contents (if applicable); location of containers; the well number the media is associated with; personnel sampling the media; sampling dates; and sampling results.

3.2.4 Containers of well development water and purge water may be stored at the well site pending first round analytical results.

3.2.5 Laboratory turn-around time must be no greater than 30 days. Upon receipt of the analytical results, a copy will be furnished to the Project Officer (PO) within 3 working

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[1] This value is defined as 2X background, where "background" values are to be determined as follows: 1) regional background values will be used where they are available 2) if regional values are not available, background may be empirically determined at uncontaminated sampling sites using on-site sensors such as organic vapor analyzers (PID or FID), scintillometers, *etc.*

days. Both the PO and contractor will evaluate the data to determine disposal requirements. A disposal decision is required within 10 days of receipt of sampling results. Appropriate disposal must be performed no later than 50 days from the decision date unless prevented by inclement weather (*e.g.* rain and muddy conditions may preclude site access, freezing weather may freeze media).

3.2.5.1 Dispose of non-hazardous media in accordance with Step 3.2.6 *et seq.* through 3.2.8 *et seq* of this procedure.

3.2.5..2 Dispose of hazardous waste in accordance with Step 3.2.9 *et seq.* of this procedure.

3.2.6 If the first round analytical data of the liquid media is below the Maximum Contaminant Levels (MCLs) established by the Federal Safe Drinking Water Act, the water may be gradually infiltrated into the ground at least fifty feet downgradient of the well.

3.2.6.1 If the well location has no downgradient area, the water will be infiltrated into the ground in an area deemed appropriate by the PO and the contractor/support personnel.

3.2.6.2 Disposal locations must allow percolation of the water and prohibit "ponding".

3.2.6.3 Upon completion of water discharge to ground, enter type of media, amount of media, date of disposal, and discharge point(s) in a bound site logbook. This information must be provided to the PO within 3 working days.

3.2.6.4 Empty containers are to be properly decontaminated, stored, and reused by the appropriate personnel. If the containers show signs of deterioration, they will be steam cleaned and delivered to DRMO in Aberdeen as scrap metal.

3.2.7 If the liquid media sampling results do not meet the required MCLs and cannot be discharged to the ground, then determine if the waste meets the sanitary sewer discharge criteria (NPDES standards) for LAAP's Wastewater Treatment Plant. Procedures for arranging sanitary sewer disposal are as follows:

3.2.7.1 Contact appropriate PO to request permission in writing from LAAP, to discharge the wastewater to the sanitary sewer.

3.2.7.2 Upon receiving written permission from LAAP to discharge the wastewater to the sanitary sewer, the PO will arrange for access to an approved discharge point through LAAP's wastewater treatment plant operator .

3.2.7.3 The PO will coordinate the actual discharge quantity and discharge time with the receiving LAAP Wastewater Treatment Plant operator and the contractor/support organization personnel.

3.2.7.4 Transport the liquid waste to the approved discharge point and discharge the wastewater into the sanitary sewer. For drums or other large quantities of wastewater, an approved sewage pump truck will be used.

3.2.7.5 Upon completion of the wastewater discharge to the sanitary sewer, enter type of waste, amount of waste, date of disposal, and discharge point in a bound site logbook. This information must be provided to the PO within 3 working days.

3.2.7.6 Empty containers are to be properly decontaminated, stored, and reused by the appropriate personnel. If the containers show signs of deterioration, they will be steam cleaned and delivered to LAAP as scrap metal.

3.2.8 If the liquid media is not approved for ground disposal, and cannot be discharged to a LAAP's Wastewater Treatment Plant, dispose of this liquid through LAAP,s Treatment, Storage and Disposal Facility (TSDF).

3.2.8.1 Ensure that the waste containers are properly labeled as per section 3.2.2.

3.2.8.2 Inform the PO of the type, amount, and location of the waste. The PO will contact LAAP personnel to arrange for waste pickup.

3.2.8.3 Contact the PO to ensure that the waste has been entered into the LAAP Hazardous Waste Tracking System (HWTS) and the barcodes have been affixed to the containers.

3.2.8.4 When the waste is removed, enter the type of waste, amount of waste, date of pickup, and destination of waste in a bound site logbook. This information must be provided to the PO within 3 working days.

3.2.9 If the liquid media is considered a hazardous waste under RCRA 40 CFR 261, dispose of this waste through LAAP 's TSDF.

3.2.9.1 Ensure that the waste container(s) is properly labeled with the words "Hazardous Waste", the name or type of waste, the EPA hazardous waste code, the date and point of generation, and a point of contact. The well number and the container number will be identified on the container.

3.2.9.2 Inform the PO of the type, amount, and location of the hazardous waste. The PO will arrange for the container(s) to be picked up by LAAP personnel within thirty (30) days of generation of known hazardous waste, or thirty (30) days of receipt of data confirming the liquid as hazardous waste.

3.2.9.3 Contact the PO to ensure that the hazardous waste has been entered into the HWTS and that the barcodes have been affixed as specified.

3.2.10 Subsequent rounds of purge/development water will be assumed to have similar characteristics as the purge/development water analyzed from the first round of sampling, and will be disposed of accordingly. The following exceptions apply:

If the first round of purge/development water was discharged to the LAAP sanitary sewer system, subsequent rounds of purge/development water will be compared to the analytical results of the corresponding round of sampling prior to disposal.

3.2.11 If at any time visual contamination of purge/development water is observed, or if organic vapor monitor readings (HNu, PID) register more than 5 ppm above background and/or rad meters register more than twice the background mrems, then the liquid will be drummed and a composite sample will be taken that day. A disposal decision will be based on the analytical results of this sample rather than the first round of analytical results.

3.3 Procedure for Solid IDM Disposal

3.3.1 If the conditions outlined in § 3.1.2 (above) are met, proceed to § **3.3.2**. Otherwise go to § **3.3.7**.

3.3.2 During drilling operations, the resulting cuttings and mud will be discharged onto the ground near the well if the following conditions are met: **1)** no visual contamination is observed, **2)** organic vapors are less than 5ppm above background, **3)** rad meter readings (if applicable) are under 2 times background, and **4)** if the potential for metals contamination exists, the medium has been screened and found to be less than 2 times background.

Proper sediment and erosion control measures shall be implemented as follows:

3.3.2.1 Drill cuttings will be uniformly spread and contoured to blend with the surroundings of the site.

3.3.2.2 If amount of solid IDM exceeds 5,000 square feet, or 100 cubic yards of material, a Sediment and Erosion Control Plan is required.

3.3.2.3 If the amount of solid IDM is under 5,000 square feet or 100 cubic yards, the site will be stabilized as soon as possible. Stabilization includes mulch, seed, and tack.

3.3.2.4 Critical areas require stabilization within 7 days from the date of well completion. Critical areas include swales, water sources, drainage ditches, etc.

3.3.2.5 All other disturbed areas require stabilization within 14 days from the date of well completion.

3.3.3 If the well location is in or near a wetland, the drill cuttings shall be drummed and transported away from the site for spreading.

3.3.4 Label all IDM containers that will not be spread on the day of generation. Each container should be labeled with the type of media, the date the container was sealed, the point of generation, and the name of the contact person. The well number and container number should be identified on the container.

3.3.5 The contractor/support personnel will log all media generated onsite into a bound site logbook. Media information should include: the date of generation, contents in containers, the number of containers with the same contents, location of containers, and the well number the media is associated with.

3.3.6 Containers shall be staged at the well site until contractor/support personnel spread the cuttings in the appropriate locations, using proper sediment and erosion control measures per section 3.3.2 *et seq.*

3.3.7 If drilling mud and cuttings show visible contamination, or organic vapor readings are more than 5ppm above background levels, or rad meter readings (if applicable) show greater than 2 times background levels, media will immediately be containerized, labeled appropriately (§ 3.2.2), and sampled on the same day.

3.3.8 The solid IDM should be sampled and appropriate Toxicity Characteristic Leaching Procedure (TCLP) analyses conducted prior to determining disposition. Laboratory turn-around time must be no greater than 30 days. Upon receipt of analytical results, a copy will be furnished to the PO within 3 working days. Both the PO and contractor will evaluate the data to determine disposal requirements within 10 days. Appropriate disposal must be performed no later than 50 days after the decision date if weather permits (see § 3.2.5).

3.3.8.1 If the solid IDM are determined to be non-hazardous and uncontaminated (see 3.3.9), go to § **3.3.9**.

3.3.8.2 If the solid IDM are determined to be non-hazardous but contaminated (see 3.3.9), go to § **3.3.10**.

3.3.8.3 If the solid IDM are found to be hazardous wastes, go to § **3.3.11**.

3.3.9 If the solid IDM are not a hazardous waste **and** analytical data shows contaminant concentrations below EPA Region III's Risk-Based Concentrations (RBCs), contact the PO for approval to discharge onto the ground near the site of generation.

3.3.9.1 Follow steps detailed in § 3.3.2 *et seq.* (above) pertaining to sediment and erosion control.

3.3.9.2 Upon completion of the solid IDM discharge to the ground, enter type of media, amount of media, date of disposal, and discharge point(s) in a bound site logbook. This information must be provided to the PO within 3 working days.

3.3.9.3 Empty containers are to be properly decontaminated, stored and reused by appropriate personnel. If the containers show signs of deterioration, they should be decontaminated and returned to LAAP as scrap metal.

3.3.10 If the intrusive media is not a hazardous waste but analytical data shows concentrations above the RBCs, dispose of the IDM through the LAAP TSDF.

3.3.10.1 Ensure that the waste containers are properly labeled as applicable in accordance with § 3.3.4 (above).

3.3.10.2 Inform the PO of the type and amount of waste, and the location of the waste. The PO will contact the LAAP personnel to arrange for waste pickup.

3.3.10.3 Contact the Project Officer to ensure that the waste has been entered into the LAAP HWTS.

3.3.10.4 When the waste is removed, enter the type of waste, amount of waste, date of pickup, and the destination of the waste in a bound site logbook. This information must be provided to the PO within 3 working days.

3.3.11 If the solid IDM is considered a hazardous waste under RCRA 40 CFR 261, dispose of this waste through the LAAP TSDF.

a. Ensure that the waste container(s) is properly labeled with the words "Hazardous Waste", the name or type of waste, the EPA hazardous waste code, the date and point of generation, and a point of contact.

b. Inform the PO of the type, amount, and location of the hazardous waste. The PO will arrange for the container(s) to be picked up by LAAP personnel within thirty (30) days of generation of known hazardous waste, or thirty (30) days of receipt of data confirming the solid as hazardous waste.

c. Contact the PO to ensure that the hazardous waste has been entered into LAAP's HWTS.

3.4 Procedures for decon solution and PPE disposal.

3.4.1 Decon solutions include catch water from steam-cleaning operations performed on large sampling equipment, drill rigs, and drums, as well as smaller quantities of soapy water and rinse solutions used in decontaminating field sampling equipment. The former are considered potentially contaminated by virtue of the fact that they are used intrusively on a CERCLA site. The latter solutions are by definition, contaminated with low levels of acids and organics used in various rinses.

3.4.1.1 At the completion of the field event, a composite sample of the decon solution will be taken. The decon solution will be treated as liquid IDM pending results (§ 3.2 *et seq.* above).

3.4.2 PPE will be containerized onsite, appropriately labeled, and disposed of in a designated APG dumpster.

4.0 MAINTENANCE

Not Applicable

5.0 REFERENCES

Environment Article § 7-201(t)

Hazardous Waste Tracking System (HWTS) User's Manual, Version 1.2. Aberdeen Proving Ground, Maryland, 1993.

Phone conversations and DSHE meetings with John Fairbank, The Maryland Department of the Environment. Dec 1993- Feb 1994.

Management of Investigation-Derived Wastes during Site Inspections PB91-921331, OERR Directive 9345.3-02, May 1991, Office of Emergency and Remedial Response U.S. Environmental Protection Agency, Washington, D.C.

STANDARD OPERATING PROCEDURE 028
HYDROLAB MULTIPARAMETER WATER QUALITY MONITORING INSTRUMENT

1.0 Purpose and Scope

The purpose of this standard operating procedure is to delineate protocols for field operation with the multiparameter water quality logging system (H2O data sonde and SCOUT 2 receiver) The system can monitor up to eight basic parameters including dissolved oxygen, percent saturation, temperature, pH, specific conductance, resistivity, salinity, total dissolved solids, redox, level, and depth.

Use of brand names in this SOP is not intended as endorsement or mandate that a given brand be used. Alternate equivalent brands of detectors, sensors, meters, etc. are acceptable. If alternate equipment is to be used, the contractor shall provide applicable and comparable SOPs for the maintenance and calibration of same.

2.0 Material

a. SCOUT 2 display
b. H2O water quality data transmitter
c. Underwater cables
d. Accessories, standards, *etc.*
e. Instrument logbook

3.0

Calibration must be performed daily before using the instrument. Calibration may be performed in the lab or in the field.

3.1 Calibration

Fill the calibration cup with the appropriate standard as follows:

a. Temperature - none required
b. Specific Conductance - KCl or seawater standards
c. pH - pH 7 buffer plus slope buffer
d. Dissolved oxygen - saturated air or saturated water
e. Redox - quinhydrone
f. Depth - set zero in air
g. Level - set zero in air
h. Salinity - uses calibration for specific conductance

3.1.1 Continue this calibration sequence:

a. Attach the cable to the transmitter
b. Connect the end of the cable to the display
c. Press the **ON/OFF** key on the display unit's control panel. Allow a few seconds for the transmitter to start sending data to the display screen.
d. Press the **CALIBRATE** button
e. Enter the value of the standard
f. Accept the new calibration number

3.2 Field operation

a. Attach the cable to the transmitter
b. Connect the end of the cable to the display
c. Press the **ON/OFF** key on the display unit's control panel. Allow a few seconds for the transmitter to start sending data to the display screen.

3.2.1 Surface-water

d. Deploy the sensor over the side of the vessel, or into the stream to be monitored into a minimum of 4" of water.

e. Write the data values displayed on the display screen in the Field Logbook (see SOP 003) and accept data record into datalogger.

f. Retrieve sensor

g. Move to next sampling location. If travel time is great, turn display off by pressing **ON/OFF** key.

h. Check the condition of the probes before each deployment.

i. When finished sampling, disconnect the transmitter.

3.2.2 Ground-water

j. Mount sampler on flow-through sampler cup

k. Start pump

l. When the pump/hose system has been purged of air bubbles, set sampling rate to record all parameters each time 1-3 liters have been removed from the well (see SOP 013).

m. Record the monitored values also in the appropriate field logbook to ensure against inadvertent data loss.

4.0 Maintenance

See the manufacturer's reference manual.

5.0 Precautions

5.1 Check the condition of the probes frequently between sampling.

5.2 Do not force pins into connections, note keying sequence.

5.3 If field readings are outside the expected range, check for bubbles on, or damage to, the probes. If there are no bubbles or damage, recalibrate the sensor.

6.0 References

Hydrolab Scout 2 Reference Manual, December 1991.

REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

Public reporting burden for this collection of information is estimated to average 1 hour per response, including the time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing this burden, to Washington Headquarters Services, Directorate for Information Operations and Reports, 1215 Jefferson Davis Highway, Suite 1204, Arlington, VA 22202-4302, and to the Office of Management and Budget, Paperwork Reduction Project (0704-0188), Washington, DC 20503.

1. AGENCY USE ONLY ***(Leave blank)***

2. REPORT DATE
March 1999

3. REPORT TYPE AND DATES COVERED
Final report

4. TITLE AND SUBTITLE
Monitored Natural Attenuation of Explosives in Groundwater-Environmental Security Technology Certification Program Completion Report

5. FUNDING NUMBERS

6. AUTHOR(S)
Judith C. Pennington, Mansour Zakikhani, Danny W. Harrelson

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
U.S. Army Engineer Waterways Experiment Station,
3909 Halls Ferry Road, Vicksburg, MS 39180-6199

8. PERFORMING ORGANIZATION REPORT NUMBER
Technical Report
EL-99-7

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)
Environmental Security Technology Certification Program Office
901 North Stuart Street, Suite 303, Arlington, VA 22203

10. SPONSORING/MONITORING AGENCY REPORT NUMBER

11. SUPPLEMENTARY NOTES
Available from National Technical Information Service, 5285 Port Royal Road, Springfield, VA 22161.

12a. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release; distribution is unlimited.

12b. DISTRIBUTION CODE

13. ABSTRACT ***(Maximum 200 words)***

Natural attenuation as a remedial alternative may be appropriate where natural processes are sufficient to protect receptors of concern. The objectives of this project were to demonstrate natural attenuation of explosives at an Army site, optimize groundwater-monitoring procedures to generate reliable trends in explosives concentrations over time, evaluate the significance of site capacity on the ultimate fate and transport at the site, apply biomarkers as monitoring tools, use models for contaminant plume definition and predictions of future contaminant extent, and develop a protocol for selection and implementation of monitored natural attenuation of explosives. The field demonstration was conducted at the Louisiana Army Ammunition Plant and validated at Joliet Army Ammunition Plant. The demonstration included groundwater monitoring and modeling, a cone penetrometry sampling event to characterize site lithology and to obtain sample material for other parts of the study. Results confirmed a declining mass of explosives in groundwater over 2 years. The groundwater model predicted a shrinking plume over 20 years. Costs for monitored natural attenuation were significantly less than costs for pump-and-treat remediation and somewhat less than costs of in situ bioremediation with intervention. Results demonstrated that natural attenuation is a viable option that should be among the options considered for remediation of explosives-contaminated sites.

14. SUBJECT TERMS

Biomarkers	Groundwater monitoring	RDX
Explosives	Intrinsic remediation	Soil partitioning
Groundwater modeling	Natural attenuation	TNT

15. NUMBER OF PAGES
230

16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT	**18. SECURITY CLASSIFICATION OF THIS PAGE**	**19. SECURITY CLASSIFICATION OF ABSTRACT**	**20. LIMITATION OF ABSTRACT**
UNCLASSIFIED	UNCLASSIFIED		

NSN 7540-01-280-5500

Standard Form 298 (Rev. 2-89)
Prescribed by ANSI Std. Z39-18
298-102