OAK RIDGE
NATIONAL LABORATORY

MANAGED BY UT-BATTELLE
FOR THE DEPARTMENT OF ENERGY

ORNL/TM-13596

PERMEATION DISPERSAL OF TREATMENT AGENTS FOR IN SITU REMEDIATION IN LOW PERMEABILITY MEDIA: 1. FIELD STUDIES IN UNCONFINED TEST CELLS

R. L. Siegrist
D. R. Smuin
N. E. Korte
D. W. Greene
D. A. Pickering
K. S. Lowe
J. Strong-Gunderson

UT-BATTELLE

ORNL-27 (4-00)

ORNL/TM-13596

PERMEATION DISPERSAL OF TREATMENT AGENTS FOR IN SITU REMEDIATION IN LOW PERMEABILITY MEDIA: 1. FIELD STUDIES IN UNCONFINED TEST CELLS

R. L. Siegrist[1]
D. R. Smuin[2]
N. E. Korte[2]
D. W. Greene[3]
D. A. Pickering[3]
K. S. Lowe[3]
J. Strong-Gunderson[4]

Period of Work: 1994 to 1998

Environmental Sciences Division
Publication No. 4761
Publication Date:

Prepared by
OAK RIDGE NATIONAL LABORATORY
P.O. Box 2008 .
Oak Ridge, Tennessee 37830-6285

Managed by
UNIVERSITY OF TENNESSEE-BATTELLE LLC
for the
U.S. DEPARTMENT OF ENERGY
Under Contract DE-AC05-000R22725

This work is funded by the Office of Science and Technology with the Department of Energy Office of Environmental Management, under the Contaminant Plume Containment Focus Area

---

[1] Associate Professor, Colorado School of Mines, Environmental Science & Engineering Division, Golden, Colo. Adjunct Faculty Research participant, Environmental Sciences Division, Oak Ridge National Laboratory, Oak Ridge, Tenn.
[2] Research Staff member, Oak Ridge National Laboratory, Environmental Sciences Division, Grand Junction, Colo.
[3] Research Staff member, Oak Ridge National Laboratory, Life Sciences Division, Grand Junction, Colo.
[4] Research Staff member, Oak Ridge National Laboratory, Environmental Sciences Division, Oak Ridge, Tenn.

TABLE OF CONTENTS

CONTENTS (continued)

LIST OF FIGURES

FIGURES (CONTINUED)

LIST OF TABLES

ABBREVIATIONS, ACRONYMS, AND INITIALISMS

bgs	below ground surface
CSM	Colorado School of Mines
CTS	Clean Test Site
d	day
DNAPL	dense nonaqueous-phase liquids
DO	dissolved oxygen
DOE	U.S. Department of Energy
ESD	Environmental Sciences Division
ft	feet or foot
g	gram
gal	gallon
GJ	Grand Junction
ID	inside diameter
in.	inch
INA	ice-nucleating activity
kg	kilogram
L	liter
LPM	low permeability media
mg	milligram
LMES	Lockheed Martin Energy Systems, Inc.
MPIS	multi-port injection system
MPN	most probable number
msl	mean sea level
mV	millivolt
ORNL	Oak Ridge National Laboratory
OST	Office of Science and Technology
oz.	ounce
PCE	perchloroethylene
PE	polyethylene
PORTS	Portsmouth Gaseous Diffusion Plant
ppm	parts per million
psi	pounds per square inch
PVC	polyvinyl chloride
s	second
SEM	scanning electron microscope
SMT	soil moisture and temperature
SOPs	standard operating procedures
TBD	to be determined
TCE	trichloroethylene
TOC	total organic carbon
U.S.	United States
USEC	United States Enrichment Corporation

EXECUTIVE SUMMARY

A research and demonstration project was completed to evaluate the viability of permeation dispersal as a delivery method for delivering treatment agents to enable in situ remediation of contaminated low permeability media soils. This report describes field-scale testing using unconfined test cells established at the Clean Test Site (CTS) at the DOE Portsmouth Gaseous Diffusion Plant near Piketon, Ohio. At this site a commercially available multi-port injection system (MPIS) was used to deliver contrasting agents into a silty clay deposit. A companion report describes laboratory studies completed at the Colorado School of Mines where intact soil cores collected from the CTS were injected with two chemical oxidants (hydrogen peroxide and potassium permanganate) (see Urynowicz and Siegrist, 2000).

At the CTS, seven unconfined test cells were established to enable evaluation of seven treatment agents. The treatment agents tested were selected based on their contrasting features and potential applicability to treatment of organic chemicals in the subsurface. Water amended with tracers was injected into one test cell (T1) to provide a reference for nonreactive fluid movement in the silty-clay soil. The treatment agents studied included: hydrogen peroxide (T2) and potassium permanganate (T5) as chemical oxidants capable of degradation of many toxic organics; a guar gum suspension of iron micropowder (T7) for reductive dechlorination; a lime slurry (T4) to elevate pH and cause alkaline destruction of organics as well as stabilize metals; a bionutrient/surfactant agent (T3) to enhance biodegradation; and compressed air (T6) to enhance permeability and aeration status and improve volatilization or biodegradation. Six of the test cells were 24 ft by 24 ft in surface area while one was 4 ft by 8 ft. All cells were injected with treatment agents at an average volumetric loading of 0.27 gal/ft^3 to a depth of 10.4 ft below ground surface using the MPIS with four rack-mounted injectors on 2-ft spacings. Extensive monitoring during injection and sampling and analysis before and after injection were completed to evaluate the effectiveness of MPIS delivery and the impacts of the various agents on the ambient subsurface conditions.

Field test results revealed that treatment agents can be rapidly delivered into the shallow subsurface using MPIS technology. The treatment agents injected appear to rapidly advect away from the injector bore in existing pathways such as root channels and fractures. For those agents that are persistent and react slowly in the subsurface, further dispersal can occur by slower advection in fine matrix pores as well as by diffusive transport processes. The initial dispersal of the treatment agents was similar to that of the conservative tracers. With time after the injections were completed, there were expanding effects in the subsurface within the lime, potassium permanganate and iron cells. Evaluation of injection rates, equipment and labor costs indicate that MPIS technology may be applied for \$2 to \$3 per cubic yard of soil not including the cost of reagents.

ACKNOWLEDGMENTS

This report on the demonstration of permeation and dispersal of reactive fluids for in situ treatment in low permeability media at the U.S. Department of Energy (DOE) Portsmouth Gaseous Diffusion Plant (PORTS) is based on the combined efforts of scientific and engineering staff at Oak Ridge National Laboratory (ORNL) and Hayward Baker Environmental in collaboration with the Colorado School of Mines (CSM) and others. Project sponsorship was provided through the Subsurface Contaminant Focus Area of the DOE Office of Science & Technology along with the DOE Office of Environmental Restoration at PORTS.

The following individuals are specifically recognized for their valuable contributions to the field demonstration:

Robert Barnett	-	Lockheed Martin Energy Systems (LMES) (In Memorium)
Skip Chamberlain	-	DOE Office of Science & Technology
Tom Early	-	Subsurface Contaminant Focus Area
Eugene Gillespie	-	DOE Site Office, PORTS
Johnny Moore	-	DOE Oak Ridge Operations Office
Elizabeth Philips	-	Subsurface Contaminant Focus Area, Product Line Manager
John Sheppard	-	DOE Site Office, Paducah
Jim Wright	-	Subsurface Contaminant Focus Area
Doug Davenport	-	LMES, Technology Applications
Tom Houk	-	Bechtel Jacobs Company (BJC), Technology Applications
Jim Ervin	-	BJC, Construction Engineering
Dianne Gates	-	Lawrence Livermore National Laboratory
Baohua Gu	-	ORNL, Environmental Sciences Division (ESD)
Chris Muhr	-	ORNL Environmental Technology Section (ETS)
Tony Palumbo	-	ORNL, ESD
Susan Pfiffner	-	Univ. Tennessee, Center for Environmental Biotechnology
Doug Pickering	-	ORNL ETS
Kirk Roemer	-	ORNL ETS
Joann Sauvage	-	ORNL ETS
Bob Schlosser	-	ORNL ETS
Jim Thate	-	ORNL ETS
Mike Urynowicz	-	CSM, Environmental Science & Engineering
Olivia West	-	ORNL ESD

1. Introduction

Chlorocarbons like trichloroethylene (TCE) are common contaminants of concern at U. S. Department of Energy (DOE) facilities and industrial sites across the United States (U.S.) and abroad (Huling and Weaver 1991; U.S.EPA 1992; MacDonald and Kavanaugh 1994). These contaminants of concern are present in source areas and in soil and ground water plumes as dissolved or sorbed phase constituents as well as dense nonaqueous-phase liquids (DNAPLs). These DNAPL compounds can be released to the environment through a variety of means including leaks in storage tanks and transfer lines, spills during transportation, and land treatment of wastes. When DNAPL compounds are present in low permeability media (LPM) like silt and clay layers or deposits, there are major challenges with assessment of their behavior and implementation of effective in situ remediation technologies.

In situ remediation technology development has largely overlooked treatment of DNAPLs in LPM. Poor accessibility to the contaminants and the difficulty in delivery of treatment agents have rendered conventional bioremediation, vapor extraction, and pump-and-treat ineffective for this type of media. As a result, effective in situ treatment methods for DNAPL compounds in fine-grained deposits was recently one of the top-ranked environmental restoration needs across the DOE Complex. Similarly, within the petroleum industry, nearly 40% of the underground storage tanks in the world are located on clay soils and remediation of contaminants from leaking underground tanks in these settings has been a major challenge.

As a result of the need for solutions and the gap in the current knowledge and technology base, a project was initiated by the DOE Office of Science and Technology (OST) and the DOE Portsmouth Gaseous Diffusion Plant (PORTS) near Piketon, Ohio in collaboration with the American Petroleum Institute (API) in 1993 (API 1995, DOE 1996). In this project, in situ remediation technologies are being evaluated for both enhanced mass removal and in place destruction of DNAPL compounds in LPM, specifically chlorinated solvents [e.g., TCE, perchloroethylene (PCE)] in the vadose and saturated zones of LPM. The overall project has included a series of related tasks including: (1) preparation of 16 DNAPL focus papers and reports, (2) a field pilot test of hydraulic fracturing for dewatering, (3) a field test of enhanced air flushing for NAPL removal, (4) a field test of hydraulic fractures for hydraulic and pneumatic control and hot fluid injection, (5) a field comparison of multiple point injection and permeation dispersal of different reactants, (6) a field-scale demonstration of soil fracturing for thermally enhanced mass recovery and reactive barrier degradation, and (7) numerical and experimental analyses of the mobility of residual NAPLs versus varying degrees of remediation. The field testing activities have occurred at both clean and contaminated sites in the U.S. and Canada.

This report describes a field demonstration that was conducted at the PORTS Clean Test Site (CTS) to evaluate the feasibility of permeation and dispersal of reagents into LPM. Various reagents and tracers were injected at seven test cells primarily to evaluate the feasibility of delivery, but also to evaluate the effects of the injected reagents on LPM. The various reagents and tracers were injected at the PORTS CTS using a multi-port injection system (MPIS) developed and provided by Hayward Baker Environmental, Inc. The work reported here was performed by personnel from Oak Ridge National Laboratory (ORNL) in collaboration with Lockheed Martin Energy Systems [(LMES), now Bechtel Jacobs Company, LLC], Hayward Baker Environmental, Inc., and others.

Supplementary laboratory experiments at the Colorado School of Mines focused on the effects of chemical oxidants on LPM using intact cores collected from the CTS. The results of the laboratory experiments are presented in the companion report, *Permeation Dispersal of Treatment Agents for In Situ Remediation in Low Permeability Media: 2. Laboratory Studies with Intact Cores* (Urynowicz and Siegrist 1999). Other facets of the project have been focused on the reaction mechanisms of reagents used in this project and alternative reagent delivery methods and the results have been reported elsewhere (e.g., API 1995; DOE 1996; Pfiffner et al. 1997; Case 1997; Gates and Siegrist 1995; Gierke et al. 1995; Murdoch et al. 1997a; Murdoch et al. 1997b; Siegrist et al. 1993; Siegrist et al. 1994; Siegrist and Lowe 1995; Siegrist et al. 1995a; Siegrist et al. 1995b; Siegrist et al. 1995c; Siegrist et al. 1996; Siegrist et al. 1998; Siegrist et al. 1999; Smuin et al. 1995; Strong-Gunderson and Palumbo 1995; Walden 1993; West et al. 1995).

1.1 Purpose and Scope

The purpose of this project was to test an innovative approach for in situ treatment of volatile organic compounds, which are common contaminants at DOE facilities.. The PORTS CTS was chosen as an appropriate location for determining the feasibility of performing multi-point injection permeation and dispersal testing because it is representative of the low permeability soils contaminated at many DOE sites. Additionally, the CTS enabled evaluation of the feasibility of the process but did not present the complications of contaminated site operations.

The various reagents and tracers injected included water, oxidants, a bionutrient, lime, air, and zero-valence iron. Water alone was injected to provide a baseline test cell. The oxidants (hydrogen peroxide and potassium permanganate) were injected because they can catalyze and chemically oxidize chlorinated organics. The bionutrient and surfactant were injected to determine the feasibility of using the mixture to enhance the natural breakdown of chlorinated solvents by indigenous bacteria. The lime injection was tested because it could be used to adjust soil pH for in situ stabilization of metals. Air was injected to test the MPIS for pneumatic fracturing of LPM and zero-valence iron (iron micropowder) was injected because it has been demonstrated to act as a reducing agent for chlorinated solvents.

The field work for this project included four tasks: (1) pre-treatment characterization of the lithology and soil conditions within seven test cells at the CTS, (2) MPIS injection and testing using various reagents and tracers at seven test cells, (3) concurrent monitoring during MPIS testing, and (4) post-treatment sampling and monitoring of the seven test cells. Several post-treatment sampling events were performed.

Samples collected during this project included soil samples for logging lithology, soil fracture characteristics and geochemical properties, and soil-pore water samples for water quality parameters and geochemical properties. Field and laboratory analysis was performed on soil samples and soil-pore water samples as indicated on Table 1.1.

The following aspects of the permeation and dispersal were evaluated during this project:

- Feasibility of using a MPIS for injection of treatment agents into the subsurface. The agents were various solutions, slurries, or emulsions of compounds that may reduce toxicity through treatment or containment, and

- Relative effectiveness of the treatment agents for in situ remediation in silty clay soils.

The general objectives of the testing and the procedures followed to achieve them are listed below.

Objective 1: To characterize fracture size and continuity in the untreated soil and determine changes in the soil after reagent injection. Pre-treatment soil samples were collected from soil borings to describe fracture morphology and determine baseline geochemical properties. Tracers were injected with the treatment agents, where compatible, in order to facilitate detection of the injected fluids and the fractures that transmitted them. Soil-pore water samples were collected from suction lysimeters to evaluate the dispersal of the injected fluids. Soil moisture probes were emplaced to monitor the increase in soil moisture due to injections. Soil samples from post-treatment borings were inspected to determine changes in fracture size and density and geochemical properties. At one location, a test pit was excavated to permit visual examination of the soil to determine if the effects of the injection technique were visible in the subsurface.

Objective 2: To determine matrix effects of the various fluids released with respect to changes in soil-pore water and soil. Suction lysimeters provided soil-pore water samples that were monitored for changes in temperature, pH, dissolved oxygen (DO), conductivity, total organic carbon (TOC), alkalinity, Fe, Mn, Cl^-, No_3^- and SO_4^{2-}. Soil moisture probes were monitored to determine the relative dispersal of the injected fluids. Soil samples were collected for evaluation of matrix effects and detection of injected fluids.

Objective 3: To determine dispersal of reactive particles in LPM. An emulsion or slurry of reactive particles (e.g., iron micropowder with guar gum) was injected into the subsurface using the MPIS. The area of influence was evaluated by collecting post-treatment core samples. These cores were macroscopically inspected and chemically analyzed to determine the presence, concentration, and distribution of the reactive particles and/or tracers. Soil-pore water samples collected from suction lysimeters also provided information on dispersal of reagents.

Objective 4: To determine dispersal of oxidants in LPM. Solutions of hydrogen peroxide and potassium permanganate were injected. The area of influence was determined by collecting core samples and by collecting soil-pore water samples. These cores and water samples were analyzed to determine the effects of the reactive fluids.

Objective 5: To determine the operation and maintenance characteristics of the MPIS equipment. Observations of injection volumes, flow rates, back pressure, operational problems, etc., were documented during field tests to evaluate multi-point injection performance.

1.2 Organization of the Report

The remainder of this report is organized as follows:

- Section 2 describes the CTS.
- Section 3 describes the technical approach for this project.
- Section 4 discusses the testing performed in each test cell and the soil and water sampling results.
- Section 5 discusses observations made related to equipment operation.
- Section 6 is the project summary.
- Section 7 discusses application of the technique to a contaminated site.

Table 1.1. Field activities and analyses for a typical test cell for MPIS testing

Pre-treatment activities	Testing during injection	Post-treatment No. 1 activities	Post-treatment No. 2 activities
Soil Analyses: Five soil borings per test cell:% moisture, grain size color, mineralogy, SEM, X-ray, pH, Eh, TOC, Fe oxides, cations, anions, bacteria	None	Five soil borings per test cell: % moisture, grain size, color, mineralogy, SEM, X-ray, pH, Eh, TOC, Fe oxides, cations, anions, bacteria, visual inspection	Two soil borings per test cell: % moisture, grain size, color, mineralogy, SEM, X-ray, pH, Eh, TOC, Fe oxides, cations, anions, bacteria
Soil-Pore Water Analyses:	Water injection with tracers: monitored penetration rate, flow rate, pressure, and reagent concentration		
Three lysimeters per test cell: temp., pH, DO, conductivity, TOC, alkalinity, Fe, Mn, Cl^-, NO_3^-, SO_4^{2-}, Br^-	Lysimeters: temp., pH, DO, conductivity, TOC, alkalinity, Fe, Mn, Cl^-, NO_3^-, SO_4^{2-}, Br^-	Lysimeters: temp., pH, DO, conductivity, TOC, alkalinity, Fe, Mn, Cl^-, NO_3^-, SO_4^{2-}, Br^-	Lysimeters: temp., pH, DO, conductivity, TOC, alkalinity, Fe, Mn, Cl^-, NO_3^-, SO_4^{2-}, Br^-
One piezometer per test cell: temp., pH, DO, conductivity, TOC, alkalinity, Fe, Mn, Cl^-, NO_3^-, SO_4^{2-}, Br^-	Piezometer: monitored water levels	Piezometer: temp., pH, DO, conductivity, TOC, alkalinity, Fe, Mn, Cl^-, NO_3^-, SO_4^{2-}, Br^-	Piezometer: temp., pH, DO, conductivity, TOC, alkalinity, Fe, Mn, Cl^-, NO_3^-, SO_4^{2-}, Br^-

Note: Not all samples were analyzed for all constituents listed. For example, only samples from one soil boring per test cell were analyzed for % moisture.
SEM = scanning electron microscope
TOC = total organic carbon

2. Background

2.1 Facility Description

PORTS is a federal facility owned by DOE and operated under a contract with United States Enrichment Corporation (USEC). LMES (now Bechtel Jacobs Company, LLC) performs DOE-required environmental restoration, waste management, and site management functions. The 3,714-acre federal reservation lies in Pike County, Ohio, between the cities of Chillicothe and Portsmouth, approximately 70 miles south of Columbus, Ohio (Fig. 2.1).

Operating since 1954, PORTS enriches uranium for commercial nuclear reactors. The enrichment process uses molecular diffusion techniques to separate the ^{235}U isotope from the ^{238}U isotope. The plant has an extensive support complex of machine shops, laboratories, utilities, and decontamination facilities. As a result of plant operations, PORTS generates a wide variety of wastes, including low-level radioactive wastes, spent solvents, polychlorinated biphenyl-contaminated oils, electroplating wastes, paint wastes, metal sludges, acids, and caustics.

2.2 Site Description

The CTS is located at the south end of PORTS, north of the intersection of Hewes Street and Perimeter Road (Figs. 2.2 and 2.3). The site lies outside the plant security fence and is in an uncontaminated area. The topography of the CTS is relatively level, with a drainage area along the western boundary and a rise of higher ground along the eastern boundary of the site (Fig. 2.4). The high point of the area is located at the northeast corner, at an approximate elevation of 667 ft above mean sea level (msl). A storm-water retention pond is located approximately 75 ft west of the northwest corner of the site, but is downgradient with respect to both surface and groundwater and does not appear to affect CTS conditions.

2.3 Site Geology as Defined by CTS Characterization

During the spring of 1994, the ORNL Grand Junction, Colorado (ORNL-GJ) characterized the geology of the CTS by installing nine boreholes to bedrock (BH01 through BH09) at a depth of approximately 30 ft below ground surface (bgs) and collecting soil samples with a hollow-stem-auger drilling rig and a GeoProbe™ rig (Fig. 2.5). The ORNL Environmental Sciences Division performed a ground-penetrating radar survey to delineate the bedrock surface. The geologic data collected from this site characterization were used to construct a bedrock surface map.

Drilling was accomplished using an all-terrain, CME 55 drill rig. The rig used hollow-stem augers with a 3-in.-outside-diameter by 5-ft-long continuous sampler that ran a few centimeters ahead of the lead auger to obtain undisturbed soil samples for lithologic logging. An average of three soil samples per hole were collected and analyzed for moisture content, liquid limit, plastic limit, and grain size. In the summer, an additional six borings (BH10 through BH15) were drilled south of the CTS to characterize the geology in that area prior to the installation of horizontal wells. A detailed lithologic log was prepared for each hole; the continuous samples obtained from the hole were labeled and archived for future use. Lithologic logs and the results of the geotechnical analyses are provided in Appendix A. Table 2.1 summarizes the surface and bedrock elevation data for all of the borings. Table 2.2 summarizes the subsurface properties at the CTS and shows the properties determined during this study.

The soil above bedrock at the CTS is composed of unconsolidated Quaternary fluvial and lacustrine deposits of the Teays Formation. Figures 2.6 and 2.7 are examples of the soil cores and stratigraphic sequence. These deposits are characterized by 15 to 22 ft of low permeability clays and silts known as the Minford Member overlying 2 to 6 ft of moderately permeable sandy gravels, gravelly sands, and silty sands known as the Gallia Member. The bedrock underlying the Quaternary deposits is composed of Mississippian-age Sunbury Shale and Berea Sandstone and Shale. The Sunbury is a very low permeability shale unit underlying the saturated alluvium at the site. Figure 2.8 shows cross sections of the geology at the CTS.

The Gallia forms the principal water-bearing unit in the alluvium at the site. Water-level measurements taken during the drilling project indicate that groundwater in the Gallia, and perhaps the lower portion of the Minford, is confined by the overlying clays and silty clays. When the confining layers were penetrated by augers, the groundwater level rose an average of 13.5 ft above the depth at which saturated sediments were first encountered during drilling (14 ft to 24.5 ft bgs).

2.4 Site Geology as Defined by Pre-Treatment Characterization

Thirty-two soil borings were completed within the CTS prior to the start of injection testing. The borings were drilled to a depth of 12 ft and were sampled continuously with a Geoprobe megabore sampler. Lithologic logs were prepared describing the soil characteristics (Appendix B). The most notable characteristics included:

- the presence of high-angle fractures in the silty clay,
- very fine laminar bedding in some sediments with multi-colored banding,
- a zone of thin-bedded gypsum (less than 1 cm thick) apparent across the site at depths between 6.5 to 8 ft bgs,

- increasing clay content with depth, and
- increasing resistance to penetration with depth.

Based on these characteristics, the upper part of the Minford appears to be primarily composed of shallow lake bed (lacustrine) sediments. There were periods during deposition when the lake dried up, thus forming the thin gypsum beds and desiccation mud cracks that were observed in the finely laminated sediments. This interpretation is consistent with the general description of the Minford given above.

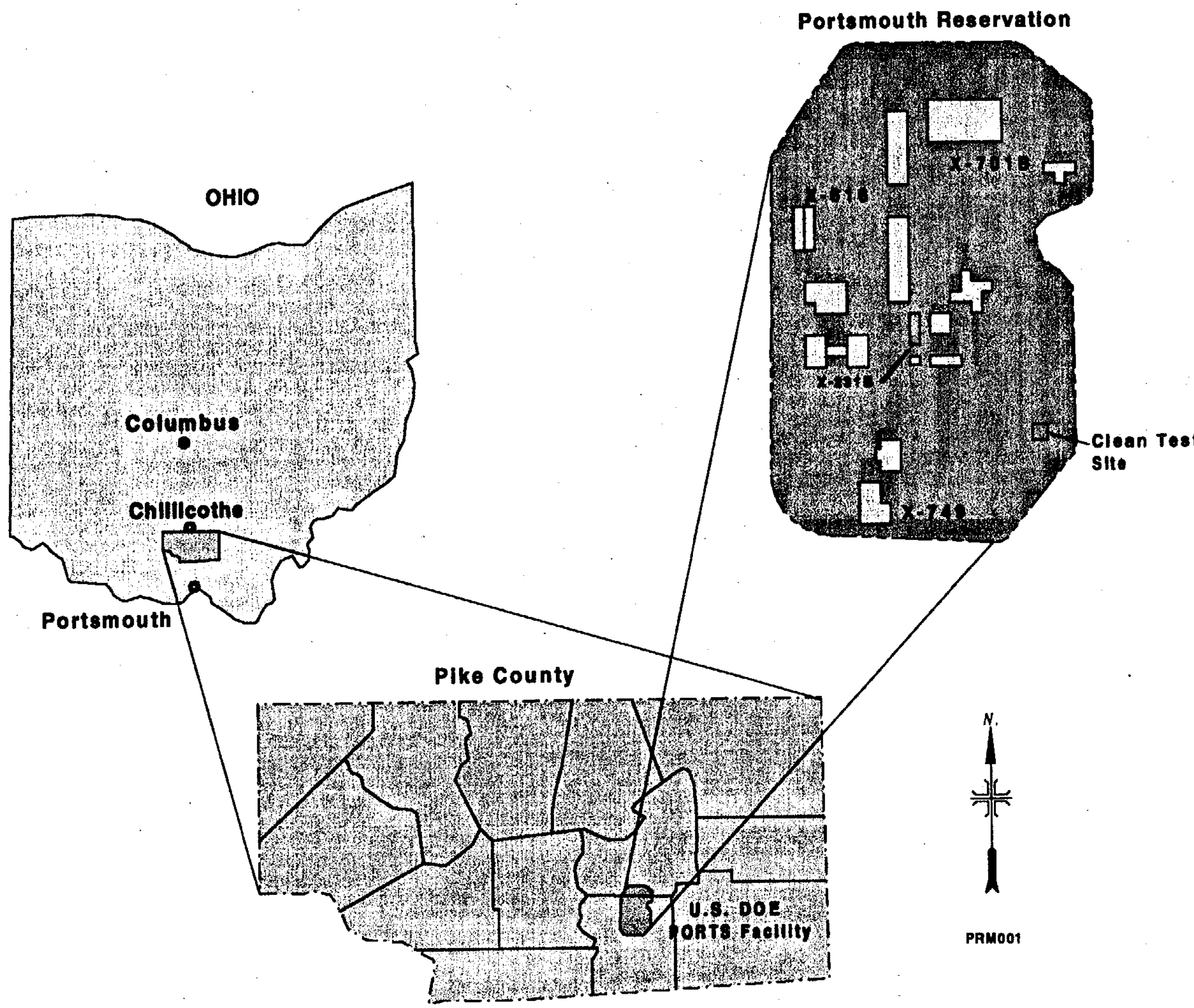


Fig. 2.1. Location of the Portsmouth Gaseous Diffusion Plant.

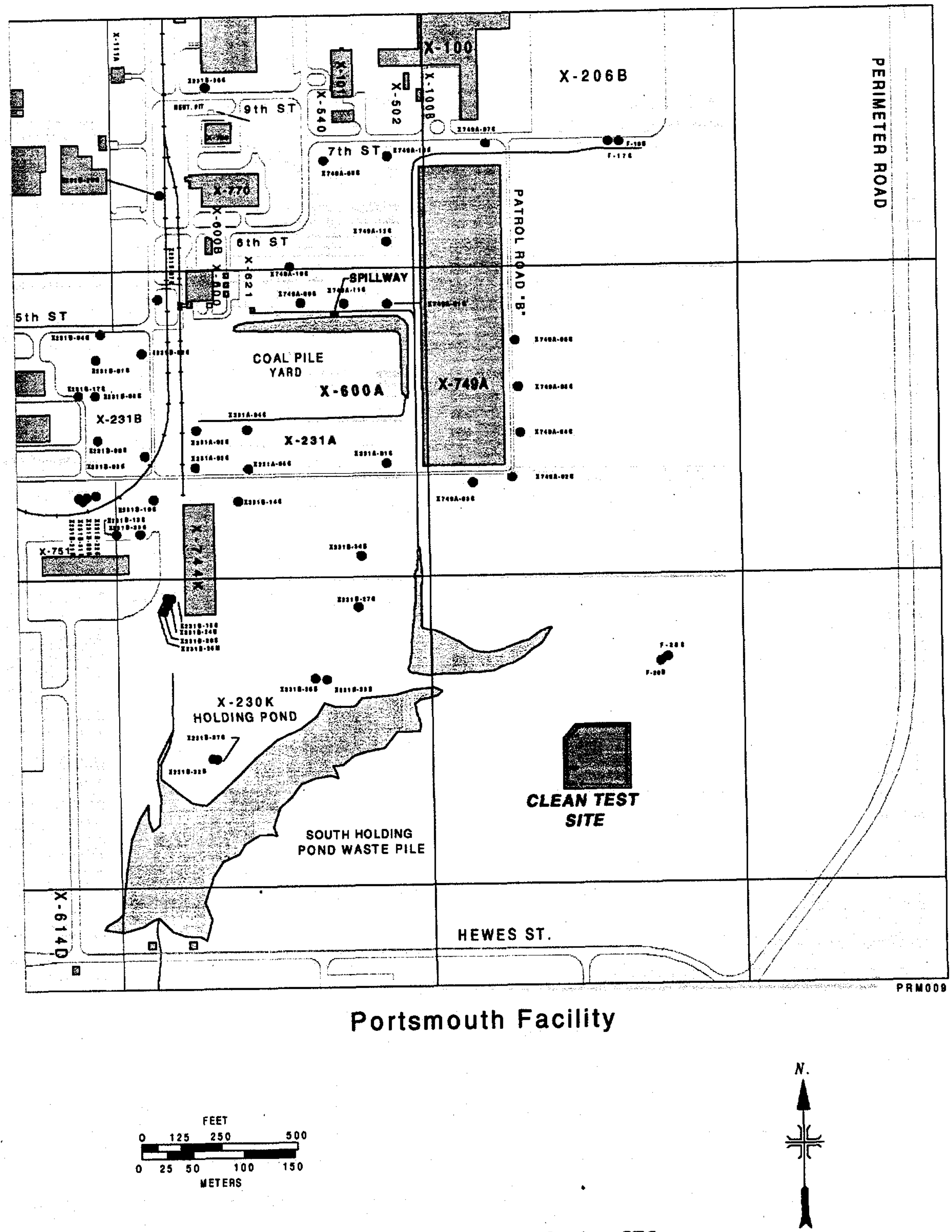


Fig. 2.2. Location of the CTS.

Fig. 2.3. Overview of the test site with the DOE plant in the background.

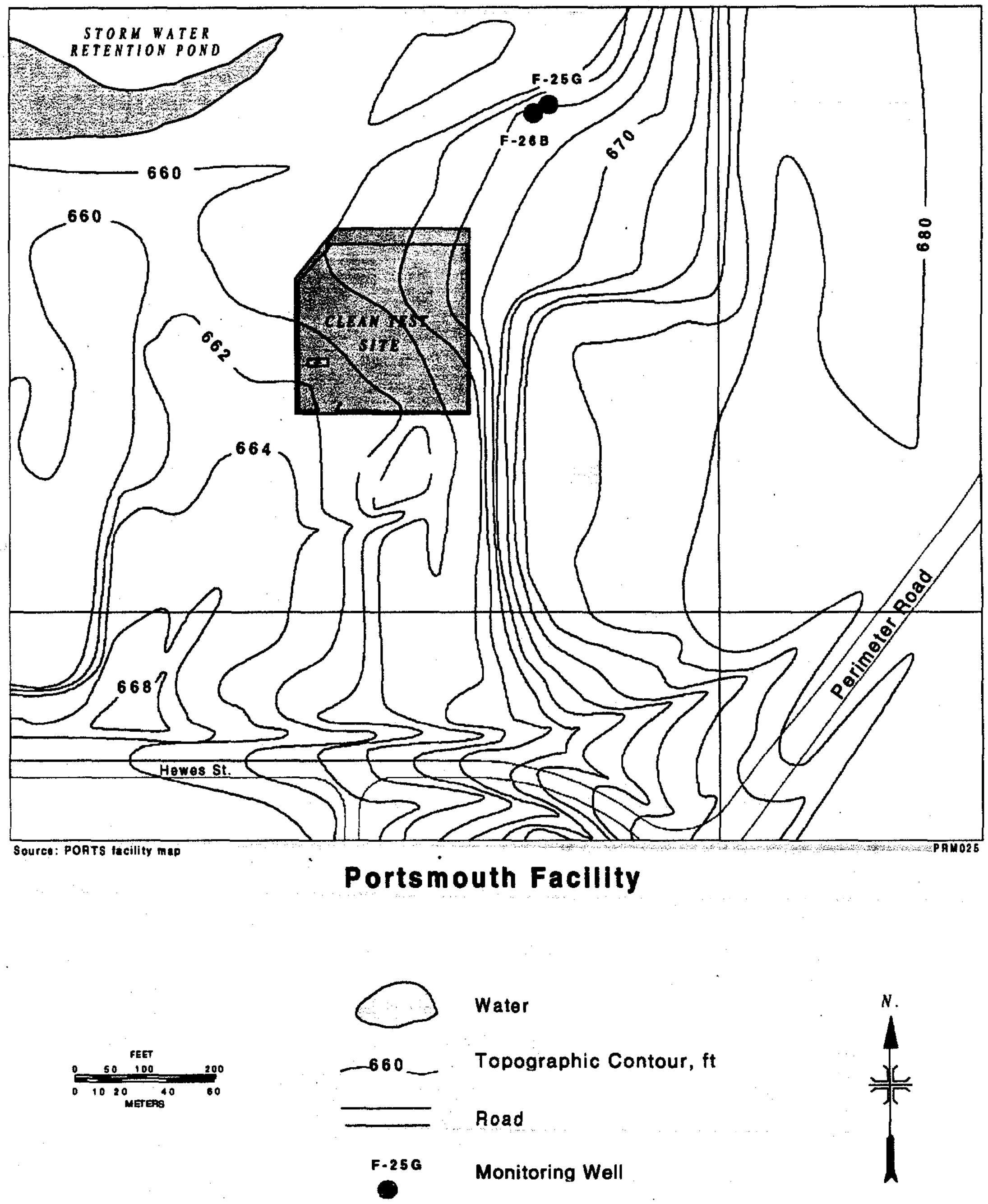


Fig. 2.4. Topography of the CTS.

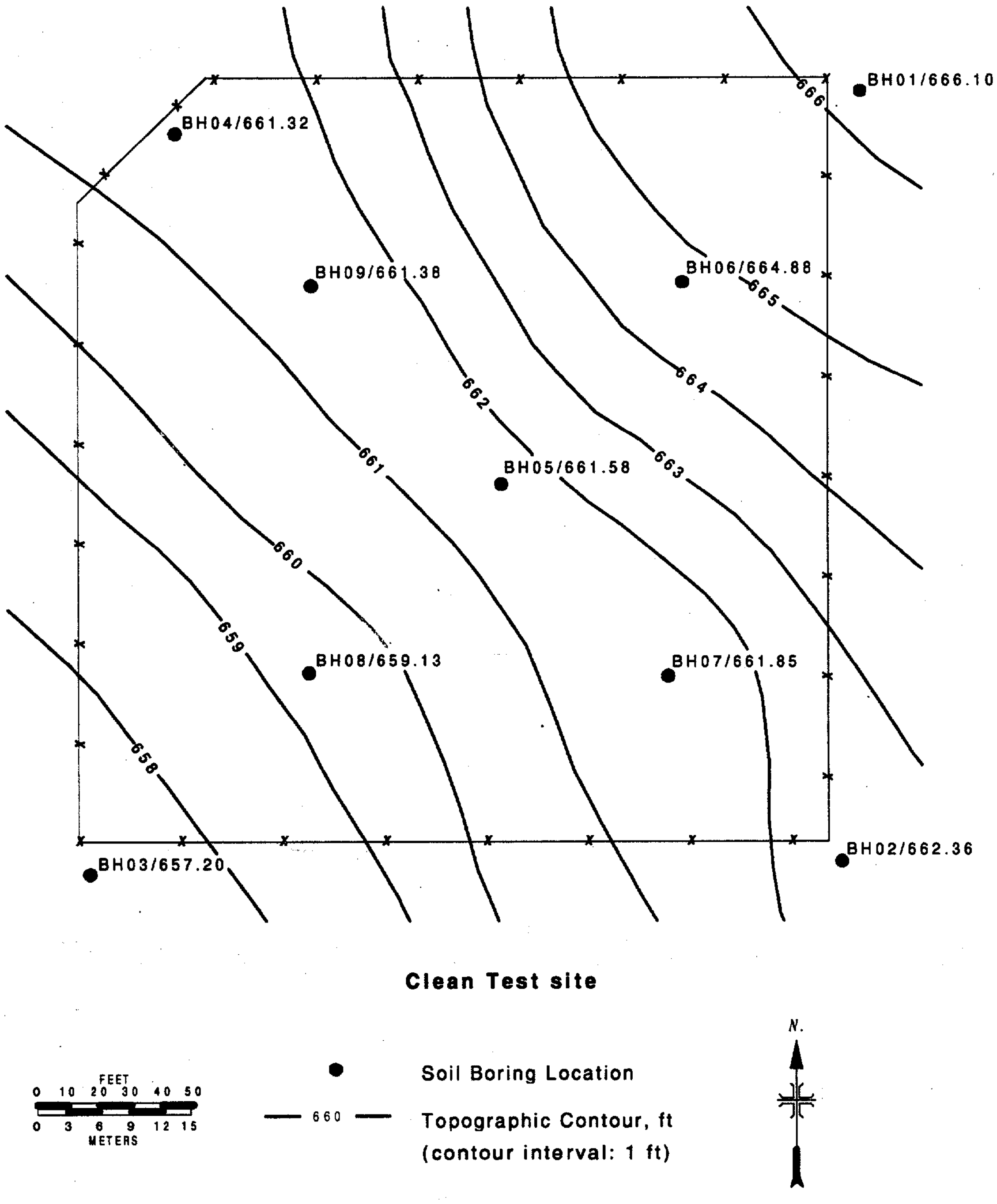
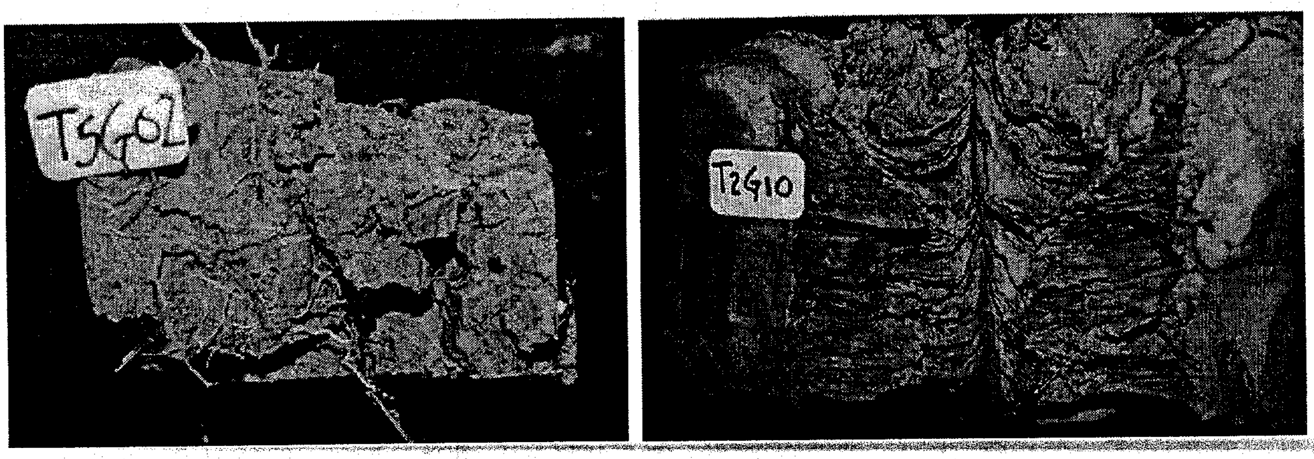


Fig. 2.5. Topography and borehole locations at the CTS.



a. Soil core sample from approx. 2-ft depth. **b.** Soil core sample from approx. 10-ft depth.

Fig. 2.6. Photographs of the CTS subsurface silty-clay media.

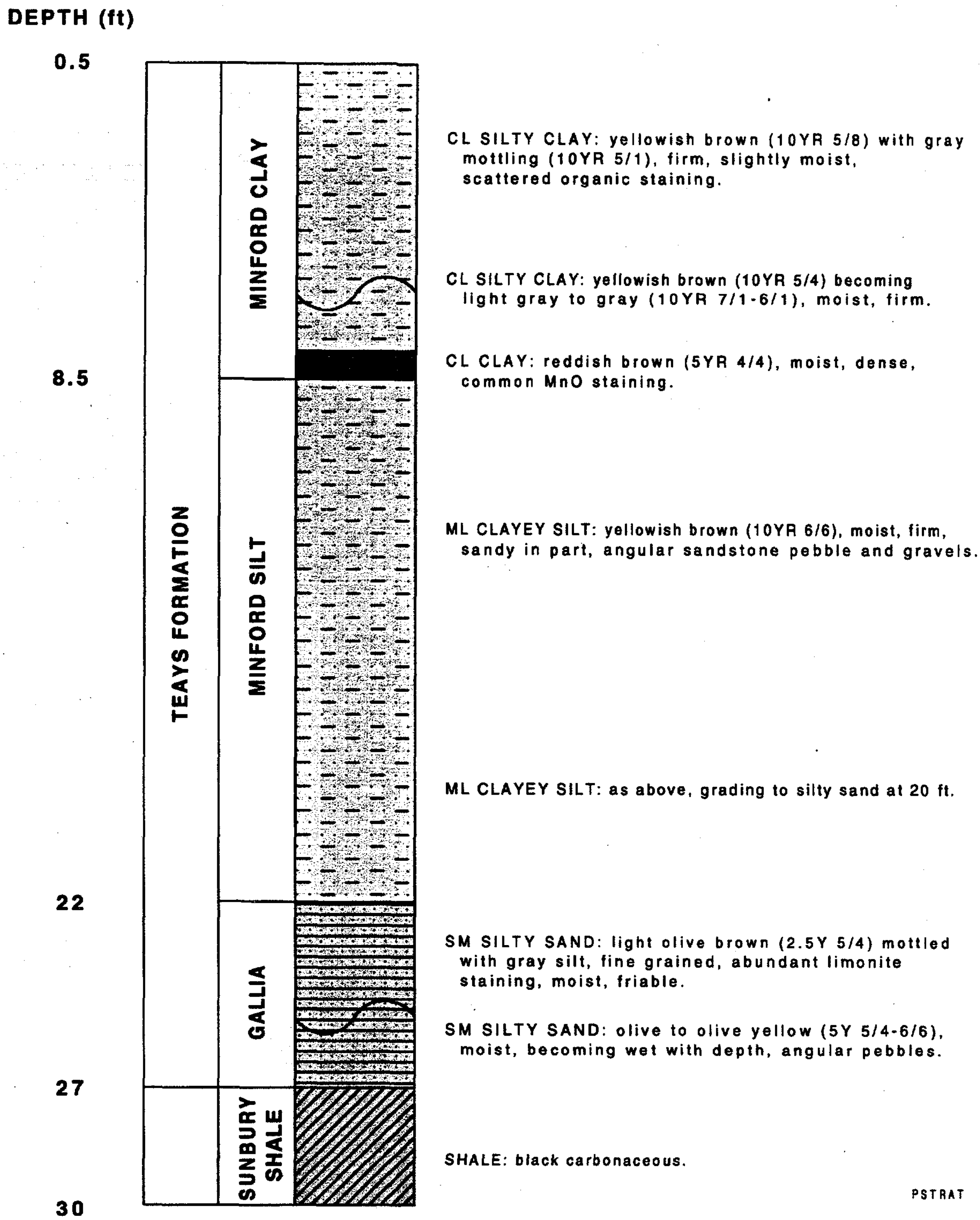


Fig. 2.7. Stratigraphic sequence of borehole number BH07.

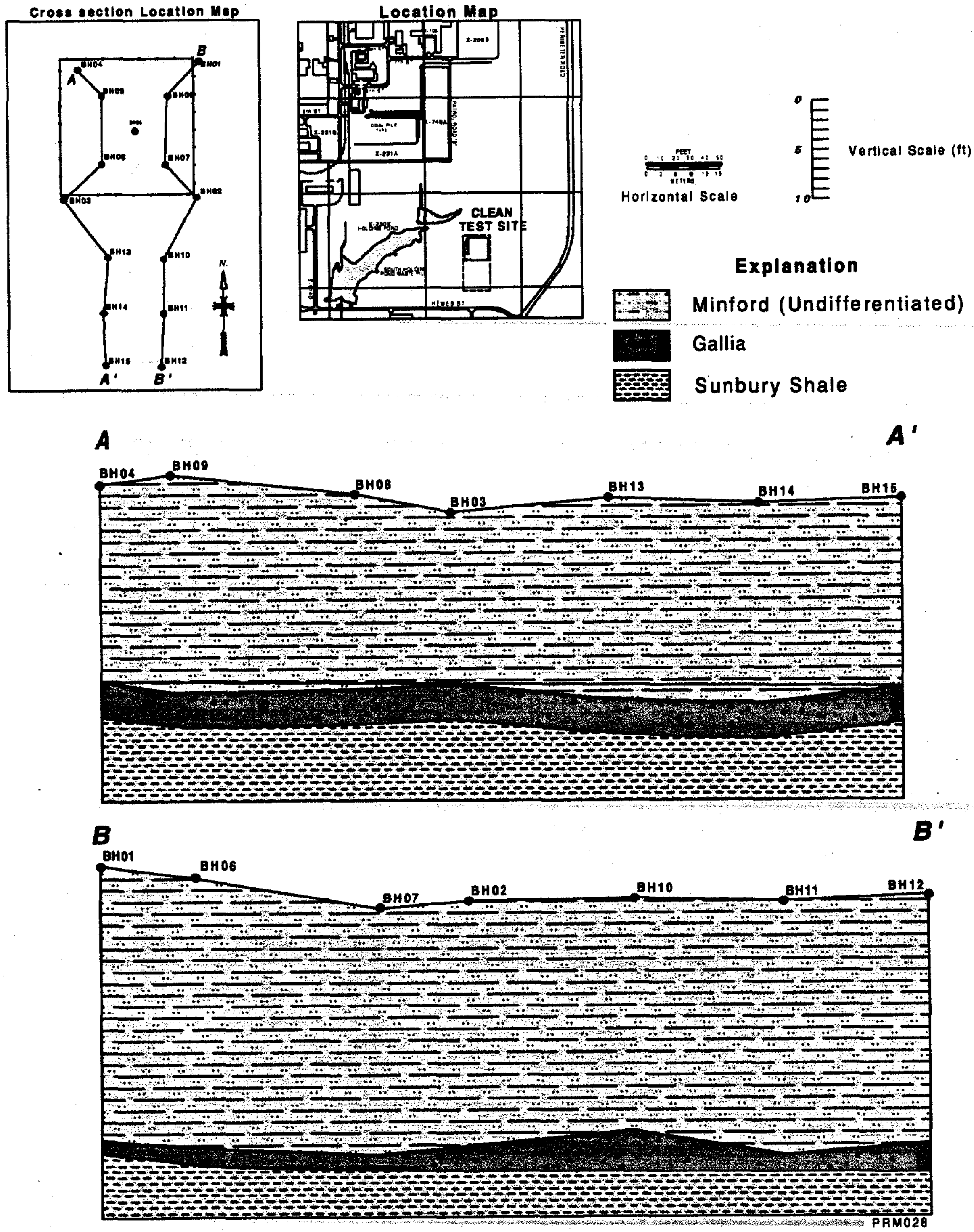


Fig. 2.8. Geologic cross sections at the CTS.

Table 2.1. Ground surface and bedrock surface elevations for CTS boreholes

Borehole number[a]	Ground elevation, ft msl	Depth to bedrock, ft bgs	Bedrock elevation, ft msl
1	666.10	29.5	636.60
2	662.36	28.5	633.86
3	657.20	21.5	635.70
4	661.32	24.5	636.86
5	661.58	26.0	635.58
6	664.88	29.7	635.18
7	661.85	27.0	634.85
8	659.13	24.0	635.13
9	661.38	26.5	634.88
10	662.70	28.3	634.40
11	662.73	28.8	633.93
12	663.07	29.1	633.97
13	658.80	24.5	634.30
14	658.12	24.5	633.62
15	658.88	24.0	634.88

[a] See Figs. 2.5 and 2.8 for borehole locations.
msl = mean sea level
bgs = below ground surface

Table 2.2. Subsurface properties of the Minford Member at the CTS

Soil type and genesis	Silty-clay deposits of fluvio-lacustrine origin. Typically 15-ft-thick upper clay unit (CH) transitioning to a lower 10-ft-thick silt unit (CL).
Soil particle-size distribution:	
Sand size (0.050 to 2.000 mm)	~0.5 dry weight %
Silt size (0.002 to 0.050 mm)	~8.5 dry weight %
Clay size (< 0.002 mm)	~10 dry weight %
Soil mineralogy	In the Minford clay unit, the sand fraction consists of mainly quartz with minor goethite. The silt fraction consists of quartz and minor feldspars, but no goethite. The clay fraction is a mixture of illite (~33%), quartz (~29%), kaolinite (~26%), and smectite (~12%).
Soil physical properties:	
Bulk density	1.8 g/cm^3
Water content	20 weight %
Liquid limit	~60%
Plastic index	~35%
Soil-pore system:	
Total fractional porosity a	0.40 v/v
Water-filled saturation	90% pores
Pore water saturation	10% pores
Soil Chemistry:	
pH (in water)	4 to 8
Eh	140 to 400 mV
Organic carbon	500 to 7000 ppm
Iron oxides	
Free	23,000 mg/kg
Amorphous	13.50 mg/kg
Cation exchange capacity	17.5 meq/100 g
Exchangeable ions:	
Mg	<10 to 45 mg/kg
Ca	<1000 to 5000 mg/kg
Soil microbiology:	
Total bacteria	100 to 1000 organisms/g

[a] estimated

Note: The information shown is based on a compilation from various sources including analyses of Minford soils from the X-231B site (ORNL 1994) and the ORNL reconnaissance boring and soil analyses completed during April and May 1994.

3. Technical Approach

Work plans prepared for the project included a technical plan, a sampling and analysis plan, a quality assurance project plan, and a health and safety plan (ORNL 1994). All plans were reviewed, revised, and finalized prior to mobilization to the CTS. To ensure that representative data were collected for this project, ORNL standard operating procedures (SOPs) were used for conducting field activities (ORNL 1993). Table 3.1 lists the SOPs that were pertinent to this project. Table 3.2 summarizes the testing performed at each test cell. A readiness review for the pre-treatment site characterization was held at the PORTS facility on October 18, 1994. The readiness review for the injection testing was held on November 3, 1994, and the project was approved for start-up.

3.1 Task 1: Geoprobe Borings and Lysimeter Installation

The first task of this project was to characterize the soils to a depth of 12 ft in each of seven test cells (Fig. 3.1). Each test cell was 24 × 24 ft in surface area except for test cell 7, which was 4 × 8 ft. The size of test cell 7 was decreased to reduce the volume of reagent required, thereby reducing the cost for the iron micropowder. Test cell design and characteristics are summarized in Table 3.3.

For the pre-treatment characterization, lithologic samples were collected from five bore-holes in each test cell (labeled A through E) (Fig. 3.2), except for test cell 7, which was characterized with one pre-treatment borehole. The lithologic logs and fracture descriptions were documented on borehole lithologic forms and used to describe pre-treatment soil conditions (Appendix B). Other baseline determinations included water content, grain size, color, mineralogy, scanning electron microscope (SEM) morphology, pH, TOC, iron oxides, cations, and anions. Note that all analyses were not performed on all soil samples because the parameters were not expected to vary significantly over the entire test area and to control analytical costs.

Personnel from ORNL-GJ, used a rig with Geoprobe™ tools to collect the lithologic samples. On-site technical direction was provided by an ORNL-GJ geologist. Continuous 4-ft-long cores were collected with a megabore sampler. The on-site geologist was responsible for visual classification of the soils encountered and for completing an accurate, depth-based soil boring log. Microscopic examination of selected samples was also performed by the geologist; however, detailed fracture morphology was evaluated through laboratory analyses at ORNL.

Task 1 included completion of 32 Geoprobe borings, five borings in each of test cells 1 through 6, one boring in test cell 7, and one in a background area. The background location was approximately 50 ft south of the southeast corner of test cell 6 (Fig. 3.1). The boring locations were staked and surveyed shortly after completion. All pre-treatment borings were backfilled with granular bentonite or completed as piezometers or lysimeters.

Task 1 also included the installation of 24 porous ceramic cup lysimeters for sampling soil-pore water. Three lysimeters were placed in each of the seven test cells and three at a background location. The three lysimeters at each location were nested in a single borehole at depths of 4, 8, and 14 ft bgs (Fig. 3.3). Pre-treatment borehole C was consistently used for the installation of these lysimeters except in test cell 7, where borehole A was used. Lysimeters were also installed in the background soil boring. The lysimeters were 1 bar type with 15-psi bubbling pressure. The average pore diameter was 2.9 μm, suitable for use in soils with 0 to 1 bar of soil suction.

Installed according to manufacturers specifications, each lysimeter body was surrounded by silica slurry pack mixed from 200 mesh, 99.88% pure crystalline silica flour and distilled water at a ratio of 150 mL of water to 450 g of silica flour. A bentonite seal was placed above each lysimeter to isolate it within the borehole. Before installation, lysimeters were pre-wetted with distilled water which was evacuated after installation. A vacuum of 22 in. of Hg was applied to each lysimeter 12 hours before anticipated sample collection. Samples were evacuated by applying positive pressure to the lysimeter and forcing the water in the lysimeter body to the surface through the sampling tube.

A total of five 2-in.-inside-diameter (ID) piezometers were also installed, one each in four of the test cells and one at the background location (Table 3.2 and Fig. 3.4). Borehole D was used for piezometer installations. Constructed with 1-ft-long screens placed at approximately 14 ft bgs, the piezometers were used for monitoring water levels and collecting groundwater samples. The lysimeters and piezometers were installed using solid-stem augers and standard well construction practices. All lysimeters and piezometers were sampled twice prior to the initiation of MPIS testing in order to establish baseline conditions.

Soil moisture and temperature (SMT) probes were installed approximately 2 ft east of each set of lysimeters. A total of 24 SMT probes were installed at depths corresponding to the lysimeter depths: 4, 8, and 14 ft bgs. The probes were seated in native soil, with wire leads routed to the ground surface inside of 1.5-in. polyethylene (PE) casing. The PE casing was backfilled with sand. An 18-in.-long piece of 4-in.-diameter polyvinyl chloride (PVC) casing with a slip-on cap was placed over the wire leads at the ground surface as a protective cover. Figure 3.5 provides a profile view of the layout for the instrumented borings.

3.2 Task 2: MPIS Testing

Task 2 consisted of a series of multi-point injections in six of the test cells with injection done on 2-ft centers (Fig. 3.2). Test cell number 6 was injected with air and had only eight injector penetrations. The MPIS developed and provided by Hayward Baker Environmental, Inc., consisted of a tractor-mounted unit with a set of four removable injection augers mounted 2 ft apart on a bar across the front of the tractor. These augers have injection ports in a spiral pattern near the tip. All four of the 2-in.-diameter augers were simultaneously pushed and turned into the soil to a depth of over 10 ft, stopping at 15-in. intervals for fluid injection (Fig. 3.6). Approximately 2 gal of fluid was injected from each auger at each interval. An operator sitting on the tractor controlled the rate of penetration and injection (Fig. 3.7). The following describes the procedure used.

- The test cell was gridded on 2-ft centers for ease of controlling the injection spacings.
- The MPIS was positioned in the northeast corner of the test cell at setup number 1.
- The augers (4) were drilled into the soil to a depth of approximately 20 in., and 2 gal of reactive fluid were injected from each auger tip simultaneously.
- The augers were then drilled to the next position, approximately 35 in. bgs, and 2 gal were injected from each auger tip.
- This process continued at 15-in. intervals (eight injector positions) until a total depth of approximately 125 in. was attained and a total of 64 gal of fluid was injected at that setup (16 gal per injector).
- Four flow meters mounted in front of the MPIS operator were used to monitor the volume of injected fluid from each injector and the operator controlled flow to each injector separately, thus ensuring that the appropriate amount of reagent was injected from each injector at each position.
- Depth calibration marks on the mast indicated the depth of the injector points. A geologist monitored the injection process to ensure that the injections were performed uniformly across each test cell.

Few, if any, soil cuttings were generated during penetration. Upon reaching a depth of 10.4 ft (125 in.), the operator reversed the hydraulics and turned the augers up out of the soil. No fluid was injected during the upstroke. The total depth of the injections was based on the capabilities of the equipment used. Larger equipment with injection capability to 40 ft bgs is available.

To assess the performance of the multi-point injection equipment by means of operational checks and practice borings, process shakedown was performed in an area north of the CTS prior to initiation of the planned injection testing.

The reagents injected into each test cell, shown in Table 3.4, were delivered to the MPIS by a hose connecting the system to a pump that pulled liquid from a battery of mixing tanks stationed nearby. An air compressor provided pressurized air for the air injection test. The oxidants were injected because hydrogen peroxide and potassium permanganate can catalyze and chemically oxidize chlorinated organics to produce carbon dioxide and water. Zero-valence iron (iron micropowder) was injected because it has been demonstrated to act as a reducing agent for chlorinated solvents. Water alone was injected to provide a baseline test cell. The lime injection was tested because it could be used to adjust soil pH for in situ stabilization of metals. The bionutrient and surfactant were injected to determine the feasibility of using the mixture to enhance the natural breakdown of chlorinated solvents by indigenous bacteria. Air was injected to test the MPIS for pneumatic fracturing of LPM.

Tracers, including potassium bromide and Snowmax®, were mixed into two of the solutions to provide a means of differentiating the injected fluid from the existing soil-pore water and to permit detection of soil fractures (Table 3.4). Bromide is a conservative tracer (i.e., travels at the same velocity and direction of the water it is dissolved in) used to track the extent of injected fluid penetration into the soil. Snowmax® is a commercially available, ice-nucleating active bacteria product that is processed (the bacteria are killed and mixed with an inert ingredient) and sold as a nucleator for artificial snow. ORNL researchers have developed an innovative and unconventional use of Snowmax® and other bacteria as environmental tracers (Strong-Gunderson 1995). Snowmax® concentration is expressed in ice-nucleating activity (INA) particles per mg of soil.

The injections were performed on a pattern starting with four simultaneous injections 2 ft apart; the tractor-mounted MPIS was then moved 2 ft backwards and another injection performed until the entire test cell had been penetrated on 2-ft centers. Table 3.5 lists the process operating conditions monitored during the MPIS testing.

Because the field work for this project was performed at an uncontaminated site, equipment cleaning procedures were minimal and were performed as necessary to maintain proper operation of the equipment and to prevent mixing of different reagents. Injectors, hoses, tanks, pumps, and mixing equipment were cleaned on site using either a fresh water rinse or a portable steam cleaner as appropriate. Fluids generated by flushing the MPIS were discharged to the ground surface away from the CTS along with other water being pumped from the site.

3.3 Task 3: Concurrent Monitoring

Monitoring was performed during the MPIS injections made in each cell (Table 3.5 and Fig. 3.8). The volume of reagent injected was monitored on four separate flow gauges mounted on the MPIS unit and on a single flow meter at the pump discharge. The separate flow gauges on the MPIS unit recorded the amount of fluid injected by each of the four injectors and the flow gauge on the pump discharge recorded the total amount of fluid injected. Other observations included penetration rate, injection rate, injection pressure, surface blowout of fluid, and temperature and moisture changes in the test cell soils. Samples of the injected fluid were collected at the connection of the delivery hose to the MPIS unit periodically throughout each test cell injection to provide information on the uniformity of the batching and mixing operations.

3.4 Task 4: Post-Injection Characterization and Data Collection

The first phase of Task 4 for each test cell included drilling and sampling five additional soil borings in test cells 1 through 5 (boreholes F through J) and two additional soil borings (boreholes B and C) in test cell 7 (Fig. 3.1). These borings were drilled within 24 h after the injections in each cell to evaluate the effective distribution of treatment agents by the system and any rapid changes occurring in the subsurface (Fig. 3.9). Soil samples were examined both macroscopically and microscopically for fracture characteristics and the presence of tracers. Morphology was evaluated in the laboratory by SEM. If bromide was injected as a tracer, soil samples were extracted and analyzed for bromide on site with an ion- selective electrode. Samples for INA analysis were sent to ORNL for analysis. Selected soil samples were also analyzed for pH, TOC, Eh, Fe oxides, and Mn.

A soil inspection trench was excavated in the shakedown area to observe the effects of lime injection on the subsurface. Because the trench did not reveal characteristics that were not observable in the soil cores, no additional soil inspection trenches were excavated.

Soil-pore water samples were collected the day after each injection and daily thereafter for several days. Water samples were collected from the lysimeters and piezometers to determine the effects of the injections on the soil-pore water chemistry. Water samples were analyzed on site for temperature, pH, DO, conductivity, alkalinity, Br^-, Fe, Mn, Cl^-, NO_3^-, and SO_4^{2-}. Analyses for metals and TOC were performed at ORNL.

The first phase of post-treatment characterization was completed within 3 days after the last injection was performed (November 21, 1994). The second phase of post-treatment characterization was performed about 2 weeks later and consisted of collecting another set of water samples from the lysimeters and piezometers on December 5, 1994. The third phase of post-treatment characterization was performed about 1 week after the second phase and consisted of drilling two additional soil borings in test cells 1 through 5 (boreholes K and L) and in test cell 7 (boreholes D and E) and collecting another set of water samples from the lysimeters and piezometers on December 15, 1994. A fourth phase of water sampling only was performed during the week of February 15, 1995, and a final round of groundwater samples were collected the week of May 6, 1996.

3.5 Surveying

The locations of all test cells, borings, lysimeters, piezometers, SMTs, and elevation bench marks were surveyed. A nearby monitoring well was used as a benchmark. The required horizontal accuracy was ± 0.5 ft, and the required vertical accuracy was ± 0.01 ft. To ensure the required accuracies, the survey was looped and closed. Surveying was performed with a theodolite equipped with electronic distance measuring and a level. Lysimeters and piezometers were identified by numbers written on the side of the protective casing. The lysimeters were numbered T1L1 and T2L1, etc., in order to identify the test cell (T1) and the lysimeter (L1). Similarly, the piezometers were marked T1P1, etc., identifying the test cell (T1) and the piezometer (P1). The soil borings were numbered in accordance with a prearranged scheme in each test cell as follows: T1-A, to indicate test cell 1, soil boring A, T1-B to indicate test cell 1, soil boring B, etc. The elevation bench marks were labeled T1S1 through T1S5 in test cell 1 and similarly in the other test cells. Elevations were checked prior to injection testing and then several times after testing to determine the amount of soil heaving caused by the injection and to determine the rate of settling.

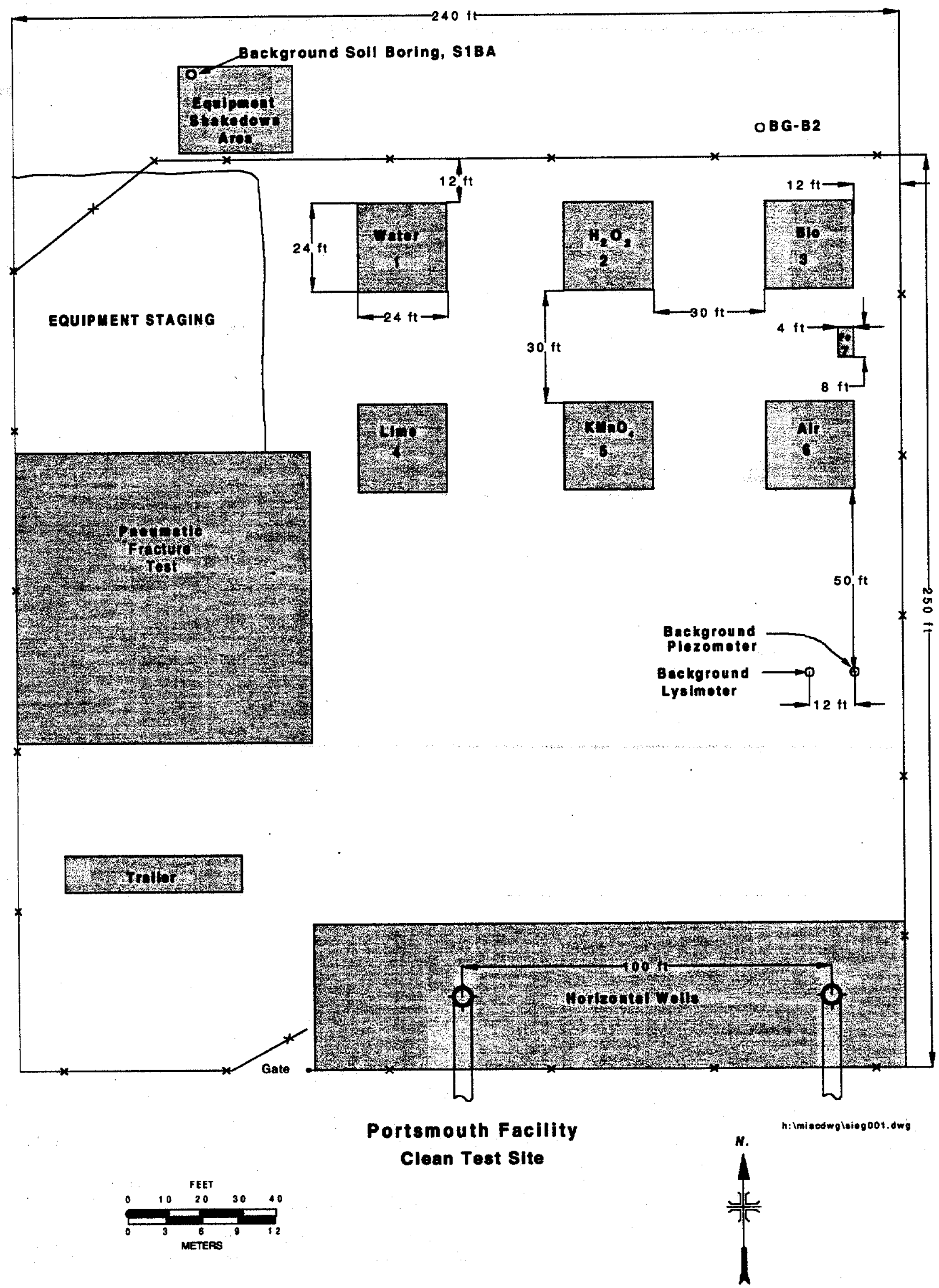
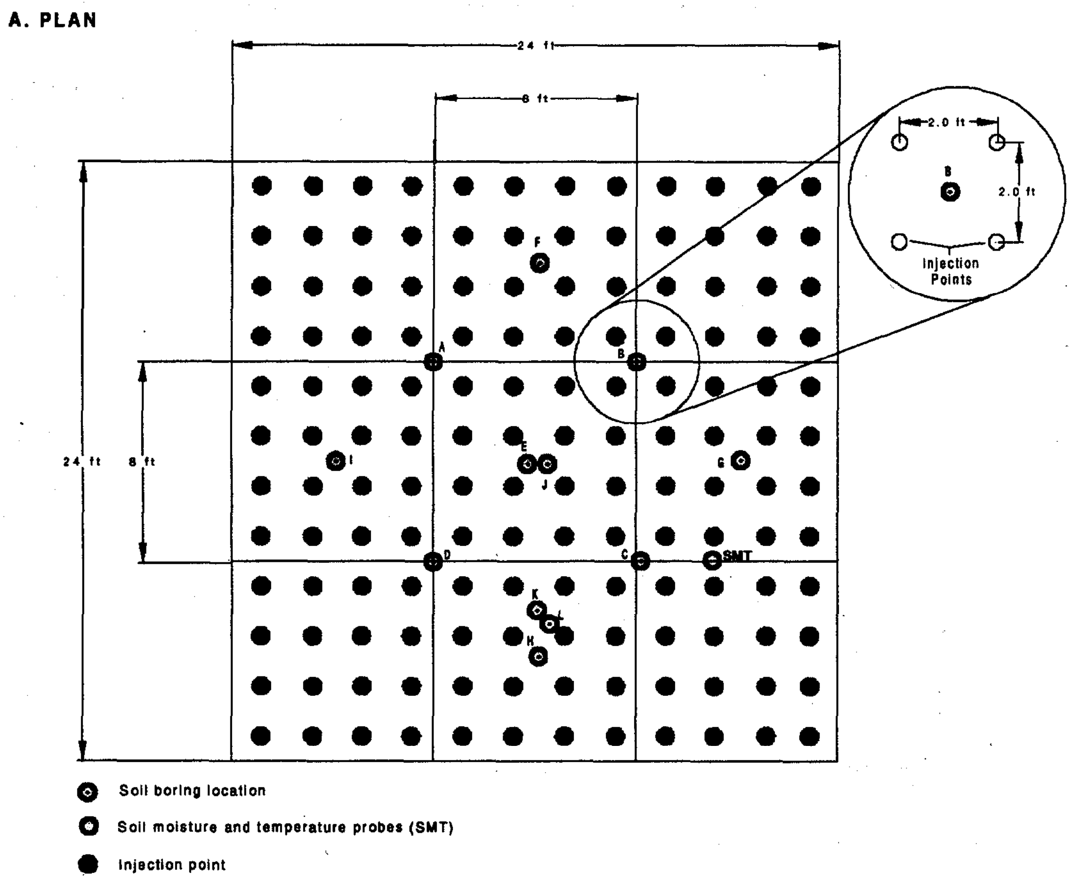


Fig. 3.1. Test cells within the CTS.



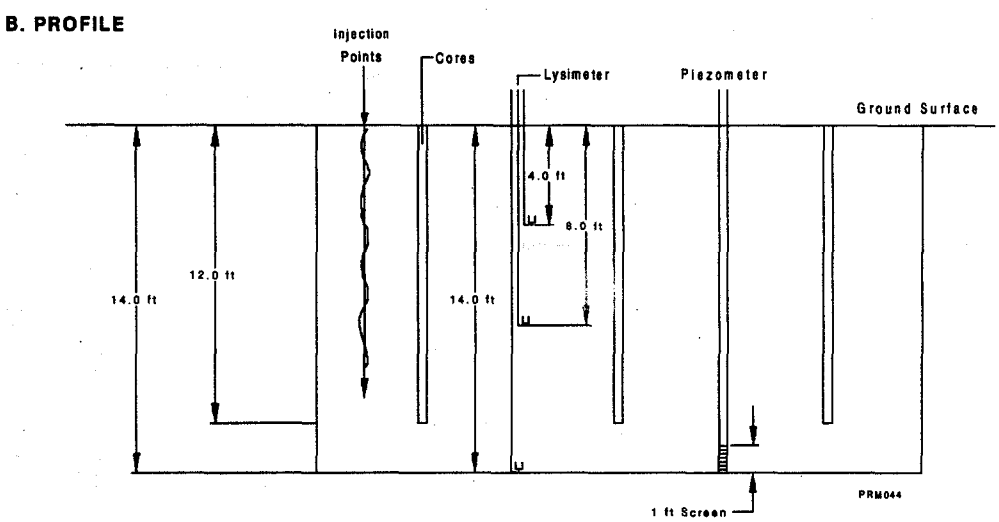


Fig. 3.2. Approximate locations for testing within a typical test cell.

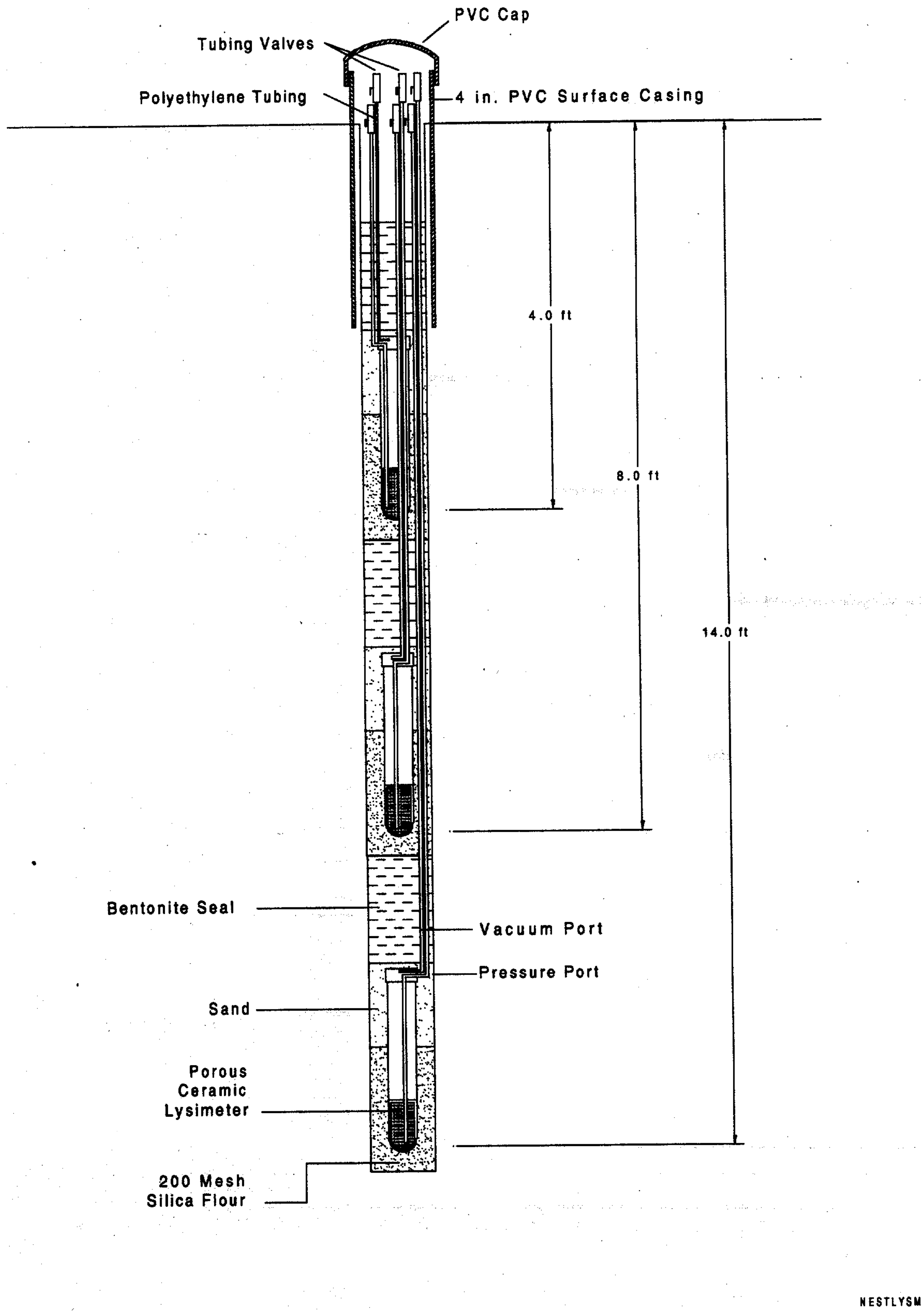


Fig. 3.3. Schematic diagram of nested lysimeters.

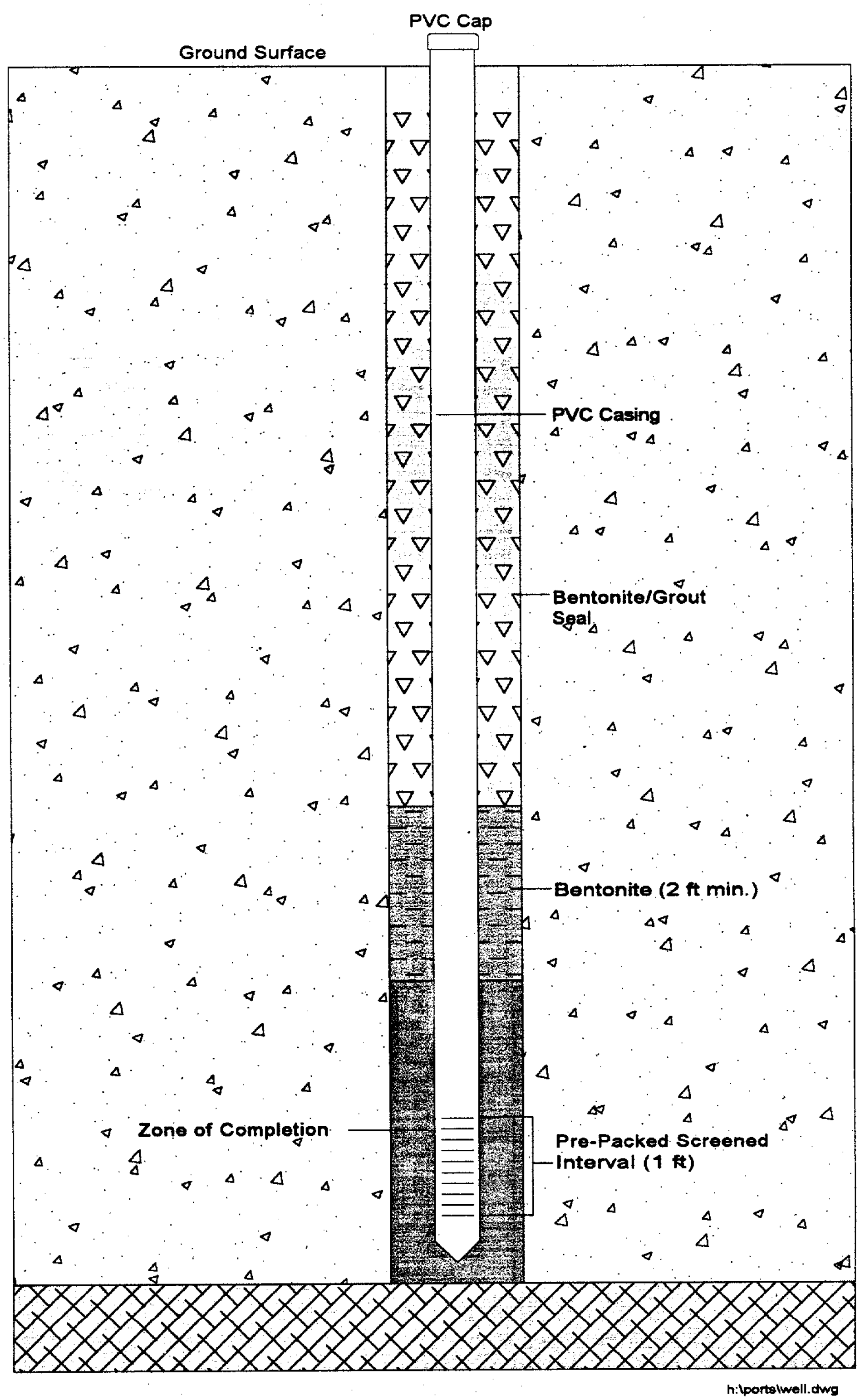


Fig. 3.4. Schematic diagram of piezometer.

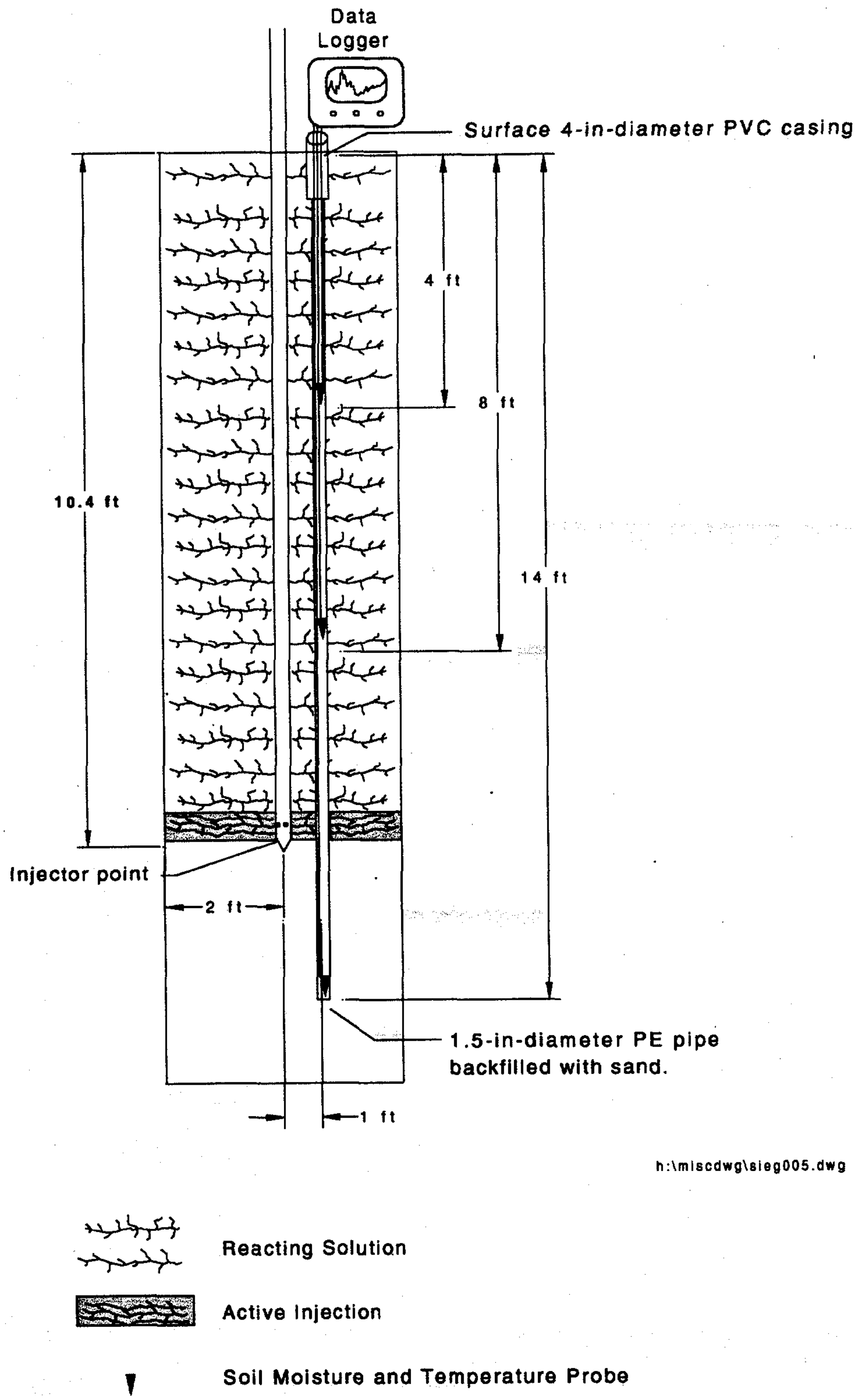


Fig. 3.5. Profile view of the layout for the instrumented borings.

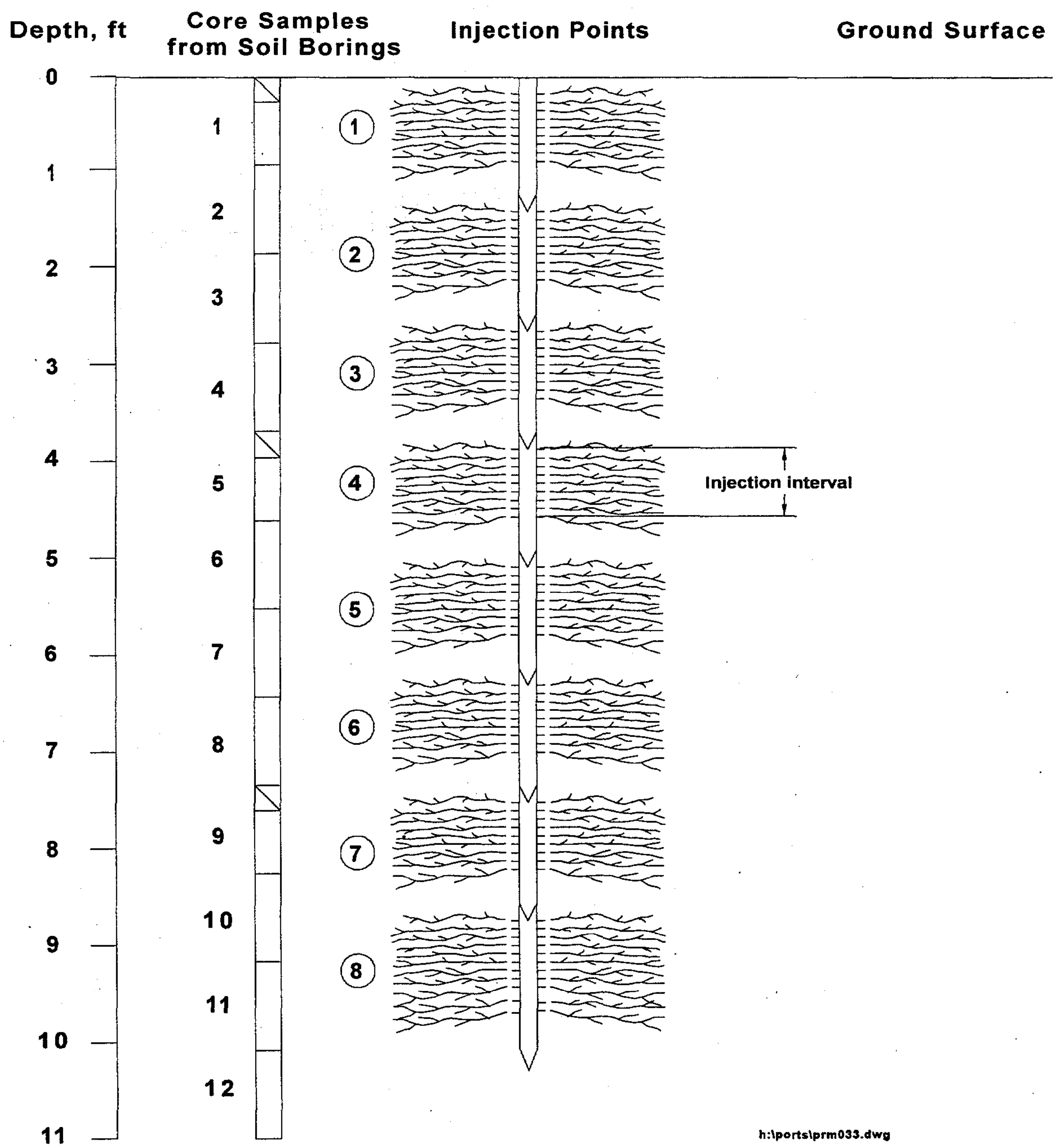


Fig. 3.6. Conceptual diagram of the MPIS process.

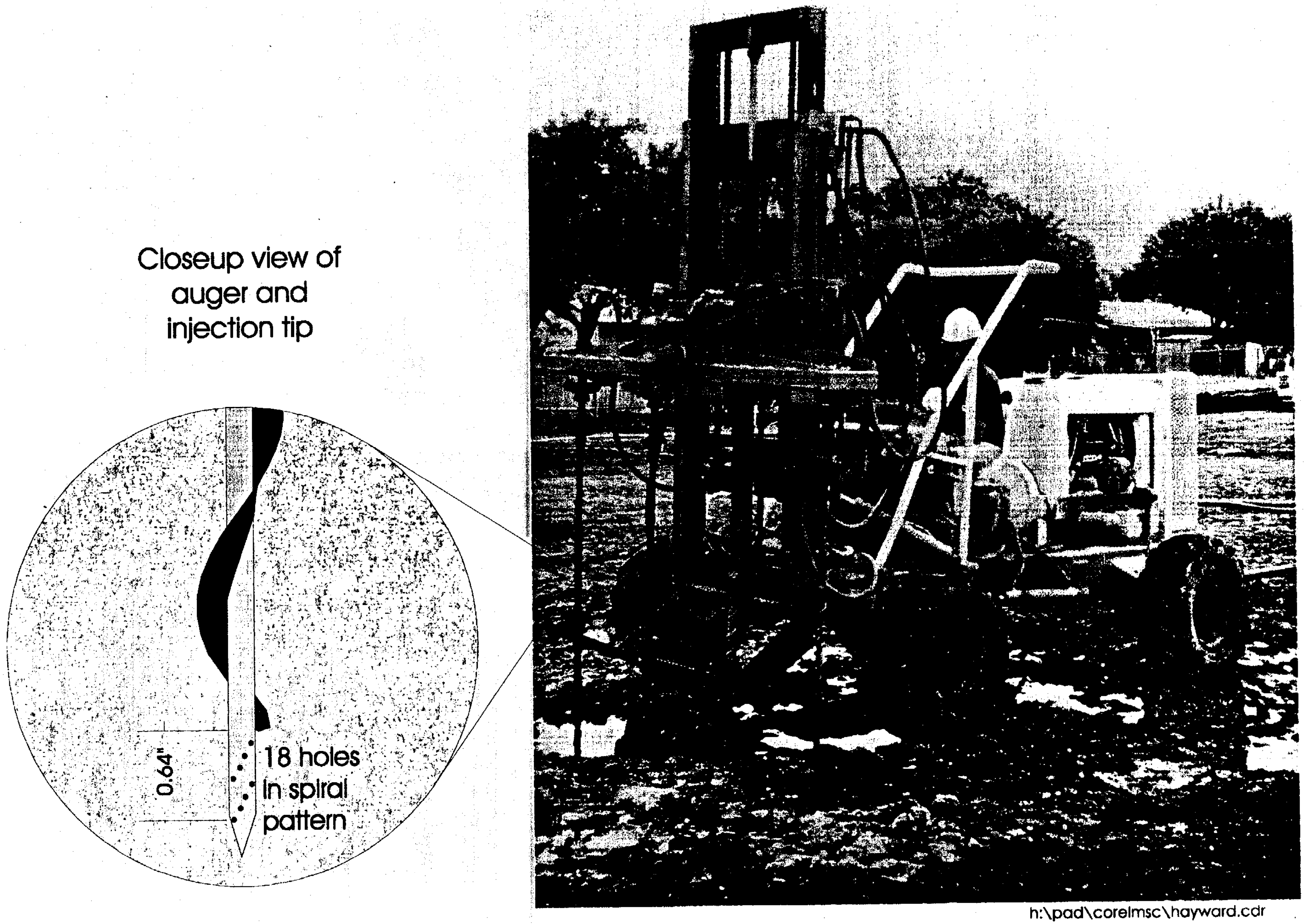
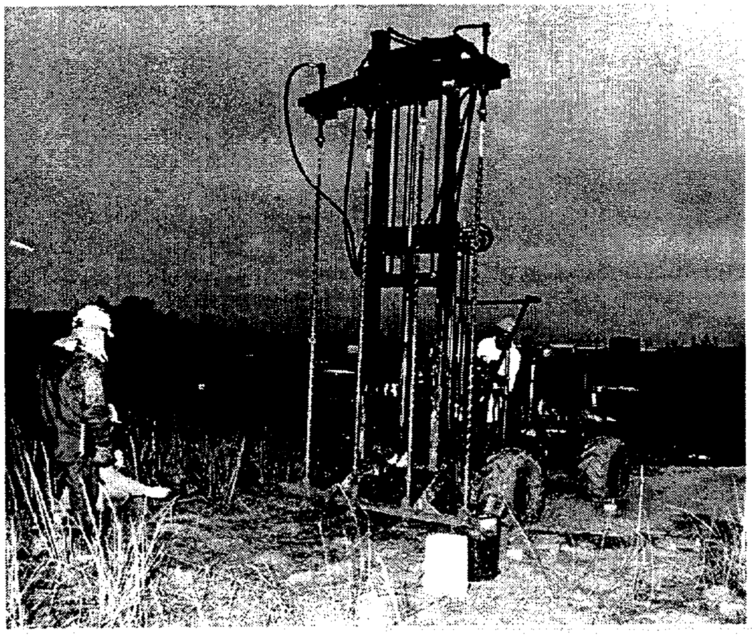
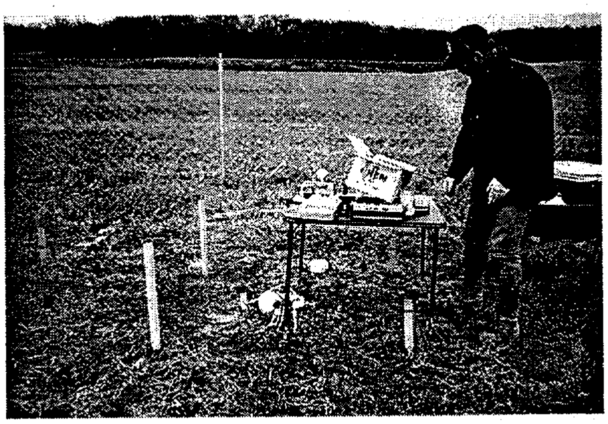


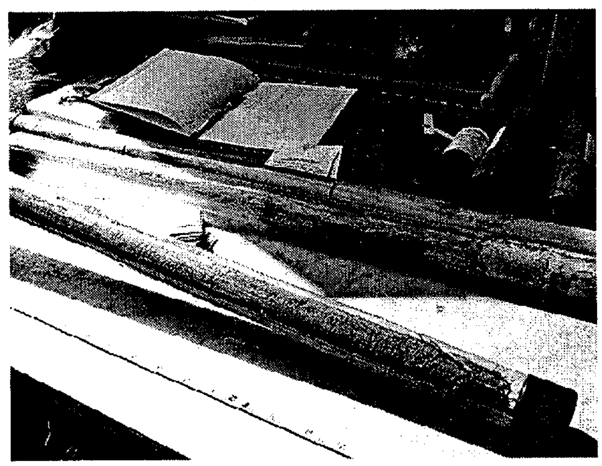
Fig. 3.7. Multi-port injection system.



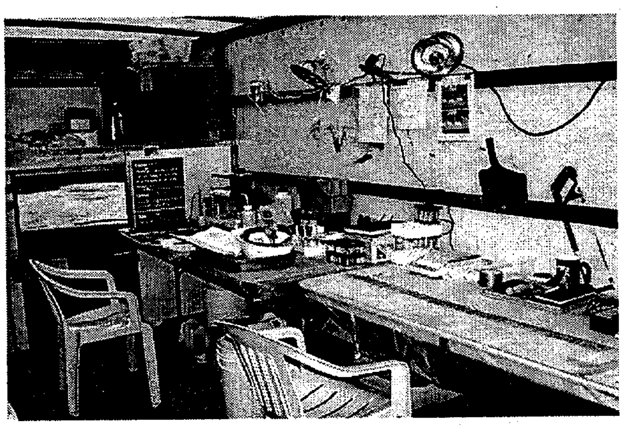
(a.) MPIS equipment performing an injection of bionutrient solution at test cell 3.



(b.) ORNL staff monitoring at test cell 7.

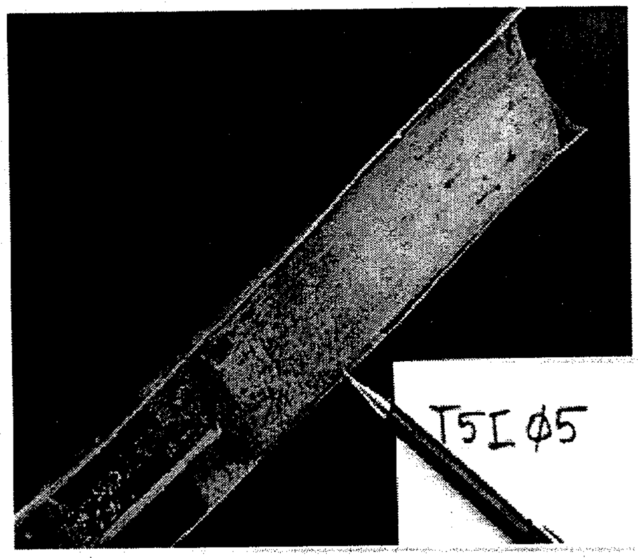


(c.) Intact soil cores used for characterization.

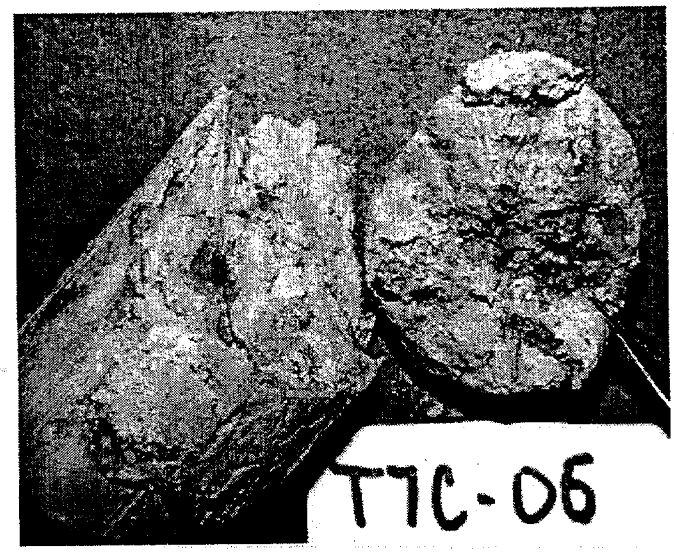


(d.) Onsite laboratory for soil core analyses.

Fig. 3.8. Photographs of the Hayward Baker MPIS rig and the monitoring and sampling analyses activities.



(a.) Permanganate impacted core at 5-ft. depth (the soil redox is dramatically elevated through core beyond the obvious purple staining.



(b.) Iron micropowder deposition within silty clay soil at 6-ft depth..

Fig. 3.9. Photographs of intact soil cores from the permanganate (T5) and iron micropowder (T7) test cells.

Table 3.1. ORNL SOPs for the MPIS demonstration

ORNL SOP number	Title
AD-050	Quality Assurance
TE-061	Measurement of pH of Water Samples
TE-062	Measurement of Electrical Conductivity of Water Samples
TE-063	Measurement of Dissolved Oxygen in Water Samples
TE-071	Sample Documentation
TE-072	Sample Packaging, Preservation, and Shipping
TE-073	Equipment Decontamination
TE-086	Soil Sampling for Field Screening Using the Geoprobe and U2CRT
TE-094	Water-Level Measurement
TE-100	Drilling Log Preparation and Well Construction Documentation
TE-105	U2CRT Operation
TE-106	Solid-Stem Augering Using the U2CRT
TE-120	Physical Surveying
TE-130	Peristaltic Pump Operation
TE-150	Combustible Gas Indicator Operation

Table 3.2. Activities performed in conjunction with MPIS testing

Test cell, injection treatment	Pre-treatment activities	Injection testing[a]	Post-injection 1 activities[a]	Post-injection 2 activities[a]
No. 1, Water	5 soil borings 3 lysimeters 1 piezometer 3 soil moisture probes 5 elevation markers	Inject water with tracers Monitor parameters	5 soil borings Sample lysimeters and piezometer Monitor parameters Surveyed elevation markers	2 soil borings Sample lysimeters and piezometer Monitor parameters Surveyed elevation markers
No. 2, H_2O_2	5 soil borings 3 lysimeters 1 piezometer 3 soil moisture probes 5 elevation markers	Inject reagent Monitor parameters	5 soil borings Sample lysimeters and piezometer Monitor parameters Surveyed elevation markers	2 soil borings Sample lysimeters and piezometer Monitor parameters Surveyed elevation markers
No. 3, Bionutrient	5 soil borings 3 lysimeters 1 piezometer 3 soil moisture probes 5 elevation markers	Inject reagent with tracers Monitor parameters	5 soil borings Sample lysimeters and piezometer Monitor parameters Surveyed elevation markers	2 soil borings Sample lysimeters and piezometer Monitor parameters Surveyed elevation markers
No. 4, Lime	5 soil borings 3 lysimeters 3 soil moisture probes 5 elevation markers	Inject reagent Monitor parameters	5 soil borings Sample lysimeters Monitor parameters Surveyed elevation markers	2 soil borings Sample lysimeters Monitor parameters Surveyed elevation markers
No. 5, $KMnO_4$	5 soil borings 3 lysimeters 1 piezometer 3 soil moisture probes 5 elevation markers	Inject reagent with tracers Monitor parameters	5 soil borings Sample lysimeters and piezometer Monitor parameters Surveyed elevation markers	2 soil borings Sample lysimeters and piezometer Monitor parameters Surveyed elevation markers

Table 3.2. (continued)

Test cell, injection treatment	Pre-treatment activities	Injection testing[a]	Post-injection 1 activities[a]	Post-injection 2 activities[a]
No. 6, Air	5 soil borings 3 lysimeters 3 soil moisture probes 5 elevation markers	Inject air Monitor parameters	Sample lysimeters Monitor parameters Surveyed elevation markers	Sample lysimeters Monitor parameters Surveyed elevation markers
No. 7, Fe	1 soil boring 3 lysimeters 3 soil moisture probes 1 elevation marker	Inject reagent Monitor parameters	2 soil borings Sample lysimeters Monitor parameters Surveyed elevation marker	2 soil borings Sample lysimeters Monitor parameters Surveyed elevation marker
Background location	1 soil boring 1 piezometer 3 lysimeters 3 soil moisture probes	Monitor parameters	Sample lysimeters and piezometer Monitor parameters	Sample lysimeters and piezometers Monitor parameters
Total	32 soil borings 24 lysimeter samples 5 piezometer samples 24 soil moisture probes	7 injections Multiple parameter data set	27 soil borings Multiple lysimeter samples Multiple groundwater samples Multiple parameter data set	12 soil borings 24 lysimeter samples 5 groundwater samples Multiple parameter data set

[a] The parameters monitored are shown in Table 1.1.

Table 3.3. Test cell design and characteristics

Test cell geometry:	24 × 24 ft
Ground surface area	576 ft^2
Soil depth	10.4 ft
Soil volume	5,990 ft^3
	44,800 gal
	169,640 L
Soil weight (wet)	305,310 kg
Soil bulk density (field moist)	1.8 g/cm^3
Soil water content:	
Field moist basis	20 weight %
Total water weight	70,450 kg
Soil-pore system:	
Total fractional porosity[a]	0.40 v/v
Total pore volume	78,280 L
Water-filled pore volume/cell	70,450 L
Water-filled porosity	36% cell
Pore water saturation	90% pores
Air-filled pore volume/cell	7,830 L
Air-filled porosity	4% cell
Pore air saturation	10% pores

[a] estimated.

Note: See Table 2.1 also.

Table 3.4. Treatment agents for MPIS testing at PORTS CTS

Test cell	Treatment type	Medium	Treatment/tracer	Concentration
1	Control	Water	Water/bromide	NA
2	Oxidant	Water	H_2O_2/none	10%
3	Bionutrient	Water	Surfactant, nutrients/ bromide and Snowmax®	10%
4	Stabilizer	Water	Lime/none	20%
5	Oxidant	Water	$KMnO_4$/none	5%
6	Fracturing	Air	None	NA
7	Reductant	Water	10-μ Fe filings, guar gum/none	20%

NA = not applicable

Table 3.5. Process operating conditions for MPIS testing at the CTS

Injector operation:	
Motion	down and up once
Injection time	2.75 to 7.9 min
Area of affected region	~12.6 ft^2
Depth of affected region	10.4 ft
Volume of affected region	130 ft^3
Injections per cell, cells 1 through 5	144
Unit area of surface per injector	~4 ft^2/point
Unit weight of soil per injector	~2445 kg/point
Water injection test:	
Volumetric water addition	0.15 to 0.25 gal/ft^3
Total volume per injector	16 gal
Total volume per cell	2400 gal
Rate of injection addition	8 to 23 gal/min
Increase in soil water content	~2.0 weight %
Solute tracers	
Br^- concentration	205 mg/L
Br^- mass loading (avg. cell)	9 mg/kg soil
H_2O_2 injection test:	
H_2O_2 solution strength	10% by weight
H_2O_2 solution addition/injection	16 gal
H_2O_2 mass loading (avg. cell)	~2.5 g/kg soil
Nutrient/surfactant test:	
Volume water addition/injection	16 gal
Surfactant concentration	10% volume
Lime Injection:	
Total volume per injector	16 gal
Injection rate	8 to 23 gal/min
Lime slurry concentration	20 weight %
Lime mass loading (avg. cell)	~6.9 g/kg soil
Permanganate test:	
$KMnO_4$ solution strength	5% weight %
$KMnO_4$ solution addition/injection	16 gal
$KMnO_4$ mass loading (avg. cell)	~1.3 g/kg soil
Air test:	
Air injection rate	60 scfm
Air pressure	60 to 200 psig
Air temperature	ambient °C
Iron test:	
Volumetric water addition/injection	16 gal
Fe(0) particle size	5 μm
Fe(0) solution concentration	20 weight %
Fe(0) mass/injection	25.5 kg
Fe(0) mass loading (avg. cell)	10.4 mg/kg soil

4. Specific Testing and Results

Field activities were documented by daily entries into the project logbook and task-specific field logbooks: a geologist's logbook, health and safety logbook, water sample logbook, soil sample logbook, survey logbook, and laboratory logbook. The project logbook provides a summary record of all field activities. Information was also recorded on forms designed specifically for this project. Prior to injection, pre-treatment elevations were surveyed using control stakes placed in each test cell. These elevations are included in the ground surface uplift graphs for each test cell that show the relative change in elevation after injection. The following is a description of the results obtained at each test cell at CTS.

4.1 Background CTS Characterization

4.1.1 Field Activities

Characterization of the geology of the CTS is described in Sect. 2.3. The site was further characterized by collecting background data specifically for this project, including drilling three additional soil borings, two in the background area (Fig. 3.1) and one in the shakedown area. Lithologic logs of these borings were prepared, and soil samples were shipped to ORNL for analysis. A piezometer was installed at boring B1-A, and three lysimeters were nested in boring B1-B. Three SMT probes were installed approximately 2 ft east of the lysimeters. Water samples collected from the piezometer and lysimeters on November 1, 1994, were shipped to ORNL for analysis. Other water samples were collected periodically from November 12, 1994 to May 9, 1996. These samples were analyzed on-site in the field laboratory, with some ancillary testing performed at ORNL.

4.1.2 Pre-Treatment Soil Testing

Measurements of pre-treatment soil conditions at the CTS were made both within individual test cells (borehole E in test cells 1 through 6 and borehole A in test cell 7) and at one background location (near the equipment shakedown area). Values from these eight locations were averaged to provide a basis for experimental design and for comparison with post-treatment soil conditions. Parameters measured included soil moisture content, bulk density, temperature, pH, Eh, TOC, grain size, bromide, manganese, and calcium. A summary of the pre-treatment soil conditions is presented in Table 4.1.

The average depth-specific soil moisture content ranged from 15 to 26% with moisture content generally increasing with depth. The moist bulk density ranged from 1.57 to 2.25 g/cc with the an overall bulk density average of approximately 1.84 g/cc. Pre-treatment soil temperatures averaged 56° F at 4 ft bgs, 58° F at 8 ft bgs, and 56° F at 14 ft bgs. Soil pH increased with depth and ranged from 4.3 to 7.4. Soil Eh, measured only at the background location near the shakedown area, was 400 mV near the ground surface and decreased to 140 mV at 12 ft bgs. Average TOC ranged from 6397 ppm near the ground surface and decreased to a minimum value of 395 ppm at 9 ft bgs.

During horizontal well installation at the CTS, selected samples were submitted for grain size distribution analysis. Of these samples, four samples were collected near the multi-point injection permeation and dispersal test area at depths of 4.5 to 5 ft bgs and 13.5 to 14 ft bgs (Appendix A). In these samples 85 to 98% of the sample passed through a #200 mesh sieve confirming the soils as silty clays. Visual inspection of the soil cores identified the soils as silty clay with colors ranging from light yellowish brown to reddish brown with gray and green mottling.

Manganese and calcium were analyzed in soil samples from pre-treatment borings in test cells 1, 2, and 4. Most values for manganese were less than 10 ppm, except for the top one foot of soil where manganese concentrations were 20 to 45 ppm. Calcium concentrations were generally less than 1000 ppm to depths of 6 or 7 ft bgs and then increased dramatically to generally more than 5000 ppm. These data indicated that calcium has been leached from the upper soil profile and probably redeposited at depths greater than 6 ft. This is consistent with the acidic pH of the upper soil, where after breakdown of $CaCO_3$, calcium would be leached from the soil. The soil would then be enriched with calcium where soil pH was more neutral, thus supporting the formation of gypsum crystals observed in the 6.5 to 8 ft bgs zone.

Discussion of the bromide data and additional detail related to cation analyses are presented with the post-treatment results within the following specific test cell sections.

4.1.3 Background Water Testing

Parameters routinely measured in water samples from the lysimeters and piezometers included water level, pH, conductivity, temperature, DO, TOC, NO_3^-, Br^-, alkalinity, Fe, Mn, Cl^-, and SO_4^{2-}. Results from the background piezometer (B1P1) and lysimeters (B1L1, B1L2, and B1L3) are shown in Table 4.2. Water pH varied from 6.1 to 8.9 during the period of November 1, 1994 to February 15, 1995. The pH values were consistently lowest in the piezometer water samples, possibly due to contact of the water with air in the casing. DO values varied from 2 mg/L to 11.2 mg/L, with no consistent trends in the data with depth or time. Conductivity measurements remained about the same for all sampling points over the duration of testing; however, it is interesting to note that the lowest conductivity values were measured in the shallowest sample B1L1 and the highest values were measured in the 8 ft sample, B1L2. Alkalinity varied from 94 to 319 mg/L. Alkalinity values measured in the shallow lysimeter were somewhat erratic, while values measured in the 8 ft and 14-ft lysimeter and the piezometer were more consistent. Bromide concentrations were less than 1 mg/L in all samples tested. Similarly, nitrate concentrations were less than 0.5 mg/L in all background samples tested. Manganese values were 1 mg/L or less and averaged approximately 0.25 mg/L. Chloride ranged from 2.5 to 23 mg/L. Sulfate concentrations ranged from 425 to 1200 mg/L.

4.2 Test Cell 1: Water Injection with Tracers

The first injection was in Test Cell 1 where water with tracers were injected. This was done to familiarize field personnel with the injection procedure and demonstrate that liquid injection was possible at this site. Thus, the test served as a practice session, while the tracers provided information on the behavior of water injected in the subsurface.

4.2.1 T1 Field Activities

Five pre-treatment soil borings, T1-A through T1-E, were drilled and sampled on October 23, 1994. Lithologic logs were prepared and soil samples shipped to ORNL for analysis. One piezometer was installed at boring T1-D, and three lysimeters were nested in boring T1-C (Fig. 4.1). Three SMT probes were installed approximately 2 ft east of the lysimeters. Water samples were collected from the piezometer and the lysimeters on November 1, 1994, and were shipped to ORNL for analysis. Preparation for injection testing at test cell 1 began on November 12, 1994. A set of water samples was collected from the lysimeters and piezometer, and elevation benchmarks were surveyed prior to the start of injection. Water with bromide and Snomax® tracers was injected on 2-ft centers to a depth of 10.4 ft starting at 2:00 p.m. The test cell injection was completed at 5:45 p.m.; thus, 225 min were required to perform 144 injections (36 MPIS set-up locations with four injector locations per setup) (Fig. 3.1). The average time for each injection setup was 6.2 min excluding 35 min to refill and mix three 500-gal tanks.

The objective was to inject 2 gal per injector at each 15-in. depth interval. With four injectors per set-up location and eight positions for each injector, the target total for injection at each setup was 64 gal (4 injectors × 8 positions × 2 gal each), and the target for 36 set-up locations was 2,304 gal (36 setups × 64 gal each) for the entire test cell. According to the flow meters, approximately 2400 gal of solution were delivered; the estimated amount of solution lost to seepage at the ground surface was 400 gal. Thus, the amount of solution injected into the subsurface was estimated to be 2000 gal.

Six batches of powdered KBr and Snomax® solution were mixed and added to each of six 500-gal batches of water. Two samples of each of the six batches were collected during injection to evaluate the uniformity of the injected solutions. The samples were analyzed for bromide in the on-site laboratory. Bromide concentrations varied from 190 to 235 mg/L with a mean of 205 mg/L.

Test Cell No.	Total solution injected	Target solution strength	Average actual solution strength	Duration of injection testing	Average time per setup	Total surface seepage
T1	2400 gal	200 mg/L Br^-	205 mg/L Br^-	225 min	6.25 min	400 gal

Soil resistance and temperature readings were taken before, during, and after the injection. Resistance measurements showed that the soil was near saturation at 14 ft bgs prior to injection, but was not saturated at 8 and 4 ft bgs. However, approximately 8 min after injection started, the backfilled soil around the subsurface probes was saturated with injected solution, and solution began to run out the top of the protective casing onto the ground surface. Soil temperature showed an increase of 3 °F at 4 ft bgs and no change at 8 and 14 ft bgs.

The first phase of post-treatment characterization began with the completion of five additional soil borings (T1-F through T1-J) to a depth of 12 ft each. The borings were continuously sampled with 48-in.-long megabore samplers, and the resulting 1.5-in.-diameter soil cores were extensively subsampled. Each core was divided into 1-ft segments, and the following samples were taken from each segment: 60 g of soil for water content, TOC, and pH; 10 g of soil for archive; 1 kg of soil for iron oxides, x-ray analysis, SEM, and conductivity; 1 kg of soil to the field lab for pH, Br^-, Cl^-, Fe, Mn, SO_4^{2-}, H_2O_2 and $KMnO_4$; and ~200 g for INA and Br^-. A few samples were wax-coated for x-ray analysis. Not all analyses were performed on all samples. Lithologic descriptions were also prepared (Appendix B).

Post-treatment water samples were collected from the lysimeters and piezometer eight times during the 9 days following the injection and again approximately 1 and 3 months after injection. Similarly, elevation benchmarks (S1, S2, S3, S4 damaged, and S5) were surveyed six times during the nine days following the injection and again about one month after injection. During the fourth week after injection, December 12 to 14, 1994, two additional soil borings (T1-K and T1-L) were cored and sampled. The subsampling performed was not as extensive as that performed during the first phase of post-treatment soil sampling and was limited to performing Eh measurements as the cores were divided into 1-ft segments, preparing a lithologic log, and shipping the cores to ORNL for additional analysis.

4.2.2 T1 Soil Sample Results

Pre-treatment soil sample results include measurements of soil pH, TOC, % moisture, temperature, and bulk density. Soil sample results are summarized in Table 4.3 and data trend graphs are presented in Appendix C. Values for pre-treatment soil pH were measured on the core from borehole E and ranged from a low of 4.3 near the ground surface to a high of 7.8 at 10 ft bgs. There was a general increase of pH with increasing depth. Because the injection of water with tracers was not expected to have much effect on soil pH, no post-injection pH measurements were performed.

TOC was evaluated on pre-treatment core samples from borehole E. The values ranged from a high of over 6000 ppm near the surface to about 350 ppm at depth. The values were highest near the ground surface due to humic material in the top soil. TOC values decreased steadily to a depth of 7 ft bgs and then were variable but less than 1000 ppm down to 12 ft bgs. Because no change in TOC was expected due to the injection of water with tracers, post-treatment TOC was not measured.

Moisture content was measured in samples from one pre-treatment boring, borehole E. Samples ranged from 15% to 27% moisture (dry wt.%). These values are consistent with other background soil moisture measurements for the CTS. Moisture content was measured at 1 ft intervals on five post-treatment borings (Fig. 4.2). Comparison of depth-specific moisture values showed that moisture content of the near-surface interval (0 to 4 ft bgs) had increased from ~15% to as much as 24%. The intermediate-depth interval (4 to 8 ft bgs) was unchanged, and the deepest interval (8 to 12 ft bgs) showed a slight increase in soil moisture. Thus, the injection of 2000 gal of water into the test cell had little effect on soil moisture content. This is consistent with predictions made which suggested an average increase of a 2.0 wt.% based on the volume of water added into the volume of media in the cell (Table 3.5).

Soil surface elevation data show that the surface of the test cell was raised about 0.1 ft by the injection and remained near that elevation through the last measurement period (three months after injection). The volume change in a 24 ft × 24-ft area that swells 0.1 ft is about 57 ft^3 or about 430 gal. Thus, 1570 gal of water are unaccounted for by swell measurements alone.

Core samples from the pre-treatment borings were carefully logged, and visible pores and fractures in the soil were noted (Appendix A). There were numerous root pores and vesicles seen from the surface down to about 5 ft deep. Open-bed partings were noted at 7.5 to 8.5 ft bgs, with infillings of authigenic gypsum crystals. Clay content and soil stiffness increased with depth. A few high-angle fractures were noted at 5 to 6 ft deep, but most of the fractures were between 9.5 and 11.5 ft deep. Some of these fractures had gray-clay infillings. Post-treatment core samples were also carefully logged. There were no differences seen between the number of fractures and the appearance of fractures before and after injection.

Bromide concentrations were determined in eight pre-treatment soil samples. Concentrations ranged from 0.7 to 1.5 ppm and averaged 0.88 ppm. Bromide concentrations were determined in post-treatment soil samples on 1-ft intervals for five borings drilled 12 ft bgs (Fig. 4.3). For the depth interval of 0 to 2 ft bgs, all measurements were above the average background bromide concentration of 0.88 ppm, mostly between 3 and 8 ppm. The interval of 2 to 5 ft bgs showed bromide concentrations ranging from background to about 6 ppm, with an average of about 3 ppm. The interval of 5 to 7 ft bgs showed concentrations ranging from background to 3.5 ppm, averaging about 1.5 ppm. The interval of 7 to 9 ft bgs showed concentrations ranging from background up to 6 ppm and averaging about 3.5 ppm. The deepest interval, 9 to 12 ft bgs, had bromide concentrations ranging from background to 4 ppm, averaging 1.0 ppm. These data indicate that different zones in the soil were preferentially enriched with bromide tracer as a result of the injection. The estimated increase in Br^- concentration to be caused by the concentration and volume of solution injected into the cell was approximately 9 ppm (Table 3.5). As observed, the entire cell down to 10 ft bgs appears to have been somewhat enriched in bromide. The greatest increase in bromide was in the near surface, 0 to 2 ft, where the soils were the least compact and had the highest density of root vesicles and pores. The zone between 7 and 9 ft, where the open-bed partings were noted in pre-treatment borings, was the second most enriched zone. The least-enriched zone was below 10 ft, which correlates to the total depth of injection of about 10.4 ft.

Snomax® tracer was evaluated by performing INA analysis on samples from five post-treatment borings (Fig. 4.4). The INA values were generally much higher in the top 4 to 5 ft of soil and ranged from 18 to 3500 particles/mg of soil. Values dropped dramatically below 5 ft and were generally less than 10 particles/mg of soil. Some borings showed an increase in INA between 7 and 9 ft bgs, again probably related to the visible, open-bed partings. Values in other borings dropped to near 0 from 7 to 12 ft bgs.

Eh was not measured on the pre-treatment soil cores, but post-treatment Eh values ranged from 275 to 500 mV in two boreholes, T1-L and -K. These values are similar to those measured in the pre-treatment background boring B1A.

4.2.3 T1 Water Sample Results

Post-treatment water sample data are presented in Table 4.4 and data trend graphs are presented in Appendix C. Water sample results indicate that the pH of the water in the lysimeters and piezometer varied from 6.5 to 8.7 with no apparent trends with depth of the water sample or time elapsed after the injection.

DO values in water samples from the three lysimeters were highest prior to the injection and decreased markedly in T1L2, the 8-ft-deep lysimeter, after the injection. DO values appeared to stabilize after about 3 days (November 17, 1994) and remained relatively constant until November 21, 1994. Then, when samples were collected on December 15 and February 16, DO values were again near pre-treatment values. Piezometer DO values were more consistent throughout the analysis period.

Electrical conductivity remained about the same before and after injection except in T1L2, the 8-ft-deep lysimeter, where conductivity doubled after injection (November 14, 1994) and remained at a higher value. Data for the December 5, 1994, sampling event show low conductivity for all samples; it appears that there may have been a problem with the conductivity meter at that time.

Background bromide concentrations were around 1 mg/L. Bromide was detected at 80 to 100 mg/L in T1L1 and T1L2 after the injection and then slowly decreased over the next several days (Fig. 4.5). These concentrations are about one-half the strength of the injected reagent, 205 mg/L, indicating dilution by the resident soil pore water. Bromide concentrations were minimal in the deep lysimeter and piezometer, both at 14 ft bgs, indicating that the bromide tracer was not migrating rapidly downward after injection.

However, samples taken in December and February from the deep lysimeter and the piezometer showed increasing Br^- concentrations, indicating that some downward infiltration of injected solution was occurring.

Other analytes tested included alkalinity, Fe, Mn, Cl^-, NO_3^-, and SO_4^{2-} but since there were no noticeable changes in concentration in the first few samples, analysis for these parameters was discontinued, and no evaluation of the limited data sets was deemed necessary.

4.3 Test Cell 2: Hydrogen Peroxide

4.3.1 T2 Field Activities

Five pre-treatment soil borings, T2-A through T2-E, were drilled and sampled on October 22, 1994. Lithologic logs were prepared, and soil samples were shipped to ORNL for analysis. One piezometer was installed at boring T2-D, and three lysimeters were nested in boring T2-C (Fig. 4.6). Three SMT probes were installed approximately 2 ft east of the lysimeters. Water samples collected from the piezometer and lysimeters on November 1, 1994, were shipped to ORNL for analysis. Preparation for injection testing at test cell 2 began the morning of November 15, 1994. A set of water samples was collected from the lysimeters and piezometer, and elevation benchmarks were surveyed prior to the start of injection. A 10% by wt. hydrogen peroxide solution was injected on 2-ft centers to a depth of 10.4 ft starting at 9:45 a.m. The first two positions were injected at a rate of 2.5 gal per injector per position; however, there was a large amount of surface seepage, so the injection rate was reduced to 2.0 gal per injection. The test cell injection was completed at 1:10 p.m.; thus, 205 min were required, and the average time for each injection setup was 5.7 min.

The objective was to inject 2 gal per injector at each 15-in. depth interval or a total of 2,304 gal (36 setups × 64 gal each) for the entire test cell. According to the flow meter at the pump, 2,352 gal were injected, and according to flow meters on the MPIS unit, 2,418 gal were injected. The estimated amount of solution lost to seepage at the ground surface was 500 gal. Thus, the amount of solution injected into the subsurface was estimated to be 1800 gal.

The solution was delivered to the site in one batch in a 3000-gal tank with no tracer added. Six samples were collected during injection to evaluate the uniformity of the injected solution. The samples were screened for H_2O_2 in the on-site laboratory and analyzed for H_2O_2 at ORNL.

Test Cell No.	Total solution injected	Target solution strength	Average actual solution strength	Duration of injection testing	Average time per setup	Total surface seepage
T2	2300 gal	10% H_2O_2	10% H_2O_2	205 min	5.7 min	500 gal

Soil resistance and temperature were measured before, during, and after the injection testing. Resistance measurements showed that the soil was near saturation at 8 to 14 ft bgs prior to injection testing, but was not saturated at 4 ft bgs. However, soon after injection started, the backfilled soil around the subsurface probes was saturated with injected solution, and solution began to run out the top of the protective casing onto the ground surface. Soil temperature was monitored throughout the test and showed an increase of 8°F at 4 ft bgs, 2°F at 8 ft bgs, and no change at 14 ft bgs. Temperature was also monitored in one of the reacting injector holes and varied from a pre-treatment value of 56°F up to 80°F less than 1 hour after injection. Temperature decreased to 70°F about 3 hours after injection was completed even though gas bubbles indicated that subsurface reactions were still in progress.

Hydrogen peroxide appeared to react with the soil immediately upon injection, and gas and mud bubbled from all injector locations for several hours after injection was completed. At the peak of reactivity, there was brown, foaming mud up to 6 in. deep over the entire test cell. The reaction of peroxide in the soil produced gases, which rose to the surface, pushing fluid and mud out of the injection holes generating the foam as part of the reaction. In addition, there was a blowout during the injection from an injector hole in test cell 1 about 40 ft away from the position being injected in test cell 2. There were several areas within and near test cell 2 where the ground surface was raised to about 8 in. above the pre-treatment position, apparently due to gas buildup beneath the sod. Most of these raised areas subsided rapidly after blowouts relieved the pressure.

The first phase of post-treatment characterization began with the completion of five additional soil borings (T2-F through T2-J) to a depth of 12 ft each. The borings were continuously sampled with 48-in.-long megabore samplers, and the resulting 1.5-in.-diameter soil cores were extensively subsampled. Each core was divided into 1-ft segments, which were then subsampled. Eh was measured on the core as it was subsampled; lithologic descriptions were also prepared.

Post-treatment water samples were collected from the lysimeters and piezometer seven times during the 7 days following the injection. Similarly, elevation benchmarks (S1 - S5) were surveyed five times during the 7 days following the injection.

Another set of water samples was collected from the lysimeters and piezometer on December 5, 1994, approximately 3 weeks after the injection. During the fourth week after injection, December 12 to 14, 1994, two additional soil borings (T2-K and T2-L) were cored and sampled. The on-site subsampling performed was not as extensive as that performed during the first phase of post-treatment soil sampling and was limited to measuring Eh as the cores were divided into 1-ft segments, preparing a lithologic log, and shipping the cores to ORNL for additional analysis. An additional set of water samples was collected from the lysimeters and piezometer in December 1994, February 1995 and May 1996.

4.3.2 T2 Soil Sample Results

Pre-treatment soil samples collected from test cell 2 were analyzed for pH, Eh, TOC, % moisture, manganese, and calcium. Samples were collected from borehole E. Analysis results were consistent with the background values discussed in Sect. 4.1. Post-treatment soil samples collected from the first five soil borings, T2-F through T2-J, were analyzed for pH, peroxide, nitrate, Eh, TOC, and % moisture. The two additional borings, T2-K and T2-L, were analyzed for Eh only. Soil sample results for test cell 2 are summarized in Table 4.5 and data trend graphs are presented in Appendix C.

Results from pH measurements were similar for all boreholes, with values ranging from 4.2 to 7.5 and pH increasing with depth. These values are similar to the pre-treatment sample pH values; thus, the peroxide injection did not effect a significant pH change.

Peroxide was detected in four of the five post-treatment borings in the 2- to 3-ft interval (Fig. 4.7). Values ranged from approximately 4 to 100 mg/L. No other peroxide was detected in the samples, excluding the 6 to 7 ft interval in borehole F.

Nitrate analysis was performed on soil extracts for which soil samples were extracted with water and the resulting water samples analyzed. Values ranged from 0 to 3.75 ppm; however, the results were sporadic. Values from borehole H were higher than those from other boreholes, however, these values are not considered to be significantly higher due to a variation in the analysis procedure. No significant trends are seen in the nitrate data.

Soil Eh measurements for all boreholes showed a general decreasing trend with depth. An average maximum of about 450 mV was measured 2 to 3 ft bgs and an average minimum of approximately 250 mV was observed at 7 to 12 ft bgs (Fig. 4.8). The higher Eh values in the 2 to 3-ft interval correspond with the depth of peroxide detection in the cell.

Post-treatment TOC measurements ranged from approximately 400 to 2900 ppm. Compared to pre-treatment measurements, there is a dramatic decrease in TOC at the 0 to 2-ft interval. Indeed, TOC content at the 1-ft interval dropped from a pre-treatment level of 6100 ppm to a post-treatment concentration of 2900 ppm. This effect correlates with the distribution of peroxide observed above and demonstrates the oxidizing potential of peroxide. Little change was observed at depths greater than 2 ft.

Post-treatment soil moisture readings ranged from approximately 12 to 28%. Comparison to pre-treatment, depth-specific moisture values shows that moisture content in the near-surface interval (0 to 4 ft) increased by approximately 3%. The intermediate depth interval (4 to 8 ft) was unchanged, and the deepest interval (8 to 12 ft) showed a slight increase in soil moisture. These results are similar to those seen for test cell 1 (see Sect. 4.2.2).

Soil surface elevation data show that the surface of the test cell was raised approximately 0.3 ft by the injection and remained near that elevation through the last measurement period (3 months after injection). Core samples from both the pre-treatment and post-treatment borings were carefully logged, and visible pores and fractures were noted. No differences were seen between the number and appearance of fractures before and after injection.

4.3.3 T2 Water Sample Results

Post-treatment results are presented in Table 4.6 and data trend graphs are presented in Appendix C. Results indicate that the pH of the water in the lysimeters and piezometer varied from 6.6 to 9.0. The only trend noted was in the shallowest lysimeter, T2L1, at 4 ft bgs, where pH decreased steadily from the high of 9.0 to about 7.4 within 6 days after injection of peroxide. DO values were between 4 and 8 mg/L the day after injection and increased dramatically in T2L1 the second day after injection (Fig. 4.9). A significant increase (to 14 mg/L) was also observed in T2L2. DO in T2L3 remained about the same for 5 days after injection (4 to 9 mg/L) and then increased to a maximum of 11.2 mg/L approximately 2 weeks later. DO values in the piezometer were steady throughout the period measured probably due to contact of the water with air inside the casing. Conductivity varied considerably with the depth of the water sample, with the shallowest lysimeter having the lowest conductivity at about 800 to 1900 μmhos and the deepest lysimeter and the piezometer having values around 4500 μmhos. These values are not significantly different from the pre-treatment values, excluding T2L2, which had an increase of approximately 1700 μmhos after injection.

Peroxide was detected in water samples from T2L1 and T2L2 the day after injection, but undetected 5 days later (Fig. 4.10). Nitrate values varied between undetected and 2 ppm for all water samples for 7 days after injection except in T2L2, where nitrate increased dramatically to 12 ppm the day after injection and then decreased to background by the fifth day after injection. It is not known if the increase in T2L2 is actual or due to a variation in the analysis procedure.

Alkalinity ranged from approximately 14 to 860 mg/L, with a general trend of increase with depth. These values are not significantly different from background values, excluding T2L2, which showed a dramatic increase the fifth day after injection. This increase corresponds to the conductivity increase observed for T2L2.

Other analytes tested included Fe, Mn, Cl^-, and SO_4^{2-}, but since there were no noticeable changes in concentration in the first few samples, analysis for these parameters was discontinued, and no evaluation of the limited data sets was deemed necessary.

4.4 Test Cell 3: Bionutrient with Tracers

4.4.1 T3 Field Activities

Five pre-treatment soil borings, T3-A through T3-E, were drilled and sampled on October 20, 1994. Lithologic logs were prepared, and soil samples were shipped to ORNL for analysis. One piezometer was installed at boring T3-D, and three lysimeters were nested in boring T3-C (Fig. 4.11). Three SMT probes were installed approximately 2 ft east of the lysimeters. Water samples collected from the piezometer and lysimeters on November 1, 1994, were shipped to ORNL for analysis. Preparation for injection testing at test cell 3 began on the morning of November 18, 1994. A set of water samples was collected from the lysimeters and piezometer, and elevation benchmarks were surveyed prior to the start of injection. A proprietary bionutrient/surfactant solution with bromide and Snomax® as tracers was injected on 2-ft centers to a depth of 10.4 ft starting at 1:35 p.m. The test cell injection was completed at 5:45 p.m.; thus, 250 min were required to perform 144 injections (36 MPIS set-up locations with four injector locations per setup). The average time for each injection setup was 6.9 min; however, this includes stopping to mix the injection solution twice during the process (approximately 45 min).

The injection solution was mixed as follows: five batches of 500 gal each (2500 gal total), with each batch containing 50 gal of bionutrient/surfactant, 450 gal of water, 421 g of KBr, and 215 g of Snomax®. The target solution strength was 10% bionutrient/surfactant, 150 mg/L Br^-, and 114 mg/L Snomax®.

The objective was to inject 2 gal per injector at each 15-in. depth interval. With four injectors per set-up location and eight positions for each injector, the target total for injection at each setup was 64 gal (4 injectors × 8 positions × 2 gal each); the target for 36 set-up locations was 2,304 gal (36 setups × 64 gal each) for the entire test cell. According to the flow meter at the pump, 2,200 gal of solution were injected, and according to flow meters on the MPIS unit, 2,160 gal were injected. The estimated amount of solution lost to the ground surface was 400 gal. Thus, the amount of solution injected into the subsurface was estimated to be 1800 gal. One sample of each of the six batches was collected during injection to evaluate the uniformity of the injected solutions.

Test Cell No.	Total solution injected	Target solution strength	Average actual solution strength	Duration of injection testing	Average time per setup	Total surface seepage
T3	2200 gal	10% bionutrient surfactant 150 mg/L Br- 114 mg/L Snowmax®	10% bionutrient surfactant 150 mg/L Br- 114 mg/L Snowmax®	250 min	6.9 min	400 gal

Soil resistance and temperature were measured before, during, and after the injection testing. Resistance measurements showed that the soil was near saturation at 14 ft bgs prior to injection testing, but was not saturated at 8 and 4 ft bgs. However, within 30 min after injection started, the backfilled soil around the subsurface probes was saturated with injected solution, and solution began to run out the top of the protective casing onto the ground surface. Soil temperature was monitored throughout the test, showing an increase of 4° F at 4 ft bgs, 1° F at 8 ft bgs, and no change at 14 ft bgs.

The bionutrient/surfactant appeared to react mildly at the surface, and a faint, musky odor was detectable. This odor persisted for several days after the test. At the peak of reactivity, brown foam up to 2 in. deep appeared at each injector location, but did not persist for more than an hour.

The first phase of post-treatment characterization began with the completion of five additional soil borings (T3-F through T3-J) to a depth of 12 ft each. The borings were continuously sampled with 48-in.-long megabore samplers, and the resulting 1.5-in.-diameter soil cores were extensively subsampled. Each core was divided into 1-ft segments and then subsampled as described in Sect. 4.2. Eh was measured on the core as it was subsampled; lithologic descriptions were also prepared.

Post-treatment water samples were collected from the lysimeters and piezometer three times during the 3 days following the injection. Similarly, elevation benchmarks (S1 - S5) were surveyed three times during the 3 days following the injection.

Another set of water samples was collected from the lysimeters and piezometer on December 5, 1994, approximately 2 weeks after the injection. During the third week after injection, December 12 to 14, 1994, two additional soil borings (T3-K and T3-L) were cored and sampled. The on-site subsampling performed was not as extensive as that performed during the first phase of post-treatment soil sampling and was limited to measuring Eh as the cores were divided into 1-ft segments, preparing lithologic logs, and shipping the cores to ORNL for additional analysis. An additional set of water samples was collected from the lysimeters and piezometer in December 1994, February 1995 and May 1996.

4.4.2 T3 Soil Sample Results

Post-treatment soil sample results are summarized in Table 4.7 and data trend graphs are presented in Appendix C. Results from pH measurements were similar for all boreholes, with values ranging from 4.7 to 7.5 and pH increasing with depth. These values are similar to the pre-treatment sample pH values; thus, the bionutrient injection did not effect a significant pH change.

Microbial biomass was evaluated using most probable number (MPN) techniques for aerobic and anaerobic heterotrophic populations. Both enumerations were based on turbidity being exhibited over a dilution range in 1% PTYEG medium (Balkwill) in screw-capped test tubes (Pfiffner 1994). Aerobic enumerations were set-up in a three tube MPN series dilution scheme. Anaerobic heterotrophic enumerations utilized the same media with the additions of cysteine hydrochloride as the reducing agent to reach anaerobic conditions, rezaurin as Eh indicator, and nitrogen/CO_2 as the headspace gas mixture (Pfiffner 1994). Aerobic enumerations were set up in a single-series dilution scheme. The results of the microbial activity are presented in Table 4.8.

The analysis of tracers injected with the bionutrients yielded different results. Bromide was detected in the soil profile at test cell 3 from a depth of 0 to 11 ft bgs (Fig. 4.12), ranging from 1 to approximately 7 ppm, with the maximum concentration at 7 ft bgs. Snomax®, measured as INA, was detected in the soil at depths from 1 to 9 ft bgs and at 12 ft bgs (Fig. 4.13). However, maximum concentrations were detected in the top 1 ft of soil. Thus, it appears that the injection resulted in adequate distribution of the solution within the soil profile.

Soil Eh increased to a maximum of about 430 mV at 2 to 4 ft bgs and then generally decreased to around 200 mV at 12 ft bgs. This trend is similar to that observed for background borings.

Post-treatment soil moisture readings ranged from approximately 13 to 26 %. Comparison to pre-treatment, depth-specific moisture values shows that moisture content in the near-surface interval (0 to 4 ft) increased by approximately 3%. The intermediate depth interval (4 to 8 ft) and the deepest interval (8 to 12 ft) were unchanged.

Soil surface elevation data show that the surface of the test cell was raised approximately 0.5 ft by the injection and remained near that elevation through the last measurement period (3 months after injection). Core samples from both the pre-treatment and post-treatment borings were carefully logged, and visible pores and fractures were noted. No differences were seen between the number and appearance of fractures before and after injection.

4.4.3 T3Water Sample Results

Post-treatment water sample results are presented in Table 4.9 and data trend graphs are presented in Appendix C. The pH of the water in the lysimeters steadily increased following injection of the bionutrient solution (Fig. 4.14). Maximum pH increases in T3L1 and T3L2 were observed approximately 2 weeks after injection, followed by a drop during the next 2 weeks. The pH of T3L3 was initially lower than in the upper lysimeters; however, the pH continued to rise through the last sampling period (4 weeks after injection). This indicates a slow percolation of the reagent through the soil, as also shown by the bromide data (Fig. 4.15). A dramatic increase in bromide concentration is observed for T3L1 and T3L2 immediately following the injection period. Approximately 2 weeks after the injection, bromide was first observed in T3L3, and concentrations in the upper lysimeters began to decrease.

DO values were slightly higher after the injection, but were inconsistent and not significantly different from background values. Conductivity remained about the same before and after injection except in T3L2, the 8-ft-deep lysimeter, where the conductivity increased dramatically after testing (November 18, 1994). Nitrate concentrations ranged from 0.1 to 1.6 ppm. Concentrations in T3L1 and T3L2 were above pre-treatment background levels, but no increases were observed in T3L3 and T3P1. The bionutrient solution probably contained a nitrate source that resulted in increases in the shallower intervals.

Alkalinity values for test cell 3 ranged from approximately 200 to 530 mg/L, with a general trend of increase with depth. These values and trend are similar to those observed in the background cell.

Other analytes tested included Fe, Mn, Cl^-, and SO_4^{2-}, but since there were no noticeable changes in concentration in the first few samples, analysis for these parameters was discontinued, and no evaluation of the limited data sets was deemed necessary.

4.5 Test Cell 4: Lime Slurry

4.5.1 T4 Field Activities

Five pre-treatment soil borings, T4-A through T4-E, were drilled and sampled on October 23 and 24, 1994. Lithologic logs were prepared, and soil samples were shipped to ORNL for analysis. No piezometer was installed in this test cell; however, three lysimeters were nested in boring T4-C (Fig. 4.11). Three SMT probes were installed approximately 2 ft east of the lysimeters. Water samples were collected from the lysimeters on November 1, 1994, and were shipped to ORNL for analysis. Preparation for injection testing at test cell 4 began on November 13, 1994. A set of water samples was collected from the lysimeters, and elevation benchmarks were surveyed prior to the start of injection. A lime solution (calcium carbonate) was then injected on 2-ft centers to a depth of 10.4 ft starting at 11:20 a.m. The test cell injection was completed at 4:05 p.m.; thus, 285 min were required to perform 144 injections (36 MPIS set-up locations with four injector locations per setup). The average time for each injection setup was 7.9 min; however, this includes 130 min of lime-slurry mixing time.

The objective was to inject 2 gal per injector at each 15-in. depth interval. With four injectors per set-up location and eight positions for each injector, the target total for injection at each setup was 64 gal (4 injectors × 8 positions × 2 gal each), and the target for 36 set-up locations was 2,304 gal (36 set-ups × 64 gal each) for the entire test cell. According to flow meters on the MPIS unit, 2,304 gal were injected. The estimated amount of solution lost to the ground surface was 500 gal. Thus, the amount of solution injected into the subsurface was estimated to be 1800 gal.

The solution was mixed as five batches of 500 gal of water with 400 lbs of dry lime each with no tracer added. This mix was approximately 20% lime by weight. One sample was collected from each batch to evaluate the uniformity of the injected solution. The average injected solution was 10.7% lime by weight.

Test Cell No.	Total solution injected	Target solution strength	Average actual solution strength	Duration of injection testing	Average time per setup	Total surface seepage
T4	2300 gal	20% lime	10.7% lime	285 min	7.9 min	500 gal

Soil resistance and temperature were measured before, during, and after the injection testing. Resistance measurements showed that the soil was near saturation at 8 and 14 ft bgs prior to injection testing, but was not saturated at 4 ft bgs. However, soon after injection started, the backfilled soil around the subsurface probes was saturated with injected solution, and solution began to run out the top of the protective casing onto the ground surface. Soil temperature was monitored throughout the test and showed an increase of 2° F at 4 ft bgs and no change at 8 and 14 ft bgs.

The first phase of post-treatment characterization began with the completion of five additional soil borings (T4-F through T4-J) to a depth of 12 ft each. The borings were continuously sampled with 48-in.-long megabore samplers, and the resulting 1.5-in.-diameter soil cores were extensively subsampled. Each core was divided into 1-ft segments and then subsampled as described above. Eh was measured on the core as it was subsampled; lithologic descriptions were also prepared.

Post-treatment water samples were collected from the lysimeters eight times during the days following the injection. Similarly, elevation benchmarks (S1 - S5) were surveyed six times during the eight days following the injection.

Another set of water samples was collected from the lysimeters on December 5, 1994, approximately three weeks after the injection. During the fourth week after injection, December 12 to 14, 1994, two additional soil borings (T4-K and T4-L) were cored and sampled. The subsampling performed was not as extensive as that performed during the first phase of post-treatment soil sampling and was limited to dividing cores into 1-ft segments, preparing a lithologic log, and shipping the cores to ORNL for analysis. An additional set of water samples was collected from the lysimeters in December 1994, February 1995 and May 1996.

4.5.2 T4 Soil Sample Results

Post-treatment soil results for test cell 4 are summarized in Table 4.10 and data trend graphs are presented in Appendix C. Post-treatment pH values ranged from 4.5 to 12.6 (Fig. 4.17). Approximately one-half of these values are greater than the maximum value measured during pre-treatment sampling. The greatest increases over pre-treatment values occurred between 0 to 2 ft and between 5 to 11 ft. Values for the 3- to 5-ft interval were near background levels. Generally, it appears that the MPIS was effective in distributing the lime slurry throughout the soil profile. Indeed, post-treatment soil moisture readings were higher than pre-treatment measurement for all depths, excluding the 7- to 8-ft interval.

Post-treatment calcium concentrations are shown in Fig. 4.18. Although depth-specific results are sporadic between boreholes, concentrations are generally higher than the pre-treatment samples. This is particularly true for the 0- to 6-ft intervals, where dramatic increases were observed. The scattered nature of the results indicates flow of the slurry through existing preferential flow channels (e.g., fractures).

Soil surface elevation data show that the surface of the test cell was raised approximately 0.15 ft by the injection and remained near that elevation for approximately one month. An additional 0.10-ft rise was observed during the last measurement period (three months after injection). Core samples from both pre-treatment and post-treatment borings were carefully logged, and visible pores and fractures were noted. Post-treatment logs indicated abundant lime in root pores and microfractures in the 0- to 2-ft interval. Some lime was seen in both vertical and horizontal fracture and bedding planes and in remnant root vesicles in the 4- to 8-ft interval.

4.5.3 T4 Water Sample Results

Post-treatment water sample results are presented in Table 4.11 and data trend graphs are presented in Appendix C. The lime injection resulted in an immediate increase in the pH of the water in the two shallower lysimeters, T4L1 and T4L2 (Fig. 4.19). Increases from 7.8 to approximately 12.4 were observed, and pH remained fairly constant for 5 weeks, at which time values began decreasing. No increases in the pH of water samples from the deep lysimeter (T4L3) were observed. Alkalinity and conductivity values correlate well with the pH measurements, indicating that the short-term influence of the lime injection primarily affected the 0 to 8-ft interval. Alkalinity values in T4L1 and T4L2 increased by 700 to 1000 mg/L following the injection and remained constant for approximately 4 weeks; however, a slight increase (approximately 200 mg/L) was also observed in T4L3 (Fig. 4.20). A similar pattern was observed for conductivity measurements; however, the deeper lysimeter showed dramatic increases above background concentrations (Fig. 4.21). In fact, values for all three lysimeters more than doubled following the injection and remained elevated for approximately

4 weeks. These data indicate that the calcium ions and the various carbonate species from the lime injection significantly affected the soil-pore water in test cell 4.

Post-treatment DO values ranged from approximately 2 to 12 mg/L. No significant changes from background values were observed. Other analytes tested included Fe, Mn, Cl^-, and SO_4^{2-}, but since there were no noticeable changes in concentration in the first few samples, analysis for these parameters was discontinued, and no evaluation of the limited data sets was deemed necessary.

4.6 Test Cell 5: Potassium Permanganate

4.6.1 T5 Field Activities

Five pre-treatment soil borings, T5-A through T5-E, were drilled and sampled on October 21 and 22, 1994. Lithologic logs were prepared, and soil samples were shipped to ORNL for analysis. One piezometer was installed at boring T5-D, and three lysimeters were nested in boring T5-C (Fig. 4.22). Three SMT probes were installed approximately 2 ft east of the lysimeters. Water samples collected from the piezometer and lysimeters on November 1, 1994, were shipped to ORNL for analysis. Preparation for injection testing at test cell 5 began the morning of November 16, 1994. A set of water samples was collected from the lysimeters and piezometer, and elevation benchmarks were surveyed prior to the start of injection. A solution of 500 gal of water and 100 kg of $KMnO_4$ was mixed for injection (5% $KMnO_4$ by weight). The $KMnO_4$ solution was injected on 2-ft centers to a depth of 10.4 ft starting at 1:40 p.m. The test cell injection was completed at 5:40 p.m.; thus, 240 min were required, with an average time for each injection setup of 6.7 min. This time included stopping twice to mix more injection solution (approximately 45 min).

The objective was to inject 2 gal per injector at each 15-in. depth interval or a total of 2,304 gal for the entire test cell. According to the flow meter at the pump, 2,223 gal were injected, and according to flow meters on the MPIS unit, 2,328 gal were injected. The estimated amount of solution lost to blowout at the ground surface was 400 gal. Thus, the amount of solution injected into the subsurface was estimated to be 1900 gal. One sample of each of five batches was collected during injection to evaluate the uniformity of the injected solution. The average injected solution was 4.2 % $KMnO_4$ by weight.

Test Cell No.	Total solution injected	Target solution strength	Average actual solution strength	Duration of injection testing	Average time per setup	Total surface seepage
T5	2300 gal	5% $KMnO_4$	4.2% $KMnO_4$	240 min	6.7 min	400 gal

Soil resistance and temperature were measured before, during, and after the injection testing. Resistance measurements showed that the soil was near saturation at 8 and 14 ft bgs prior to injection testing, but was not saturated at 4 ft bgs. However, about 40 min after injection started, the backfilled soil around the subsurface probes was saturated with injected solution, and solution began to run out the top of the protective casing onto the ground surface. Soil temperature was monitored throughout the test and showed an increase of 2° F at 4 ft bgs, 1° F at 8 ft bgs, and no change at 14 ft bgs. The $KMnO_4$ reacted mildly upon injection, with only small amounts of gas produced; however, the fact that the soil-pore water samples were still dark purple 4 weeks later indicated that the reagent was persistent in the soil.

The first phase of post-treatment characterization began with the completion of five additional soil borings (T5-F through T5-J) to a depth of 12 ft each. The borings were continuously sampled with 48-in.-long megabore samplers, and the resulting 1.5-in.-diameter soil cores were extensively subsampled as described in Sect. 4.2. Each core was divided into 1-ft segments and then subsampled. Eh was measured on the core as it was subsampled; lithologic descriptions were also prepared.

Post-treatment water samples were collected from the lysimeters and piezometer 5 times during the 5 days following the injection. Similarly, elevation benchmarks (S1, S2, S3 damaged, S4, and S5) were surveyed 4 times during the 5 days following the injection.

Another set of water samples was collected from the lysimeters and the piezometer on December 5, 1994, approximately 3 weeks after the injection. During the fourth week after injection, December 12 to 14, 1994, two additional soil borings (T5-K and T5-L) were cored and sampled. The on-site subsampling performed was not as extensive as that performed during the first phase of post-treatment soil sampling and was limited to preparing a lithologic log and segmenting the core for shipment to ORNL for analysis. An additional set of water samples was collected from the lysimeters and piezometer in December 1994, February 1995 and May 1996.

4.6.2 T5 Soil Sample Results

Post-treatment soil sample results are summarized in Table 4.12 and data trend graphs are presented in Appendix C. Soil sample results show a pH ranging from 4.3 to 7.8, with a trend of increasing pH values with depth. These values and trend are similar to the pre-treatment sample results; thus, no significant changes in pH were observed. Purple staining was noted in many of the soil extracts indicating that the $KMnO_4$ had penetrated the soil. Core samples from the post-treatment borings showed purple staining in the upper 8-in. of soil from surface infiltration. The deepest soil sample with purple-colored soil extract was the 8 to 9-ft sample, and this condition was noted in three of the five borings. Purple-stained zones were observed on the soil cores at depths of 5 and 9 ft bgs.

Compared to pre-treatment conditions, post-treatment soil moisture content increased slightly in the 0- to 4-ft interval, decreased slightly in the 5- to 8-ft interval, and remained approximately the same in the 9- to 12-ft interval. Therefore, it appears that the bulk of the solution was injected in the top 4 to 5 ft of the soil. This is also indicated by the post-treatment manganese concentrations measured (Fig. 4.23). Manganese concentrations at depths of 0 to 5 ft bgs ranged from approximately 20 to 250 mg/L above background levels; however, no increases were observed in the 6- to 12-ft interval. Post-treatment Eh measurements ranged from 240 to 880 mV (Fig. 4.24). Dramatic increases in Eh were observed throughout the soil profile, where readings were approximately double pre-treatment measurements with the exception of the 0- to 2-ft interval. Thus, this treatment appeared to have the greatest effect on soil Eh.

Soil surface elevation data show that the surface of the test cell was raised approximately 0.1 ft by the injection and remained near that elevation through the last measurement period (three months after injection). Core samples from both pre-treatment and post-treatment borings were carefully logged and visible pores and fractures were noted. No differences were seen between the number and appearance of fractures before and after injection, excluding the purple staining noted above.

4.6.3 T5 Water Sample Results

Post-treatment water sample results are presented in Table 4.13 and data trend graphs are presented in Appendix C. Manganese results ranged from background (<1 mg/L) to approximately 18,000 mg/L (Fig. 4.25). The maximum concentration was detected the day after injection in the intermediate-depth lysimeter, T5L2 (8 ft bgs). Concentrations in T5L2 slowly dropped to near background levels over a 5-week period. Concentrations in the shallow lysimeter, T5L1, followed a similar trend; however, the maximum concentration was lower (4,500 mg/L). The initial field description of water collected from the lysimeters was "very purple" and "purple" respectively. A maximum concentration of 50 mg/L was detected in the deepest lysimeter, T5L3, the day after injection. The maximum concentration in the piezometer was 8 ppm. These results indicate that injection was effective in distributing the solution to the top 8 ft of the test-cell soil.

Post-treatment pH results ranged from approximately 6.0 to 8.1. Initial average values for individual lysimeters were similar to pre-treatment levels, excluding T5L1, where an average 0.5 pH unit decrease was observed. The lowest value observed in T5L1 occurred 5 days after injection. DO values were difficult to determine because the purple color of the water interfered with the colorimetric analysis. Due to intermittent data collection and questions regarding the validity of the measurements, no conclusions can be drawn from the DO data.

Electrical conductivity results were scattered; however, post-treatment results for T5L1 and T5L2 were generally higher than pre-treatment readings. No significant changes were observed in T5L3 or the piezometer. Post-treatment alkalinity values ranged from approximately 100 to 630 mg/L. No pre-treatment alkalinity measurements were taken in test cell 5; thus, values were compared to samples taken from the background cell. Values for all depths at test cell 5 are approximately twice those from the background cell; however, this difference is likely a result of natural geochemical variation rather than an effect caused by the solution injection. Other analytes tested included Fe, Mn, Cl^-, and SO_4^{2-}, but since there were no noticeable changes in concentration in the first few samples, analysis for these parameters was discontinued, and no evaluation of the limited data sets was deemed necessary.

4.7 Test Cell 6: Air

4.7.1 T6 Field Activities

Five pre-treatment soil borings, T6-A through T6-E, were drilled and sampled on October 21, 1994. Lithologic logs were prepared, and soil samples were shipped to ORNL for analysis. Three lysimeters were nested in boring T6-C (Fig. 4.26). Three SMT probes were installed approximately 2 ft east of the lysimeters. Water samples collected from the lysimeters on November 1, 1994, were shipped to ORNL for analysis. Preparation for injection testing at test cell 6 began the morning of November 19, 1994. A set of water samples was collected from the lysimeters, and elevation benchmarks were surveyed prior to the start of injection. Air was injected with two injectors at four locations within the test cell to a depth of 10.4 ft starting at 4:10 p.m. The test cell injection was completed at 4:30 p.m.; thus, 20 min were required, with an average time for each injection setup of 5 min.

The objective was to inject air at each setup until air pressure reached at least 100 psi or until surface blowout was achieved. Three additional locations south of the test cell were penetrated with the injectors. However, no air was injected into these three holes since a gaseous-phase tracer study was planned at a later date to evaluate the extent of air-induced fracturing from the air injections performed within the test cell. All injector holes, including the three locations south of the test cell, were completed by placing 1/4-in.-diameter tubing in the holes and backfilling with sand and bentonite.

The first phase of post-treatment characterization began with the collection of water samples from the lysimeters three times during the three days following the injection. Additional sets of water samples were collected from the lysimeters on December 5, 1994, approximately 3 weeks after the injection; on December 15, 1994, approximately 4 weeks after injection; on February 15, 1995, approximately 13 weeks after injection; and on May 7, 1996, approximately one and a half years after injection.

4.7.2 T6 Soil Sample Results

No post-treatment soil samples were collected from test cell 6. Soil surface elevation data show no significant increases in elevation following the air injection.

4.7.3 T6 Water Sample Results

Post-treatment water sample results are presented in Table 4.14. Results for test cell 6 are limited due to poor sample recovery. However, little change was expected from the air injection. Because the upper lysimeter was consistently dry, only one sample was collected from T6L1. Results for pH, DO, and conductivity measurements are within the background range. Other analytes tested included Fe, Mn, Cl^-, NO_3^-, and SO_4^{2-}, but since there were no noticeable changes in concentration in the first few samples, analysis for these parameters was discontinued, and no evaluation of the limited data sets was deemed necessary.

4.8 Test Cell 7: Micropowder Iron

4.8.1 T7 Field Activities

One pre-treatment soil boring, T7-A, was drilled and sampled on October 24, 1994. A lithologic log was prepared, and soil samples were shipped to ORNL for analysis. No piezometer was installed in this test cell; however, three lysimeters were nested in boring T7-A (Fig. 4.27). Three SMT probes were installed approximately 2 ft east of the lysimeters. Water samples collected from the lysimeters on November 1, 1994, were shipped to ORNL for analysis. Preparation for injection testing at Test Cell 7 began the morning of November 19, 1994, when a set of water samples was collected from the lysimeters. A solution of iron micropowder (approximately 20% by weight), water, and guar gum was injected on 2-ft centers to a depth of 10.4 ft at the 4 ft by 8-ft test cell. The injection started at 12:40 p.m. and was completed at 1:02 p.m.; thus, 22 min were required to perform 16 injections (four MPIS set-up locations with four injector locations per setup). The average time for each injection setup was 5.5 min.

The objective was to inject 2 gal per injector at each 15-in. depth interval. With four injectors per set-up location and four positions for each injector, the target total for injection at each setup was 64 gal (4 injectors × 8 positions × 2 gal each), and the target for four set-up locations was 256 gal (4 setups × 64 gal each) for the entire test cell. According to the flow meter at the pump, 308 gal were injected. Because the flow meters on the MPIS unit were not working, no readings were obtained from them. The estimated amount of solution lost to the ground surface was 20 gal. Thus, the amount of solution injected into the subsurface was estimated to be 290 gal. The solution was mixed as a single batch of 500 gal of water with 400 lbs of dry iron micropowder (5 um nominal particle size) and 25 lbs of guar gum. The guar gum was added to keep the iron in suspension during injection. However, the tank required continuous stirring to prevent settling of the iron micropowder. The mixture was approximately 20% iron by weight.

Test Cell No.	Total solution injected	Target solution strength	Average actual solution strength	Duration of injection testing	Average time per setup	Total surface seepage
T7	308 gal	20% iron	not determined	22 min	5.5 min	20 gal

Soil resistance and temperature were measured before, during, and after the injection testing. Resistance measurements showed that the soil was near saturation at 14 ft bgs prior to injection testing, but was not saturated at 4 and 8 ft bgs. However, soon after injection started, the backfilled soil around the subsurface probes was saturated with injected solution, and solution began to run out the top of the protective casing onto the ground surface. Soil temperature was monitored before and after the test and showed an increase of 2° F at 4 ft bgs, 1° F at 8 ft bgs, and no change at 14 ft bgs.

The first phase of post-treatment characterization began with the completion of two additional soil borings (T7-B through T7-C) to a depth of 12 ft each. The borings were continuously sampled with 48-in.-long megabore samplers, and the resulting 1.5-in.-diameter soil cores were extensively subsampled. Each core was divided into 1-ft segments and then subsampled as described in Sect. 4.2. Eh was measured on the core as it was subsampled; lithologic descriptions were also prepared.

Post-treatment water samples were collected from the lysimeters twice during the 2 days following the injection. Similarly, the elevation benchmark was surveyed two times during the 2 days following the injection. Another set of water samples was collected from the lysimeters on December 5, 1994, approximately 2 weeks after the injection. During the third week after injection, December 12 to 14, 1994, two additional soil borings (T7-D and T7-E) were cored and sampled. The on-site subsampling performed was not as extensive as that performed during the first phase of post-treatment soil sampling and was limited to dividing cores into 1-ft segments, preparing a lithologic log, and shipping the cores to ORNL for analysis. An additional set of water samples was collected from the lysimeters in December 1994, February 1995 and May 1996.

4.8.2 T7 Soil Sample Results

Post-treatment soil samples are summarized in Table 4.15 and data trend graphs are presented in Appendix C. Samples were analyzed for pH, Eh, and iron. The pH ranged from 5.2 to 7.1, with a trend of increasing values with depth. These values are within the background range of samples collected from the site. Post-treatment Eh values ranged from 135 to 420 mV, increasing to a maximum at 2 to 3 ft bgs and then steadily decreasing with depth. These values and trend are consistent with sample data from the background cell.

Soil iron results showed concentrations ranging from less than 1 ppm to over 30 ppm. No pre-treatment samples were analyzed for iron; thus, a direct comparison cannot be made. Also, analytical results cannot be compared to a regional background range of values due to differences in the analysis methods (water extraction vs acid digestion). However, based on a relative comparison of the post-treatment data collected from test cell 7, substantial increases in iron were observed at the 1 to 3-ft interval and the 4 to 5-ft interval of borehole C. The particle size of the micropowder iron was approximately 5 μm and was suspended with the guar gum.

Soil surface elevation data show that the surface of the test cell was raised approximately 0.1 ft by the injection, and remained near that elevation through the last measurement period (3 months after injection). Core samples from both pre-treatment and post-treatment borings were carefully logged, and visible pores and fractures were noted. Guar gum was observed in fractures and voids at 1 to 3 ft bgs and at 6 to 7 ft bgs.

4.8.3 T7 Water Sample Results

Post-treatment water sample results are presented in Table 4.16 and data trend graphs are presented in Appendix C. Post-treatment iron concentrations in test cell 7 ranged from 0.1 to over 30 ppm (Fig. 4.28). Two samples from the test cell (December 15 samples from T7L1 and T7L2) were recorded as "over range" by the analysis method. The upper limit of detection for the analysis was approximately 30 ppm. These points are graphed as 30 ppm on Fig. 4.28. Background concentrations of iron in water, based on analyses from other test cells, ranged from 0.1 to 1.2 ppm. Therefore, iron levels above this range are considered significant. No effects were observed in lysimeter samples collected immediately after the injection (days 1 through 3); however, dramatic increases were observed in T7L1 and T7L2 approximately 2 weeks later. This evidence suggests that some of the injected iron was reduced to soluble Fe^{+2} between sampling periods. Iron levels in these lysimeters began to drop after approximately 4 weeks. Concentrations in the deep lysimeter, T7L3, steadily increased to a maximum of 1.8 ppm at the last sampling period. This was possibly the result of percolation from the upper soil zone.

Post-treatment pH values from lysimeter samples ranged from 6.2 to 8.8. There is a trend of decreasing pH in the upper lysimeters, T7L1 and T7L2, following the injection period. This correlates with the reduction of iron discussed above. Hydrogen ions, produced as a result of iron reduction, would effect a decrease in pH. Measurements in T7L3 were sporadic; however, there is no clear trend with respect to pH.

DO values are scattered, and no significant changes are indicated when compared to background measurements. It appears that DO increased and then decreased after the injection. However, this is attributed to variation in the field measurements observed at all test cells. Conductivity values ranged from approximately 600 to 4400 μmhos. Conductivity from the deepest lysimeter, T7L3, appears to have increased over background levels; however, no significant changes were observed in T7L1 and T7L2. Other analytes tested included alkalinity, Mn, Cl^-, NO_3^-, and SO_4^{2-}, but since there were no noticeable changes in concentration in the first few samples, analysis for these parameters was discontinued, and no evaluation of the limited data sets was deemed necessary.

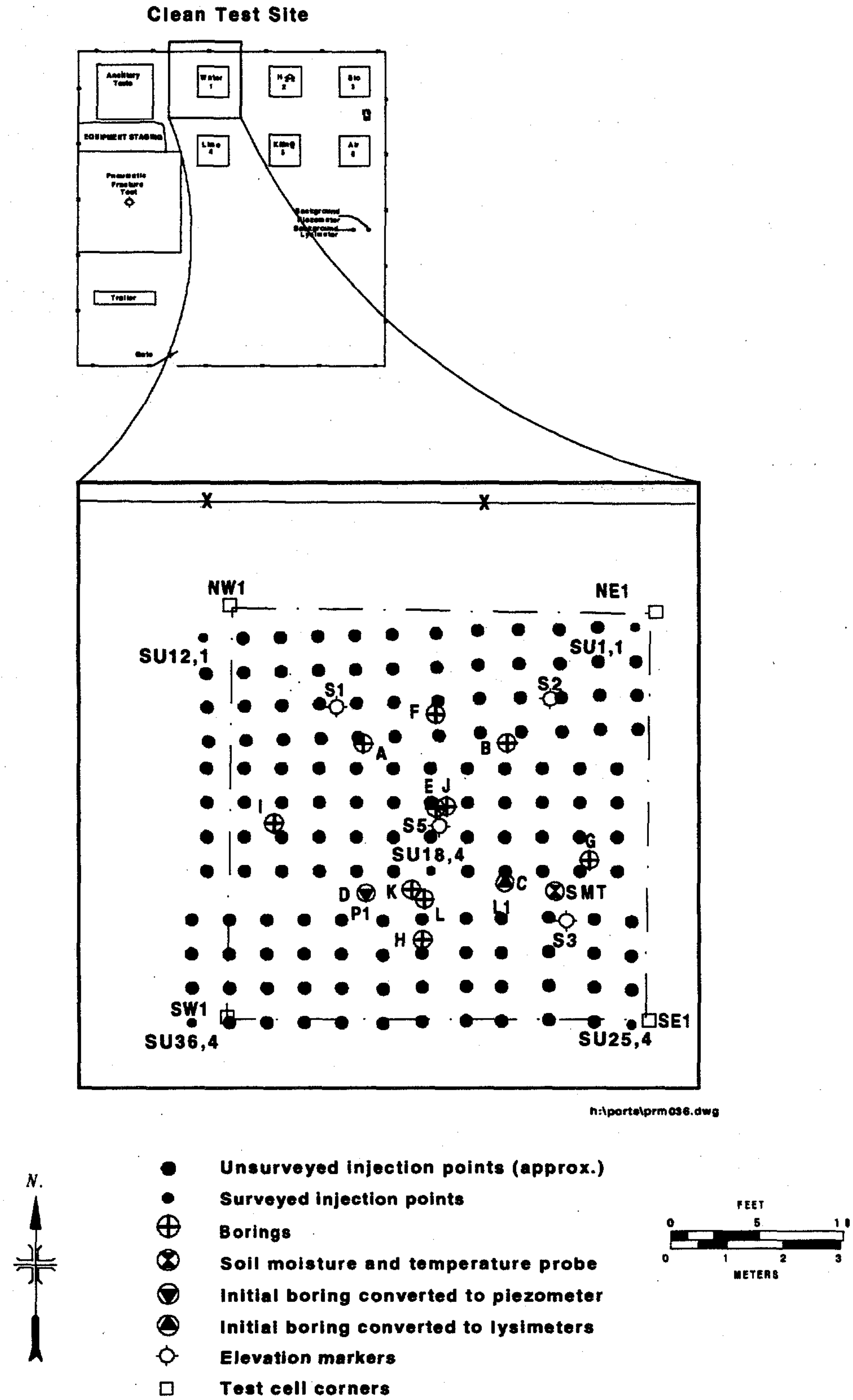


Fig. 4.1. Test cell 1 sample locations.

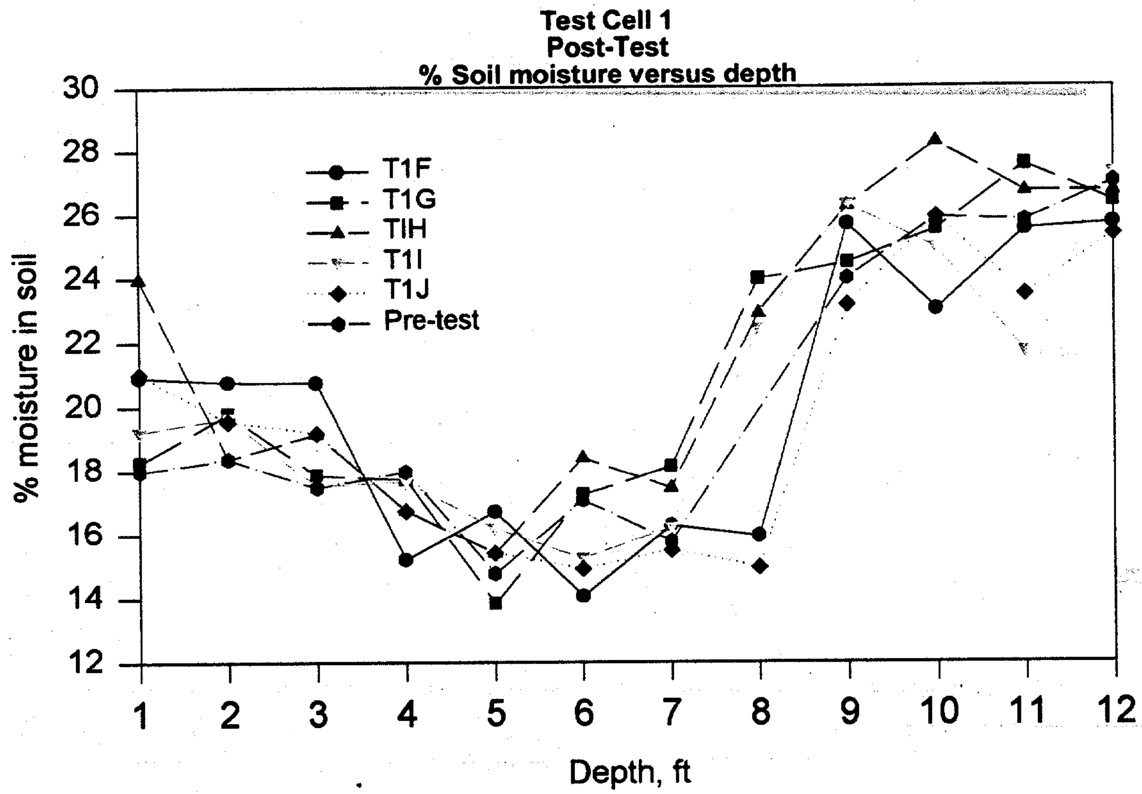


Fig. 4.2. Test cell 1 - post-treatment soil moisture content.

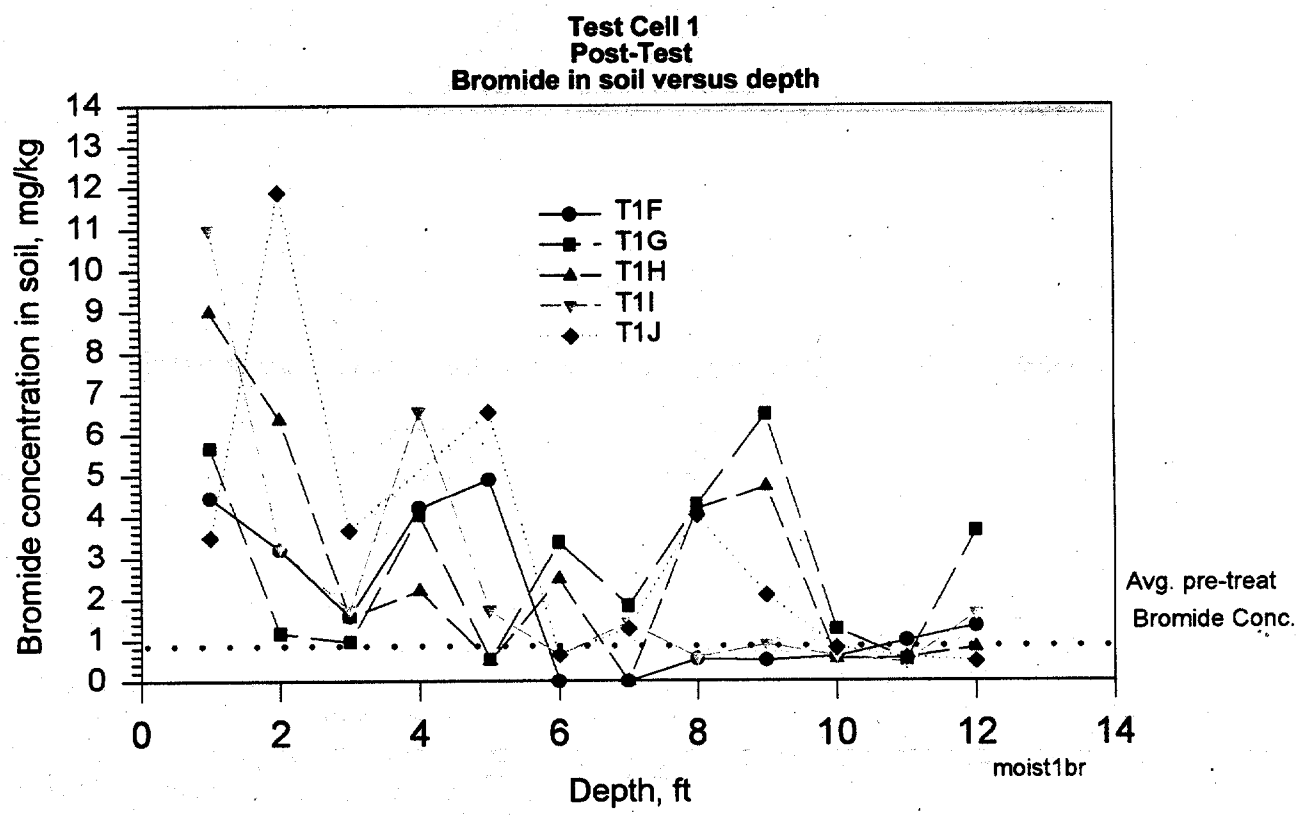


Fig. 4.3. Test cell 1 - post-treatment soil bromide levels.

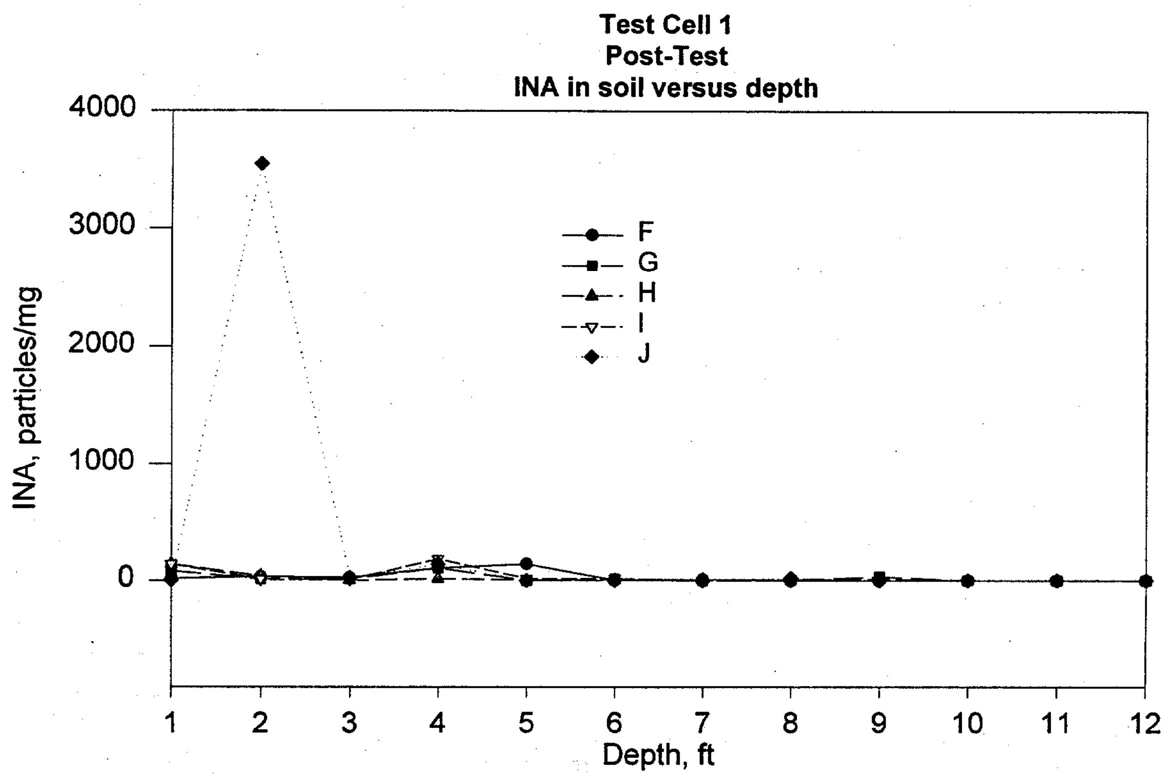


Fig. 4.4. Test cell 1 - post-treatment soil INA levels.

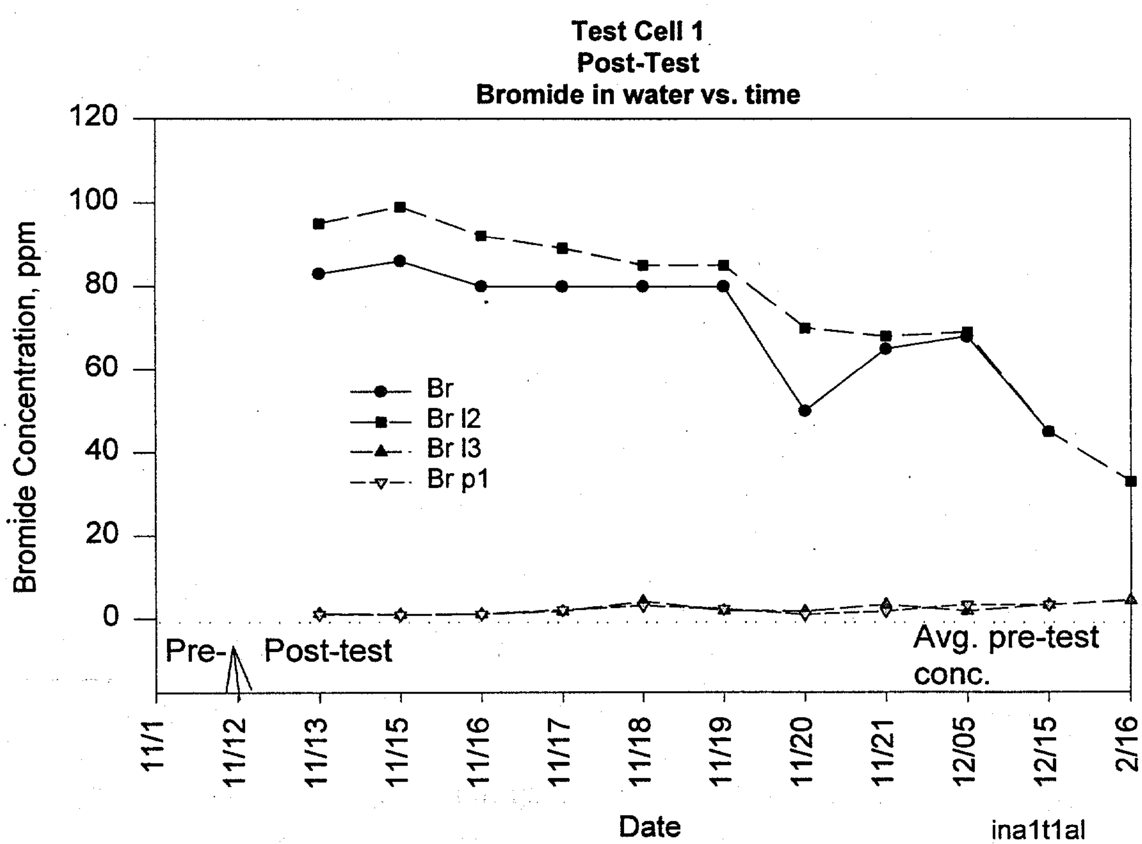


Fig. 4.5. Test cell 1 - post-treatment water bromide levels.

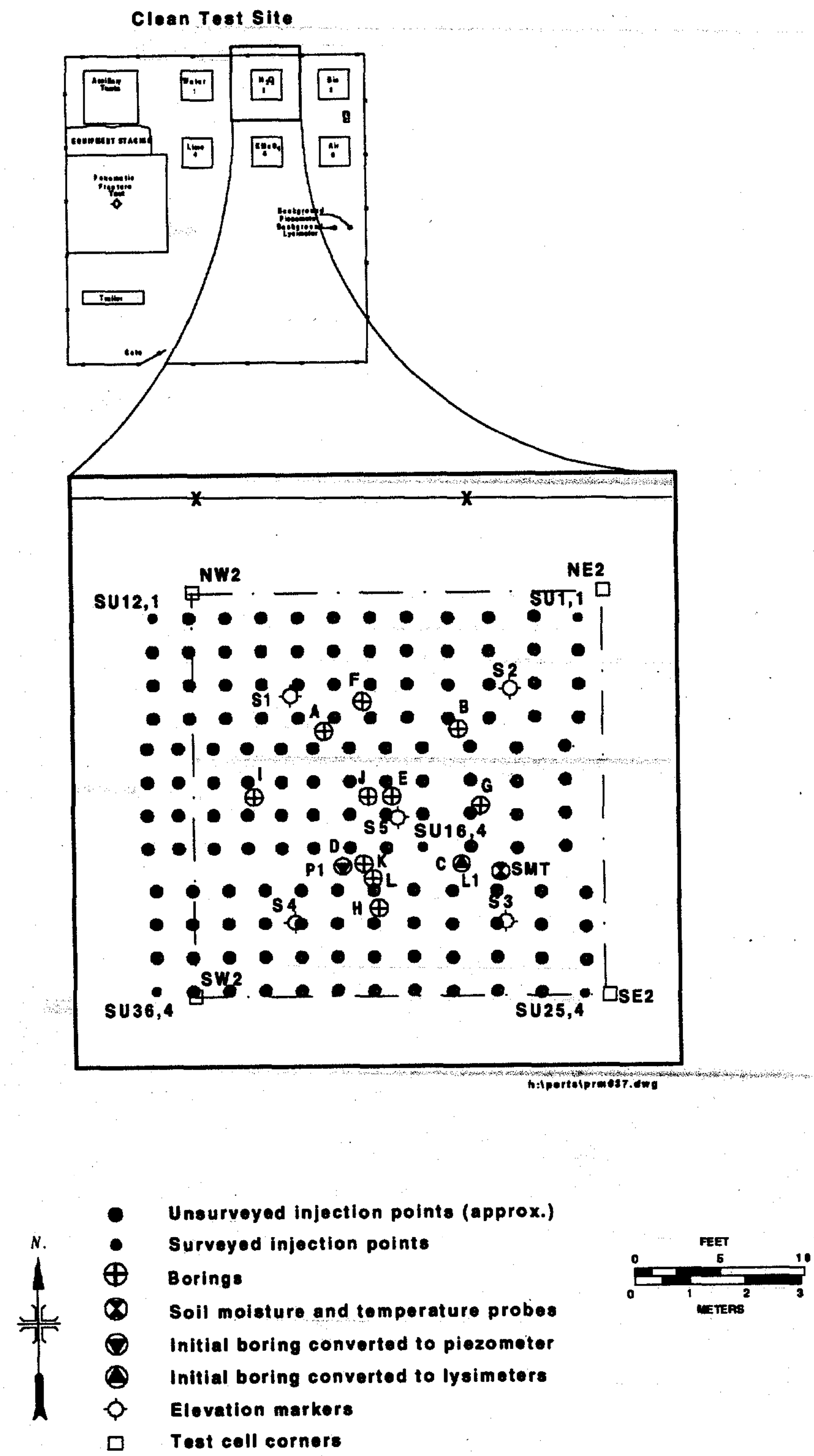


Fig. 4.6. Test cell 2 sample locations.

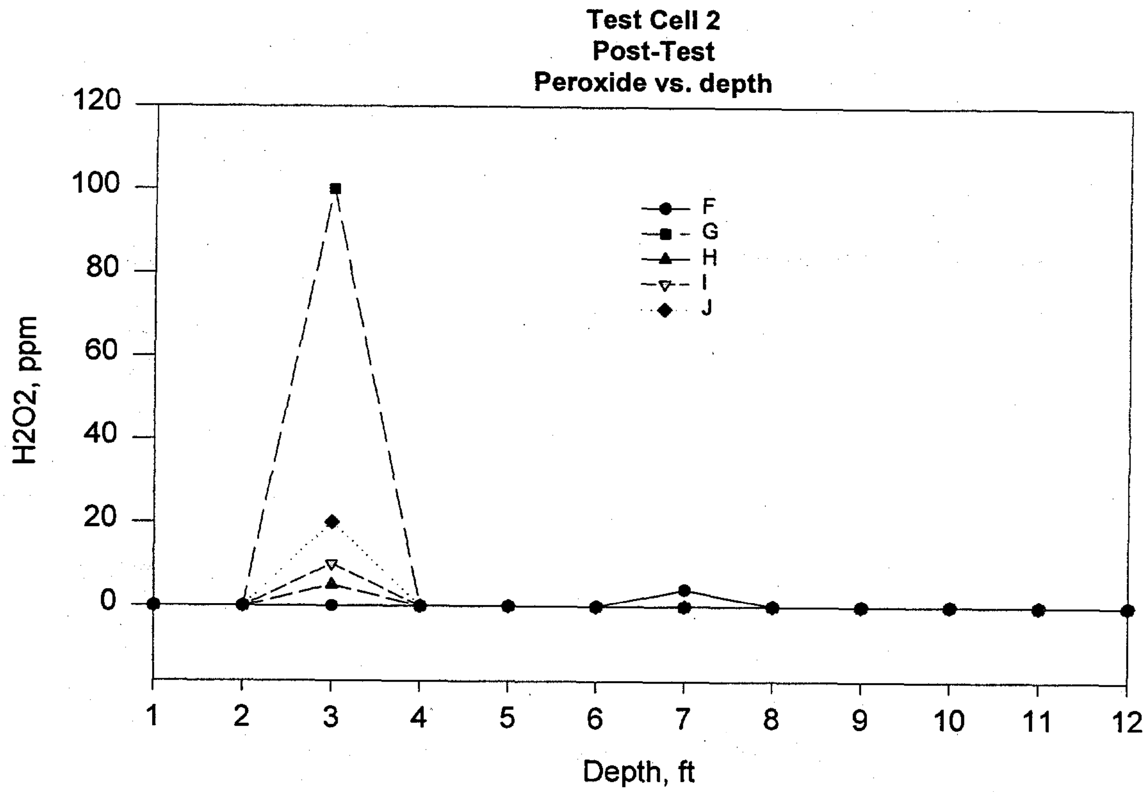


Fig. 4.7. Test cell 2 - post-treatment soil peroxide levels.

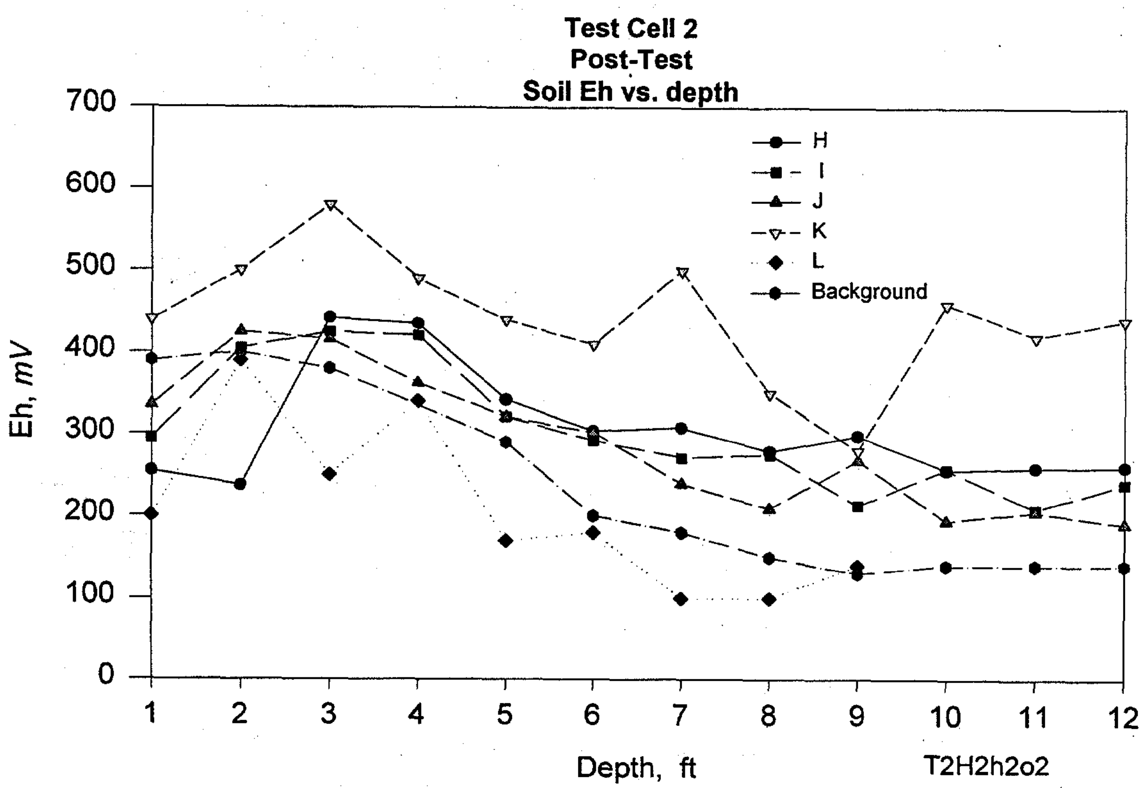


Fig. 4.8. Test cell 2 - post-treatment soil Eh data.

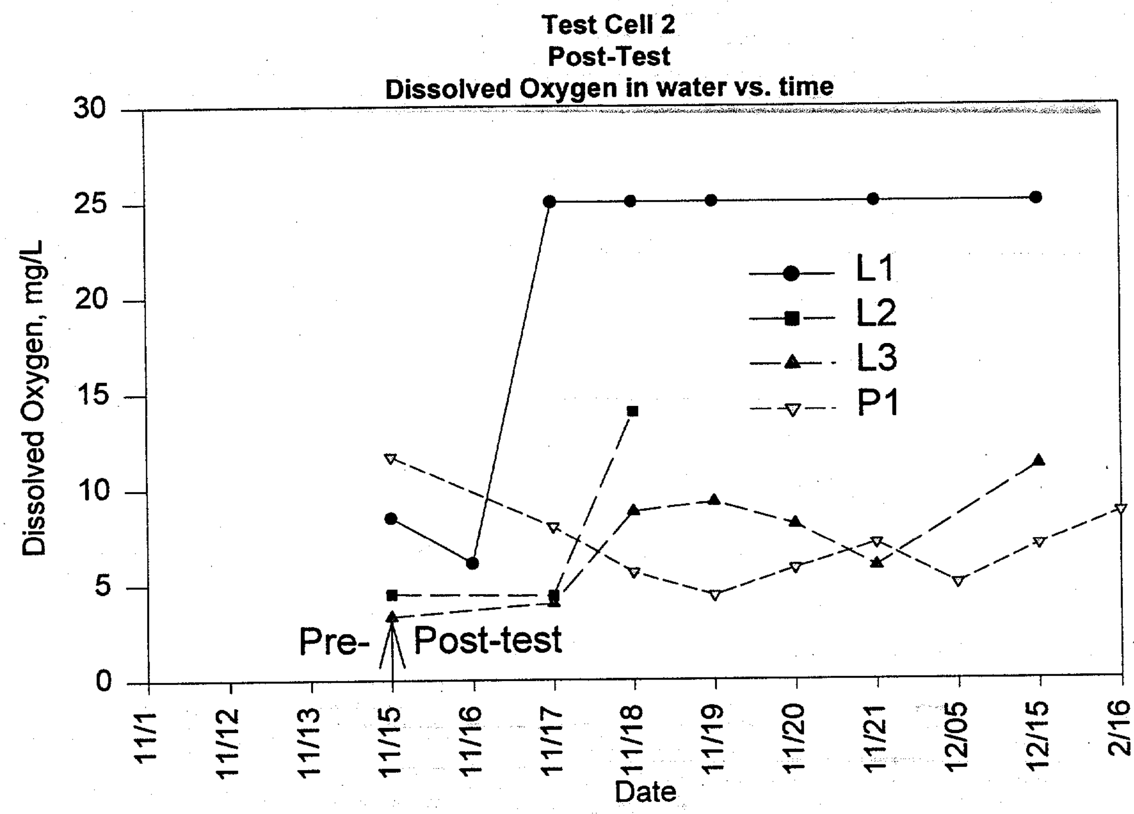


Fig. 4.9. Test cell 2 - post-treatment water DO levels.

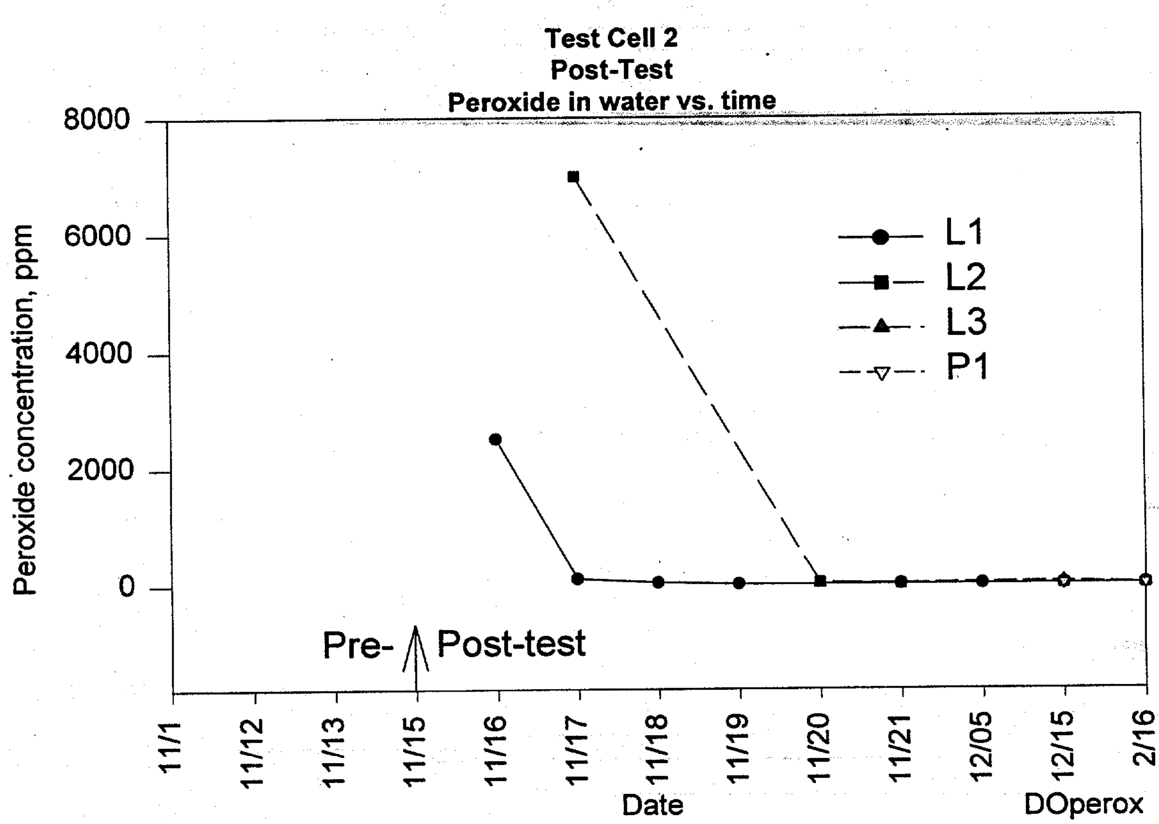


Fig. 4.10. Test cell 2 - post-treatment water peroxide levels.

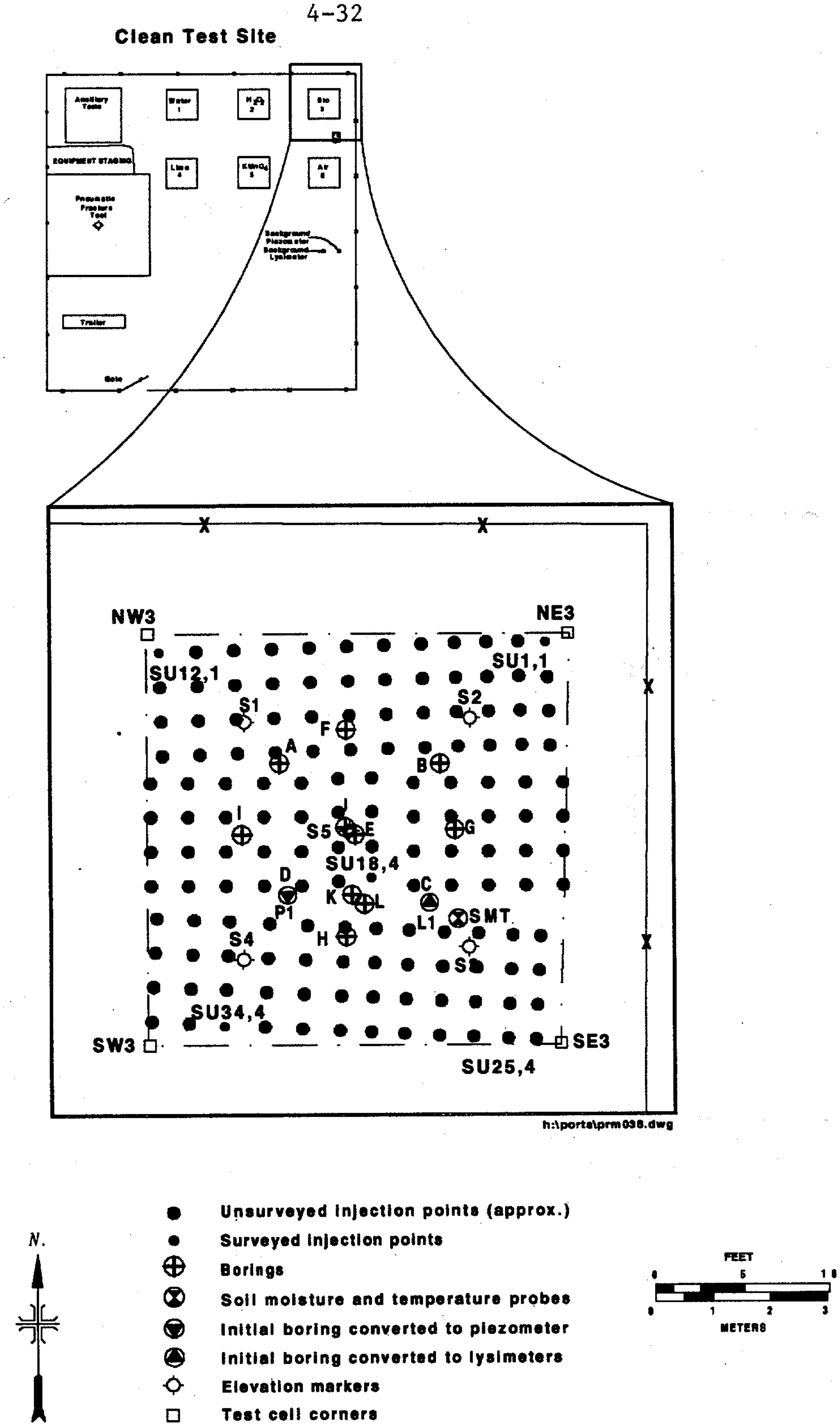


Fig. 4.11. Test cell 3 sample locations.

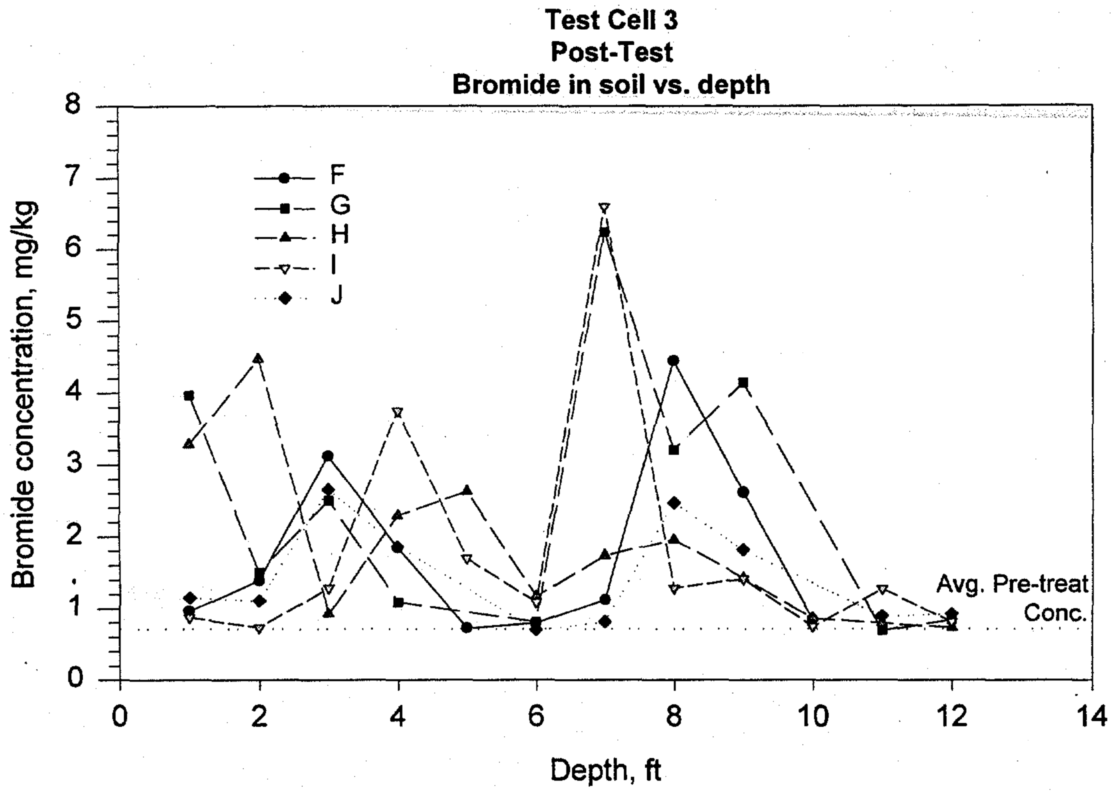


Fig. 4.12. Test cell 3 - post-treatment soil bromide levels.

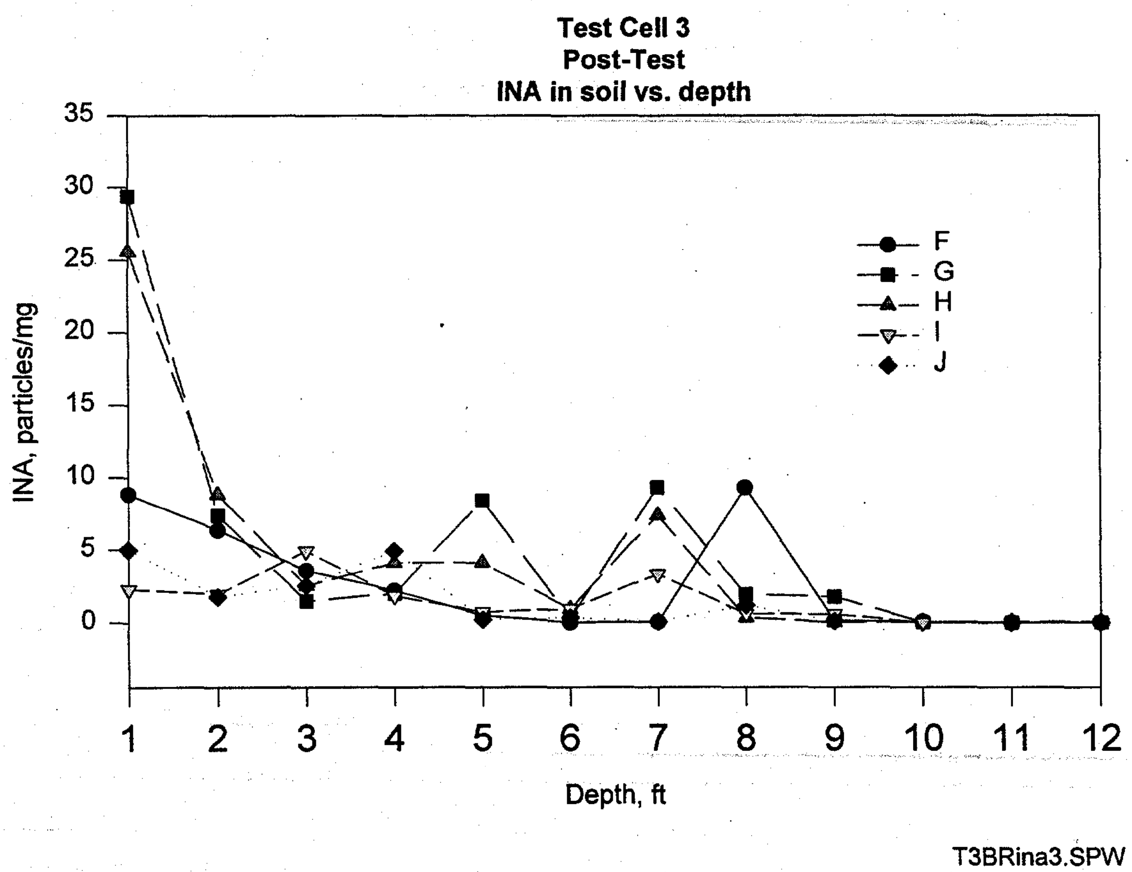


Fig. 4.13. Test cell 3 - post-treatment soil INA levels.

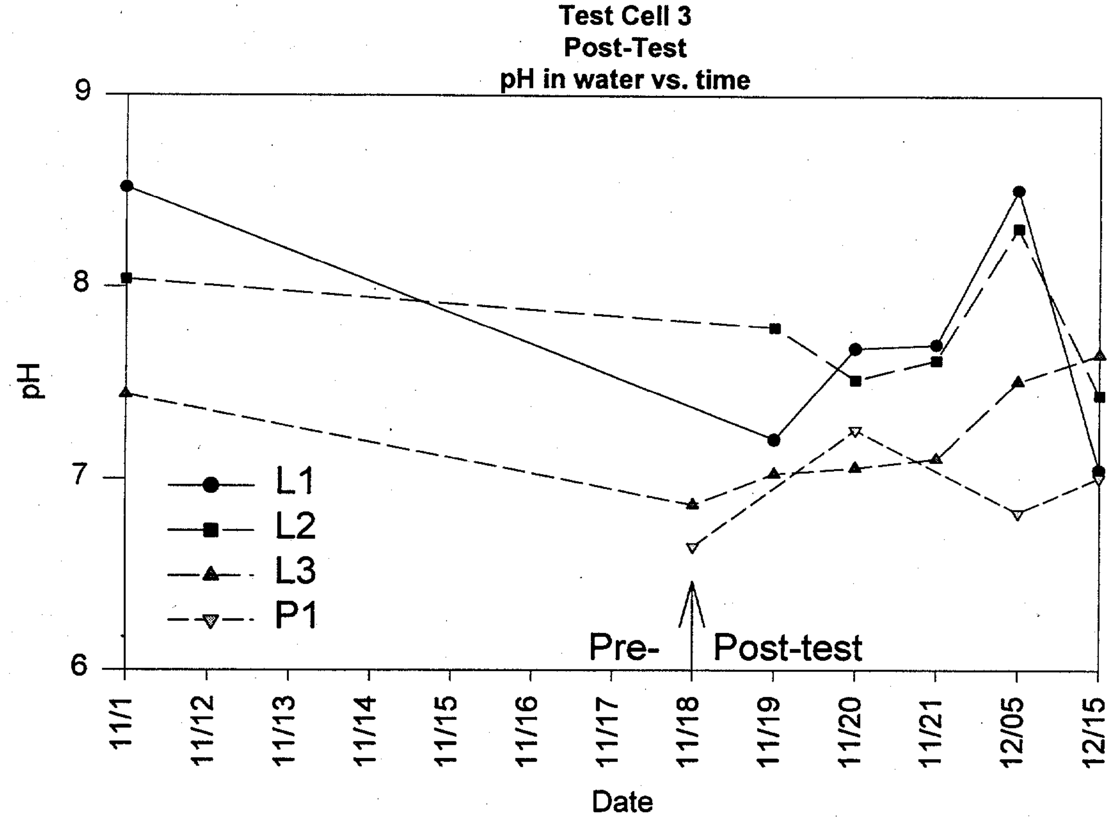


Fig. 4.14. Test cell 3 - post-treatment water pH.

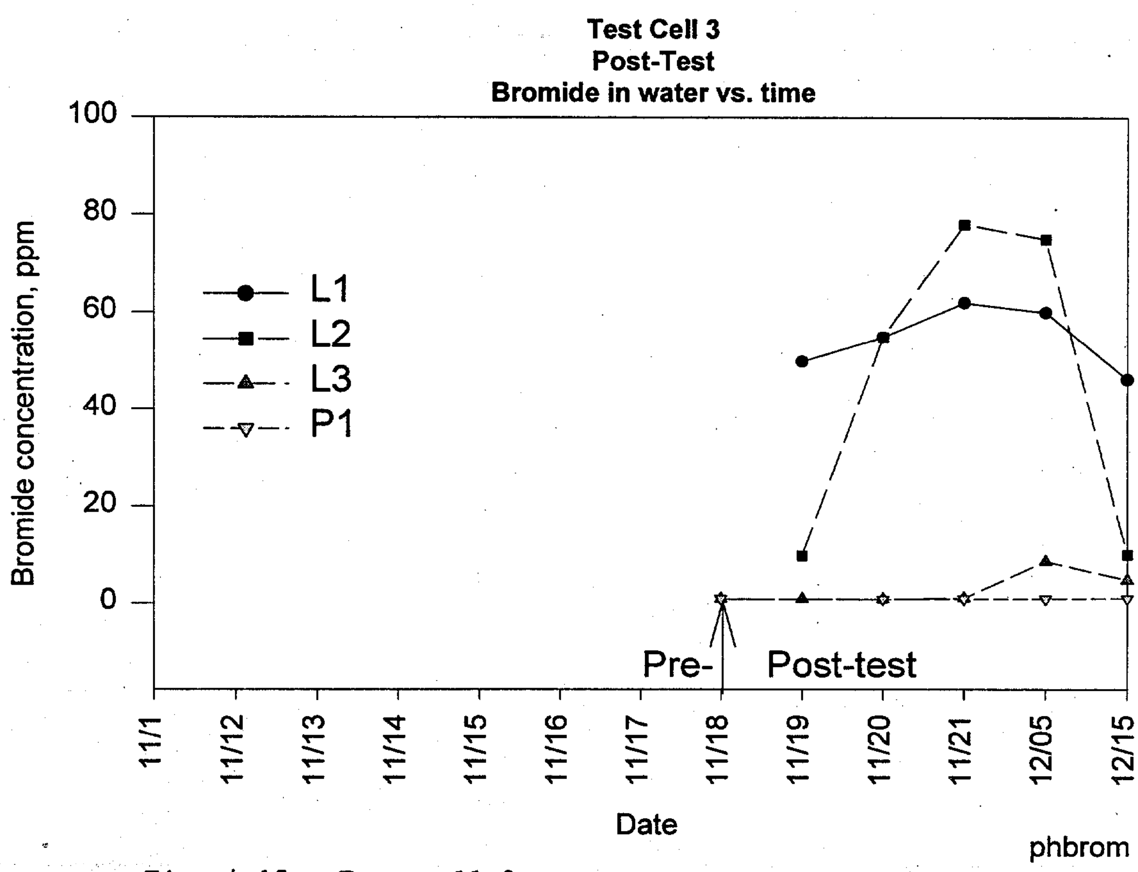


Fig. 4.15. Test cell 3 - post-treatment water bromide data.

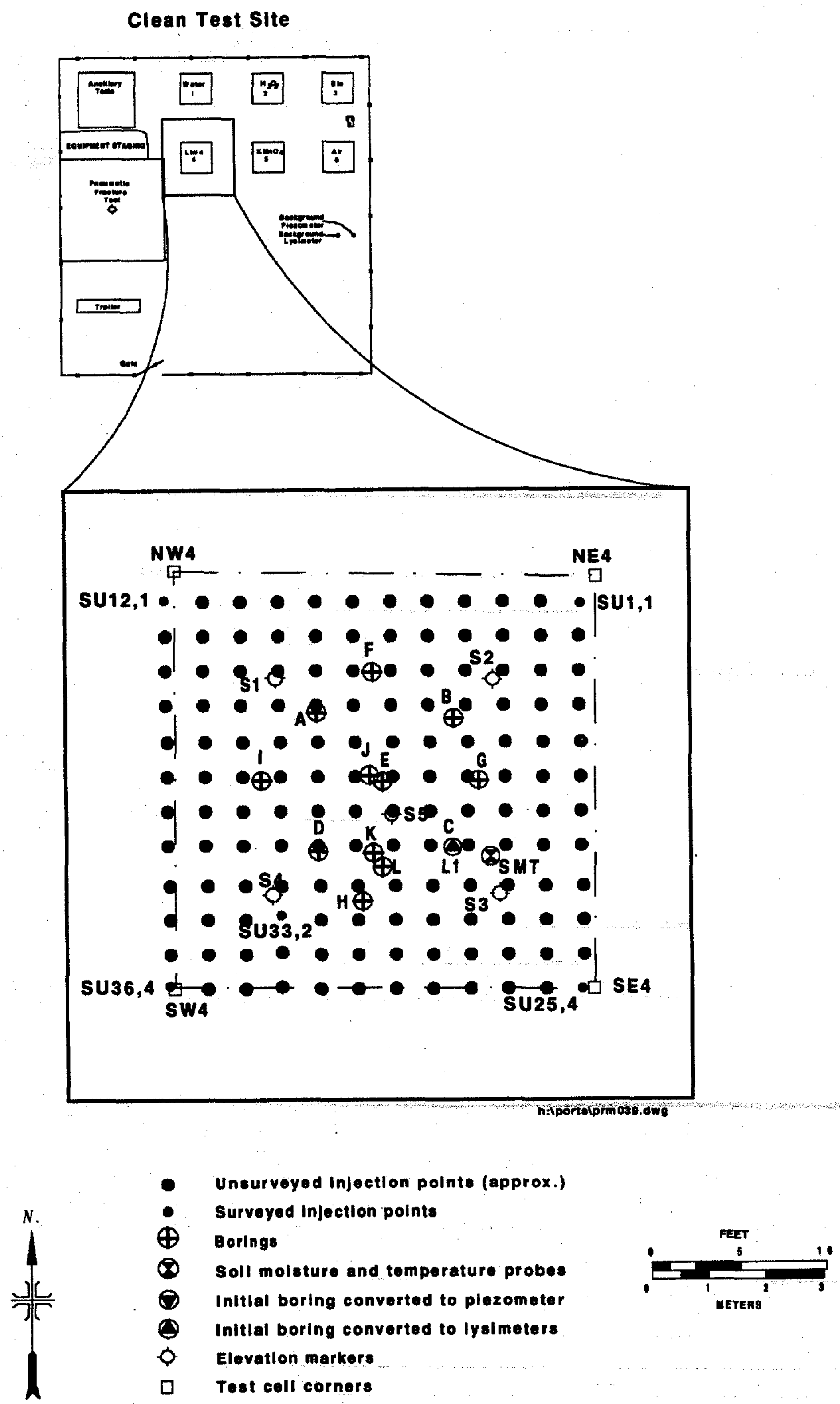


Fig. 4.16. Test cell 4 sample locations.

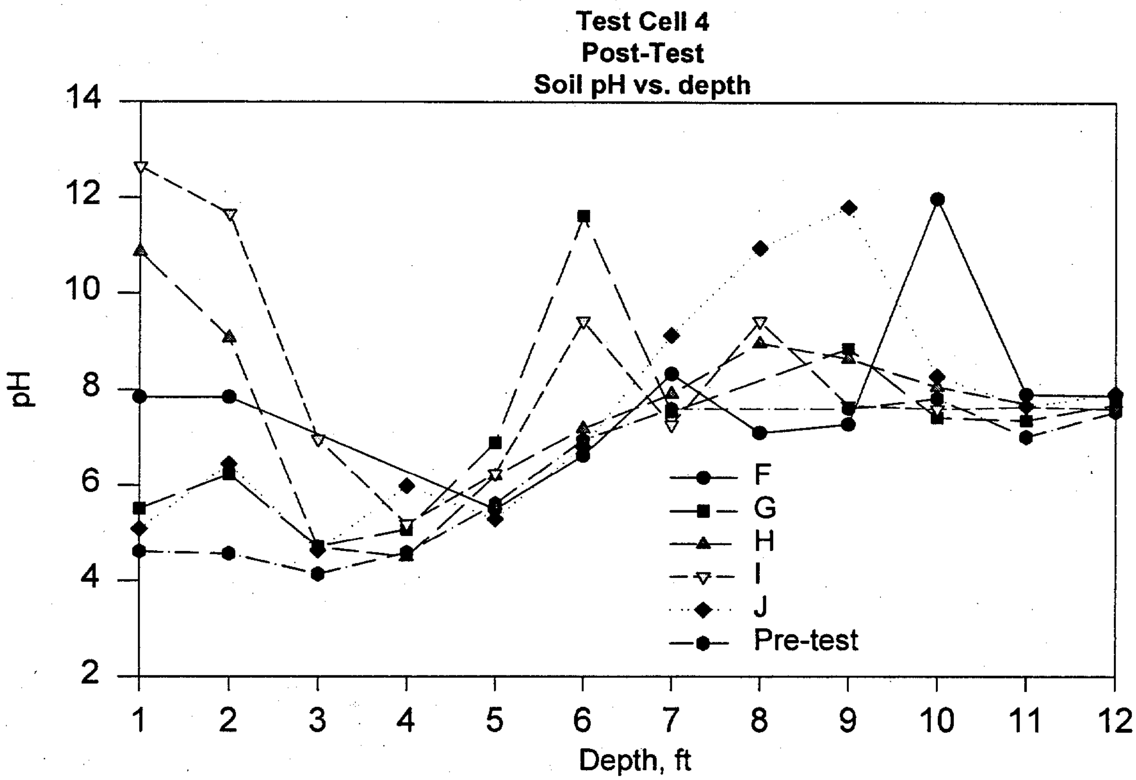


Fig. 4.17. Test cell 4 - post-treatment soil pH.

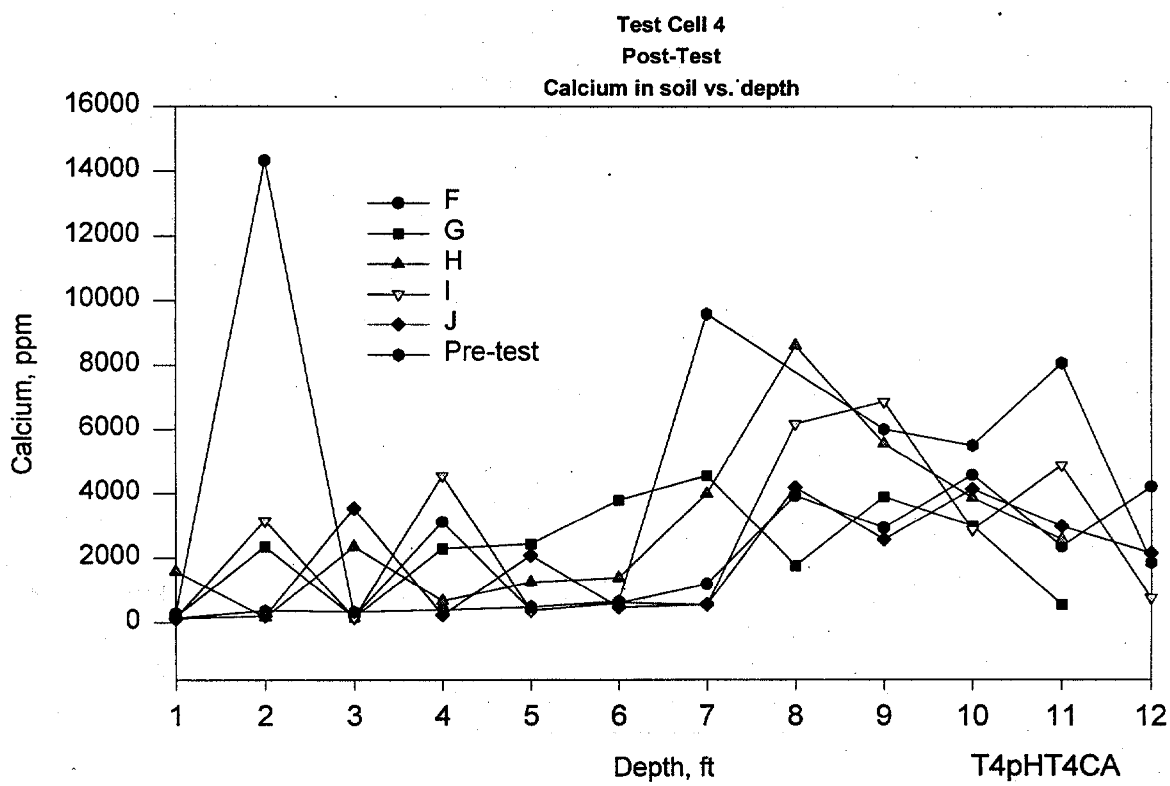


Fig. 4.18. Test cell 4 - post-treatment soil calcium levels.

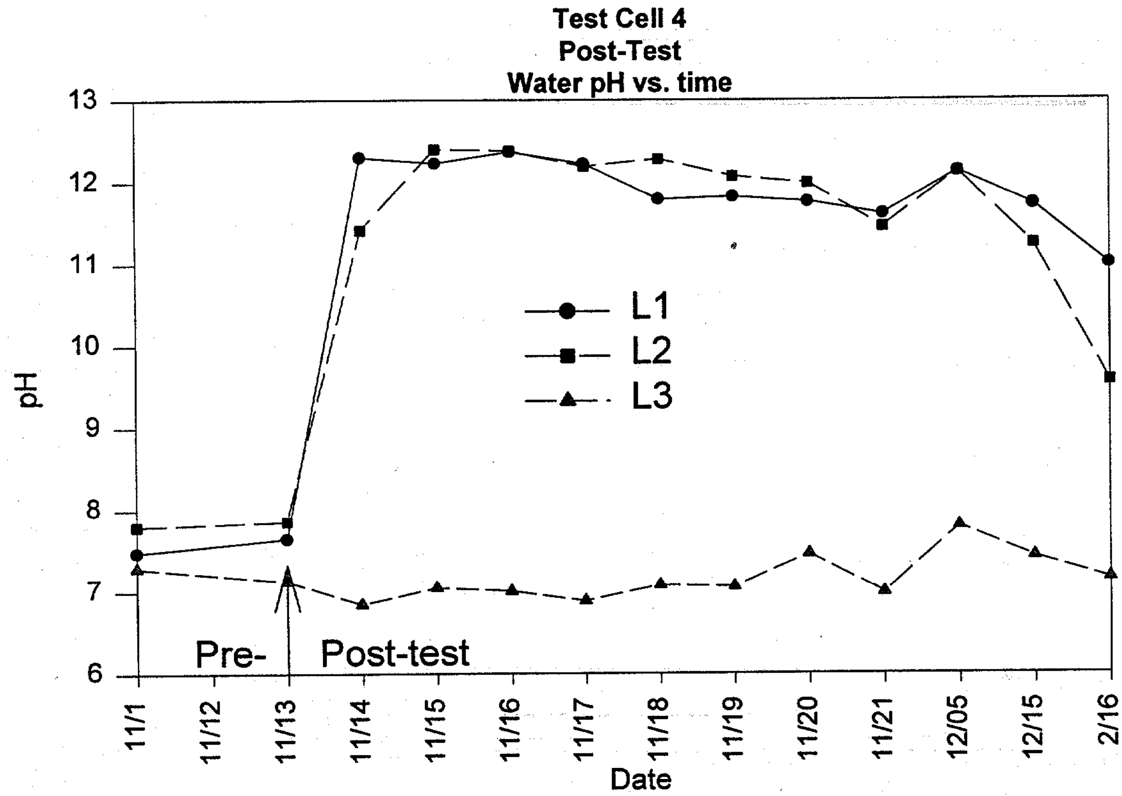


Fig. 4.19. Test cell 4 - post-treatment water pH.

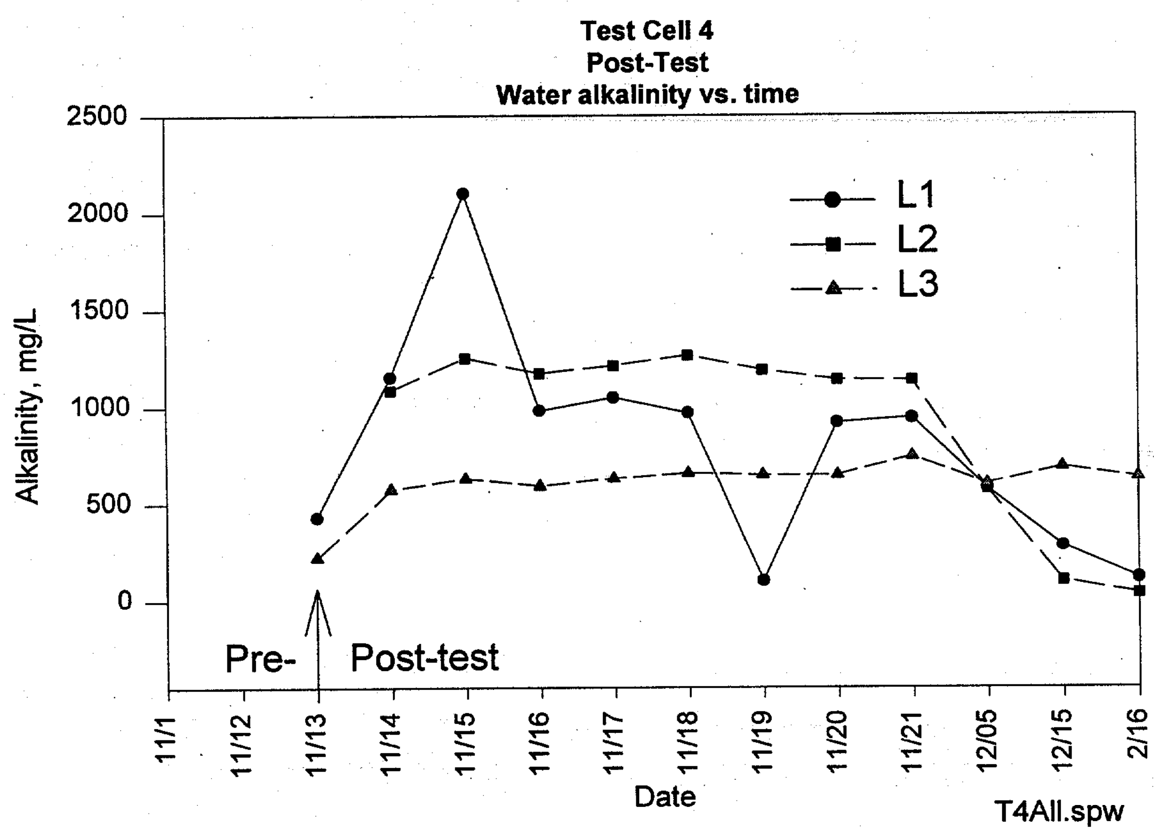


Fig. 4.20. Test cell 4 - post-treatment water alkalinity levels.

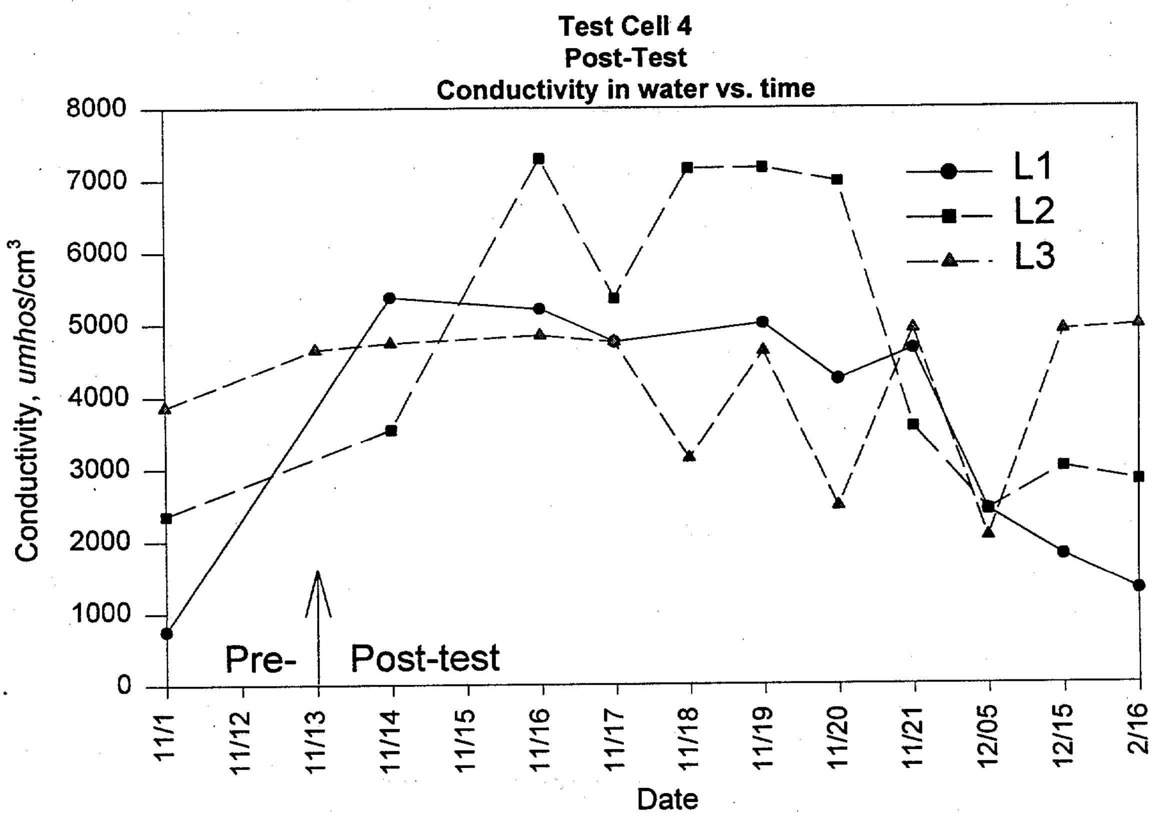


Fig. 4.21. Test cell 4 - post-treatment water conductivity levels.

T4COND

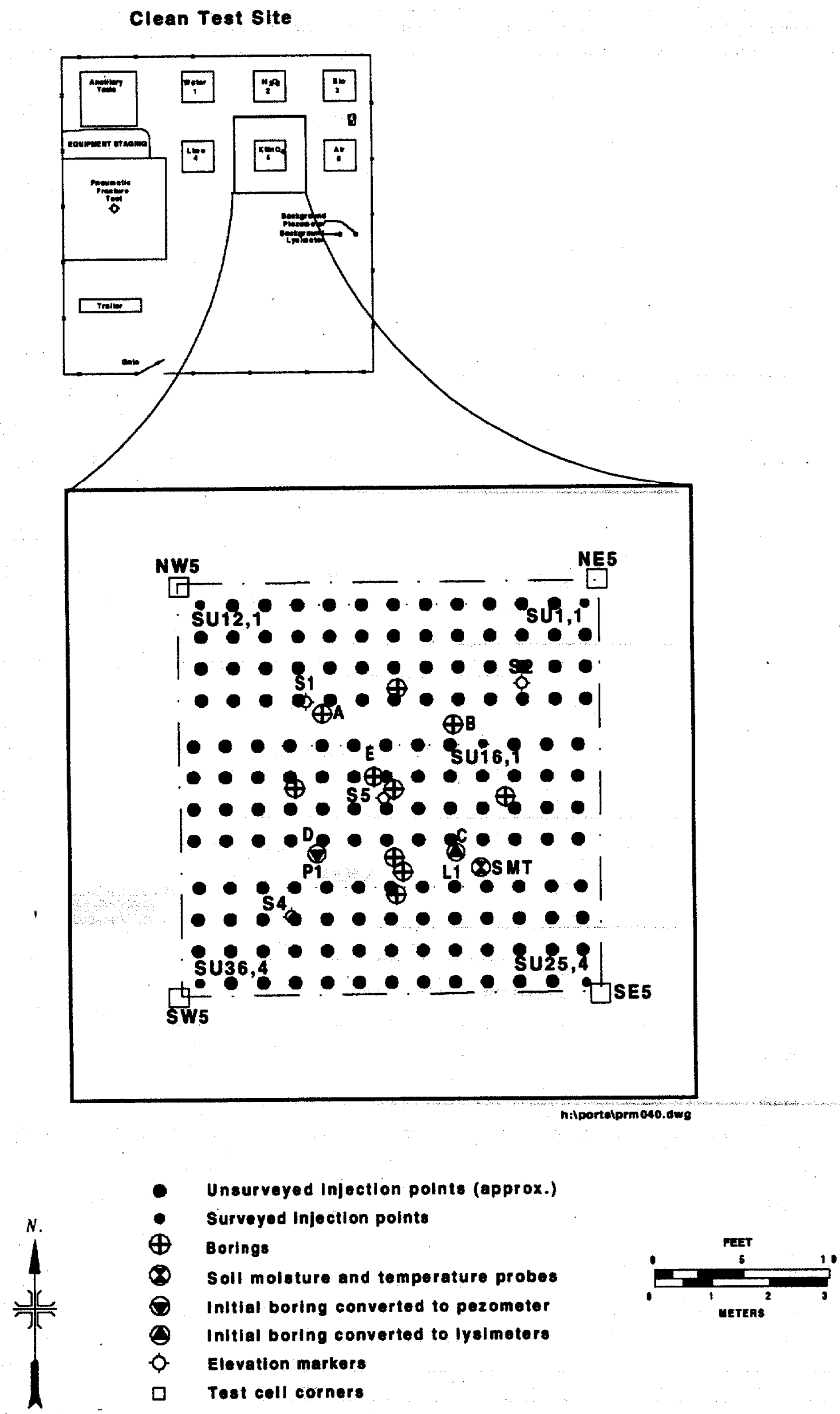


Fig. 4.22. Test cell 5 sample locations.

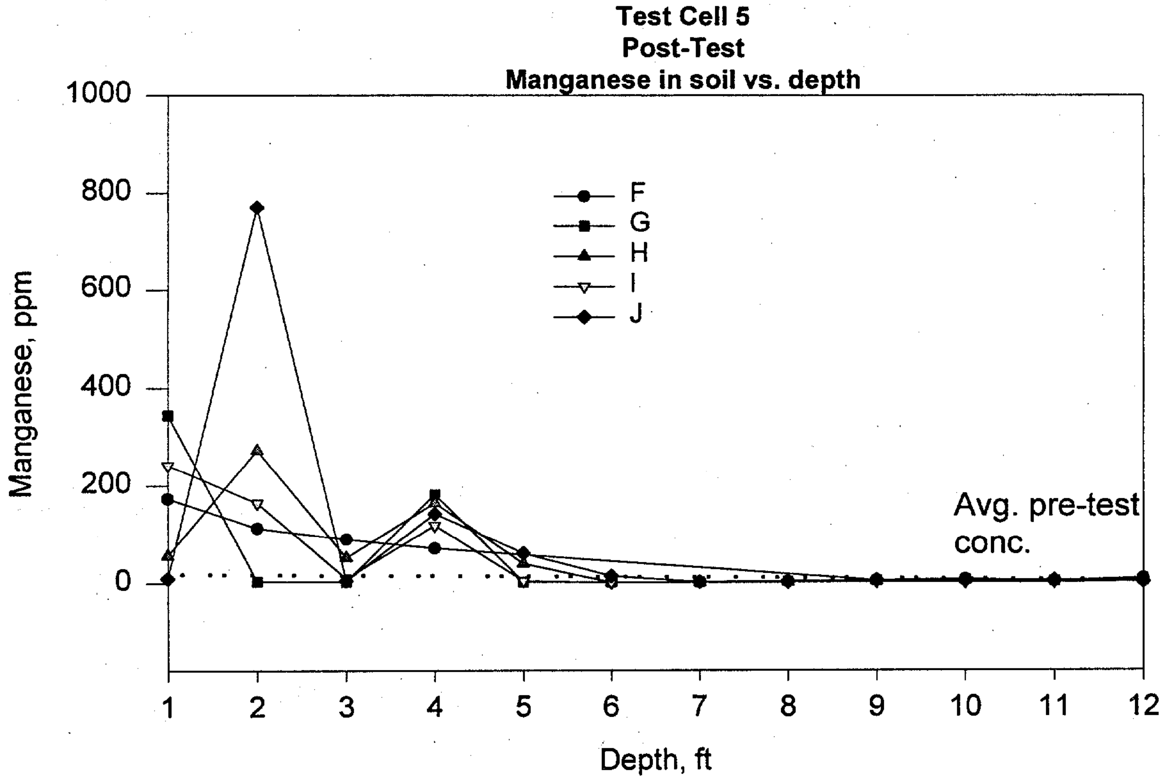


Fig. 4.23. Test cell 5 - post-treatment soil manganese levels.

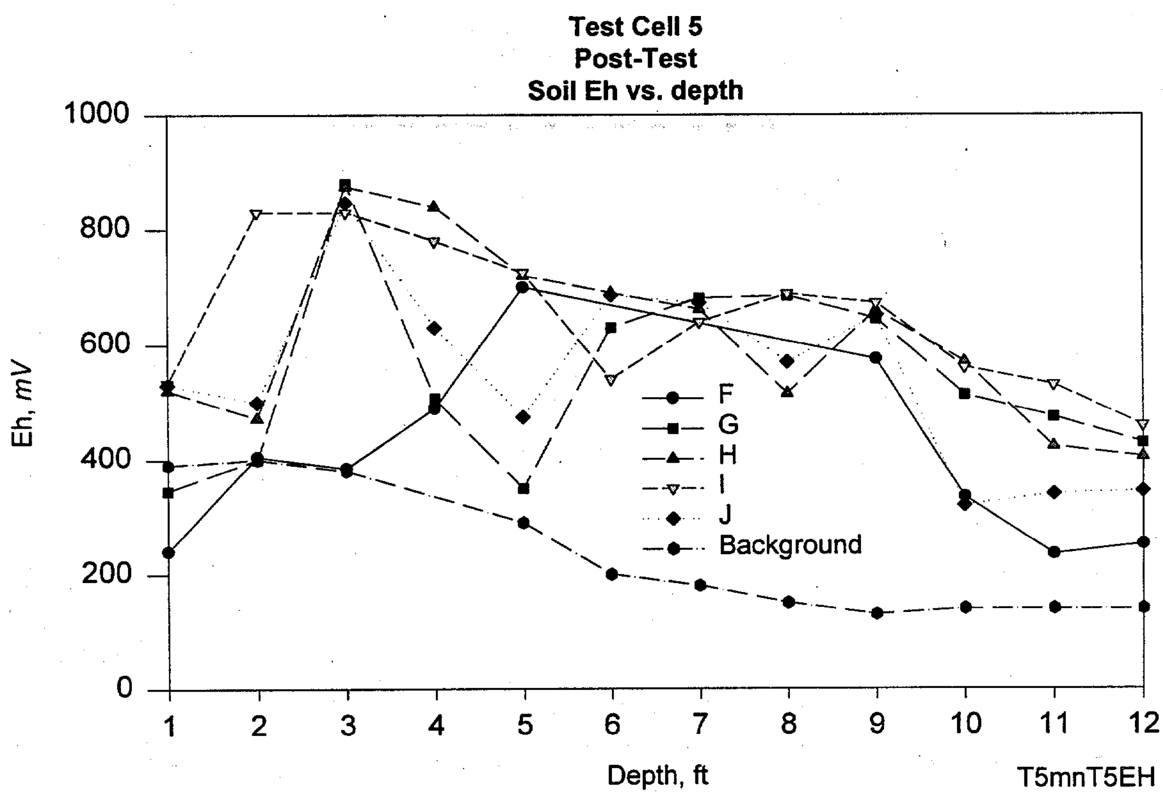


Fig. 4.24. Test cell 5 - post-treatment soil Eh levels.

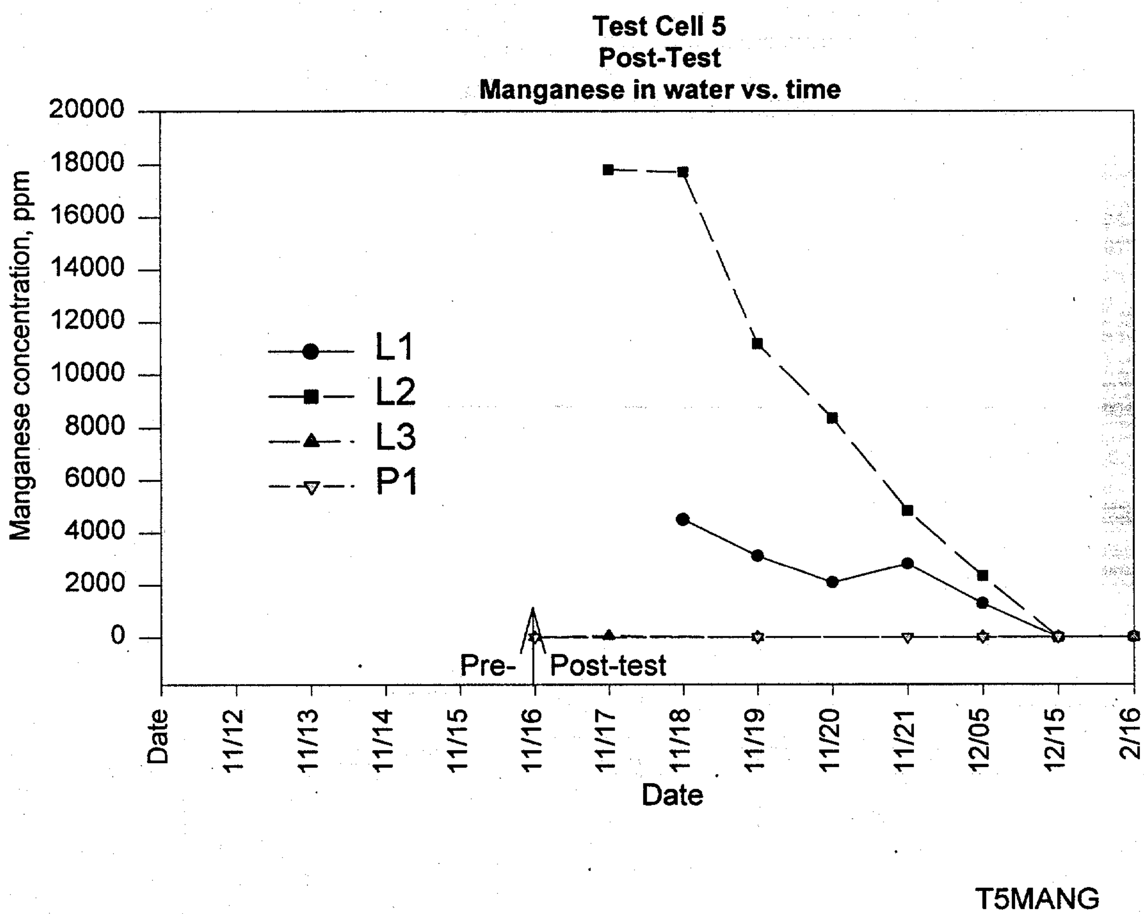


Fig. 4.25. Test cell 5 - post-treatment water manganese levels.

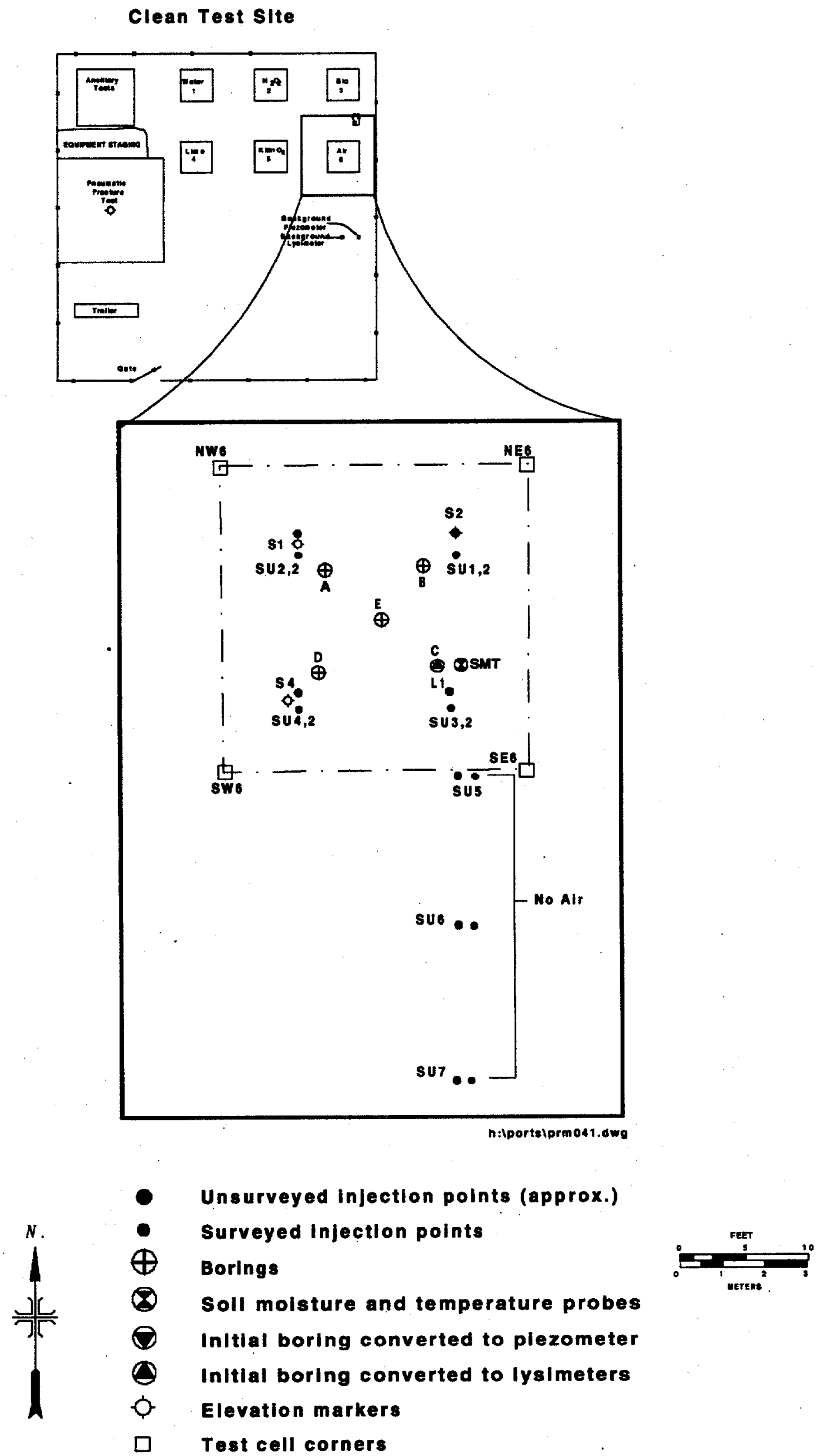


Fig. 4.26. Test cell 6 sample locations.

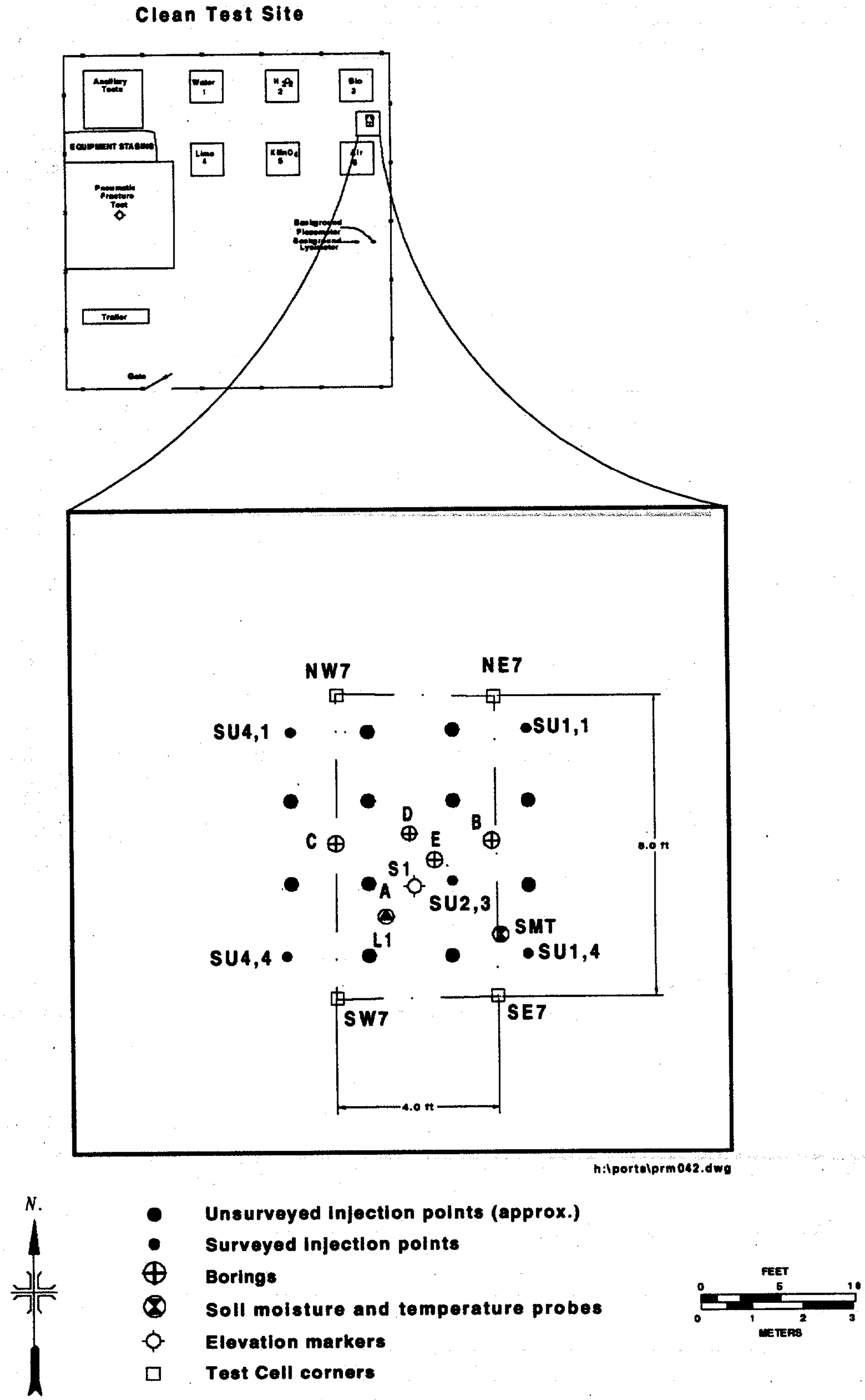


Fig. 4.27. Test cell 7 sample locations.

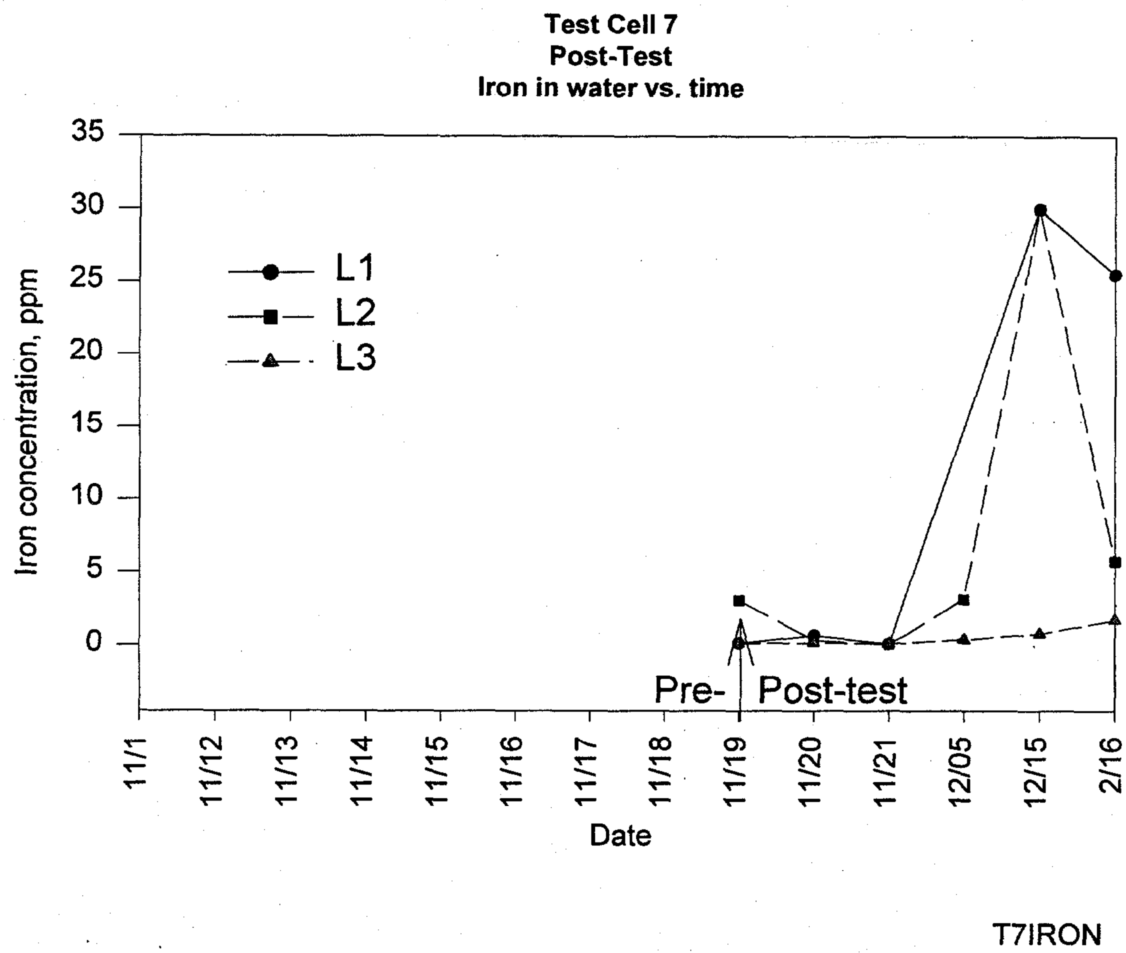


Fig. 4.28. Test cell 7 - post-treatment water iron data.

Table 4.1. Summary of background soil results

Depth, ft	Soil moisture,[a] %	Moist bulk density,[a] g/cm^3	pH[a]	Eh,[b] mV	TOC,[a] ppm
1	17	1.93	4.9	390	6397
2	18	1.66	4.5	400	1630
3	19	1.79	4.3	380	1448
4	15	1.83	4.7	--	1082
5	15	1.99	5.7	290	1021
6	16	1.96	6.5	200	995
7	18	--	6.6	180	615
8	21	2.07	7.0	150	558
9	24	1.90	7.2	130	395
10	26	1.81	7.6	140	421
11	24	1.87	7.4	140	543
12	24	1.95	7.4	140	526

[a] Values averaged from borehole E in test cells 1 through 6, from borehole A in test cell 7 and the background borehole in the shakedown area.

[b] Values from borehole 1 in the shakedown area (S1BA)

-- = No measurement taken

Table 4.2. Water sample results from background piezometer and lysimeters

Sample location	Date sampled	Temperature, °C	pH	DO, mg/L	Electrical conductivity, μmhos	Alkalinity, mg/L	Br^-, mg/L	Fe, mg/L	Mn, mg/L	Cl^-, mg/L	NO_3^-, mg/L	SO_4^{2-}, mg/L
B1L1	11/01/94	12.4	8.7		960							
	11/12/94	17.4	8.3		1112	132		0	0.25	23.3	0.1	550
	11/13/94	14.3	7.9		1250	319	1.0	0	0.25			525
	11/14/94	12.5	8.0	7.3	1390	157		0.15	0.25	15.0		
	11/15/94	13.1	7.8	3.8	1430					16.8		
	11/18/94	15.6	7.9	4.8	1440	216	0.9	0		9.5	0.4	475
	11/21/94	13.7	7.7	3.7	1520	153	0.9	0	0	11.0	0	650
	12/05/94		7.9									
	02/16/95	3.9	8.0	2.5	1076	94	0.6	0.15	0		0	
B1L2	11/01/94	12.9	8.9									
	11/12/94											
	11/13/94	15.4	7.9	3.6	2112	204	0.9	0.05	0.25			1075
	11/14/94	13.8	8.1	3.3	2190	229		0.10	0.25	10.5		
	11/15/94	14.5	7.2	4.7	2210					9.0		
	11/18/94	15.1	8.1	8.1	1430	252	0.9	0	0.30	11.2	0.1	1100
	11/21/94	13.7	7.4	2.2	2330	248	0.8	0.25	0.17	7.8	0.2	1200
	12/15/94	10.6	8.3	4.5	1130	99	0.8	0	0.18		0.1	
	02/16/95	4.9	7.7	3.4	2910	246	0.3	0	0.20			
B1L3	11/01/94	12.5	7.9		1530							
	11/12/94	20.6	7.5	2.7	1652	212		0	0.25	7.8	0	800
	11/13/94	15.6	7.4	2.8	1700	186	0.9	0.05	0.25			750
	11/14/94	14.2	7.4	4.9	1760	240		0.10	0.25	6.3		
	11/15/94	14.1	6.6	6.2	1800					6.3		
	11/18/94	15.3	8.1	4.2	1790	277	0.9	0		3.2	0.1	
	11/21/94	14.9	7.1	2.8	1700	238	0.7	0	0.17	5.2	0	750
	12/05/94		8.2			213	0.8	0.02	0.10			850
	12/15/94	12.3	8.3	11.2	2530	260	0.8	0.025	0.90			
	02/16/95	6.3	6.6	2.3	1730	218	0	0.025	0		0.1	

Table 4.2. (continued)

Sample location	Date sampled	Temperature, °C	pH	DO, mg/L	Electrical conductivity, μmhos	Alkalinity, mg/L	Br^-, mg/L	Fe, mg/L	Mn, mg/L	Cl^-, mg/L	NO_3^-, mg/L	SO_4^{2-}, mg/L
B1P1	11/01/94	12.3	7.2		1480							
duplicate	11/01/94	12.3	7.2		1480							
	11/12/94	17.2	6.6	1.9	1547	188		0.125	0.25	5.5	0.1	750
	11/13/94	16.3	7.1	4.2	1520	169	0.9	0.075	0.25			650
	11/14/94	13.9	6.6	2.6	1600	174		0.125	0.25	9.5		
duplicate	11/14/94			4.4		182				5.0		
	11/15/94	14.1	6.6	2.0	1590		0.9			5.0		
	11/18/94	15.3	6.8	2.9	1580	194	0.9	0.05	1.00	2.5	0.1	425
	11/21/94	15.0	6.1	4.9	1520	198	0.8	0.18		6.5	0	700
	12/05/94	15.3	6.9	3.1	1240	190	0.7	0.08	0.10			725
	12/15/94	15.0	7.0	4.3	1550	198	0.8	0.23	0.36			
	02/16/95	7.3	7.5	NA	1650	192	0.1	NA	0		0	

See Fig. 3.1 for boring locations.

Table 4.3. Tracer test cell (T1) soil sample results

Depth, ft	pH	Eh, mV	TOC, ppm	% Soil moisture		Bromide, ppm	INA, particles/mg
	Pre[a]	Post[b]	Pre[a]	Pre[a]	Post[b]	Post[b]	Post[b]
1	4.3	360 to 380	6258	18.0	18.3 to 24.0	4 to 11	4 to 178
2	4.4	350	1295	18.4	18.4 to 20.8	1 to 12	12 to 3543
3	4.6	390 to 460	2130	17.5	17.6 to 20.8	1 to 4	4 to 26
4	4.6	390 to 430	1471	18.0	15.7 to 17.8	2 to 7	18 to 181
5	4.8	395 to 490	1226	14.8	13.9 to 18.7	1 to 7	2 to 138
6	6.0	370 to 390	1216	17.1	14.1 to 18.4	1 to 3	3 to 16
7	7.0	280 to 350	685	15.8	15.5 to 18.2	1 to 2	1 to 9
8	--	305 to 325	--	--	15.0 to 24.0	1 to 4	0 to 20
9	7.1	320 to 340	354	24.0	23.2 to 26.3	1 to 7	0 to 34
10	7.8	295 to 305	333	25.9	23.0 to 28.3	1 to 2	0 to 1
11	7.6	305 to 330	653	25.8	21.7 to 27.5	1	0
12	7.4	275 to 330	555	27.0	25.4 to 27.3	1 to 4	0

[a] Pre-treatment results
[b] Ranges of values are from five post-treatment soil borings.
– No sample taken

Table 4.4. Water sample results for the tracer test cell (T1), injection date 11/12/95

Sample location	Date sampled	Temperature, °C	pH	DO, mg/L	Electrical conductivity, μmhos	Alkalinity, mg/L	Br^-, mg/L	Fe, mg/L	Mn, mg/L	Cl^-, mg/L	NO_3^-, mg/L	SO_4^{2-}, mg/L
T1L1	11/01/94	12.8	8.4		1270							
	11/12/94		6.6	13.9				0.075	0.25	22.50	1.0	600
	11/13/94	11.6	6.6	8.2	1311	148	83	0	0.25	OR		425
	11/15/94		7.1	6.9		220	86	0.15		OR		475
	11/16/94	12.7	6.9	6.1	1410	244	80					
	11/17/94	13.4	6.8	5.2	1700		80	0.3				
	11/18/94	14.3	6.7	5.0	1400		80					
	11/19/94	12.9	6.9	6.4	1270		80					
	11/20/94	11.7	7.0	5.2	1230		50					
	11/21/94	13.9	7.3	5.6	1130		65					
	12/05/94	12.9	8.7	12.7	1054		68					
	12/15/94	8.2	7.1	12.0	1260		45					
	02/16/95	4.0	6.5		1775		34					
	05/07/96	12.7	6.1	0.3	530							
	05/08/96	16.5	6.6	0.2	1100			0.00				
	05/09/96	16.0	5.9	0.8	520			0.07				
T1L2	11/01/94	11.7	7.7		2110							
	11/12/94	16.3	6.7							15.50	1.0	2100
	11/13/94	13.1	6.6	8.9	2250	115	95	0.25	0.25	OR		950
	11/15/94		7.3	1.7		196	99	0.25		OR		13,007
	11/16/94	14.1	7.1	1.8	4180	223	92					
	11/17/94	13.7	7.1	4.3	4220	260	89	0.05				
	11/18/94	15.4	7.0	3.1	4310		85					
	11/19/94	14.4	7.1	3.8	4230		85					
	11/20/94	13.5	6.9	3.2	4270		70					
	11/21/94	15.3	7.3	2.4	4320		68					
	12/05/94	13.9	7.9	9.3	3170		69					
	12/15/94	9.8	7.5	5.7	5100		45					
	02/16/95	5.5	6.9	10.0	5650		33					
	05/07/96	12.2	6.9	0.7	5370							
	05/08/96	13.8	7.0	1.9	5310			0.04				
	05/09/96	14.6	7.1	1.1	5150			0.18				
T1L3	11/01/94	12.1	7.7		3650							
	11/12/94	15.6	7.4	4.5	4960	540		1.08	0.75	9.75	0.2	
	11/13/94	13.0	6.9	6.5	5060	448	1.2	4.7	0.50	7.00		3050
	11/15/94		7.2	2.7		570	0.95	0.88	1.20	9.80		3050
	11/16/94	13.6	7.1	2.2	5230	592	1.0					3150
	11/17/94		7.3	3.0	5120	657	1.6	1.2				
	11/18/94	15.5	7.0	2.8	5210		4.0					
	11/19/94	12.6	7.2	2.0	5200		1.8					
	11/20/94	13.8	7.0	2.3	5100		1.6					
	11/21/94	15.0	7.3	1.6	5320		3.2					
	12/05/94	14.1	7.4		4090		1.6					
	12/15/94	11.6	7.5	2.8	5420		3.2					
	02/16/95	5.8	7.0	6.6	5380		4.2					
	05/07/96	11.8	7.2	2.3	5600							
	05/08/96	14.0	7.3	1.9	5550			0.03				
	05/09/96	16.8	7.1	1.4	9240			0.07				

Table 4.4. (continued)

Sample location	Date sampled	Temperature, °C	pH	DO, mg/L	Electrical conductivity, μmhos	Alkalinity, mg/L	Br^-, mg/L	Fe, mg/L	Mn, mg/L	Cl^-, mg/L	NO_3^-, mg/L	SO_4^{2-}, mg/L
T1P1	11/01/94	11.4	7.2		5060							
	11/12/94	16.0	6.8	5.4	5150	560		0	0	10.50	0.6	3250
	11/13/94	14.3	7.0	6.4	5340		1.0	0.125	0.50	7.25		3450
	11/15/94		6.8			601	0.9	0.1		10.30		3250
	11/16/94	13.9	6.8	5.3	5250	564	1.0					
	11/17/94	14.6	6.8	4.3	5140	602	2.0	0.02				
	11/18/94	14.9	6.8	4.6	5200		3.0					
	11/19/94	13.5	6.8	5.6	5260		2.2					
	11/20/94	13.4	6.9	2.3	4980		0.9					
	11/21/94	15.0	7.0	5.4	5170		1.6					
	12/05/94	14.5	7.1	4.6	4050		3.2					
	12/15/94	12.0	7.0		5300		3.2					
	02/16/95	5.8	7.1		5060							
	05/07/96											
	05/08/96	16.5	7.2	5.8	4850			0.02				
	05/09/96	19.0	7.0	3.9	8470			0.11				
B1P1	5/09/96	19.2	6.9	11.8	1700			0.42				
B1L1	5/09/96	20.0	8.1	2.4	450			0.05				
B1L2	5/09/96	14.8	7.7	0.7	3550			0.06				
B1L3	5/09/96	19.2	8.2	2.5	1020			0.05				

OR = over range

Table 4.5. Hydrogen peroxide test cell (T2), soil sample results

Depth, ft	pH		Eh, mV	TOC, ppm		% Soil moisture		Nitrate, ppm	Peroxide, mg/L
	Pre[a]	Post[b]	Post[b]	Pre[a]	Post[b]	Pre[a]	Post[b]	Post[b]	Post[b]
1	4.6	4.7 to 5.4	200 to 440	6107	2495 to 2896	17.6	19.5 to 23.1	0 to 3.75	0
2	4.3	4.2 to 4.7	237 to 500	1576	1747 to 1525	19.5	19.4 to 21.2	0 to 1.25	0
3	4.1	4.5 to 4.6	250 to 580	1083	1437 to 1770	17.8	16.9 to 20.5	0 to 3.75	5 to 100
4	4.6	4.8 to 4.9	340 to 490	993	1048 to 1163	15.7	15.2 to 15.4	0 to 1.20	0
5	5.9	6.1 to 6.9	170 to 440	1353	958 to 1006	16.0	12.1 to 14.7	0 to 1.25	0
6	6.9	6.5 to 7.0	180 to 410	890	976 to 1329	17.2	15.6 to 17.9	0 to 1.25	0
7	7.0	6.2 to 7.3	100 to 500	431	653 to 782	17.3	18.1 to 19.6	--	0 to 4
8	--	6.7 to 7.2	100 to 350	--	401 to 2079	--	15.9 to 22.0	0 to 1.25	0
9	7.8	7.2 to 7.5	140 to 298	288	427 to 545	24.6	22.1 to 26.5	0 to 2.50	0
10	7.7	5.5 to 7.5	194 to 460	436	543 to 630	25.0	23.0 to 27.6	--	0
11	7.8	7.1 to 7.5	205 to 420	425	608 to 771	25.8	22.1 to 27.6	0 to 2.50	0
12	7.7	7.2 to 7.4	190 to 440	640	648 to 784	21.8	20.7 to 27.0	0 to 1.25	0

[a] Pre-treatment results
[b] Ranges of values are from five post-treatment soil borings.
-- No sample taken

Table 4.6. Water sample results for the hydrogen peroxide test cell (T2), injection date 11/15/95

Sample location	Date sampled	Temperature, °C	pH	DO, mg/L	Electrical conductivity, μmhos	Alkalinity, mg/L	H_2O_2, mg/L	Fe, mg/L	Mn, mg/L	Cl^-, mg/L	NO_3^-, mg/L	SO_4^{2-}, mg/L
T2L1	11/01/94	12.7	9.0		790							
	11/15/94	14.0	8.5	8.5	1198	102		0.18	0	22.8	0	40
	11/16/94	13.9	8.1	6.1	1326	146	2500			16.5	1.3	550
	11/17/94	16.3	8.2	25.0	1380		100				1.6	
	11/18/94	16.2	7.7	25.0	792	108	30				1.8	
	11/19/94	14.5	7.3	25.0	1610	95	1				2.3	
	11/20/94											
	11/21/94	15.4	7.4	25.0	1380	114	0				2.1	
	12/05/94	13.7	8.7		1420	204	0					
	12/15/94	10.0	7.4	25.0	1750	180	0					
	02/16/95	4.5	7.0	OR	1920	194	0				1.3	
	05/07/96	13.9	6.6	11.0	1820							
	05/08/96	14.0	6.7	11.0	1920			0.00				
	05/09/96	16.5	6.5	8.6	2130			0.07				
T2L2	11/01/94	14.4	8.2		2010							
	11/14/94	14.6	7.1	4.5								
	11/15/94		7.3			265				8.0	0	2250
	11/16/94	11.5	6.9	4.4	3680		7000			6.0	12.0	2200
	11/17/94		7.6	14.0	3580	14					8.5	
	11/18/94	17.1	7.4		3550	221					4.0	
	11/19/94	14.6	7.2		3710	375	30				2.4	
	11/20/94	16.4	7.4		3880	254	1				1.8	
	11/21/94											
	12/05/94	14.5	8.9		3700	614	3					
	12/15/94	11.5	7.6		4930	860	0					
	02/16/95	4.3	7.1	OR	5460	402	0				0.6	
	05/07/96											
	05/08/96			13.0								
	05/09/96			13.0				0.05				
T2L3	11/01/94	12.6	7.5		4250							
	11/14/94	14.4	7.0	3.3	4580							
	11/15/94		7.4			685		0.1	0.25	4.0	0	2750
	11/16/94	12.1	7.0	4.0	4570	551		0		4.0	0	2600
	11/17/94	15.5	7.0	8.8	4500	576						
	11/18/94	15.5	7.4	9.3	4500	613					0	
	11/19/94	13.8	7.5	8.1	4320	625	0				0.1	
	11/20/94	14.8	7.0	5.9	4520	595					0	
	11/21/94	15.2	6.6		2390	604						
	12/05/94	14.5	8.3	11.2	3890	732	30					
	12/15/94	12.3	7.1		4610	615	0					
	02/16/95	4.8	6.8		4840	620	0				0.1	
	05/07/96	13.4	6.9	1.0	4390							
	05/08/96	14.7	7.0	4.9	4490			0.15				
	05/09/96	15.4	6.9	2.2	4540			0.85				

Table 4.6. (continued)

Sample location	Date sampled	Temperature, °C	pH	DO, mg/L	Electrical conductivity, μmhos	Alkalinity, mg/L	H_2O_2, mg/L	Fe, mg/L	Mn, mg/L	Cl^-, mg/L	NO_3^-, mg/L	SO_4^{2-}, mg/L
T2P1	11/01/94	11.6	7.4		4410							
	11/14/94	14.4	6.6	11.7	4850							
	11/15/94		6.9			570/587		0.1	0.25	4.0	0.8	3500
	11/16/94	12.7	6.8	8.0	4720	549		0		3.8	0.4	2750
	11/17/94	16.0	6.9	5.6	4700	662					1.2	
	11/18/94	15.6	6.8	4.4	4380	561					0.6	
	11/19/94	14.3	7.0	5.8	4530	560					0.6	
	11/20/94	14.4	7.2	7.1	4370	556					0.8	
duplicate	11/20/94	14.4	7.0	7.1	4370	556						
	11/21/94	15.0	6.7	5.0	2500	604					0	
	12/05/94	14.7	7.0	7.0	3700	569	0					
	12/15/94	11.6	7.0	8.7	4071	597	0					
	02/16/95	7.3	7.4		4610	560	0				0.5	
	05/07/96			4.8								
	05/08/96	14.9	7.3	5.3	4180			0.6				
	05/09/96	18.7	7.1	5.6	7410			0.13				

OR = over range

Table 4.7. Bionutrient test cell (T3), soil sample results

Depth, ft	pH		Eh, mV	TOC, ppm	% Soil moisture		Bromide, ppm	INA, particles/mg
	Pre[a]	Post[b]	Post[b]	Pre[a]	Pre[a]	Post[b]	Post[b]	Post[b]
1	4.9	5.2 to 6.2	335 to 360	7713	17.9	19.4 to 22.3	1 to 4	2 to 29
2	4.3	4.9 to 5.6	360 to 402	1851	18.2	19.5 to 20.8	1 to 4	2 to 9
3	4.2	4.9 to 5.6	350 to 400	1261	20.9	19.3 to 21.2	1 to 3	1 to 5
4	4.4	4.7 to 5.6	300 to 430	954	17.6	15.8 to 17.5	1 to 4	2 to 5
5	5.5	5.5 to 6.5	300 to 375	947	18.0	13.6 to 19.2	0 to 3	0 to 8
6	6.5	6.5 to 6.8	250 to 295	1062	15.0	12.7 to 20.7	0 to 1	0 to 1
7	6.2	6.7 to 6.9	180 to 275	836	12.7	17.8 to 19.4	1 to 7	0 to 9
8	7.0	6.4 to 6.8	160 to 270	304	21.8	21.2 to 23.7	1 to 4	0 to 9
9	7.5	7.1 to 7.5	180 to 263	498	27.0	23.9 to 26.0	1 to 4	0 to 1
10	7.8	7.1 to 7.5	190 to 240	613	27.0	21.2 to 26.1	0 to 1	0
11	7.4	6.7 to 7.4	195 to 210	432	26.7	24.6 to 25.7	0 to 1	0
12	7.1	6.5 to 7.0	190 to 200	337	20.0	23.2 to 23.8	0 to 1	12

[a] Pre-treatment results
[b] Ranges of values are from five post-treatment soil borings.

Table 4.8. Bionutrient test cell (T3) heterotrophic enumerations, cells/g

	Aerobic		Anaerobic	
Location/Time	4 ft depth	10 ft depth	4 ft depth	10 ft depth
T1/Pretest	>1,100,000	2400	100	10
T2/Pretest	>1,100,000	3900	10	10
T3/Pretest	>1,100,000	2400	1000	10
T3-G/3 days after injection	15,000 (2800 fungal)[a]	240	10	1
T1-J /3 days after injection	3000	ng[b]	10	ng
T3-J /3 days after injection	46,000 (750 fungal)	240	1	ng
T1-K/30 days after injection	230	230	ng	100
T1-L/30 days after injection	230	23	10	10
T3-K/30 days after injection	23,000	23	ng	10
T3-L/30 days after injection	230	23	ng	ng

[a] fungal growth observed in serial dilutions in addition to bacterial growth.
[b] ng = no growth observed.

Note: sample results shown are two week observations, while the "ng" results are four week observations.

Source: Pfiffner 1994.

Table 4.9. Water sample results for the bionutrient test cell (T3), injection date 11/18/95

Sample location	Date sampled	Temperature, °C	pH	DO, mg/L	Electrical conductivity, μmhos	Alkalinity, mg/L	Br^-, mg/L	Fe, mg/L	Mn, mg/L	Cl^-, mg/L	NO_3^-, mg/L	SO_4^{2-}, mg/L
T3L1	11/01/94	13.2	8.5		800							
	11/19/94	14.8	7.2		1550	323	50	1.40	0.86	55.0	1.4	250
	11/20/94	12.6	7.7	3.7	1490	298	55		0.50	60.0	1.2	450
	11/21/94	14.3	7.7	4.9	1490	228	62				0.7	
	12/05/94	13.4	8.5		1066	240	60					
	12/15/94	9.7	7.1	12.0	1290	188	46.3					
	02/16/95	5.1	6.6	2.1	1040	202	23.1				0.3	
	05/07/96	13.0	6.4	0.8	990							
	05/08/96			2.8				0.59				
	05/09/96	16.1	6.4	0.8	1380			OR				
T3L2	11/01/94	13.5	8.0		1650							
	11/19/94	14.7	7.8		1790	196	9.7	0.20	0	36.2	1.3	2375
	11/20/94	13.6	7.5	3.7	3500	194	55	0.15		54.0	1.6	2125
	11/21/94	15.2	7.6	7.0	3910	211	78				1.6	
	12/05/94	14.6	8.3		3310	218	75					
	12/15/94	11.9	7.4	3.3	4750	270	9.9					
	02/16/95	5.8	7.0	2.2	4280	316	20.4				0.3	
	05/07/96			1.7								
	05/08/96											
	05/09/96	15.6	7.2	3.2	4430			0.37				
T3L3	11/01/94	12	7.4		3110							
	11/18/94	14.1	6.9	1.6	4190	517	0.9	0.12	8.80	3.2	0.1	2625
	11/19/94	9.3	7.0	6.4	4630	530	0.9	0.25	1.15	3.0	0.1	2375
	11/20/94	13.7	7.1	3.0	4390	518	0.8	0.28		3.0	0.1	2750
	11/21/94	15	7.1	4.2	4470	513	1				0.1	
	12/05/94	14.3	7.5	5.3	3260	480	8.5					
	12/15/94	12.9	7.7	10.9	4550	520	4.7					
	02/16/95	6.6	6.9	0.6	4060	486	5.1				0.1	
	05/07/96	14.4	6.8	0.5	4790							
	05/08/96											
	05/09/96	16.4	6.8	3.2	5020			2.69				

Table 4.9. (continued)

Sample location	Date sampled	Temperature, °C	pH	DO, mg/L	Electrical conductivity, μmhos	Alkalinity, mg/L	Br^-, mg/L	Fe, mg/L	Mn, mg/L	Cl^-, mg/L	NO_3^-, mg/L	SO_4^{2-}, mg/L
T3P1	11/18/94	14.6	6.7	5.0	3240	410	0.9	0.20	2.00	5.2	0.3	1375
	11/19/94											
	11/20/94	11.9	7.3	5.4	3710	395	0.8	0.33			0.1	2000
	11/21/94	15.3			3540	388	0.9				0.1	
	12/05/94	14.7	6.9	2.5	3050	387	0.9					
	12/15/94	14.1	7.0		3960	420	0.96					
	02/16/95	7.8	7.0		4180	430	1.3				0.1	
	05/07/96	16.1	6.7	3.0	3800							
	05/08/96	17.8	6.9	2.9	3930			2.95				

OR - over range

Table 4.10. Lime slurry test cell (T4), soil sample results

Depth, ft	pH		Eh, mV	Ca, ppm		TOC, ppm	% Soil moisture	
	Pre[a]	Post[b]	Post[b]	Pre[a]	Post[b]	Pre[a]	Pre[a]	Post[b]
1	4.6	5.1 to 12.6	360 to 380	128	121 to 1584	6933	16.0	18.6 to 20.4
2	4.6	6.2 to 11.7	350	365	159 to 14,322	1707	17.8	17.8 to 20.1
3	4.1	4.6 to 7.0	390 to 460	322	136 to 3533	1724	21.1	20.1 to 22.4
4	4.6	4.5 to 6.0	390 to 430	378	225 to 4545	977	16.8	17.4 to 20.6
5	5.6	5.3 to 6.9	395 to 490	475	355 to 2410	889	14.6	15.0 to 20.1
6	7.0	6.6 to 11.6	370 to 390	645	464 to 3787	1187	15.3	17.3 to 21.5
7	7.6	7.3 to 9.1	280 to 350	9575	526 to 4545	420	23.8	20.2 to 22.9
8	--	7.1 to 11.0	305 to 325	--	3925 to 8607	--	--	23.0 to 25.6
9	7.6	7.3 to 11.8	320 to 340	6000	1750 to 6859	412, 430	24.0	22.3 to 27.1
10	7.8	7.4 to 12.0	295 to 305	3500	2852 to 4573	305, 412	26.9	22.9 to 26.9
11	7.0	7.3 to 7.9	305 to 330	8075	2341 to 4885	305	23.2	23.4 to 47.6
12	7.5	7.6 to 7.9	275 to 330	1838	549 to 4200	821	25.3	22.7 to 26.2

[a] Pre-treatment results
[b] Ranges of values are from five post-treatment soil borings.
-- No sample taken

Table 4.11. Water sample results for the lime slurry test cell (T4), injection date 11/13/95

Sample location	Date sampled	Temperature, °C	pH	DO, mg/L	Electrical conductivity, μmhos	Alkalinity, mg/L	Fe, mg/L	Mn, mg/L	Cl^-, mg/L	SO_4^{2-}, mg/L
T4L1	11/01/94	13.2	7.5		750					
	11/13/94	11.6	7.7			430	0.15	0.25		
	11/14/94	12.3	12.3	6.5	5380	1150			23.3	425
	11/15/94		12.2	7.4		2100			29.8	180
	11/16/94	13.4	12.4	5.1	5210	980				175
	11/17/94	14.4	12.2	3.1	4750	1047				
	11/18/94		11.8			968				
	11/19/94	12.9	11.8	3.1	5000	100				
	11/20/94	13.5	11.8	3.4	4230	918				
	11/21/94	15.0	11.6	1.8	4650	942				
	12/05/94	13.2	12.1	11.7	2420	574				
	12/15/94	10.6	11.7	3.5	1790	280				
	02/16/95	13.8	11.0	3.1	1305	113				
	05/07/96	14.2	7.7	1.4	1980					
	05/08/96	15.3	9.2	0.3	2100		0.21			
	05/09/96	17.5	8.2	1.0	2450		0.41			
T4L2	11/01/94	14.4	7.8		2350					
	11/13/94	12.8	7.9						20.0	1500
	11/14/94	14.4	11.4	12.0	3550	1084		0.75	17.8	1600
	11/15/94		12.4	5.0		1250	0.23		22.5	2125
	11/16/94	14.8	12.4	6.3	7300	1170				1500
	11/17/94	15.1	12.2	2.7	5360	1210				
	11/18/94	16.2	12.3	2.6	7160	1262				
	11/19/94	14.1	12.1	3.1	7170	1187				
	11/20/94	14.4	12.0		6980	1138				
	11/21/94	15.8	11.5	2.9	3580	1136				
	12/05/94	13.2	12.1	11.7	2420	574				
	12/15/94	12.6	11.3	7.9	3010	100				
	02/16/95	4.7	9.6	3.2	2820	33				
	05/07/96	13.9	6.9	2.1	4660					
	05/08/96	13.5	9.0	3.0	3910		0.23			
	05/09/96			7.4			0.18			

Table 4.11. (continued)

Sample location	Date sampled	Temperature, °C	pH	DO, mg/L	Electrical conductivity, μmhos	Alkalinity, mg/L	Fe, mg/L	Mn, mg/L	Cl^-, mg/L	SO_4^{2-}, mg/L
T4L3	11/01/94	12.8	7.3	2.0	3860					
	11/13/94	14.1	7.1	3.1	4650	220	0.08	0.25	6.0	2600
	11/14/94	10.3	6.9	5.2	4740	570	0.13	0.25	7.0	2700
	11/15/94		7.1	1.9		626	0.05		6.8	3250
	11/16/94	14.1	7.0	1.9	4840	588				2900
	11/17/94	14.9	6.9	3.3	4750	627				
	11/18/94	15.5	7.1	4.1	3140	655				
	11/19/94	13.7	7.1	9.2	4620	646				
	11/20/94	14.4	7.5	2.2	2470	645				
	11/21/94	15.4	7.0	12.5	4920	741				
	12/05/94	14.0	7.8	4.6	2050	598				
	12/15/94	12.5	7.4	1.4	4900	685				
	02/16/95	6.6	7.2		4960	631				
	05/08/96	14.7	7.1	1.4	4740		0.01			
	05/09/96	16.3	6.8	1.5	4830		0.07			

Table 4.12. Potassium permanganate test cell (T5), soil sample results

Depth, ft	pH		Eh, mV	TOC, ppm	% Soil moisture		Manganese, ppm
	Pre[a]	Post[b]	Post[b]	Pre[a]	Pre[a]	Post[b]	Post[b]
1	4.7	4.7 to 5.3	240 to 533	3483	15.7	17.4 to 20.8	9 to 344
2	4.7	4.4 to 4.8	400 to 830	1295	19.0	19.3 to 20.8	4 to 770
3	4.3	4.4 to 4.9	385 to 880	1103	16.9	14.8 to 21.4	3 to 89
4	4.7	4.4 to 5.0	490 to 840	1108	12.3	14.1 to 17.4	71 to 181
5	6.7	6.0 to 7.1	350 to 725	989	18.4	12.7 to 17.0	0 to 60
6	7.1	6.8 to 7.0	540 to 690	405	19.8	17.1 to 19.2	0 to 14
7	6.2	6.7 to 7.2	639 to 680	286	21.5	18.6 to 19.7	0 to 1
8	7.8	7.4 to 7.6	515 to 688	367	24.4	21.6 to 24.2	0 to 3
9	7.5	6.8 to 7.7	575 to 672	381	25.3	25.1 to 25.9	1 to 5
10	7.7	6.9 to 7.6	320 to 570	396	26.3	26.1 to 27.4	1 to 7
11	7.6	7.3 to 7.6	235 to 530	492	27.8	19.9 to 27.1	1 to 6
12	6.9	7.4 to 8.0	252 to 460	630	22.5	22.7 to 26.9	2 to 10

[a] Pre-treatment results

[b] Ranges of values are from five post-treatment soil borings.

Table 4.13. Water sample results for the potassium permanganate test cell (T5), injection date 11/16/94

Sample location	Date sampled	Temperature, °C	pH	DO, mg/L	Electrical conductivity, μmhos	Alkalinity, mg/L	Fe, mg/L	Mn, mg/L	Cl^-, mg/L	NO_3^-, mg/L	SO_4^{2-}, mg/L
T5L1	11/01/94	13.1	7.6		760						
	11/16/94	12.1	7.3		1560				21.8		
	11/17/94										
	11/18/94	15.0	6.4			240		4500			
	11/19/94	14.2	6.6		4270	200		3112			
	11/20/94	14.3	6.6		2200	314		2086			
	11/21/94	15.0	6.0		4260	353		2797			
	12/05/94	13.7	7.6		2850	372		1282			
	12/15/94	11.0	6.8		2610	480		0			
	02/16/95	4.1	6.5	3.2	2210	626		0			
	05/07/96	13.6	6.2	1.7	1700						
	05/08/96	14.2	6.4	0.9	1580		0.02				
	05/09/96	15.2	6.2	0.6	1590		0.07				
T5L2	11/01/94	15.1	8.1		1650						
	11/16/94	13.5	7.4	4.7	3280						
	11/17/94		7.0			545		17,800			
	11/18/94	15.6	7.3			250		17,700			
	11/19/94	14.9	7.2		1241	279		11,180			
	11/20/94	14.5	7.6		1027	298		8362			
	11/21/94	15.6	6.7		7800	335		4831			
	12/05/94	14.1	7.7		4700	450		2329			
	12/15/94	12.7	7.4		4920	474		0			
	02/16/95	5.8	7.3	11.6	4980	527		10.6			
	05/07/96	12.7	6.9		4990						
	05/08/96	14.7	7.2	0.5	4910		0.09				
	05/09/96	14.9	7.0	1.2	5160		0.25				

Table 4.13. (continued)

Sample location	Date sampled	Temperature, °C	pH	DO, mg/L	Electrical conductivity, μmhos	Alkalinity, mg/L	Fe, mg/L	Mn, mg/L	Cl^-, mg/L	NO_3^-, mg/L	SO_4^{2-}, mg/L
T5L3	11/01/94	12.9	7.4		3010						
	11/16/94	13.5	7.1	6.0	4320	530	0	0.6	7.8	0.1	2050
duplicate	11/16/94		7.2						6.5		
	11/17/94		7.0			523		50.4	8.0		2750
	11/18/94	15.0	6.9			568					
	11/19/94	15.0	7.4	3.5	4420	294		1.75			
	11/20/94	14.6	7.2	2.3	4660	578					
	11/21/94	15.5	6.5	0.9	4660	560					
	12/05/94	14.2	7.3	6.4	3810	603		6.6			
	12/15/94	13.0	7.0	2.5	4830	588		4.89			
	02/16/95	6.7	6.8	4.3	4710	570		0			
	05/07/96	12.9	6.9	1.4	4420						
	05/08/96	15.0	7.0	4.2	4330		0.07				
	05/09/96	17.4		1.5	4520		0.14				
T5P1	11/01/94	11.6	7.1		4370						
	11/16/94	13.7	6.7	5.7	4860	570	0.1	0	4.0	0.2	
	11/17/94		6.9			545	0		5.3		2650
	11/18/94	15.5	7.5			570					2800
	11/19/94	15.3	6.8		2500	249		0.4			
	11/20/94	14.6	7.0	6.1	4270	525					
	11/21/94	15.5	6.7	12.8	960	98		0.34			
	12/05/94	14.5	6.8	4.7	3760	562		0			
	12/15/94	12.9	7.0		5040	587		8.14			
	02/16/94	7.0	7.4		4780	565					
	05/07/96			8.3							
	05/08/96	17.0	7.1	4.6	4350		0.00				
	05/09/96	19.8	6.8	3.2	4690		0.25				

Table 4.14. Water sample results for air test cell (T6), injection date 11/19/94

Sample location	Date sampled	Temperature, °C	pH	DO, mg/L	Electrical conductivity, μmhos	Alkalinity, mg/L	Fe, mg/L	Mn, mg/L	Cl^-, mg/L	NO_3^-, mg/L	SO_4^{2-}, mg/L
T6L1	11/01/94	dry									
	11/19/94	dry									
	11/20/94	dry									
	11/21/94	dry									
	12/05/94	dry									
	12/15/94	13.0	8.3								
	02/16/95	dry									
	05/07/96	15.3	6.3	4.7	430						
	05/08/96	15.5	6.4	1.8	430		0.13				
	05/09/96	15.8	6.1	2.6	450		0.24				
T6L2	11/01/94	dry									
	11/19/94	11.5	7.4		1380	275	0.12	0.4	13.5	0.2	500
	11/20/94	dry									
	11/21/94	15.5	7.2	6.1	1350						
	12/05/94	dry									
	12/15/94	13.0		4.0	2230						
	02/16/95	7.5	8.0	8.7	2190						
	05/07/96										
	05/08/96	14.3	7.3	2.7	1310		0.37				
	05/09/96	15.0	7.3	2.9	1600		0.30				
T6L3	11/01/94	12.9	7.8		1720						
	11/19/94	13.0	7.4	2.9	1300	258	0.12	0.7	5.8	0	875
	11/20/94	13.6	7.3	3.8	1170	271	0.18	1.55	3.8	0.1	975
	11/21/94	15.1	6.7		1070						
	12/05/94	14.2	7.3	1.7	884						
	12/15/94	13.0		4.0	2230						
	02/16/95	6.4	7.3	3.4	1938						
	05/07/96	14.4	7.0	2.8	520						
	05/08/96	17.1	7.3	4.5	460		0.01				
	05/09/96	17.6	7.1	3.4	520		0.04				

Table 4.15. Iron micropowder test cell (T7), soil sample results

Depth, ft	pH		Eh, mV	TOC, ppm	Iron, ppm
	Pre[a]	Post[b]	Post[b]	Pre[a]	Post[b]
1	6.5	5.4 to 5.5	330 to 380	6893	3.0 to 3.5
2	4.6	5.7 to 6.4	380 to 390	1903	13.1 to OR
3	4.7	5.2 to 5.4	410 to 420	1110	0.9 to 29.5
4	4.9	5.5 to 5.6	370 to 380	1277	0.5 to 1.2
5	6.4	5.5 to 6.3	270 to 280	866	2.3 to 32.8
6	6.7	6.4 to 6.4	210 to 240	1631	1.0 to 1.0
7	6.5	6.4 to 6.5	200 to 230	531	2.4 to 3.5
8	7.4	6.4 to 6.6	150 to 200	385	0.9 to 1.2
9	7.0	6.8 to 7.1	150 to 180	383	0.2 to 1.2
10	6.9	6.5 to 6.7	135 to 165	394	1.2 to 1.7
11	6.9	6.6 to 6.8	140 to 165	033	1.3 to 1.8
12	7.7	6.1	170	393	1.4 to 3.2

[a] Pre-treatment results
[b] Ranges of values are from five post-treatment soil borings.
OR = over range

Table 4.16. Water sample results for iron micropowder test cell (T7), injection date 11/19/94

Sample location	Date sampled	Temperature, °C	pH	DO, mg/L	Electrical conductivity, μmhos	Alkalinity, mg/L	Br^-, mg/L	Fe, mg/L	Mn, mg/L	Cl^-, mg/L	NO_3^-, mg/L	SO_4^{2-}, mg/L
T7L1	11/01/94	12.7	8.8		460							
	11/19/94	9.2	7.6		860	200		0.1	0.4	34.0	1.1	150
	11/20/94	12.0	7.9		790	163	0.9	0.7		3.7	1.1	188
	11/21/94	15.4	7.2	6.5	590			0.1				188
	12/05/94											
	12/15/94	11.6	6.6	10.4	795			OR	2.0			
	02/16/95	4.0	6.2	11.0	833			25.5	2.7			
	05/07/96	14.7	6.1	1.8	430							
	05/08/96	15.8	5.9	1.2	280			2.98				
	05/09/96	15.9	5.9	1.0	490			OR				
T7L2	11/01/94	14.7	9.0		1030							
	11/19/94	9.1	8.0		820	188		3.1	0.4	10.5	0.6	330
	11/20/94	13.0	8.0	5.2	1000	173	0.7	0.3	0.2	11.2	0.2	900
	11/21/94	15.8	7.4	3.3	1610			0.1	0.2			700
	12/05/94	14.8	7.3	11.5	1381			3.2	0.5			850
	12/15/94	12.7	6.9	3.0	2580			OR				
	02/16/95	4.8	7.3	5.6	1913			5.8				
	05/07/96	13.7	7.2	0.9	2140							
	05/08/96	13.7	7.2	1.2	2120			OR				
	05/09/96	16.4	7.2	2.4	2000			OR				

Table 4.16. (continued)

Sample location	Date sampled	Temperature, °C	pH	DO, mg/L	Electrical conductivity, μmhos	Alkalinity, mg/L	Br^-, mg/L	Fe, mg/L	Mn, mg/L	Cl^-, mg/L	NO_3^-, mg/L	SO_4^{2-}, mg/L
T7L3	11/01/94	13.0	7.6		2780							
	11/19/94	13.0	7.3	1.6	3520	380		0.1	1.6	4.0	0.1	900
	11/20/94	13.3	7.3	3.1	2090	451	0.7	0.2	2.2	3.2	0.6	2432
	11/21/94	15.1	6.8	9.4	3620			0.1	2.0			2375
	12/05/94	14.8	8.5					0.4	1.5			
	12/15/94	13.2	7.2	4.9	4390			0.8	3.3			
	02/16/95	5.8	7.0	1.7	4350			1.8	1.3			
	05/07/96	14.1	6.9	1.0	3840							
	05/08/96	14.8	7.1	3.5	3740			0.06				
	05/09/96	17.1	6.9	2.3	3920			0.16				

OR = over range
Blanks indicate insufficient sample volume for analyses

5. Equipment Operations Observations

One of the objectives of this field test was to determine the operational characteristics of the MPIS process. This objective was accomplished by observation and documentation during the field tests. Observations included injection volumes, flow rates, back pressure, general equipment operations, and operational and maintenance problems.

The average volume of fluid injected into the soil at the CTS was about 0.27 gal/ft^3, calculated in the following way:

7,030 ft^3 = cell volume (effective treated cell size of 26 ft x 26 ft x 10.4 ft),
1900 gal = average volume injected (2300 gal per test cell minus 400 gal lost to surface seepage)
0.27 gal/ft^3 = 1900 gal/7,098 ft^3.

The approximate volume of the air-filled pores within each test cell prior to injection was estimated at about 2,000 gal or 270 ft^3. This was in part, the basis for the target injection volume. If the injected fluid, which equaled approximately 1900 gal, entered the air filled pores, then the soil within each test cell should have been 100% saturated after injection. Post-treatment soil sample data indicate that the soil was not uniformly 100% saturated; thus, some of the injected fluid must have moved outside of the test cell boundaries along fractures and other preferred flow paths.

Although the average injection pressure was about 100 psi, it fluctuated between 60 and 200 psi depending on the resistance of the soil to injection. This injection pressure range is similar to that used during a previous conventional soil fracturing test conducted at the CTS and may have had similar effects (i.e., creating fractures in the fine-grained media). During fluid injection, the flow rates varied from 15 to 40 gal/min, again depending on the resistance of the soil to injection. Activities performed, production rates, and total time for each major activity are shown on Table 5.1.

Based on the work conducted, it appears that the system is capable of delivering approximately 2 gal of reagent per injector per 15-in. interval to a depth of 10.4 ft in about 5 to 6 min per injection location. The cost per day for subcontractor equipment and labor was approximately $1300 (1994 cost). The equipment is capable of delivering reagent to between 10,500 and 16,000 ft^3 of soil in an 8-h work day. Thus, the cost per cubic foot of soil at the CTS was between $0.12/ft^3 and $0.08/ft^3 ($3.24 to $2.16/cubic yard). The cost for reagents varied considerably, depending on the particular chemical, the purity, and the desired concentration of the injected solution. Extrapolation of these costs to a contaminated site would require a multiplier to account for additional operating requirements such as waste management, a higher level of worker protection, and other issues.

During the injections, several operational requirements were noted. The machine operates by performing an injection and then backing up 2 ft to start the next injection. Because the solution delivery hose connects to the back of the machine, the hose must be moved manually so the machine does not run over it. Much time can be spent in mixing reagent solutions and the injection progresses much more rapidly if enough solution is mixed to inject the entire area to be treated prior to starting the injection. This could require mixing almost 5,000 gal of solution for a full day of injection activities. The individual injector ports can clog with soil very easily when stop-and-go injection is performed. It is prudent to check the injector ports aboveground occasionally to see if all injectors are open. If there are clogged ports, they can be easily cleared with a piece of wire. If work is being conducted in a contaminated area, some means of containing any seepage to the ground surface should be in place prior to the start of injection to prevent spreading contamination in runoff from the injected site. This could be accomplished with a shallow trench, filter booms, and/or silt fencing. Work can be conducted in relatively restricted surroundings as the equipment is highly maneuverable and is capable of angled injections.

Generally speaking, the MPIS provides a rapid means of injecting reagent into the subsurface to a depth of 10.4 ft. There are other units available capable of injecting to 30 or 40 ft, but these are not as maneuverable and their cost is considerably more than the system tested for this demonstration. The system tested is largely nondisruptive to subsurface supports such as footers or pipe beds, and injections can be performed close to buildings and other cultural features. The system is also capable of being using an angles up to 45° from vertical.

Table 5.1. Task summary for MPIS testing

Activity	Production rate	Total time
Pre-treatment characterization	Pre-treatment borings, 6 to 7/d	5 d/32 borings
	Lysimeters, 12/d	2 d/24 lysimeters
	Piezometers, 5/d	1 d/5 piezometers
	SMT probes, 24/d	1 d/24 SMT probes
	Water samples, 30/d	1 d/30 samples
Mobilization and shakedown	Mobilization, 2 d Shakedown, 2 d	4 d
Reagent mixing	0.5 to 1 h/1000 gal batch	10 h/13,000 gal
Test cell 1 injection	5.3 min/setup	190 min for 36 setups
Test cell 2 injection	5.7 min/setup	205 min for 36 setups
Test cell 3 injection	5.7 min/setup	205 min for 36 setups
Test cell 4 injection	4.3 min/setup	155 min for 36 setups
Test cell 5 injection	5.4 min/setup	195 min for 36 setups
Test cell 6 injection	5 min/setup	20 min for four setups
Test cell 7 injection	5.5 min/setup	22 min for four setups
Post-treatment characterization	Soil borings, 5 to 6/d Water samples, 12 to 30/d	7 d/37 borings 11 d/200 samples

6. Summary and Conclusions

The purpose of the permeation and dispersal of reactive fluids project at the PORTS CTS was to evaluate:

- the feasibility of using the MPIS for injection of treatment agents into the subsurface, and
- the relative effectiveness of injecting contrasting treatment agents for in situ remediation of low permeability soils.

The stated objectives of this project were to:

- characterize pore fracture size and continuity in the untreated soil and then determine changes in fracture size and continuity as affected by reagent or air injection,
- determine matrix effects of the various fluids released with respect to changes in soil pH, TOC, conductivity, etc.,
- determine dispersal of reactive particles in LPM,
- determine dispersal of oxidants in LPM, and
- determine the operation and maintenance characteristics of the injection tool.

Performance testing of the MPIS at the PORTS CTS has demonstrated that it is feasible to use the MPIS for injection of various reagents into relatively shallow depths of low permeability soil. However, observations suggest that the treatment agents injected advect along pre-existing preferential flow paths and only in cases of persistent agents, do they diffuse into matrix blocks. Observations of the various injections also indicate that the initial effect generally occurred in the upper more structured zone of the subsurface at the test site. Percolation of the injected media from the saturated upper soils over time resulted in subsequent, and less dramatic, changes to the deeper portions of the cells.

The relative success of injecting the various treatments appears to be similar. Post-treatment soil sampling results and boring logs indicate that the distribution patterns for the treatment agents were comparable. Thus, the slurry mixtures (i.e., lime, iron micropowder/guar gum) flowed through the injector system and penetrated the subsurface equally as well as other media (e.g., peroxide solution). From an operational standpoint, no problems occurred with the MPIS during injection of any of the treatments; however, the tank containing the iron micropowder required continuous stirring to prevent settling of the metal particles.

Pre-treatment and post-treatment soil boring logs were prepared for each test cell to assess macroscopic changes in pore fracture size and continuity. No significant changes were observed, excluding the filling of the existing fractures and macropores with the injected media. Sample cores from each test cell were also collected for x-ray and SEM analysis to assess pre- and post-treatment fracture morphology. X-ray data were inconclusive, and SEM analyses were not completed.

Varying matrix effects were observed for the various treatment injections. No notable effects were observed for test cell 1 (water with tracers) and test cell 6 (air). The most significant effect observed in test cell 2 (hydrogen peroxide) was a significant decrease in TOC at a depth of up to 2 ft bgs; however, little change was observed at greater depths. The peroxide injection also effected a significant increase in DO in the lysimeter (water) samples. Results from test cell 2 also indicate that the peroxide reacts rapidly in the fine-grained soil and degrades in a relatively short time (a few days). No significant matrix effects were observed in test cell 3 (bionutrients with tracers) soils. However, increased nitrate levels were measured in lysimeter samples as a result of the nutrient ingredients.

Significant matrix effects were observed in test cell 4 (lime slurry). The lime injection resulted in dramatic pH increases in both soil and lysimeter samples. Alkalinity and conductivity measurements also increased substantially in the water samples. These effects appear to be fairly long lasting (at least 4 weeks). Post-treatment results from test cell 5 (potassium permanganate) indicated dramatic increases in soil Eh throughout the soil profile and a slight decrease in pH in the water samples. Post-treatment manganese concentrations in lysimeter samples remain elevated for approximately 5 weeks. Thus, of the oxidants injected, the potassium permanganate appears to react mildly but will persist longer than the peroxide. No significant matrix effects were observed for test cell 7 (iron micropowder) soils, excluding an increase in the iron concentration. However, a decrease in pH was observed in the water samples in conjunction with an increase in the soluble iron concentration.

The dispersal of the various treatment agents in low permeability soils was generally related to the success of the injection. Thus, there was a similar pattern of initial dispersal in each test cell as discussed previously. However, additional dispersal in the subsurface over time was observed for those treatments (i.e., lime, potassium permanganate, and iron) that were soluble and more persistent. This appeared to occur as affected water percolated downward through the soil.

Based on the results of the testing at the PORTS CTS, the MPIS shows promise for treatment of contaminants in shallow, low permeability soils. The injected treatment agents follow pre-existing preferential flow paths in low permeability soils (e.g., fractures) but do not appear to create new fractures. The system could be used to deliver a treatment medium into the preferential flow paths, thereby preventing further migration of contaminants, at least until the agent was exhausted or flushed out by surface recharge. Additional treatment could occur by subsequent percolation of affected water through the contaminated soil layer. The MPIS would probably be very effective at delivering solutions into unconsolidated sandy sediments or loose tailings.

Based on their inherent reactive characteristics, three of the treatments tested at the CTS have potential application for in situ remediation of VOCs in low permeability soils. These include hydrogen peroxide, potassium permanganate, and iron micropowder. Further testing of these treatments in conjunction with the MPIS is recommended for a contaminated site. The other treatments tested at the CTS are generally not effective for chlorinated solvents; however, they could be delivered with the MPIS for in situ treatment at other contaminated sites.

7. References

American Petroleum Institute. 1995. Petroleum Contaminated Low Permeability Soil: Hydrocarbon Distribution Processes, Exposure Pathways and In Situ Remediation Technologies. Health and Environmental Sciences Dept. Publication No. 4631, September.

Case, T. 1997. Reactive permanganate grouts for horizontal permeable barriers and in situ treatment of ground water. M.S. thesis, Environmental Science & Engineering Division, Colorado School of Mines, Golden, Colorado.

Davenport, D.T., D.J. Georgopoulos, R.L. Siegrist, M.I. Morris, and O.R. West. 1994. Technology Demonstration, Assessment, and Application for a RCRA Closure: Observations and Lessons Learned in the Process. Proc. Spectrum '94, Atlanta, August, 1994.

Gates, D.D. and R.L. Siegrist. 1995. In Situ Chemical Oxidation of Trichloroethylene Using Hydrogen Peroxide. *ASCE Journal of Environmental Engineering*, **121**(9):639-644.

Gierke, J.S., C. Wang, O.R. West, and R.L. Siegrist. 1995. "In Situ Mixed Region Vapor Stripping of Low Permeability Media: 3. Modeling of Field Tests". *Environ. Science & Technology*, **29**(9):2208-2216.

Huling, S.G. and J.W. Weaver. 1991. Dense Nonaqueous Phase Liquids. Ground Water Issue Paper, EPA/540/4-91-002. Office of Research and Development, Washington, D.C. 20460.

Johnson, R., D. Grady, T. Walden, and H. Hopkins. 1995. Remediation of Gasoline Contaminated Low Permeability Media as Evaluated at a Controlled Release Test Site. Invited presentation at the Second International Conference on Challenges and Innovations in the Management of Hazardous Wastes. Air and Waste Management Conference, May, 1995, Washington, D.C.

Johnson, R.L., and D. Grady. 1995. Remediation of Tight Soils Using Air Flushing: Summary of 1994 Field Experiments at Sarnia Ontario. Prepared for the American Petroleum Institute by Oregon Graduate Institute Center for Groundwater Research, Beaverton, Oregon.

MacDonald, J. A. and M. Kavanaugh. 1994. Restoring Contaminated Groundwater: An Achievable Goal? 1994. *Environmental Science & Technology*, **28**(8):362A-368A.

Murdoch, L., B. Slack, B. Siegrist, S. Vesper, and T. Meiggs. 1997a. Hydraulic Fracturing Advances. *Civil Engineering*, May, pp. 10A-12A.

Murdoch, L., W. Slack, R. Siegrist, S. Vesper, and T. Meiggs. 1997b. Advanced Hydraulic Fracturing Methods to Create In Situ Reactive Barriers. Proc. International Containment Technology Conference and Exhibition. February 9-12, 1997, St. Petersburg, FL. In press.

ORNL. 1994. *Final Work Plan for Multi-port Injector System Testing in Low-Permeability Soils at the Clean Test Site*. Oak Ridge National Laboratory, Grand Junction, Colorado.

ORNL. 1993. *Environmental Technology Section (formerly Pollutant Assessments Group) Procedures Manual.* ORNL-6645/R2. Oak Ridge National Laboratory, Grand Junction, Colorado.

Pfiffner, S.M., R.L. Siegrist, K.S. Lowe, D.B. Ringleberg, and A.V. Palumbo. 1997. Sarnia: Bioremediation Processes Demonstrated at a Controlled Release Site. Symposium on In Situ and On-Site Bioremediation. April 1997. New Orleans.

Pfiffner, S. 1994. Written communication with R. L. Siegrist, ORNL from Susan Pfiffner, University of Tennessee Center for Environmental Biotechnology, Microbial Enumerations and Activities.

Siegrist, R. L., K. S. Lowe, L. C. Murdoch, D. A. Pickering, and T. L. Case. 1999. In Situ Oxidation by Fracture Emplaced Reactive Solids. *J. Environmental Engineering.* **125**(5):429-440.

Siegrist, R. L., K. S. Lowe, L. C. Murdoch, W. W. Slack, and T. C. Houk. 1998. *X-231A Demonstration of In Situ Remediation of DNAPL Compounds in Low Permeability Media by Soil Fracturing with Thermally Enhanced Mass Recovery or Reactive Barrier Destruction*. ORNL/TM-13534. Oak Ridge National Laboratory, Oak Ridge, Tennessee.

Siegrist, R.L., N.E. Korte, D. Smuin, O.R. West, D.D. Gates, and J.S. Gunderson. 1996. In Situ Treatment of Contaminants in Low Permeability Soils: Biogeochemical Enhancement by Subsurface Manipulation. Invited presentation at First International Conference on Contaminants in the Soil Environment in the Australasia-Pacific Region. February 1996, Adelaide, South Australia.

Siegrist, R.L. and K.S. Lowe (ed.). 1995. In Situ Remediation of DNAPL Compounds in Low Permeability Media - Interim Report. Interim project report prepared by Oak Ridge National Laboratory with contributions from an ad hoc team of scientists and engineers from DOE national laboratories, academia, and industry.

Siegrist, R.L., O.R. West, M. I. Morris, D. A. Pickering, D. W. Greene, C. A. Muhr, D. D. Davenport and J .S. Gierke.. 1995a. In Situ Mixed Region Vapor Stripping of Low Permeability Media. 2. Full Scale Field Experiments. *Environ. Science & Technology*. **29**(9):2198-2207.

Siegrist, R.L., N. E. Korte, M.T. Muck, D.R. Smuin, A.D. Laase, O.R. West, D.T. Davenport, and J. Walker. 1995b. Field Evaluation of Subsurface Manipulation by Fracturing, Multipoint Injection/Dispersal, and Directional Drilling Using Unconfined Test Cells. Invited presentation at the Second International Conference on Challenges and Innovations in the Management of Hazardous Wastes. Air and Waste Management Conference, May, 1995, Washington, D.C.

Siegrist R.L., N.E. Korte, M.T. Muck, D.R. Smuin, A.D. Laase, O.R. West, D.T. Davenport, and J. Walker. 1995c. Field Evaluation of Subsurface Manipulation by Fracturing, Permeation Dispersal, and Horizontal Well Recirculation Using Unconfined Test Cells. Invited presentation at the National Ground Water Association Annual Educational Conference, October, 1995, Indianapolis, IN.

Siegrist, R. L., M. I. Morris, O. R. West, D. A. Pickering, C. A. Muhr, D. W. Greene, D. D. Gates, T. J. Mitchell, R. A. Jenkins, and T. McKnight. 1994a. *X-231B Technology Demonstration for In Situ Treatment of Contaminated Soil: Field Evaluation of Mixed Region Vapor Stripping, Chemical Oxidation, and Solidification Processes.* ORNL/TM-12261. Oak Ridge National Laboratory, Oak Ridge, Tennessee.

Siegrist, R. L., M. I. Morris, O. R. West, D. D. Gates, D. A. Pickering, R. A. Jenkins, T. J. Mitchell, D. W. Greene, C. A. Muhr, S. E. Herbes, T. M. Gilliam, H. L. Jennings, A. J. Lucero, J. Zutman, T. McKnight, and J. S. Watson. 1995. *The X-231B Technology Demonstration for In Situ Treatment of Contaminated Soil: Field Demonstration and Testing of Vapor Stripping, Peroxidation, and Solidification.* ORNL/TM-12261. Oak Ridge National Laboratory, Oak Ridge, Tennessee.

Siegrist, R.L., O. R. West, D. D. Gates, S. E. Herbes, M. I. Morris, T. M. Gilliam, H. L. Jennings, A. J. Lucero, J. S. Watson, D. A. Pickering, D. W. Greene, C. A. Muhr, J. Zutman, R. A. Jenkins, T. J. Mitchell, T. McKnight, D. T. Davenport. 1993. **In:** Post, R. G. Full-scale Field Demonstration and Testing of Physicochemical Processes for In Situ Treatment of Contaminated Soil. Proc. Waste Management '93. Feb. 28 - Mar. 4 1993. Tucson, AZ. American Nuclear Society, pp. 849 - 854.

Smuin, D.R., R.L. Siegrist, N.E. Korte, O.R. West, J. Strong-Gunderson, and P.M. Kearl. 1995. Bromide Tracer Evaluation of a Multipoint Injection System for Soil Treatment. Presentation at American Geophysical Union, Fall, 1995 meeting.

Strong-Gunderson. J. M., and A. V. Palumbo. 1995. Laboratory Studies Demonstrate an Innovative Colloid Tracer: Real Time, Sensitive, and Non-Persistent.

Urynowicz, M. A. and R. L. Siegrist. 2000. Permeation Dispersal of Treatment Agents for In Situ Remediation in Low Permeability Media: 2. Laboratory Studies with Intact Cores. ORNL/TM-13597. Oak Ridge National Laboratory, Oak Ridge, Tennessee.

U.S. DOE. 1996. *In Situ Remediation of DNAPL Compounds in Low Permeability Media Fate/Transport, In Situ Constol Technologies, and Risk Reduction.* ORNL/TM-13305. Oak Ridge National Laboratory, Oak Ridge, Tennessee.

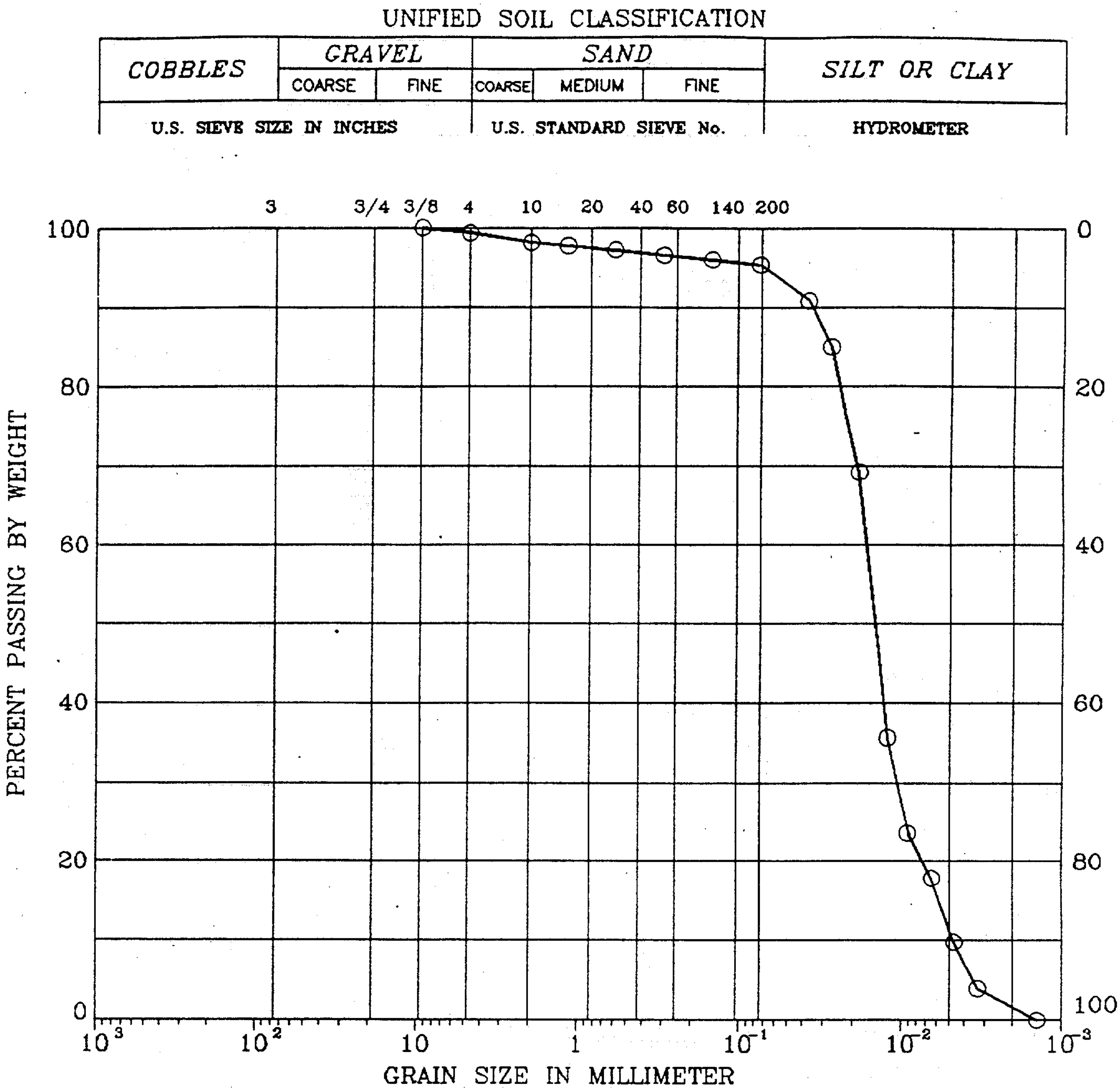
U.S. EPA. 1992. Dense Nonaqueous Phase Liquids -- A workshop Summary. EPA/600/R-92/030. Office of Research and Development, Washington, D.C. 20460.

Walden, T. 1993. Remediation of Low Permeability Soils: An API Research Program. Proc. 1993 Petroleum Hydrocarbons and Organic Chemicals in Groundwater: Prevention, Detection, and Restoration. Houston, TX. *National Water Well Assn.* pp. 623-629.

West, Or. R., R. L. Siegrist, J. S. Gierke, S. W. Schmunk, A. J. Lucero, and H. L. Jennings. 1995. In Situ Mixed Region Vapor Stripping of Low Permeability Media. 1. Process Features and Laboratory Experiments. Environmental Science & Technology. **29**(9):2191 - 2197.

APPENDIX A

GEOTECHNICAL, BACKGROUND, AND GRAIN SIZE DISTRIBUTION RESULTS FOR THE CTS



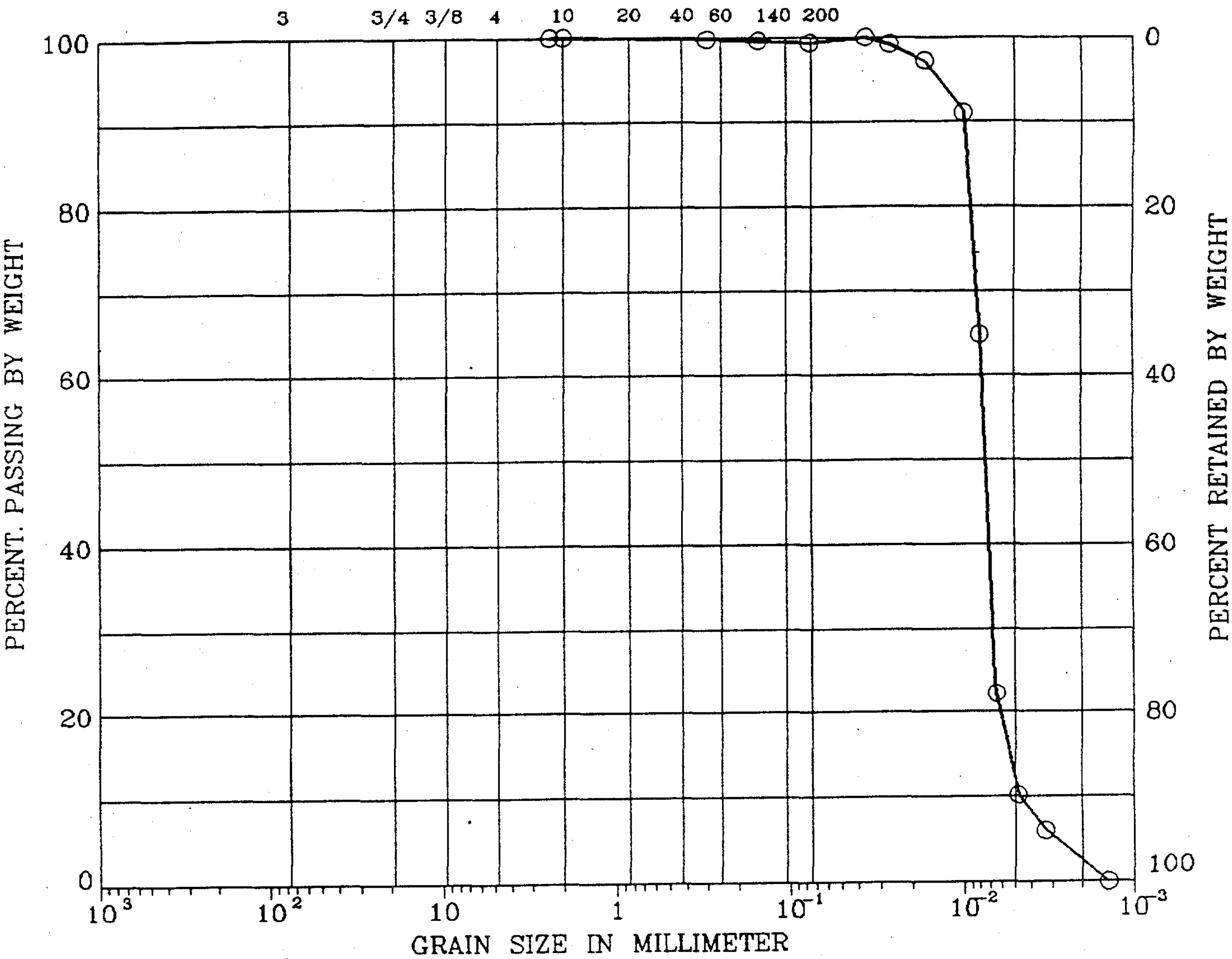
SYMBOL	BORING	DEPTH (ft)	LL (%)	PI (%)	DESCRIPTION
O	BH1-05	5.0	49	31	CLAY, silty, lt yelsh br, mott gr, w/ rts USC=CL

Remark : Martin Marietta Energy Systems, Inc.

Project No.0-4267	Portsmouth – OTD Mini Characterization
OGDEN ENVIRONMENTAL	GRAIN SIZE DISTRIBUTION April 5, 1994

UNIFIED SOIL CLASSIFICATION

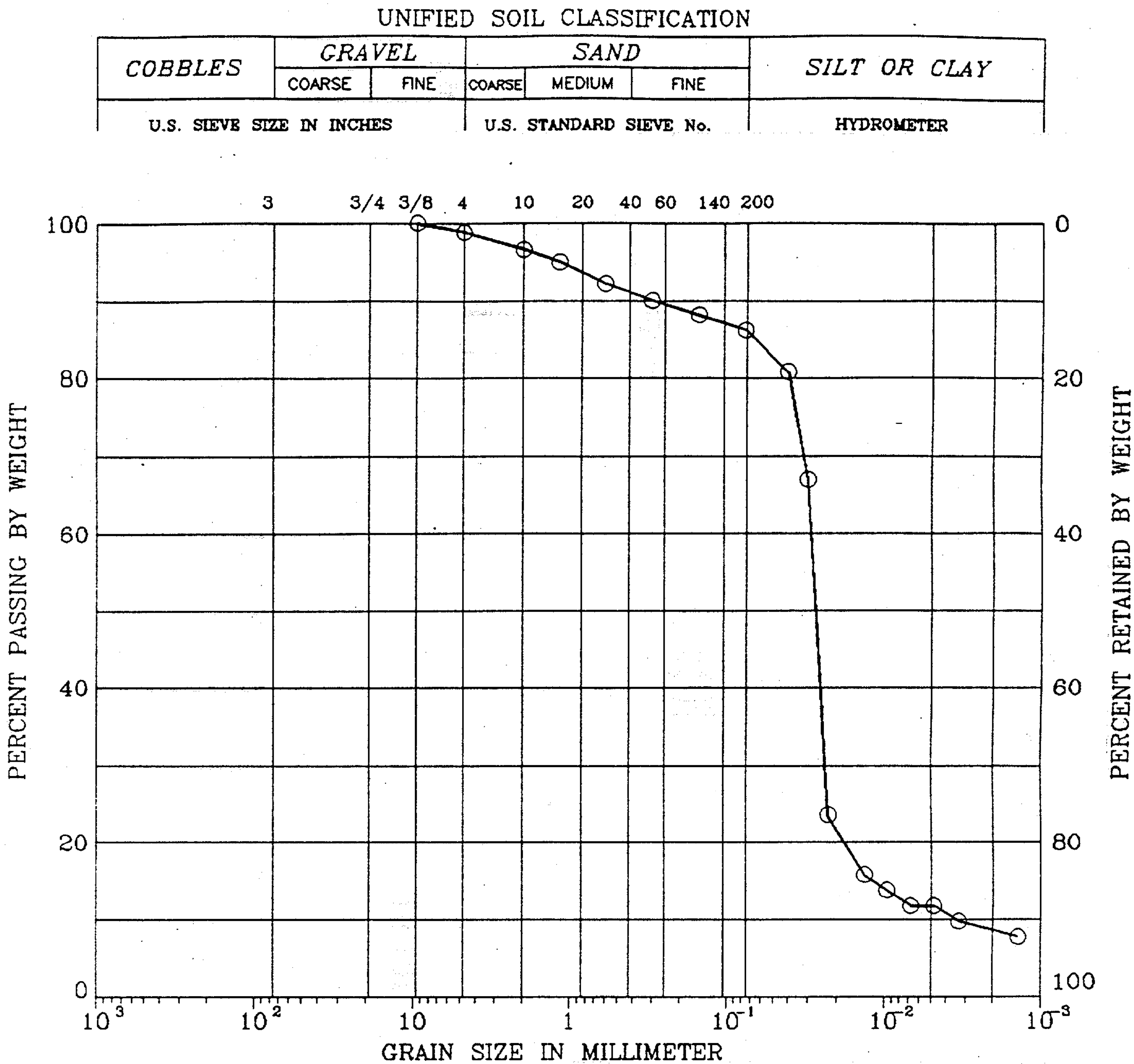
COBBLES	GRAVEL		SAND			SILT OR CLAY
	COARSE	FINE	COARSE	MEDIUM	FINE	
U.S. SIEVE SIZE IN INCHES			U.S. STANDARD SIEVE No.			HYDROMETER



SYMBOL	BORING	DEPTH (ft)	LL (%)	PI (%)	DESCRIPTION	
○	BH1-13.5	13-13.5	64	38	CLAY, silty, rdsh br, mott blk	USC=CH

Remark : Martin Marietta Energy Systems, Inc.

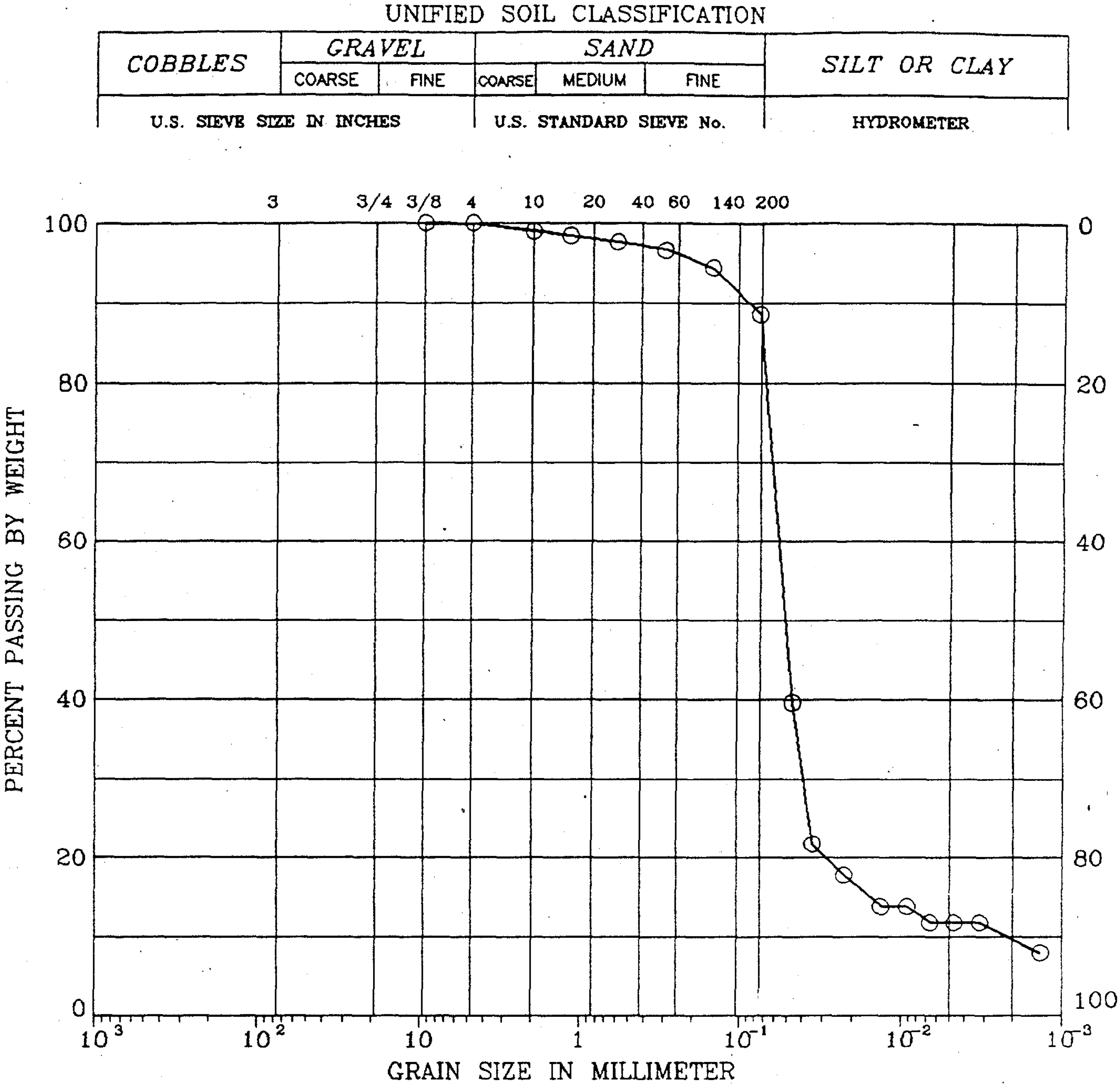
Project No.0-4267	Portsmouth – OTD Mini Characterization
OGDEN ENVIRONMENTAL	GRAIN SIZE DISTRIBUTION April 5, 1994



SYMBOL	BORING	DEPTH (ft)	LL (%)	PI (%)	DESCRIPTION
○	BH2-05	4.5-5.0	33	14	CLAY,slty,lt ylsh br mott gr & br w/rk frgsUSC=CL

Remark : Martin Marietta Energy Systems, Inc.

Project No.0-4267	Portsmouth – OTD Mini Characterization
OGDEN ENVIRONMENTAL	GRAIN SIZE DISTRIBUTION April 5, 1994



SYMBOL	BORING	DEPTH (ft)	LL (%)	PI (%)	DESCRIPTION	
○	BH2-14	13.5-14	26	12	CLAY, silty, yellowish brown	USC=CL

Remark : Martin Marietta Energy Systems, Inc.

Project No.0-4267	Portsmouth – OTD Mini Characterization
OGDEN ENVIRONMENTAL	GRAIN SIZE DISTRIBUTION April 5, 1994

SUMMARY OF LABORATORY TEST RESULTS

Project: Portsmouth ODT Mini Characterization

Project Number: 0-4267-0088

Date: May 20, 1994

Hole No.	Sample No.	Sample Type*	Depth (ft)	Natural Moisture (%)	UNIT WEIGHT (PCF) Wet	Dry	SPECIFIC GRAVITY G_s	ATTERBERG LIMITS Liquid Limit (%)	Plasticity Index (%)	Unified Soil Classification	Other Test **	Soil Description
BH-1-05		SS	5.0	23.4			2.66	49	31	CL		CLAY, silty, light yellowish brown mottled gray with roots
BH-1-13.5		SS	13.0 - 13.5	32.4			2.63	64	38	CH		CLAY, silty, reddish-brown mottled black
BH-1-22		SS	21.5 - 22.0	21.2			2.67	27	15	CL		CLAY, silty, light yellowish brown mottled brown with weathered shale fragments
BH-2-05		SS	4.5 - 5.0	22.6			2.60	33	14	CL		CLAY, silty, light yellowish brown mottled gray and brown with rock fragments
BH-2-14		SS	13.5 - 14.0	22.6			2.69	26	12	CL		CLAY, silty, slightly sandy, tan
BH-2-28		SS	27.5 - 28.0	19.1			2.75	31	13	CL		CLAY, silty, dark yellowish brown with rock fragments
BH-3-09		SS	8.5 - 9.0	24.5			2.66	50	28	CL		CLAY, silty, tan mottled light gray
BH-3-12		SS	11.5 - 12.0	35.5			2.73	72	49	CH		CLAY, silty, light brown mottled gray
BH-3-19		SS	18.5 - 19.0	17.7			2.68	23	11	CL		CLAY, silty, dark greenish brown with rock fragments
BH-4-07		SS	6.5 - 7.0	26.7			2.69	60	35	CH		CLAY, silty, light brown mottled gray and yellowish-brown
BH-4-15		SS	14.5 - 15.0	31.0			2.69	69	43	CH		CLAY, silty, light brown mottled gray

*ST-SHELBY TUBE SAMPLE, SS-SPLIT SPOON SAMPLE, B-BAG SAMPLE
**TEST RESULTS REPORTED ON OTHER SHEETS:

C-CONSOLIDATION
S-SIEVE OR GRAIN SIZE ANALYSIS
U-UNCONFINED COMPRESSION TEST
P-PROCTOR TEST
D-DIRECT SHEAR TEST
T-TRIAXIAL TEST

DATA CHECKED BY

GA Technical Services

SUMMARY OF LABORATORY TEST RESULTS

Project: Portsmouth ODT Mini Characterization

Project Number: 0-4267-0088

Date: May 20, 1994

Hole No.	Sample No.	Sample Type*	Depth (ft)	Natural Moisture (%)	Unit Weight (PCF) Wet	Unit Weight (PCF) Dry	Specific Gravity G_s	Atterberg Limits Liquid Limit (%)	Atterberg Limits Plasticity Index (%)	Unified Soil Classification	Other Test **	Soil Description
BH-4-21		SS	20.5 - 21.0	36.7			2.72	48	26	CL		CLAY, silty, brown mottled gray and reddish-brown
BH-5-08		SS	7.5 - 8.0	32.3			2.69	69	44	CH		CLAY, silty, light brown mottled gray
BH-5-13		SS	12.5 - 13.0	39.9			2.70	46	25	CL		CLAY, silty, light brown mottled gray yellowish-brown and reddish-brown
BH-5-19		SS	18.5 - 19.0	20.7			2.66	26	11	CL		CLAY, silty, yellowish-brown mottled light gray with rock fragments
BH-5-23		SS	22.5 - 23.0	30.9			2.70	28	15	CL		CLAY, silty slightly sandy light yellowish-brown
BH-6-02		SS	1.5 - 2.0	25.9			2.62	41	25	CL		CLAY, silty, light yellowish-brown
BH-6-18		SS	17.5 - 18.0	21.7			2.65	26	13	CL		CLAY, silty, light yellowish-brown
BH-6-29		SS	28.5 - 29.0	14.3			2.69					CLAY, silty, dark brown with rock fragments
BH-7-12		SS	11.5 - 12.0	20.7			2.70	28	14	CL		CLAY, silty, slightly sandy, light yellowish-brown
BH-7-20		SS	19.5 - 20.0	19.3			2.65	30	14	CL		CLAY, silty, slightly sandy, yellowish-brown
BH-7-26		SS	25.5 - 26.0	17.3			2.65	29	12	CL		CLAY, silty, dar brown

*ST-SHELBY TUBE SAMPLE, SS-SPLIT SPOON SAMPLE, B-BAG SAMPLE
**TEST RESULTS REPORTED ON OTHER SHEETS:

C-CONSOLIDATION
S-SIEVE OR GRAIN SIZE ANALYSIS
U-UNCONFINED COMPRESSION TEST
P-PROCTOR TEST
D-DIRECT SHEAR TEST
T-TRIAXIAL TEST

DATA CHECKED BY JR

GA Technical Services

SUMMARY OF LABORATORY TEST RESULTS

Project: Portsmouth ODT Mini Characterization

Project Number: 0-4267-0088

Date: May 20, 1994

Hole No.	Sample No.	Sample Type*	Depth (ft)	Natural Moisture (%)	UNIT WEIGHT (PCF) Wet	UNIT WEIGHT (PCF) Dry	SPECIFIC GRAVITY G_s	ATTERBERG LIMITS Liquid Limit (%)	ATTERBERG LIMITS Plasticity Index (%)	Unified Soil Classification	Other Test **	Soil Description
BH-8-13		SS	12.5 - 13.0	33.5			2.68	61	41	CH		CLAY, silty, reddish-brown
BH-8-22		SS	21.5 - 22.0	28.5			2.72	26	12	CL		CLAY, silty, dark brown mottled dark gray with rock fragments
BH-9-09		SS	8.5 - 9.0	33.6			2.70	71	48	CH		CLAY, silty, light reddish-brown mottled gray and yellowish-brown
BH-9-21		SS	20.9 - 21.0	36.4			2.73	53	28	CH		CLAY, silty, gray mottled reddish-brown
BH-9-21.5		SS	21.0 - 21.5	29.9			2.75	51	26	CH		CLAY, silty, gray mottled greenish-brown

*ST-SHELBY TUBE SAMPLE, SS-SPLIT SPOON SAMPLE, B-BAG SAMPLE
**TEST RESULTS REPORTED ON OTHER SHEETS:

C-CONSOLIDATION
S-SIEVE OR GRAIN SIZE ANALYSIS
U-UNCONFINED COMPRESSION TEST

P-PROCTOR TEST
D-DIRECT SHEAR TEST
T-TRIAXIAL TEST

DATA CHECKED BY JR

GA Technical Services

MPIS Baseline Soil Characteristics: Moisture Content, Bulk Density, Porosity, pH, TOC

Pan ID	Sample Name	Depth	% Moisture based on dry wt	% Moisture based on wet wt	Wt bulk Density, g/cc	Dry bulk Density, g/cc	Dry wt % moisture	% volume porosity	% volume water-filled porosity	% volume air-filled porosity	pH	TOC, ppm	Avg. % soil moisture (wet wt)	Avg. pH	Avg. bulk density (moist), g/cc	Avg. TOC, ppm
1	T1-BE-00-01	1	21.95	18							4.26	6253	16.73	4.89		6396.63
14	T2-BE-00-01	1	21.4	17.63		median moist bulk density					4.61	6107				
27	T3-BE-00-01	1	21.82	17.91		1.83					4.87	7713				
40	T4-BE-00-01	1	19.03	15.99							4.62	6933				
53	T5-BE-00-01	1	18.66	15.72							4.67	3483				
66	T6-BE-00-01	1	21.76	17.87							4.93	6893				
79	T7-BA-00-01	1	18.21	15.41							6.5	6662				
92	SI-BA-00-01	1	18.09	15.32							4.68	7129				
2	TI-BE-01-02	2	22.52	18.38							4.42	1295	18.39	4.49		1629.50
15	T2-BE-01-02	2	24.4	19.61							4.3	1576				
28	T3-BE-01-02	2	22.26	18.21							4.34	1851				
41	T4-BE-01-02	2	21.75	17.86							4.57	1707				
54	T5-BE-01-02	2	23.5	19.03							4.74	1296				
67	T6-BE-01-02	2	24.6	19.74							4.51	1903				
80	T7-BA-01-02	2	22.41	18.3							4.6	1693				
93	S1-BA-01-02	2	19.03	15.99							4.43	1716				
3	T1-BE-02-03	3	21.31	17.57							4.6	2130	18.69	4.33	1.67	1447.75
16	T2-BE-02-03	3	21.82	17.91							4.13	1083				
29	T3-BE-02-03	3	26.13	20.72							4.23	1261				
42	T4-BE-02-03	3	26.78	21.12							4.14	1724				
55	T5-BE-02-03	3	19.97	16.64	1.67	1.4	19.22	49.2	26.85	22.35	4.33	1103				
68	T6-BE-02-03	3	21.96	18.01							4.47	1110				
81	T7-BA-02-03	3	22.34	18.26							4.66	2016				
94	S1-BA-02-03	3	23.89	19.29							4.1	1155				
4*	T1-BE-03-04	4	22	18.03							4.65	1471	15.46	4.67		1082.38
17	T2-BE-03-04	4	18.7	15.76							4.62	993				
30	T3-BE-03-04	4	21.34	17.59							4.36	954				
43	T4-BE-03-04	4	19.85	16.56							4.59	977				
56	T5-BE-03-04	4	13.77	12.1							4.73	1108				
69	T6-BE-03-04	4	16.17	13.92							4.99	1277				
82	T7-BA-03-04	4	16.69	14.3							4.92	1014				
95	S1-BA-03-04	4	18.19	15.39							4.48	865				
5	T1-BE-04-05	5	17.27	14.73	2.25	1.96	15.12	28.79	29.61	-0.82	4.81	1226	15.33	5.73	1.88	1021.13
18	T2-BE-04-05	5	19.1	16.04	1.57	1.32	19.42	52.09	25.59	26.51	5.94	1353				
31	T3-BE-04-O5	5	22	18.03	1.71	1.37	24.3	50.03	33.39	16.65	5.48	947				
44	T4-BE-04-05	5	14.99	13.03	1.88	1.59	18.18	42.05	28.96	13.09	5.62	889				
57	T5-BE-04-05	5	22.44	18.32	2.03	1.65	23.23	40.11	38.27		6.66	989				

MPIS Baseline Soil Characteristics: Moisture Content, Bulk Density, Porosity, pH, TOC

Pan ID	Sample Name	Depth	% Moisture based on dry wt	% Moisture based on wet wt	Wt bulk Density, g/cc	Dry bulk Density, g/cc	Dry wt % moisture	% volume porosity	% volume water-filled porosity	% volume air-filled porosity	pH	TOC, ppm	Avg. % soil moisture (wet wt)	Avg. pH	Avg. bulk density (moist), g/cc	Avg. TOC, ppm
70	T6-BE-04-05	5	14.38	12.57	1.89	1.66	14.03	39.77	23.23	16.54	6.18	866				
83	T7-BA-04-05	5	16.52	14.18	1.85	1.57	18.1	42.94	28.4	14.54	6.37	1081				
96	S1-BA-04-05	5	18.67	15.73	1.82	1.54	17.58	43.82	27.16	16.66	4.79	818				
7	T1-BE-O5-06	6	20.66	17.12							6.04	1217	16.08	6.47		994.88
20	T2-BE-05-06	6	20.91	17.3							6.89	890				
33	T3-BE-05-06	6	17.64	14.99							6.46	1062				
46	T4-BE-O5-06	6	18.04	15.28							6.95	1187				
59	T5-BE-05-06	6	24.59	19.74							7.07	405				
72	T6-BE-05-06	6	20.6	17.08							6.08	1631				
85	T7-BA-05-O6	6	15.5	13.42							6.74	1065				
98	S1-BA-05-06	6	15.87	13.7							5.5	502				
8	T1-BE-O6-07	7	18.61	15.69							7	685	17.79	6.57	1.72	615.00
21	T2-BE-06-07	7	21.18	17.48							6.99	431				
34	T3-BE-06-07	7	14.35	12.55							6.22	836				
47	T4-BE-06-07	7	31.15	23.75							7.61	420				
60	T5-BE-06-07	7	27.29	21.44	1.72	1.36	26.17	50.42	35.68	14.74	6.23	286				
73	T6-BE-06-07	7	23.09	18.76							6.67	531				
86	T7-BA-O6-07	7	20.81	17.23							6.47	894				
99	S1-BA-O6-07	7	18.27	15.45							5.38	837				
9	T1-BE-07-OS	8	no core										20.77	7.03		558.20
22	T2-BE-07-08	8	no core													
35	T3-BE-07-08	8	27.91	21.82							6.95	305				
48	T4-BE-07-OB	8	no core													
61	T5-BE-07-08	8	31.67	24.05							7.75	367				
74	T6-BE-07-08	8	28.27	22.04							6.74	385				
87	T7-BA-07-08	8	24.72	19.82							7.44	567				
100	S1-BA-07-08	8	19.2	16.11							6.27	1167				
10	T1-BE-08-09	9	31.65	24.04							7.08	354	24.13	7.21	1.98	395.00
23	T2-BE-08-09	9	32.52	24.54							7.75	288				
36	T3-BE-08-09	9	36.93	26.97							7.48	498				
49	T4-BE-08-09	9	31.65	24.04							7.61	420				
62	T5-BE-08-09	9	34.05	25.4	1.98	1.5	31.77	45.33	47.77	-2.43	7.51	381				
75	T6-BE-08-09	9	21.99	18.03							6.99	383				
88	T7-BA-08-09	9	32.49	24.52							7	403				
101	S1-BA-08-09	9	34.17	25.47							6.29	433				
11	T1-BE-09-10	10	35.01	25.93							7.78	333	26.27	7.55		421.00
24	T2-BE-09-10	10	33.22	24.93							7.68	436				
37	T3-BE-09-10	10	36.88	26.94							7.82	613				

MPIS Baseline Soil Characteristics: Moisture Content, Bulk Density, Porosity, pH, TOC

Pan ID	Sample Name	Depth	% Moisture based on dry wt	% Moisture based on wet wt	Wt bulk Density, g/cc	Dry bulk Density, g/cc	Dry wt % moisture	% volume porosity	% volume water-filled porosity	% volume air-filled porosity	pH	TOC, ppm	Avg. % soil moisture (wet wt)	Avg. pH	Avg. bulk density (moist), g/cc	Avg. TOC, ppm
50	T4-BE-09-10	10	36.72	26.86							7.83	412				
63	T5-BE-09-10	10	35.8	26.36							7.74	396				
76	T6-BE-09-10	10	39.39	28.26							7.37	394				
89	T7-BA-09-10	10	33.36	25.01							6.93	334				
102	S1-BA-09-10	10	34.89	25.87							7.34	450				
12	T1-BE-10-11	11	34.56	25.69	1.8	1.34	34.47	51.2	46.25	4.95	7.56	653	23.98	7.43	1.82	543.38
25	T2-BE-10-11	11	34.75	25.79	1.76	1.29	37	53.16	47.66	5.5	7.75	425				
38	T3-BE-10-11	11	35.96	26.45	1.74	1.29	34.67	53.13	44.68	8.45	7.36	432				
51	T4-BE-10-11	11	30.36	23.29	1.92	1.53	25.5	44.43	38.97	5.46	7.02	305				
64	T5-BE-10-11	11	38.2	27.64	1.75	1.26	38.54	54.19	48.55	5.64	7.55	492				
77	T6-BE-10-11	11	28.93	22.44	1.92	1.5	27.89	45.43	41.86	3.57	7.76	933				
90	T7-BA-10-11	11	24.76	19.85	1.83	1.48	23.38	46.03	34.71	11.33	6.92	493				
103	S1-BA-10-11	11	26.06	20.67	1.84	1.46	26.6	47.07	38.72	8.35	7.52	614				
13	T1-BE-11-12	12	37.03	27.03							7.41	555	23.57	7.39		525.88
26	T2-BE-11-12	12	27.76	21.73							7.74	640				
39	T3-BE-11-12	12	24.74	19.83							7.13	337				
52	T4-BE-11-12	12	33.62	25.16							7.54	821				
65	T5-BE-11-12	12	28.69	22.29							6.9	630				
78	T6-BE-11-12	12	28.24	22.02							6.87	393				
91	T7-BA-11-12	12	34.29	25.53							7.73	510				
104	S1-BA-11-12	12	33.26	24.96							7.81	321				

APPENDIX B

LITHOLOGIC LOGS FOR TEST CELL SOIL BORINGS

Borehole Summary Information

ornl OAK RIDGE NATIONAL LABORATORY

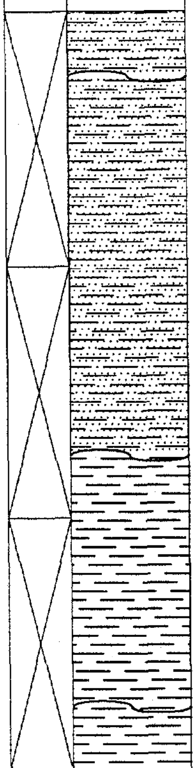
Prepared By: S.R. Sturm Date: 10/23/94 Page: 1 OF 1

Hole No.: S1BA Ground Elevation: NA

Total Depth: 12' Rig Type: ORNL U2CRT Location: Shakedown area

Auger Size: NA Sample Type: Geoprobe "Megabore 2" OD X 4'

Project: PORTS MPIS Data Verified By: Date:



DEPTH (FEET)	SAMPLE TYPE	DESCRIPTION
0		
		CL SILTY CLAY: dk brown (7.5YR3/4) soft, damp, abund humus, root bundles, weathered surface of subjacent unit, Topsoil
2	CS	
		CL SILTY CLAY: yellowish brown (10YR5/8), friable damp, common Fe staining, clay faces on vertical blocky structures, some Mn oxide, increasing stiffness
4		
6	CS	High angle fracture at 7.8' w/ argillaceous inf
8		CH CLAY: brown (7.5YR5/6), stiff, damp, very fat and plastic, homogenous texture, w/greenish gray silt laminae, authegenic gypsum crystals at 8.1', high angle fracture at 10.5' & 10.7'
10	CS	
		CH CLAY: brown (7.5YR5/6), stiff, damp, very fat and plastic, prominent bed partings, homogenous
12		
14		
16		
18		
20		

Borehole Summary Information

ornl OAK RIDGE NATIONAL LABORATORY

Prepared By: R.M. Schlosser Date: 11/20/94 Page: 1 OF 1

Hole No.: BD2 Ground Elevation: NA

Total Depth: 12' Rig Type: ORNL U2CRT Location: Background cell

Auger Size: NA Sample Type: Geoprobe "Megabore 2" OD X 4'

Project: PORTS MPIS Data Verified By: ______ Date: ______

DEPTH (FEET)	SAMPLE TYPE	SAMPLE INTV	LITHOLOGY	DESCRIPTION
0				
				CL **SILTY CLAY:** brown (10YR5/3) soft, well developed root mass, friable, dry
2	CS			CL **SILTY CLAY:** yellowish brown (10YR5/8), some Fe oxides, soft, moist, friable, becoming more oxidized w/depth, pebbles @ 4', lt gray mottle
4				
				CL **SILTY CLAY:** yellowish brown lt gray mottle, abund Fe & MN oxides, pebbles @ 5.5'3" thick bed, 2 - 6mm nodules highly oxidized
6	CS			
				CH **CLAY:** dk yellow brown (10YR4/4), mottled lt gray w/ lt gray inter-lams , scattered pebbles less mottling @ 8', well defined beds, stiff, plastic, fracture @ 8.1' w/gypsum infill
8				
10	CS			CH **CLAY:** some dry desicated surfaces w/1 - 2mm cracks from drying @ 9.4', 9.6, & 11.4',v stiff well developed bedding, plastic, waxy appearance
12				
14				
16				
18				
20				

Borehole Summary Information

ornl OAK RIDGE NATIONAL LABORATORY

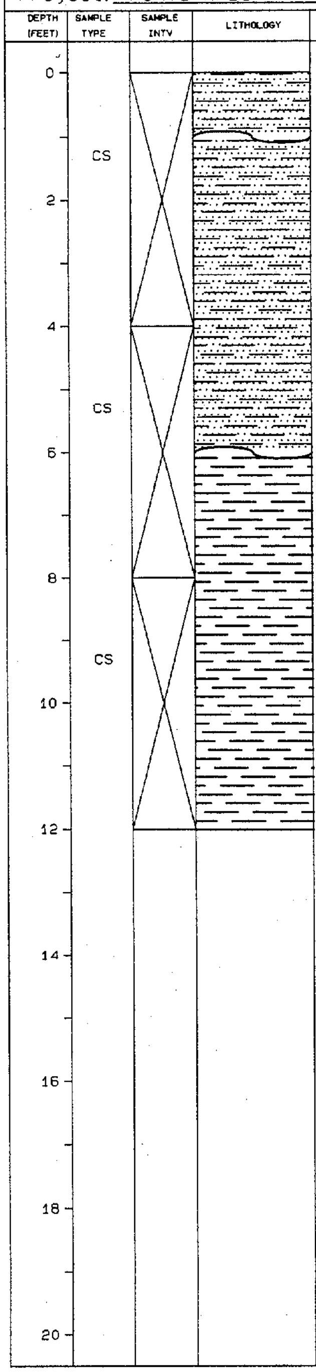
Prepared By: S.R. Sturm — Date: 10/23/94 — Page: 1 OF 1

Hole No.: T1BA — Ground Elevation: NA

Total Depth: 12' — Rig Type: ORNL U2CRT — Location: Test Cell #1

Auger Size: NA — Sample Type: Geoprobe "Megabore 2" OD X 4'

Project: PORTS MPIS — Data Verified By: ____ — Date: ____



DESCRIPTION

CL SILTY CLAY: dk brown (7.5YR3/4) soft, damp, abund humus, root bundles, Topsoil

CH SILTY CLAY: yellowish brown (10YR5/8), friable damp, occasional Fe staining from 2-5', open root pores, blocky structure

LOST CORE 6' TO 8'

CH CLAY: brown (7.5YR5/6), stiff, damp, very fat and plastic, homogenous texture, pronounced bed partings <1mm thick, high angle fractures at 9.4', 10.2', 10.3', and 11.5'.

Borehole Summary Information

ornl OAK RIDGE NATIONAL LABORATORY

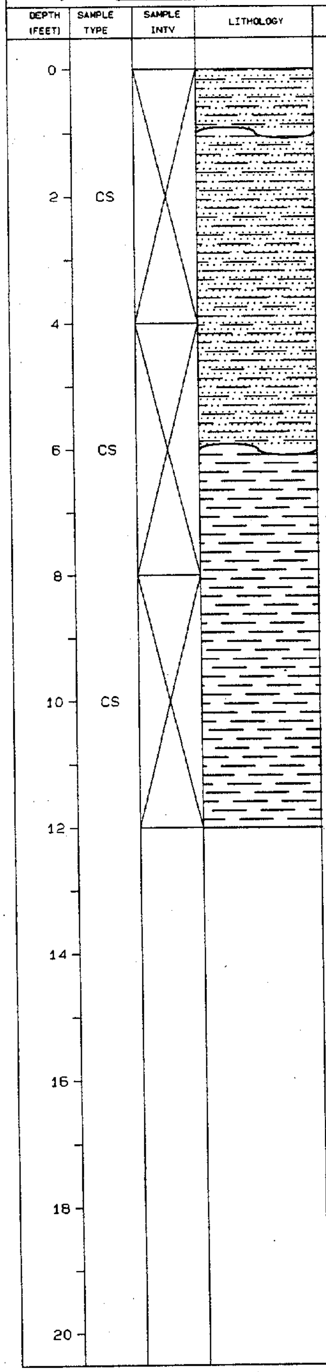
Prepared By: S.R. Sturm   Date: 10/23/94   Page: 1 OF 1

Hole No.: T1BB   Ground Elevation: NA

Total Depth: 12'   Rig Type: ORNL U2CRT   Location: Test Cell #1

Auger Size: NA   Sample Type: Geoprobe "Megabore 2" OD X 4'

Project: PORTS MPIS   Data Verified By: ________   Date: ________



DESCRIPTION

CL **SILTY CLAY:** dk brown (7.5YR3/4) soft, damp, abund humus, root bundles, Topsoil

CL **SILTY CLAY:** yellowish brown (10YR5/8), friable damp, open root pores, blocky structure, scattered sandstone pebbles, argillaceous infill in verticle dessication fracts

CH **CLAY:** brown (7.5YR5/6), stiff, damp, very fat and plastic, homogenous texture, w/intbdd gray silt laminae, authigenic gypsum crystals parallel continuous bedding, 10mm thick mudstone pebble bed at 9'

Borehole Summary Information

ornl OAK RIDGE NATIONAL LABORATORY

Prepared By: S.R. Sturm   Date: 10/23/94   Page: 1 OF 1

Hole No.: T1BC   Ground Elevation: NA

Total Depth: 12'   Rig Type: ORNL U2CAT   Location: Test Cell #1

Auger Size: NA   Sample Type: Geoprobe "Megabore 2" OD X 4'

Project: PORTS MPIS   Data Verified By: ______   Date: ______

DEPTH (FEET)	SAMPLE TYPE	SAMPLE INTV	LITHOLOGY	DESCRIPTION
0				
				CL SILTY CLAY: dk brown (7.5YR3/4) soft, damp, abund humus, root bundles, weathered surface of subjacent unit, Topsoil
2	CS	0–4		
				CL SILTY CLAY: yellowish brown (10YR5/8), friable damp, common Fe staining, open root pores, blocky structure, lt gray mottle
4				
6	CS	4–8		CH CLAY: brown (7.5YR5/6), stiff, damp, very fat and plastic, homogenous texture, w/greenish gray silt laminae, authegenic gypsum crystals at 7.9', mudstone pebble bed at 9'
8				
10	CS	8–12		
				CH CLAY: brown (7.5YR5/6), stiff, damp, very fat and plastic, prominent bed partings
12				
14				
16				
18				
20				

Borehole Summary Information

ornl OAK RIDGE NATIONAL LABORATORY

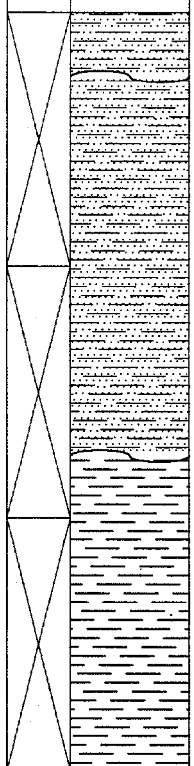
Prepared By: S.R. Sturm Date: 10/23/94 Page: 1 OF 1

Hole No.: T1BD Ground Elevation: NA

Total Depth: 12' Rig Type: ORNL U2CRT Location: Test Cell #1

Auger Size: NA Sample Type: Geoprobe "Megabore 2" OD X 4'

Project: PORTS MPIS Data Verified By: Date:



DEPTH (FEET)	SAMPLE TYPE	SAMPLE INTV	LITHOLOGY	DESCRIPTION
0				
				CL SILTY CLAY: dk brown (7.5YR3/4) soft, damp, abund humus, root bundles, weathered surface of subjacent unit, Topsoil
2	CS			CL SILTY CLAY: yellowish brown (10YR5/8), friable damp, common Fe staining, open root pores, blocky structure, lt gray mottle
4				
				Becoming stiff increased clay content occasional sandstone pebbles
6	CS			
8				CH CLAY: brown (7.5YR5/6), stiff, damp, very fat and plastic, with intrbdd greenish gray silt laminae, flecks of Mn oxide, parallel continuous bedding, becoming very homogenous
10	CS			
12				
14				
16				
18				
20				

Borehole Summary Information

ornl OAK RIDGE NATIONAL LABORATORY

Prepared By: S.R. Sturm Date: 10/23/94 Page: 1 OF 1

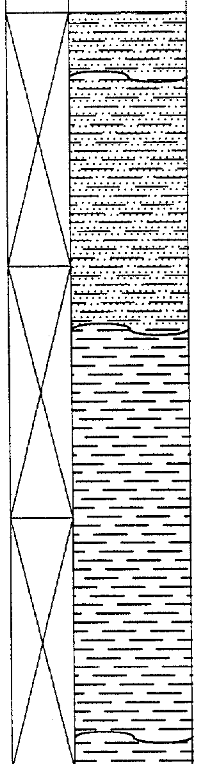
Hole No.: T1BE Ground Elevation: NA

Total Depth: 12' Rig Type: ORNL U2CRT Location: Test Cell #1

Auger Size: NA Sample Type: Geoprobe "Megabore 2" OD X 4'

Project: PORTS MPIS Data Verified By:______ Date:______

DEPTH (FEET)	SAMPLE TYPE	SAMPLE INTV	LITHOLOGY	DESCRIPTION
0				
				CL **SILTY CLAY:** dk brown (7.5YR3/4) soft, damp, abund humus, root bundles, weathered surface of subjacent unit, Topsoil
2	CS			
				CL **SILTY CLAY:** yellowish brown (10YR5/8), friable damp, mod stiff, common Fe staining, open root pores, blocky structure, lt gray mottle, occassional sandstone pebbles
4				
6	CS			CH **CLAY:** brown (7.5YR5/6), stiff, damp, very fat and plastic, homogenous texture, w/greenish gray silt laminae, authegenic gypsum crystals at 8.1', mudstone pebble bed at 9'
8				
10	CS			
				CH **CLAY:** brown (7.5YR5/6), very stiff, damp, very fat and plastic, < 1mm bedding
12				
14				
16				
18				
20				



Borehole Summary Information

ornl OAK RIDGE NATIONAL LABORATORY

Prepared By: R.M. Schlosser Date: 11/13/94 Page: 1 OF 1

Hole No.: T1-BF Ground Elevation: NA

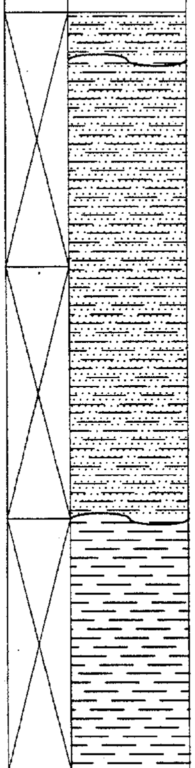
Total Depth: 12' Rig Type: ORNL U2CRT Location: Test Cell #1

Auger Size: NA Sample Type: Geoprobe "Megabore 2" OD X 4'

Project: PORTS MPIS Data Verified By: - Date:

DEPTH (FEET)	SAMPLE TYPE	DESCRIPTION
0		CL **SILTY CLAY:** brown (10YR5/3), 10" with well developed root mass.
2	CS	CL **SILTY CLAY:** yellowish brown (10YR5/8), friable damp, abundant Fe staining from 2-5', some scattered 2-4mm pebbles.
4		CL **SILTY CLAY:** as above, with abundant Mn oxides in root pores, mottled light gray along perimeter of root pores, friable, moist.
6	CS	
		CL **SILTY CLAY:** abundant root pores with infill of light gray as above, scattered Fe nodules 2-4mm mottled light gray throughout.
8		CL **CLAY:** strong brown (7.5YR5/6), mottled light gray (7.5YRN7/), very stiff, plastic, very gypsiferous at 9.5', no apparent voids.
10	CS	CL **CLAY:** as above, well defined bedding surfaces, mottled light gray in vertical areas, 2-4mm pebbles scattered throughout, stiff, moist, waxy apperance.
12		
14		
16		
18		
20		

SAMPLE INTV / LITHOLOGY:



Borehole Summary Information

ornl OAK RIDGE NATIONAL LABORATORY

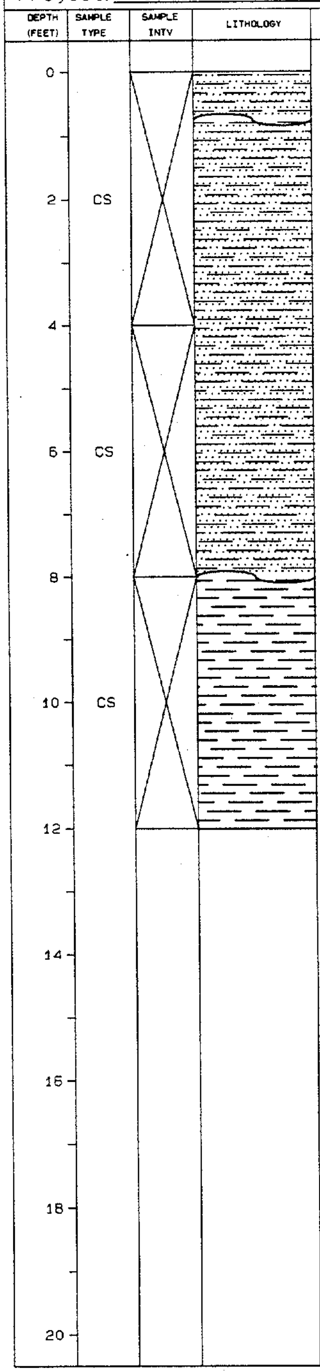
Prepared By: R.M. Schlosser Date: 11/13/94 Page: 1 OF 1

Hole No.: T1-BH Ground Elevation: NA

Total Depth: 12' Rig Type: ORNL U2CRT Location: Test Cell #1

Auger Size: NA Sample Type: Geoprobe "Megabore 2" OD X 4'

Project: PORTS MPIS Data Verified By: ____ Date: ____



DESCRIPTION

CL **SILTY CLAY:** brown (10YR5/3), 10"-11" well developed root mass, becoming yellowish brown (10YR5/8) at 1', abundant Fe staining at 2.3'.

CL **SILTY CLAY:** yellowish brown (10YR5/8), mottled light gray along root pores, friable.

CL **SILTY CLAY:** as above, becoming mottled both brown and light gray throughout, abundant remnant pores, scattered Mn oxides and Fe staining, some scattered Fe nodules.

CL **CLAY:** yellowish brown (7.5YR5/6) mottled light gray (7.5YRN7/), blocky, plastic, stiff, waxy apperance, scattered very fine roots, well defined bedding planes, HIGH ANGLE FRACTURES at approximately 9.5' and 10.5'. FRACTURE at 11' has light gray clay infill. Very mottled throughout, some remnant roots, very stiff, plastic, waxy apperance, becoming completely brown (7.5YR5/6) with no mottle at 11.5'.

Borehole Summary Information

ornl OAK RIDGE NATIONAL LABORATORY

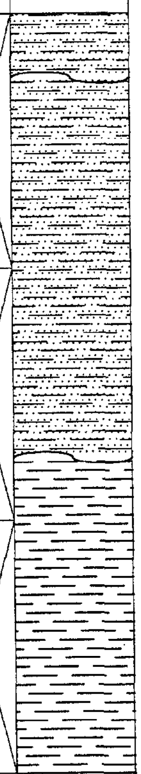
Prepared By: R.M. Schlosser Date: 11/13/94 Page: 1 OF 1

Hole No.: T1-BI Ground Elevation: NA

Total Depth: 12' Rig Type: ORNL U2CRT Location: Test Cell #1

Auger Size: NA Sample Type: Geoprobe "Megabore 2" OD X 4'

Project: PORTS MPIS Data Verified By: Date:



DEPTH (FEET)	SAMPLE TYPE	SAMPLE INTV	LITHOLOGY	DESCRIPTION
0				CL SILTY CLAY: brown (10YR5/3), abundant roots, mottling, becoming yellowish brown at 1', abundant Fe staining beginning at 1.5', soft, friable
2	CS			CL SILTY CLAY: yellowish brown (10YR5/8), mottled, friable, root hairs, scattered Fe staining, occassional nodules, abundant Fe staining at 5'
4				
6	CS			CL CLAY: brownish yellow (10YR6/6) mottled light brownish gray, abundant root pores, some Mn staining along pores, some staining on desiccated surfaces, friable
8				CL CLAY: dark brown (10YR2/2) becoming stiff, very mottled as above, abundant Mn staining along pores, some staining on desiccated surfaces, friable
10	CS			CL CLAY: brownish yellow (10YR5/8) no mottling, very stiff, plastic, waxy appearance, damp High angle fracture at 11.5'
12				
14				
16				
18				
20				

Borehole Summary Information

ornl OAK RIDGE NATIONAL LABORATORY

Prepared By: R.M. Schlosser Date: 11/13/94 Page: 1 OF 1

Hole No.: T1-BJ Ground Elevation: NA

Total Depth: 12' Rig Type: ORNL U2CRT Location: Test Cell #1

Auger Size: NA Sample Type: Geoprobe "Megabore 2" OD X 4'

Project: PORTS MPIS Data Verified By: Date:

DEPTH (FEET)	SAMPLE TYPE	SAMPLE INTV	LITHOLOGY	DESCRIPTION
2	CS			
6	CS			
10	CS			

CL SILTY CLAY: brown (10YR5/3), abundant roots very friable

CL SILTY CLAY: yellowish brown (10YR5/8), abundant roots as above, very soft, some scattered two - 3 mm pebbles

CL SILTY CLAY: Lt brownish yellow (10YR6/4) mottled yellowish brown (10YR5/6) very soft, friable abundant Fe staining.

CL SILTY CLAY: Lt. brownish yellow (10YR6/4) abundant Mn and Fe staining along root pores, occasional nodules

CL CLAY: brownish yellow (10YR5/8) friable, some scattered Fe nodules, friable, blocky structure

CL CLAY: brownish yellow (10YR5/8), mottled lt gray on bedding surfaces

siltstone in desiccation surfaces.

CL CLAY: as above with abundant well developed bedding surfaces, very stiff, waxy appearance

Borehole Summary Information

ornl OAK RIDGE NATIONAL LABORATORY

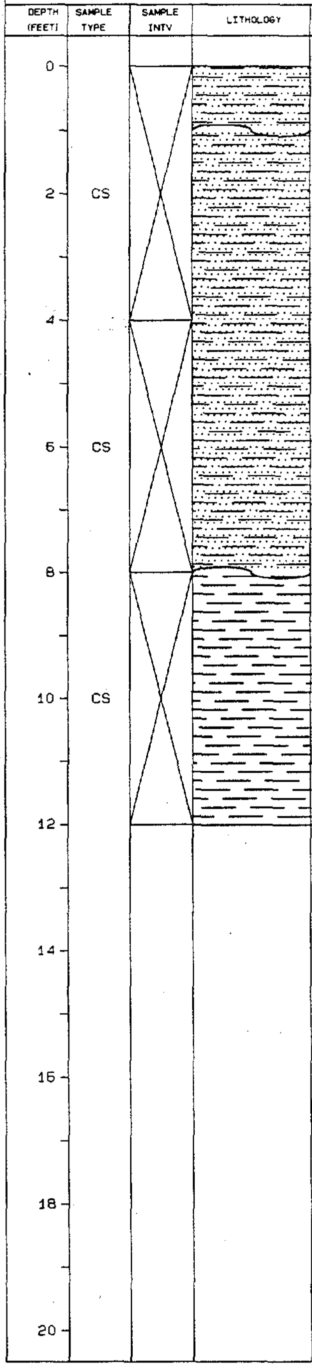
Prepared By: S.R. Sturm   Date: 12/13/94   Page: 1 OF 1

Hole No.: T1BK   Ground Elevation: NA

Total Depth: 12'   Rig Type: ORNL U2CRT   Location: Test Cell #1

Auger Size: NA   Sample Type: Geoprobe "Megabore 2" OD X 4'

Project: PORTS MPIS   Data Verified By: ____   Date: ____



DESCRIPTION

CL SILTY CLAY: dk brown (7.5YR3/4) soft, damp, abund humus, root bundles, Topsoil

CL SILTY CLAY: yellowish brown (10YR6/6), friable damp, open root pores, blocky structure, Becoming v stiff, increasing silt content, limonite staining, abund Fe nods 5' to 7'

CH CLAY: brown (7.5YR5/6) , stiff, damp, very fat and plastic, homogenous texture, w/intbdd gray silt laminae, no visible fractures or alterations

Borehole Summary Information

orn1 OAK RIDGE NATIONAL LABORATORY

Prepared By: S.R. Sturm Date: 12/13/94 Page: 1 OF 1

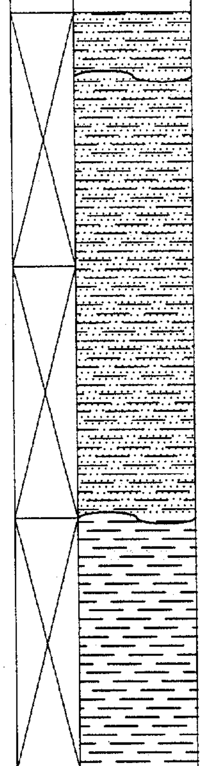
Hole No.: T1BL Ground Elevation: NA

Total Depth: 12' Rig Type: ORNL U2CRT Location: Test Cell #1

Auger Size: NA Sample Type: Geoprobe "Megabore 2" OD X 4'

Project: PORTS MPIS Data Verified By: ________ Date: ________

DEPTH (FEET)	SAMPLE TYPE	SAMPLE INTV	LITHOLOGY	DESCRIPTION
0				
				CL SILTY CLAY: dk brown (7.5YR3/4) soft, damp, abund humus, root bundles, Topsoil
2	CS			
				CL SILTY CLAY: yellowish brown (10YR6/6), friable damp, open root pores, blocky structure. Becoming v stiff, increasing silt content, limonite staining, abund Fe nods 5' to 7'
4				
6	CS			
8				CH CLAY: brown (7.5YR5/6), stiff, damp, very fat and plastic, homogenous texture, w/intbdd gray silt laminae, no visible fractures or alterations
10	CS			
12				
14				
16				
18				
20				



Borehole Summary Information

ornl OAK RIDGE NATIONAL LABORATORY

Prepared By: S.R. Sturm Date: 10/22/94 Page: 1 OF 1

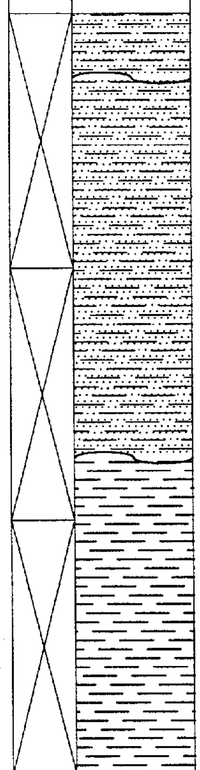
Hole No.: T2BA Ground Elevation: NA

Total Depth: 12' Rig Type: ORNL U2CRT Location: Test Cell #2

Auger Size: NA Sample Type: Geoprobe "Megabore 2" OD X 4'

Project: PORTS MPIS Data Verified By: Date:

DEPTH (FEET)	SAMPLE TYPE	SAMPLE INTV	LITHOLOGY	DESCRIPTION
0				
				CL SILTY CLAY: dk brown (7.5YR3/4) soft, damp, abund humus, root bundles, weathered surface of subjacent unit, Topsoil
2	CS			
				CL SILTY CLAY: yellowish brown (10YR5/8), friable damp, mod stiff, common Fe staining, open root pores, blocky structure, lt gray mottle, occassional sandstone pebbles
4				
				Fe nodules up to 10 mm, verticle dessication planes with Mn oxide dendritic staining
6	CS			
8				CH CLAY: brown (7.5YR5/6), stiff, damp, very fat and plastic, homogenous texture, w/greenish gray silt laminae, authegenic gypsum crystals at 7.9', mudstone pebbles in gray silt bed at 9.2'
10	CS			
12				
14				
16				
18				
20				



Borehole Summary Information

ornl OAK RIDGE NATIONAL LABORATORY

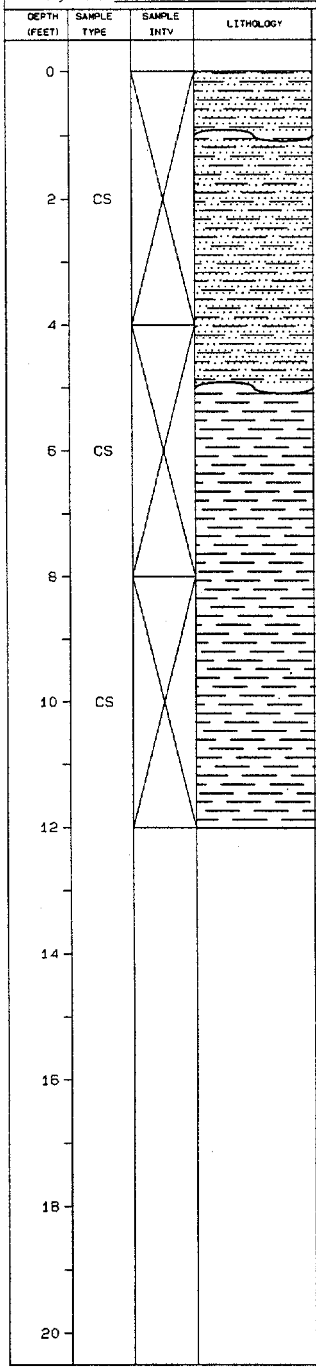
Prepared By: S.R. Sturm Date: 10/22/94 Page: 1 OF 1

Hole No.: T2BB Ground Elevation: NA

Total Depth: 12' Rig Type: ORNL U2CAT Location: Test Cell #1

Auger Size: NA Sample Type: Geoprobe "Megabore 2" OD X 4'

Project: PORTS MPIS Data Verified By: Date:



DESCRIPTION
CL **SILTY CLAY:** dk brown (7.5YR3/4) soft, damp, abund humus, root bundles, weathered surface of subjacent unit, Topsoil
CL **SILTY CLAY:** yellowish brown (10YR5/8), friable damp, mod stiff, common Fe staining, open root pores, blocky structure, lt gray mottle, scattered Fe nodules
CH **CLAY:** brown (7.5YR5/6), stiff, damp, very fat and plastic, homogenous texture, w/greenish gray silt laminae
CH **CLAY:** as above with 2 - 4 mm beds of silt with dessication fractures

Borehole Summary Information

ornl OAK RIDGE NATIONAL LABORATORY

Prepared By: S.R. Sturm Date: 10/22/94 Page: 1 OF 1

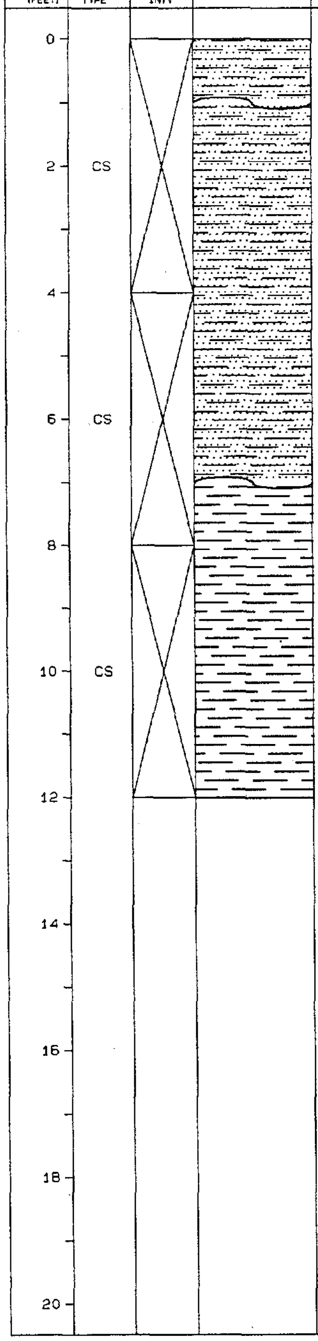
Hole No.: T2BC Ground Elevation: NA

Total Depth: 12' Rig Type: ORNL U2CRT Location: Test Cell #2

Auger Size: NA Sample Type: Geoprobe "Megabore 2" OD X 4'

Project: PORTS MPIS Data Verified By: ______ Date: ______

DEPTH (FEET)	SAMPLE TYPE	SAMPLE INTV	LITHOLOGY	DESCRIPTION



CL SILTY CLAY: dk brown (7.5YR3/4) soft, damp, abund humus, root bundles, weathered surface of subjacent unit, Topsoil

CL SILTY CLAY: yellowish brown (10YR5/8), friable damp, mod stiff, common Fe staining, open root pores, blocky structure, lt gray mottle, scattered Fe nodules

CH CLAY: brown (7.5YR5/6), stiff, damp, very fat and plastic, homogenous texture, w/greenish gray silt laminae, flecks of Mn oxide

Mudstone pebbles at 10.5'

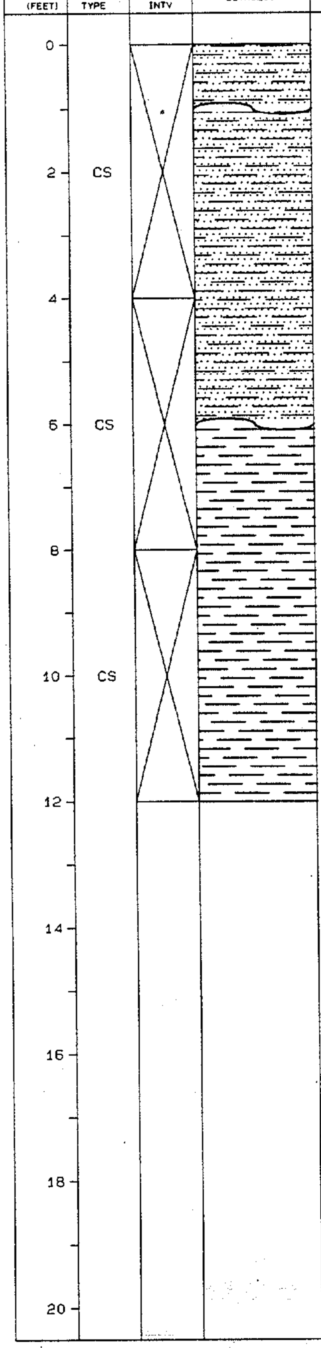
High angle fracture at 11.4'

Borehole Summary Information

ornl OAK RIDGE NATIONAL LABORATORY

Prepared By: S.R. Sturm	Date: 10/22/94	Page: 1 OF 1
Hole No.: T2BD	Ground Elevation: NA	
Total Depth: 12'	Rig Type: ORNL U2CRT	Location: Test Cell #2
Auger Size: NA	Sample Type: Geoprobe "Megabore 2" OD X 4'	
Project: PORTS MPIS	Data Verified By:	Date:

DEPTH (FEET)	SAMPLE TYPE	SAMPLE INTV	LITHOLOGY	DESCRIPTION



CL SILTY CLAY: dk brown (7.5YR3/4) soft, damp, abund humus, root bundles, weathered surface of subjacent unit, Topsoil

CL SILTY CLAY: yellowish brown (10YR5/8), friable damp, mod stiff, common Fe staining, open root pores, blocky structure, lt gray mottle, scattered Fe nodules up to 20 mm

CH CLAY: brown (7.5YR5/6), stiff, damp, very fat and plastic, homogenous texture, w/greenish gray silt laminae, authegenic gypsum crystals at 8'

Prominent bed partings, silt with dessication fracturing at 10.6 and 11.4'

Borehole Summary Information

orn l OAK RIDGE NATIONAL LABORATORY

Prepared By: S.R. Sturm Date: 10/22/94 Page: 1 OF 1

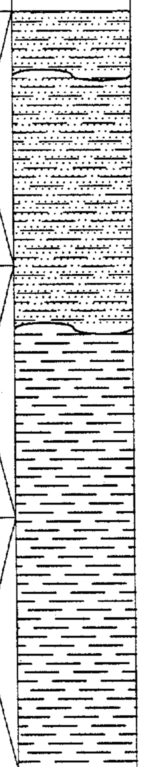
Hole No.: T2BE Ground Elevation: NA

Total Depth: 12' Rig Type: ORNL U2CRT Location: Test Cell #2

Auger Size: NA Sample Type: Geoprobe "Megabore 2" OD X 4'

Project: PORTS MPIS Data Verified By: ______ Date: ______

DEPTH (FEET)	SAMPLE TYPE	SAMPLE INTV	LITHOLOGY	DESCRIPTION
0				
				CL **SILTY CLAY:** dk brown (7.5YR3/4) soft, damp, abund humus, root bundles, weathered surface of subjacent unit, Topsoil
2	CS			CL **SILTY CLAY:** yellowish brown (10YR5/8), friable damp, mod stiff, some Fe nodules, open root pores with Mn infill, blocky structure
4				
				CH **CLAY:** brown (7.5YR5/6), stiff, damp, very fat and plastic, homogenous texture, w/greenish gray silt laminae
6	CS			
8				
10	CS			
				Prominent bed partings, silt with dessication fracturing
12				
14				
16				
18				
20				



Borehole Summary Information

ornl OAK RIDGE NATIONAL LABORATORY

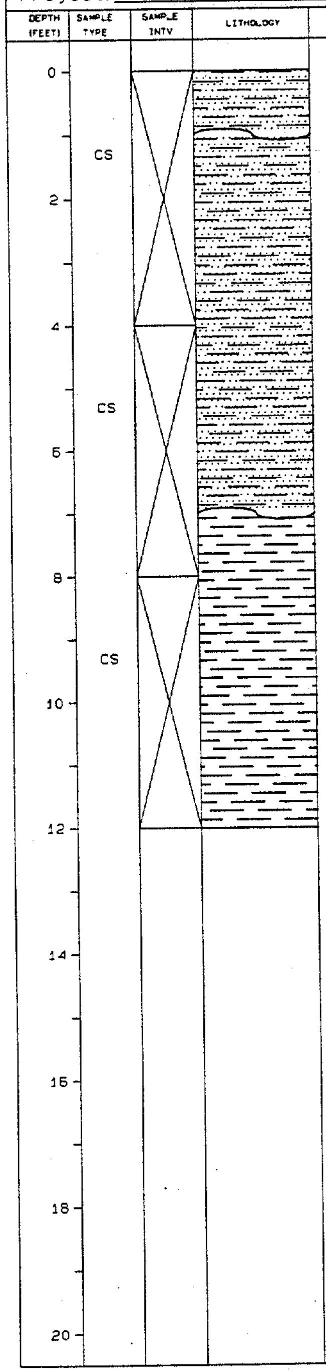
Prepared By: R.M. Schlosser Date: 11/16/94 Page: 1 OF 1

Hole No.: T2-BF Ground Elevation: NA

Total Depth: 12' Rig Type: ORNL U2CRT Location: Test Cell #2

Auger Size: NA Sample Type: Geoprobe "Megabore 2" OD X 4'

Project: PORTS MPIS Data Verified By: Date:



DESCRIPTION

CL **SILTY CLAY:** brown (10YR5/3), 10"-11" with roots very wet from surface penetration of rain

CL **SILTY CLAY:** yellowish brown (10YR5/8), mottled light gray with root mass, occassional Fe staining, becoming much more stained with depth occassional Mn staining, soft, friable, damp, Mn staining increasing with depth, mottling very light gray

CL **SILTY CLAY:** as above, becoming denser, firm

CL **CLAY:** yellowish brown (7.5YR5/6) mottled light gray (7.5YRN7/), damp, very firm, scattered nodules, becoming less mottled with depth @ 9.5' clay layer 5mm thick, scattered remnant root masses.

CL **CLAY:** yellowish brown (7.5YR5/6) well defined bedding planes, stiff, fat, damp, slight waxy appearance

Borehole Summary Information

ornl OAK RIDGE NATIONAL LABORATORY

Prepared By: R.M. Schlosser Date: 11/16/94 Page: 1 OF 1

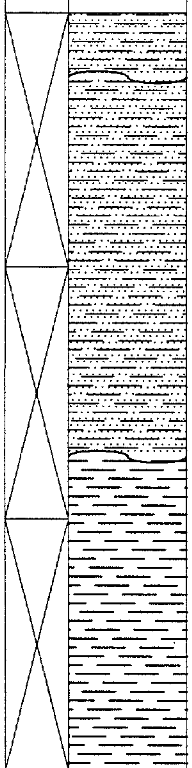
Hole No.: T2BG Ground Elevation: NA

Total Depth: 12' Rig Type: ORNL U2CRT Location: Test Cell #2

Auger Size: NA Sample Type: Geoprobe "Megabore 2" OD X 4'

Project: PORTS MPIS Data Verified By: Date:

DEPTH (FEET)	SAMPLE TYPE	SAMPLE INTV	LITHOLOGY	DESCRIPTION
0				
2	CS			CL SILTY CLAY: brown (10YR5/3), 10"-11" with roots becoming yellow brn lt gray mottle, some pebs, highly oxidized Fe and Mn @ 3.5', soft, friable lt gray mottle on vertical planes- old fracs ?
4				CL SILTY CLAY: yellowish brown (10YR5/8), abund pebs @ 5', firmer, damp, strong Fe staining, becoming less silty, dk gray brn alteration in root vesicles, blocky structure
6	CS			
8				CL CLAY: yellowish brown (7.5YR5/4) mottled light gray (7.5YRN7/), firm, plastic, occ gypsiferous zones, some large crystal development in voids, strong red oxides on vertical micro-fractures, gray layer w/mudstone on desiccated surface
10	CS			
				CL CLAY: yellowish brown (7.5YR5/6) well defined bedding planes, stiff, fat, damp, slight waxy appearance, gypsum in voids mottled strong brn
12				
14				
16				
18				
20				



Borehole Summary Information

orn1 OAK RIDGE NATIONAL LABORATORY

Prepared By: R. M. Schlosser Date: 11/16/94 Page: 1 OF 1

Hole No.: T2-BH Ground Elevation: NA

Total Depth: 12' Rig Type: ORNL U2CRT Location: Test Cell #2

Auger Size: NA Sample Type: Geoprobe "Megabore 2" OD X 4'

Project: PORTS MPIS Data Verified By: Date:

DEPTH (FEET)	SAMPLE TYPE	SAMPLE INTV	LITHOLOGY	DESCRIPTION
0				
				CL SILTY CLAY: brown (10YR5/3), 10"-11" with roots very wet from pooled surface water
2	CS			CL SILTY CLAY: brownish yellow (10YR6/8), mottled reddish brown from Fe staining and lt gray mottle , occasional root hairs, friable, Mn staining on vertical frac surfaces
4				
				CL SILTY CLAY: as above, dense, abund Fe oxides, less silty, damp, scattered 1 - 3mm pebbles
6	CS			
8				CL CLAY: yellowish brown (10YR5/4) mottled light gray (10YR6/1), gray clay on vertical fractures (.3 mm), stiff, damp
10	CS			CL CLAY: yellowish brown (10YR5/4) well defined bedding planes, stiff, waxy appearance, v fat high angle fracture @ 11'
12				
14				
16				
18				
20				

Borehole Summary Information

orn1 OAK RIDGE NATIONAL LABORATORY

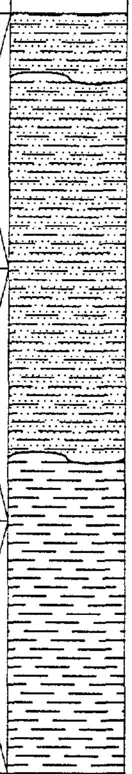
Prepared By: R.M. Schlosser Date: 11/16/94 Page: 1 OF 1

Hole No.: T2-BI Ground Elevation: NA

Total Depth: 12' Rig Type: ORNL U2CRT Location: Test Cell #2

Auger Size: NA Sample Type: Geoprobe "Megabore 2" OD X 4'

Project: PORTS MPIS Data Verified By: Date:

DEPTH (FEET)	SAMPLE TYPE	SAMPLE INTV	LITHOLOGY	DESCRIPTION
0–4	CS	0–4		desiccated surface, gypsiferous zones @ 7.9'and at 8.0' some crystal development in vugs 3-5mm, gray bed @ 8.5', 4 - 6mm CL SILTY CLAY: brown (10YR5/3), 8 - 10" with roots organic rich, pooled surface water CL SILTY CLAY: brownish yellow (10YR6/8), mottled lt gray , some Fe oxides, friable, damp, slight gypsiferous
4–8	CS	4–8		CL SILTY CLAY: as above, friable, abund Fe oxides a few scattered 2 - 3 mm well rounded pebbles CL CLAY: yellowish brown (10YR5/4) mottled light gray (10YR6/1), gray clay on vertical micro-frac
8–12	CS	8–12		CL CLAY: yellowish brown (10YR5/4) well defined bedding planes, stiff, waxy appearance, v fat high angle fracture @ 10, more homogenous @ 10.5

Depth scale: 0, 2, 4, 6, 8, 10, 12, 14, 16, 18, 20

Borehole Summary Information

ornl OAK RIDGE NATIONAL LABORATORY

Prepared By: R.M. Schlosser Date: 11/16/94 Page: 1 OF 1

Hole No.: T2-BJ Ground Elevation: NA

Total Depth: 12' Rig Type: ORNL U2CRT Location: Test Cell #2

Auger Size: NA Sample Type: Geoprobe "Megabore 2" OD X 4'

Project: PORTS MPIS Data Verified By: Date:

DEPTH (FEET)	SAMPLE TYPE	SAMPLE INTV	LITHOLOGY	DESCRIPTION
0				
				CL SILTY CLAY: brown (10YR5/3), 8 - 10" with roots organic rich, wet from surface water
2	CS			CL SILTY CLAY: brownish yellow (10YR6/8), mottled lt gray , Fe staining throughout, soft, friable scattered oxidized s.s. pebbles
4				
				CL SILTY CLAY: as above, friable, abund Fe oxides a few scattered 1-3mm pebbles, lt gray mottle
6	CS			
				CL CLAY: yellowish brown (10YR5/4) mottled light gray (10YR6/1), low angle fracture 1-3mm wide with lt gray silt infill, very firm, blocky structure, slighty waxy appearance, gypsiferous @ 9.0' - 9.5
8				
10	CS			CL CLAY: yellowish brown (10YR5/4) gray reduction occuring on vertical .2 - .5 mm bands, v fat waxy appearance, more homogenous @ 11.5'
12				
14				
16				
18				
20				

Borehole Summary Information

ornl OAK RIDGE NATIONAL LABORATORY

Prepared By: S.R. Sturm Date: 12/13/94 Page: 1 OF 1

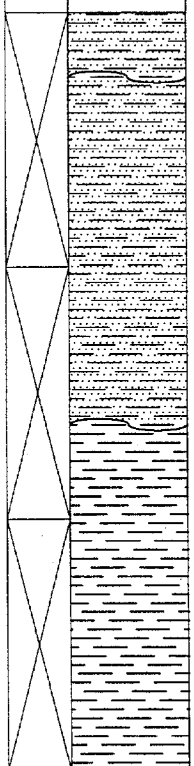
Hole No.: T2BK Ground Elevation: NA

Total Depth: 12' Rig Type: ORNL U2CRT Location: Test Cell #2

Auger Size: NA Sample Type: Geoprobe "Megabore 2" OD X 4'

Project: PORTS MPIS Data Verified By: ______ Date: ______

DEPTH (FEET)	SAMPLE TYPE	SAMPLE INTV	LITHOLOGY	DESCRIPTION
0				
				CL **SILTY CLAY:** dk brown (10YR5/3) soft, damp, abund humus, root bundles, Topsoil
2	CS			CL **SILTY CLAY:** brownish yellow (10YR6/6), friable damp, lt gray mottle, blocky structure, Fe staining common, scattered oxidized sandstone pebbles
4				
6	CS			
8				CH **CLAY:** brown (7.5YR5/6), stiff, damp, very fat and plastic, homogenous texture, w/intbdd gray silt laminae, horizontal fracture with additional moisture at 7', bedded gypsum at 8'
10	CS			
12				
14				
16				
18				
20				



Borehole Summary Information

ornl OAK RIDGE NATIONAL LABORATORY

Prepared By: S.R. Sturm Date: 10/20/94 Page: 1 OF 1

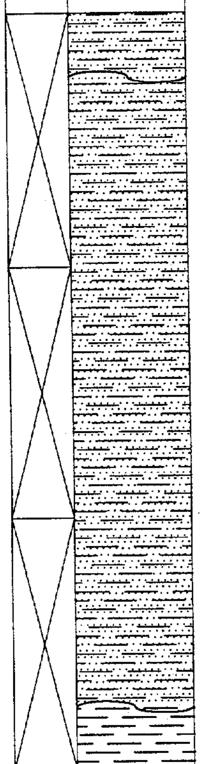
Hole No.: T3BA Ground Elevation: NA

Total Depth: 12' Rig Type: ORNL U2CRT Location: Test Cell #3

Auger Size: NA Sample Type: Geoprobe "Megabore 2" OD X 4'

Project: PORTS MPIS Data Verified By: ____ Date: ____

DEPTH (FEET)	SAMPLE TYPE	SAMPLE INTV	LITHOLOGY	DESCRIPTION
0				
	CS			**CL SILTY CLAY:** dk brown (7.5YR3/4) soft, damp, abund humus, root bundles, Topsoil
2				
4				**CL SILTY CLAY:** yellowish orange (10YR6/6), mod stiff, damp, common Fe nods, with some Mn nods root pores with Mn infill
	CS			
6				
8				
	CS			**CL SILTY CLAY:** lt brown (10YR5/6), with lt gray silt laminations, mod stiff, some yellowish orange clay inter-laminae, moist, light gray silt laminations up to 5mm at 11'
10				
12				**CH CLAY:** yellowish red (5YR4/6), damp, stiff, fat and plastic, with lt gray silt laminae up to 3mm oxidized Mn O2 nodules forming crystalline druzs around a soft mineral core
14				
16				
18				
20				



Borehole Summary Information

ornl OAK RIDGE NATIONAL LABORATORY

Prepared By: S.R. Sturm Date: 10/20/94 Page: 1 OF 1

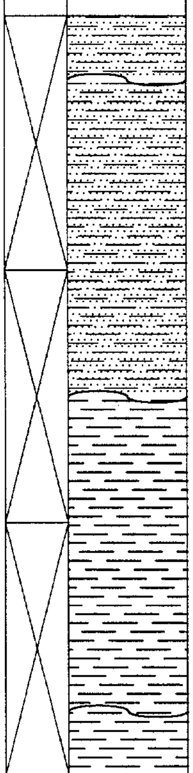
Hole No.: T3BB Ground Elevation: NA

Total Depth: 12' Rig Type: ORNL U2CRT Location: Test Cell #3

Auger Size: NA Sample Type: Geoprobe "Megabore 2" OD X 4'

Project: PORTS MPIS Data Verified By: Date:

DEPTH (FEET)	SAMPLE TYPE	SAMPLE INTV	LITHOLOGY	DESCRIPTION
0				
				CL SILTY CLAY: dk brown (7.5YR3/4) soft, damp, abund humus, root bundles, Topsoil
2	CS			
				CL SILTY CLAY: yellowish brown (10YR5/8), mod stiff, damp, common Fe nods, with some Mn nods
4				
				Decreasing nodules
6	CS			
				CH CLAY: lt yellow brown (10YR6/4), with lt gray silt laminations, mod stiff, damp, laminar bedding, fat, mod plastic
8				
10	CS			
				CH CLAY: Lt yellow brn (2.5YR6/4), damp, very fat and plastic, with lt gray silt laminae, pronounced bed partings
12				
14				
16				
18				
20				



Borehole Summary Information

ornl OAK RIDGE NATIONAL LABORATORY

Prepared By: S.R. Sturm Date: 10/20/94 Page: 1 OF 1

Hole No.: T3BC Ground Elevation: NA

Total Depth: 12' Rig Type: ORNL U2CRT Location: Test Cell #3

Auger Size: NA Sample Type: Geoprobe "Megabore 2" OD X 4'

Project: PORTS MPIS Data Verified By: Date:

DEPTH (FEET)	SAMPLE TYPE	DESCRIPTION
0		
1		CL SILTY CLAY: dk brown (7.5YR3/4) soft, damp, abund humus, root bundles, Topsoil
2	CS	
3		CL SILTY CLAY: yellowish brown (10YR5/8), mod stiff, damp, common Fe nods, with some Mn nods
4		
6	CS	CH CLAY: lt yellow brown (10YR5/4), with lt gray silt laminations, stiff, damp, laminar bedding, fat, mod plastic
8		
10	CS	
11		CH CLAY: Lt yellow brn (2.5YR6/4), damp, very fat and plastic, v. stiff, lt gray silt laminae, pronounced bed partings
12		
14		
16		
18		
20		

Borehole Summary Information

ornl OAK RIDGE NATIONAL LABORATORY

Prepared By: S.R. Sturm Date: 10/21/94 Page: 1 OF 1

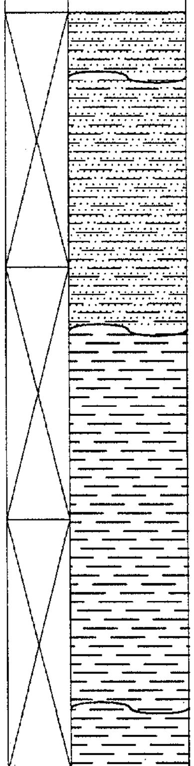
Hole No.: T3BD Ground Elevation: NA

Total Depth: 12' Rig Type: ORNL U2CRT Location: Test Cell #3

Auger Size: NA Sample Type: Geoprobe "Megabore 2" OD X 4'

Project: PORTS MPIS Data Verified By: ____ Date: ____

DEPTH (FEET)	SAMPLE TYPE	SAMPLE INTV	LITHOLOGY	DESCRIPTION
0				
				CL SILTY CLAY: dk brown (7.5YR3/4) soft, damp, abund humus, root bundles, Topsoil
2	CS			
				CL SILTY CLAY: yellowish brown (10YR6/8), mod stiff, damp, common Fe nods, some are dusky red, root pores w/ fine sand infill
4				
6	CS			CH CLAY: yellow brown (10YR5/6), with pale olive (5y6/3) mottle, stiff, damp, laminar bedding, coarse sand lens at 7.5' & 7.8'
8				
10	CS			
				CH CLAY: Lt yellow brn (2.5YR6/4), damp, slighty plastic, with lt gray silt laminae, pronounced bed partings
12				
14				
16				
18				
20				



Borehole Summary Information

ornl OAK RIDGE NATIONAL LABORATORY

Prepared By: S.R. Sturm Date: 10/20/94 Page: 1 OF 1

Hole No.: T3BE Ground Elevation: NA

Total Depth: 12' Rig Type: ORNL U2CRT Location: Test Cell #3

Auger Size: NA Sample Type: Geoprobe "Megabore 2" OD X 4'

Project: PORTS MPIS Data Verified By: ________ Date: ________

DEPTH (FEET)	SAMPLE TYPE	SAMPLE INTV	LITHOLOGY	DESCRIPTION
0				
1				CL SILTY CLAY: dk brown (7.5YR3/4) soft, damp, abund humus, root bundles, Topsoil
2	CS			
3				CL SILTY CLAY: yellowish brown (10YR5/8), mod stiff, damp, common Fe nods, Fe oxide on blocky structure clay faces
4				
6	CS			Clay as above but larger Fe nodules that are dusky red (10R3/4)
8				CH CLAY: dk yellow brown (10YR4/4), very stiff, damp, very fat and plastic, with lt gray silt laminations
10	CS			
11				CH CLAY: Lt yellow brn (2.5YR6/4), damp, very fat and plastic, with lt gray silt laminae, pronounced bed partings
12				
14				
16				
18				
20				

Borehole Summary Information

ornl OAK RIDGE NATIONAL LABORATORY

Prepared By: R.M. Schlosser Date: 11/19/94 Page: 1 OF 1

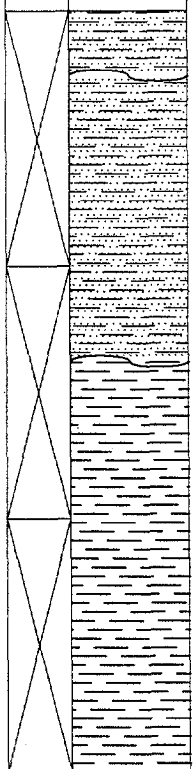
Hole No.: T3BF Ground Elevation: NA

Total Depth: 12' Rig Type: ORNL U2CRT Location: Test Cell #3

Auger Size: NA Sample Type: Geoprobe "Megabore 2" OD X 4'

Project: PORTS MPIS Data Verified By: ______ Date: ______

DEPTH (FEET)	SAMPLE TYPE	SAMPLE INTV	LITHOLOGY	DESCRIPTION
0				
				CL SILTY CLAY: dk brown (7.5YR3/4) soft, damp, abund humus, root bundles, wet from injection
2	CS			CL SILTY CLAY: yellowish brown (10YR5/8), mod stiff, damp, abund Fe staining 2 - 3', friable heavy Fe stained pebbles @ 4', lt gray mottle becoming more mottled with depth
4				
6	CS			CH CLAY: yellowish brown lt gray mottle, abund Fe and Mn oxides @ 5 - 5.5', scattered root hairs vessicles to 7', becoming firmer, waxy
8				
				CH CLAY: dk yellow brown (10YR4/4), mottled lt gray as above, well defined gray beds at 8.4' @ 8.6'
10	CS			
				lost core 10.1'- 12.0'
12				
14				
16				
18				
20				



Borehole Summary Information

orn1 OAK RIDGE NATIONAL LABORATORY

Prepared By: R.M. Schlosser Date: 11/19/94 Page: 1 OF 1

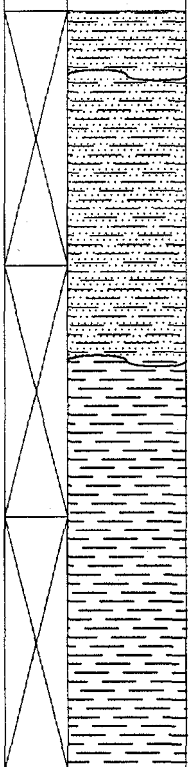
Hole No.: T3BG Ground Elevation: NA

Total Depth: 12' Rig Type: ORNL U2CRT Location: Test Cell #3

Auger Size: NA Sample Type: Geoprobe "Megabore 2" OD X 4'

Project: PORTS MPIS Data Verified By: Date:

DEPTH (FEET)	SAMPLE TYPE	SAMPLE INTV	LITHOLOGY	DESCRIPTION
0				
				CL SILTY CLAY: dk brown (7.5YR3/4) soft, damp, established root system to 12", friable
2	CS			CL SILTY CLAY: yellowish brown (10YR5/8), mod stiff, damp, abund Fe staining 1.5'- 4', friable Mn oxides and Fe nods from 3' - 5.5', oxides on vertical fractures and root vesicles
4				homogenous at 10'- 12', waxy appearance, damp, low angle fractures at 7'& 7.5'
6	CS			CH CLAY: yellowish brown lt gray mottle, becomes more defined @ 8.5' w/ mottling on vertical micro-fracs, firm, blocky structure, lower
8				
10	CS			
				CH Clay: yellowish brn 10YR5/8, as above, v stiff, well defined gray bed @ 9', 3 - 6mm thick
12				
14				
16				
18				
20				



Borehole Summary Information

ornl OAK RIDGE NATIONAL LABORATORY

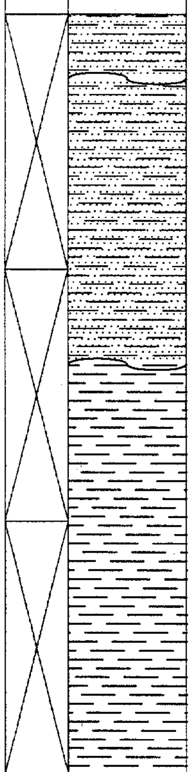
Prepared By: R.M. Schlosser | Date: 11/19/94 | Page: 1 OF 1

Hole No.: T3BH | Ground Elevation: NA

Total Depth: 12' | Rig Type: ORNL U2CRT | Location: Test Cell #3

Auger Size: NA | Sample Type: Geoprobe "Megabore 2" OD X 4'

Project: PORTS MPIS | Data Verified By: | Date:



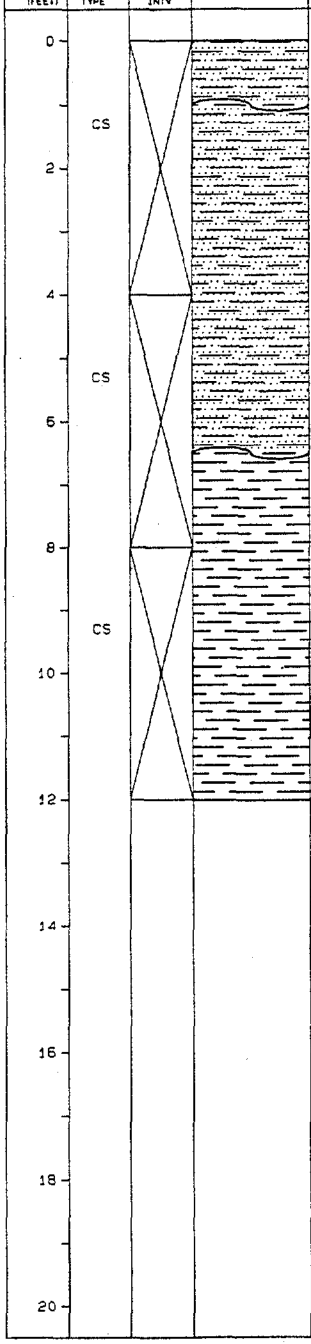
DEPTH (FEET)	SAMPLE TYPE	DESCRIPTION
0		
		CL SILTY CLAY: dk brown (7.5YR3/4) soft, damp, some yellow brown mottling, friable
2	CS	CL SILTY CLAY: yellowish brown (10YR5/8), mod stiff, damp, abund Fe staining 3'- 4', blocky structure, scattered Fe ox and pebbles 4.5' 5.5'
4		
6	CS	CH CLAY: yellowish brown lt gray mottle, some Mn oxides, scattered 2-3mm pebbles @ 7.5' well rnd becoming firm, Mn oxide in remnant root vesicles high angle fracture at 8.5'
8		
		CH CLAY: dk yellow brown (10YR4/4), mottled lt gray on beds and on vertical micro-fracs, trace roots @ 9', very stiff, well defined bedding, waxy
10	CS	
		CH ClAY: as above also mottled brownish yellow
12		
14		
16		
18		
20		

Borehole Summary Information

ornl OAK RIDGE NATIONAL LABORATORY

Prepared By: R.M. Schlosser Date: 11/19/94 Page: 1 OF 1
Hole No.: T3BI Ground Elevation: NA
Total Depth: 12' Rig Type: ORNL U2CRT Location: Test Cell #3
Auger Size: NA Sample Type: Geoprobe "Megabore 2" OD X 4'
Project: PORTS MPIS Data Verified By: Date:

DEPTH (FEET)	SAMPLE TYPE	SAMPLE INTV	LITHOLOGY	DESCRIPTION



CL SILTY CLAY: dk brown (10YR5/3) soft, damp, abund roots, organic rich

CL SILTY CLAY: yellowish brown (10YR5/8), lt gray mottle, some Fe staining @ 1' common by 4', soft friable, red oxidized pebbles, less silt w/depth

CL as above, abund pebbles 6 - 12mm dia., angular, heavy Fe staining

CL SILTY CLAY: yellowish brn, lt gray mottle on bed ding and some in vertical fractures, gypsiferous at 7.5', high angle fracture at 7.5'.

CH CLAY: yellowish brown (10YR5/8), mottled lt gray on beds, very thin distinct bedding, plastic, moist

Borehole Summary Information

ornl OAK RIDGE NATIONAL LABORATORY

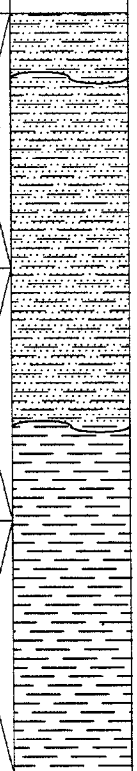
Prepared By: R.M. Schlosser Date: 11/19/94 Page: 1 OF 1

Hole No.: T3BJ Ground Elevation: NA

Total Depth: 12' Rig Type: ORNL U2CRT Location: Test Cell #3

Auger Size: NA Sample Type: Geoprobe "Megabore 2" OD X 4'

Project: PORTS MPIS Data Verified By: ______ Date: ______

DEPTH (FEET)	SAMPLE TYPE	SAMPLE INTV	LITHOLOGY	DESCRIPTION
0–4	CS	0–4		CL SILTY CLAY: dk brown (10YR5/3) soft, damp, abund roots, organic rich CL SILTY CLAY: yellowish brown (10YR5/8), lt gray mottle, Fe staining throughout, friable, soft
4–8	CS	4–8		CL SILTY CLAY: as above, abund pebbles @ 5'- 6.5' slight fracture at 6.7', less silty @ 6.5, gypsiferous @ 7.5', friable, stiffer @ 7' CH CLAY: yellowish brown (10YR5/8), mottled lt gray on beds, some lt gray on vertical micro fracs, lt gray reduced mudstone on dessicated surface @ 11.5', plastic, waxy appearance
8–12	CS	8–12		

Depth scale: 0, 2, 4, 6, 8, 10, 12, 14, 16, 18, 20

Borehole Summary Information

ornl OAK RIDGE NATIONAL LABORATORY

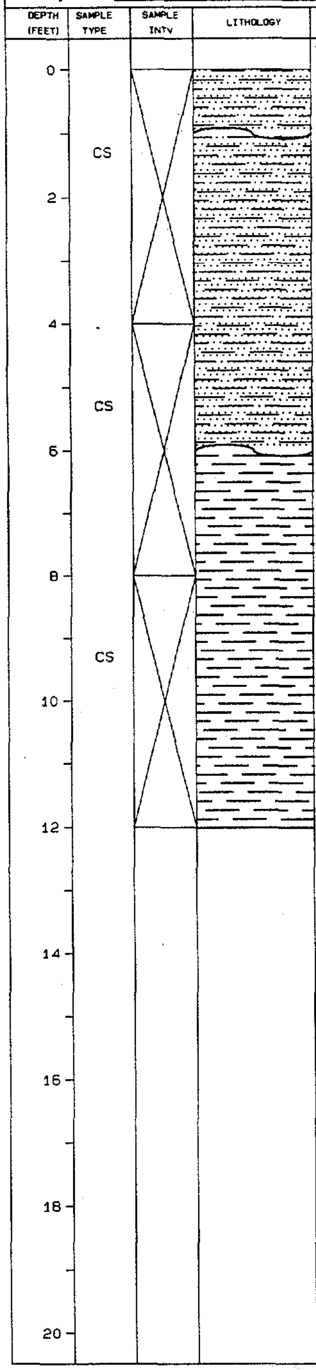
Prepared By: S.R. Sturm Date: 12/13/94 Page: 1 OF 1

Hole No.: T3BK Ground Elevation: NA

Total Depth: 12' Rig Type: ORNL U2CRT Location: Test Cell #3

Auger Size: NA Sample Type: Geoprobe "Megabore 2" OD X 4'

Project: PORTS MPIS Data Verified By: ______ Date: ______



DESCRIPTION

CL SILTY CLAY: dk brown (10YR5/3) soft, damp, abund humus, root bundles, Topsoil

CL SILTY CLAY: brownish yellow (10YR6/6), friable damp, lt gray mottle, some Mn oxides Fe staining common, scattered oxidized sandstone pebbles

CL CLAY: color change to 10 YR5/6, increasing clay content with olive green laminae, stiff, plastic

CH CLAY: brown (7.5YR5/6), stiff, damp, very fat and plastic, plastic texture, w/intbdd gray silt laminae, near vertical fracture at 6.7 becoming reddish at 11' - 12'

Borehole Summary Information

ornl OAK RIDGE NATIONAL LABORATORY

Prepared By: S.R. Sturm   Date: 12/13/94   Page: 1 OF 1

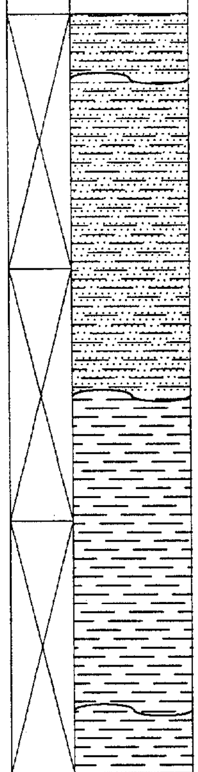
Hole No.: T3BL   Ground Elevation: NA

Total Depth: 12'   Rig Type: ORNL U2CRT   Location: Test Cell #3

Auger Size: NA   Sample Type: Geoprobe "Megabore 2" OD X 4'

Project: PORTS MPIS   Data Verified By: Date:

DEPTH (FEET)	SAMPLE TYPE	SAMPLE INTV	LITHOLOGY	DESCRIPTION
0				
1				CL SILTY CLAY: dk brown (10YR5/3) soft, damp, abund humus, root bundles, Topsoil
2	CS			CL SILTY CLAY: brownish yellow (10YR6/6), friable damp, lt gray mottle, some Mn oxides Fe staining common2.5 - 6.5', scattered oxidized sandstone pebbles
4				
6	CS			
8				CH CLAY: brown (7.5YR5/6), stiff, damp, very fat and plastic, plastic texture, w/intbdd gray silt laminae, gypsum crystals at 8.8'
10	CS			
11				CH CLAY: becoming red brown
12				
14				
16				
18				
20				



Borehole Summary Information

ornl OAK RIDGE NATIONAL LABORATORY

Prepared By: S.R. Sturm   Date: 10/23/94   Page: 1 OF 1

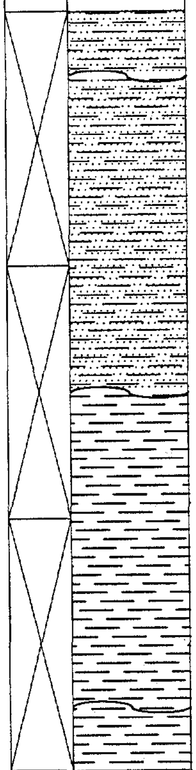
Hole No.: T4BA   Ground Elevation: NA

Total Depth: 12'   Rig Type: ORNL U2CRT   Location: Test Cell #4

Auger Size: NA   Sample Type: Geoprobe "Megabore 2" OD X 4'

Project: PORTS MPIS   Data Verified By: ____   Date: ____

DEPTH (FEET)	SAMPLE TYPE	SAMPLE INTV	LITHOLOGY	DESCRIPTION
0				
				CL SILTY CLAY: dk brown (7.5YR3/4) soft, damp, friable, abund humus, root bundles, Topsoil
2	CS			
				CL SILTY CLAY: yellowish brown (10YR5/8), very stiff, dry, common Fe nods, some Mn flecks
4				
				High angle fractures with argillaceous faces @ 5.5', 6.3', 7.5'
6	CS			
				CH CLAY: lt yellow brown (10YR5/4), intbdd lt gray silt laminations, stiff, damp, laminar bedding, fat, mod plastic, authegenic gypsum crystals beds @ 7.0' and 7.5'
8				
10	CS			Mudstone pebbles @ 10.5'
12				CH CLAY: Lt yellow brn (2.5YR6/4), damp, very fat and plastic, v. stiff, pronounced bed parting
14				
16				
18				
20				



Borehole Summary Information

ornl OAK RIDGE NATIONAL LABORATORY

Prepared By: S.R. Sturm Date: 10/24/94 Page: 1 OF 1

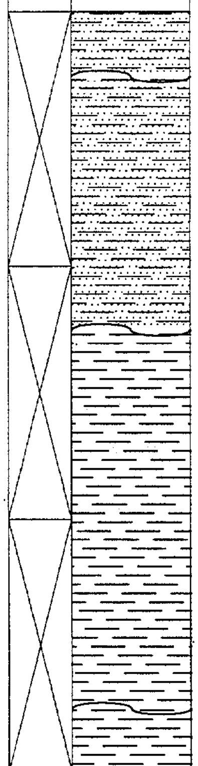
Hole No.: T4BB Ground Elevation: NA

Total Depth: 12' Rig Type: ORNL U2CRT Location: Test Cell #4

Auger Size: NA Sample Type: Geoprobe "Megabore 2" OD X 4'

Project: PORTS MPIS Data Verified By: ______ Date: ______

DEPTH (FEET)	SAMPLE TYPE	SAMPLE INTV	LITHOLOGY	DESCRIPTION
0				
				CL SILTY CLAY: dk brown (7.5YR3/4) soft, damp, friable, abund humus, root bundles, breaks into stair step planar faces
2	CS			
4				CL SILTY CLAY: yellowish brown (10YR5/8), very stiff, dry, common Fe nods, some Mn flecks
				High angle fractures with argillaceous faces @ 5.5', 5.9' & 7.2'
6	CS			
				CH CLAY: lt yellow brown (10YR5/4), intbdd lt gray silt laminations, stiff, damp, laminar bedding, fat, mod plastic, authegenic gypsum crystals beds @ 7.0', lost core 7.1' to 8.0'
8				
				High angle fractures @8.3', 8.4', 8.5', 8.6' and
10	CS			
				CH CLAY: brn (7.5YR5/4), damp, very fat and plastic with intbdd yellow brn and red laminae, variegated
12				
14				
16				
18				
20				



Borehole Summary Information

ornl OAK RIDGE NATIONAL LABORATORY

Prepared By: S.R. Sturm Date: 10/24/94 Page: 1 OF 1

Hole No.: T4BC Ground Elevation: NA

Total Depth: 12' Rig Type: ORNL U2CRT Location: Test Cell #4

Auger Size: NA Sample Type: Geoprobe "Megabore 2" OD X 4'

Project: PORTS MPIS Data Verified By: Date:

DEPTH (FEET)	SAMPLE TYPE	SAMPLE INTV	LITHOLOGY	DESCRIPTION
0				
				CL SILTY CLAY: dk brown (7.5YR3/4) soft, damp, friable, abund humus, root bundles, Topsoil
2	CS			
				CL SILTY CLAY: yellowish brown (10YR5/8), very stiff, damp, common Fe nods, some are dusky red
4				
				CL Clay: brn (7.5YR5/6) with greenish gray silt laminae, fat and plastic, damp
6	CS			
				CH CLAY: lt yellow brown (10YR5/4), intbdd lt gray silt laminations, stiff, damp, laminar bedding, fat, mod plastic, authegenic gypsum crystals beds @ 7.2', 7.4' and 7.6'
8				
				CH CLAY: brn (7.5YR5/6) fat, plastic, stiff, damp, homogenous
10	CS			
				CH CLAY: brn (7.5YR5/6) damp, mod plastic, stiff, variegated by yellow (10YR7/8) and red laminae
12				
14				
16				
18				
20				

Borehole Summary Information

ornl OAK RIDGE NATIONAL LABORATORY

Prepared By: S.R. Sturm Date: 10/23/94 Page: 1 OF 1

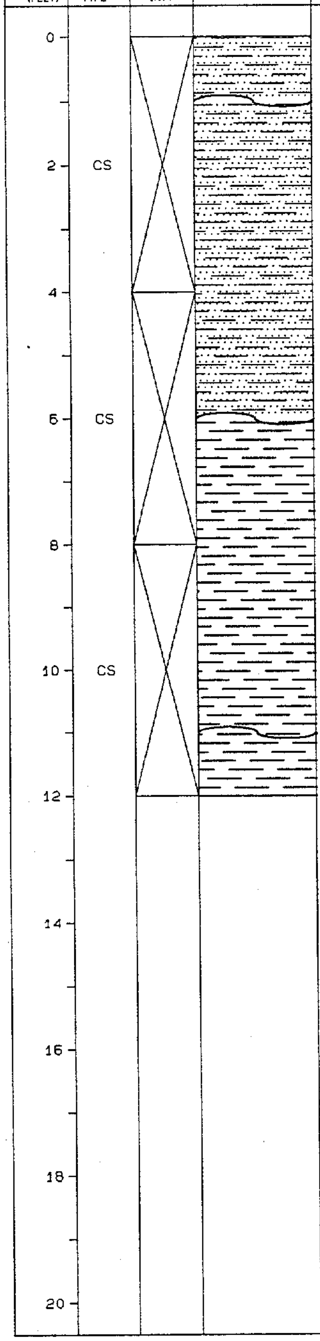
Hole No.: T4BD Ground Elevation: NA

Total Depth: 12' Rig Type: ORNL U2CRT Location: Test Cell #4

Auger Size: NA Sample Type: Geoprobe "Megabore 2" OD X 4'

Project: PORTS MPIS Data Verified By: Date:

DEPTH (FEET)	SAMPLE TYPE	SAMPLE INTV	LITHOLOGY	DESCRIPTION



CL SILTY CLAY: dk brown (7.5YR3/4) soft, damp, friable, abund humus, root bundles, Topsoil

CL SILTY CLAY: yellowish brown (10YR5/8), with lt gray mottle, damp, friable, common Fe staining, becoming dry and hard at 4'

High angle fractures at 6.7', 7.0' and 7.1', latter two intersect and have xtal gypsum infill

CH CLAY: lt yellow brown (10YR5/4), intbdd lt gray silt laminations, stiff, damp, laminar bedding, fat, mod plastic, authegenic gypsum crystals beds @ 7.9'

Dendritic Mn oxide staining on silt laminae partings

CH CLAY: brn (7.5YR5/4), damp, very fat and plastic, v. stiff, pronounced bed partings, homogenous

Borehole Summary Information

ornl OAK RIDGE NATIONAL LABORATORY

Prepared By: S.R. Sturm Date: 10/23/94 Page: 1 OF 1

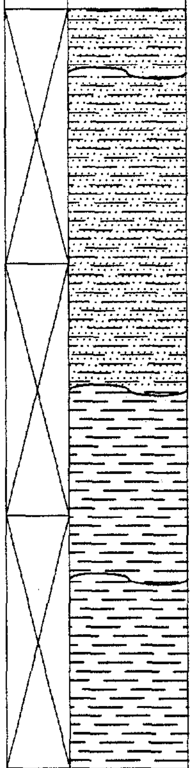
Hole No.: T4BE Ground Elevation: NA

Total Depth: 12' Rig Type: ORNL U2CRT Location: Test Cell #4

Auger Size: NA Sample Type: Geoprobe "Megabore 2" OD X 4'

Project: PORTS MPIS Data Verified By: Date:

DEPTH (FEET)	SAMPLE TYPE	SAMPLE INTV	LITHOLOGY	DESCRIPTION
0				
				CL SILTY CLAY: dk brown (7.5YR3/4) soft, damp, friable, abund humus, root bundles, Topsoil
2	CS			
				CL SILTY CLAY: yellowish brown (10YR5/8), with lt gray mottle, friable, damp, common Fe staining. becomes hard and dry by 4' with abund Fe nods
4				
				High angle fracture at 6.1'
6	CS			CH CLAY: lt yellow brown (10YR5/4), intbdd lt gray silt laminations, stiff, damp, laminar bedding, fat, mod plastic, authegenic gypsum crystals beds @ 7.0'
8				LOST CORE 7.0 - 8.0'
10	CS			
12				CH CLAY: brn (7.5YR5/4), damp, very fat and plastic, v. stiff, pronounced 1mm bed partings, homogenous
14				
16				
18				
20				



Borehole Summary Information

ornl OAK RIDGE NATIONAL LABORATORY

Prepared By: R.M. Schlosser Date: 11/14/94 Page: 1 OF 1

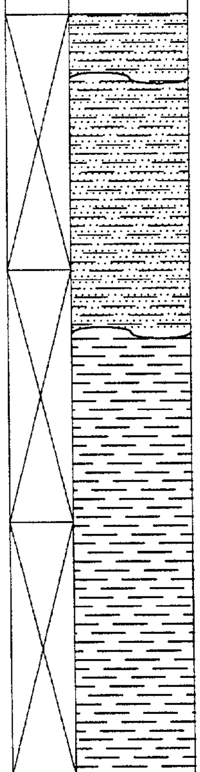
Hole No.: T4BF Ground Elevation: NA

Total Depth: 12' Rig Type: ORNL U2CRT Location: Test Cell #4

Auger Size: NA Sample Type: Geoprobe "Megabore 2" OD X 4'

Project: PORTS MPIS Data Verified By: Date:

DEPTH (FEET)	SAMPLE TYPE	SAMPLE INTV	LITHOLOGY	DESCRIPTION
0				
				CL SIBTY CLAY: brown (10YR5/3) soft, damp . friable, CaCo3 in root pores
2	CS			CL SILTY CLAY: yellowish brown (10YR5/8), with lt Fe staining throughout, roots as above
4				CL SILTY CLAY: as above, abund Fe oxides, Mn oxides on open pores, and some CaCo3, 4'- 8'
6	CS			CH CLAY: yellow brown (7.5YR5/4), some silt and Mn oxide on desicated surfaces, lt gray mottle throughout interval, very firm, plastic, occ
8				
10	CS			CH CLAY: yellow brn (7.5YR5/4), well defined bed partings @ 10', 10.2', 10.6', & 10.9', lt gray mottle throughout decreasing w/depth, high angle fracture @ 11.5'
12				
14				
16				
18				
20				



Borehole Summary Information

ornl OAK RIDGE NATIONAL LABORATORY

Prepared By: R.M. Schlosser Date: 11/14/94 Page: 1 OF 1

Hole No.: T4BG Ground Elevation: NA

Total Depth: 12' Rig Type: ORNL U2CRT Location: Test Cell #4

Auger Size: NA Sample Type: Geoprobe "Megabore 2" OD X 4'

Project: PORTS MPIS Data Verified By: Date:

DEPTH (FEET)	SAMPLE TYPE	SAMPLE INTV	LITHOLOGY	DESCRIPTION
0				
				CL **SILTY CLAY:** brown (10YR5/3) soft, damp , friable, CaCo3 from injection in root pores
2	CS			CL **SILTY CLAY:** yellowish brown (10YR5/8), with lt Fe staining throughout, soft, friable
4				CL **SILTY CLAY:** as above, abund Fe oxides, some red Fe nodules
6	CS			CH **CLAY:** brown (7.5YR5/4), mottled lt gray
				on desicated surfaces, abund Mn & Fe oxide, some scattered red nodules, lost core 7'- 8'
8				
10	CS			CH **CLAY:** yellow brn (7.5YR5/4), gypsiferous, some Fe nodules, desication surface @ 10.5'desication cracksw/ lt gray silt infill
12				
14				
16				
18				
20				

Borehole Summary Information

ornl OAK RIDGE NATIONAL LABORATORY

Prepared By: R.M. Schlosser Date: 11/14/94 Page: 1 OF 1

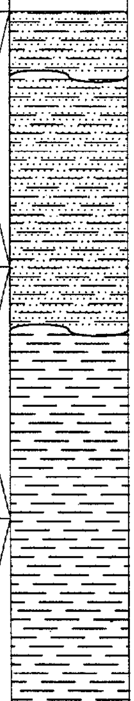
Hole No.: T4BH Ground Elevation: NA

Total Depth: 11' Rig Type: ORNL U2CRT Location: Test Cell #4

Auger Size: NA Sample Type: Geoprobe "Megabore 2" OD X 4'

Project: PORTS MPIS Data Verified By: Date:

DEPTH (FEET)	SAMPLE TYPE	SAMPLE INTV	LITHOLOGY	DESCRIPTION
0				
				CL SILTY CLAY: brown (10YR5/3) soft, damp , friable, CaCo3 from injection in root pores
2	CS			CL SILTY CLAY: yellowish brown (10YR5/8), with lt Fe staining w/occasional Mn staining & oxides
4				CL SILTY CLAY: yellowish brown w/ lt gray mottle trace CaCo3 from injection, occasional Fe nods @ 5'
6	CS			CH CLAY: brown (7.5YR5/4), mottled lt gray
				on desicated surfaces, abund Mn & Fe staining
8				and homogenous at 10'
10	CS			CH CLAY: yellow brn (7.5YR5/4), silt on erosional surface @ 9', 9.5', & 9.8', some silt fragments
12				
14				
16				
18				
20				



ornl OAK RIDGE NATIONAL LABORATORY

Borehole Summary Information

Prepared By: R.M. Schlosser Date: 11/14/94 Page: 1 OF 1

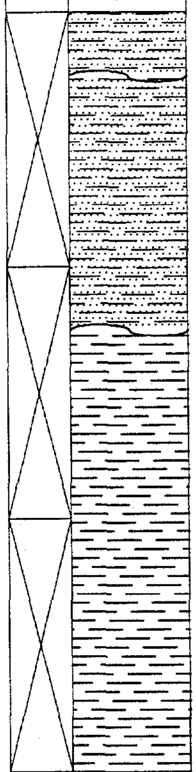
Hole No.: T4BI Ground Elevation: NA

Total Depth: 12' Rig Type: ORNL U2CRT Location: Test Cell #4

Auger Size: NA Sample Type: Geoprobe "Megabore 2" OD X 4'

Project: PORTS MPIS Data Verified By: ______ Date: ______

DEPTH (FEET)	SAMPLE TYPE	SAMPLE INTV	LITHOLOGY	DESCRIPTION



Depth (feet): 0, 2, 4, 6, 8, 10, 12, 14, 16, 18, 20

Sample type: CS (2), CS (6), CS (10)

CL SILTY CLAY: brown (10YR5/3) well developed root mass, some CaCo3 from injection around roots, soft, friable

CL SILTY CLAY: yellowish brown (10YR5/8), with lt Fe staining, some CaCo3 on bedding surfaces, soft, friable, vertical micro-fracs w/ CaCo3

CL SILTY CLAY: yellowish brown , CaCo3along small vertical fracture planes, high angle fracture @ 5', 3 - 5mm angular Fe stained sandstone liths becoming firm, scattered 1 - 2mm Fe? nods

CH CLAY: brown (7.5YR5/4), mottled lt gray 7.5YRN7/ firm, slightly plastic, gypsiferous zones @ 7.2'

gypsum filled vugs @ 11.5', 2 - 5mm thick

CH CLAY: yellow brn (7.5YR5/4), mottled bands @ 9.5

CH CLAY: yellow brown, very firm, fat & plastic, waxy appearance.

Borehole Summary Information

ornl OAK RIDGE NATIONAL LABORATORY

Prepared By: R.M. Schlosser Date: 11/14/94 Page: 1 OF 1

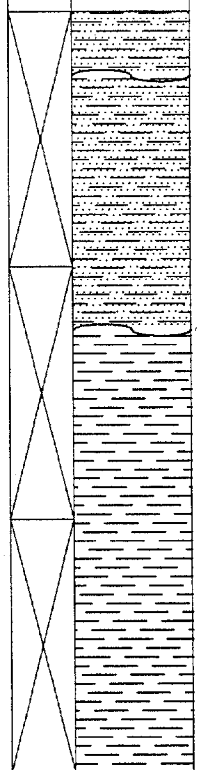
Hole No.: T4BJ Ground Elevation: NA

Total Depth: 12' Rig Type: ORNL U2CRT Location: Test Cell #4

Auger Size: NA Sample Type: Geoprobe "Megabore 2" OD X 4'

Project: PORTS MPIS Data Verified By: ______ Date: ______

DEPTH (FEET)	SAMPLE TYPE	SAMPLE INTV	LITHOLOGY	DESCRIPTION
0				
				CL SILTY CLAY: brown (10YR5/3) well developed root mass, some CaCo3 from injection around roots, soft, friable
2	CS			CL SILTY CLAY: yellowish brown (10YR5/8), abund Fe staining, abund CaCo3 along bedding fractures occasional Mn staining
4				CL SILTY CLAY: yellowish brown , CaCo3 along horiz bedding planes, some CaCO3 along remnant & root vesicles, strong Mn staining @ 5'
6	CS			
				CH CLAY: brown (7.5YR5/4), mottled lt gray 7.5YRN7/ high angle fracture @ 6', bedding fracture @ 7' very firm, plastic, occasional gypsiferous zones waxy appearance, lt gray bed at 9', 3 - 4mm silt stone bed @ 9.5', vug w/ gypsum @ 9.8'
8				
10	CS			
				CH CLAY: yellow brown, less mottling, dense, fat waxy appearance.
12				
14				
16				
18				
20				



Borehole Summary Information

ornl OAK RIDGE NATIONAL LABORATORY

Prepared By: S.R. Sturm Date: 12/13/94 Page: 1 OF 1

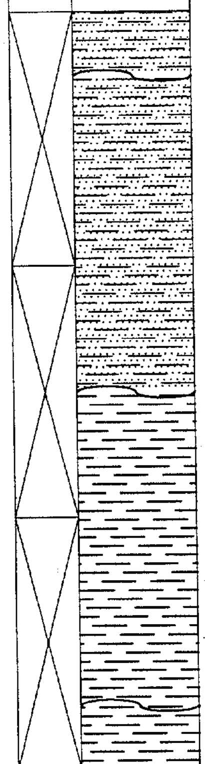
Hole No.: T4BK Ground Elevation: NA

Total Depth: 12' Rig Type: ORNL U2CRT Location: Test Cell #4

Auger Size: NA Sample Type: Geoprobe "Megabore 2" OD X 4'

Project: PORTS MPIS Data Verified By: ______ Date: ______

DEPTH (FEET)	SAMPLE TYPE	SAMPLE INTV	LITHOLOGY	DESCRIPTION
0				
				CL SILTY CLAY: dk brown (10YR5/3) soft, damp, abund humus, root bundles, Topsoil
2	CS			CL SILTY CLAY: brownish yellow (10YR6/6), friable damp, lt gray mottle, some Mn oxides Fe staining common 1'- 7', scattered oxidized sandstone pebbles, bed parting at 4.5' no infill
4				
6	CS			
				CH CLAY: brown (7.5YR5/6), stiff, damp, very fat and plastic, plastic texture, w/intbdd gray silt laminae, gypsum crystals at 6.5'& 7' mudstone pebbles at 9.8'
8				
10	CS			
				CH CLAY: becoming red brown
12				
14				
16				
18				
20				



Borehole Summary Information

orn l OAK RIDGE NATIONAL LABORATORY

Prepared By: S.R. Sturm Date: 12/13/94 Page: 1 OF 1

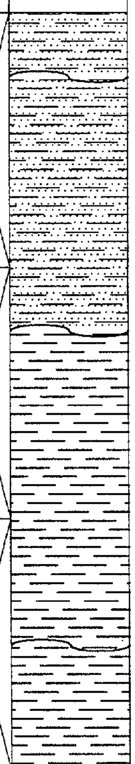
Hole No.: T4BL Ground Elevation: NA

Total Depth: 12' Rig Type: ORNL U2CRT Location: Test Cell #4

Auger Size: NA Sample Type: Geoprobe "Megabore 2" OD X 4'

Project: PORTS MPIS Data Verified By: Date:

DEPTH (FEET)	SAMPLE TYPE	SAMPLE INTV	LITHOLOGY	DESCRIPTION
0				
				CL SILTY CLAY: dk brown (10YR5/3) soft, damp, abund humus, root bundles, Topsoil
2	CS			CL SILTY CLAY: brownish yellow (10YR6/6), friable damp, lt gray mottle, some Mn oxides Fe staining common 1'- 5', scattered oxidized sandstone pebbles, bed parting at 3.2' with lime precipitates
4				
6	CS			
				CH CLAY: brown (7.5YR5/6), stiff, damp, very fat and plastic, plastic texture, w/intbdd gray silt laminae, gypsum crystals at 7.8', low angle fracture at 6.2'- no infill
8				CH CLAY: becoming red brown
10	CS			
12				
14				
16				
18				
20				



Borehole Summary Information

ornl OAK RIDGE NATIONAL LABORATORY

Prepared By: S.R. Sturm Date: 10/21/94 Page: 1 OF 1

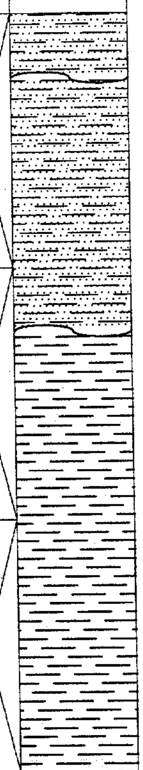
Hole No.: T5BA Ground Elevation: NA

Total Depth: 12' Rig Type: ORNL U2CRT Location: Test Cell #5

Auger Size: NA Sample Type: Geoprobe "Megabore 2" OD X 4'

Project: PORTS MPIS Data Verified By: ______ Date: ______

DEPTH (FEET)	SAMPLE TYPE	SAMPLE INTV	LITHOLOGY	DESCRIPTION
0				
				CL SILTY CLAY: dk brown (7.5YR3/4) soft, damp, friable, abund humus, root bundles, Topsoil
2	CS			
				CL SILTY CLAY: yellowish brown (10YR5/8), with lt gray mottle, friable, damp, common Fe staining, becomes hard and dry by 3'with abund Fe nods
4				
				High angle fracture at 5.2'and 6.3'
6	CS			CH CLAY: lt yellow brown (10YR5/4), intbdd pale olive silt laminations, stiff, damp, very fat, mod plastic, parallel discontinous bedding.
				LOST CORE 7.0 - 8.0'
8				
10	CS			CH CLAY: as above with dendritric Mn oxide on bed partings
12				
14				
16				
18				
20				



Borehole Summary Information

ornl OAK RIDGE NATIONAL LABORATORY

Prepared By: S.R. Sturm Date: 10/22/94 Page: 1 OF 1

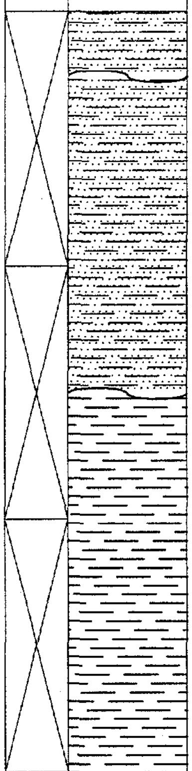
Hole No.: T5BB Ground Elevation: NA

Total Depth: 12' Rig Type: ORNL U2CRT Location: Test Cell #5

Auger Size: NA Sample Type: Geoprobe "Megabore 2" OD X 4'

Project: PORTS MPIS Data Verified By: Date:

DEPTH (FEET)	SAMPLE TYPE	SAMPLE INTV	LITHOLOGY	DESCRIPTION
0				
				CL SILTY CLAY: dk brown (7.5YR3/4) soft, damp, friable, abund humus, root bundles, Topsoil
2	CS			
				CL SILTY CLAY: yellowish brown (10YR5/8), friable blocky structure, abund Fe nods <1mm, becomes dry and hard by 4'
4				
6	CS			**CH CLAY:** lt yellow brown (10YR5/8), intbdd lt gray silt laminations, stiff, damp, laminar bedding, fat, mod plastic, occasional greenish gray (5G5/1) silt laminae w/ dendritic Mn oxide
8				LOST CORE 7.0 - 8.0'
10	CS			
12				**CH CLAY:** brn (7.5YR5/4), damp, very fat and plastic, v. stiff, pronounced 1mm bed partings, homogenous
14				
16				
18				
20				



Borehole Summary Information

ornl OAK RIDGE NATIONAL LABORATORY

Prepared By: S.R. Sturm Date: 10/22/94 Page: 1 OF 1

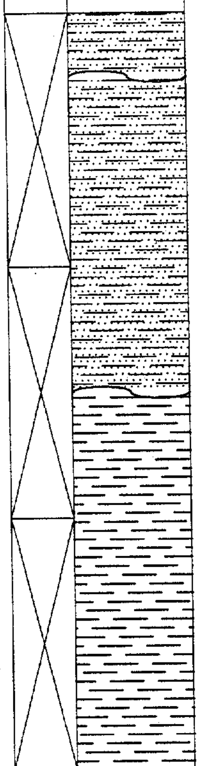
Hole No.: T5BC Ground Elevation: NA

Total Depth: 12' Rig Type: ORNL U2CRT Location: Test Cell #5

Auger Size: NA Sample Type: Geoprobe "Megabore 2" OD X 4'

Project: PORTS MPIS Data Verified By: ____ Date: ____

DEPTH (FEET)	SAMPLE TYPE	SAMPLE INTV	LITHOLOGY	DESCRIPTION
0				
				CL SILTY CLAY: dk brown (7.5YR3/4) soft, damp, friable, abund humus, root bundles, Topsoil
2	CS			
				CL SILTY CLAY: yellowish brown (10YR5/8), increased clay becomes hard and dry by 4' with abund Fe nod up to 2mm
4				
6	CS			CH CLAY: lt yellow brown (10YR5/4), intbdd lt gray silt laminations, stiff, damp, paralell laminar bedding, fat, plastic
				LOST CORE 7.0 - 8.0'
8				
10	CS			
12				CH CLAY: brn (7.5YR5/4), with lt gray silt laminae easily split at bed partings, stiff, damp, uneven parallel beds
14				
16				
18				
20				



Borehole Summary Information

ornl OAK RIDGE NATIONAL LABORATORY

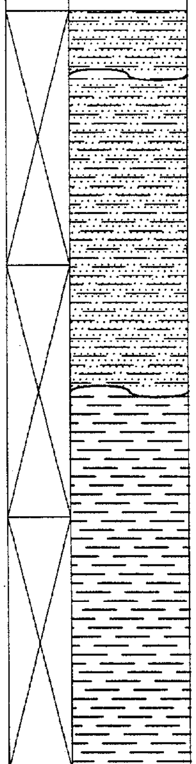
Prepared By: S.R. Sturm Date: 10/22/94 Page: 1 OF 1

Hole No.: T5BD Ground Elevation: NA

Total Depth: 12' Rig Type: ORNL U2CRT Location: Test Cell #5

Auger Size: NA Sample Type: Geoprobe "Megabore 2" OD X 4'

Project: PORTS MPIS Data Verified By: Date:

DEPTH (FEET)	SAMPLE TYPE	SAMPLE INTV	LITHOLOGY	DESCRIPTION
0				
				CL SILTY CLAY: dk brown (7.5YR3/4) soft, damp, friable, abund humus, root bundles, Topsoil
2	CS			
				CL SILTY CLAY: yellowish brown (10YR5/8), friable but stiff, damp, common Fe nodules < 1mm becomes hard and dry by 3'
4				
				High angle fracture w/ clay skins @ 5.8'
6	CS			CH CLAY: lt yellow brown (10YR5/8), intbdd lt gray silt laminations, stiff, damp, laminar bedding, fat, mod plastic
8				LOST CORE 7.0 - 8.0'
				CH CLAY: yellow brn (10YR5/4), damp, very fat and plastic, w/ intbdd dk brn clay and green gray silt laminae, lt gray mudstone pebbles in a dessicated zone at 11.9'
10	CS			
12				
14				
16				
18				
20				

Borehole Summary Information

ornl OAK RIDGE NATIONAL LABORATORY

Prepared By: S.R. Sturm Date: 10/21/94 Page: 1 OF 1

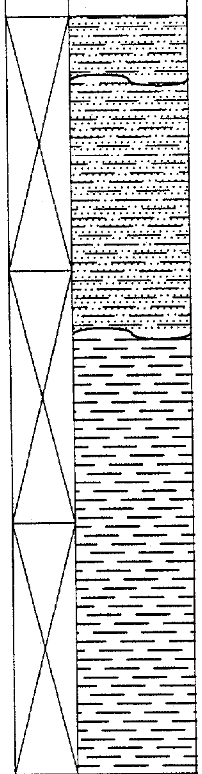
Hole No.: T5BE Ground Elevation: NA

Total Depth: 12' Rig Type: ORNL U2CRT Location: Test Cell #5

Auger Size: NA Sample Type: Geoprobe "Megabore 2" OD X 4'

Project: PORTS MPIS Data Verified By: Date:

DEPTH (FEET)	SAMPLE TYPE	SAMPLE INTV	LITHOLOGY	DESCRIPTION
0				
				CL SILTY CLAY: dk brown (7.5YR3/4) soft, damp, friable, abund humus, root bundles, Topsoil
2	CS			
				CL SILTY CLAY: yellowish brown (10YR5/8), with lt gray mottle, friable, damp, common Fe staining, becomes hard and dry by 3' with abund Fe nods
4				
				High angle fracture at 6.1' and 6.2'
6	CS			CH CLAY: lt yellow brown (10YR5/4), intbdd pale olive silt laminations, stiff, damp, very fat, mod plastic, parallel discontinous bedding,
8				LOST CORE 7.6' - 8.0'
				High angle fracture at 9.0' @ 9.5'
10	CS			CH CLAY: as above with increased silt lams and zones of friable silt with dessication fractures
12				
14				
16				
18				
20				



ornl OAK RIDGE NATIONAL LABORATORY

Borehole Summary Information

Prepared By: R.M. Schlosser Date: 11/17/94 Page: 1 OF 1

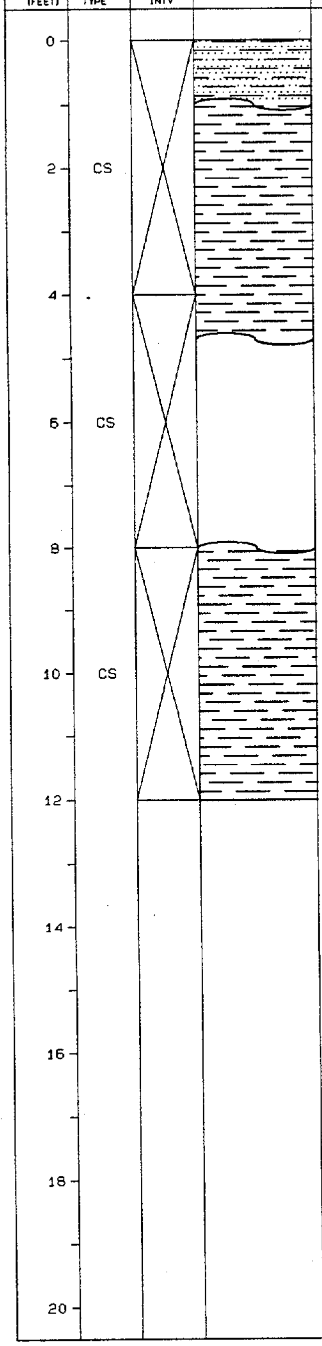
Hole No.: T5BF Ground Elevation: NA

Total Depth: 12' Rig Type: ORNL U2CRT Location: Test Cell #5

Auger Size: NA Sample Type: Geoprobe "Megabore 2" OD X 4'

Project: PORTS MPIS Data Verified By: Date:

DEPTH (FEET)	SAMPLE TYPE	SAMPLE INTV	LITHOLOGY	DESCRIPTION



CL **SILTY CLAY:** brown (10YR5/3), some purple staining from KMNO4 in upper 8", from surface penetration, friable.

CL **SILTY CLAY:** as above, KMNO4 staing @ 3', 4.5' and at 4.7.
CL **SILTY CLAY:** Yellowish brown, (10YR6/8), mottled slightly light gray, friable, Fe staining throughout.

LOST 4.7'-8.0'.

CL **CLAY:** yellowish brown mottled light gray along bedding fraxtures at 9.2',9.4', and 9.5', firm, stiff, waxy apperance, becoming more homogeneous less reduction at 10.0'.

Borehole Summary Information

ornl OAK RIDGE NATIONAL LABORATORY

Prepared By: R.M. Schlosser Date: 11/17/94 Page: 1 OF 1

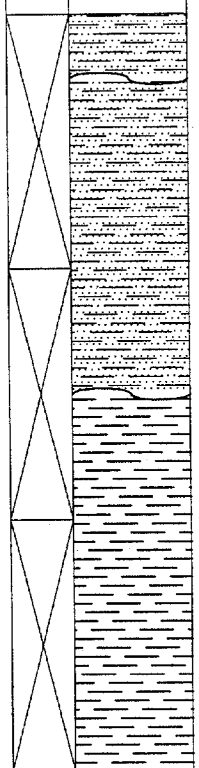
Hole No.: T5BG Ground Elevation: NA

Total Depth: 12' Rig Type: ORNL U2CRT Location: Test Cell #5

Auger Size: NA Sample Type: Geoprobe "Megabore 2" OD X 4'

Project: PORTS MPIS Data Verified By: Date:

DEPTH (FEET)	SAMPLE TYPE	SAMPLE INTV	LITHOLOGY	DESCRIPTION
0				
				CL SILTY CLAY: brown (10YR5/3), abund roots
2	CS			CL SILTY CLAY: yellowish brown (10YR5/8), very strong KMNO4 along fracture at 3.1', some Fe & Mn staining
4				CL SILTY CLAY: as above, lt KMNO4 staining at 3.5' (staining 10R5/4 weak red) some Mn oxides @ 4'
				CL SILTY CLAY: yellowish brown, strong Fe stained pebbles @ 5.5', abundant Mn oxides 4' - 5.5', pebbly zone @ 5.6' stained w/KMNO4, lt staining @ 5.7', 6.1', & 6.9', strong staining & fracs @ 7.1' & 7.5', less silt becoming clay @ 6.5'
6	CS			
8				
				CH CLAY: yellow brn (7.5YR5/4), mottled lt gray, lt gray zone 4 - 6mm wide @ 8.5', KMNO4 along bedding @ 8.7', 9', 10', 10.2', bed parting at
10	CS			
				some weak red staining @ 11.5'
12				
14				
16				
18				
20				



Borehole Summary Information

ornl OAK RIDGE NATIONAL LABORATORY

Prepared By: R.M. Schlosser	Date: 11/17/94	Page: 1 OF 1
Hole No.: T5BH	Ground Elevation: NA	
Total Depth: 12'	Rig Type: ORNL U2CRT	Location: Test Cell #5
Auger Size: NA	Sample Type: Geoprobe "Megabore 2" OD X 4'	
Project: PORTS MPIS	Data Verified By:	Date:

DEPTH (FEET)	SAMPLE TYPE	SAMPLE INTV	LITHOLOGY	DESCRIPTION
0				
				CL **SILTY CLAY**: brown (10YR5/3), abund roots top 6", KMNO4 staining from surface seepage, friable, soft, moist
2	CS			CL **SILTY CLAY**: yellowish brown (10YR5/8), very strong KMNO4 staining 2cm wide at 2.9', lt staining along fractures @ 3.9'& 4.2', lt gray mottle
4				CL **SILTY CLAY**: as above, abundant Mn & Fe oxides occasional 2 - 3mm pebbles, strong KMNO4 stain in pebbly zones @ 4.8', 5.5', 5.8', & 7.8'
6	CS			
				CH **CLAY**: yellowish brown, mottled lt gray , lt gray reduced zone 3 - 8mm wide @ 8.5', occasionl roots
8				
10	CS			CH **CLAY**: yellow brn (7.5YR5/4), mottled lt gray, becoming darker w/depth, moist, firm, well defined beds, KMNO4 staining @ 8.7', 8.9', & 9'
12				
14				
16				
18				
20				

Borehole Summary Information

ornl OAK RIDGE NATIONAL LABORATORY

Prepared By: R.M. Schlosser Date: 11/17/94 Page: 1 OF 1

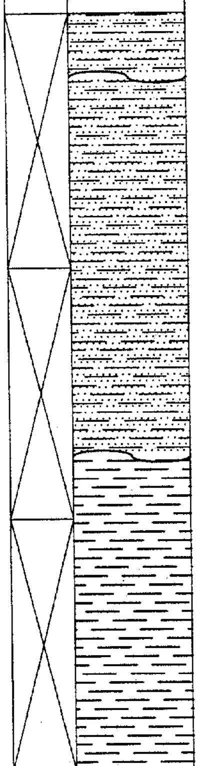
Hole No.: T5BI Ground Elevation: NA

Total Depth: 12' Rig Type: ORNL U2CRT Location: Test Cell #5

Auger Size: NA Sample Type: Geoprobe "Megabore 2" OD X 4'

Project: PORTS MPIS Data Verified By: ____ Date: ____

DEPTH (FEET)	SAMPLE TYPE	SAMPLE INTV	LITHOLOGY	DESCRIPTION
0				
2	CS			
4				
6	CS			
8				
10	CS			
12				
14				
16				
18				
20				



CL **SILTY CLAY:** brown (10YR5/3), well developed root mass, some Fe staining, some faint KMNO4 staining in upper 2'

CL **SILTY CLAY:** yellowish brown (10YR5/8), Fe staining and Mn oxides, roots, KMNO4 staining very strong @ 2.8', friable, soft, scattered pebbles @ 3.5', mottled vertically and horzontal w/lt gray silt

CL **SILTY CLAY:** as above, abundant pebbles @ 4.2' Mn & Fe staining and oxides, KMNO4 staining on fracture @ 3.8'; staining on bedding @ 6.1', 6.3

CH **CLAY:** yellowish brown, lt gray mottle, occasional Fe stained pebbles 5'- 6', KMNO4 staining 10R4/4 - 10R5/4 weak red to red

gray-brn mudstone on desicated surface, very gypsiferous from 10.2' - 10.5', some crystal development, very well defined beds

CH **CLAY:** yellow brn (7.5YR5/4), KMNO4 staining @ 8.2

Borehole Summary Information

ornl OAK RIDGE NATIONAL LABORATORY

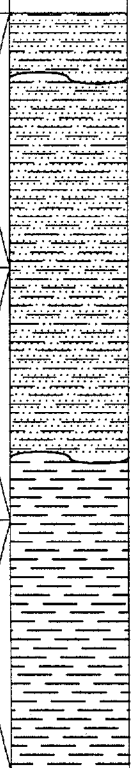
Prepared By: R.M. Schlosser   Date: 11/17/94   Page: 1 OF 1

Hole No.: T5BJ   Ground Elevation: NA

Total Depth: 12'   Rig Type: ORNL U2CRT   Location: Test Cell #5

Auger Size: NA   Sample Type: Geoprobe "Megabore 2" OD X 4'

Project: PORTS MPIS   Data Verified By: ______   Date: ______

DEPTH (FEET)	SAMPLE TYPE	SAMPLE INTV	LITHOLOGY	DESCRIPTION
0–4	CS	0–4		CL SILTY CLAY: brown (10YR5/3), well developed root mass, some Fe staining, becoming yellow brn @ 1.5', dark KMNO4 stain at 3', 2.5cm wide, abund pebbles @ 3.5'strongly oxidized, soft to 3' becoming firm
4–8	CS	4–8		CL SILTY CLAY: yellowish brown (10YR5/8), Fe staining and Mn oxides, roots, KMNO4 staining very strong @ 5', 6', 6.8', lt staining @ 7.5' & at 8', root development to 7', firm, lt gray vertical & horizontal mottling, roots w/reduced area @ 7', blocky structure, KMNO4 staining weak red
8–12	CS	8–12		CH CLAY: yellowish brown, lt gray mottle, some mottle along old root vesicles, dark KMNO4 staining @ 9', 9.2', 9.6', gypsiferous @ 10.2 w/lt gray brown @ 10.4', becoming more dense w/depth, well defined bedding , mudstone on desicated surface @ 10', w/gypsum infill in voids, KMNO4 staining weak red, 10R5/4.
12–20				

Borehole Summary Information

ornl OAK RIDGE NATIONAL LABORATORY

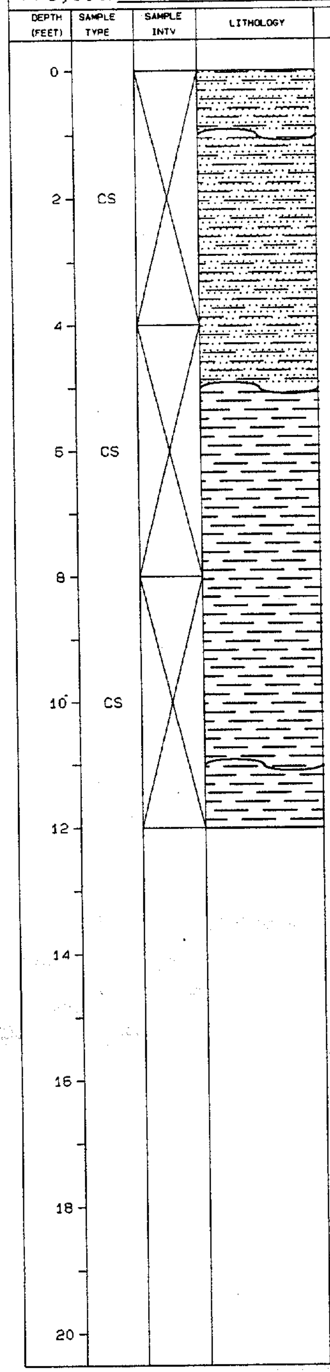
Prepared By: S.R. Sturm Date: 12/13/94 Page: 1 OF 1

Hole No.: T5BK Ground Elevation: NA

Total Depth: 12' Rig Type: ORNL U2CRT Location: Test Cell #5

Auger Size: NA Sample Type: Geoprobe "Megabore 2" OD X 4'

Project: PORTS MPIS Data Verified By: Date:



DESCRIPTION

CL **SILTY CLAY:** dk brown (10YR5/3) soft, damp, abund humus, root bundles, Topsoil

CL **SILTY CLAY:** brownish yellow (10YR6/6), friable, damp, lt gray mottle, some Mn oxides Fe staining common 1'- 5', 10-20mm oxidized s.s. pebbles at 4'-5', bed parting at 5' no visible alterations

CH **CLAY:** brown (7.5YR5/6), stiff, damp, very fat and plastic, plastic texture, w/intbdd gray silt laminae

CH **CLAY:** red brown (2.5YR4/4), v. stiff, plastic, prominent bed partings at 11.4' & 11.7' not altered

Borehole Summary Information

ornl OAK RIDGE NATIONAL LABORATORY

Prepared By: S.R. Sturm Date: 12/13/94 Page: 1 OF 1

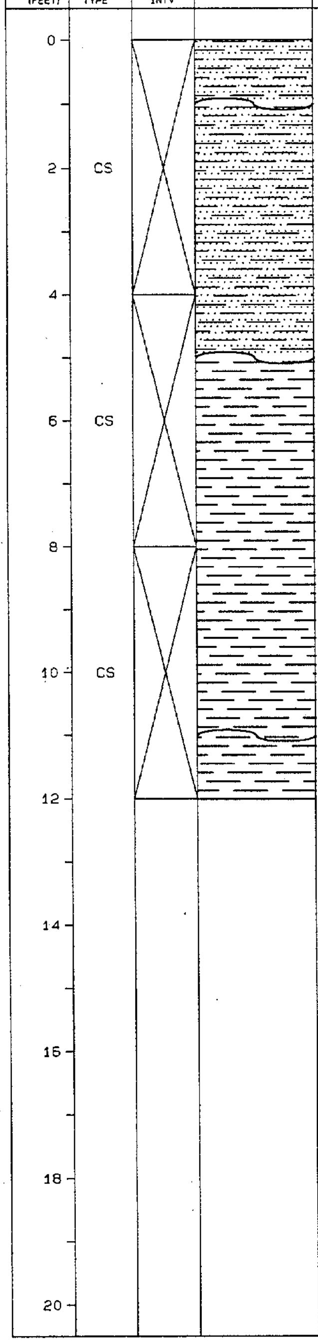
Hole No.: T5BL Ground Elevation: NA

Total Depth: 12' Rig Type: ORNL U2CRT Location: Test Cell #5

Auger Size: NA Sample Type: Geoprobe "Megabore 2" OD X 4'

Project: PORTS MPIS Data Verified By: ____ Date: ____

DEPTH (FEET)	SAMPLE TYPE	SAMPLE INTV	LITHOLOGY	DESCRIPTION



CL **SILTY CLAY:** dk brown (10YR5/3) soft, damp, abund humus, root bundles, Topsoil

CL **SILTY CLAY:** brownish yellow (10YR6/6), friable, damp, lt gray mottle, some Mn oxides Fe staining common 1'- 5', 10-20mm oxidized s.s. pebbles at 4'-5'

CH **CLAY:** brown (7.5YR5/6), stiff, damp, very fat and plastic, w/intbdd gray silt laminae, 45 degree open fracture@ 6.8' - not altered

CH **CLAY:** red brown (2.5YR4/4), v. stiff, plastic, homogenous

Borehole Summary Information

ornl OAK RIDGE NATIONAL LABORATORY

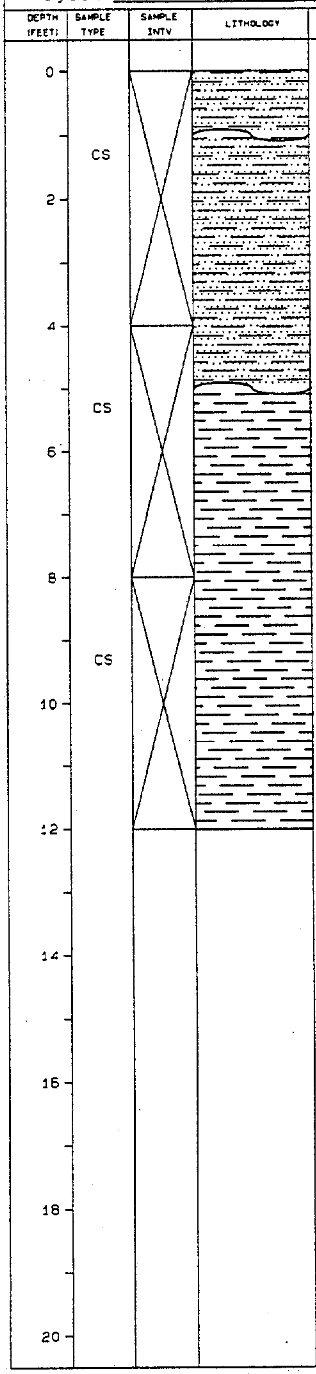
Prepared By: S.R. Sturm Date: 10/21/94 Page: 1 OF 1

Hole No.: T6BA Ground Elevation: NA

Total Depth: 12' Rig Type: ORNL U2CRT Location: Test Cell #6

Auger Size: NA Sample Type: Geoprobe "Megabore 2" OD X 4'

Project: PORTS MPIS Data Verified By: Date:



DESCRIPTION

CL SILTY CLAY: dk brown (7.5YR3/4) soft, damp, friable, abund humus, root bundles, Topsoil

CL SILTY CLAY: yellowish brown (10YR5/8), blocky structure, friable, damp, abundant Fe nodules at 4' to 5'

High angle fracture with clay infill at 7'

CH CLAY: lt yellow brown (10YR5/4), intbdd pale olive silt laminations, stiff, damp, very fat, mod plastic, parallel discontinous bedding,

CH CLAY: yellow brn (10YR5/4), intbdd pale olive silt, as above with high angle fractures at 10.6' @ 11.5', both with clay infill.

Borehole Summary Information

ornl OAK RIDGE NATIONAL LABORATORY

Prepared By: S.R. Sturm Date: 10/21/94 Page: 1 OF 1

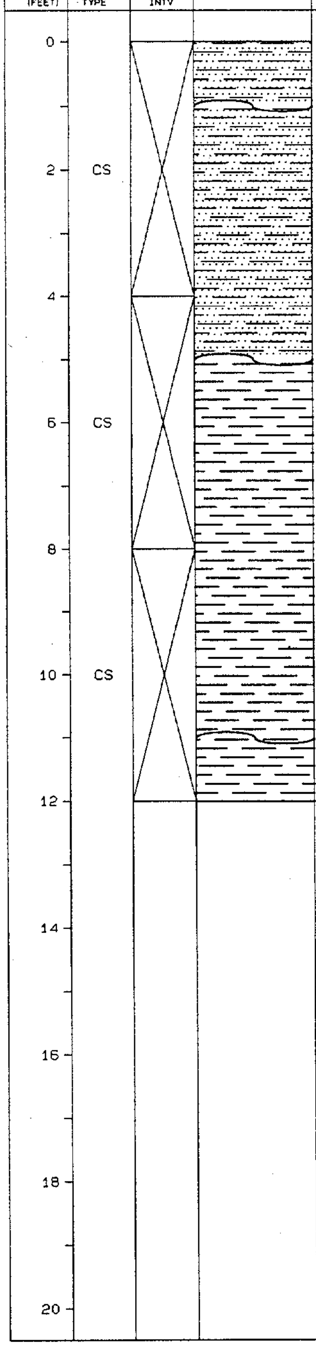
Hole No.: T6BB Ground Elevation: NA

Total Depth: 12' Rig Type: ORNL U2CRT Location: Test Cell #6

Auger Size: NA Sample Type: Geoprobe "Megabore 2" OD X 4'

Project: PORTS MPIS Data Verified By: ______ Date: ______

DEPTH (FEET)	SAMPLE TYPE	SAMPLE INTV	LITHOLOGY	DESCRIPTION



CL SILTY CLAY: dk brown (7.5YR3/4) soft, damp, friable, abund humus, root bundles, Topsoil

CL SILTY CLAY: yellowish brown (10YR5/8), blocky structure, mod stiff, damp, abundant Fe nods at 3' to 4'

High angle fractures with clay infill and Mn oxide at 5', 6.3', 6.5' and 6.8'

CH CLAY: lt yellow brown (10YR5/4), intbdd pale olive silt laminations, stiff, damp, very fat, mod plastic, parallel discontinous bedding,

CH CLAY: red (2.5YR4/8), damp, stiff, thin laminar bedding easily split on bed partings with Mn oxide, dendritic staining

Borehole Summary Information

ornl OAK RIDGE NATIONAL LABORATORY

Prepared By: S.R. Sturm Date: 10/21/94 Page: 1 OF 1

Hole No.: T6BC Ground Elevation: NA

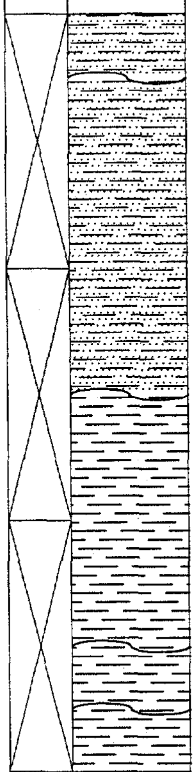
Total Depth: 12' Rig Type: ORNL U2CRT Location: Test Cell #6

Auger Size: NA Sample Type: Geoprobe "Megabore 2" OD X 4'

Project: PORTS MPIS Data Verified By: ______ Date: ______

DEPTH (FEET)	SAMPLE TYPE	DESCRIPTION
0		
		CL **SILTY CLAY:** dk brown (7.5YR3/4) soft, damp, friable, abund humus, root bundles, Topsoil
2	CS	
		CL **SILTY CLAY:** yellowish brown (10YR5/8), blocky structure, soft, damp, common Fe nods, scattered friable s.stone pebbles
4		
		High angle fractures with clay infill at 5.8'.
6	CS	CH **CLAY:** lt yellow brown (10YR5/4), intbdd pale olive silt laminations, stiff, damp, very fat, mod plastic, parallel discontinous bedding,
8		
10	CS	CH **CLAY:** red (2.5YR4/8), damp, stiff, thin laminar bedding easily split on bed partings with Mn oxide, dendritic staining
12		CH **CLAY:** lt yellow brn (10YR5/4), intbdd pale olive laminae with Mn oxide on bed partings creating tri- color effect, parallel discontinous varves <1 mm, occasional v fine sand laminae
14		
16		
18		
20		

Sample intervals / Lithology:



Borehole Summary Information

ornl OAK RIDGE NATIONAL LABORATORY

Prepared By: S.R. Sturm	Date: 10/21/94	Page: 1 OF 1
Hole No.: T6BD	Ground Elevation: NA	
Total Depth: 12'	Rig Type: ORNL U2CRT	Location: Test Cell #6
Auger Size: NA	Sample Type: Geoprobe "Megabore 2" OD X 4'	
Project: PORTS MPIS	Data Verified By:	Date:

DEPTH (FEET)	SAMPLE TYPE	SAMPLE INTV	LITHOLOGY	DESCRIPTION
0		0–4		
1				CL **SILTY CLAY:** dk brown (7.5YR3/4) soft, damp , friable, abund humus, root bundles, Topsoil
2	CS			CL **SILTY CLAY:** yellowish brown (10YR6/8), blocky structure, soft, damp, common Fe nods 4' to 6' root pores with clay infill, argillaceous "skins" also apparent on blocky structures
4		4–8		
6	CS			CH **CLAY:** lt yellow brown (10YR5/4), intbdd pale olive silt laminations, stiff, damp, very fat, mod plastic, parallel discontinous bedding,
8		8–12		
10	CS			
11				CH **CLAY:** red (2.5YR4/8), damp, stiff, thin laminar bedding, rare Mn oxide stains , very pronounced bed parting top of hard red clay, erosional ?
12				
14				
16				
18				
20				

Borehole Summary Information

ornl OAK RIDGE NATIONAL LABORATORY

Prepared By: S.R. Sturm Date: 10/21/94 Page: 1 OF 1

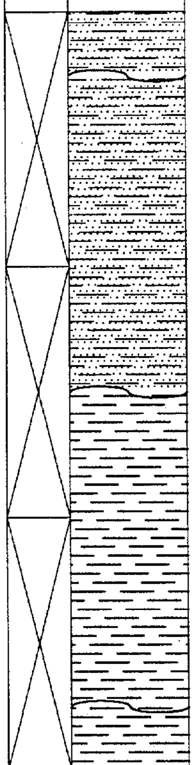
Hole No.: T6BE Ground Elevation: NA

Total Depth: 12' Rig Type: ORNL U2CRT Location: Test Cell #6

Auger Size: NA Sample Type: Geoprobe "Megabore 2" OD X 4'

Project: PORTS MPIS Data Verified By: ______ Date: ______

DEPTH (FEET)	SAMPLE TYPE	SAMPLE INTV	LITHOLOGY	DESCRIPTION
0				
				CL SILTY CLAY: dk brown (7.5YR3/4) soft, damp, friable, abund humus, root bundles, Topsoil
2	CS			CL SILTY CLAY: yellowish brown (10YR6/8), blocky structure, soft, damp, common Fe nods 4' to 5'
4				
6	CS			CH CLAY: lt yellow brown (10YR5/4), intbdd pale olive silt laminations, stiff, damp, very fat, mod plastic, parallel discontinous bedding,
8				
10	CS			Saturated, perched water on red clay
				CH CLAY: red (2.5YR4/8), damp, stiff, thin laminar bedding, rare Mn oxide stains, very pronounced bed parting top of hard red clay, erosional ?
12				
14				
16				
18				
20				



orn1 OAK RIDGE NATIONAL LABORATORY

Borehole Summary Information

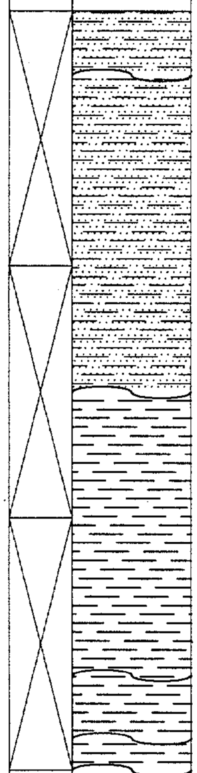
Prepared By: S.R. Sturm Date: 10/24/94 Page: 1 OF 1

Hole No.: T7BA Ground Elevation: NA

Total Depth: 12' Rig Type: ORNL U2CRT Location: Test Cell #7

Auger Size: NA Sample Type: Geoprobe "Megabore 2" OD X 4'

Project: PORTS MPIS Data Verified By: Date:



DEPTH (FEET)	SAMPLE TYPE	DESCRIPTION
0		
		CL SILTY CLAY: dk brown (7.5YR3/4) soft, damp, friable, abund humus, root bundles, Topsoil
2	CS	CL SILTY CLAY: yellowish brown (10YR5/8), blocky structure, damp, common Fe flecks, mod stiff Fe oxide infill in root pores-limonite
4		
6	CS	CH CLAY: lt yellow brown (10YR5/4), intbdd pale olive silt laminations, stiff, damp, very fat, mod plastic, high angle fractures 6.7', 7.5'
8		LOST CORE 7.5' to 8'
10	CS	
		CH CLAY: red (2.5YR4/8), damp, stiff, thin laminar bedding, rare Mn oxide stains, very pronounced bed parting top of hard red clay, erosional ?
12		
14		
16		
18		
20		

Borehole Summary Information

ornl OAK RIDGE NATIONAL LABORATORY

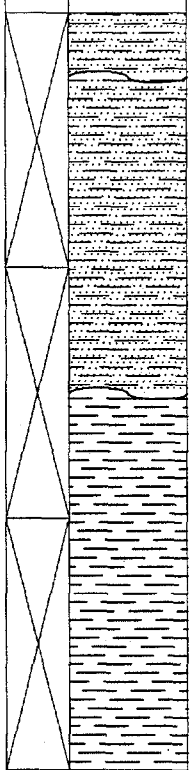
Prepared By: R.M. Schlosser Date: 11/20/94 Page: 1 OF 1

Hole No.: T7BB Ground Elevation: NA

Total Depth: 12' Rig Type: ORNL U2CRT Location: Test Cell #7

Auger Size: NA Sample Type: Geoprobe "Megabore 2" OD X 4'

Project: PORTS MPIS Data Verified By: Date:



DEPTH (FEET)	SAMPLE TYPE	DESCRIPTION
0		
		CL SILTY CLAY: brown (10YR5/3) soft, well , developed root bundles, friable
2	CS	CL SILTY CLAY: yellowish brown (10YR5/8), mod stiff, damp, abund Fe staining 2 - 3', friable heavy Fe stained pebbles @ 4', lt gray mottle becoming more mottled with depth, occ. roots
4		
		CL SILTY CLAY: yellowish brown lt gray mottle, abundant pebbles 5' - 5.8', some Fe nodules from 4.5', MN oxides occasional
6	CS	CH CLAY: dk yellow brown (10YR4/4), mottled lt gray as above, slighty plastic, moist,
8		
		CH CLAY: brn (7.5YR5/2) very firm, plastic, well developed beds w/ly gray clay on bed surfaces, stiff, moist, waxy appearance
10	CS	
		CH CLAY: yellow brn varieagated w/lt gray grn & lt brownish gray, stiff plastic becoming red brown 5YR4/4 to yellowish red 5YR4/6, stiff, homogenous
12		
14		
16		
18		
20		

Borehole Summary Information

ornl OAK RIDGE NATIONAL LABORATORY

Prepared By: R.M. Schlosser Date: 11/20/94 Page: 1 OF 1

Hole No.: T7BC Ground Elevation: NA

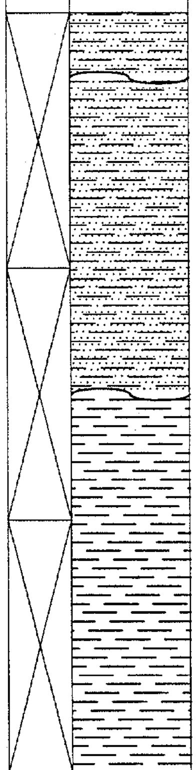
Total Depth: 12' Rig Type: ORNL U2CRT Location: Test Cell #7

Auger Size: NA Sample Type: Geoprobe "Megabore 2" OD X 4'

Project: PORTS MPIS Data Verified By: Date:

DEPTH (FEET)	SAMPLE TYPE	DESCRIPTION
0		
		CL SILTY CLAY: brown (10YR5/3) soft, well developed soil w/root mass
2	CS	CL SILTY CLAY: yellowish brown (10YR5/8), some Fe oxides, soft, moist, friable, becoming stiff
4		CL SILTY CLAY: yellowish brown lt gray mottle, some Fe & MN oxides, some Guar-gum @ 5.5'in fractures, becoming v stiff, moist, blocky structure, Guargum in void @ 6.2'
6	CS	
		CH CLAY: dk yellow brown (10YR4/4), mottled lt gray as above, increasing mottle w/depth, fracture @ 7'
8		
10	CS	CH CLAY: lt gray green clay mottled yellow brn LOST CORE 11' - 12'
12		
14		
16		
18		
20		

SAMPLE INTV / LITHOLOGY:



Borehole Summary Information

ornl OAK RIDGE NATIONAL LABORATORY

Prepared By: S.R. Sturm Date: 12/14/94 Page: 1 OF 1

Hole No.: T7BD Ground Elevation: NA

Total Depth: 12' Rig Type: ORNL U2CRT Location: Test Cell #7

Auger Size: NA Sample Type: Geoprobe "Megabore 2" OD X 4'

Project: PORTS MPIS Data Verified By: ____ Date: ____

DEPTH (FEET)	SAMPLE TYPE	SAMPLE INTV	LITHOLOGY	DESCRIPTION
0				
				CL SILTY CLAY: dk brown (10YR5/3) soft, damp, abund humus, root bundles, Topsoil
2	CS			**CL SILTY CLAY:** brownish yellow (10YR6/6), friable, damp, lt gray mottle, open root pores some w/roots Fe staining common 3'- 5', 10-20mm oxidized s.s. pebbles at 4'-5'
4				
6	CS			**CH CLAY:** yellow brown (10YR5/6), stiff, damp, very fat and plastic, w/intbdd gray silt laminae, 45 degree open fracture @ 7.2 shows Fe staining and recent hydration of surrounding clay
8				
10	CS			**CH CLAY:** red brown (2.5YR4/4), v. stiff, plastic, intbdd lt gray silt laminae, numerous bed partings, no visible alterations
12				
14				
16				
18				
20				

ornl OAK RIDGE NATIONAL LABORATORY

Borehole Summary Information

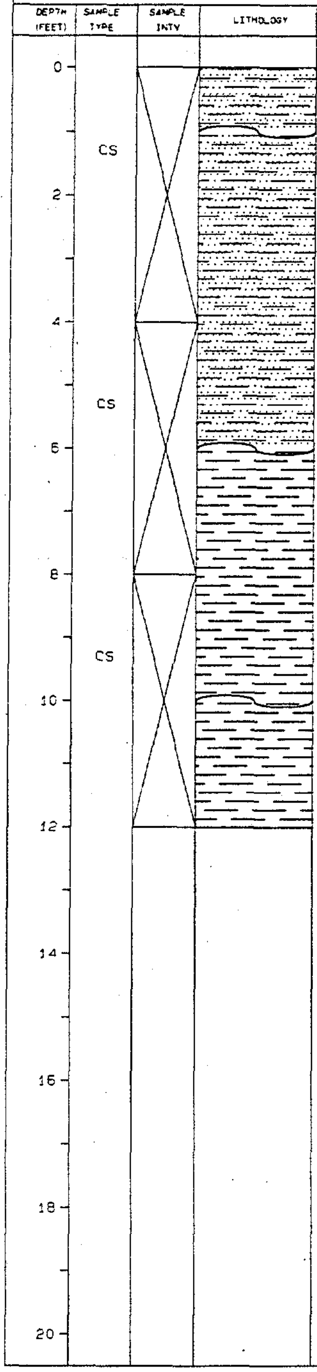
Prepared By: S.R. Sturm Date: 12/14/94 Page: 1 OF 1

Hole No.: T78E Ground Elevation: NA

Total Depth: 12' Rig Type: ORNL U2CRT Location: Test Cell #7

Auger Size: NA Sample Type: Geoprobe "Megacore 2" OD X 4'

Project: PORTS MPIS Data Verified By: Date:



DESCRIPTION

CL SILTY CLAY: dk brown (10YR5/3) soft, damp, abund humus, root bundles, Topsoil

CL SILTY CLAY: brownish yellow (10YR6/6), friable, damp, lt gray mottle, Fe staining common, high angle fracture 1' to 3' with Guar gum infill, numerous 5 - 25 mm dark red s.s. pebbles 5'-6'

CH CLAY: yellow brown (10YR5/6), stiff, damp, very fat and plastic, w/intbdd gray silt laminae, 3 high angle / vertical fractures @ 6.1' 6.3' and at 7', each with Guar gum infill

CH CLAY: red brown (2.5YR4/4), v. stiff, plastic, intbdd lt gray silt laminae, numerous bed partings 9'- 11', no visible alterations

APPENDIX C

DATA TREND GRAPHS FOR VARIOUS GEOCHEMICAL PARAMETERS IN SOIL AND SOIL-PORE WATER

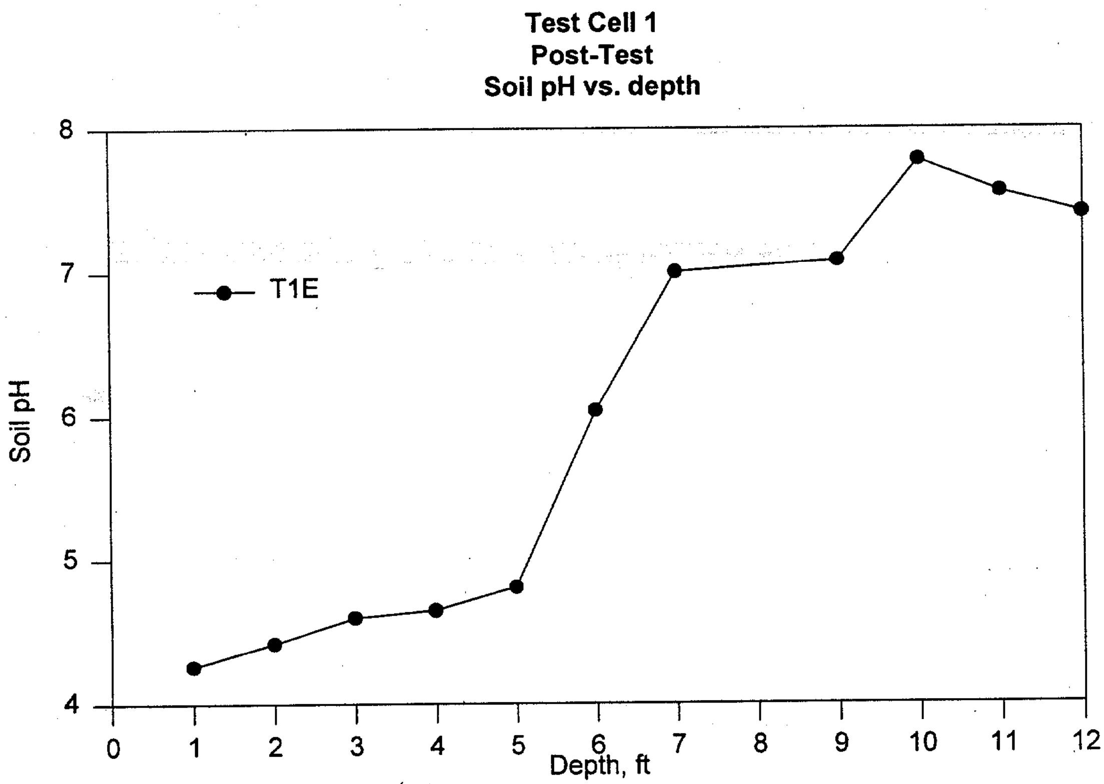


Fig. C.1. Test cell 1 - post-treatment soil pH.

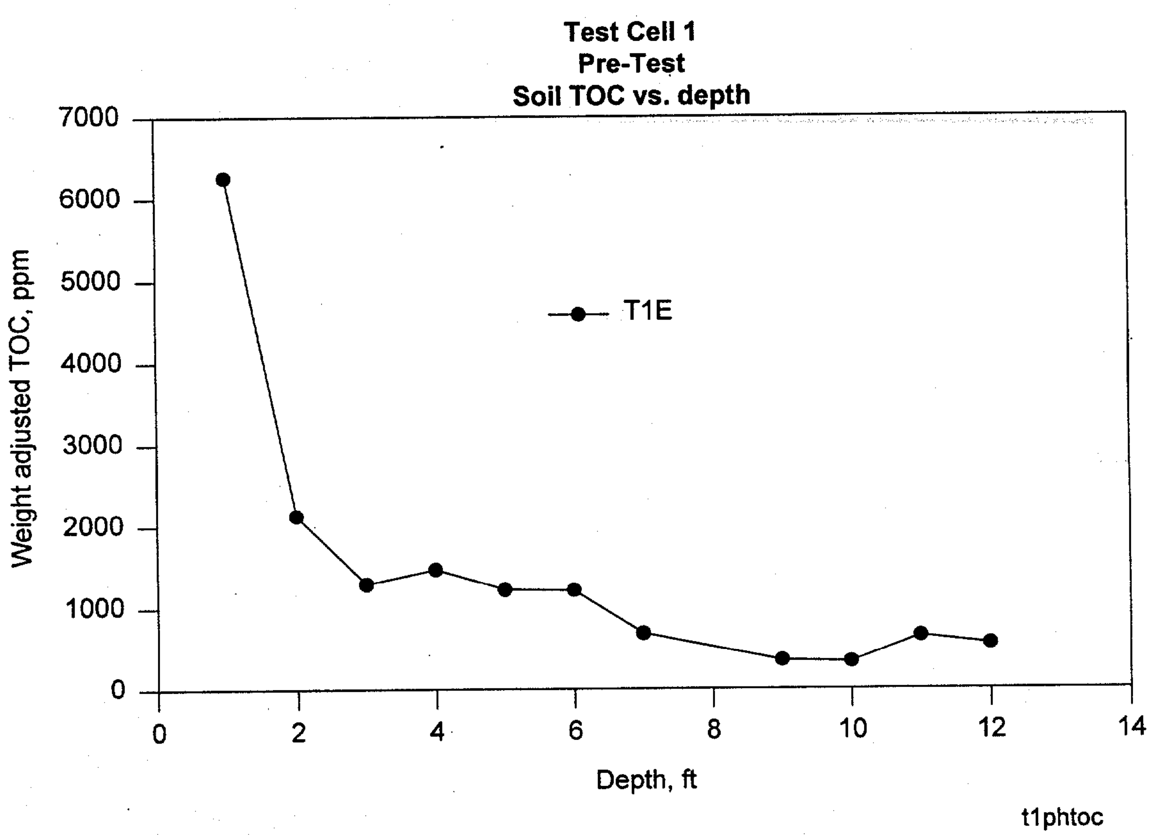


Fig. C.2. Test cell 1 - pre-treatment soil TOC content.

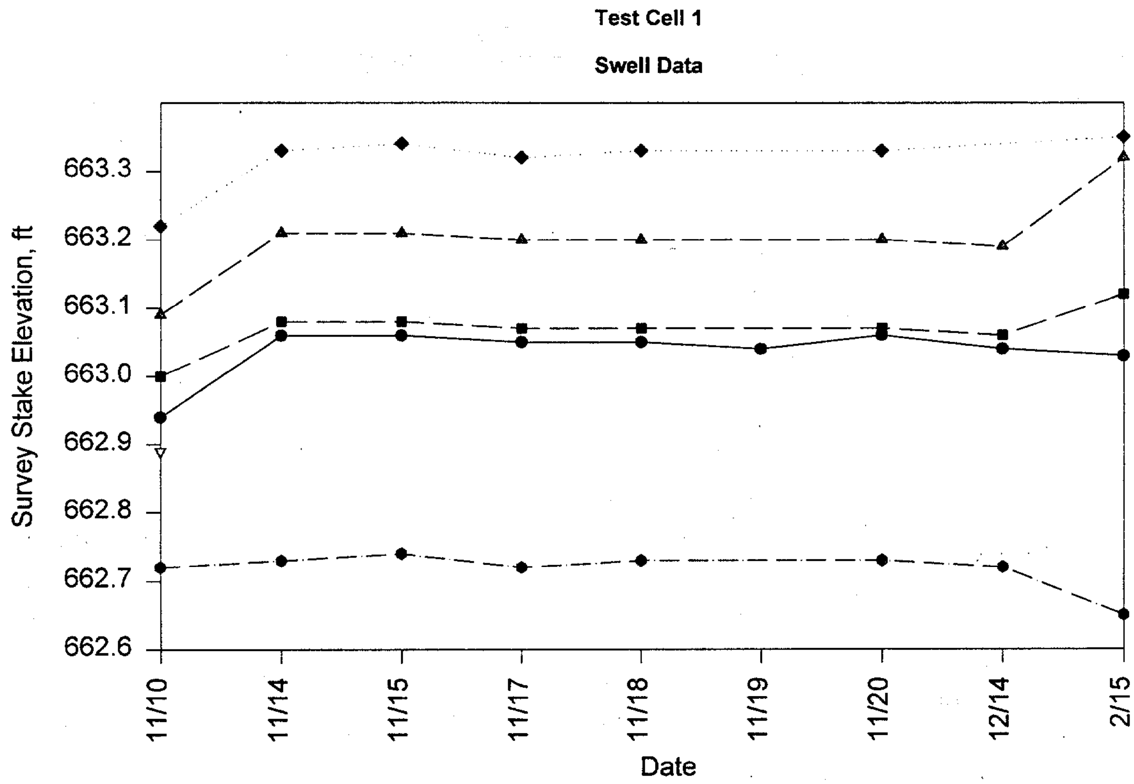


Fig. C.3. Test cell 1 - post-treatment soil swell data.

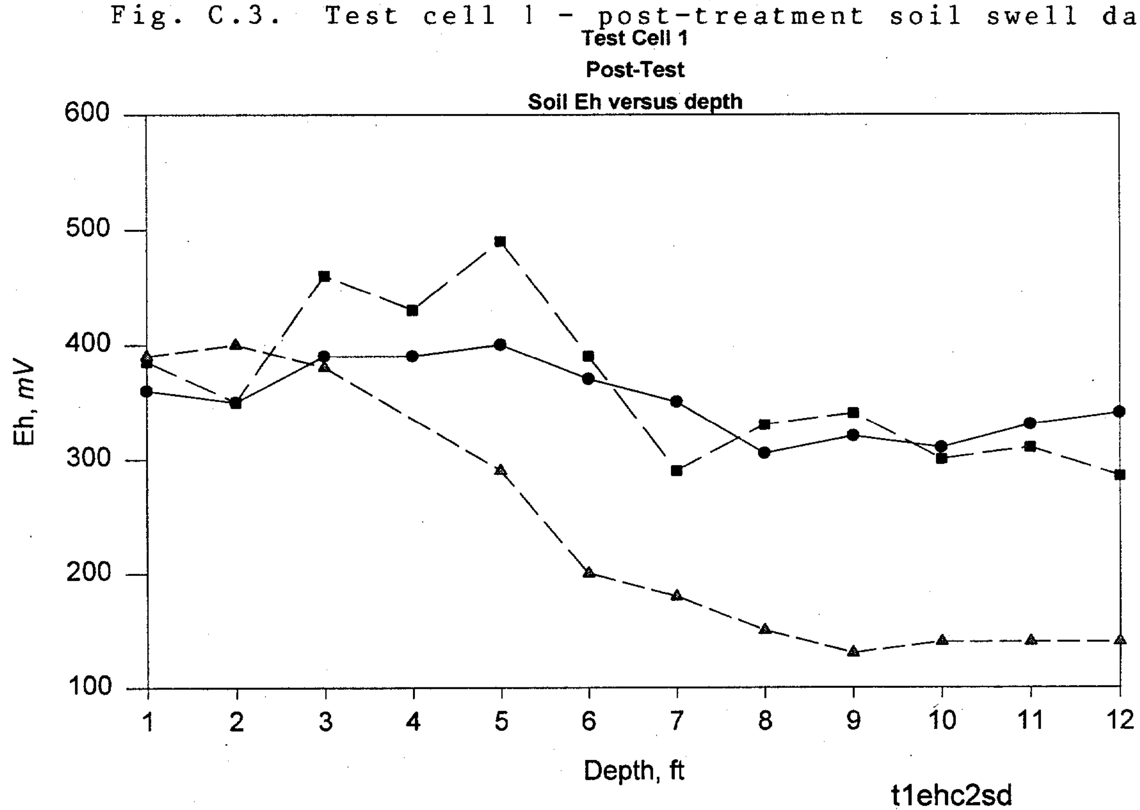


Fig. C.4. Test cell 1 - post-treatment soil Eh.

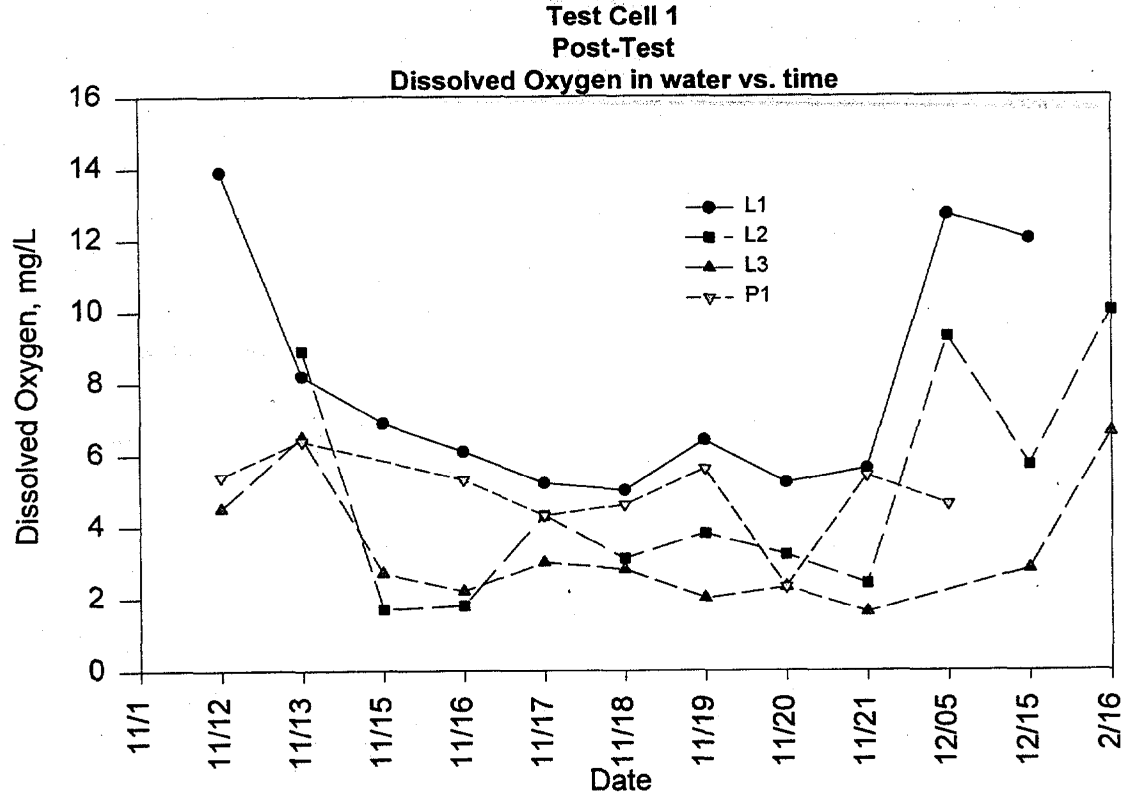


Fig. C.5. Test cell 1 - post-treatment water DO levels.

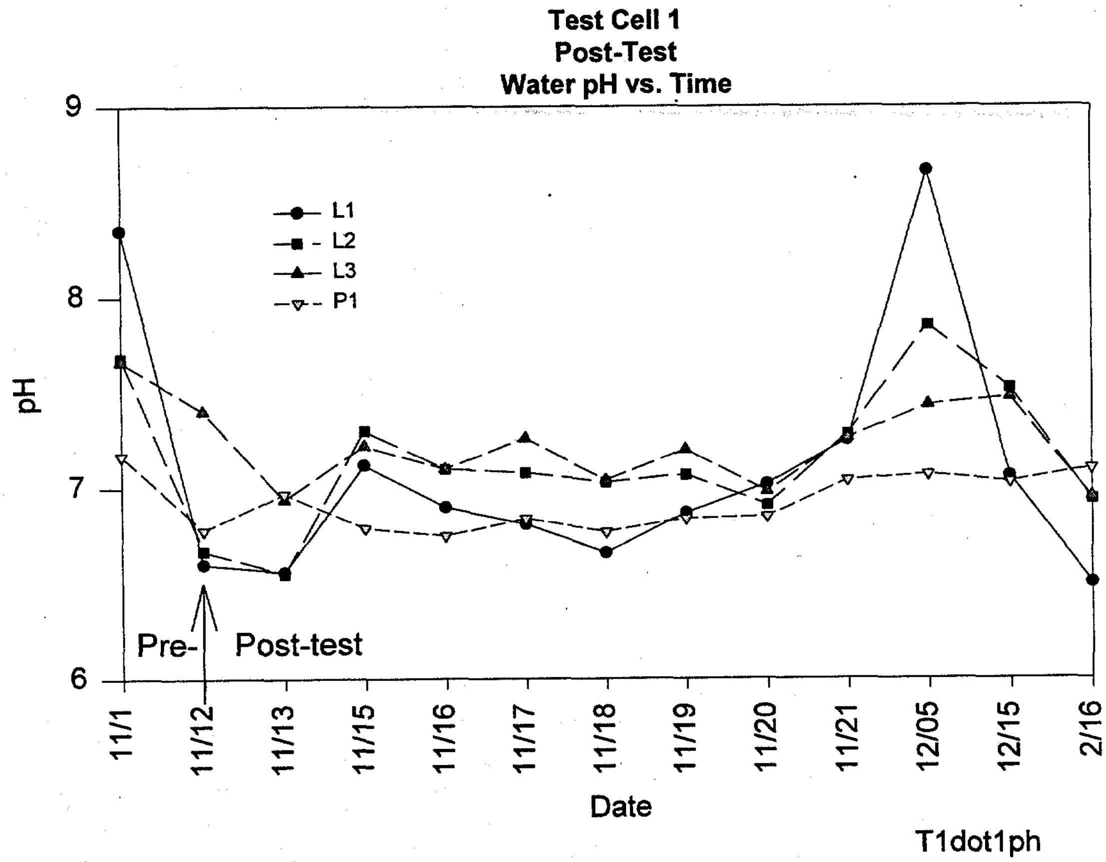


Fig. C.6. Test cell 1 - post-treatment water pH.

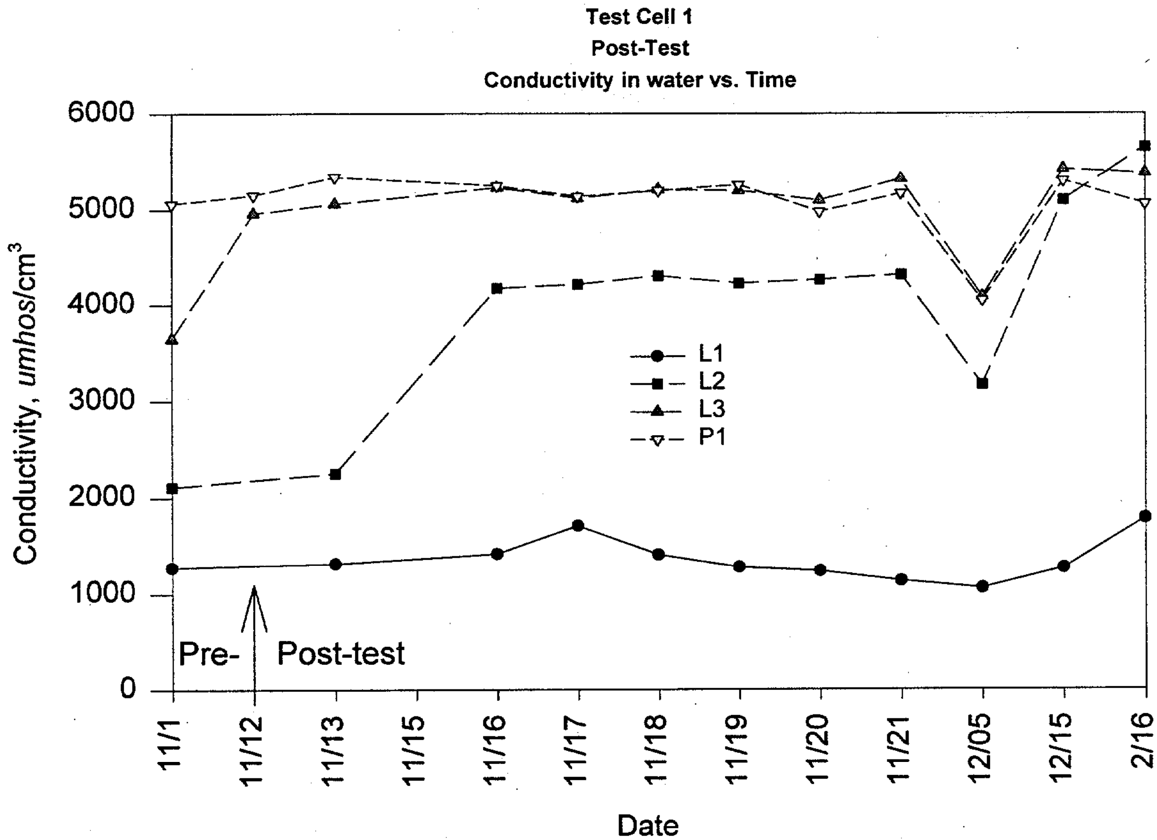


Fig. C.7. Test cell 1 - post-treatment water conductivity levels.

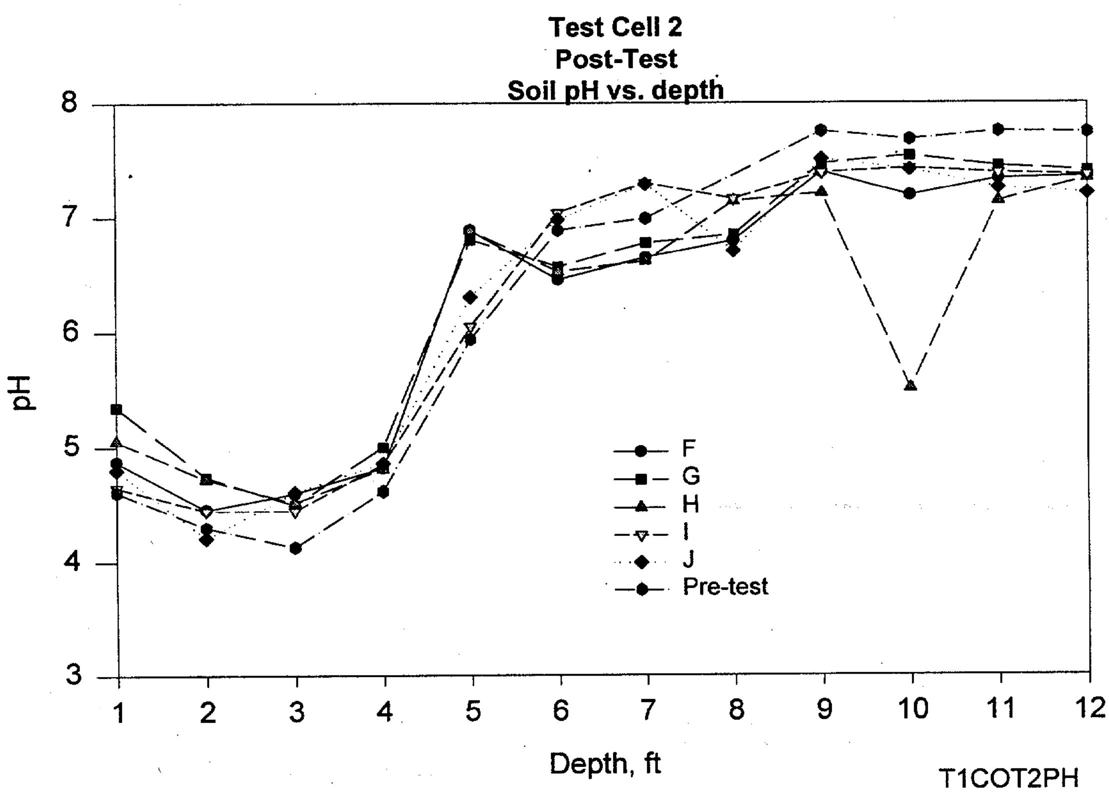


Fig. C.8. Test cell 2 - post-treatment soil pH.

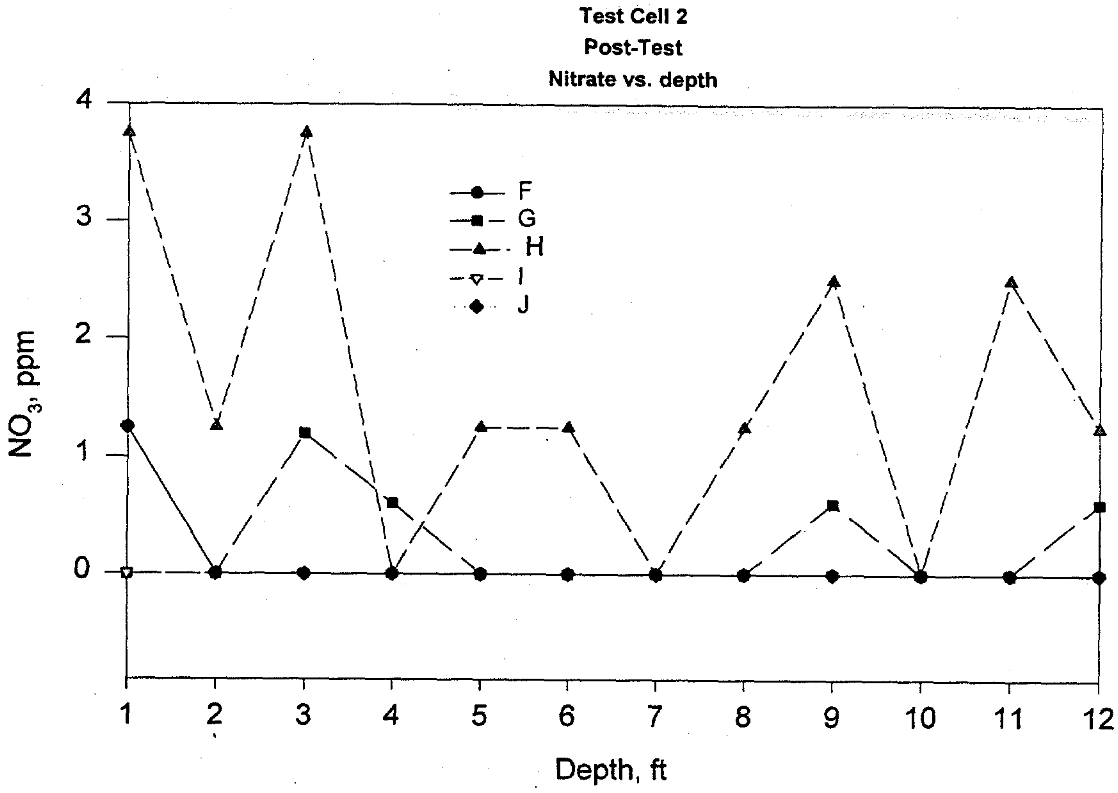


Fig. C.9. Test cell 2 - post-treatment soil nitrate levels.

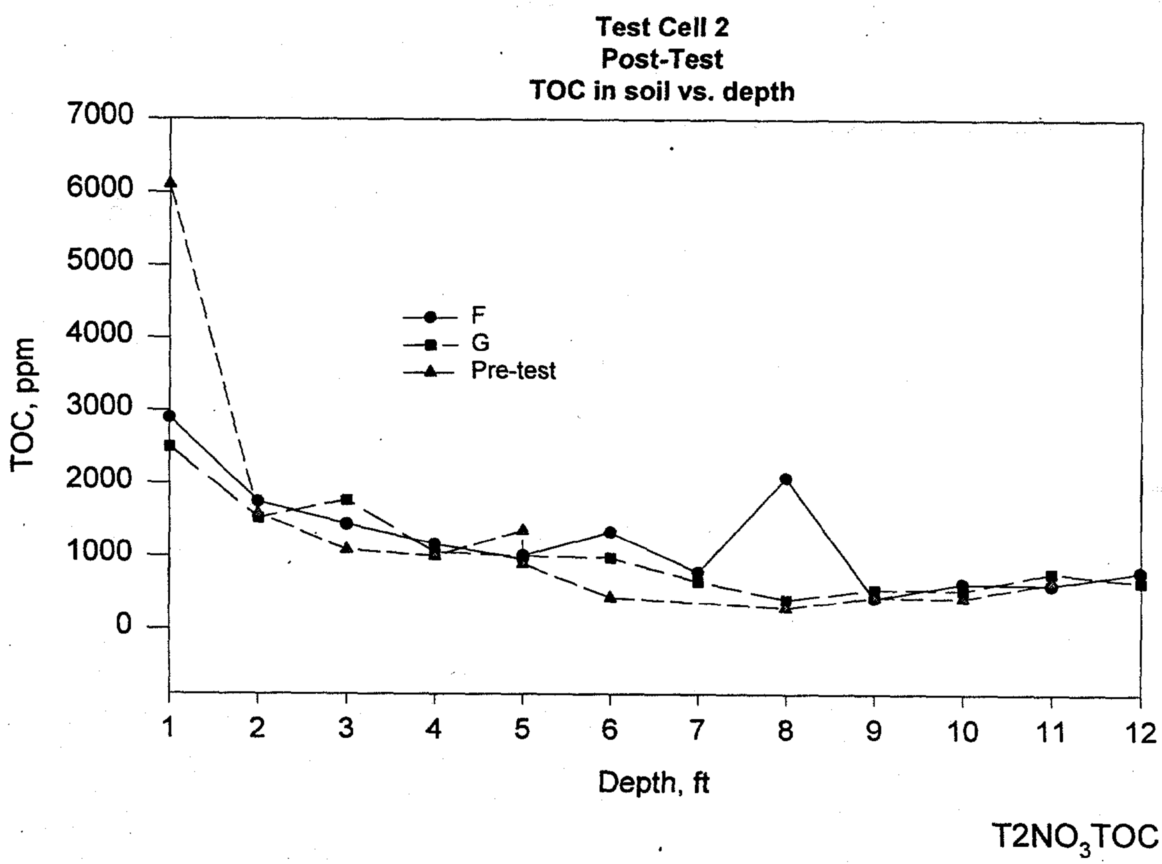


Fig. C.10. Test cell 2 - post-treatment soil TOC content.

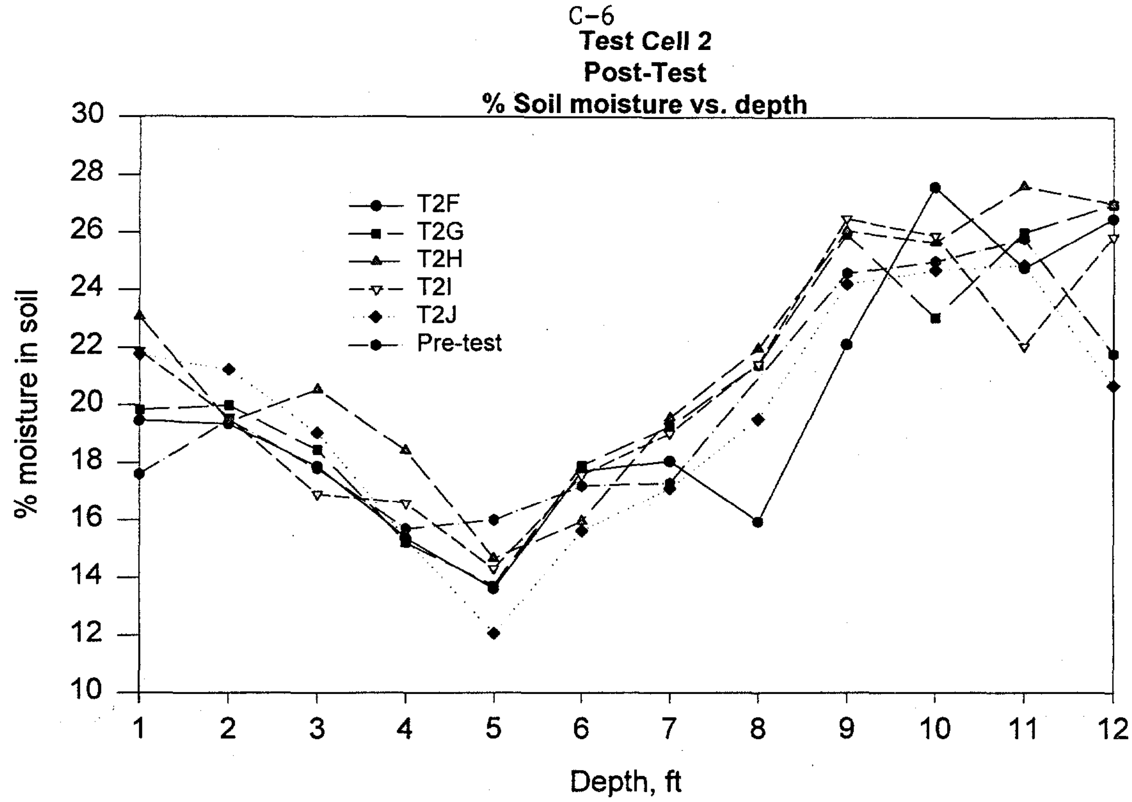


Fig. C.11. Test cell 2 - post-treatment soil moisture content.

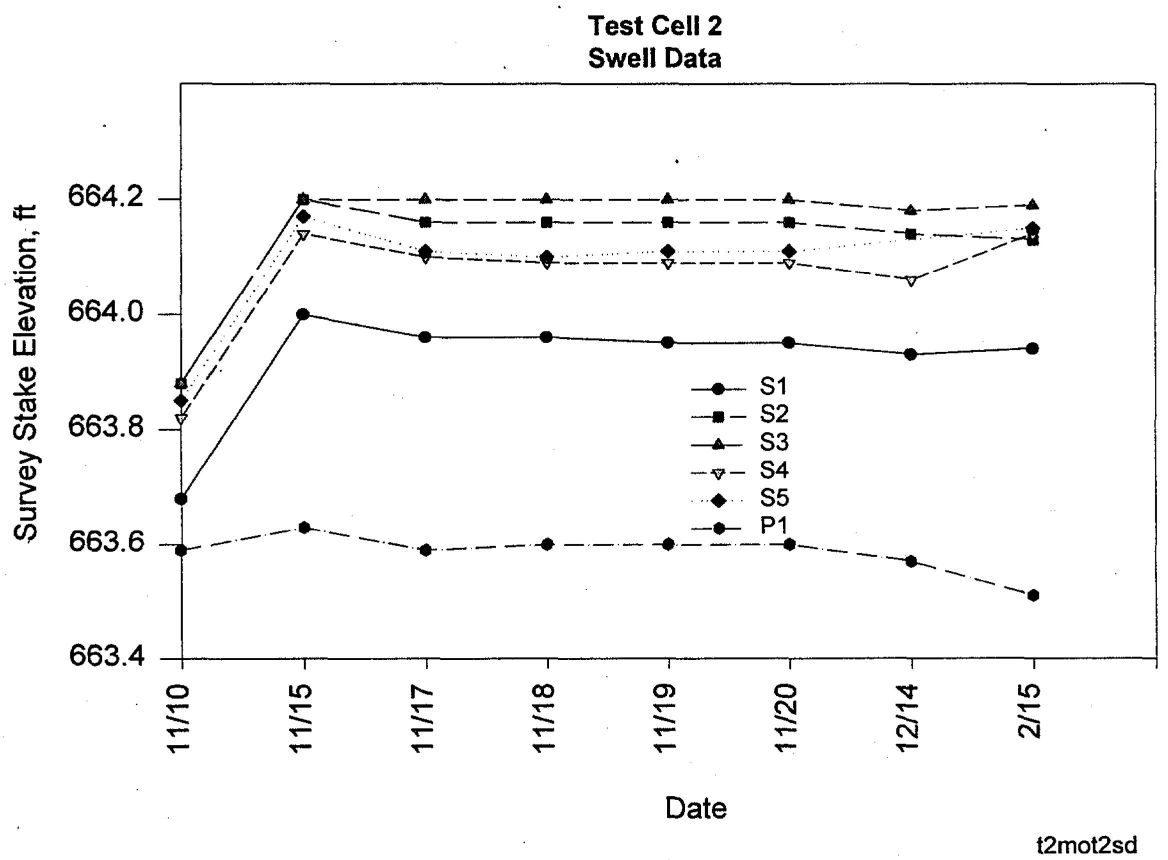


Fig. C.12. Test cell 2 - post-treatment soil swell data.

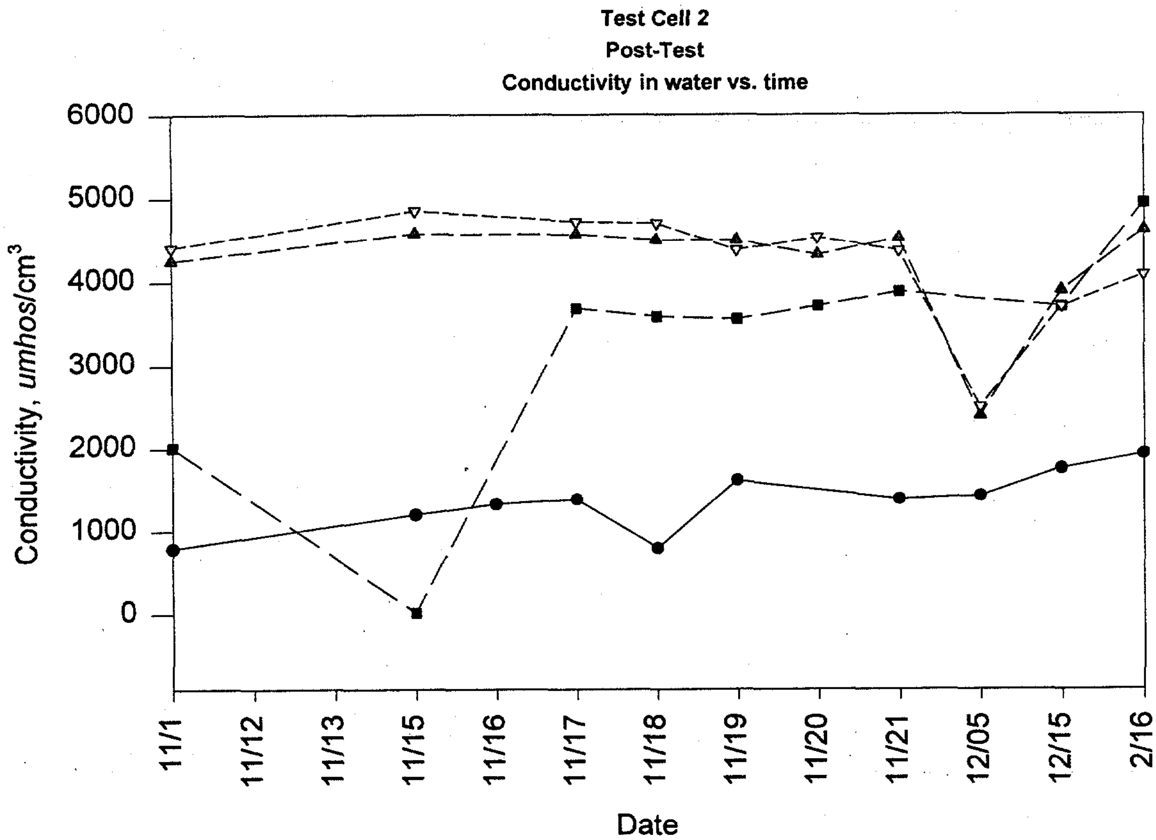


Fig. C.13. Test cell 2 - post-treatment water conductitivity levels.

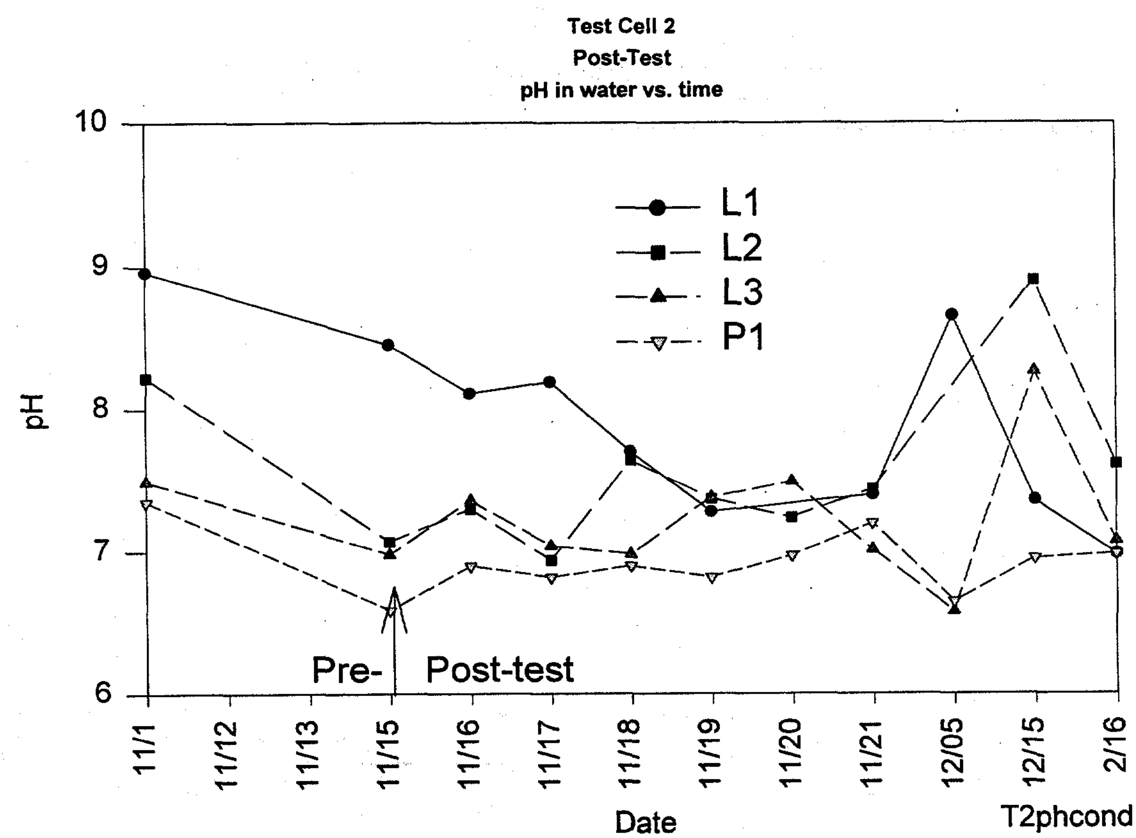


Fig. C.14. Test cell 2 - post-treatment water pH.

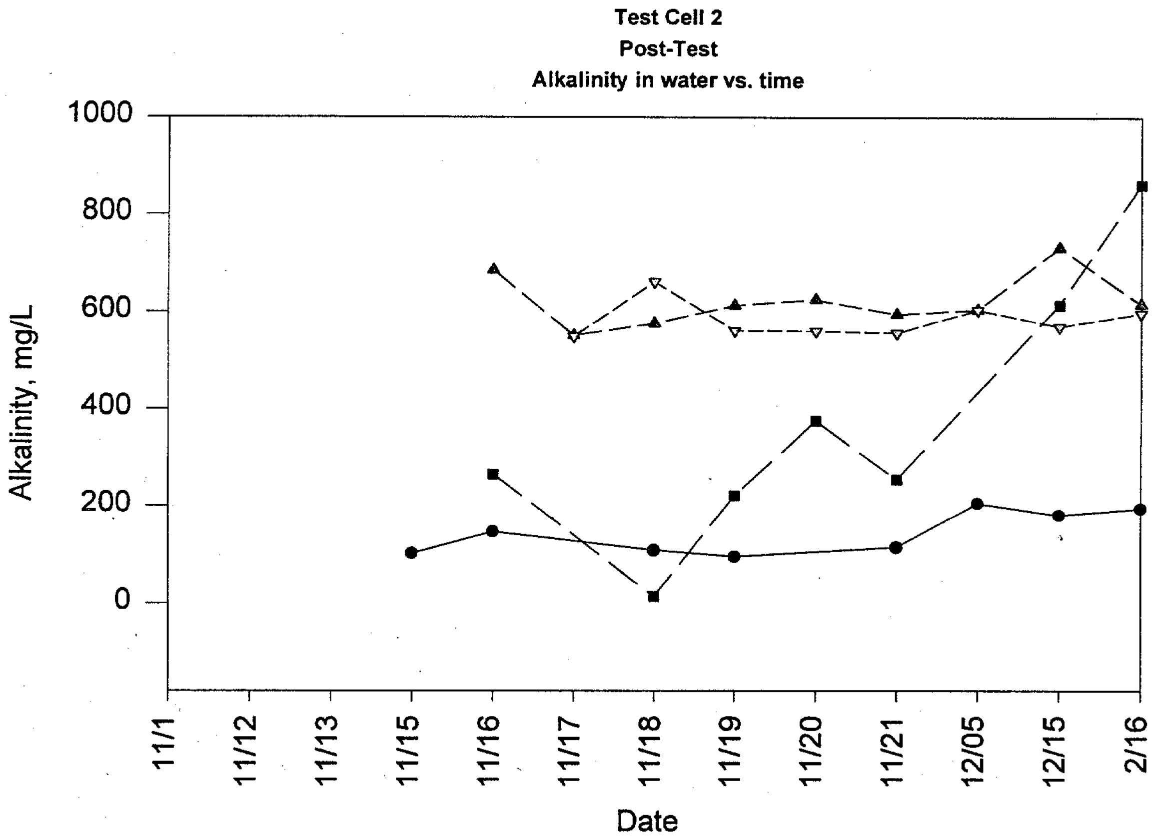


Fig. C.15. Test cell 2 - post-treatment water alkalinity levels.

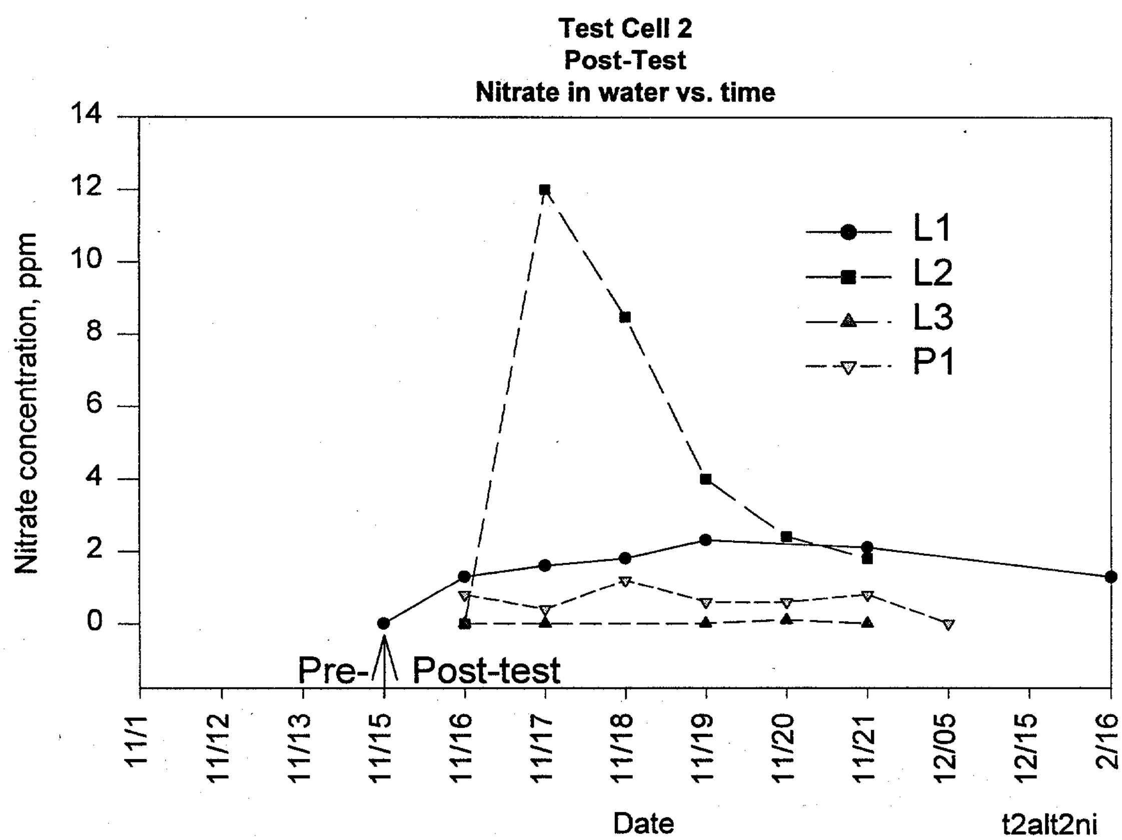


Fig. C.16. Test cell 2 - post-treatment water nitrate levels.

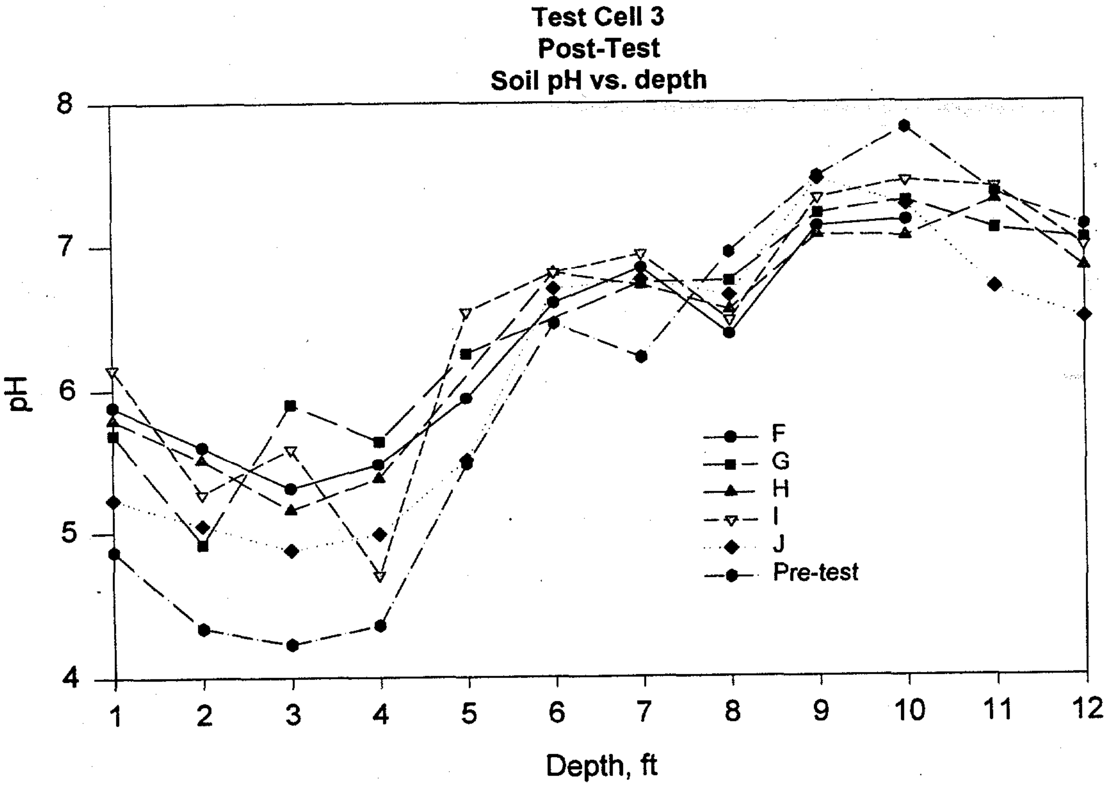


Fig. C.17. Test cell 3 - post-treatment soil pH.

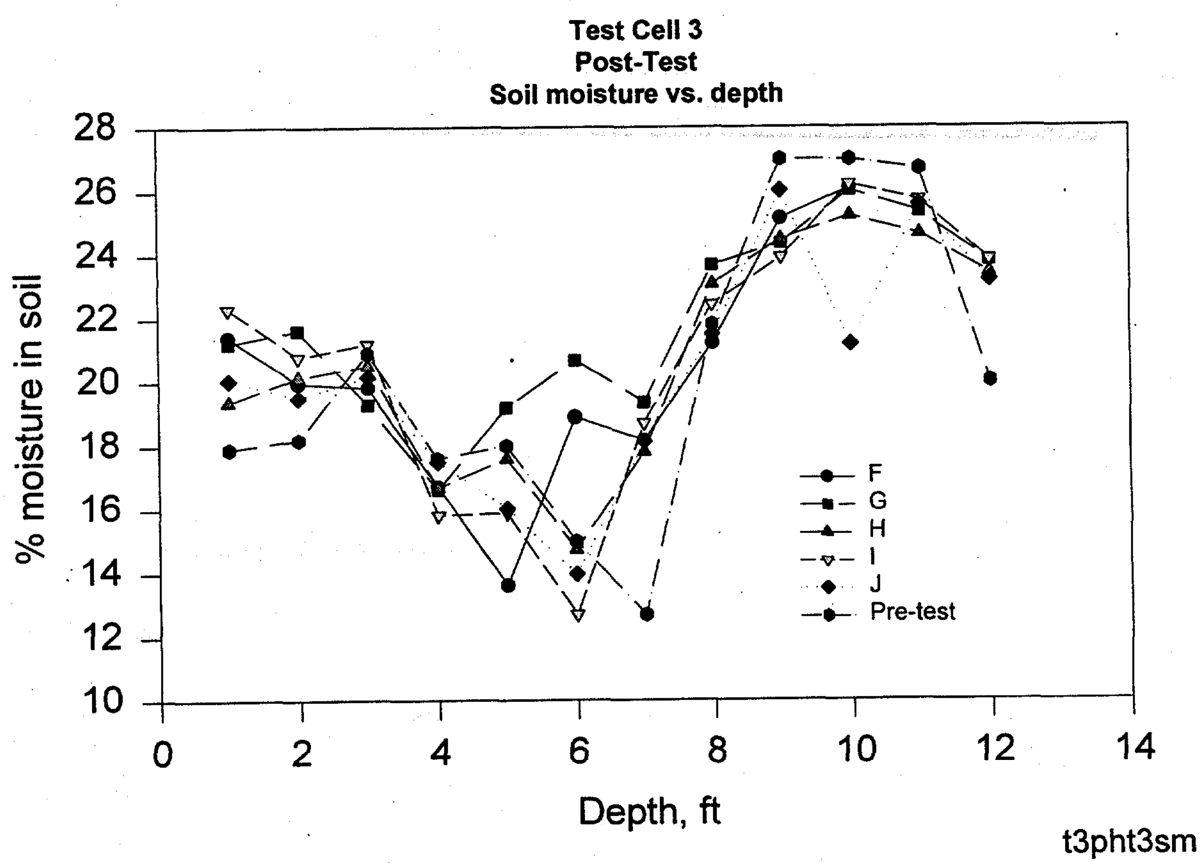


Fig. C.18. Test cell 3 - post-treatment soil moisture levels.

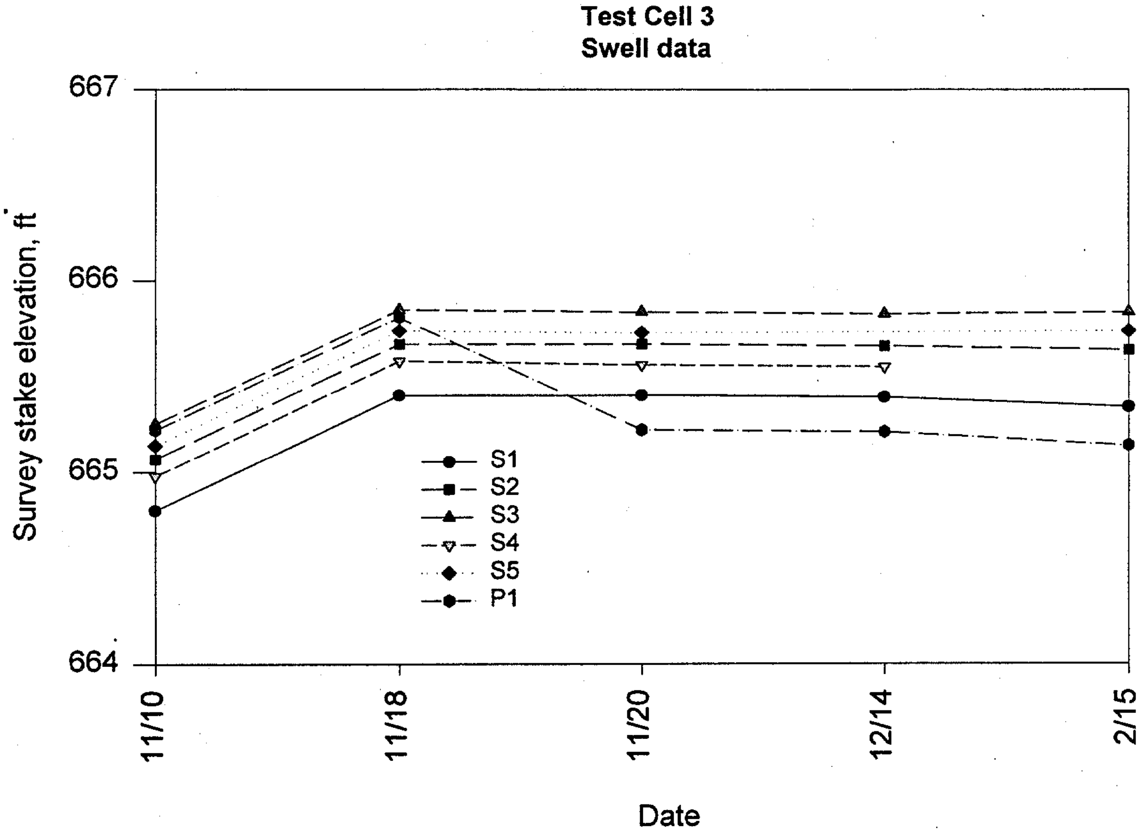


Fig. C.19. Test cell 3 - post-treatment soil swell data.

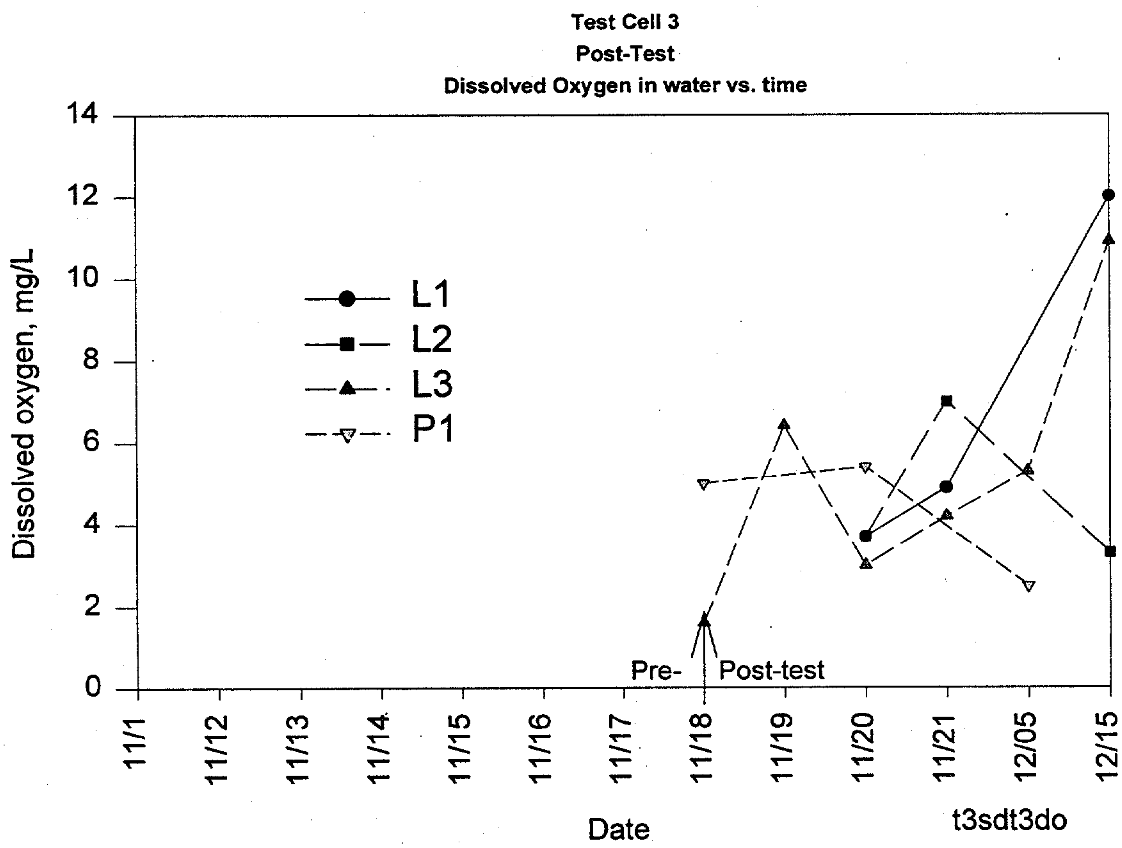


Fig. C.20. Test cell 3 - post-treatment water DO levels.

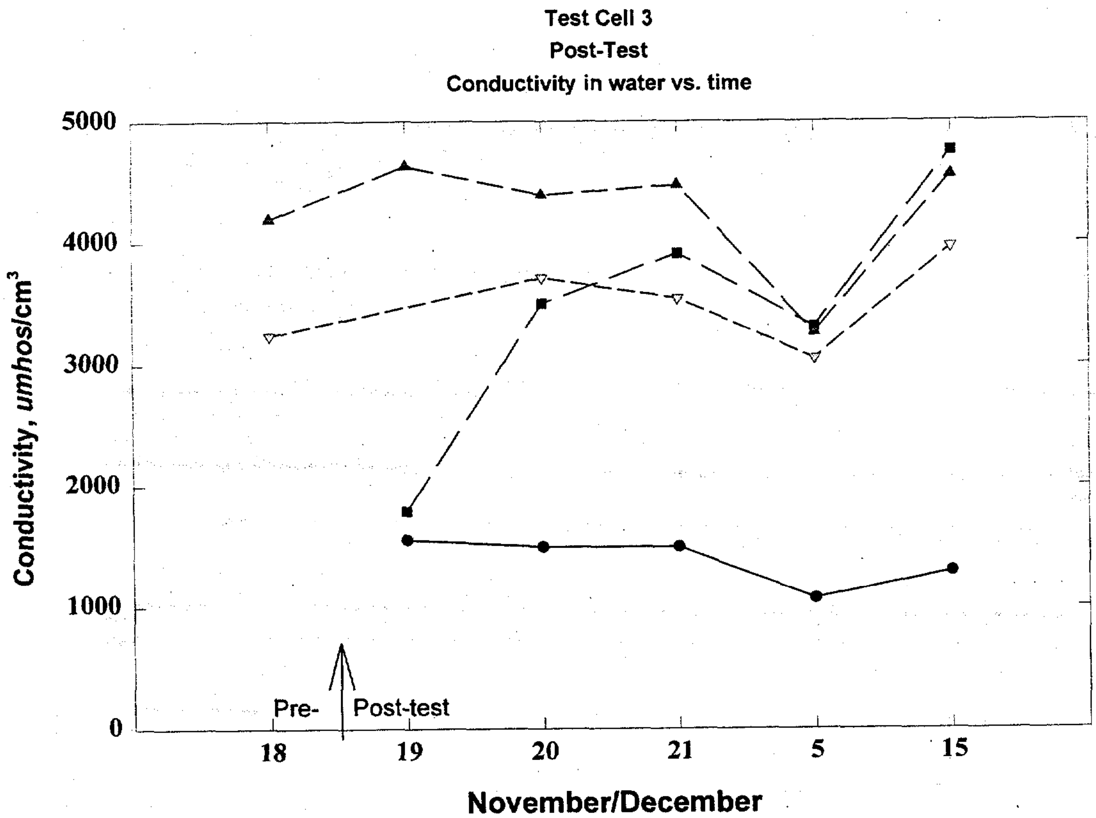


Fig. C.21. Test cell 3 - post-treatment water conductivity levels.

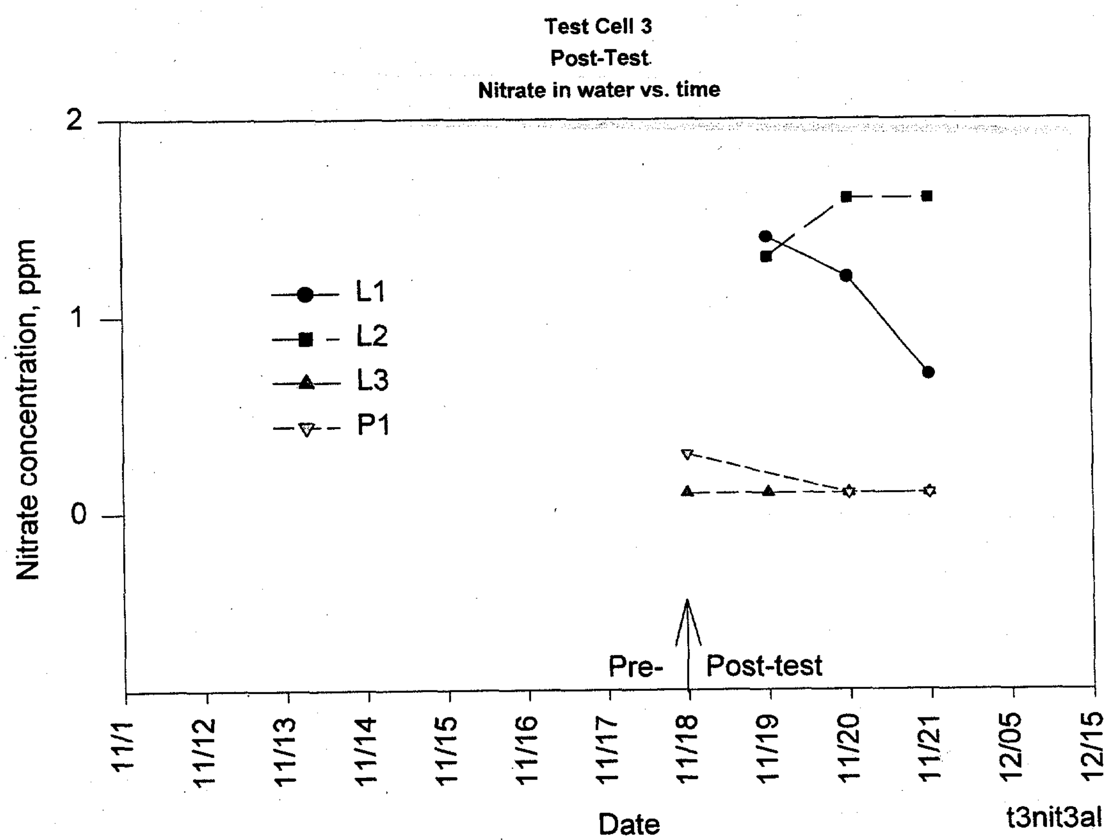


Fig. C.22. Test cell 3 - post-treatment water nitrate levels.

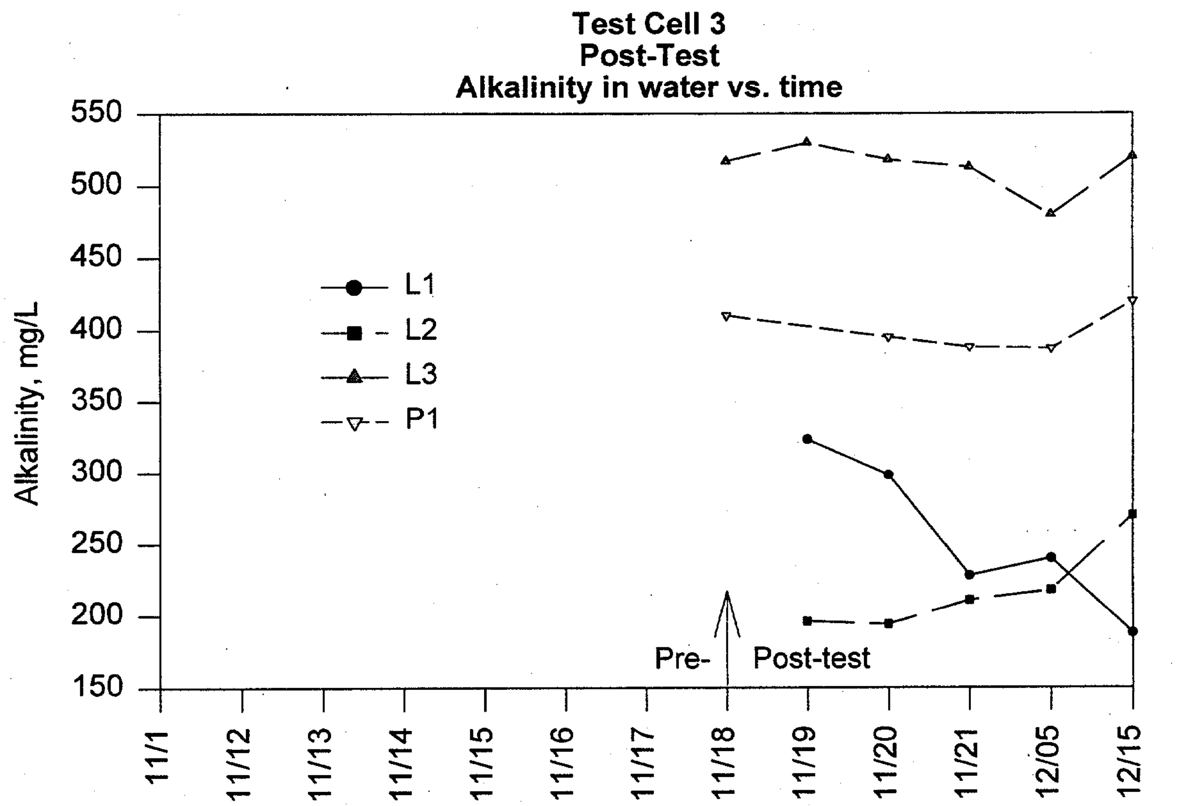


Fig. C.23. Test cell 3 - post-treatment water alkalinity levels.

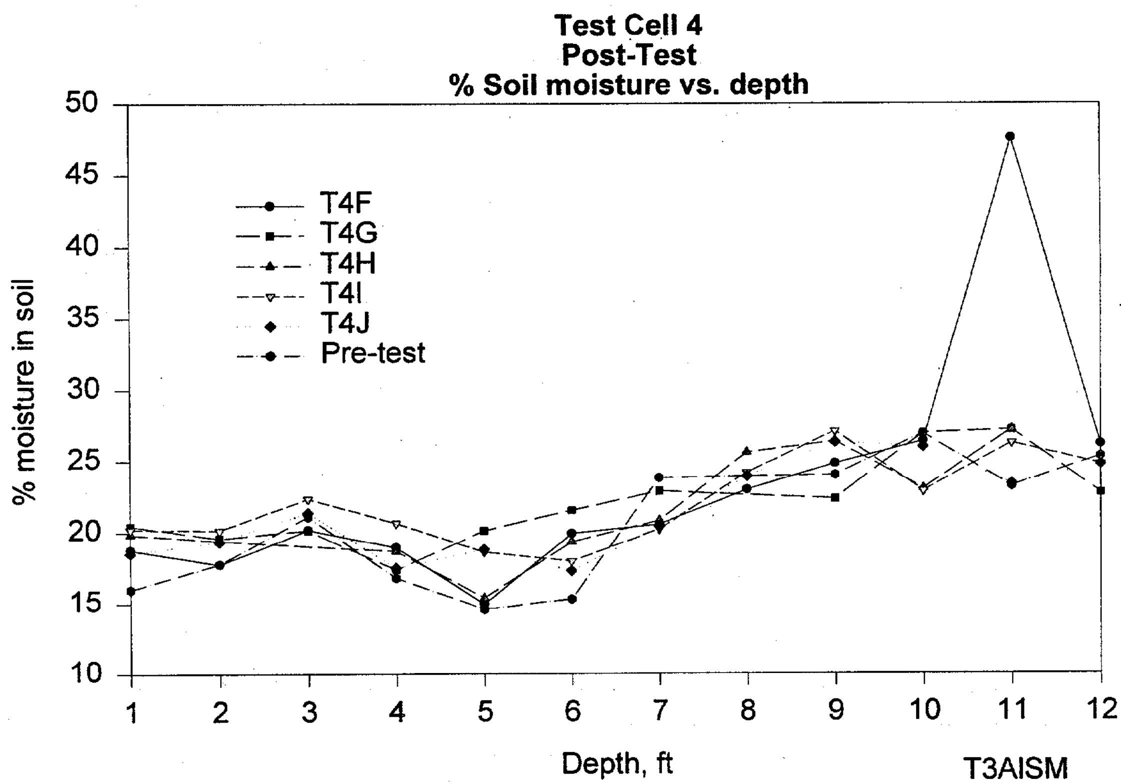


Fig. C.24. Test cell 4 - post-treatment soil moisture levels.

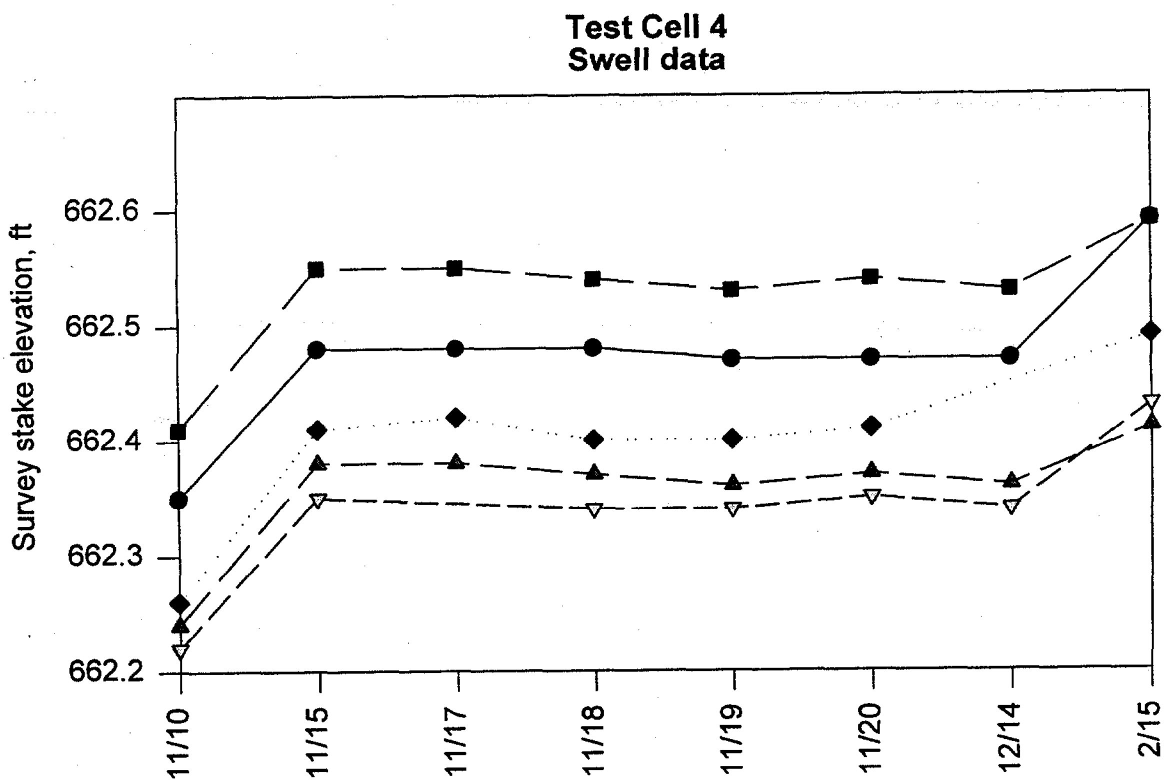


Fig. C.25. Test cell 4 - post-treatment soil swell data.

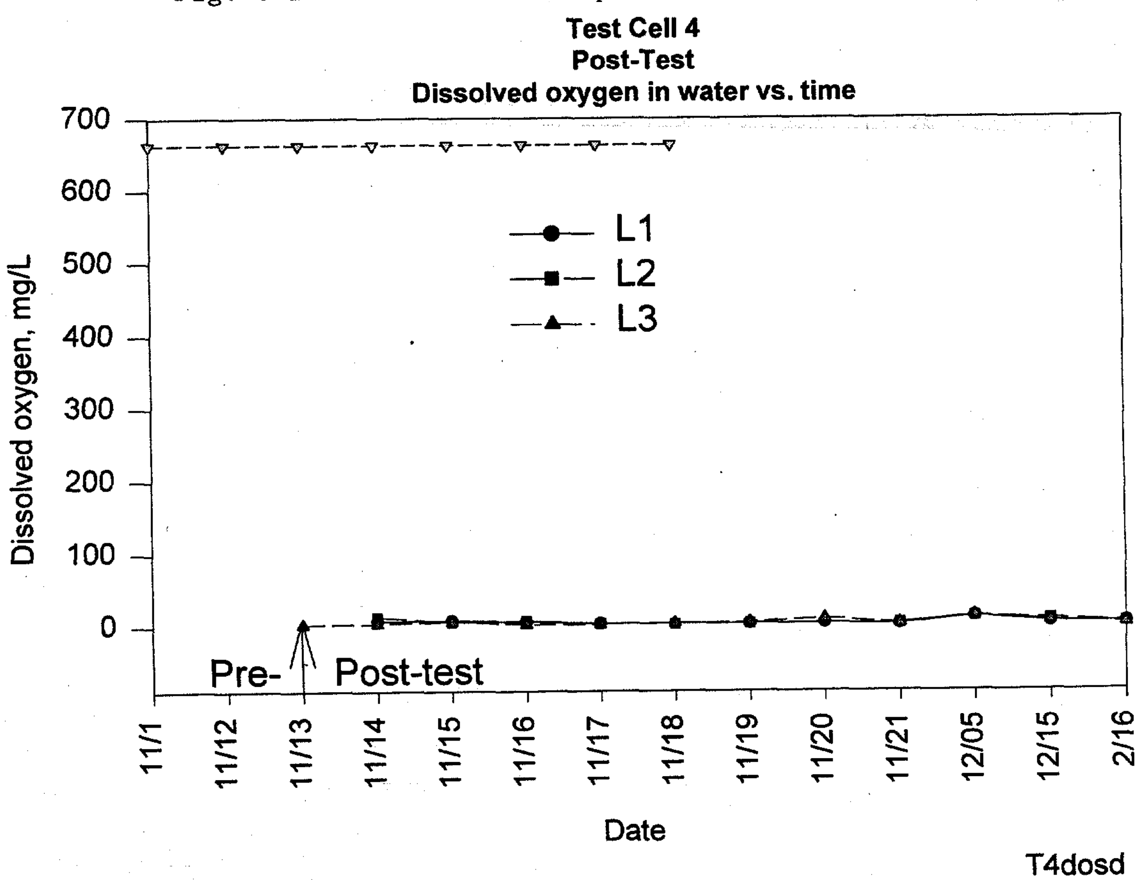


Fig. C.26. Test cell 4 - post-treatment water DO levels.

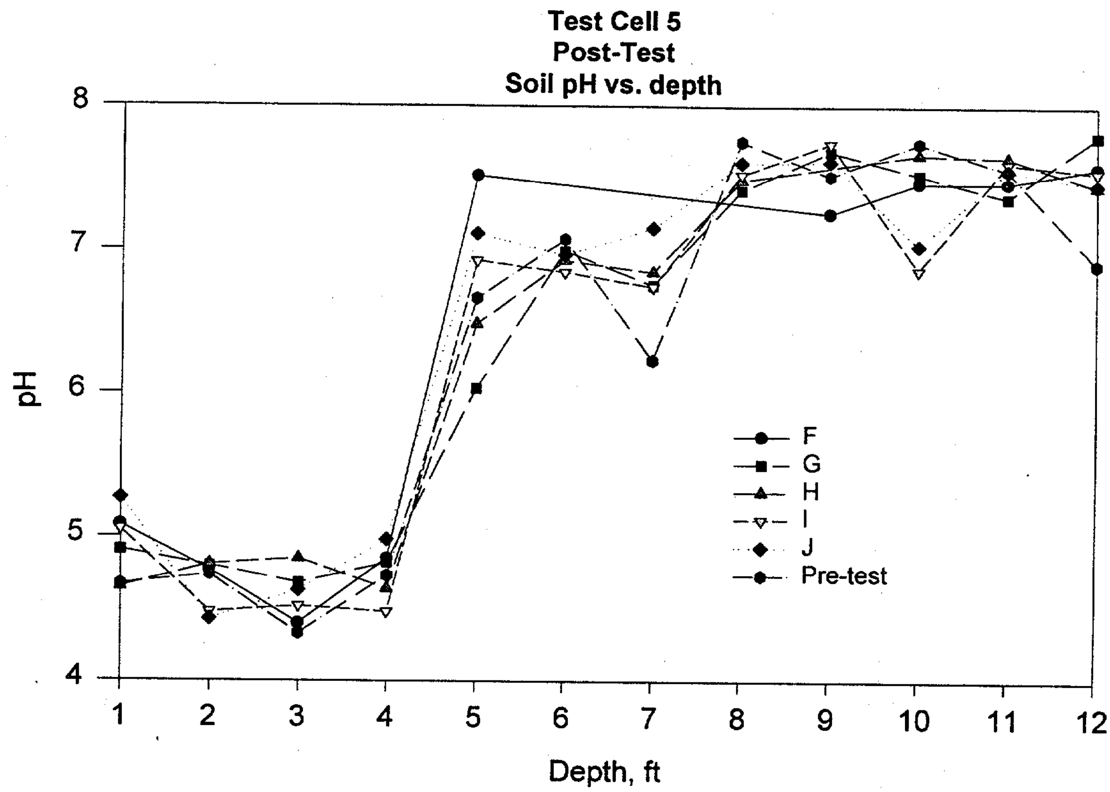


Fig. C.27. Test cell 5 - post-treatment soil pH.

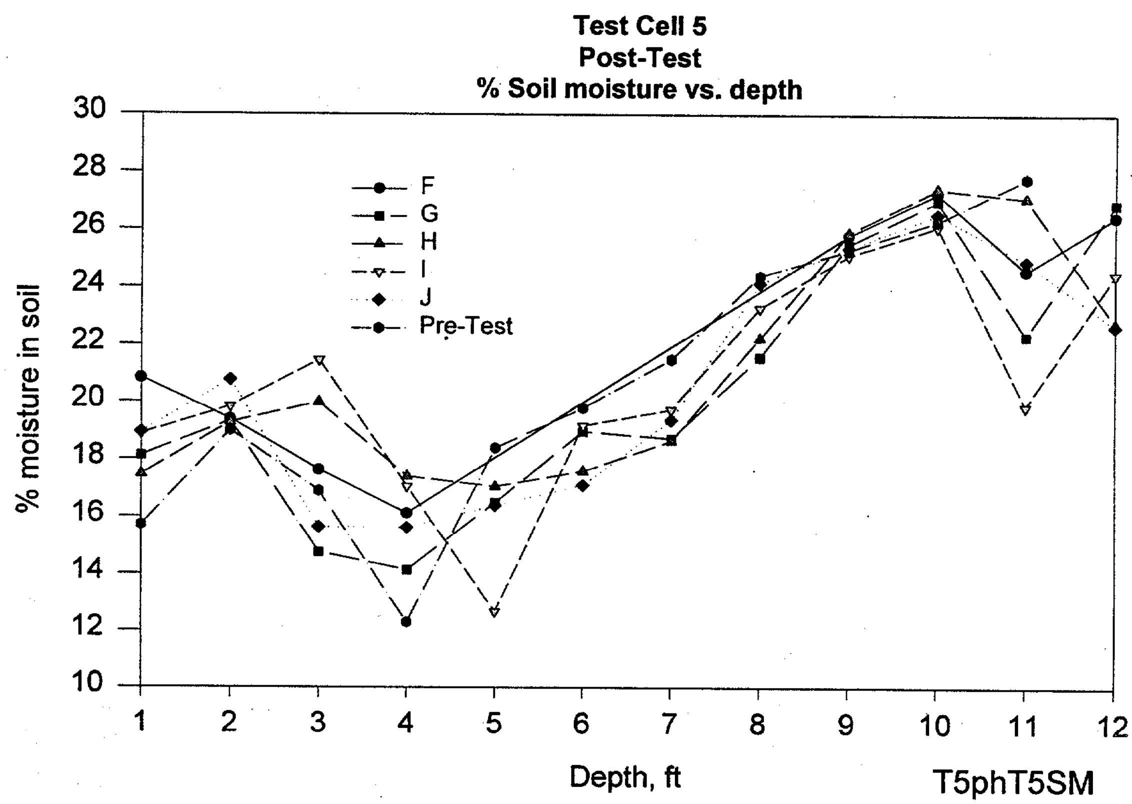


Fig. C.28. Test cell 5 - post-treatment soil moisture levels.

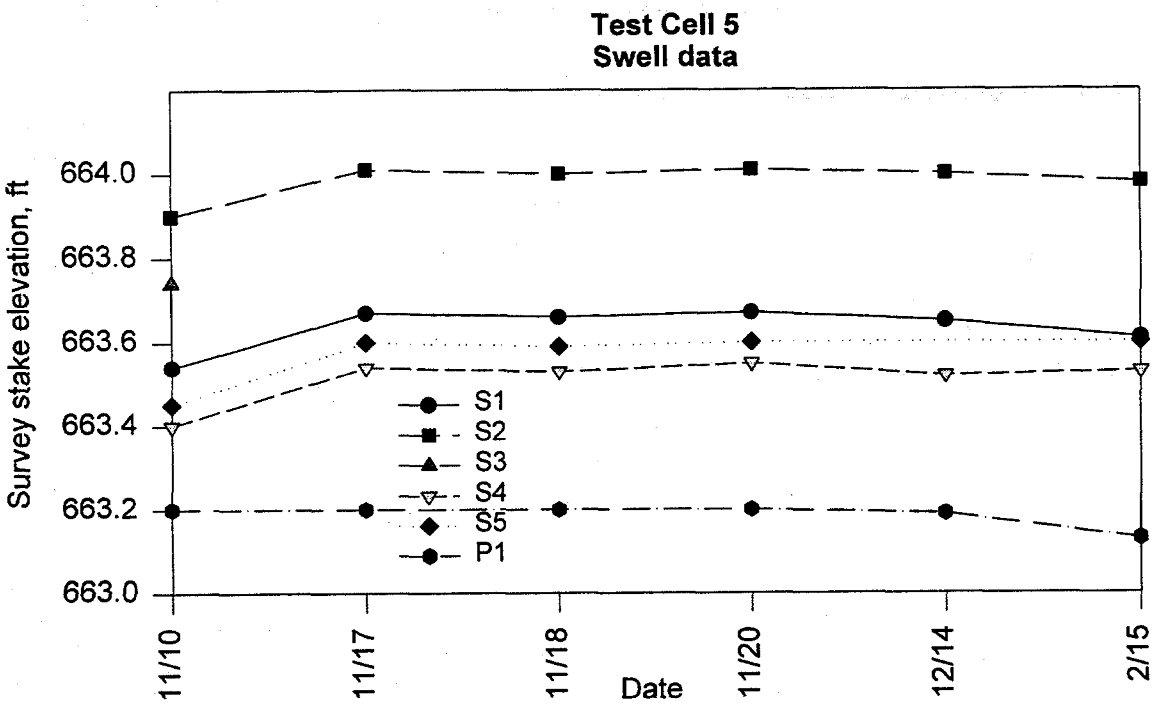


Fig. C.29. Test cell 5 - post-treatment soil swell data.

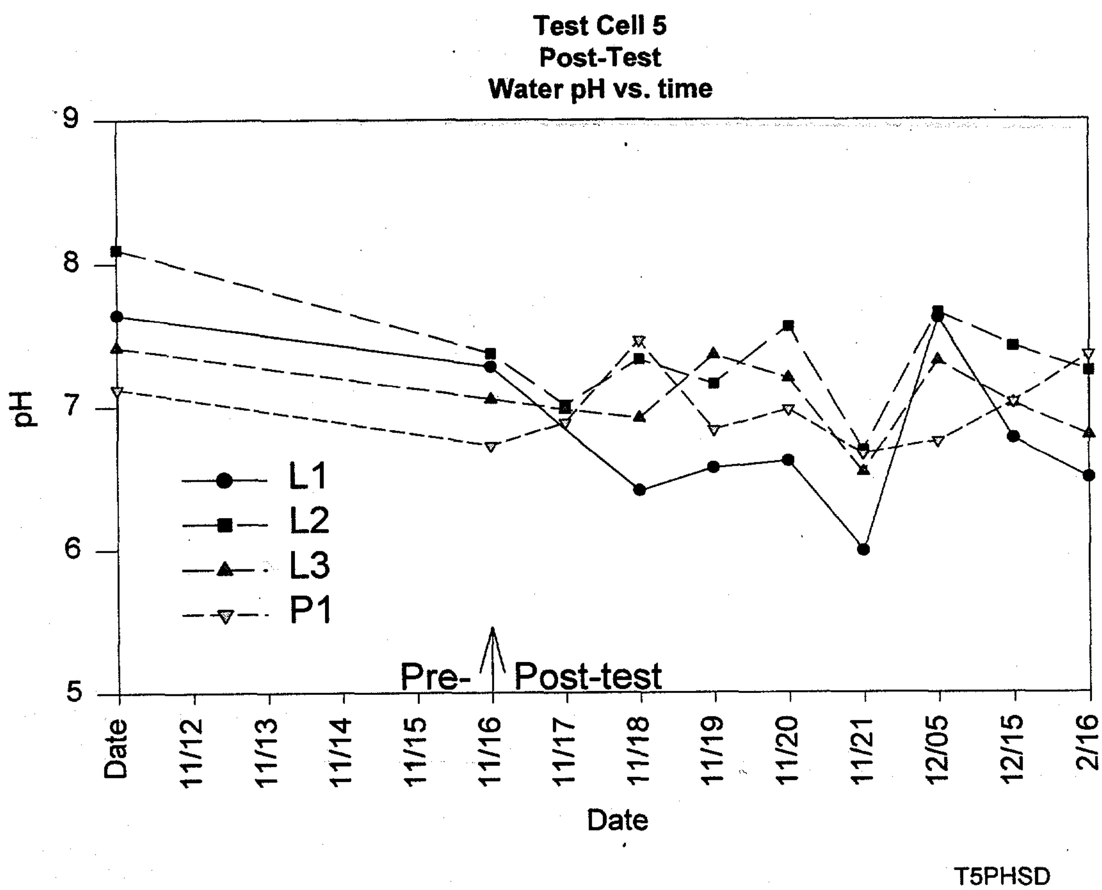


Fig. C.30. Test cell 5 - post-treatment water pH.

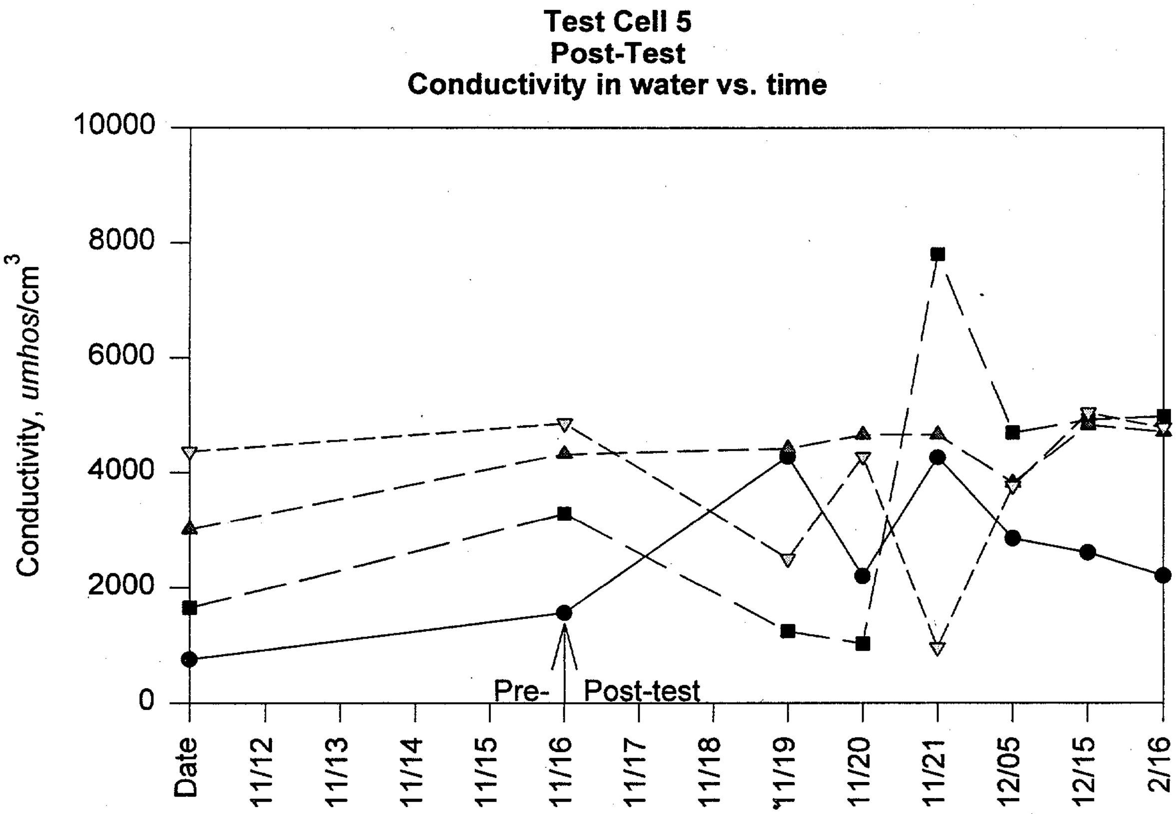


Fig. C.31. Test cell 5 - post-treatment water conductivity levels.

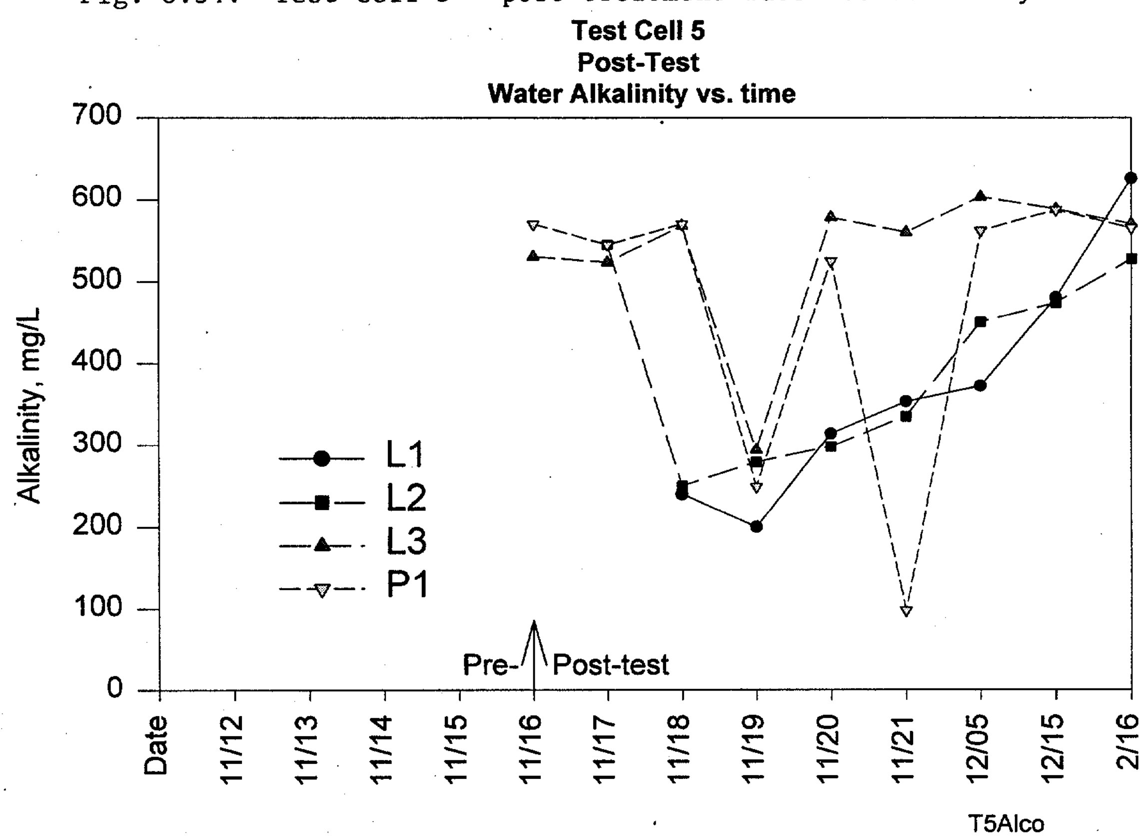


Fig. C.32. Test cell 5 - post-treatment water alkalinity levels.

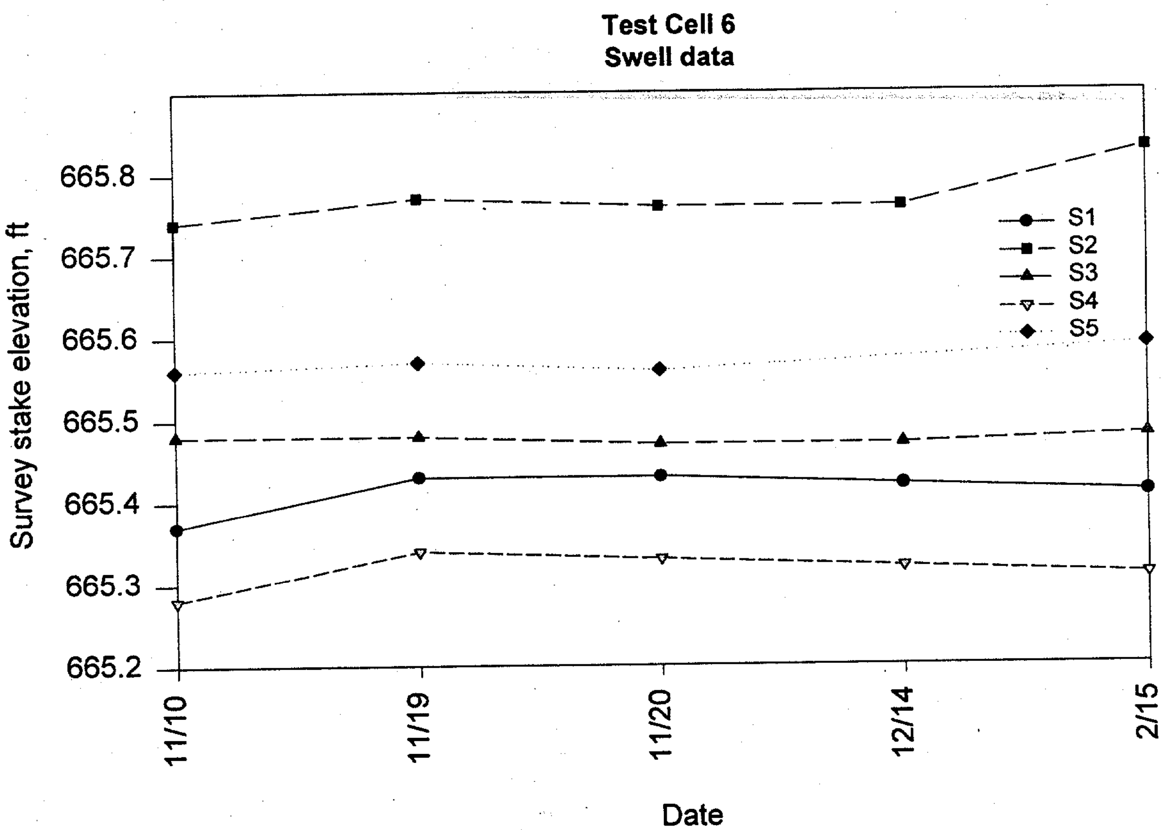


Fig. C.33. Test cell 6 - post-treatment soil swell data.

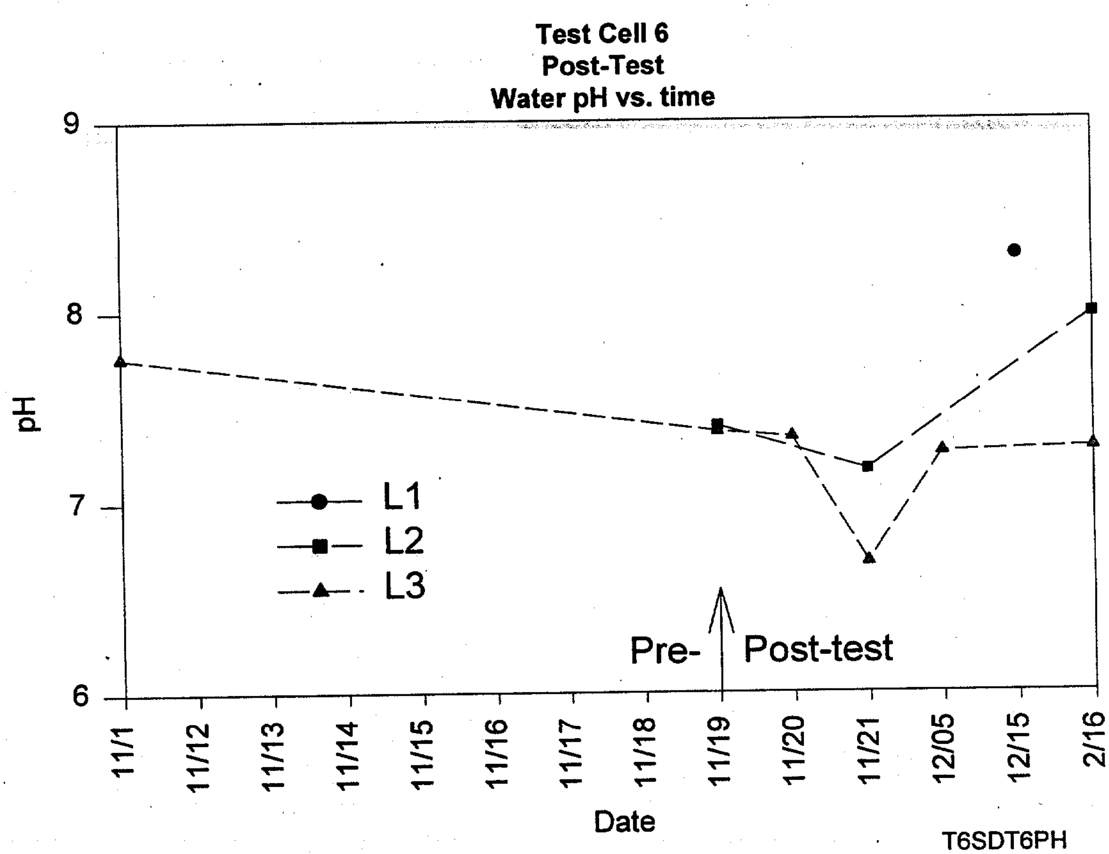


Fig. C.34. Test cell 6 - post-treatment water pH levels.

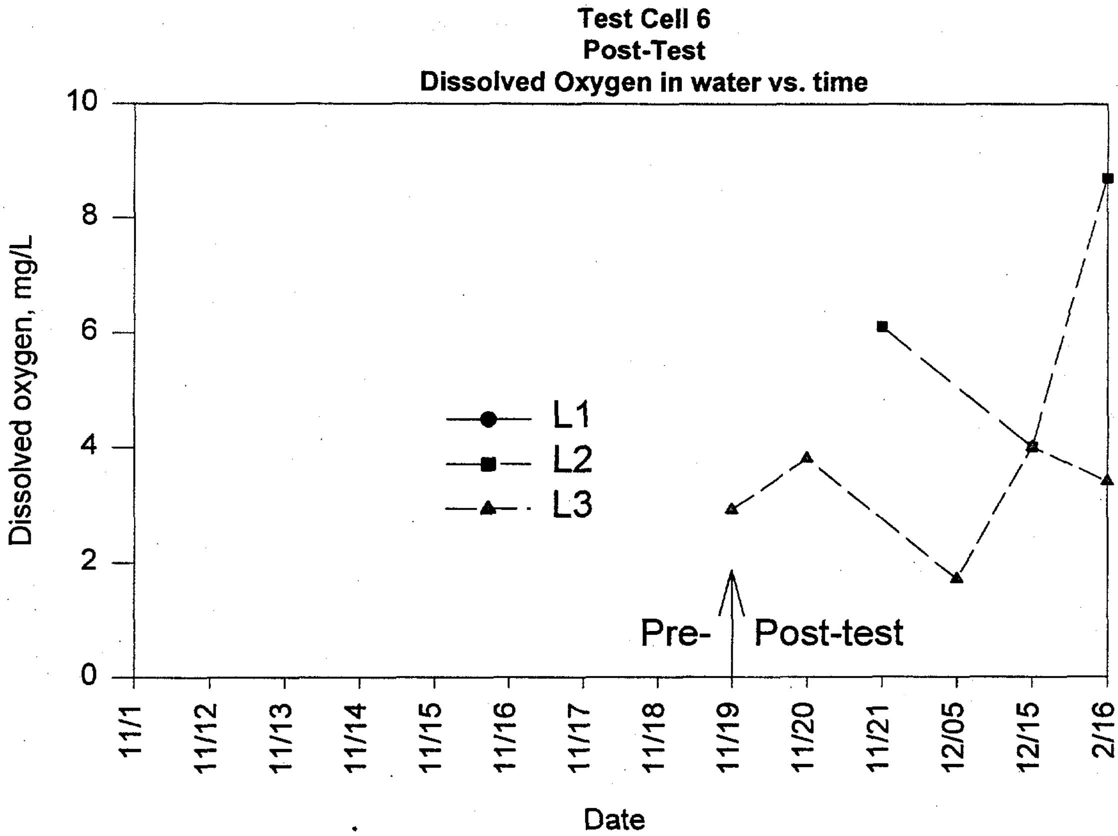


Fig. C.35. Test cell 6 - post-treatment water DO levels.

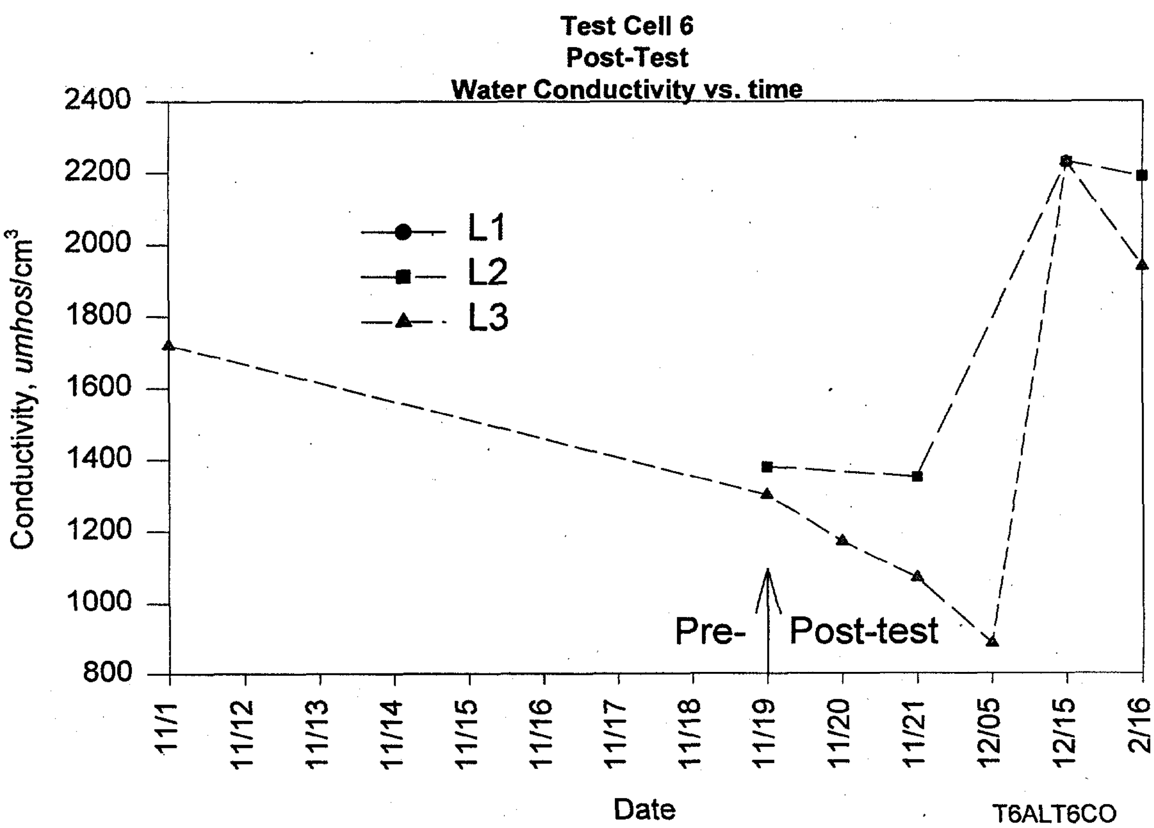


Fig. C.36. Test cell 6 - post-treatment water conductivity levels.

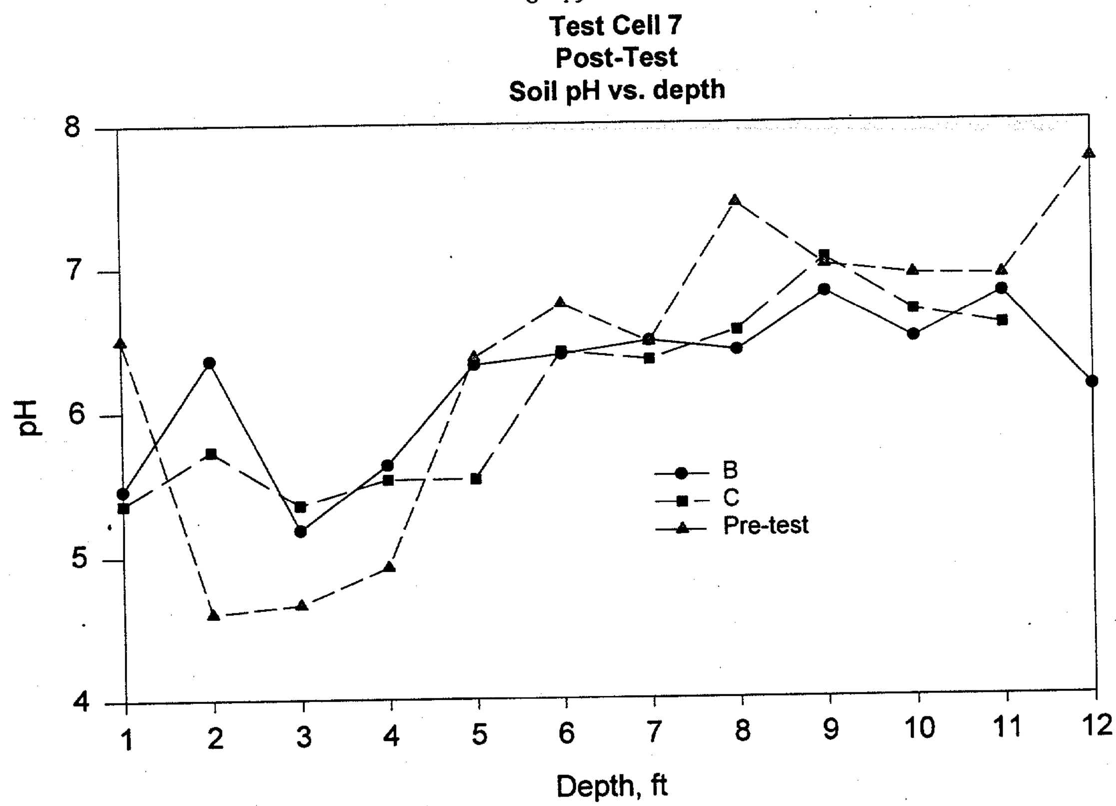


Fig. C.37. Test cell 7 - post-treatment soil pH.

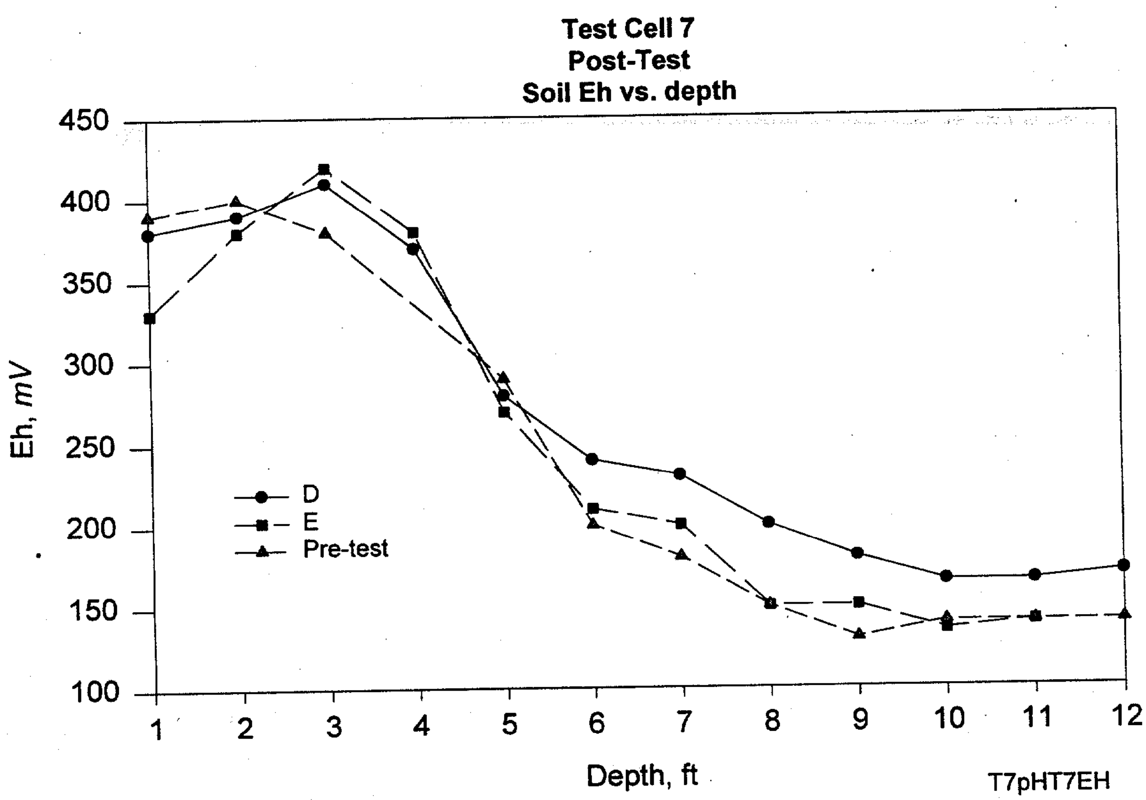


Fig. C.38. Test cell 7 - post-treatment soil Eh levels.

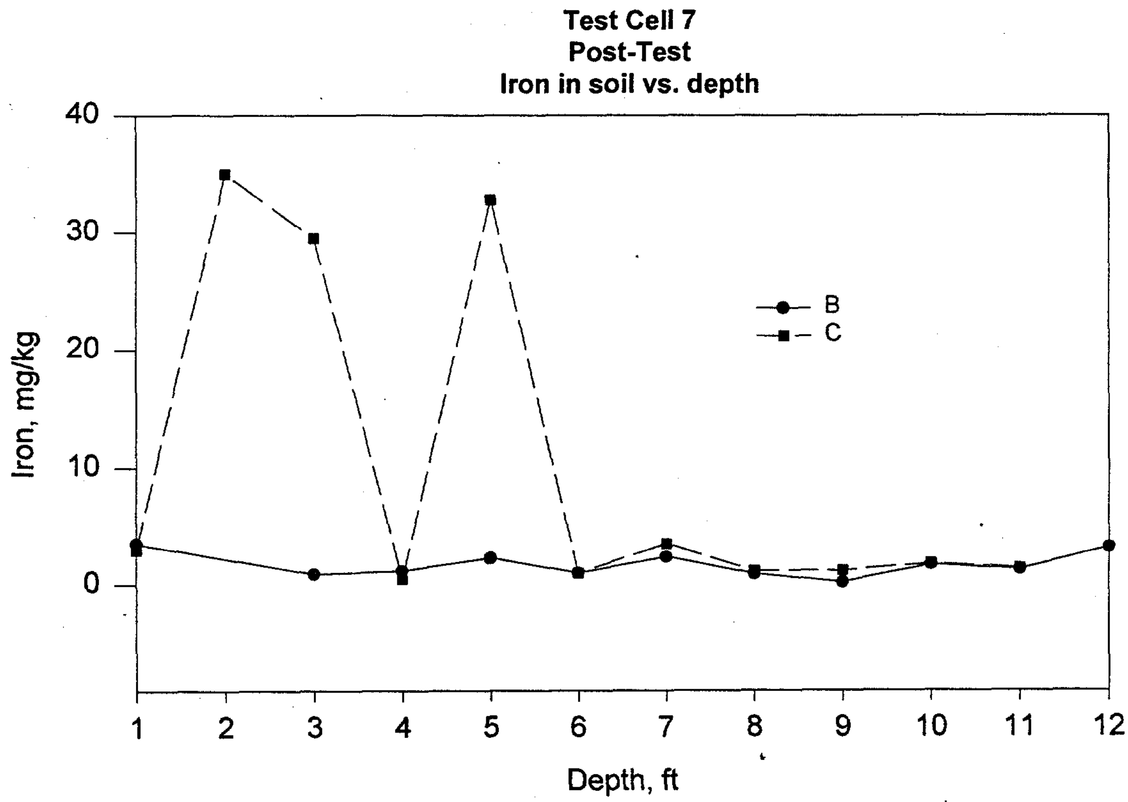


Fig. C.39. Test cell 7 - post-treatment soil iron levels.

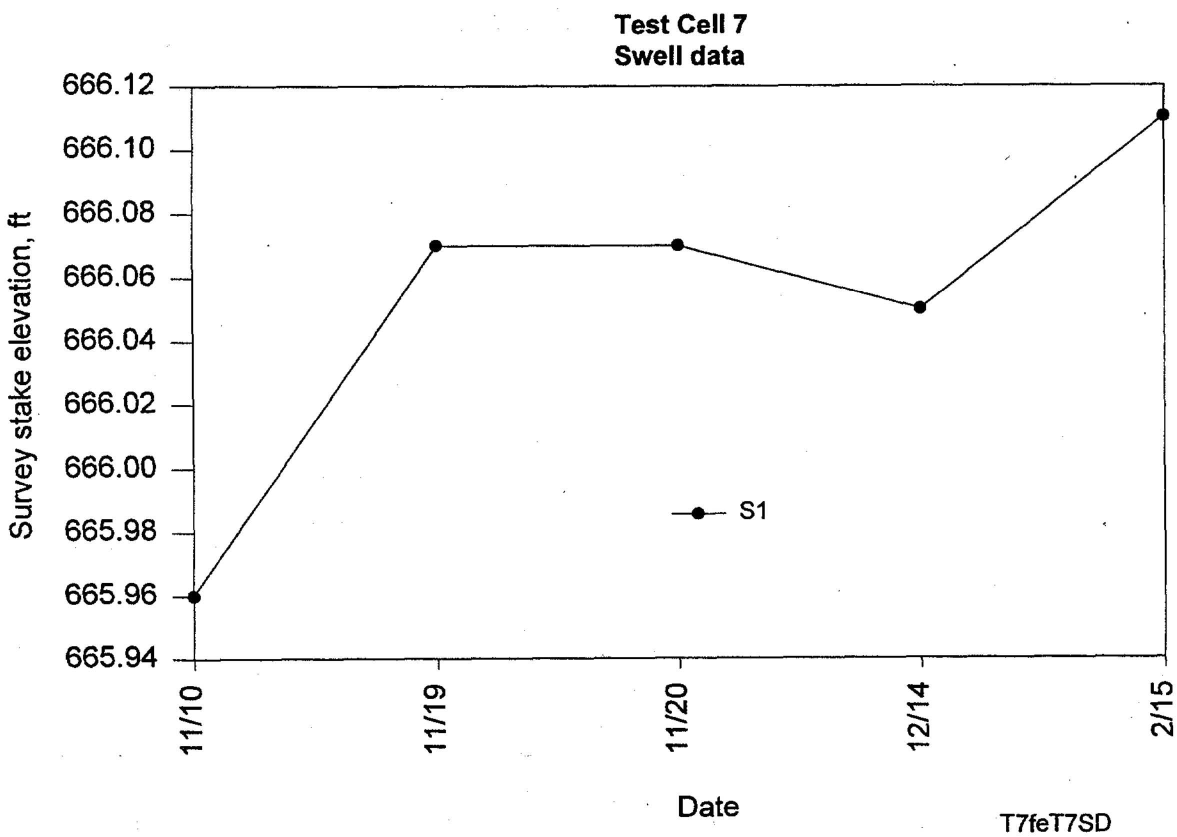


Fig. C.40. Test cell 7 - post-treatment swell data.

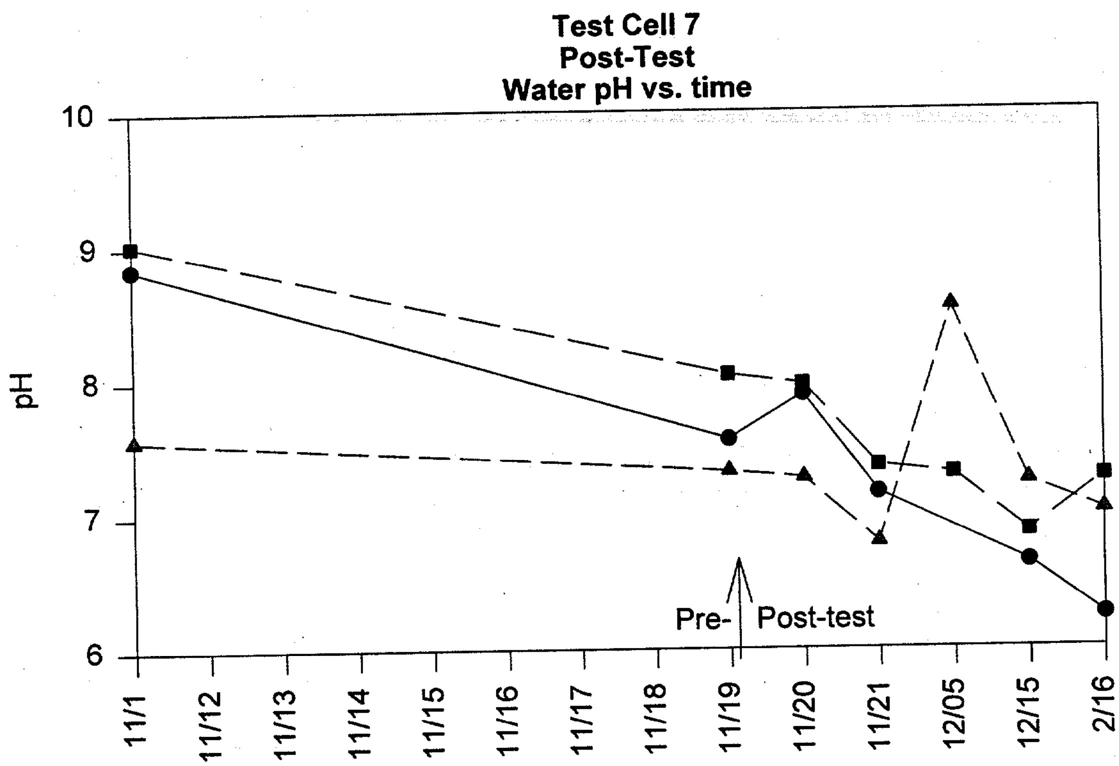


Fig. C.41. Test cell 7 - post-treatment water pH.

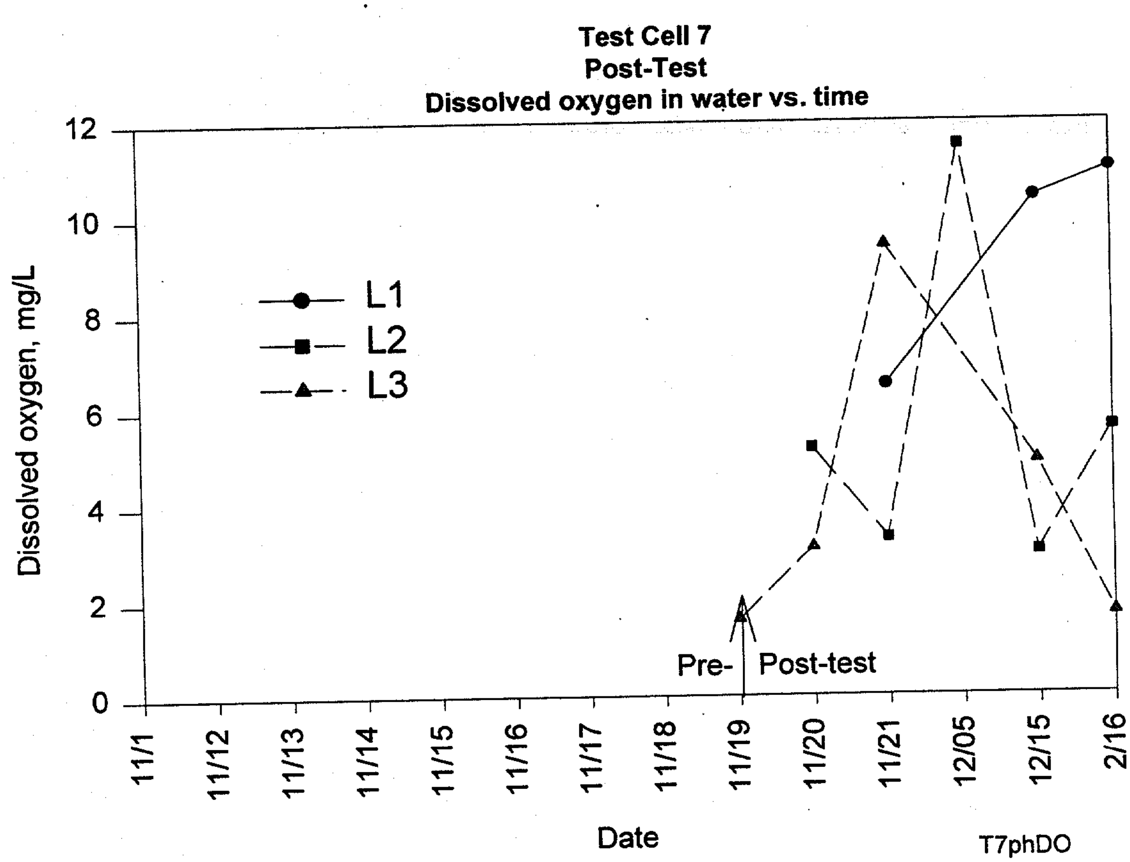


Fig. C.42. Test cell 7 - post-treatment water DO levels.

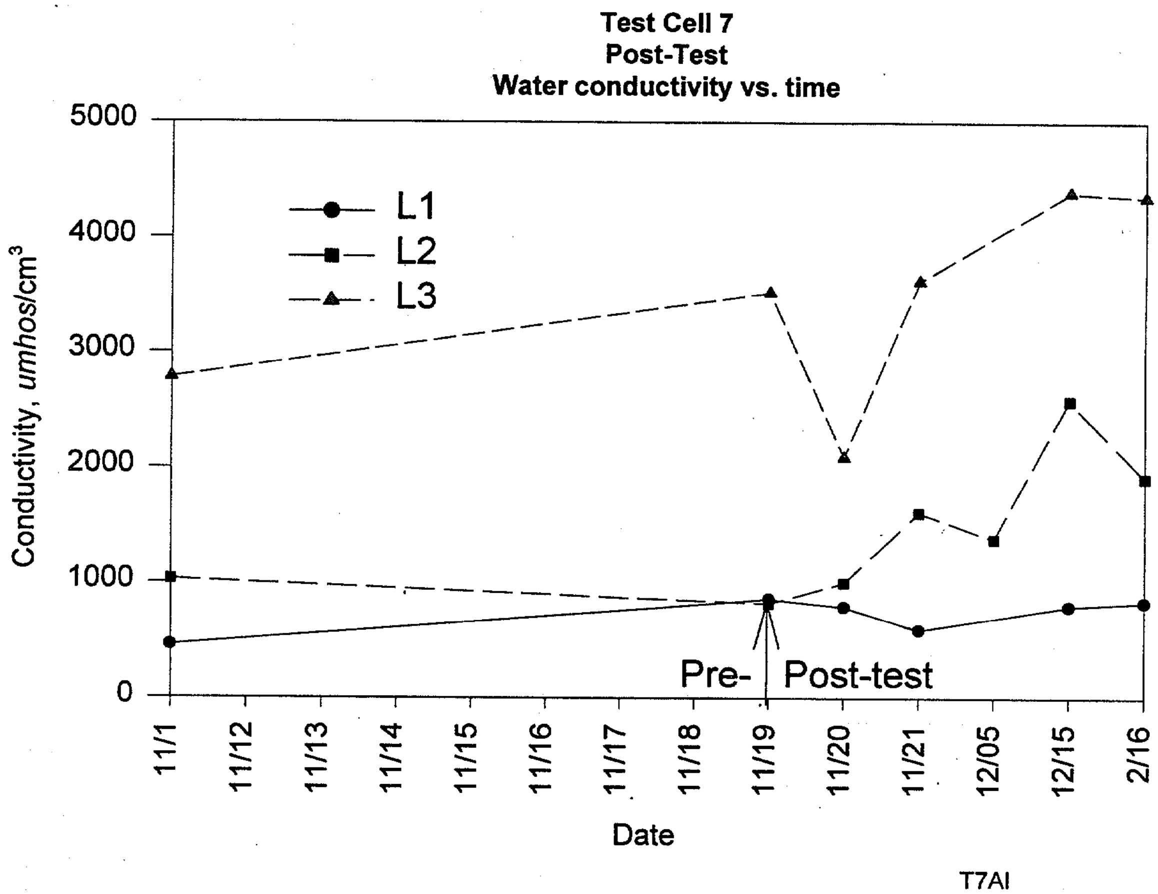


Fig. C.43. Test cell 7 - post-treatment water conductivity levels.

INTERNAL DISTRIBUTION

1. B. A. Berven
2. J. H. Cushman
3. T. O. Early
4. D. E. Fowler
5 D. W. Greene
6. B. Gu
7. S. G. Hildebrand
8. G. K. Jacobs
9. P. Kanciruk
10. N. E. Korte
11. C. A. Little
12. J. M. Loar
13-14. K. S. Lowe
15. R. C. Mann
16. T. E. Myrick
17. D. A. Pickering
18. D. E. Reichle
19. C. Rightmire
20. R. M. Schlosser
21. D. S. Shriner
22-26. R. L. Siegrist
27. O. R. West
28. Central Research Library
29-31. ESD Library
32-33. Laboratory Records Dept
34. Labortatory Records, ORNL-RC
35. ORNL Patent Section

EXTERNAL DISTRIBUTION

36. M. Broido, Director, Environmental Sciences Division, ER-74, Department of Energy, 19901 Germantown Road, Germantown MD 20874

37. S. Chamberlain, Subsurface Contaminant Focus Area Program Manager, Department of Energy, EM-53, 19901 Germantown Road, Gemantown, MD 20874

38. E. G. Cumesty, ORNL Site Manager, Department of Energy, Oak Ridge National Laboratory, P. O. Box 2008, Oak Ridge, TN 37831-6269

39. D. Davenport, 4725 Sheboygan #136, Madison, WI 53705

40. H. H. Hopkins, American Petroleum Institute, Health and Environmental Sciences Department, 1220 L Street, NW, Washington, D.C. 20005

41. T. C. Houk, Bechtel Jacobs LLC, Technology Applications, Portsmouth Gaseous Diffusion Plant, Highway 23 South, Building 3012, Piketon, OH 45661

42. M. C. MacCracken, Director, Office of the U. S. Global Change Research Program, Code YS-1, 300 E Street, SW, Washington, DC 20546

43. J. Moore, Technical Program Officer, Department of Energy, Oak Ridge Operations, 3 Main Street, Oak Ridge, TN 37830

44. E. Philips, Subsurface Contaminant Focus Area DNAPL Product Line Manager, Department of Energy, Oak Ridge Operations, 3 Main Street, Oak Ridge, TN 37830

45. D. R. Smuin, 4221 Purdy Mesa Rd. Whitewater, CO 81527-9642

46. J. S. Walker, Office of Science and Technology, Department of Energy, EM-53, 12800 Middlebrook Road, Gemantown, MD 20874

47. J. Wright, Subsurface Contaminant Focus Area Lead Office Manager, Department of Energy, Savannah River Operations, Building 703A, Rm B202, Highway 125, Aiken, SC 29802

48. Office of Assistant Manger for Energy Research and Development, U. S. Department of Energy Oak Ridge Operations, P. O. Box 2001, Oak Ridge, TN 37831-8600

49-50. Office of Scientific and Technical Information, P. O. Box 62, Oak Ridge, TN 37831