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LIST OF ACRONYMS

amsl	above mean sea level
bgs	below ground surface
BTEX	benzene, toluene, ethylbenzene, and xylene
CH_4	methane
CO_2	Carbon dioxide
DBS&A	Daniel B. Stephens & Associates, Inc.
DCE	1,1-dichloroethene
EDB	Ethylene dibromide
EPA	Environmental Protection Agency
ESE	Environmental Science & Engineering, Inc.
GC	gas chromatography
H_2O	water
HDPE	high-density polyethylene
HDS	heat dissipation sensor
HSA	hollow-stem auger
I.D.	inside diameter
LANL	Los Alamos National Laboratory
LP	landfill perimeter
LPS	landfill perimeter slant
MPSG	multi-port soil gas
MW	molecular weight
N_2	nitrogen
NAT	neutron access tube
PCE	tetrachloroethene (perchloroethylene)
PE	performance evaluation
PID	photoionization detector
ppbv	parts per billion by volume
psia	pounds per square inch, absolute
psig	pounds per square inch, gauge
PVC	polyvinyl chloride
O_2	oxygen
O.D.	outside diameter
QA	quality assurance
QC	quality control
RCRA	Resource Conservation and Recovery Act
RFI	RCRA Facility Investigation
RPD	relative percent difference
RVD	relative vapor density
SL	suction lysimeter
SOG	Standard Operating Guideline
TA	Technical Area
TC	thermocouple
TCE	trichloroethene
UV	ultraviolet
VC	vinyl chloride
VOC	volatile organic compound

EXECUTIVE SUMMARY

Daniel B. Stephens & Associates, Inc. (DBS&A), was retained by Los Alamos National Laboratory (LANL) as part of the Resource Conservation and Recovery Act Facility Investigation at Field Unit 1 by the Environmental Restoration Program at Los Alamos. DBS&A assisted in the investigation and subsurface characterization of the abandoned landfill at TA-73, identified as TA-73-001a, to determine whether contaminants were present and, if so, assess the potential for contaminant migration through the vadose zone.

This Phase I report focuses on the installation and monitoring of vadose zone instruments in boreholes drilled along the perimeter of the abandoned landfill during October and November 1994. The results of this investigation are being used to identify contaminants of concern and their respective concentrations, to refine the geologic and hydrologic conceptual model of the site, to develop realistic boundary conditions for numerical modeling, and in conjunction with the upcoming CPT investigation results, to develop source input for numerical simulations of contaminant migration through the vadose zone. The 11 boreholes were completed as vadose zone monitor wells, containing a total of 30 soil gas ports, 7 suction lysimeters, 12 heat dissipation sensors, 18 thermocouples, and 11 neutron access tubes.

Monthly monitoring of the vadose zone instruments began in January 1995. Continuous monitoring of atmospheric pressure, downhole soil gas pressure, and downhole temperature began in March 1995 at four of the monitor wells. A monthly monitoring program includes soil gas sampling from each of the downhole soil gas ports, pore liquid sampling from selected suction lysimeters, and monitoring of each neutron access tube, heat dissipation sensor, and thermocouple not connected to the continuous monitoring system.

Based upon preliminary results of the first two months of soil gas sampling and analysis (February and March 1995), high concentrations of landfill gas (methane and carbon dioxide) exist in the soil gas surrounding the landfill and are present to a depth of at least 160 feet below ground surface. The methane and carbon dioxide act as a "carrier gas" for advective transport of hazardous volatile organic compounds (VOCs). Chlorinated VOCs are present in soil vapor at concentrations as high as 36,000 ppbv, with the predominant compounds being 1,2-DCE,

Freon-22, vinyl chloride, and Freon-12, listed in approximate decreasing concentrations. Landfill gas and individual VOC and total VOC concentrations generally decline with depth, with the highest concentrations observed in the uppermost soil gas port in each monitor well. Gas concentrations are relatively constant over time. Chlorinated VOCs show a strong positive correlation with methane concentration; that is, methane is always present in soil gas containing chlorinated VOCs.

Continuous monitoring of barometric pressure fluctuations due to atmospheric tides and synoptic weather systems during March and April 1995 suggest that the pressure fluctuations propagate with only slight attenuation through the vadose zone soil gas to a depth of at least 160 feet below ground surface, the deepest depth monitored.

Temperatures of up to 27°C have been measured in the subsurface volcanic tuff, and significant thermal gradients exist in the vertical temperature profile. The high temperatures are apparently the result of methane oxidation along the anaerobic/aerobic boundary at the perimeter of the landfill gas plume.

Preliminary results from the first five months of neutron access tube and heat dissipation sensor monitoring and suction lysimeter sampling suggest that vertical downward moisture movement is occurring in the subsurface volcanic tuff along the perimeter of the landfill. Soil pore water has been collected from six of the seven suction lysimeters to a maximum depth of 55 feet below ground surface, the deepest depth instrumented with a suction lysimeter. Determination of the magnitude of the vertical downward moisture flux rate and pore liquid chemical characteristics is ongoing.

1. INTRODUCTION

Daniel B. Stephens & Associates, Inc., (DBS&A) was contracted to assist in the Resource Conservation and Recovery Act (RCRA) Facility Investigation (RFI) of an abandoned landfill located in Technical Area 73 (TA-73) of the Los Alamos National Laboratory (LANL). The landfill is located at the Los Alamos Airport, east of the terminal building and immediately north of the hotpad road (Figure 1). The landfill is being investigated by LANL Field Unit 1 and constitutes Solid Waste Management Unit TA-73-001a, as defined by the Environmental Protection Agency (EPA). The objectives of the work performed at the inactive landfill, as defined by the RFI Work plan for the former Operable Unit 1071 (LANL, 1992), are to (1) determine the nature and extent of releases of hazardous constituents from the landfill and (2) evaluate the potential for migration of hazardous constituents from the landfill to the accessible environment via the ground-water, atmospheric, or direct surface contact pathways.

This report addresses a portion of the first objective and thus constitutes DBS&A's deliverable under work release 94-0002 of subcontract 2763M0004-3V. The report focuses primarily on installation and monitoring of vadose zone instruments in boreholes along the perimeter of the abandoned landfill. The methods for installing vadose zone instruments in the boreholes are described, and preliminary monitoring results are provided. The second objective is being addressed concurrently by DBS&A through development of a site-specific hydrologic conceptual model and numerical simulation of the principal flow, transport processes, and attenuation mechanisms for contaminant migration through the vadose zone at the landfill.

The scope of work for this deliverable included (1) oversight during drilling of 11 perimeter boreholes to determine appropriate locations for installation of vadose zone monitoring equipment, (2) installation of vadose zone monitor wells containing soil gas ports, suction lysimeters, heat dissipation sensors, thermocouples, and neutron probe access tubes, (3) periodic subsurface monitoring of the vadose zone instrumentation, and (4) compilation of the preliminary vadose zone monitoring results.

A total of 30 soil gas ports, 7 suction lysimeters, 12 heat dissipation sensors, and 18 thermocouples were installed in the 11 boreholes. The correct installation depth of the monitoring

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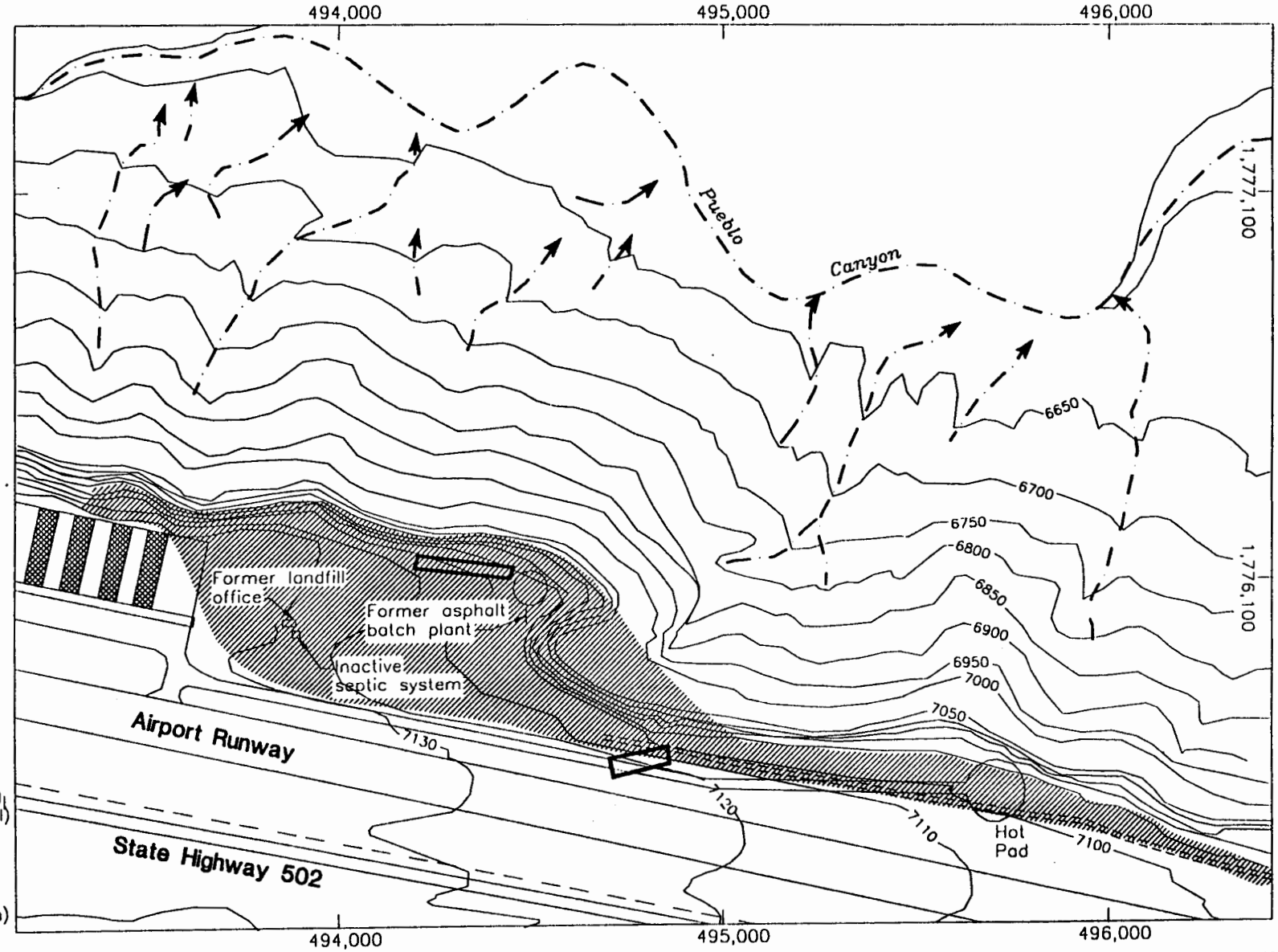

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0 400 ft

Explanation

- Building
- Former building or structure
- SWMU 73-001(a) (Municipal Landfill)
- Paved area
- Trench (on 1946 aerial photograph)
- Dirt road
- Fence
- Intermittent stream

Source: LA-FM-53, Sheet L7-NM, 1"=100', flown 1962

LANL RFI SUPPORT

Site Location Map
Former Municipal Landfill
Los Alamos Airport (TA-73)
Los Alamos, New Mexico

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Figure 1

instruments in each borehole was ensured by attaching each instrument to a 2-inch polyvinyl chloride (PVC) riser pipe, which extends the length of the borehole. Each riser pipe also serves as an access tube for the neutron probe used for soil moisture logging.

DBS&A began monthly subsurface monitoring of the vadose zone instruments in February 1995, with ERM/Golder providing technical support. The monthly monitoring program includes soil gas sampling from each of the downhole soil gas ports and pore water sampling from selected suction lysimeters. Each neutron access tube, heat dissipation sensor, and thermocouple is also monitored to estimate relative changes in subsurface moisture content, matric potential, and temperature, respectively. Continuous monitoring of atmospheric pressure, downhole soil gas pressure, and downhole temperature began in March 1995 in four of the wells equipped with dataloggers. These data are downloaded to a computer on a monthly basis.

This report is organized into five sections. Section 2 describes the drilling and well installation procedures employed during field activities conducted during October-November 1994. Section 3 discusses the vadose zone instruments installed in each borehole. Section 4 provides preliminary results for the first few months of monitoring beginning February 1995. Finally, Section 5 provides recommendations for follow-up work.

2. SITE INVESTIGATION

ERM/Golder, Inc., and DBS&A conducted field activities during October and November 1994 along the exterior perimeter of the abandoned municipal landfill located at the Los Alamos Airport. The activities included drilling, geologic logging, and collection of soil and rock samples from 11 auger borings drilled into the Bandelier Tuff. A vadose zone monitor well was installed in each boring immediately after removal of the hollow stem augers. Each monitor well contains instrumentation to permit collection of pore liquid and soil vapor samples and the measurement of subsurface properties, such as temperature, moisture content, and matric potential. These instruments include soil gas sampling ports, suction lysimeters, heat dissipation sensors, thermocouples, and neutron access tubes. A report being prepared by ERM/Golder describes drilling, geologic logging, and sampling procedures in considerable detail. This report provides only a brief summary of the drilling, logging, and subsurface sampling methodologies, focusing instead on the techniques employed during monitor well installation and subsequent monitoring of the vadose zone instrumentation.

2.1 Drilling, Logging, and Sampling

ERM/Golder supervised the drilling of 11 borings along the exterior of the abandoned municipal landfill to depths ranging from 45 to 205 feet. Health and safety concerns and restrictions precluded drilling directly into the landfill refuse; thus it was necessary to install all borings on the periphery of the abandoned municipal landfill. Nine of the borings were drilled vertically (<10 degree angle from vertical) and were designated LP-1 through LP-9 (landfill perimeter). Angle borings (>10 degree angle from vertical) were designated LPS-1 and LPS-2 (landfill perimeter slant). The boring locations are shown in Figure 2.

Layne Environmental Services performed the drilling using a hollow-stem auger (HSA) drill rig equipped with 7⅞-inch outside diameter (O.D.) augers. Core samples were collected through the HSA at 2½-foot intervals using a wireline coring system. In general, the HSA drill easily penetrated the volcanic rocks of the Bandelier Tuff without using any drilling fluids, and caving problems were minimal.

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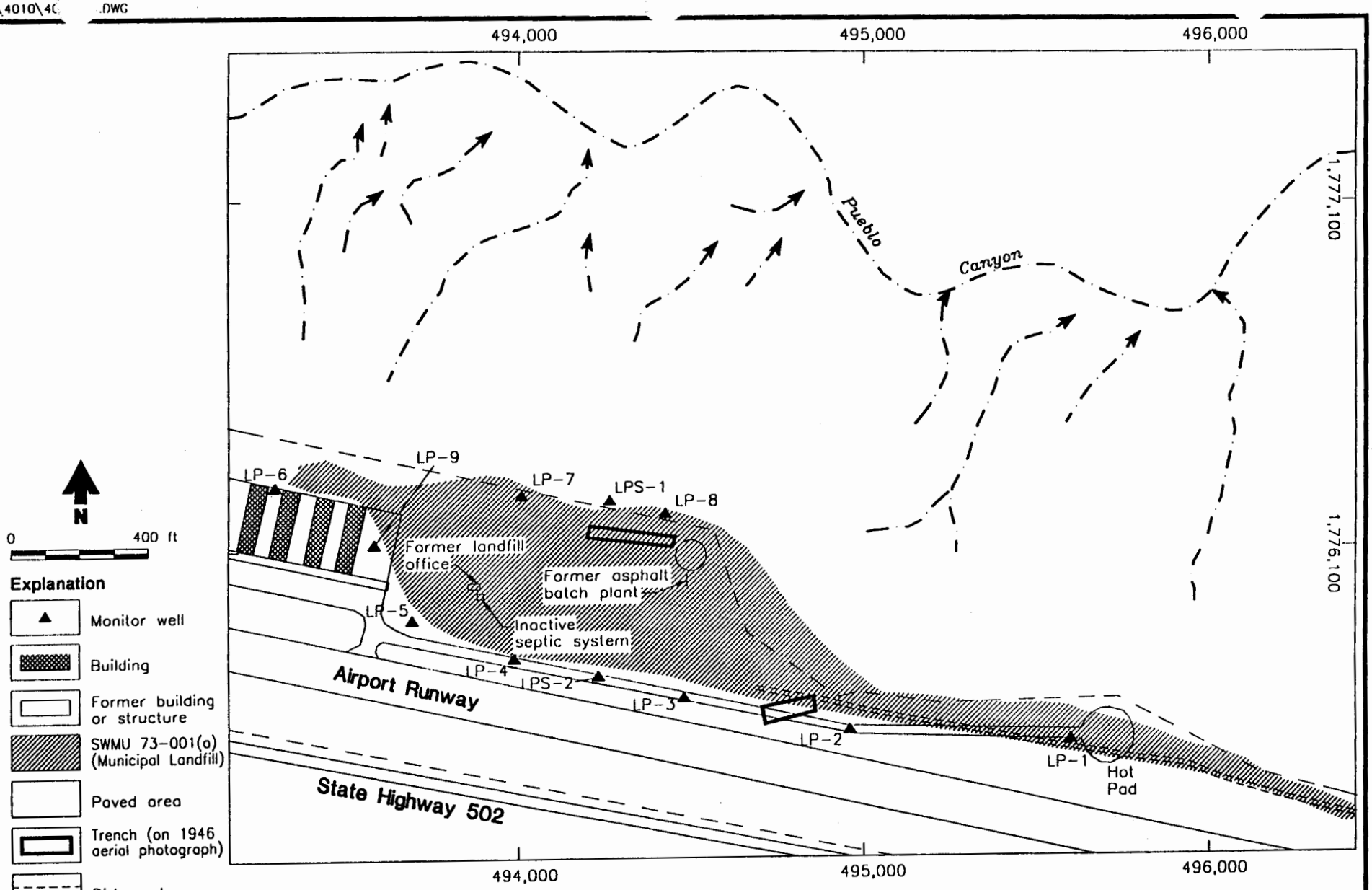

Source: LA-FM-53, Sheet L7-NM, 1"=100', flown 1962

LANL RFI SUPPORT

Monitor Well Location Map
Los Alamos Airport (TA-73)
Los Alamos, New Mexico

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Figure 2

Core samples were collected at 2½-foot intervals from the ground surface to total depth at each boring. ERM/Golder conducted detailed logging of each recovered core sample, including field screening for volatile organic compounds (VOCs) and radiological constituents, geologic logging, and soil/rock sampling for laboratory analyses at discrete intervals. Additional details can be found in the ERM/Golder summary report (ERM/Golder, 1995). DBS&A provided technical support during drilling of the boreholes. In particular, DBS&A assisted the ERM/Golder Field Team Leader in making decisions regarding the location of boreholes, drilling depths, sample locations, and other details not specifically addressed in the field sampling plan. DBS&A performed independent geologic logging of core samples to enable rapid, informed decisions regarding the well completions. This was essential in order to comply with airport requirements that the wells be installed as quickly as possible to minimize disruption of airport activities.

Geologic logging conducted by DBS&A focused on identifying pertinent characteristics of the Bandelier Tuff, including apparent moisture content, relative induration, welding, and fracturing. Additional information provided by ERM/Golder, included radiation monitoring field screening, photoionization detector (PID) and flame-ionization detector (FID) screening for VOCs on each section of recovered core and gravimetric moisture content determined at 2½-foot intervals. These data were used to determine the depths and locations of vadose zone instruments that were installed by DBS&A with the assistance of Layne Environmental Services. Lithologic logs for each boring are provided in Appendix A. A brief description of each boring is provided in the following paragraphs.

Monitor well LP-1 is located near the east end of the former landfill, south of the hotpad road and immediately west of the hotpad (Figure 2). This boring was drilled in an attempt to locate a buried trench identified during the existing data review and to assess possible contaminant migration in this area. The monitor well was drilled through essentially undisturbed tuff (Tshirege Unit 3).

Monitor well LP-2 is located on the south side of the hotpad road approximately 700 feet west of the hotpad (Figure 2). The boring was drilled through approximately 7 feet of fill material and into undisturbed tuff (Tshirege Unit 3) from 7 feet to the total boring depth.

Monitor well LP-3 is located on the south side of the hotpad road and approximately 550 feet west of LP-2 (Figure 2). The boring was drilled to a total depth of 110 feet to assess lateral migration of contaminants from the southern edge of the landfill. Geologic units encountered during drilling consisted of approximately 4 feet of fill material overlying the lowermost portion of Tshirege Member Unit 3, the non-welded unit beneath it, and the uppermost portion of Tshirege Unit 2. Of particular interest was an interval of unusually wet tuff observed from 19 to 21 feet bgs. The wet zone appeared to correlate with the presence of a near-vertical fracture observed in the core samples from this depth.

Monitor well LP-4 is located in the center of the hotpad road approximately 750 feet west of LP-3 (Figure 2). The boring was drilled to a total depth of 112.5 feet to assess lateral migration of contaminants from the southern edge of the landfill. Geologic materials encountered during drilling included approximately 7 feet of fill material, variably weathered tuff from roughly 7 feet to 85 feet, and essentially unweathered tuff from 85 feet to the total boring depth. The weathered intervals appear to correspond with a near-vertical fault or fracture zone that extends through at least Tshirege Member Unit 3 and the underlying non-welded unit. The weathered zone is characterized by distinct limonite (Fe_2O_3) staining and relatively high gravimetric moisture contents determined on core samples.

Monitor well LP-5 is located north of the hotpad road at the southeast corner of the aircraft tiedown pad and approximately 350 feet west of LP-4 (Figure 2). The boring was drilled to the total depth of 40 feet to assess contaminant migration from the southwest portion of the abandoned landfill. The boring was drilled through approximately 12 feet of fill and then undisturbed tuff (Tshirege Unit 3). Unusually wet undisturbed tuff was encountered to approximately 25 feet bgs.

Monitor well LP-6 is located in the aircraft tiedown pad area between the two western-most hangars (Figure 2). The boring was drilled in an attempt to locate a buried trench identified during the existing data review and to assess potential contaminant migration in this area. The boring was drilled through approximately 12 feet of fill and then undisturbed tuff (Tshirege Unit 3).

Monitor well LP-7 is located on the northern boundary of the landfill approximately 400 feet north of LP-4 (Figure 2). The boring was drilled at a 10 degree angle from vertical to a total uncorrected depth of 115 feet. Fill material was encountered to approximately 10 feet bgs; thenceforth, relatively undisturbed tuff was penetrated to the total depth. The lowermost portion of Tshirege Member Unit 3, the non-welded unit beneath, and the uppermost portion of Tshirege Unit 2 were penetrated during drilling. Of particular interest was an abrupt doubling of gravimetric moisture content that was observed at 54 feet bgs; the elevated moisture content continued to the total depth. The abrupt increase in moisture content appeared to correlate with the presence of a near-vertical fracture observed in the core at 55 feet.

Monitor well LP-8 is located approximately 450 feet north-northwest of LP-3 on a bedrock bench north of the landfill on the edge of Pueblo Canyon (Figure 2). The boring was drilled to its total depth of 102.5 feet through undisturbed tuff, penetrating the lowermost portion of Tshirege Unit 3, the non-welded unit beneath it, and the uppermost portion of Tshirege Unit 2. Of particular interest was the extremely low moisture content measured in core recovered below 70 feet.

Monitor well LP-9 is located in the aircraft tiedown pad area approximately 40 feet east of the easternmost hangar and roughly 250 feet northwest of LP-5 (Figure 2). The well was drilled in an attempt to locate a buried trench identified during the existing data review and assess any contaminant migration.

Apparently the boring was drilled into the backfilled trench, as undisturbed tuff was not encountered until approximately 17 feet bgs. As expected, the waste material had been replaced with tuffaceous fill in order to construct the airport tiedown pad and hangars. The boring was drilled to its total depth of 45 feet through 17 feet of tuffaceous fill material and then undisturbed tuff (Tshirege Unit 3). Of particular interest was an interval of unusually wet tuff observed from 25 to 26 feet bgs. The wet zone appeared to correlate with the presence of several nearly horizontal fractures observed in core samples from this depth.

Monitor well LPS-1 is located approximately 150 feet west of LP-8 on the bedrock bench north of the landfill (Figure 2). The boring was drilled toward the south (N180°) at a 20-degree angle from vertical.

Undisturbed tuff was encountered to the total uncorrected depth of 162.5 feet (roughly 153 vertical feet). The lowermost portion of Tshirege Unit 3, the non-welded unit beneath it, and the uppermost portion of Tshirege Unit 2 were penetrated during drilling. Of particular interest were two intervals of unusually wet tuff observed at uncorrected depths of 118 and 132 feet bgs. Both wet zones appear to correlate with the presence of near vertical fractures observed in core samples from this depth.

Monitor well LPS-2 is located in the center of the hotpad road approximately 300 feet west of LP-3 (Figure 2). The boring was drilled at a 25 degree angle from vertical oriented toward N45E to a total uncorrected depth of 205 feet (roughly 186 vertical feet).

Relatively undisturbed tuff was encountered beneath the fill/tuff contact from 10 feet bgs to the total depth. As with the other borings that were drilled deeper than 90 feet, the lowermost portion of Tshirege Unit 3, the non-welded unit beneath it, and the uppermost portion of Tshirege Unit 2 were penetrated during drilling. Of particular interest was the generally dry nature of the tuff observed in core samples from LPS-2, especially below 135 feet bgs. From 135 to 205 feet bgs, gravimetric moisture content remained consistently below 3 percent. In addition, a zone of slightly increased moisture content was observed in core at approximately 60 feet bgs associated with near vertical fractures.

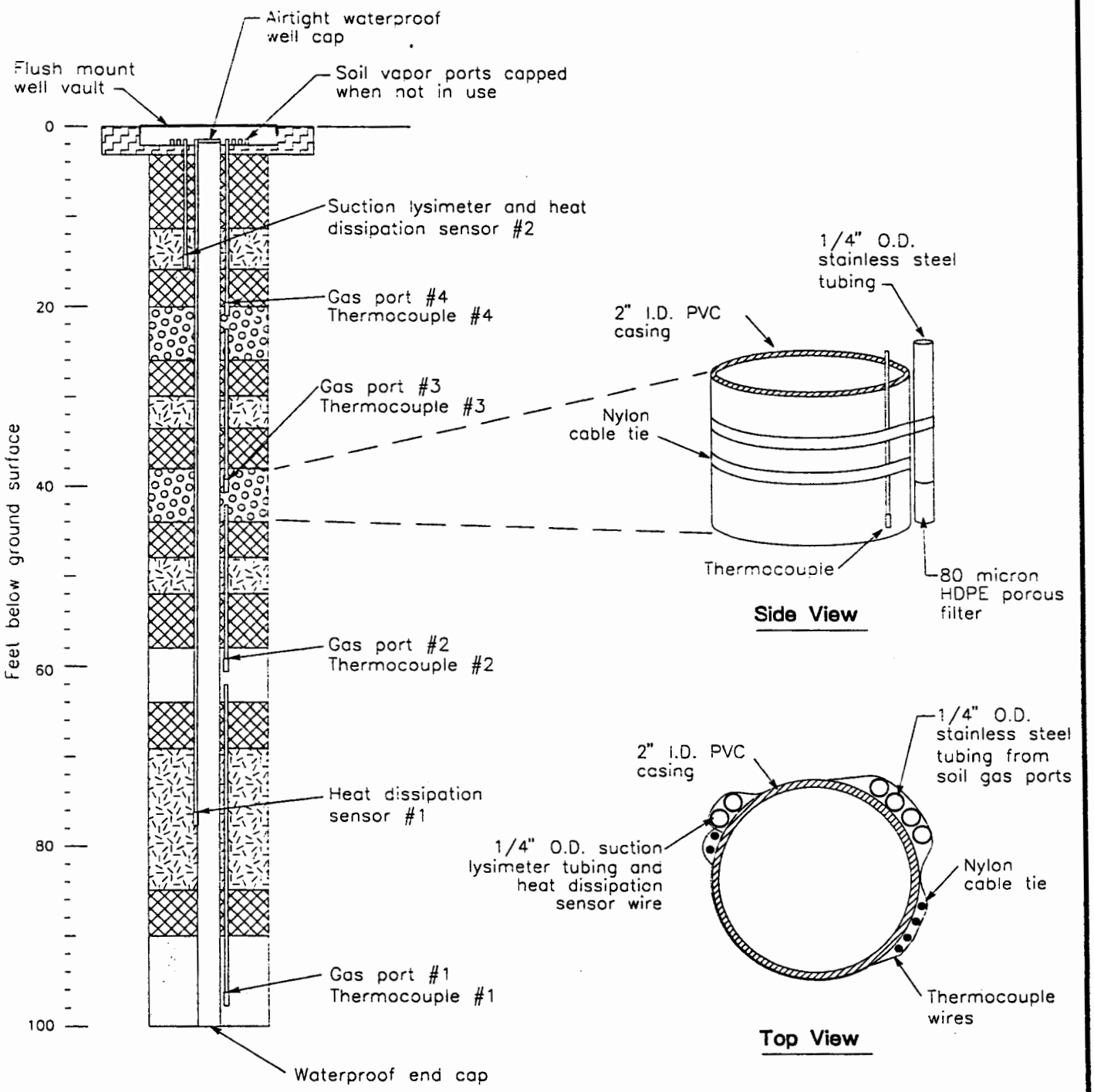
2.2 Vadose Zone Monitor Well Installation

Vadose zone monitor wells were installed in accordance with the following LANL-approved DBS&A standard operating guidelines (SOGs): 13.7.5, *Suction Lysimeter Installation and Sampling*, 13.7.6, *Neutron Probe Access Tube Design and Installation*, 13.7.10, *Soil Moisture and Matric Potential Sensor Installation and Monitoring*, and 13.7.11, *Down-Hole Soil Vapor Well Design and Installation.* Table 1 provides a list of the instruments installed in each of the boreholes. The general design of the vadose zone monitor wells is presented in Figure 3 and construction details are presented below. Appendix A contains well completion logs for each of the borings. A summary of well completion information is provided in Table 2.

Table 1. Vadose Zone Monitor Wells and Instrumentation

Monitoring Instrument Type	Vadose Zone Monitor Well[a] Instruments (Instrument ID No. and Depth)										
	LP-1	LP-2	LP-3	LP-4	LP-5	LP-6	LP-7[b]	LP-8	LP-9	LPS-1[b]	LPS-2[b]
Soil gas port[c]	GP1 @ 40.2' GP2 @ 10.2'	GP1 @ 35.9'	GP1 @ 99.2' GP2 @ 91.2' GP3 @ 39.2' GP4 @ 9.2'	GP1 @ 99.3' GP2 @ 75.3' GP3 @ 46.3' GP4 @ 13.3'	GP1 @ 33.5'	GP1 @ 27.0'	GP1 @ 100.0' GP2 @ 28.0' GP3 @ 16.0'	GP1 @ 91.5 GP2 @ 43.5' GP3 @ 15.5'	GP1 @ 41.0' GP2 @ 11.1'	GP1 @ 145.0' GP2 @ 114.0' GP3 @ 61.0' GP4 @ 22.0' GP5 @ 7.5'	GP1 @ 178.0' GP2 @ 125.0' GP3 @ 87.0' GP4 @ 29.0'
Thermocouples[d]	--	--	--	T1 @ 99.3' T2 @ 75.3' T3 @ 46.3' T4 @ 13.3'	--	--	T1 @ 100.0' T2 @ 28.0' T3 @ 16.0'	T1 @ 91.5' T2 @ 43.5' T3 @ 15.5'	--	T1 @ 145.0' T2 @ 114.0' T3 @ 61.0' T5 @ 7.5'	T1 @ 178.0' T2 @ 125.0' T3 @ 87.0' T4 @ 29.0'
Suction lysimeters[e]	--	--	SL @ 20.2'	SL @ 34.3'	SL @ 10.7'	SL @ 11.0'	SL @ 55.0'	--	SL @ 26.0	--	SL @ 62.0'
Heat dissipation sensors[f]	HDS1 @ 34.2'	--	HDS1 @ 20.4'	HDS1 @ 34.5'	HDS1 @ 23.0' HDS2 @ 11.0'	HDS1 @ 11.2'	HDS1 @ 55.2' HDS2 @ 40.0'	HDS1 @ 54.5'	HDS1 @ 26.2'	--	HDS1 @ 160.0' HDS2 @ 62.0'
Neutron probe access tube[g]	From ground to 42.6' bgs	From ground to 39.3' bgs	From ground to 101' bgs	From ground to 99.9' bgs	From ground to 37.8' bgs	From ground to 37.8' bgs	From ground to 106.2' bgs	From ground to 92.7' bgs	From ground to 42.9' bgs	From ground to 147.5' bgs	From ground to 186' bgs

[a] LP = Vertical boring around landfill perimeter; LPS = slanted boring around landfill perimeter
[b] Depth's listed are uncorrected for the drilling angle: LP-7 drilled at 10° < from vertical, LPS-1 drilled at 20° < from vertical, LPS-2 drilled at 25° < from vertical
[c] Soil gas ports constructed of ¼" stainless steel tubing
[d] Thermocouples for determining soil temperature
[e] Suction lysimeters for collecting soil water samples
[f] Heat dissipation sensors for determining soil temperature and matric potential
[g] Neutron probe access tube for soil moisture content logging, constructed of 2" PVC pipe



Not to scale

Explanation

- Bentonite pellets
- 50/50 bentonite and sand
- 10–20 silica sand
- Sieved tuff

LANL RFI SUPPORT

Generalized Vadose Zone Monitor Well Design

DANIEL B. STEPHENS & ASSOCIATES, INC.

8-95 JN 4010

Figure 3

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Table 2. Vadose Zone Monitor Well Completion Information

Monitor Well	Total Boring Depth (ft bgs)	Depth to Slough (ft bgs)	Instrumentation[a]					Neutron Access Tube Interval (ft bgs)	Centralizer Depth (ft bgs)
			NAT	GP	TC	HDS	SL		
LP-1	45	42.6	•	2		1		0.0 to 42.6	41.5
LP-2	42.5	40.1	•	1				0.0 to 40.1	37.5
LP-3	110	101.1	•	4		1	1	0.0 to 101.1	98.0
LP-4	112.5	99.9	•	4	4	1	1	0.0 to 99.9	97.5
LP-5	40	37.8	•	1		2	1	0.0 to 37.8	36.0
LP-6	40	37.8	•	1		1	1	0.0 to 37.8	36.0
LP-7	115[b]	106.2[b]	•	3	3	2	1	0.0 to 99.9[b]	50 and 104[b]
LP-8	102.5	92.7	•	3	3	1		0.0 to 92.7	89.0
LP-9	45	42.9	•	2		1	1	0.0 to 42.9	42.0
LPS-1	162.5[c]	147.5[c]	•	5	4			0.0 to 147.5[c]	78.5 and 145.5[c]
LPS-2	205[d]	186.0[d]	•	4	4	2	1	0.0 to 186.0[d]	50, 105, and 185[d]

[a] NAT = Neutron access tube
GP = Soil gas port
TC = Thermocouple
HDS = Heat dissipation sensor
SL = Suction lysimeter

[b] Not corrected for drilling angle (10° from vertical)
[c] Not corrected for drilling angle (20° from vertical)
[d] Not corrected for drilling angle (25° from vertical)

2.2.1 Field Monitoring Instruments

Immediately prior to completion of each well, the open annulus of the boring was monitored at discrete depths for methane (CH_4), carbon dioxide (CO_2), oxygen (O_2), and total VOC concentrations. If methane or VOCs were detected, the boring was purged with nitrogen (N_2) before installing the monitor well. This was done to eliminate the possibility that explosive conditions could develop in the borehole during well completion and minimize the risk of exposure to hazardous VOCs.

Two field instruments, a Landtec GA-90 and a PID, were used to quantify fixed gas and total VOC concentrations, respectively. The GA-90 multi-gas monitor employs an infrared detector to determine the concentrations of methane and carbon dioxide and a polarographic sensor to measure oxygen concentrations.

The PID was used to estimate total organic vapor concentrations when measured methane concentrations were below 1 percent by volume. DBS&A's field experience at various landfills suggests that the PID may be unreliable for determining VOC concentrations in soil gas from landfills, due to the presence of high concentrations of biogenic methane, which may interfere with the PID response. Nyquist et al. (1990) examined this effect by introducing methane at various concentrations to gas mixtures containing known concentrations of toluene and gasoline and observing PID response. The tests showed an exponential decrease in PID response with increasing methane concentrations. A 30 percent decrease in PID response was observed in the presence of 0.5 percent methane and a 90 percent decrease at 5 percent methane. Nyquist et al. attributed this decrease in PID sensitivity to the absorption of ultraviolet (UV) light by methane within the detector. The absorption of UV energy by methane reduces the number of photons available to ionize VOCs in the gas mixture and thus results in decreased sensitivity of the instrument. Therefore, whenever the GA-90 multi-gas meter indicated the presence of methane, the PID readings were viewed with caution, and the boring was purged with nitrogen immediately prior to well installation both to minimize the risk of exposure to hazardous VOCs and eliminate the possibility of explosion or fire.

Field screening during drilling and laboratory analysis of soil gas samples collected during subsequent monitoring events suggest that no significant methane or VOC contaminations are present in the vicinity of wells LP-1, LP-2, LP-5, LP-8, LP-9, and LPS-1. However, field screening detected VOCs in well LP-6 and high levels of methane in wells LP-3, LP-4, LP-7, and LPS-2. Therefore, in order to reduce the risk of exposure to hazardous VOCs and eliminate the possibility of explosion or fire, these borings were purged with nitrogen immediately before well completion.

2.2.2 Vadose Zone Instrumentation

The vadose zone monitor wells were completed variously as neutron access tube (NAT), multi-port soil gas (MPSG), thermocouple (TC), heat dissipation sensor (HDS), and suction lysimeter (SL) installations. Table 1 lists the types, numbers, and depths of instruments used in the 11 vadose zone monitor well installations. Figure 3 presents a generalized vadose zone monitor well design for the TA-73 landfill wells. Each well was completed with 2-inch-inside-diameter (I.D.) flush-threaded, Schedule 40 PVC pipe (with O-ring joint seals), a threaded end-plug at the bottom, and an expansion cap at the surface. The PVC casing served as a riser pipe to support the various attached monitoring instruments and as an access tube for neutron probe logging to estimate relative changes in soil moisture content. No free water was encountered during the drilling operations; therefore, well screens were not installed in any of the wells.

Soil gas sampling ports were installed in each of the borings to allow soil gas samples to be collected from discrete depths within the vadose zone. Each soil gas port consists of an 80-micron high-density polyethylene (HDPE) porous filter attached to an appropriate length of ¼-inch O.D., 0.020-inch wall beverage-grade, welded 304 stainless steel tubing. The hydrophobic HDPE filters, which were used to prevent entry of water or sediment into the stainless steel soil gas sampling tubes, were attached to the tubing using stainless steel Swagelok union fittings. The stainless steel tubing is manufactured in 50-foot sections, thus requiring that individual lengths be joined with stainless steel Swagelok union fittings for those installations greater than 50 feet deep. A total of 30 soil gas ports were installed in the 11 vadose zone wells. Table 2 shows the number of soil gas ports installed in each of the wells.

Thermocouples were installed in some of the wells, especially those in which high downhole methane and carbon dioxide concentrations indicated that a significant thermal gradient may exist due to exothermic oxidation of biogenic methane. Each thermocouple consists of a pair of 20-gauge wires, one of copper and the other of constantin (type T), which were twisted and soldered together and emplaced adjacent to soil gas ports. The thermocouple wires extend to the surface for connection to a Campbell Scientific 21X Micrologger. A total of 18 thermocouples were installed, each adjacent to a soil gas port. Table 1 shows the number and locations of thermocouples emplaced in each monitor well.

HDSs, which measure matric potential, were installed to (1) determine whether a particular suction lysimeter should be sampled at a particular time and (2) assess the driving force (gradient) for potential liquid movement in the Bandelier Tuff adjacent to the landfill. Each HDS consists of a thermistor/thermocouple assembly embedded in a porous ceramic tip. Wires extend to the surface for connection to a Campbell Scientific 21X Micrologger. The HDS device operates on the principle that wet soil dissipates heat more rapidly than dry soil. The heat dissipation rate at various matric potentials is measured in the laboratory to develop a calibration curve for each HDS. A total of 12 heat dissipation sensors were installed. Table 1 lists the number and locations of heat dissipation sensors installed in each monitor well, and Appendix B contains the calibration data for each HDS.

Seven deep sampling suction lysimeters were installed to allow collection of pore water from the unsaturated volcanic tuff around the landfill. The lysimeters were installed at locations from which core samples exhibited gravimetric moisture contents in excess of 10 percent. The suction lysimeters consist of a porous cup mounted on the bottom of a PVC plastic body tube, with pressure-vacuum and liquid discharge tubes extending to the surface. A heat dissipation sensor, located adjacent to each suction lysimeter, is monitored on roughly a monthly basis to ascertain whether the tuff is wet enough to permit pore water samples to be collected from that particular suction lysimeter. In general, lysimeters can only be used to collect pore water samples at matric potentials less (wetter) than 0.8 bar tension. A total of seven suction lysimeters were installed at the site. Table 2 lists the monitor wells in which suction lysimeters were installed.

In order to collect pore water samples using a suction lysimeter, it is imperative that good contact be maintained between the porous cup and surrounding soil. Such contact is normally attained by mixing a slurry of backfill material and distilled water and emplacing it around the suction lysimeter using a tremie pipe. However, due to the relatively dry in-situ tuff encountered during drilling at the TA-73 landfill, the addition of water to each borehole was minimized in order to reduce the disturbance to the natural flow field. Immediately prior to installation in a borehole, distilled/deionized water containing 10-mg/L bromide as a conservative tracer was pulled through the lysimeter cup to eliminate entrapped air. The tracer also serves to qualitatively assess the degree to which the water derived from lysimeter installation has been purged from the borehole during subsequent sampling events. The water was left in the lysimeter body during installation to maintain cup wetness.

An annular seal consisting of a mixture of 50 weight percent dry powdered Wyoming bentonite and 50 weight percent 10-20 silica sand was emplaced into the borehole using a tremie pipe and tamped until just below the HDS/SL location. Dry, sieved tuff was then added to the borehole by tremie until the instruments were completely covered (the types of backfill materials and emplacement methods are discussed below). One-half to one gallon of distilled/deionized water containing the bromide tracer (10 mg/L Br as potassium bromide) was then added by tremie, and a tamping rod was used to carefully compact the wetted sieved tuff about the suction lysimeter. Upon completion of the well, the tracer solution in the lysimeter was removed.

2.2.3 Backfill Materials and Method

Three different annular backfill materials were emplaced in the boreholes during well completion in order to (1) facilitate soil gas and liquid sampling, (2) limit vertical movement of liquid and gases in the boreholes, and (3) allow for monitoring of relative changes in moisture content. The three types of backfill materials included 10-20 silica sand, powdered Wyoming bentonite, and sieved Bandelier Tuff. Bentonite pellets were also emplaced to serve as a base for the surface completion.

Sand filter packs were constructed adjacent to each of the soil gas sampling ports using 10-20 silica sand (Figure 3). The sand layers were emplaced dry in the borehole annulus using a tremie pipe, and the top and bottom of each layer was verified using a weighted tape measure.

A mixture of 50 weight percent dry powdered Wyoming bentonite and 50 weight percent 10-20 silica sand was installed as an annular seal above and below each of the sand filter packs, below the suction lysimeters, and below depth intervals where increased moisture content were observed. Powdered bentonite was used to eliminate downward seepage from the wet fill material/tuff contact and from the surface. The powdered bentonite/sand mixture was prepared dry using a portable cement mixer, and layers of this mixture were installed as annular seals to prevent cross-communication between adjacent soil gas ports. The annular seals were emplaced dry, in equilibrium with the ambient humidity, to avoid potential desiccation and cracking of the seals that might occur if a hydrated bentonite slurry were used in this vadose zone application. The dry bentonite powder swells as it wets to the ambient water potential of the surrounding tuff.

Air permeabilities in the range of 0.1 darcy (10^{-4} cm/sec) were measured on the dry annular seal mixture in the DBS&A laboratory and are similar to those determined on samples of Bandelier Tuff obtained from Los Alamos. Wetting of the bentonite powder in the mixture to the ambient matric potential following emplacement significantly reduces the air permeability of the annular seals, thereby preventing vertical vapor movement along the borehole annulus. As described later in Section 3, chemical analyses and soil gas pressure measurements have demonstrated that the annular seals effectively isolate adjacent soil gas ports.

Sieved Bandelier Tuff was used as annular material around the heat dissipation sensors and suction lysimeters and as annular backfill material between annular seals (Figure 3). The rationale for the use of the tuff backfill was to emplace these instruments in material very similar to the undisturbed Bandelier Tuff into which the borings were drilled. Due to health and safety restrictions, cuttings from the borings themselves could not be utilized as backfill material. The tuff backfill material was collected directly from the wall of the TA-53 borrow pit and delivered to the staging area at TA-73 for sieving. Sieving was accomplished by hand, using a sieve with ¼-inch openings. To facilitate installation, all of the sieved tuff was air dried prior to emplacement in the boreholes using a tremie pipe. The TA-53 borrow pit is situated in the same geologic unit

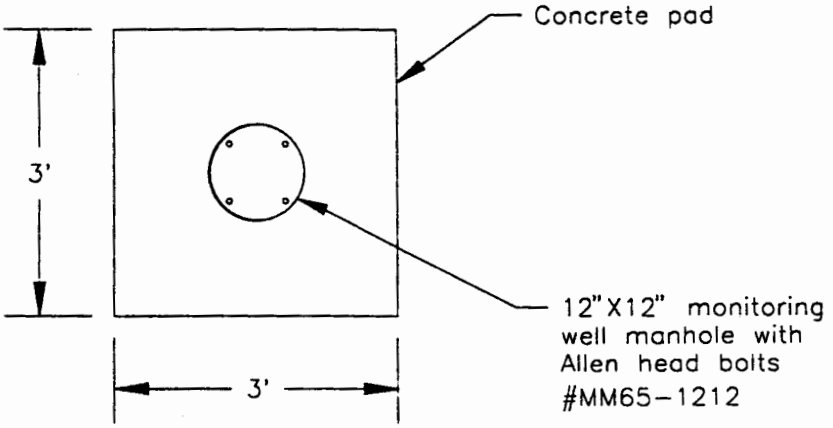
as that in the near subsurface at TA-73 (the non-welded unit between Tshirege Member Units 2 and 3). Additionally, the tuff could be easily removed from the borrow pit wall, thereby minimizing the need for mechanical crushing and the possibility for contamination of the material. The sieved air-dry tuff was monitored with a PID to verify the absence of VOCs prior to installing the material as backfill in the borings.

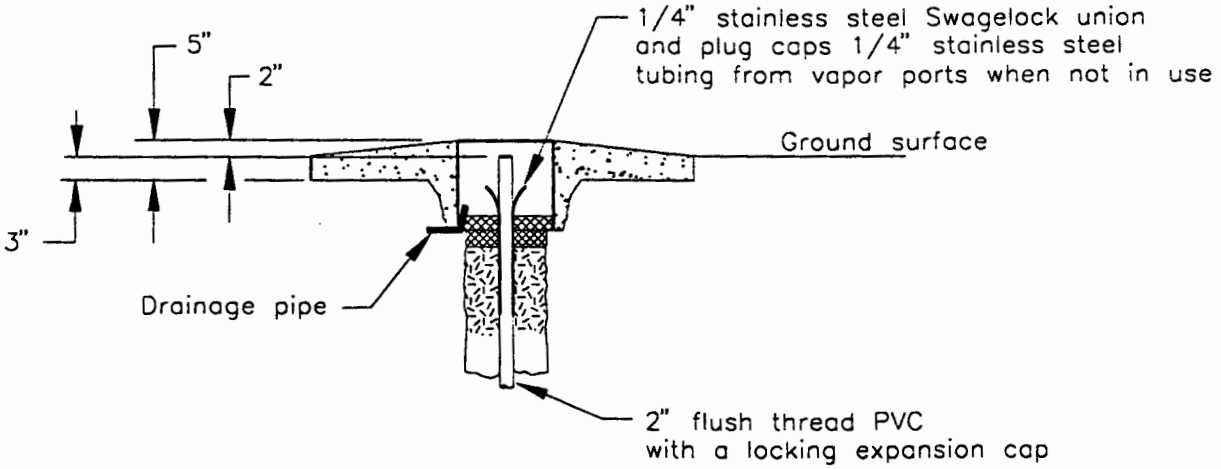
In order to assess bulk density variations within a particular backfill material, the rise in backfill material per unit volume of emplaced material was documented during the completion of each monitor well. In general, little variation in bulk density was recorded for the silica sand and annular seal mixtures with or without tamping. However, the sieved Bandelier Tuff exhibited a wide range of bulk densities when tamped. Because many of the in-situ tuff units at Los Alamos are air-fall tuffs that exhibit low bulk densities (on the order of 1.35 grams per cubic centimeter [g/cm^3]), overcompaction of the tuff backfill was to be avoided, and tamping of the annular backfill was discontinued following completion of monitor well LP-3.

2.2.4 Surface Completions

The surface completions for each monitor well consist of 12-inch diameter subgrade well vaults cemented in place. Four of the wells (LP-4, LP-6, LP-9, and LPS-2) were drilled and completed through the asphalt of the airport taxiway or tie-down pads. Those situations required that the well vaults be cemented flush with the asphalt to allow for snow removal.

The surface completions at wells LP-3, LP-4, LP-7, LP-8, LPS-1, and LPS-2 contain access ports for connection of the instrumentation to a datalogger located within an adjacent vault (Figures 4a and 4b). Figure 5 shows a generalized completion for those well vaults that do not contain a datalogger access port. Installation of the access ports at LP-4 and LPS-2, located in the center of the hotpad road, required trenching through the taxiway to permit connections to be made to the datalogger installations along the north side of the taxiway. Each of the remaining well vaults was installed within a 3-foot-square by 0.5-foot-thick concrete pad (Figure 4).





Note:

Concrete pad thickness decreases from approximately 5" at the manhole to 3" at the edges, resulting in a slightly raised and tapered surface completion.

0 2 ft

Explanation

Concrete

Bentonite/sand mixture

Tamped backfill material

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General Surface Completion

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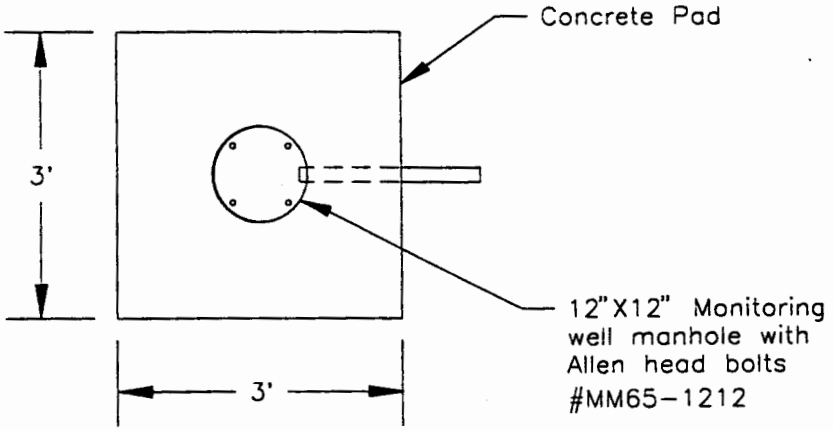
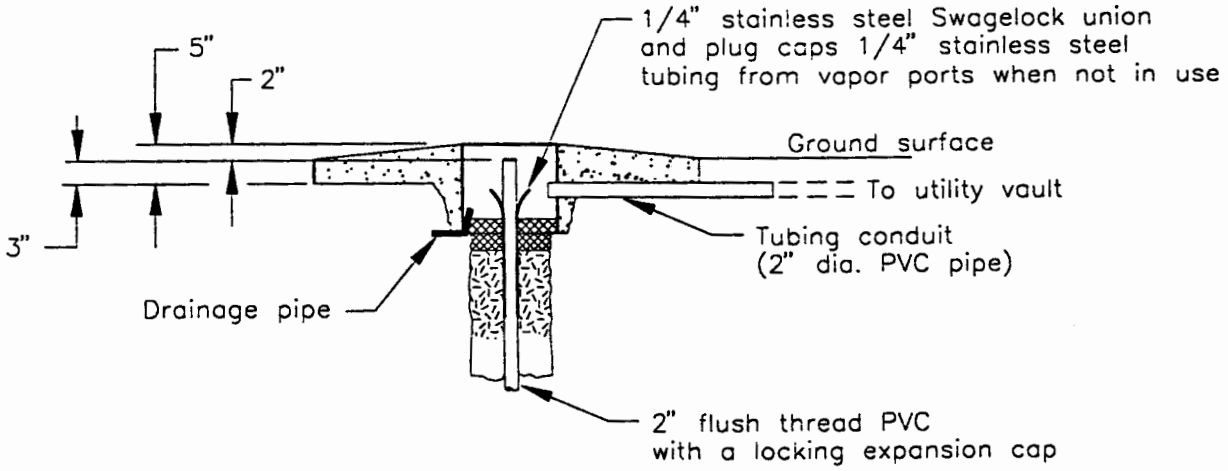
Figure 4a

J/4010/4C .DWG





Note:

Concrete pad thickness decreases from approximately 5" at the manhole to 3" at the edges, resulting in a slightly raised and tapered surface completion.

0 2 ft

Explanation

- Concrete
- Bentonite/sand mixture
- Tamped backfill material

LANL RFI SUPPORT

Surface Completion: Data Logging Installations

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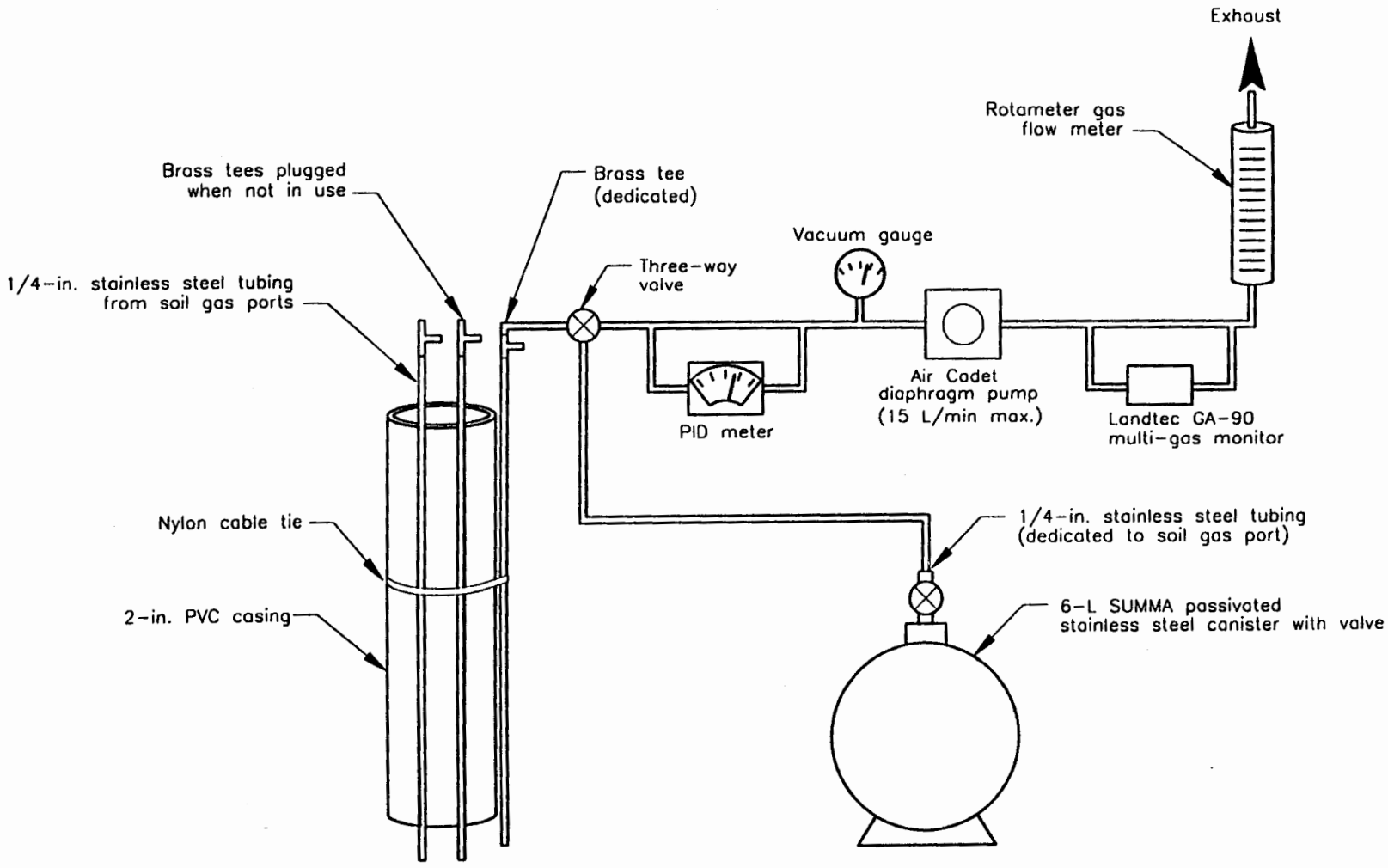
Figure 4b

S/4010/401040Q.DWG



LANL RFI SUPPORT

Soil Gas Sampling System for Multi-Port Soil Gas Monitor Wells

Figure 5

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2.2.5 Continuous Downhole Pressure Monitoring Systems

Automated, continuous monitoring of absolute barometric pressure, downhole soil gas pressures and downhole temperatures at discrete depths within the vadose zone was made possible through the installation of dedicated data acquisition systems developed by DBS&A. Connections to the soil gas ports of a particular monitor well are made through a 2-inch PVC access port in the side of the monitor well vault. Tygon tubing was used to connect the top of each soil gas port to the solenoid valves in the data acquisition system enclosure.

Each data acquisition system is housed inside two enclosures. The interior enclosure is a fiberglass box that contains all of the relays, valves, sensors and equipment used for continuous data acquisition. This fiberglass enclosure is contained within a larger, watertight aluminum enclosure (suitable for subgrade burial) near the monitor well. The external aluminum enclosure has a feed-through port to accept the electrical leads from the monitor well vault. Two additional ports are used as vents and are located on opposite sides of the external enclosure. The vent ports allow a small, low power fan to purge the enclosure with fresh air prior to solenoid valve actuation. Due to the high methane concentrations that exist in the shallow soil gas, the fan is required to prevent the buildup of potentially explosive gases within the enclosure prior to the actuation of the solenoids.

During the period of March 2 to April 15, several of the data acquisition units experienced problems related to condensation accumulating in the datalogger enclosures. The original design of the burial enclosure was modified for automated venting of each enclosure to prevent the potential buildup of explosive methane levels. However, the venting has allowed condensate to accumulate inside the dataloggers and has caused a few temporary datalogger malfunctions. In order to minimize such malfunctions, when condensate is encountered the datalogger units are removed, dried, and replaced. Since this problem was identified, desiccant has been placed inside the housings and is changed frequently to minimize condensate accumulation. However, condensation is likely to continue due to the venting requirements.

The data acquisition system at each monitored well consists of a single Campbell Scientific 21X Micrologger and relay configured to record absolute barometric pressure, downhole soil gas

pressure, and downhole temperature at 45-minute intervals. The system is powered by a single 12-volt, 17-amp-hour battery that is charged monthly when the data are downloaded. Alkaline batteries housed in the datalogger enclosure are used for continuous backup and keep the system operational while the rechargeable batteries are being replaced. The following paragraphs briefly describe the instruments used to collect the pressure and temperature data.

A single Druck PDCR911 15-psia pressure transducer is used to measure temporal fluctuations in barometric pressure at the wellhead. This absolute pressure sensor is connected directly to the 21X datalogger and vented to the atmosphere outside the data acquisition system aluminum enclosure.

A single Omega PX170 14DV 0.51 psig pressure sensor is used to measure the gauge differences between a particular soil gas port and the atmosphere. The gauge pressure transducer is used to make measurements at each soil gas port via individual solenoid valves connecting the different downhole ports to a single manifold. Switching between ports is controlled by the datalogger's internal programming and an external multi-channel control port relay. The frequency of pressure measurements is controlled by the datalogger and can be as frequent as once every 2 minutes. In order to allow convenient manipulation of the data through the techniques of spectral analysis, the pressure data in this report were collected at a frequency of one measurement every 45 minutes, or 32 measurements per day. Gauge pressures are converted into absolute pressures by adding the gauge pressure value to the absolute barometric pressure measured by the Druck transducer. As currently configured, each data acquisition system can monitor up to three soil gas ports at 45-minute intervals for up to one month unattended.

Downhole temperatures are measured by connecting the downhole thermocouple leads directly to the 21X datalogger. The datalogger uses an internal thermistor as a reference junction for the thermocouple measurements. The downhole temperature measurements collected every 45 minutes were averaged over one-day intervals to eliminate artifacts resulting from diurnal temperature fluctuations of the datalogger installations at the surface. This issue is discussed further in Section 3.5.

3. PRELIMINARY RESULTS OF MONITORING PROGRAM

The following section summarizes preliminary results of the ongoing subsurface monitoring program at the Los Alamos Airport. The monitoring was conducted in accordance with the requirements of work release 94-0002 subcontract 2763M0004-3V and LANL-approved DBS&A SOGs 13.7.5., *Calibration and Operation of a Neutron Moisture Meter*, and 13.7.19., *Soil Moisture and Matric Potential Sensor Installation and Monitoring*. In addition, LANL-ER-SOP-06.22, *Canister Sampling for Organics - EPA Method TO-14*, was used as a guideline for soil gas sampling from the dedicated downhole soil gas ports. The soil gas sampling methodology used at TA-73 and deviations from LANL-ER-SOP-06.22 are described in detail in Section 3.1.1.

The TA-73 monitoring program includes the following elements:

- Monthly soil gas sampling from the downhole soil gas ports
- Continuous downhole pressure measurements in selected boreholes
- Monthly neutron probe measurements in a minimum of five boreholes
- Quarterly sampling of the suction lysimeters, plus an additional two sampling events for snowmelt, runoff, or other special circumstances

Following completion of drilling and monitor well installation in November 1994, monthly monitoring of hydraulic parameters was initiated in January 1995. Monthly soil gas sampling using SUMMA canisters began in February 1995. Continuous monitoring of downhole soil gas pressure in selected gas ports at selected monitor wells began in March 1995. Some preliminary data are now available, and the following observations are based on these preliminary data.

3.1 Soil Gas Monitoring Program

As described in Section 2, each of the 11 monitor wells installed around the TA-73 landfill perimeter was constructed to allow sampling of subsurface soil gas. A total of 30 soil gas

monitoring ports were installed to depths ranging from 7 to 160 feet bgs. Individual monitor wells include between one and four soil gas ports completed to different depths. The number and depths of the soil gas ports in each of the 11 monitor wells are shown on the attached well completion logs (Appendix A).

The soil gas ports were installed to (1) allow collection of depth-specific soil vapor samples for laboratory chemical analysis and (2) permit monitoring of soil gas pressures at various depths within the vadose zone. Construction details for the soil gas ports may be found in Section 2 of this report. Each port is capped when not in use to prevent air movement (breathing) in and out of the port in response to surface barometric pressure fluctuations. The soil gas monitoring program includes the following elements:

- Monthly monitoring of soil gas composition (major gases and VOCs)
- Continuous monitoring of soil gas pressures in selected wells

The following subsections describe the soil gas monitoring program in detail and preliminary results for the first two months.

3.1.1 Soil Gas Sampling and Analysis Methods

Soil gas samples have been collected on a monthly basis in evacuated 6-liter SUMMA canisters from each of the 30 soil gas ports around the landfill perimeter. SUMMA canisters are specially designed for collection and storage of gas samples. The inner surface of the spherical stainless steel canister is SUMMA passivated, a process whereby a pure chrome-nickel oxide coating is created on the stainless steel to reduce the sorption of VOCs that would otherwise occur. This process increases the stability of gas samples during storage such that samples may be held for up to 30 days prior to analysis with no appreciable loss of VOCs.

The soil gas sampling protocol employed by DBS&A is as follows. The soil gas sampling system shown in Figure 5 is first connected to the brass tee at the top of the soil gas port using a short section of ¼-inch stainless steel tubing equipped with Swagelok fittings. Next, the soil gas port

is purged for approximately 5 minutes at a gas flow rate of about 3 to 10 liters per minute. During the purging period, the concentrations of methane, carbon dioxide, and oxygen in the purge gas stream are monitored at 30-second intervals using a Landtec GA-90 multi-gas analyzer. The concentrations of these three major gases are recorded on a purge log form, along with the gas flow rate and downhole vacuum. The concentrations of the major gases were generally found to stabilize within the first minute of purging.

VOC concentrations were also monitored during purging using an HNu 101 or ThermoEnvironmental 580B PID meter connected to the purge line. However, the PID was found to give erroneous readings in the presence of even small concentrations of methane, as discussed previously in Section 2. The presence of methane at concentrations above a few tenths volume percent results in a PID "quenching" effect, whereby most or all of the UV energy is absorbed by the methane, and no energy remains to ionize any VOCs that may be present (Nyquist et al, 1990). The result is that the PID may display zero, or even a negative value, even though VOCs may indeed be present in the soil gas. Because many of the soil gas samples collected around the perimeter of the landfill contained methane at percent levels, PID values of zero recorded on the purge log forms do not necessarily indicate the absence of VOCs.

Following stabilization of major gas concentrations during purging, the three-way valve shown in Figure 5 is switched to connect the evacuated SUMMA canister directly to the soil gas port, and the valve on the canister opened, allowing the evacuated canister to fill with soil gas. The canister valve is then adjusted to allow the canister to fill at approximately the same gas flow rate as the purge rate, which resulted in a one- to two-minute sampling interval for filling the canisters. For the collection of duplicate soil gas samples, two canisters were connected in parallel, and both canisters were allowed to fill simultaneously at the same flow rate.

For each canister sample collected, the following information was recorded on the chain-of-custody form: canister serial number, LANL identification number, time, date, sample location, ambient atmospheric pressure, ambient air temperature, and the time required to fill the canister.

Each month, a total of 5 quality assurance/quality control (QA/QC) samples are submitted in canisters for laboratory analysis, along with the 30 primary soil gas samples. The 5 QA/QC

samples may include field duplicates, performance evaluation (PE) gas samples of known composition, and air blanks. The purpose of the field duplicates is to permit estimation of the overall precision of the sampling and analysis program, while the PE samples are intended to verify that all procedures are being performed properly and the correct concentrations are being reported by the laboratory. Air blanks containing "clean" outside air are submitted to ensure that the canisters and analytical system are clean prior to analysis of each gas sample.

During the February sampling event, the first PE sample consisted of a SUMMA canister filled with a 10-ppmv mixture in nitrogen of the following eight common halogenated VOCs:

- 1,1-dichloroethene (1,1-DCE)
- cis-1,2-DCE
- 1,1-dichloroethane (1,1-DCA)
- 1,2-DCA
- ethylene dibromide (EDB)
- tetrachloroethene (PCE)
- 1,1,1-trichloroethane (1,1,1-TCA)
- Vinyl chloride

The standard VOC gas mixture was obtained from Scott Specialty Gases in Plumsteadville, Pennsylvania (Toxic Organic Mixture #1046676, Blend 2). A manufacturer's certificate of analysis accompanied the gas mixture, and a copy of the certificate is included in Appendix C of this report. The 10-ppmv concentration was chosen because it was believed to be representative of the higher VOC concentrations expected in the soil gas samples being collected around the landfill perimeter.

The second PE sample submitted during the February sampling event consisted of a SUMMA canister filled with a gas mixture containing 15% carbon dioxide, 15% methane, and balance nitrogen. This mixture was obtained from Landfill Control Technologies of Commerce, California. Each PE sample was collected by connecting a SUMMA canister to the appropriate compressed gas cylinder using a minimal-length section of Tygon tubing with a Tedlar gas sampling bag connected in parallel using a plastic "tee". The Tedlar bag allows the canister to be filled to

ambient pressure with no over-pressure or under-pressure. The two PE samples and three field duplicates were submitted to the laboratory with fictitious sample identification numbers along with the primary soil gas samples.

Soil gas samples and QA/QC samples collected in canisters during each monthly sampling event are submitted to the Environmental Science & Engineering, Inc., (ESE) laboratory in Gainesville, Florida, for analysis of the following gaseous constituents:

- VOCs (TO-14 list of 42 compounds)
- CO_2
- H_2
- CH_4
- N_2
- O_2

VOCs are determined by gas chromatography/mass spectrometry (GC/MS) using EPA Method TO-14 (EPA, 1988). Details regarding the VOC analytical procedures are provided in ESE's case narratives in Appendix D.

Concentrations of the five major gases were determined by ESE using Method 133 for "Fixed Gases" (Lodge, 1989). Method 133 employs a GC equipped with a thermal conductivity detector and quantifies all of the expected major gaseous components of the soil vapor (i.e., N_2, O_2, CO_2, and CH_4) except argon and water vapor. Atmospheric air contains about 0.9% argon. According to Mike Winslow of ESE, argon co-elutes with oxygen under the GC conditions employed in their laboratory. Because the detector response for oxygen and argon are similar, the reported oxygen concentrations may be considered to represent the sum of oxygen plus argon.

The relative humidity of soil vapor is nearly always close to 100%. Because the vapor pressure of water is strongly temperature dependent, the absolute concentration of water vapor in air varies from 5 mg/L (7,800 ppmv) at 0°C to 30 mg/L (52,000 ppmv) at 30°C (Draeger, 1992). Thus the proportion of water in the soil vapor may vary between 0.78 and 5.2 percent by volume,

depending on the temperature of the soil gas. Assuming an average ground temperature of 20°C, we may expect a water vapor concentration of approximately 3 percent by volume in the soil gas.

3.1.2 Preliminary Results of Soil Gas Analysis

Tables 3 and 4 show the concentrations of major gases and VOCs in soil vapor samples collected by DBS&A from the landfill perimeter wells during the February and March 1995 sampling events. Ranges of major gas concentrations observed in the various soil vapor ports are as follows:

- CO_2: 0% to 30%
- CH_4: 0% to 27%
- N_2: 42% to 90%
- O_2: 0% to 21%
- H_2: <0.1%

As shown in Table 3, the highest CO_2 and CH_4 concentrations have been observed in the shallowest ports of those wells nearest to the center of the landfill. Concentrations of these two biogenic gases decline with depth and distance away from the refuse. This is consistent with the fact that CO_2 and CH_4 are products of the anaerobic decomposition of organic matter (symbolized CH_2O) through the following fermentation reaction mediated by methanogenic bacteria:

$$2CH_2O \rightarrow CO_2 + CH_4$$

The detailed chemistry and stoichiometry of refuse decomposition in a landfill is considerably more complex, involving the production of numerous intermediate organic acid compounds, such as acetic acid. Nevertheless, the simplified reaction shown above illustrates the overall process of methanogenesis in a landfill, whereby organic matter is converted to carbon dioxide and methane. Landfill gas produced via methanogenesis thus consists of roughly equal quantities of these two gases. Subsequent oxidation of methane around the aerobic perimeter of a landfill may result in elevated carbon dioxide concentrations at the expense of methane via the following reaction mediated by methanotrophic bacteria:

$$CH_4 + 2O_2 \rightarrow CO_2 + 2H_2O$$

Table 3. Preliminary Laboratory Results, Major Gas Concentrations in Soil Vapor

Monitor Well	Soil Gas Port	Depth (ft)	Concentration (vol. pct)[a]							
			Methane (CH_4)		Carbon Dioxide (CO_2)		Oxygen (O_2)		Nitrogen (N_2)	
			2/95[b]	3/95[c]	2/95[b]	3/95[c]	2/95[b]	3/95[c]	2/95[b]	3/95[c]
LP-1	GP1	40.2	<0.200	<0.100	1.57	1.43	21.5	20.3	80.4	75.8
	GP2	10.2	<0.200	<0.100	2.14	2.07	20.8	19.6	80.8	75.4
LP-2	GP1	35.9	<0.200	<0.100	6.94	6.13	16.7	14.8	84.2	75.2
LP-3	GP1	99.2	3.16	2.72	20.1	19.0	2.16	1.19	72.8	75.1
	GP2	91.2	3.34	3.81	19.5	19.5	0.807	1.15	73.3	74.8
	GP3	39.2	10.9	12.2	21.4	24.3	1.88	1.01	66.8	62.3
	GP4	9.2	21.0	19.5	26.7	26.7	1.44	0.886	57.1	52.0
LP-4	GP1	99.35	6.92	5.99	21.3	19.8	0.996	1.08	74.2	68.2
	GP2	75.35	8.30	8.15	21.4	21.5	1.76	1.17	65.8	66.2
	GP3	46.35	16.8	10.8[d]	26.5	17.5[d]	1.58	5.94[d]	61.6	61.2[d]
	GP4	13.35	26.5	26.3	26.7	27.4	1.10	0.789	44.0	44.2
LP-5	GP1	33.5	<0.200	<0.100	15.9	14.3	2.46	7.04	89.6	76.8
LP-6	GP1	27.0	<0.100	<0.100	3.46	3.01	7.12	18.2	80.7	73.7
LP-7	GP1	100.0	<0.100	<0.100	15.9	16.2	2.56	3.56	89.3	77.1
	GP2	28.0	6.34	8.71	23.1	24.4	1.91	1.06	69.1	63.0
	GP3	16.0	16.0	14.8	26.8	27.7	1.43	0.932	56.2	54.3

[a] Soil gas concentrations in volume percent as reported by ESE-Gainesville laboratory for soil gas samples collected in 6-liter SUMMA canisters and analyzed using GC-TCD Method 133 (Lodge, 1989).
[b] February 1995 sampling event conducted 2/21/95 through 2/23/95.
[c] March 1995 sampling event conducted 3/27/95 through 3/29/95.
[d] Air leak occurred during sampling; values not representative of subsurface conditions.

Table 3. Preliminary Laboratory Results, Major Gas Concentrations in Soil Vapor

Monitor Well	Soil Gas Port	Depth (ft)	Concentration (vol. pct)[a]							
			Methane (CH_4)		Carbon Dioxide (CO_2)		Oxygen (O_2)		Nitrogen (N_2)	
			2/95[b]	3/95[c]	2/95[b]	3/95[c]	2/95[b]	3/95[c]	2/95[b]	3/95[c]
LP-8	GP1	91.5	<0.100	<0.100	9.25	<0.100	10.2	21.0	83.3	77.0
	GP2	43.5	<0.100	<0.100	0.564	<0.100	19.5	20.7	76.5	75.9
	GP3	15.5	<0.100	<0.100	1.55	1.29	18.6	20.0	76.3	75.6
LP-9	GP1	41	<0.100	<0.100	14.8	13.8	10.3	8.40	76.4	76.3
	GP2	11.15	<0.100	<0.100	10.1	12.9	1.22	7.40	88.2	78.9
LPS-1	GP1	145	0.165	<0.100	7.33	6.81	2.32	13.0	79.1	75.9
	GP2	114	<0.100	<0.100	6.67	5.72	16.6	15.1	85.8	77.2
	GP3	61	<0.100	<0.100	3.09	2.83	8.53	18.3	76.3	76.3
	GP4	22	<0.100	<0.100	10.00	11.1	0.494	9.35	75.4	74.7
	GP5	7.5	<0.100	<0.100	10.00	9.55	5.51	11.6	74.0	77.0
LPS-2	GP1	178	4.35	4.07	19.4	18.1	3.03	2.57	80.5	74.6
	GP2	125	8.49	7.51	22.5	20.4	0.133	1.15	74.3	67.2
	GP3	87	13.9	9.52[d]	22.5	15.6[d]	1.51	7.43[d]	58.2	64.1[d]
	GP4	29	24.1	24.7	26.2	27.4	1.09	0.783	44.1	45.1

[a] Soil gas concentrations in volume percent as reported by ESE-Gainesville laboratory for soil gas samples collected in 6-liter SUMMA canisters and analyzed using GC-TCD Method 133 (Lodge, 1989).
[b] February 1995 sampling event conducted 2/21/95 through 2/23/95.
[c] March 1995 sampling event conducted 3/27/95 through 3/29/95.
[d] Air leak occurred during sampling; values not representative of subsurface conditions.

Table 4. Preliminary Laboratory Results, VOCs Detected in Soil Gas

Monitor Well	Soil Gas Port	Sampling Date	Concentration (ppbv)[a]																				
			1,1-Dichloroethylene	cis-1,2-Dichloroethene	trans-1,2-Dichloroethene	1,2,4-Trimethylbenzene	1,3,5-Trimethylbenzene	1,4-Dichlorobenzene	Benzene	Chlorobenzene	Chlorodifluoromethane	Chloroethane	Chloromethane	Dichlorodifluoromethane	Ethylbenzene	Freon 114	Methylene Chloride	Tetrachloroethene	Toluene	Trichloroethene	Vinyl Chloride	m,p-Xylene	o-Xylene
LP-1	GP1	2/95[b]	<1.00	<1.00	<1.00	<1.00	<1.00	<1.00	<1.00	<1.00	<1.00	<1.00	4.02	1.48	<1.00	<1.00	<1.00	1.18	<1.00	<1.00	<1.00	<1.00	<1.00
		3/95[c]	<1.00	<1.00	<1.00	<1.00	<1.00	<1.00	<1.00	<1.00	<1.00	<1.00	4.18	1.16	<1.00	<1.00	<1.00	<1.00	<1.00	<1.00	<1.00	<1.00	<1.00
LP-1	GP2	2/95	<1.00	<1.00	<1.00	<1.00	<1.00	<1.00	<1.00	<1.00	<1.00	<1.00	4.30	1.32	<1.00	<1.00	<1.00	<1.00	<1.00	<1.00	<1.00	<1.00	<1.00
		3/95	<1.00	<1.00	<1.00	<1.00	<1.00	<1.00	<1.00	<1.00	<1.00	<1.00	4.60	1.06	<1.00	<1.00	<1.00	<1.00	<1.00	<1.00	<1.00	<1.00	<1.00
LP-2	GP1	2/95	<1.00	1.52	<1.00	<1.00	<1.00	<1.00	<1.00	<1.00	<1.00	<1.00	3.52	105	<1.00	4.64	1.00	47.4	<1.00	<1.00	<1.00	<1.00	<1.00
		3/95	<1.00	<1.00	<1.00	<1.00	<1.00	<1.00	<1.00	<1.00	<1.00	<1.00	4.28	136	<1.00	6.80	<1.00	39.2	<1.00	<1.00	<1.00	<1.00	<1.00
LP-3	GP1	2/95	7.40	464	5.20	17.2	6.90	21.9	10.6	<5.00	310	<5.00	<5.00	710	<5.00	87.9	15.0	121	<5.00	11.6	29.9	12.3	<5.00
		3/95	3.34	290	6.68	16.0	6.08	23.0	13.2	4.60	405	6.50	5.60	495	4.66	72.2	2.12	133	2.04	13.6	30.9	2.82	<1.00
LP-3	GP2	2/95	<50.0	7340	218	91.0	50.0	90.0	114	<50.0	1210	88.0	213	989	<50.0	80.0	87.0	75.0	<50.0	<50.0	730	<50.0	<50.0
		3/95	<5.00	650	8.95	<5.00	<5.00	10.1	10.3	<5.00	438	5.66	20.7	541	<5.00	54.9	<5.00	52.8	<5.00	7.29	46.3	<5.00	<5.00
LP-3	GP3	2/95	<50.0	1370	<50.0	<50.0	<50.0	55.0	77.0	<50.0	8970	<50.0	974	523	<50.0	<50.0	83.0	<50.0	<50.0	<50.0	355	<50.0	<50.0
		3/95	37.2	6760	159	80.4	38.8	71.8	84.6	34.2	1880	49.2	35.8	994	<10.00	169	46.0	65.2	10.8	52.0	659	39.2	10.4
LP-3	GP4	2/95	91.0	8650	270	61.0	<50.0	<50.0	112	<50.0	1920	<50.0	273	1210	<50.0	244	71.0	<50.0	<50.0	<50.0	1280	<50.0	<50.0
		3/95	56.4	7490	298	46.0	24.0	26.0	93.2	12.6	1170	66.6	79.0	585	<10.00	189	39.0	27.6	10.2	58.6	784	38.0	13.0
LP-4	GP1	2/95	<50.0	1010	<50.0	<50.0	<50.0	<50.0	<50.0	<50.0	400	<50.0	189	830	<50.0	<50.0	56.0	129	<50.0	<50.0	74.0	<50.0	<50.0
		3/95	11.8	2820	25.8	<10.00	<10.00	22.0	31.8	<10.00	2300	18.0	104	761	<10.00	68.8	35.2	129	30.4	13.0	170	27.2	<10.00
LP-4	GP2	2/95	<50.0	3880	52.0	<50.0	<50.0	<50.0	60.0	<50.0	1490	<50.0	268	828	<50.0	119	87.0	145	<50.0	<50.0	325	<50.0	<50.0
		3/95	15.4	3350	57.8	18.6	<10.00	29.2	42.8	<10.00	5400	22.2	273	449	<10.00	<10.00	41.8	102	11.6	15.4	206	34.4	<10.00
LP-4	GP3	2/95	<50.0	3660	60.0	<50.0	<50.0	58.0	78.0	<50.0	2680	<50.0	343	683	<50.0	156	81.0	68.0	<50.0	<50.0	456	<50.0	<50.0
		3/95	15.2	1670	35.4	16.6	<10.00	36.4	40.8	<10.00	1580	21.8	96.6	277	<10.00	<10.00	72.0	38.6	63.2	11.8	191	24.6	<10.00

[a] VOC concentrations as reported by ESE-Gainesville for soil gas samples collected in 6-liter SUMMA canisters and analyzed by EPA method TO-14.
[b] February 1995 sampling event conducted 2/21/95 through 2/23/95.
[c] March 1995 sampling event conducted 3/27/95 through 3/29/95.

Table 4. Preliminary Laboratory Results, VOCs Detected in Soil Gas

Monitor Well	Soil Gas Port	Sampling Date	Concentration (ppbv)[a]																				
			1,1-Dichloroethylene	cis-1,2-Dichloroethene	trans-1,2-Dichloroethene	1,2,4-Trimethylbenzene	1,3,5-Trimethylbenzene	1,4-Dichlorobenzene	Benzene	Chlorobenzene	Chlorodifluoromethane	Chloroethane	Chloromethane	Dichlorodifluoromethane	Ethylbenzene	Freon 114	Methylene Chloride	Tetrachloroethene	Toluene	Trichloroethene	Vinyl Chloride	m,p-Xylene	o-Xylene
LP-4	GP4	2/95	<50.0	1670	<50.0	<50.0	<50.0	<50.0	83.0	<50.0	8530	<50.0	<50.0	<50.0	<50.0	<50.0	62.0	<50.0	<50.0	<50.0	369	<50.0	<50.0
		3/95	11.6	1110	53.6	25.6	<10.00	48.4	65.6	10.2	4690	25.8	173	295	13.6	<10.00	28.6	14.8	19.4	13.8	277	52.0	<10.00
LP-5	GP1	2/95	<5.00	5.30	<5.00	<5.00	<5.00	<5.00	<5.00	<5.00	15.2	<5.00	<5.00	735	<5.00	61.8	10.4	284	<5.00	<5.00	<5.00	8.70	<5.00
		3/95	<1.00	<1.00	<1.00	<1.00	<1.00	<1.00	<1.00	<1.00	13.2	<1.00	<1.00	492	<1.00	49.1	<1.00	96.3	<1.00	1.78	<1.00	<1.00	<1.00
LP-6	GP1	2/95	<1.00	2.26	<1.00	<1.00	<1.00	<1.00	<1.00	<1.00	2.34	<1.00	3.58	39.4	<1.00	<1.00	<1.00	30.0	<1.00	15.2	<1.00	<1.00	<1.00
		3/95	<1.00	<1.00	<1.00	<1.00	<1.00	<1.00	<1.00	<1.00	2.68	<1.00	4.24	45.8	<1.00	2.16	1.06	32.8	4.04	14.3	<1.00	<1.00	<1.00
LP-7	GP1	2/95	<5.00	6.60	<5.00	<5.00	<5.00	<5.00	<5.00	<5.00	25.7	<5.00	31.5	459	<5.00	36.6	9.60	64.2	<5.00	<5.00	<5.00	7.90	<5.00
		3/95	<1.00	1.44	<1.00	<1.00	<1.00	<1.00	<1.00	<1.00	22.3	<1.00	3.94	307	<1.00	31.8	<1.00	73.3	<1.00	2.26	<1.00	<1.00	<1.00
LP-7	GP2	2/95	<50.0	4830	50.0	256	104	239	74.0	<50.0	59.9	<50.0	230	1300	245	142	112	132	501	94.0	251	625	112
		3/95	25.2	4470	51.6	201	82.2	187	101	28.2	612	31.2	69.0	481	302	71.6	79.0	119	695	101	246	731	124
LP-7	GP3	2/95	59.0	11100	140	750	447	352	333	164	1410	<50.0	216	1260	1210	135	156	130	848	108	803	2150	179
		3/95	35.8	9080	111	467	193	238	229	117	900	75.4	<10.00	474	826	92.2	135	105	711	88.4	559	1590	155
LP-8	GP1	2/95	<1.00	<1.00	<1.00	<1.00	<1.00	<1.00	<1.00	<1.00	<1.00	<1.00	4.28	12.3	<1.00	<1.00	<1.00	3.60	<1.00	<1.00	<1.00	<1.00	<1.00
		3/95	<1.00	<1.00	<1.00	<1.00	<1.00	<1.00	<1.00	<1.00	1.78	<1.00	3.74	15.4	<1.00	1.12	1.36	4.00	<1.00	<1.00	<1.00	<1.00	<1.00
LP-8	GP2	2/95	<1.00	2.22	<1.00	<1.00	<1.00	<1.00	<1.00	<1.00	1.92	<1.00	3.92	32.9	<1.00	3.90	2.28	10.7	1.72	<1.00	<1.00	<1.00	<1.00
		3/95	<1.00	<1.00	<1.00	<1.00	<1.00	<1.00	<1.00	<1.00	<1.00	<1.00	3.62	24.0	<1.00	3.28	<1.00	7.92	<1.00	<1.00	<1.00	<1.00	<1.00
LP-8	GP3	2/95	<1.00	<1.00	<1.00	<1.00	<1.00	<1.00	<1.00	<1.00	<1.00	<1.00	3.66	21.1	<1.00	1.28	<1.00	4.88	<1.00	<1.00	<1.00	<1.00	<1.00
		3/95	<1.00	<1.00	<1.00	<1.00	<1.00	<1.00	<1.00	<1.00	4.36	<1.00	3.62	29.7	<1.00	7.96	<1.00	5.76	<1.00	<1.00	<1.00	<1.00	<1.00
LP-9	GP1	2/95	<5.00	15.9	<5.00	<5.00	<5.00	<5.00	<5.00	<5.00	52.1	<5.00	28.1	463	<5.00	44.6	19.9	419	<5.00	33.4	<5.00	8.30	<5.00
		3/95	<1.00	1.06	<1.00	<1.00	<1.00	<1.00	<1.00	<1.00	58.0	<1.00	4.28	287	<1.00	38.0	<1.00	157	<1.00	34.5	<1.00	<1.00	<1.00

[a] VOC concentrations as reported by ESE-Gainesville for soil gas samples collected in 6-liter SUMMA canisters and analyzed by EPA method TO-14.
[b] February 1995 sampling event conducted 2/21/95 through 2/23/95.
[c] March 1995 sampling event conducted 3/27/95 through 3/29/95.

Table 4. Preliminary Laboratory Results, VOCs Detected in Soil Gas

Monitor Well	Soil Gas Port	Sampling Date	Concentration (ppbv)[a]																				
			1,1-Dichloroethylene	cis-1,2-Dichloroethene	trans-1,2-Dichloroethene	1,2,4-Trimethylbenzene	1,3,5-Trimethylbenzene	1,4-Dichlorobenzene	Benzene	Chlorobenzene	Chlorodifluoromethane	Chloroethane	Chloromethane	Dichlorodifluoromethane	Ethylbenzene	Freon 114	Methylene Chloride	Tetrachloroethene	Toluene	Trichloroethene	Vinyl Chloride	m,p-Xylene	o-Xylene
LP-9	GP2	2/95	<1.00	1.40	<1.00	<1.00	<1.00	<1.00	<1.00	<1.00	8.70	<1.00	5.36	152	<1.00	7.74	<1.00	155	<1.00	5.36	<1.00	<1.00	<1.00
		3/95	<1.00	<1.00	<1.00	<1.00	<1.00	<1.00	<1.00	<1.00	13.2	<1.00	4.34	193	<1.00	21.4	<1.00	180	<1.00	5.40	<1.00	<1.00	<1.00
LPS-1	GP1	2/95	<2.50	5.80	<2.50	<2.50	<2.50	<2.50	<2.50	<2.50	43.8	<2.50	12.0	312	<2.50	25.6	5.45	113	2.65	7.35	<2.50	3.35	<2.50
		3/95	<1.00	1.00	<1.00	<1.00	<1.00	<1.00	<1.00	<1.00	51.2	<1.00	3.80	221	<1.00	20.6	<1.00	119	<1.00	7.82	<1.00	<1.00	<1.00
LPS-1	GP2	2/95	<1.00	2.12	<1.00	<1.00	<1.00	<1.00	<1.00	<1.00	7.86	<1.00	4.20	130	<1.00	11.0	<1.00	72.9	<1.00	<1.00	<1.00	<1.00	<1.00
		3/95	<1.00	<1.00	<1.00	<1.00	<1.00	<1.00	<1.00	<1.00	13.1	<1.00	3.74	197	<1.00	16.7	<1.00	71.6	<1.00	<1.00	<1.00	<1.00	<1.00
LPS-1	GP3	2/95	<1.00	1.10	<1.00	<1.00	<1.00	<1.00	<1.00	<1.00	1.68	<1.00	3.94	52.0	<1.00	4.16	<1.00	14.1	<1.00	<1.00	<1.00	<1.00	<1.00
		3/95	<1.00	<1.00	<1.00	<1.00	<1.00	<1.00	<1.00	<1.00	2.54	<1.00	3.62	55.1	<1.00	5.48	<1.00	14.3	<1.00	<1.00	<1.00	<1.00	<1.00
LPS-1	GP4	2/95	<1.00	1.02	<1.00	<1.00	<1.00	<1.00	<1.00	<1.00	1.64	<1.00	4.38	129	<1.00	16.7	<1.00	29.4	<1.00	<1.00	<1.00	<1.00	<1.00
		3/95	<10.00	<10.00	<10.00	<10.00	<10.00	<10.00	<10.00	<10.00	<10.00	<10.00	50.0	173	<10.00	95.0	34.4	26.0	<10.00	<10.00	<10.00	11.6	<10.00
LPS-1	GP5	2/95	<1.00	1.26	<1.00	<1.00	<1.00	<1.00	<1.00	<1.00	<1.00	<1.00	4.40	109	<1.00	13.3	1.66	21.4	<1.00	<1.00	<1.00	<1.00	<1.00
		3/95	<5.00	15.2	<5.00	<5.00	<5.00	<5.00	<5.00	<5.00	9.90	<5.00	19.4	197	<5.00	84.6	7.50	20.5	<5.00	<5.00	<5.00	12.3	<5.00
LPS-2	GP1	2/95	<5.00	92.5	<5.00	<5.00	<5.00	<5.00	<5.00	<5.00	533	<5.00	<5.00	1020	<5.00	92.3	10.00	340	<5.00	14.1	<5.00	7.20	<5.00
		3/95	<1.00	107	2.44	<1.00	<1.00	2.94	1.90	<1.00	<1.00	<1.00	<1.00	124	<1.00	77.2	1.06	93.5	15.2	15.4	<1.00	<1.00	<1.00
LPS-2	GP2	2/95	<50.0	3180	<50.0	<50.0	<50.0	<50.0	<50.0	<50.0	992	57.0	224	824	<50.0	<50.0	84.0	156	<50.0	<50.0	229	<50.0	<50.0
		3/95	<10.00	1940	17.8	<10.00	<10.00	19.0	23.2	<10.00	33100	14.2	<10.00	1120	<10.00	104	21.0	237	49.8	27.8	75.2	13.8	<10.00
LPS-2	GP3	2/95	<50.0	813	<50.0	<50.0	<50.0	<50.0	<50.0	<50.0	17.9	<50.0	234	127	<50.0	<50.0	50.0	<50.0	<50.0	<50.0	73.0	<50.0	<50.0
		3/95	21.8	5240	55.0	20.4	<10.00	51.8	56.5	11.4	1930	38.6	43.8	750	<10.00	81.8	49.2	136	64.6	39.6	337	26.8	<10.00
LPS-2	GP4	2/95	106	32700	349	34.5	<25.0	181	216	27.5	2640	150	<25.0	869	<25.0	140	140	81.0	137	66.5	1990	<25.0	<25.0
		3/95	83.0	23600	351	41.4	<10.00	158	200	38.2	5230	109	102	769	21.2	125	80.8	73.2	98.6	69.0	1750	63.8	<10.00

[a] VOC concentrations as reported by ESE-Gainesville for soil gas samples collected in 6-liter SUMMA canisters and analyzed by EPA method TO-14.
[b] February 1995 sampling event conducted 2/21/95 through 2/23/95.
[c] March 1995 sampling event conducted 3/27/95 through 3/29/95.

Thus, the soil vapor samples collected from the perimeter wells may be considered as mixtures of air and landfill gas end members, with subsequent conversion of methane to carbon dioxide around the aerobic perimeter of the landfill gas plume. Figure 6 shows an idealized conceptual model of some of the chemical and biological processes operating in and around a landfill.

The densities of pure gases are proportional to their molecular weights (MW). For example, at a given temperature and total pressure, CO_2 (MW=44) is more than twice as dense as CH_4 (MW=16). In addition, the density of a gas mixture depends on the relative proportions of its individual components. Other things being equal, the larger the proportion of higher molecular weight compounds in the gas, the greater the vapor density of the gas mixture. This may be termed the "composition effect" on vapor density. If we know the concentrations of all of the major components of the soil gas, it is possible to calculate its relative vapor density (RVD) with respect to the density of pure air (MW = 28.75 g/mol). This calculation is performed as follows:

$$RVD = \frac{\left[16\left(\frac{\%CH_4}{100}\right) + 32\left(\frac{\%O_2}{100}\right) + 44\left(\frac{\%CO_2}{100}\right) + 28\left(\frac{\%N_2}{100}\right)\right]}{28.75} \qquad (1)$$

Applying Equation 1 to the soil gas results reported for samples obtained from the multi-port monitor wells at TA-73, we calculate that the RVD of the soil vapor ranges from 1.01 to 1.08. The highest RVD values represent those samples containing the highest concentrations of CO_2 which has a molecular weight significantly greater than those of nitrogen and oxygen. These values imply that the soil gas underlying the perimeter of the landfill is between 1 and 8 percent denser than air. Although increasing methane content results in a decrease in vapor density, gas samples that contain the highest methane concentrations are still predicted to be several percent denser than air, as a result of their correspondingly high CO_2 concentrations. Given sufficiently high air permeabilities in the Bandelier Tuff, this suggests that there is a potential for sinking of dense soil vapor through the vadose zone as a result of density differences.

In making the vapor density calculations, several complicating factors have been ignored, including the temperature effect and the water vapor effect. In accordance with the ideal gas law,

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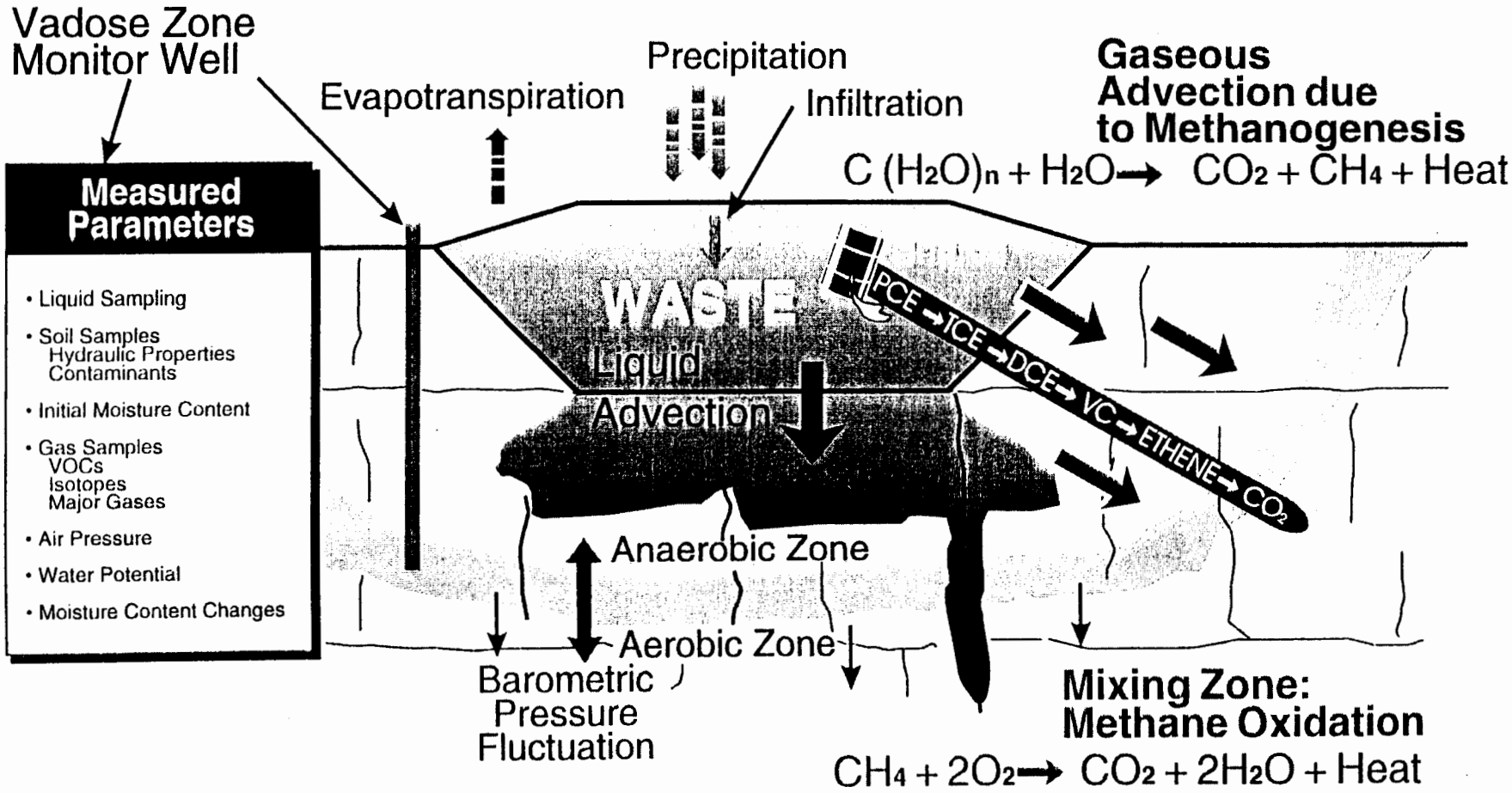

Not to Scale

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Conceptual Model of Landfill Geochemical and Biological Processes

Figure 6

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vapor density decreases linearly with increasing temperature. The density change is proportional to the difference in absolute temperature ($^{o}K_1$-$^{o}K_2$). In the temperature range of interest here (0-30°C), a 10°C difference in gas temperature results in approximately a 3 percent density change. Therefore, the temperature effect is probably insufficient to completely cancel the density increase calculated for the soil gas due to the composition effect. Thus, warm landfill gas containing high concentrations of methane and carbon dioxide would remain more dense than cold soil air that surrounds it, in spite of the temperature effect that acts in the opposite direction.

The "water vapor effect" refers to the fact that humid air has a density less than that of dry air. This results from the fact that water (MW=18) has a lower molecular weight than does air (MW=28.75). At the temperature existing in the Bandelier Tuff surrounding the landfill, the water vapor content of the soil gas is approximately 3 percent by volume. The water vapor effect on gas density is such that the soil air (100 percent RH) would be about 1 percent less dense than dry air at the same temperature and total pressure. It is therefore apparent that the magnitude of the water vapor effect is insufficient to significantly influence soil gas density, especially when one considers that the relative humidity of the soil vapor is almost always close to 100 percent and spatial variations in moisture content of the soil gas are negligible.

The soil gas samples were analyzed by EPA Method TO-14 for 42 target VOCs. All concentrations were reported in units of parts per billion by volume (ppbv). Concentrations reported in volume-per-volume units (e.g., ppbv) are independent of the total gas pressure, in contrast to mass-per-volume units (e.g., µg/L). Therefore, although the average atmospheric pressure at Los Alamos (≈775 mbar) is significantly less than that at the laboratory in Gainesville, Florida (≈1000 mbar), where the gas samples were analyzed, the soil gas VOC concentrations reported in ppbv are identical at both locations.

Of the 42 target VOCs, 28 compounds were detected in one or more of the soil gas samples, and 21 of those compounds were detected at concentrations greater than 100 ppbv (Table 4). The 6 VOCs detected at the highest concentrations include, in approximate order of decreasing concentration, cis 1,2-DCE, Freon-22, vinyl chloride, Freon-12, xylenes, and ethylbenzene. Each of these compounds was detected at a concentration of greater than 1000 ppbv in one or more of the soil gas samples. The most prevalent compound, cis 1,2-DCE, was detected at

concentrations of up to 36,000 ppbv, while the remaining 5 VOCs were present at concentrations in the range of 1,000 to 10,000 ppbv.

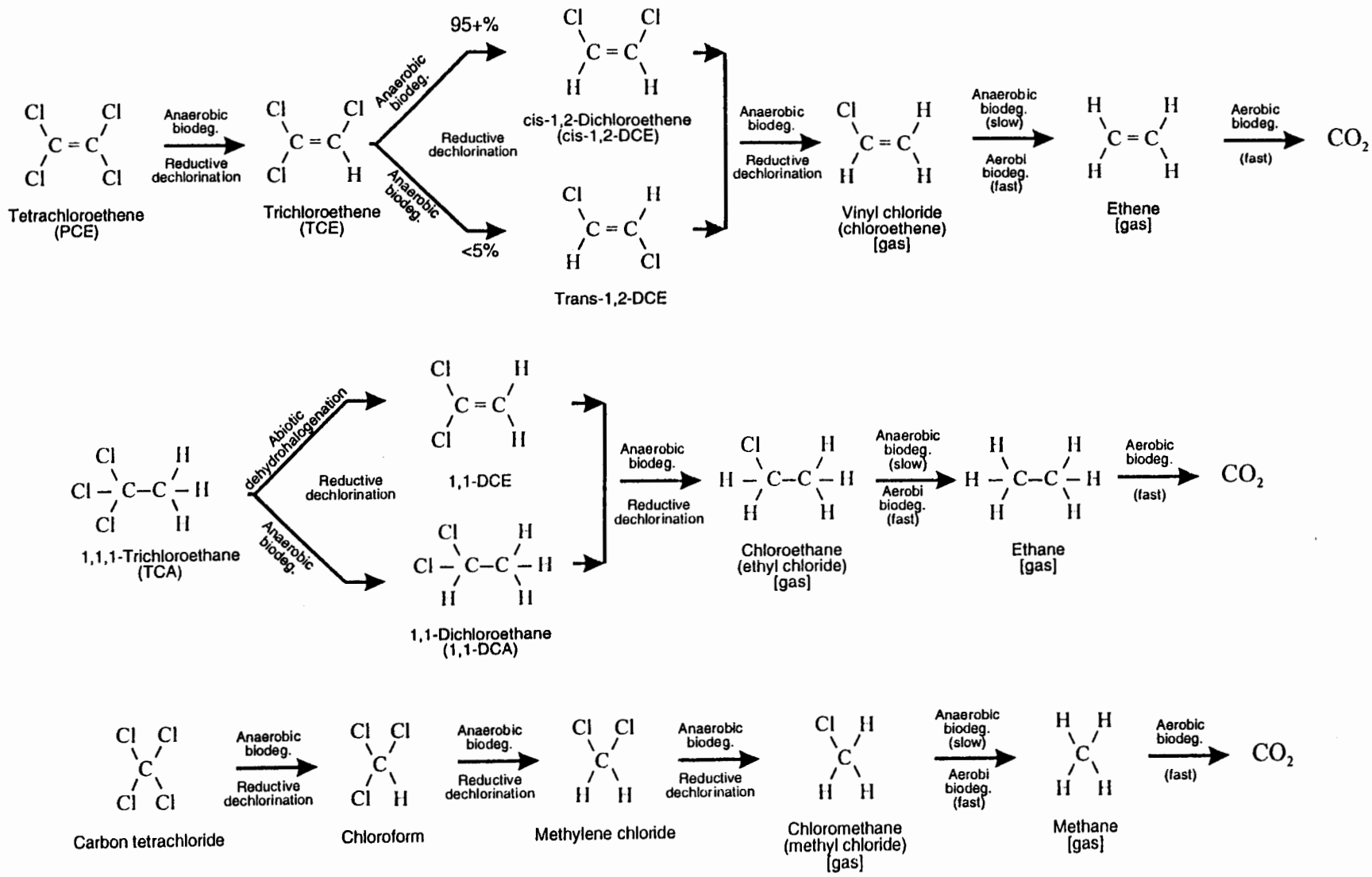
VOCs detected in the soil gas may be conveniently classified into two broad groups: (1) chlorinated solvent compounds (e.g., PCE, TCE, Freons) and their degradation products (e.g. DCE, vinyl chloride) and (2) non-chlorinated aromatic fuel hydrocarbons (e.g., ethylbenzene, xylenes). While both types of hydrocarbons may occur together in the soil vapor, the two classes of VOCs most likely derive from separate sources within the landfill.

Figure 7 shows the biodegradation pathways for several common chlorinated solvents. The most abundant VOCs in the soil vapor samples collected from the multi-port soil gas monitor wells are those that lie along the PCE degradation pathway, particularly cis-1,2-DCE and vinyl chloride. These two VOCs are products of the anaerobic dechlorination of the parent compound, PCE, which likely represents the primary waste liquid solvent that was placed directly in the landfill.

VOC concentration profiles for cis-1,2-DCE and vinyl chloride are plotted versus depth for the February and March sampling events in Figures 8a/8b and 9a/9b, respectively. These plots indicate that (1) the highest concentrations of these compounds are found in monitor wells LPS-2, LP-3, LP-4, and LP-7 and (2) VOC concentrations generally decline with depth below the surface, with the highest concentrations observed in the uppermost soil gas port in each monitor well.

In addition, the presence of chlorinated VOCs in soil vapor appears to correlate with the presence of methane. This relationship is shown graphically in Figures 10a and 10b. As discussed above, methane is a major component of landfill gas that is generated during anaerobic decomposition of organic refuse. Landfill gas thus apparently serves as the "carrier gas" for transport of chlorinated VOCs from the landfill refuse into the surrounding volcanic tuff.

Another observation is that the chlorinated VOCs cis-1,2-DCE and vinyl chloride appear to be rapidly biodegraded upon contact with free oxygen along the perimeter of the anoxic landfill gas plume. This accounts for the observation that in every soil gas sample in which DCE or vinyl chloride was detected, methane was also present. Based on these data, methane apparently serves as a reasonably reliable surrogate, or indicator compound, for the presence of hazardous chlorinated VOCs in soil vapor.



Sources: McCarty, 1994
Arizona Dept. of Environmental Quality, unpublished data

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Chlorinated Hydrocarbon Degradation Pathways

Figure 7

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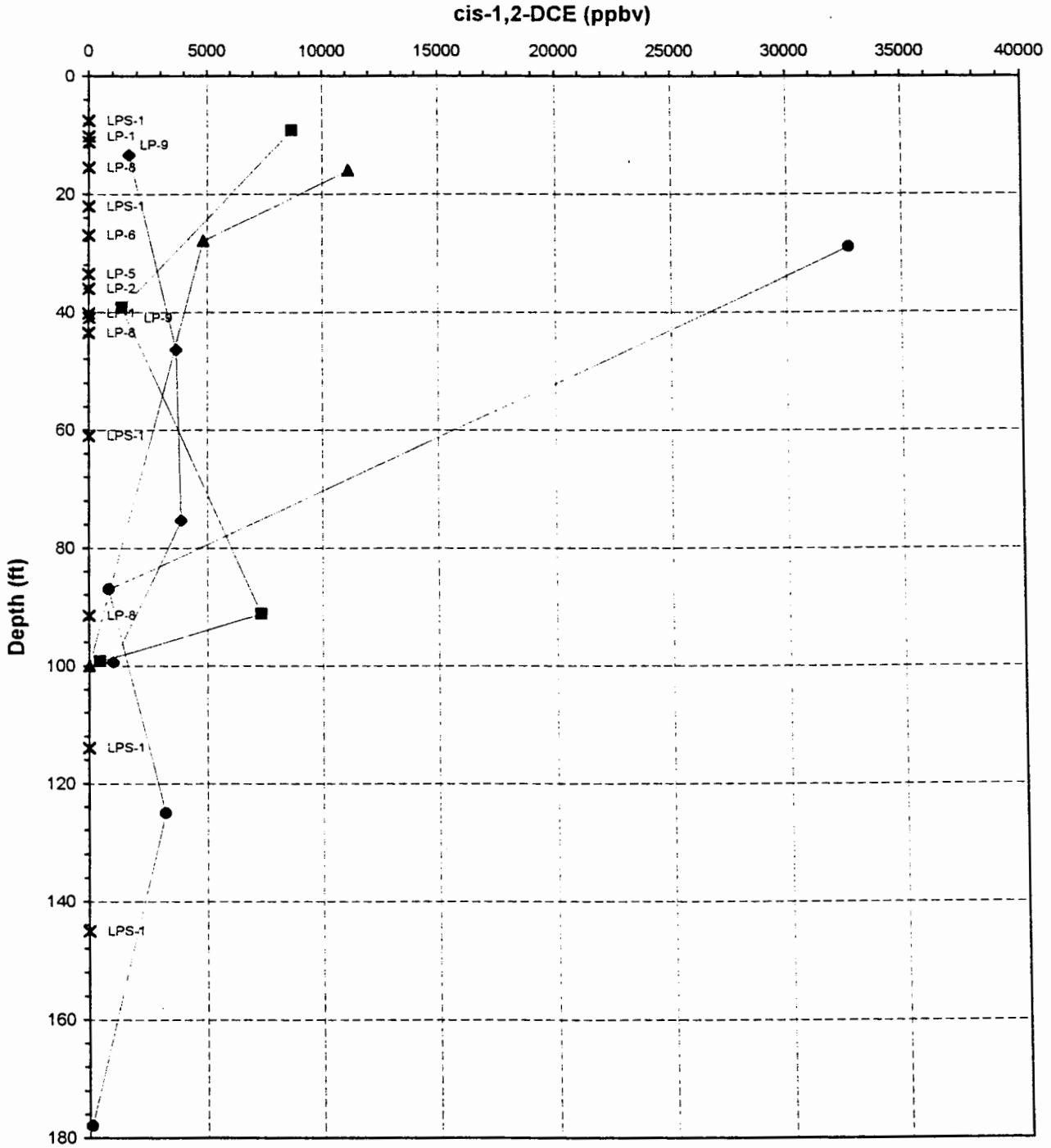

Explanation

- ▲ LP-7
- ● LPS-2
- ◆ LP-4
- ■ LP-3

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cis-1,2-DCE Concentration vs. Depth
February 1995

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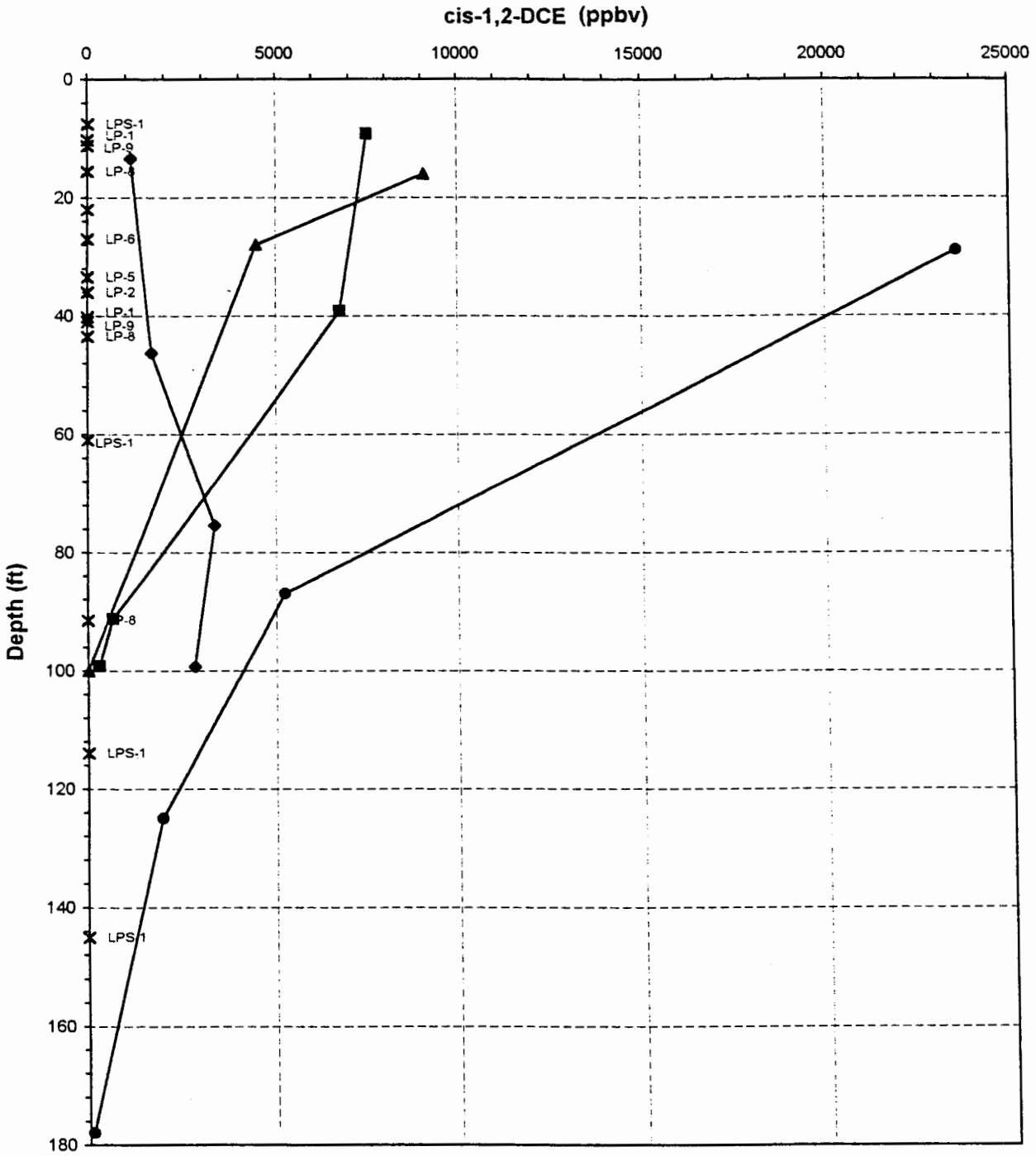
Figure 8a



Explanation

- ▲ LP-7
- ● LPS-2
- ◆ LP-4
- ■ LP-3

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cis-1,2-DCE Concentration vs. Depth
March 1995

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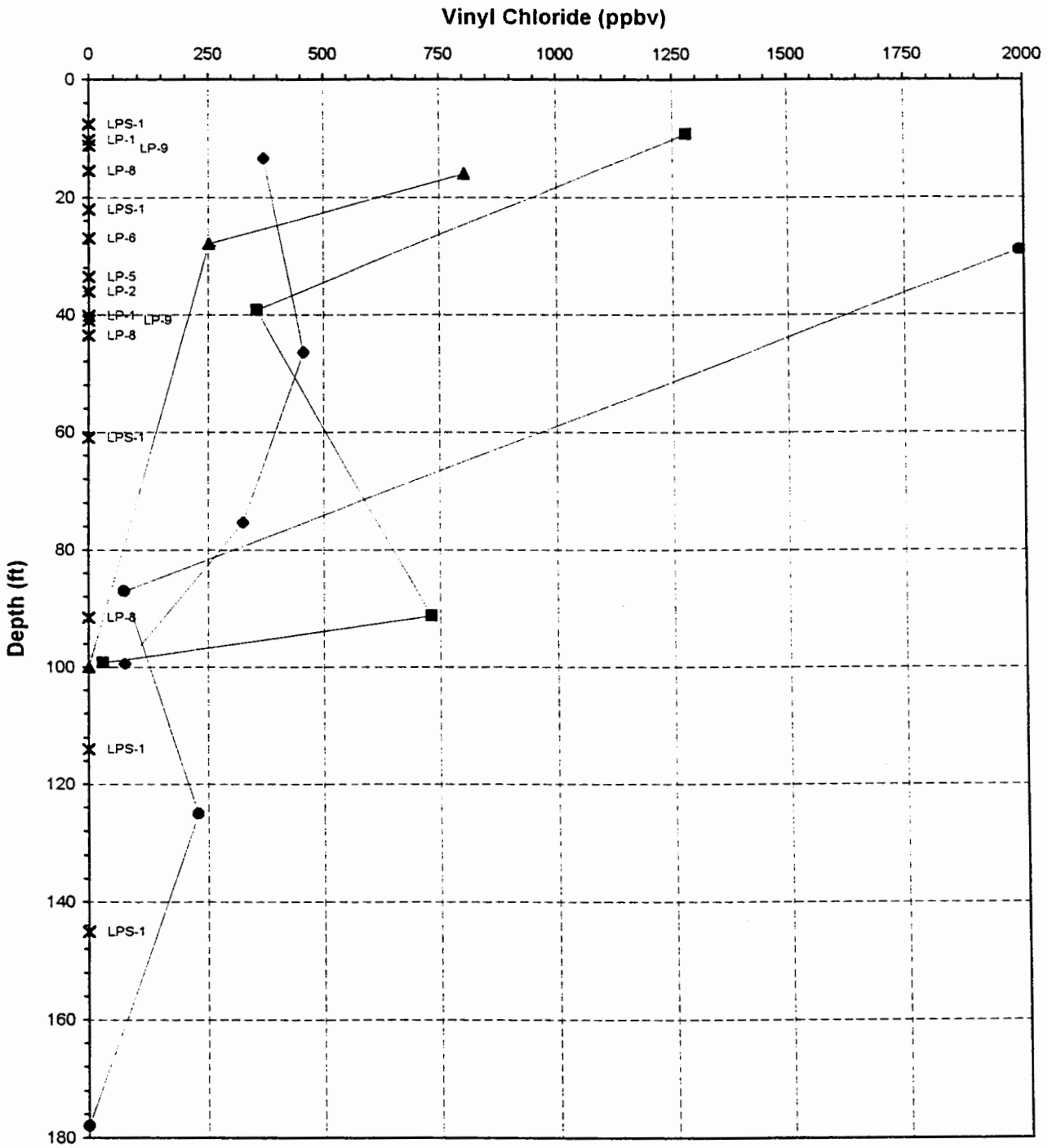
Figure 8b



Explanation

- ▲ LP-7
- ● LPS-2
- ◆ LP-4
- ■ LP-3

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Vinyl Chloride Concentration vs. Depth
February 1995

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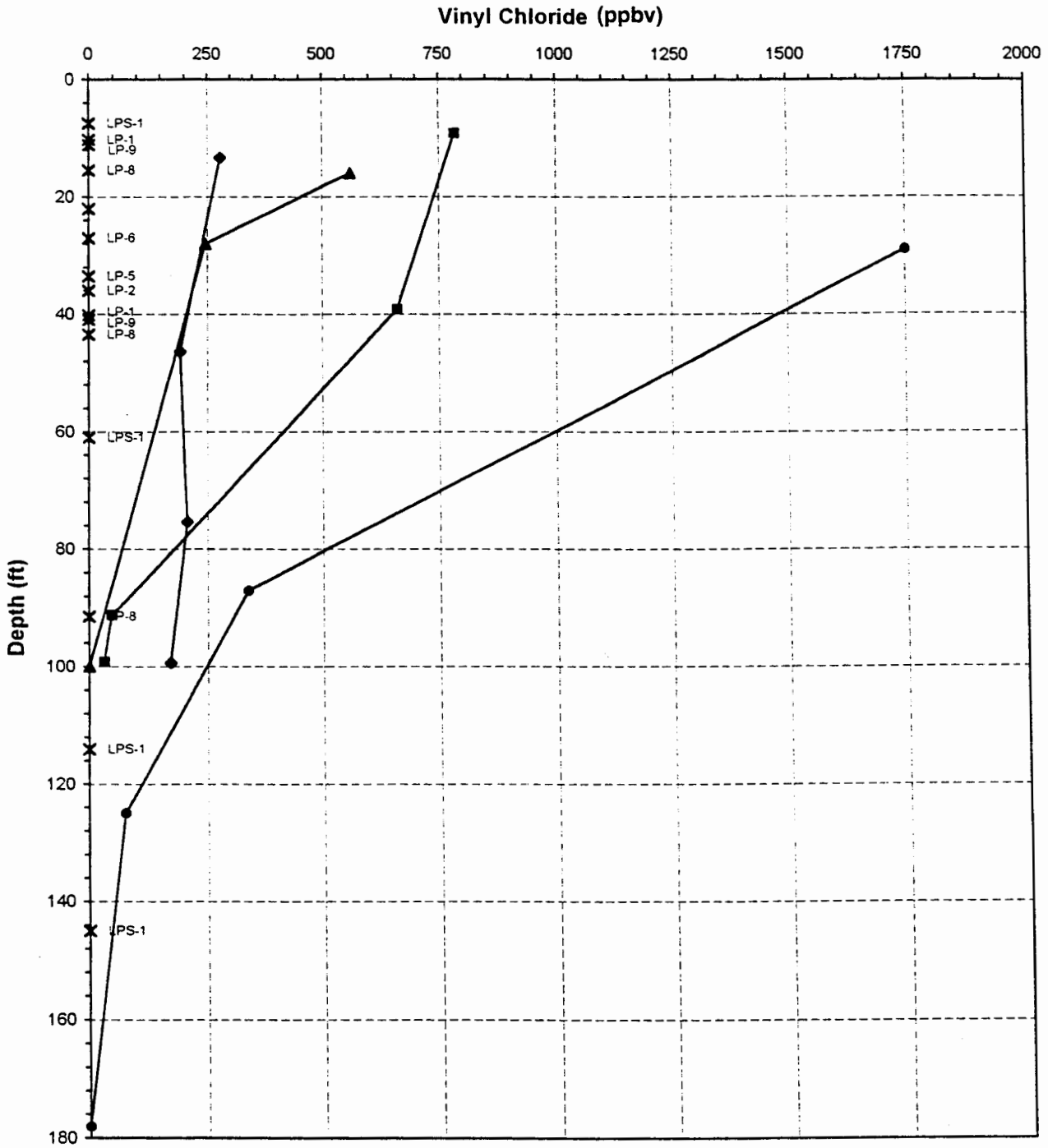
Figure 9a



Explanation

- ▲ LP-7
- ● LPS-2
- ◆ LP-4
- ■ LP-3

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Vinyl Chloride Concentration vs. Depth
March 1995

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Figure 9b

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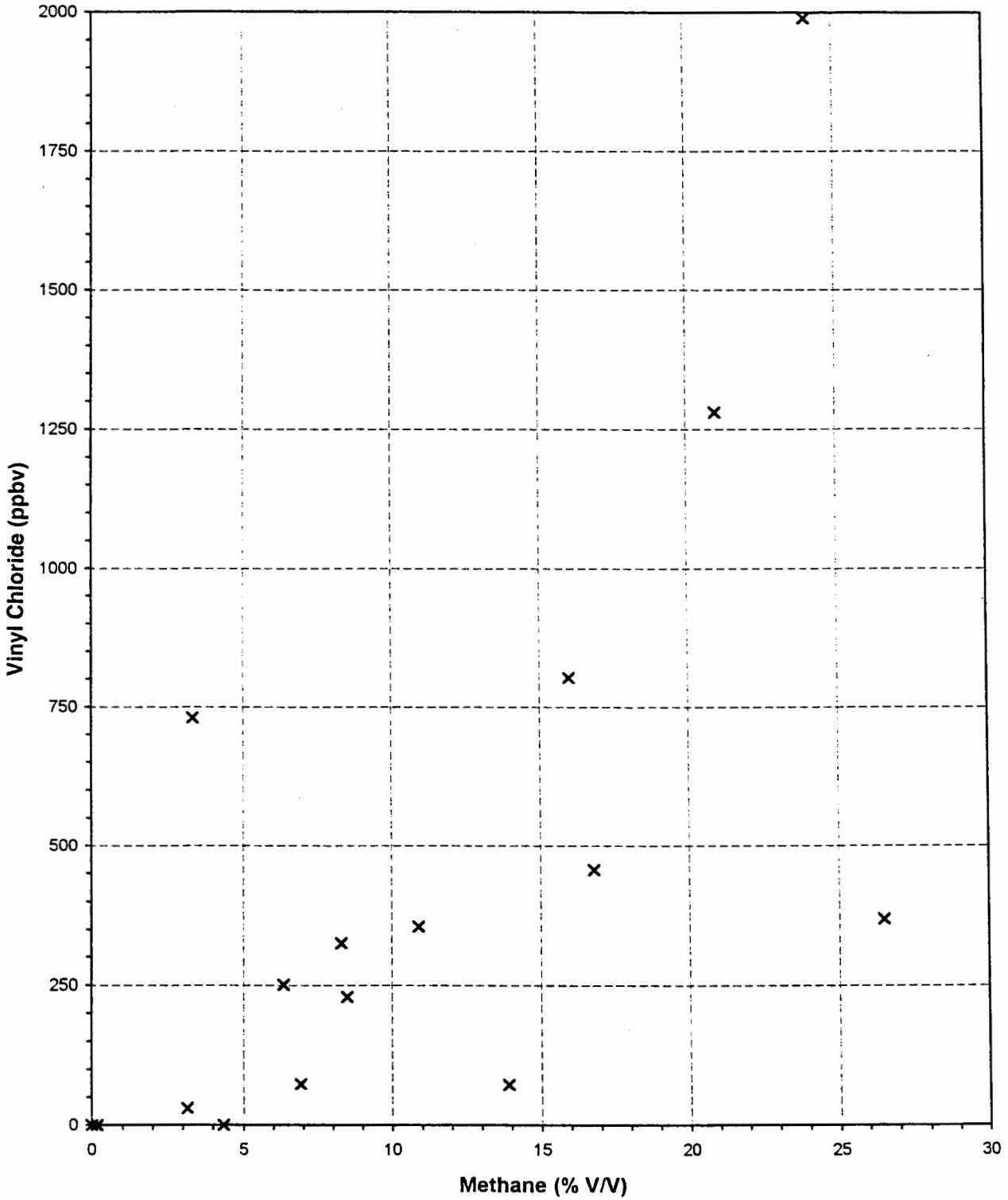

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Vinyl Chloride vs. Methane
February 1995

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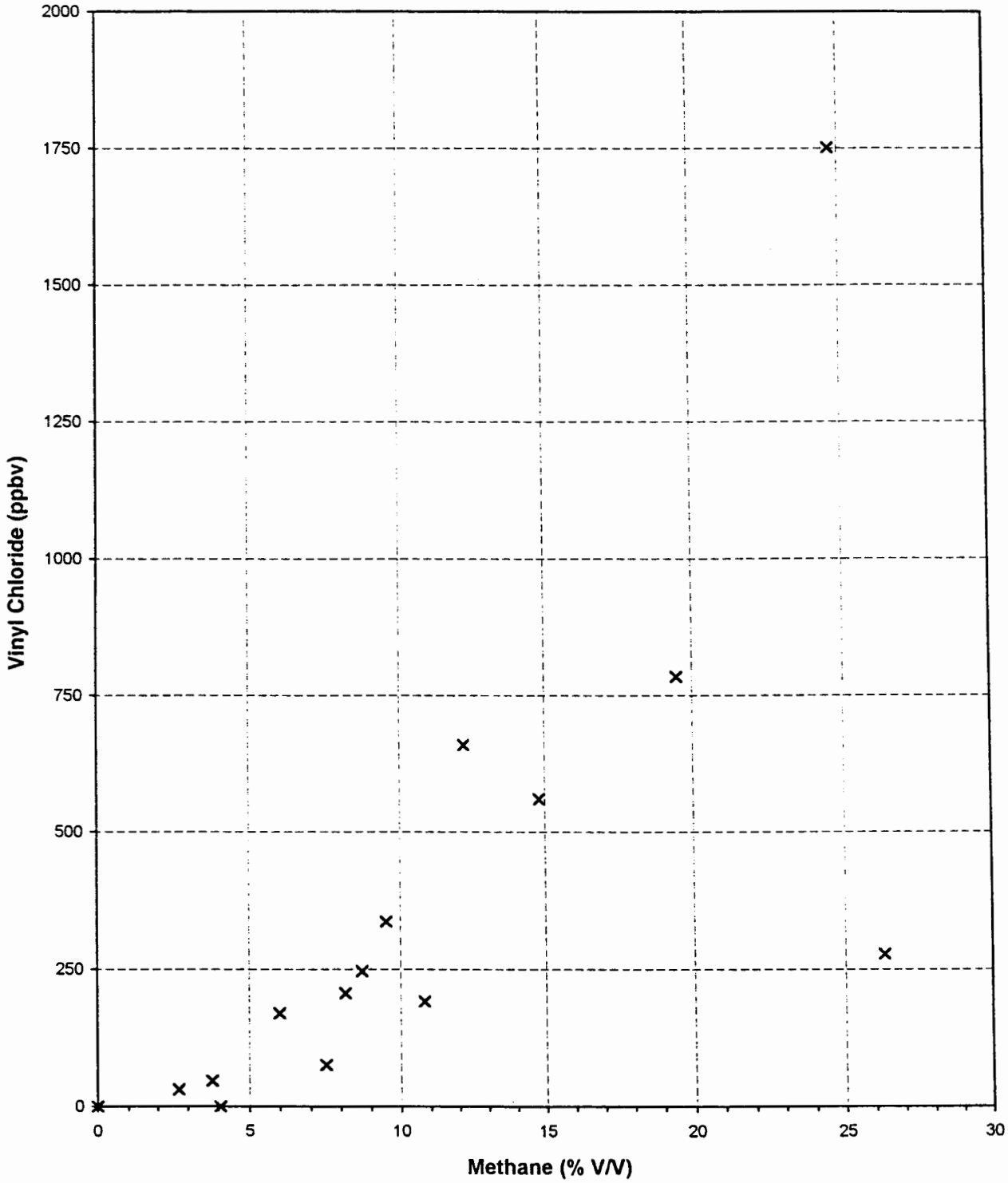
Figure 10a



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Vinyl Chloride vs. Methane
March 1995

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Figure 10b

The concentrations of benzene, toluene, ethylbenzene, and xylenes (BTEX) in soil gas are generally much lower than those of the chlorinated VOCs. With the exception of the uppermost two ports in monitor well LP-7, BTEX concentrations in soil gas are below 100 ppbv. However, soil vapor samples obtained from LP-7 show concentrations in the range of 100 to 1600 ppbv for the individual BTEX compounds, indicating that this well is situated in the vicinity of a source of fuel hydrocarbons in the landfill. As was observed for the chlorinated VOCs, the highest concentrations of BTEX compounds were reported for the shallowest soil vapor sample, suggesting a near-surface source within the refuse.

Based on the first two months of soil vapor sampling, both major gas and VOC concentrations at a given depth within the vadose zone appear to be relatively stable over time. Table 3 shows the concentrations of CH_4, CO_2, and N_2 in soil vapor samples collected during February and March 1995. These data show that, with the exception of LP-8 near the mesa edge, the major gas composition of soil vapor at a particular depth has remained nearly constant over this two-month period. Likewise, VOC concentrations also appear relatively constant or are changing only slowly over time (Table 4). However, seasonal effects on soil vapor composition may become apparent as additional samples are collected.

The following conclusions are based on the results of the first two months of soil gas sampling and analysis; they should be regarded as preliminary and will be re-evaluated as additional soil gas samples are collected and analyzed.

- High concentrations of CH_4 (up to 27 percent) and CO_2 (up to 30 percent) exist in soil gas surrounding the landfill as a result of anaerobic decomposition of refuse and subsequent lateral migration of landfill gas.

- Chlorinated VOCs are present in soil vapor surrounding the landfill perimeter at concentrations as high as 36,000 ppbv, with the predominant compounds being cis-1,2-DCE, Freon-22, vinyl chloride, and Freon-12, in approximate decreasing order of abundance.

- Soil vapor concentrations of chlorinated VOCs show a strong positive correlation with methane concentrations; methane is always present in soil gas containing chlorinated VOCs.

- Preliminary results indicate that soil vapor concentrations of major gases and VOCs at a particular depth remain relatively constant over time.

- Landfill gas appears to serve as a "carrier gas" for the advective transport of hazardous VOCs, and landfill gas is present to a depth of at least 160 feet, the deepest depth monitored.

- Several of the volatile compounds, such as the Freons, are primary solvents that apparently were placed directly in the landfill, while others, such as cis-1,2-DCE and vinyl chloride, are biodegradation products of the anaerobic dechlorination of parent solvent compounds, such as PCE and TCE.

- VOC concentrations generally decline with depth below the surface, with the highest concentrations observed in the uppermost soil gas port in each monitor well.

- Soil vapor containing significant quantities of landfill gas is predicted to be more dense than ordinary soil air, and thus the potential for sinking of dense gas exists.

- Both the diffusion (concentration) and advection (density) gradients suggest the possibility for downward migration of landfill gases containing VOCs.

3.1.3 QA/QC Sample Results

In general, the concentrations of CO_2, CH_4, and O_2 reported by the laboratory for canister samples agree quite well with those determined in the field using the portable multi-gas monitor, generally differing within ±1% by volume (Table 5). Likewise, the major gas concentrations reported by the laboratory for field duplicates collected simultaneously in identical SUMMA canisters are in reasonably good agreement. Table 6 shows the major gas results for duplicate

Table 5. Comparison of Field- and Laboratory-Measured Concentrations of Major Gases in Soil Vapor

Monitor Well	Soil Gas Port	Depth (ft)	Sample Date	Concentration (% vol)							
				Methane (CH_4)		Carbon Dioxide (CO_2)		Oxygen (O_2)		Nitrogen	Hydrogen
				Field[a]	Laboratory[b]	Field[a]	Laboratory[b]	Field[a]	Laboratory[b]	Laboratory[a]	Laboratory[b]
LP-1	GP1	40.2	02/21/95	0.0	<0.200	1.1	1.57	20.5	21.5	80.4	<0.100
			03/27/95	0.0	<0.100	1.5	1.43	20.4	20.3	75.8	<0.100
	GP2	10.2	02/21/95	0.1	<0.200	1.7	2.14	20.1	20.8	80.8	<0.100
			03/27/95	0.0	<0.100	1.8	2.07	20.6	19.6	75.4	<0.100
LP-2	GP1	36	02/21/95	0.0	<0.200	4.9	6.94	14.9	16.7	84.2	<0.100
			03/27/95	0.0	<0.100	4.9	6.13	15.2	14.8	75.2	<0.100
LP-3	GP1	99.2	02/22/95	2.0	3.16	16.9	20.1	3.2	2.16	72.8	<0.100
			03/29/95	2.5	2.72	21.0	19.0	1.8	1.19	75.1	<0.100
	GP2	91.2	02/22/95	2.4	3.34	17.9	19.5	1.7	0.807	73.3	<0.100
			03/29/95	3.7	3.81	19.8	19.5	2.7	1.15	74.8	<0.100
	GP3	39.2	02/22/95	12.9	10.9	24.9	21.4	0.6	1.88	66.8	<0.100
			03/29/95	13.6	12.2	27.1	24.3	0.6	1.01	62.3	<0.100
	GP4	9.2	02/22/95	20.0	21.0	28.7	26.7	0.7	1.44	57.1	<0.100
			03/29/95	20.7	19.5	29.0	26.7	0.2	0.886	52.0	<0.100
LP-4	GP1	99.35	02/22/95	7.0	6.92	22.3	21.3	0.6	0.996	74.2	<0.100
			03/28/95	6.9	5.99	21.9	19.8	0.6	1.08	68.2	<0.100
	GP2	75.35	02/22/95	8.8	8.30	22.7	21.4	0.6	1.76	65.8	<0.100
			03/28/95	8.6	8.15	23.2	21.5	0.6	1.17	66.2	<0.100
	GP3	46.35	02/22/95	16.6	16.8	27.2	26.5	0.6	1.58	61.6	<0.100
			03/28/95	11.6[c]	10.8[c]	18.5[c]	17.5[c]	6.0[c]	5.94[c]	61.2[c]	<0.100[c]

[a]Soil gas composition determined in the field during purging using Landtec GA-90 multi-gas monitor.
[b]Soil gas composition reported by ESE-Gainesville (preliminary results) for SUMMA canister samples analyzed by GC-TCD Method 133 (Lodge, 1989).
[c]Air leak occurred during sampling; values not representative of subsurface conditions.

Table 5. Comparison of Field- and Laboratory-Measured Concentrations of Major Gases in Soil Vapor

Monitor Well	Soil Gas Port	Depth (ft)	Sample Date	Concentration (% vol)							
				Methane (CH_4)		Carbon Dioxide (CO_2)		Oxygen (O_2)		Nitrogen	Hydrogen
				Field[a]	Laboratory[b]	Field[a]	Laboratory[b]	Field[a]	Laboratory[b]	Laboratory[a]	Laboratory[b]
LP-4 (cont.)	GP4	13.35	02/22/95	27.5	26.5	29.6	26.7	0.6	1.10	44.0	<0.100
			03/28/95	26.6	26.3	28.3	27.4	0.4	0.789	44.2	<0.100
LP-5	GP1	33.5	02/21/95	0.0	<0.200	10.1	15.9	9.5	2.46	89.6	<0.100
			03/28/95	0.0	<0.100	14.4	14.3	6.7	7.04	76.8	<0.100
LP-6	GP1	27	02/23/95	0.0	<0.100	3.5	3.46	18.5	7.12	80.7	<0.100
			03/28/95	0.0	<0.100	3.5	3.01	17.5	18.2	73.7	<0.100
LP-7	GP1	100	02/23/95	0.0	<0.100	15.0	15.9	5.3	2.56	89.3	<0.100
			03/29/95	0.0	<0.100	16.0	16.2	3.4	3.56	77.1	<0.100
	GP2	28	02/23/95	6.3	6.34	24.5	23.1	0.5	1.91	69.1	<0.100
			03/29/95	8.9	8.71	24.4	24.4	0.6	1.06	63.0	<0.100
	GP3	16	02/23/95	17.0	16.0	31.4	26.8	0.8	1.43	56.2	<0.100
			03/29/95	14.9	14.8	27.9	27.7	0.7	0.932	54.3	<0.100
LP-8	GP1	91.5	02/23/95	0.1	<0.100	0.4	9.25	20.4	10.2	83.3	<0.100
			03/27/95	0.0	<0.100	0.4	<0.100	20.9	21.0	77.0	<0.100
	GP2	43.5	02/23/95	0.1	<0.100	1.5	0.564	19.8	19.5	76.5	<0.100
			03/27/95	0.0	<0.100	1.1	<0.100	20.1	20.7	75.9	<0.100
	GP3	15.5	02/23/95	0.1	<0.100	1.4	1.55	19.6	18.6	76.3	<0.100
			03/27/95	0.0	<0.100	1.3	1.29	19.7	20.0	75.6	<0.100
LP-9	GP1	41	02/22/95	0.0	<0.100	13.5	14.8	7.6	10.3	76.4	<0.100
			03/28/95	0.0	<0.100	13.0	13.8	7.9	8.40	76.3	<0.100

[a]Soil gas composition determined in the field during purging using Landtec GA-90 multi-gas monitor.
[b]Soil gas composition reported by ESE-Gainesville (preliminary results) for SUMMA canister samples analyzed by GC-TCD Method 133 (Lodge, 1989).
[c]Air leak occurred during sampling; values not representative of subsurface conditions.

Table 5. Comparison of Field- and Laboratory-Measured Concentrations of Major Gases in Soil Vapor

Monitor Well	Soil Gas Port	Depth (ft)	Sample Date	Concentration (% vol)							
				Methane (CH_4)		Carbon Dioxide (CO_2)		Oxygen (O_2)		Nitrogen	Hydrogen
				Field[a]	Laboratory[b]	Field[a]	Laboratory[b]	Field[a]	Laboratory[b]	Laboratory[a]	Laboratory[b]
LP-9 (cont.)	GP2	11.15	02/22/95	0.0	<0.100	11.9	10.1	6.6	1.22	88.2	<0.100
			03/28/95	0.0	<0.100	13.0	12.9	7.2	7.40	78.9	<0.100
LPS-1	GP1	145	02/23/95	0.0	0.165	5.6	7.33	14.2	2.32	79.1	<0.100
			03/27/95	0.0	<0.100	5.8	6.81	13.2	13.0	75.9	<0.100
	GP2	114	02/23/95	0.0	<0.100	4.9	6.67	15.8	16.6	85.8	<0.100
			03/27/95	0.0	<0.100	4.8	5.72	14.7	15.1	77.2	<0.100
	GP3	61	02/23/95	0.0	<0.100	2.4	3.09	18.2	8.53	76.3	<0.100
			03/27/95	0.0	<0.100	2.7	2.83	17.3	18.3	76.3	<0.100
	GP4	22	02/23/95	0.0	<0.100	8.1	10.00	11.6	0.494	75.4	<0.100
			03/27/95	0.0	<0.100	8.3	11.1	11.0	9.35	74.7	<0.100
	GP5	7.5	02/23/95	0.0	<0.100	6.8	10.00	13.0	5.51	74.0	<0.100
			03/27/95	0.0	<0.100	5.9	9.55	13.5	11.6	77.0	<0.100
LPS-2	GP1	178	02/22/95	4.1	4.35	17.6	19.4	2.6	3.03	80.5	<0.100
			03/29/95	4.3	4.07	19.4	18.1	1.5	2.57	74.6	<0.100
	GP2	125	02/22/95	8.8	8.49	21.7	22.5	0.6	0.133	74.3	<0.100
			03/29/95	8.6	7.51	23.7	20.4	0.0	1.15	67.2	<0.100
	GP3	87	02/22/95	15.8	13.9	26.2	22.5	0.6	1.51	58.2	<0.100
			03/29/95	10.3	9.52[c]	16.5[c]	15.6[c]	7.9[c]	7.43[c]	64.1[c]	<0.100[c]
	GP4	29	02/22/95	27.0	24.1	30.8	26.2	0.6	1.09	44.1	<0.100
			03/29/95	25.8	24.7	28.6	27.4	0.3	0.783	45.1	<0.100

[a]Soil gas composition determined in the field during purging using Landtec GA-90 multi-gas monitor.
[b]Soil gas composition reported by ESE-Gainesville (preliminary results) for SUMMA canister samples analyzed by GC-TCD Method 133 (Lodge, 1989).
[c]Air leak occurred during sampling; values not representative of subsurface conditions.

Table 6. Comparison of Concentrations of Major Gases for Duplicate Soil Gas Samples (February and March 1995 Sampling Events)

Constituent	Concentration[a] (% vol.)														
	LP-4/GP4 (2/22/95)			LP-7/GP3 (2/23/95)			LPS-2/GP4 (2/22/95)			LPS-1/GP4 (3/27/95)			LP-4/GP3 (3/28/95)		
	SUMMA GL039	SUMMA GL014	RPD[b] (%)	SUMMA GL083	SUMMA GL003	RPD[b] (%)	SUMMA GL011	SUMMA GL059	RPD[b] (%)	SUMMA GL011	SUMMA GL094	RPD[b] (%)	SUMMA GL106	22 SUMMA	RPD[b] (%)
CO_2	26.7	25.8	3	26.8	29.7	10	26.2	24.6	6	11.1	11.4	3	17.5	17.7	1
CH_4	26.5	25.5	4	16.0	17.7	10	24.1	22.6	6	<0.1	<0.1	NC	10.8	10.9	1
N_2	44.0	42.5	3	56.2	60.7	8	44.1	49.9	12	74.7	76.4	2	61.2	62.5	2
O_2	1.10	1.06	4	1.43	1.56	9	1.09	1.29	17	9.35	9.63	3	5.94	6.15	3
H_2	<0.1	<0.1	NC	<0.1	<0.1	NC	<0.1	<0.1	NC	<0.1	<0.1	NC	<0.1	<0.1	NC

[a] Gas concentrations as reported by ESE-Gainesville (preliminary results) for soil gas samples collected in SUMMA canisters and analyzed by GC-TCD Method 133 (Lodge, 1989).
[b] Relative percent difference (RPD) between duplicates calculated as $(X_1 - X_2)/[(X_1 + X_2)/2]$, where X_1 and X_2 represent the two concentrations reported by the laboratory.

NC = Not calculated

soil gas samples collected during both the February and March sampling events. Relative percent differences for major gas concentrations of field duplicates collected during February range from 3 to 17 percent, while those for the March sampling event range from 1 to 3 percent. The improvement in analytical precision during analysis of the March samples probably reflects better consistency in performing the laboratory procedures.

Due to a laboratory error, the major gas PE sample submitted along with the February soil gas samples was inadvertently lost. However, the major gas concentrations reported for the PE sample submitted during March 1995 are shown in Table 7, along with the expected nominal concentrations. The laboratory results for CH_4 and CO_2 reported by ESE are slightly outside the project-specific accuracy objective of ±1 percent for the major gases; otherwise, the results appear acceptable.

Table 8 shows the laboratory results for VOC analysis of the PE sample submitted during the February and March sampling events. During the first monthly sampling event (February 1995), low VOC recoveries were observed for two of the compounds present in the VOC PE sample: PCE and EDB. Recoveries for these two compounds were 67 and 46 percent, respectively. Recoveries for the remaining six compounds ranged from 94 to 115 percent. It was observed that the two compounds with low recoveries were those with the lowest vapor pressures and the highest molecular weights. It was then surmised that the low recoveries were probably attributable to sorption of the higher molecular weight VOCs on the dry interior of the SUMMA canister, a phenomenon sometimes referred to as the "wall effect" (Rasmussen, 1995).

Wall effects are negligible for soil vapor samples, because the high water vapor content of soil gas results in a thin layer of water molecules covering the interior surface of the canister. Wall effects are significant for dry gases, however, such as the VOC gas standard obtained from Scott Specialty Gases. Dr. Reinhold Rasmussen, who manufactures the SUMMA canisters, suggested that canisters used to collect the dry VOC PE samples should be "humidified" with clean water prior to filling them with the gas sample. During subsequent monthly sampling events, therefore, approximately 0.2 mL of distilled water has been introduced into the canister prior to filling with the VOC gas standard in order to minimize sorption of VOCs. Humidification of the SUMMA canisters prior to collection of the VOC PE samples appears to have eliminated the sorption problem beginning with the March PE sample (Table 8).

Table 7. Laboratory Results for Major Gases Performance Evaluation Sample

Constituent	Nominal Concentration[a] (vol. pct.)	SUMMA GL079[b] (vol. pct.)	Percent Recovery[c]
CO_2	15	13.0	87
CH_4	15	13.1	87
N_2	70	67.6	96
O_2	0	2.13	NC
H_2	0	<0.1	NC

NC = Not calculated

[a] Stated concentration for calibration gas obtained from Landfill Control Technologies, Commerce, Calif. (Batch #543758-120993).
[b] Laboratory results reported by ESE-Gainesville for performance evaluation sample collected March 29, 1995, in SUMMA canister #GL079.
[c] Percentage of nominal concentration reported by ESE-Gainseville.

Table 8. Laboratory Results for VOCs, Performance Evaluation Sample[a]

Constituent	Nominal Concentration (ppmv)	Scott Analysis[b] (ppmv)	February 1995 ESE Analysis[c] (ppmv)	Percent Recovery	March 1995 ESE Analysis[c] (ppmv)	Percent Recovery
cis 1,2-DCE	10	10.6	11.3	107	13.2	125
1,2-dibromoethane (EDB)	10	10.7	4.9	46	10.7	100
1,1-DCA	10	10.8	10.2	94	18.5	171
1,2-DCA (EDC)	10	9.98	11.5	115	13	130
PCE	10	10.7	7.2	67	12.5	117
1,1,1-TCA	10	10.2	11.2	110	14.7	144
Vinyl chloride	10	10.6	10.4	98	12.1	114
1,1-DCE (vinylidene chloride)	10	10.8	11.7	108	13.1	121

[a] VOC performance evaluation sample = Scott Specialty Gases Item #01046676 10 ppmv toxic organic mixture, blend 2
[b] Gas composition as reported on Certificate of Analysis from Scott Specialty Gases.
[c] Laboratory results reported by ESE-Gainesville for SUMMA canisters filled with the VOC performance evaluation sample purchased from Scott Specialty Gases.

Table 9 shows the VOC laboratory results for field duplicate SUMMA canisters collected during the first two sampling events, along with the calculated relative percent difference (RPD) for the duplicate values. The data quality objective for precision, as determined by analysis of field duplicates, is <20 percent RPD. Most of the duplicate results do meet this criterion; however a few have larger differences between the two values. As expected, analytical precision appears to become worse for those samples and constituents whose concentrations are close to the detection limit. Nearly all of the VOCs detected at concentrations of greater than 1 ppmv meet the precision criteria.

3.2 Soil Gas Pressure Monitoring Program

Continuous monitoring of soil gas pressure is being conducted at four monitor wells: LP-4, LP-7, LP-8, and LPS-2. Three soil gas sampling ports from each of the monitor wells are connected to a data acquisition system. The depths of the gas ports being monitored in each well are shown in Table 10. The data acquisition system and methods of data acquisition are discussed in Section 2. Downhole soil gas pressure data generated from March 1 to April 14, 1995, are shown in Appendix E.

Downhole pressure measurements are made every 45 minutes at monitor wells LP-4, LP-7, LP-8, and LPS-2, each of which is equipped with a data acquisition system. A non-zero gauge pressure recorded at a soil gas port represents a pressure gradient between the surface and the subsurface at the depth of the port. Such differential pressures result from oscillations in surface barometric pressure in response to so-called atmospheric tides. The magnitude of the pressure differential depends primarily on the permeability of the intervening geologic materials. Large pressure gradients imply inefficient communication (low air permeability) between the surface and the subsurface depth interval being monitored. Conversely, small pressure gradients imply good communication (high air permeability).

Typically, subsurface pressure responses at depths of more than 100 feet are commonly attenuated in amplitude and out of phase with respect to the corresponding atmospheric pressure oscillations at the surface. Both the attenuation in amplitude and out-of-phase nature can be explained in terms of the resistance to air flow of the geologic materials, which results in energy

Table 9. Comparison of Concentrations of VOCs for Duplicate Soil Gas Samples February and March 1995 Sampling Events

Constituent	Concentration[a] (ppbv)														
	LP-4/GP4 (2/22/95)			LP-7/GP3 (2/23/95)			LPS-2/GP4 (2/22/95)			LPS-1/GP4 (3/27/95)			LP-4/GP3 (3/28/95)		
	SUMMA GL039	SUMMA GL014	RPD[b] (%)	SUMMA GL083	SUMMA GL003	RPD[b] (%)	SUMMA GL011	SUMMA GL059	RPD[b] (%)	SUMMA GL011	SUMMA GL094	RPD[b] (%)	SUMMA[c] GL106	SUMMA[c] 22	RPD[b] (%)
Freon 12	<50	<50	NC	1260	1160	8	869	841	3	173	214	21	277	263	5
Chloromethane	<50	<50	NC	216	308	35	<25	129	NC	50.0	37.4	29	96.6	58.8	49
Freon 114	<50	<50	NC	135	143	6	140	138	1	95.0	88.2	7	<10	<10	NC
Vinyl chloride	369	290	24	803	754	6	1990	1990	0	<10	<10	NC	191	182	5
Chloroethane	<50	<50	NC	<50	135	NC	150	160	6	<10	<10	NC	21.8	20.2	8
1,1-DCE	<50	<50	NC	59	<62.5	NC	106	199	61	<10	<10	NC	15.2	14.2	7
Methylene chloride	62	81	27	156	160	2	140	133	5	34.4	<10	NC	72.0	31.6	78
cis 1,2-DCE	1670	1380	19	11,100	10,700	4	32,700	36,000	10	<10	32.8	NC	1670	1620	3
trans 1,2-DCE	<50	<50	NC	140	110	24	349	338	3	<10	<10	NC	35.4	33.4	6
1,1-DCA	<50	<50	NC	<50	<62.5	NC	<25	101	NC	<10	<10	NC	<10	<10	NC
1,2-DCA	<50	<50	NC	<50	<62.5	NC	<25	110	NC	<10	<10	NC	<10	<10	NC
1,1,1-TCA	<50	<50	NC	<50	<62.5	NC	<25	90.5	NC	<10	<10	NC	<10	<10	NC
Benzene	83	84	1	333	296	12	216	214	1	<10	<10	NC	40.8	38.8	5

[a] Gas concentrations as reported by ESE-Gainesville for soil gas samples collected in SUMMA canisters and analyzed by GC-TCD Method 133 (Lodge, 1989).
[b] Relative percent difference (RPD) between duplicates calculated as $(X_1 - X_2)/[(X_1 + X_2)/2]$, where X_1 and X_2 represent the two concentrations reported by the laboratory.
[c] Air leak occurred during sampling; values may be slightly lower than actual subsurface soil gas concentrations.

NC = Not calculated

Table 9. Comparison of Concentrations of VOCs for Duplicate Soil Gas Samples February and March 1995 Sampling Events

Constituent	Concentration[a] (ppbv)														
	LP-4/GP4 (2/22/95)			LP-7/GP3 (2/23/95)			LPS-2/GP4 (2/22/95)			LPS-1/GP4 (3/27/95)			LP-4/GP3 (3/28/95)		
	SUMMA GL039	SUMMA GL014	RPD[b] (%)	SUMMA GL083	SUMMA GL003	RPD[b] (%)	SUMMA GL011	SUMMA GL059	RPD[b] (%)	SUMMA GL011	SUMMA GL094	RPD[b] (%)	SUMMA[c] GL106	SUMMA[c] 22	RPD[b] (%)
TCE	<50	<50	NC	108	91.3	17	66.5	64.5	3	<10	<10	NC	11.8	12.2	3
Toluene	<50	<50	NC	848	680	22	137	155	12	<10	<10	NC	63.2	48.8	26
EDB	<50	<50	NC	<50	<62.5	NC	<25	65.5	NC	<10	<10	NC	<10	<10	NC
PCE	<50	<50	NC	130	101	25	81	151	60	26.0	24.4	6	38.6	40.0	4
Chlorobenzene	<50	<50	NC	164	<62.5	NC	27.5	28.0	2	<10	<10	NC	<10	<10	NC
Ethylbenzene	<50	<50	NC	1210	1120	8	<25	<25	NC	<10	<10	NC	<10	<10	NC
M,P-xylenes	<50	<50	NC	2150	1990	8	<25	<25	NC	11.6	17.2	40	24.6	28.6	15
O-xylene	<50	<50	NC	179	141	24	<25	<25	NC	<10	<10	NC	<10	<10	NC
1,3,5-Trimethylbenzene	<50	<50	NC	447	379	16	<25	<25	NC	<10	<10	NC	<10	<10	NC
1,2,4-Trimethylbenzene	<50	<50	NC	750	675	11	34.5	29.5	16	<10	<10	NC	16.6	15.0	10
1,4-Dichlorobenzene	<50	<50	NC	352	301	16	<25	154	NC	<10	<10	NC	36.4	34.2	6
Freon 22	8530	7840	8	1410	120	168	2640	2390	10	<10	<10	NC	1580	1520	4

[a] Gas concentrations as reported by ESE-Gainesville for soil gas samples collected in SUMMA canisters and analyzed by GC-TCD Method 133 (Lodge, 1989).
[b] Relative percent difference (RPD) between duplicates calculated as $(X_1 - X_2)/[(X_1 + X_2)/2]$, where X_1 and X_2 represent the two concentrations reported by the laboratory.
[c] Air leak occurred during sampling; values may be slightly lower than actual subsurface soil gas concentrations.

NC = Not calculated

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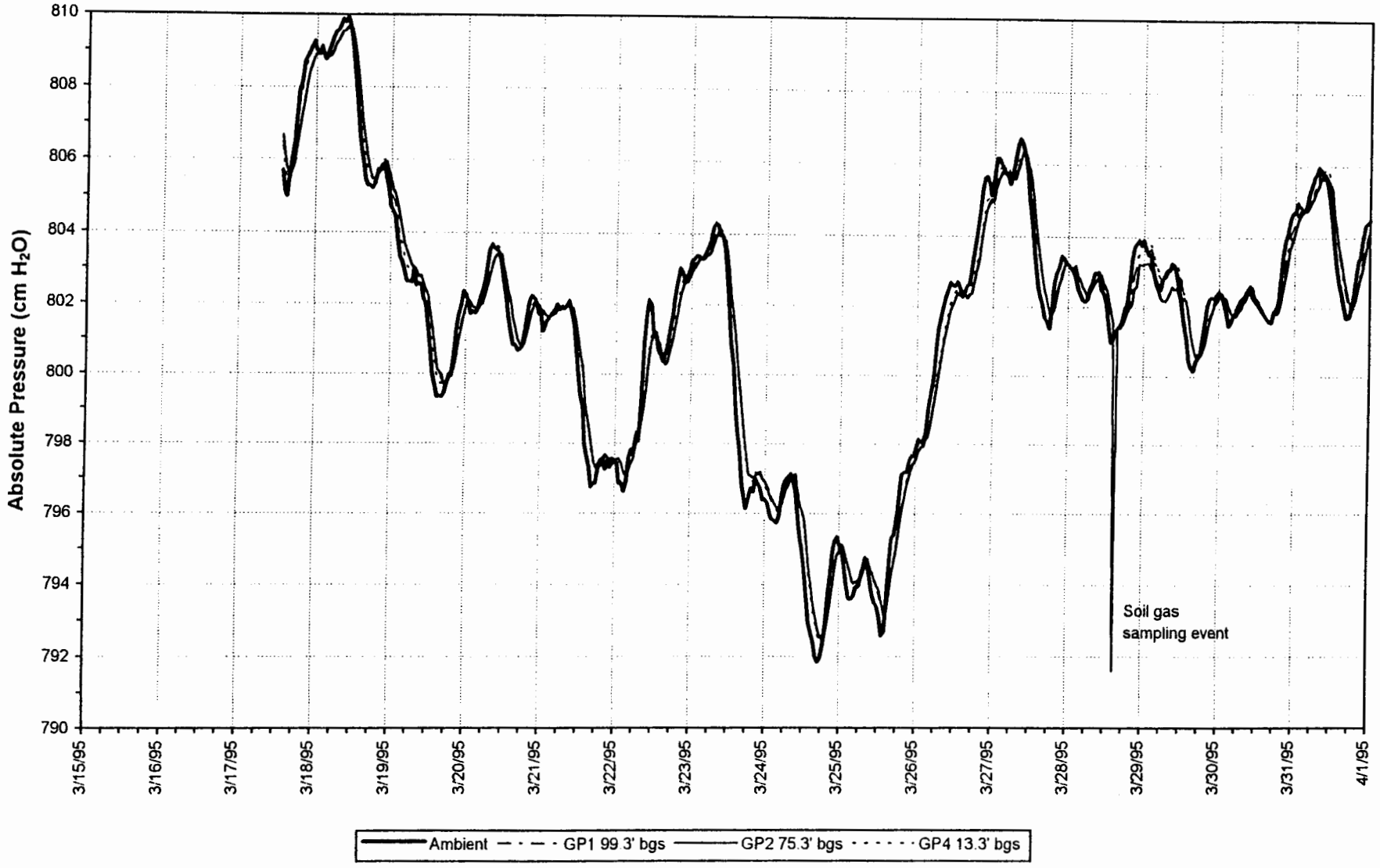

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LP-4 Absolute Soil Gas Pressures

Figure 11

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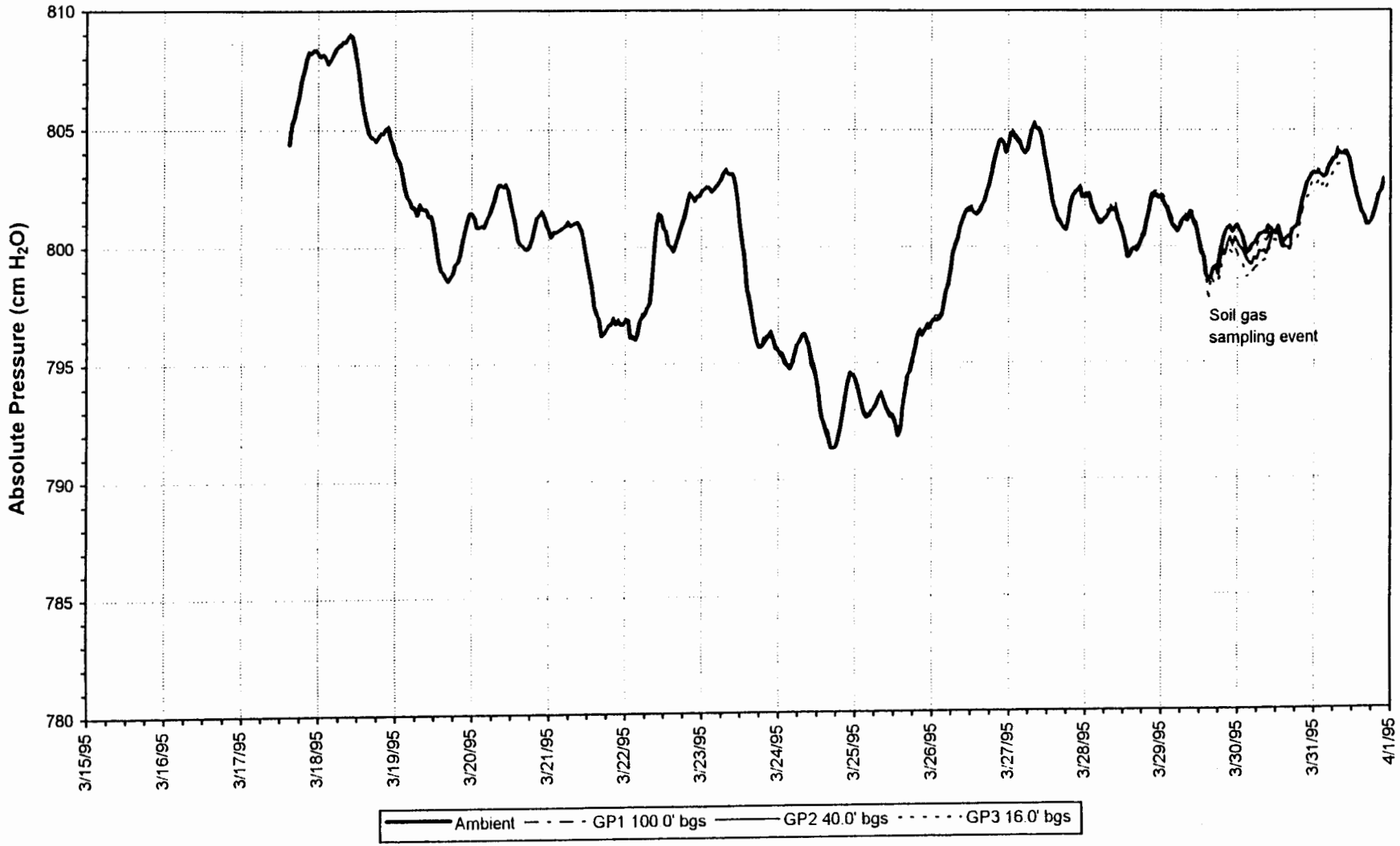
Gas pressure monitoring at the three soil gas ports in monitor well LP-7 shows virtually no pressure attenuation or lag from atmospheric pressure with depth (Figure 12). All three gas ports appear to be in excellent communication with the surface and/or with Pueblo Canyon. With the exceptions of the vacuum anomaly produced by gas sampling on March 29, no pressure differentials (ambient vs. soil gas port) greater than 1 cm water have been recorded. After soil gas sampling of the three ports in March, a persistent, relatively low pressure was noted in the monitored ports. Upon further inspection and after changing the data acquisition system to eliminate possible hardware problems, the low pressure measured appears to be the result of water accumulation within the stainless steel gas port tubing. Soil gas sampling has apparently allowed water to build up in the tubing, probably by condensation, thereby yielding an apparent vacuum equal to the length of water in the tube. While future sampling may induce the same problem, the effect on the continuous pressure monitoring data is insignificant.

As at LP-7, gas pressure measurements at monitor well LP-8 show virtually no pressure attenuation or lag (Figure 13). All of the gas ports are in good communication with the atmosphere. Pressure differentials between soil gas and the atmosphere are usually in the range of 0.2 cm water, although a few have been recorded as high as 0.8 cm.

Figure 14 shows pressure responses at three soil gas ports in monitor well LPS-2. This monitor well shows the largest pressure differentials recorded to date. Gas port GP1, at an uncorrected depth of 178 feet, shows the greatest attenuation and lag from atmospheric pressure. The maximum differential recorded was over 10 cm of water. Commonly, the differential recorded at GP1 is in the range of 4 cm. The other shallower ports, GP2 and GP4, show a roughly 2-cm differential and track each other very closely. All three ports are out of phase with the atmosphere, and GP1 is out of phase with GP2 and GP4 as well. GP3 has not been monitored continuously to date.

In conclusion, the results of the first month's monitoring of soil gas pressure suggest that barometric pressure fluctuations propagate with only slight attenuation through the vadose zone soil vapor to a depth of at least 160 feet below surface.



Note: Gas port depths are not corrected for drilling angle. LP-7 drilled at 10° from vertical.

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LP-7 Absolute Soil Gas Pressures

Figure 12

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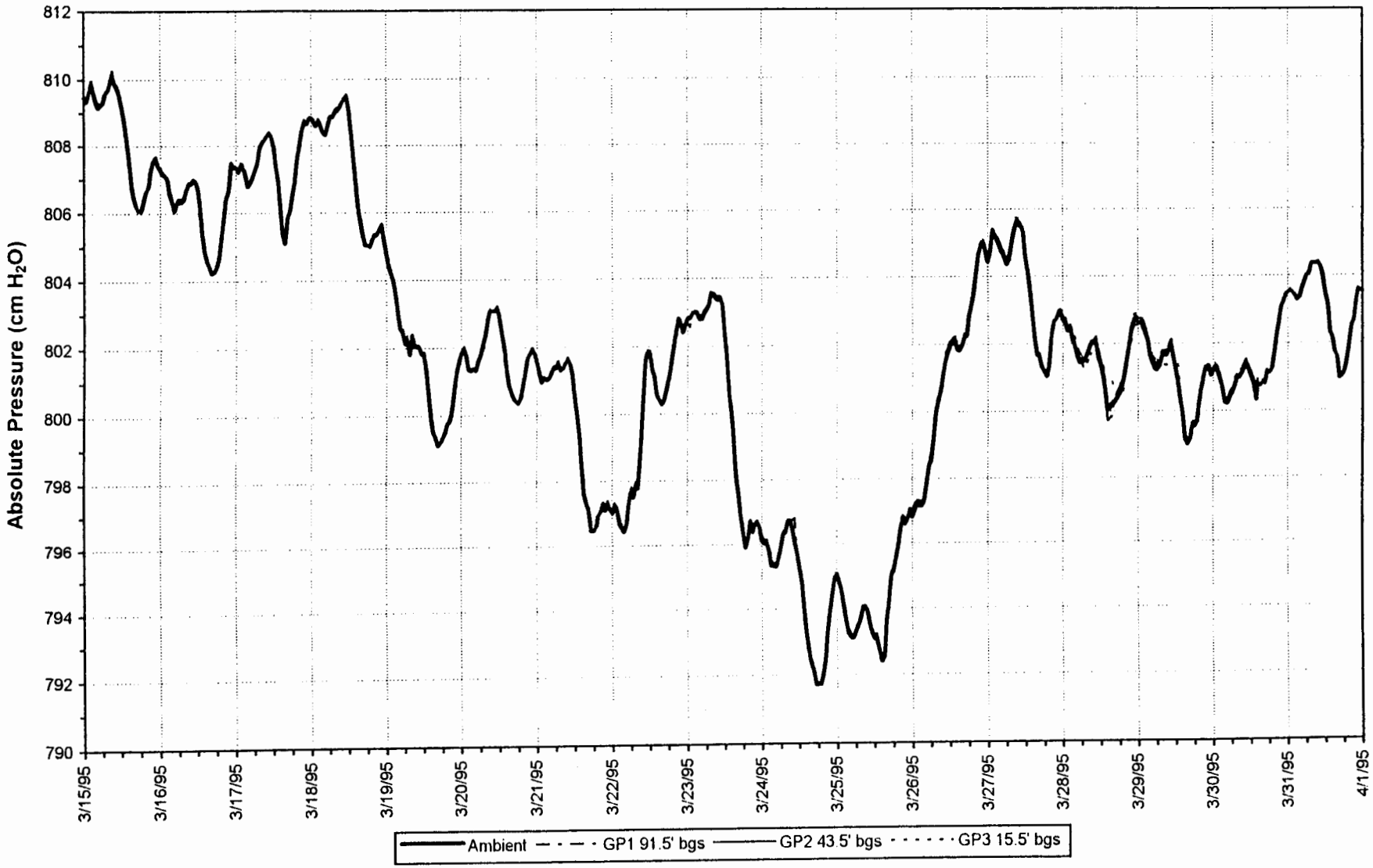

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LP-8 Absolute Soil Gas Pressures

Figure 13

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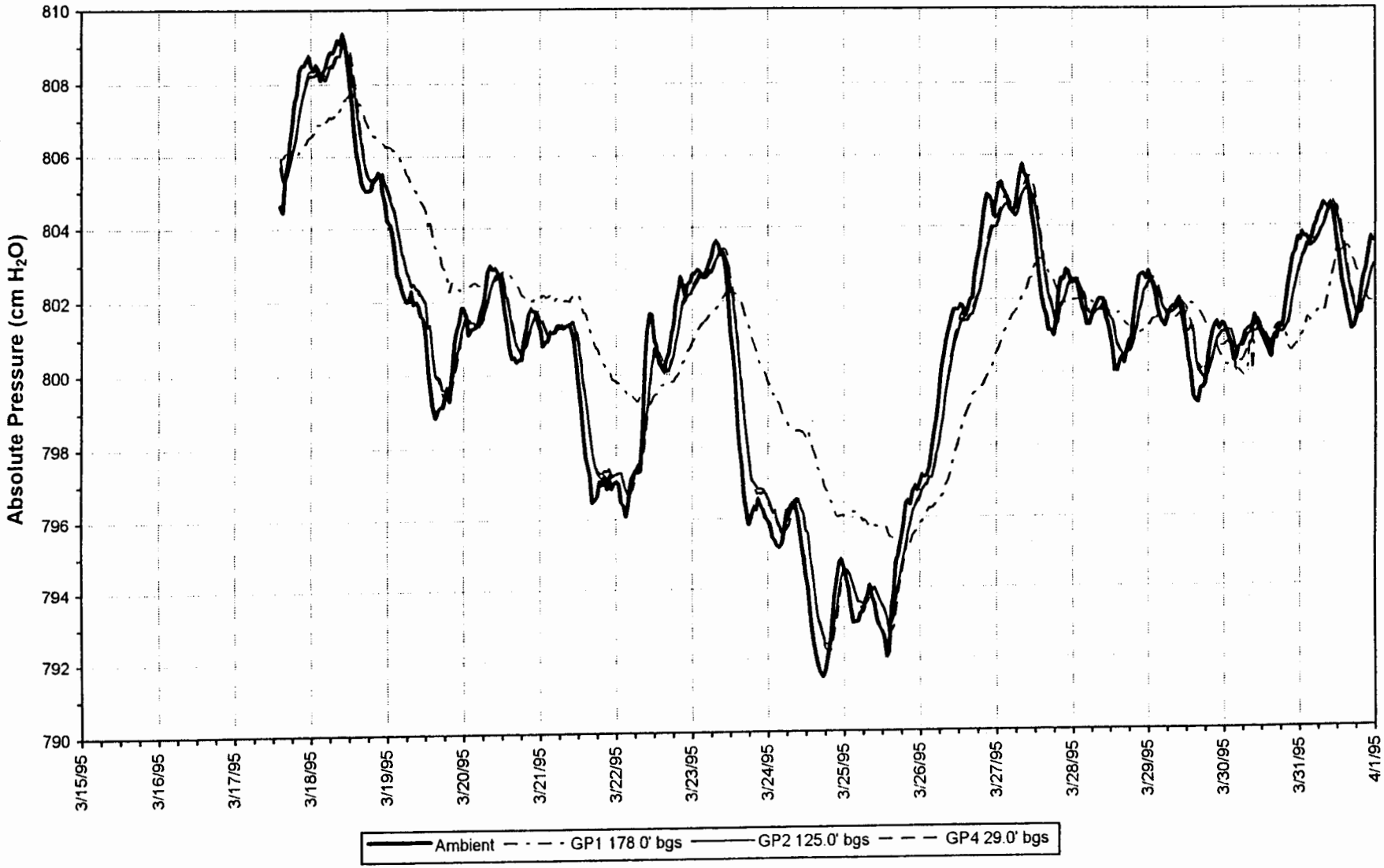

Note: Gas port depths are not corrected for drilling angle. LPS-2 drilled at 25° from vertical.

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LPS-2 Absolute Soil Gas Pressures

Figure 14

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3.3 Neutron Access Tube Monitoring Program

A neutron access tube was installed in each of the 11 boreholes to allow for periodic monitoring of relative changes in subsurface moisture content. The neutron access tubes consist of 2-inch-I.D., flush-threaded, Schedule 40 PVC (with O-ring joint seals), a threaded end-plug, and a locking expansion cap. Monitor well completions are shown on the attached well completion logs (Appendix A).

Moisture content is monitored using neutron moisture logging, a standard method used to monitor changes in moisture content at different depths in unsaturated materials. Data from these logs can provide an indication of whether the geologic materials surrounding the boreholes are losing water, gaining water, or are in a steady-state condition (i.e., losses are balanced by gains). However, these data alone cannot provide specific information regarding the direction of water movement. Matric potential data (described in Section 3.4) are necessary to predict the direction of flow.

A Campbell Pacific Nuclear (CPN) Model 503DR Hydroprobe (50 mCi americium 241/beryllium source) was used to monitor subsurface moisture content at different depths. The output, or count ratio, from the neutron moisture meter is generally linearly related to moisture content. This relationship can be determined by conducting a linear regression of moisture contents of core samples (i.e., the dependent variable) versus count ratios (i.e., the independent variable) measured at depths corresponding to core sample depths. The resulting calibration curve is dependent on a number of borehole-, backfill-, casing-, and formation-specific factors and therefore must be determined separately for different borehole, backfill, casing, and formation types.

3.3.1 Neutron Probe Monitoring Methods

Neutron count ratio measurements have been conducted in each of the monitor wells on a monthly basis beginning in January 1995. The neutron access tube monitoring protocol employed by DBS&A is as follows. Prior to mobilization to the site with the hydroprobe, LANL ESH-12 is informed as to the location and timeframe of its use at Los Alamos. Upon arrival at the first

monitoring location, a standard count is performed to verify instrument operation within the expected range. Prior to neutron count ratio measurements in a monitor well, the well head and access tube are checked for damage or accumulated moisture by lowering a dummy probe to the total depth of the access tube. Count ratio measurements will not be conducted in a damaged access tube until it has been adequately repaired. Condensation is normally swabbed from the access tube using absorbent materials.

Water accumulated in the access tubes of monitor wells LP-3 and LPS-2 in January and March 1995, respectively. In both instances, the water appears to have been the result of surface run-on flooding the well vault, allowing water to enter the neutron probe access tube. Less than 2 gallons of water was bailed from each access tube on both occasions and stored in a 55-gallon drum. Field screening instruments showed the purged water to be low in electrical conductivity (<400 µmhos/cm @ 25°C), of generally neutral pH (>6), and did not suggest the presence of VOCs. A program of ensuring and maintaining a tight seal on each of the access tubes appears to have eliminated the problem.

If the access tube is undamaged and contains no water, the neutron probe is set atop it, the probe is lowered to the desired depth, and a measurement is conducted. The measurements are conducted using a 32-second counting period at 1-foot intervals beginning at 1.5 feet bgs to the total depth of each well. The cable stop number corresponding to the measurement depth and the measured count ratio are recorded in a field notebook. Upon completion of measurements, a desiccant pack is hung in the access tube, the expansion cap is securely tightened, and the well vault is closed. After all the wells are logged, a standard count is again performed to verify instrument performance.

3.3.2 Neutron Probe Monitoring Preliminary Results

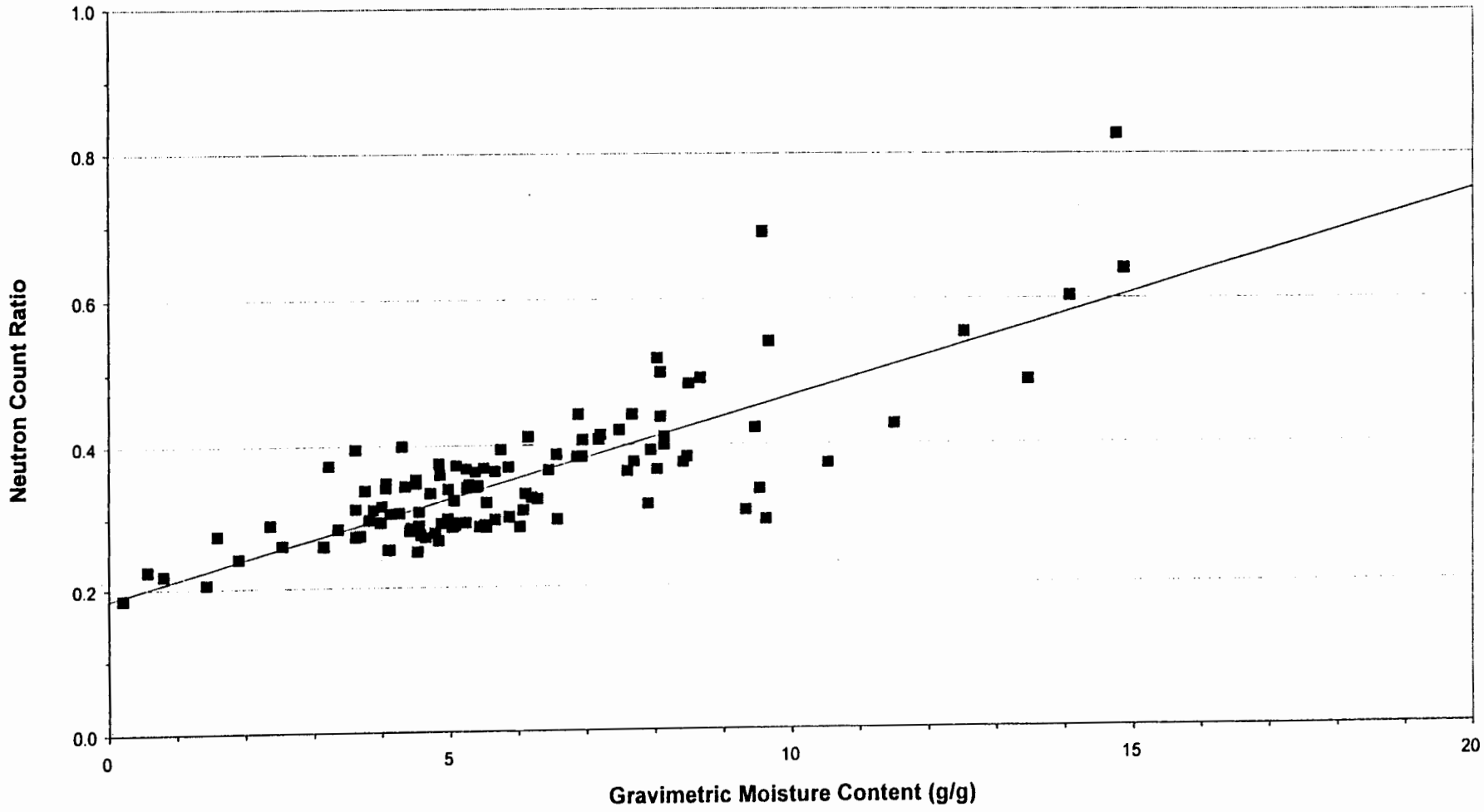
As described in Section 2, each of the 11 monitor wells installed around the TA-73 landfill perimeter was constructed to allow monitoring of relative changes in moisture content using the neutron probe. To date, the 11 monitor wells have been logged on four occasions (January, February, March, and April 1995). Graphs of neutron count ratio versus depth are presented in Appendix F. Monitor wells LP-1, LP-2, LP-3, LP-6, and LP-7 show almost no variation in count

ratio (or moisture content) since the January measurements. A slight shift since January in the logs of the remaining monitor wells may indicate that the formation moisture content increased slightly. Alternatively, the difference in logs may simply be due to measurement or instrument error. Several additional monitoring episodes will be required to determine whether this apparent trend toward increasing moisture content is real or is an artifact.

Calibration curves were developed for the sieved-tuff- and silica-sand-backfilled intervals in the 11 boreholes by correlating gravimetric moisture content values determined for core samples from these intervals with neutron probe count ratios at corresponding intervals from the January 1995 logging event (Figures 15 and 16). The gravimetric moisture content of core samples was determined at 2½-foot intervals in each borehole beginning at 2½ feet, while the count ratio measurements were conducted at 1-foot intervals in each well beginning at 1.5 feet. As a result, there is a 6-inch offset between gravimetric moisture content sample locations and neutron count ratio locations for whole number core sampling depths. Therefore, the count ratio measured 6 inches above and 6 inches below a whole number core sample depth were averaged to develop the calibration curves.

Further, it was assumed that the two-month period between monitor well installation and neutron logging was sufficient for the silica sand and sieved tuff backfill intervals to come into hydraulic equilibrium with the surrounding native tuffs and that significant changes in subsurface moisture content did not occur during the intervening time period. Count ratio measurements conducted in monitor wells LP-1 and LP-7 during November 1994 and monthly measurements since January 1995 suggest that some slight changes in moisture content occurred in the sieved tuff backfill material between November 1994 and January 1995. However, the count ratio data for both wells has shown little variation since January, suggesting that equilibrium occurred prior to that date (Appendix F).

No attempt was made to develop a calibration curve for the annular seal intervals due to the extended period of time required for the annular seals to come into equilibrium with the surrounding formation (i.e., the rate at which each annular seal is imbibing water is dependent upon the surrounding tuff moisture content and matric potential). Given the relatively low (wet) matric potentials measured in the subsurface at the landfill, once the seals have reached



Slope = 0.028
Intercept = 0.185

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Moisture Content vs. Count Ratio
Sieved Tuff Backfill Intervals

Figure 15

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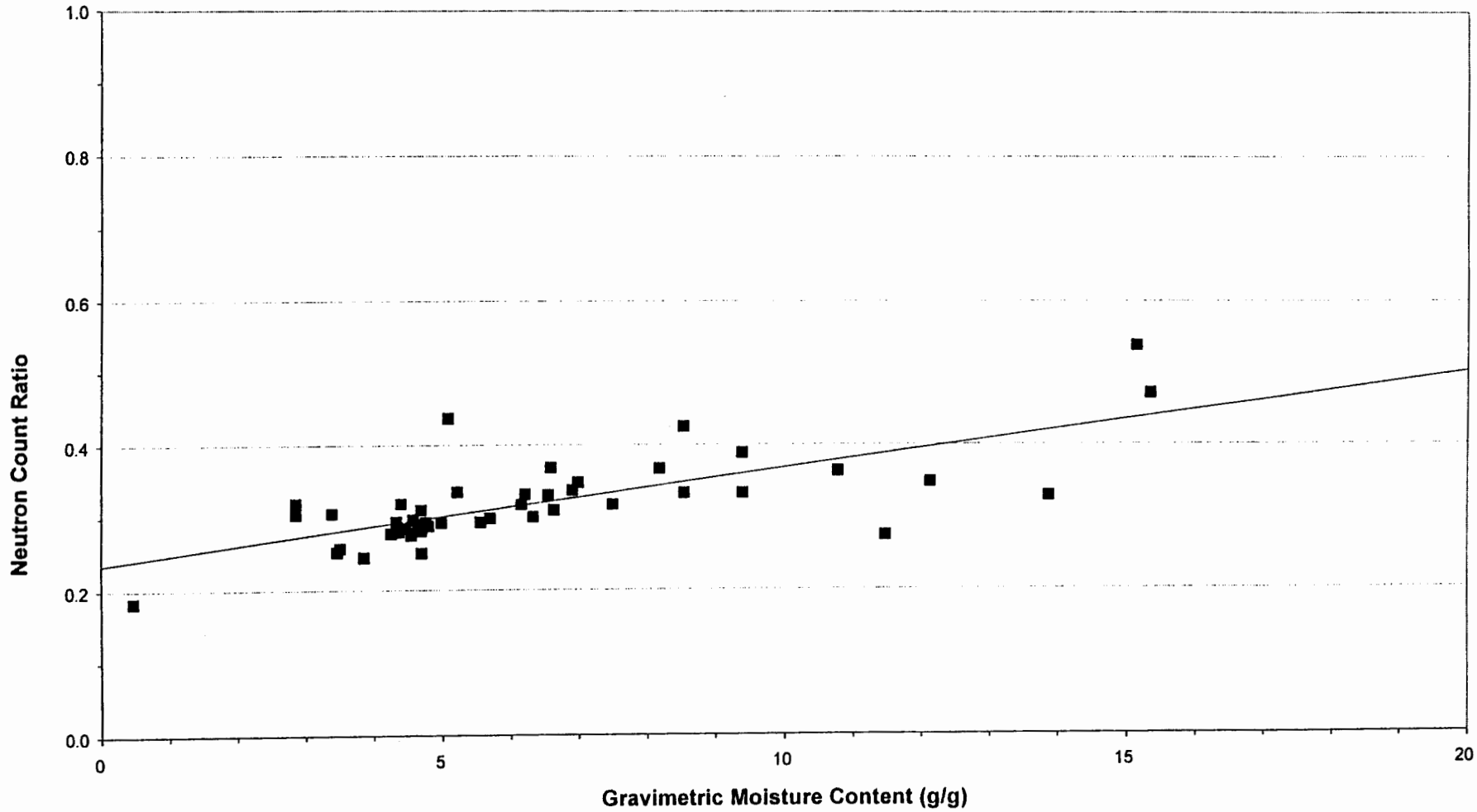

Slope = 0.013
Intercept = 0.234

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Moisture Content vs. Count Ratio
Silica Sand Backfill Intervals

Figure 16

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equilibrium, measured count ratios are expected to be quite similar for all the annular seal intervals. Therefore, little response of the annular seal count ratio to changes in the surrounding material moisture content is anticipated in the future.

Linear regression equations and graphs of the calibration curves are presented in Figures 15 and 16. The coefficient of determination (r^2) for the straight line calibration curve of the sieved tuff backfill (0.6372) is somewhat higher than that for the silica sand backfill (0.5075). This result is not surprising given the limited moisture retention response of the silica sand backfill (10-20 mesh) over the range of measured matric potential. In effect, the silica sand will remain relatively dry unless the surrounding tuff approaches saturation. Thus, count ratio measurements in the silica sand backfill intervals are relatively insensitive to changes in the moisture content of the surrounding native tuff.

The utility of each of the linear regression equations was checked by conducting zero slope tests and calculating confidence intervals on the slopes of each equation. In both cases, the zero slope tests suggested that measured count ratios contribute information to the prediction of gravimetric moisture content at the 97.5% significance level. However, calculated confidence intervals of ±15% for the silica-sand backfill slope and ±12% for the sieved-tuff backfill slope reflect the significant uncertainty of predicted gravimetric moisture content for both linear regression equations.

While there is considerable uncertainty associated with the accuracy of each field calibration, these calibration curves are repeatable. This indicates that the precision of the instrument and measurement methods are high. Therefore it is possible to monitor relative changes in formation moisture content of the sieved tuff backfill intervals over long periods of time.

3.4 Matric Potential Monitoring Program

A total of 12 HDSs were installed in 10 boreholes along the perimeter of the landfill at true depths ranging from 11 to 145 feet bgs. The HDSs were installed to monitor matric potential at suction lysimeters and in selected locations to assess boundary conditions for numerical modeling purposes. HDSs provide a means of measuring soil moisture content in situ. A current is applied

to each HDS, thereby causing heat to be generated. After discontinuing the current, the heat then dissipates into the surrounding soil. The wetter the soil, the faster the heat is dissipated. Thus, they are used to (1) assess whether sufficient moisture is present near a suction lysimeter for collection of a sample, (2) estimate in situ matric potential, and (3) estimate temporal changes in matric potential.

The HDS monitoring program consists of monthly monitoring of each heat dissipation sensor using a Campbell Scientific 21X datalogger and excitation module as described in Section 2. Sections 3.4.1 and 3.4.2 briefly describe calibration and installation methods and preliminary results for the first four months of HDS monitoring.

3.4.1 HDS Calibration, Installation, and Monitoring Methods

The HDSs were purchased from Campbell Scientific, Inc., (Logan, Utah) and calibrated in the DBS&A Hydrologic Testing Laboratory. The instruments were calibrated in a pressure plate against a series of descending matric potentials from saturation to about 5 bars. The output, or temperature differential, of these sensors is exponentially related to the matric potential of surrounding porous medium, assuming that the energy of the water in the porous sensors is in equilibrium with the surrounding porous medium. Appendix B describes the calibration procedure, the calibration equations relating each sensor's output to known matric potentials, and graphical plots of the calibration data.

In the testing laboratory, temperature differential was generally measured at each applied potential until consecutive readings agreed to approximately ±0.02°C. Such agreement results in confidence intervals on matric potential ranging from approximately ±0.05 bar at 1.0 bar applied potential to ±0.2 bar at 4 bars. In the field, however, accuracy will be affected to a greater degree by a number of factors including hysteresis, the hydraulic properties of the sensors, and the sensor to soil contact. Hysteresis describes whether the moisture content of the soil and/or sensor is increasing or decreasing. The HDSs were calibrated to decreasing matric potential and, therefore, decreasing moisture content. Further, the hydraulic properties of the sensors themselves and/or inadequate contact of the sensors with the backfill tuff may cause a time lag between the matric potential in the porous sensor as compared with the surrounding porous

medium. The accuracy may also be affected by thermal effects associated with use of the 21X datalogger. In spite of these uncertainties, the heat dissipation sensors measurements have successfully guided sampling of suction lysimeters at the site as described in Section 3.6.

To conduct a measurement, the wires from the HDS are connected to the 21X datalogger and excitation module and the measurement program is initiated. The date, time, datalogger temperature, downhole temperature, and differential temperature are recorded in a field notebook.

In addition to providing measurements of matric potential, HDSs provide measurements of in-situ temperature versus depth. Preliminary results from the HDS temperature monitoring and thermocouple monitoring are presented in Section 3.5.

3.4.2 Matric Potential Preliminary Results

Figures 17 and 18 show changes in calculated matric potential from November 1994 through May 1995 for HDSs in monitor wells LP-5 and LPS-2, respectively. In general, these two plots are characteristic of both the range of matric potential measured at the landfill at a given time and the degree of variability of matric potential through time at a given location. Measured matric potentials in boreholes located immediately adjacent to the landfill to a depth of at least 60 feet below ground surface are quite low (less than 1 bar tension) and generally invariant (±0.5 bar). The matric potential is somewhat higher (generally more than 1.5 bars tension) and considerably more variable (±1 bar) for instruments located in boreholes more removed from the landfill and for the one HDS installed at a depth greater than 60 feet bgs. HDS1 in monitor well LPS-2 is located at a depth of 145 feet bgs. Appendix G contains plots of matric potential versus time for all HDSs installed at the site.

Graphs of total head versus depth were generated to determine liquid flow patterns in the tuff around the perimeter of the landfill. For all the graphs, total head data are negative in sign given the datum elevation of 7,150 ft above mean sea level (amsl). Thus, liquid flow occurs from less negative to more negative total head. Total head is calculated as follows:

$$H = h + z$$

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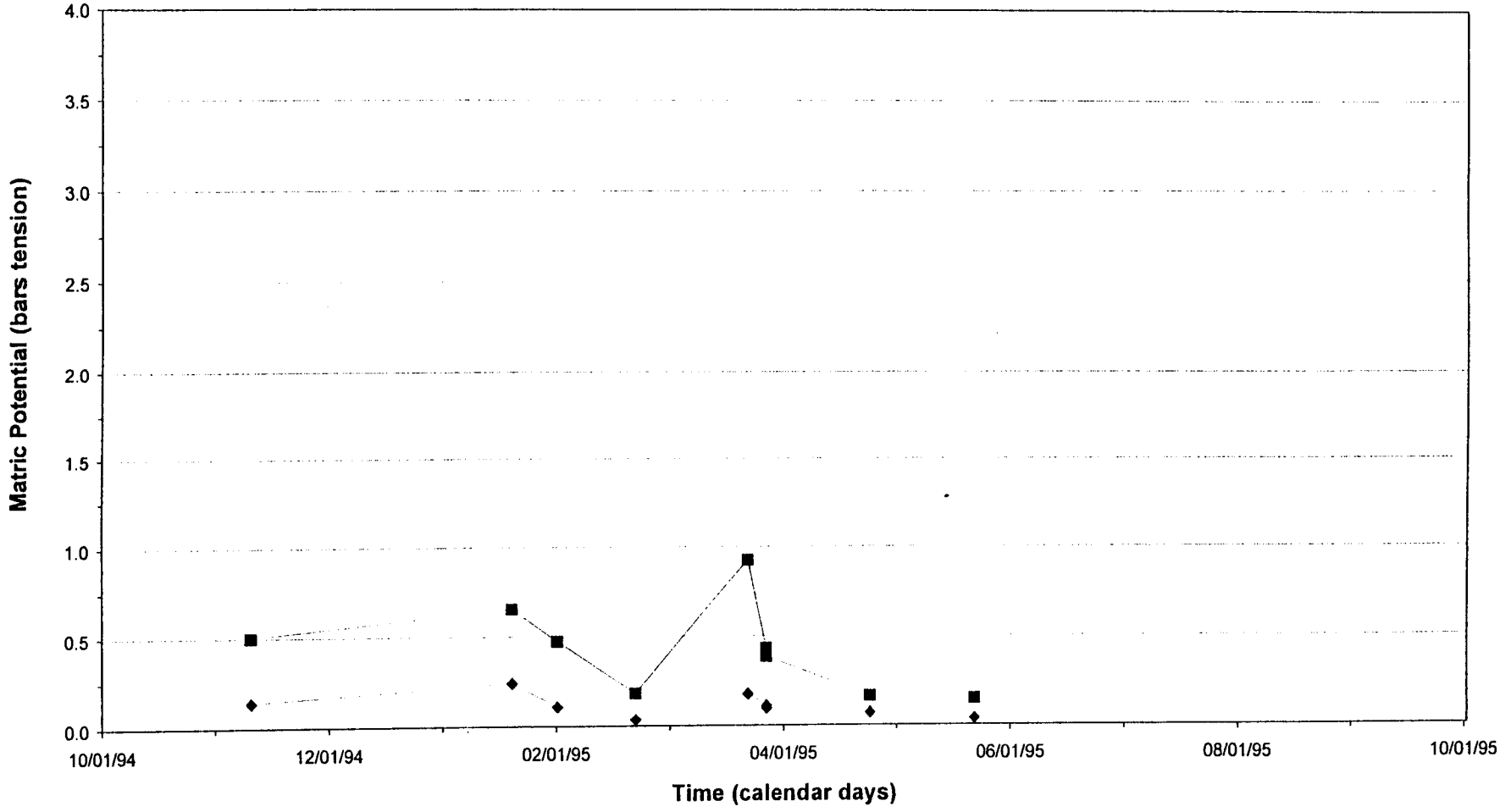

Explanation

- ■ 23 ft depth
- ◆ 11.5 ft depth

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LP-5 Matric Potential vs. Time

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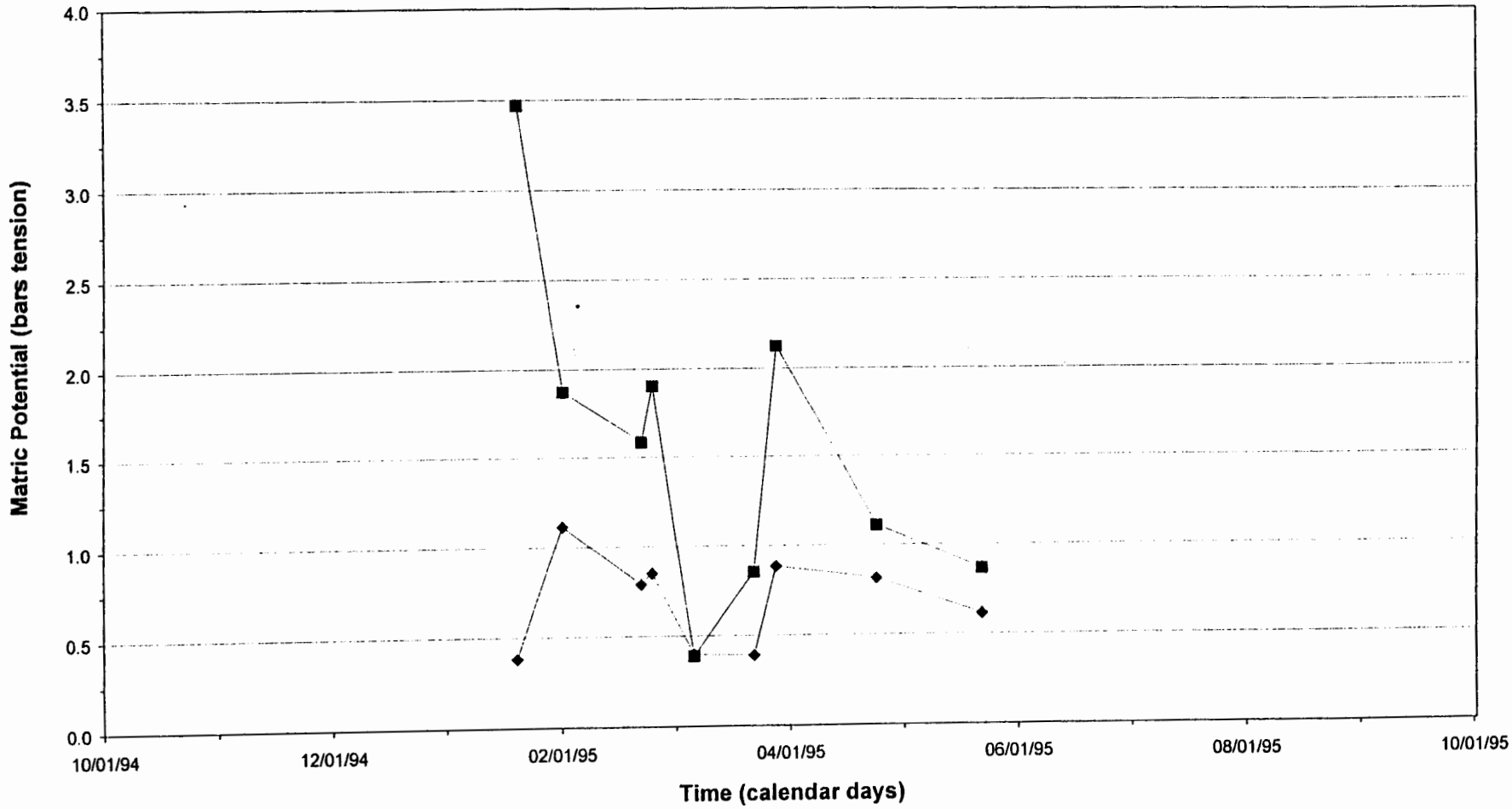
Figure 17



Explanation

- ■ 160 ft depth
- ◆ 62 ft depth

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LPS-2 Matric Potential vs. Time

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Figure 18

where H = total head or hydraulic head (length)

h = elevation head or gravitational potential (length) (datum = 7150 ft amsl)

z = matric potential (length)

Figures 19 through 21 depict total head with depth (from datum) at monitor wells LP-5, LP-7, and LPS-2, respectively, for the period from January 31 through June 28, 1995. The 0-m H_2O matric potential line represents saturated tuff matric potential with depth. These figures show measured variation in matric potential on at least a monthly basis, at each monitor well equipped with more than one HDS. The variability of matric potential through time suggests that transient downward vertical moisture movement is occurring in the tuff around the perimeter of the landfill. These data will be compared with the neutron moisture logging data presented in Section 3.3 during Phase II of this project to provide less ambiguous information regarding the direction of water movement.

Table 11 lists gradients calculated between sensors at LP-5, LP-7, and LPS-2 on a monthly basis from January through June 1995. In general, the gradients are quite variable, ranging between 1 and 2 at monitor well LP-5 and 0.5 and 1.8 at monitor well LP-7. The variability may be due to a number of factors including, but not limited to, transient moisture movement and field measurement error. As discussed earlier, no attempt has yet been made to correlate HDS

Table 11. Calculated Hydraulic Gradient at Monitor Wells LP-5, LP-7, and LPS-2

Monitor Well	Calculated Gradient[a] (dimensionless)						
	11/10/94	01/31/95	02/21-22/95	03/28-29/95	04/25/95	05/23/95	06/28/95
LP-5	2.0	2.0	1.4	1.8	1.25	1.3	1.1
LP-7	2.5	0.5	0.8	1.25	1.8	0.5	0.8
LPS-2	NA	1.3	1.3	1.5	1.1	1.1	1.2

[a] Hydraulic gradient calculated as the difference in total head between adjacent heat dissipation sensors in a monitor well, divided by the distance between them.

NA = Not available

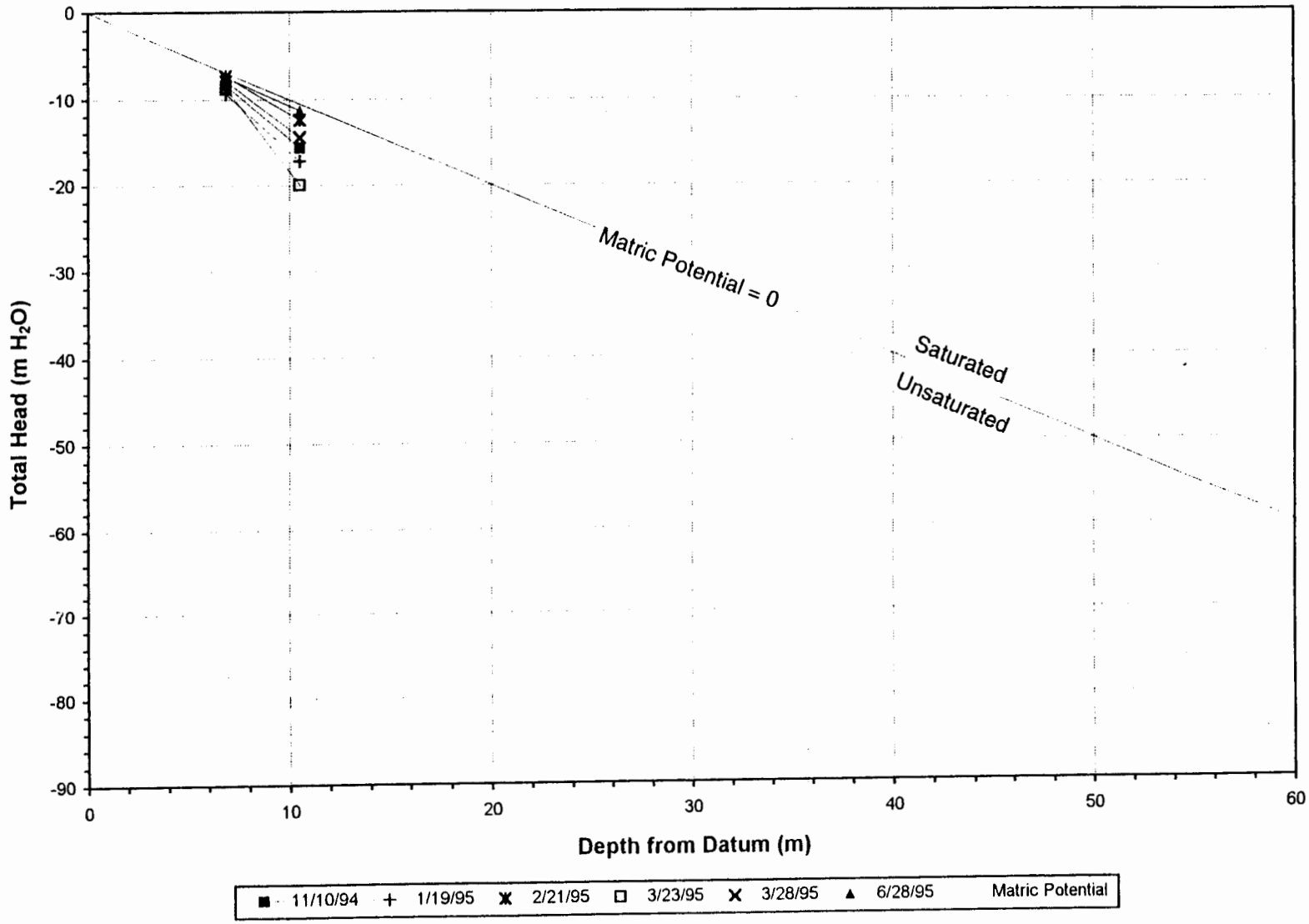

Figure 19

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LP-5 Total Head vs. Depth

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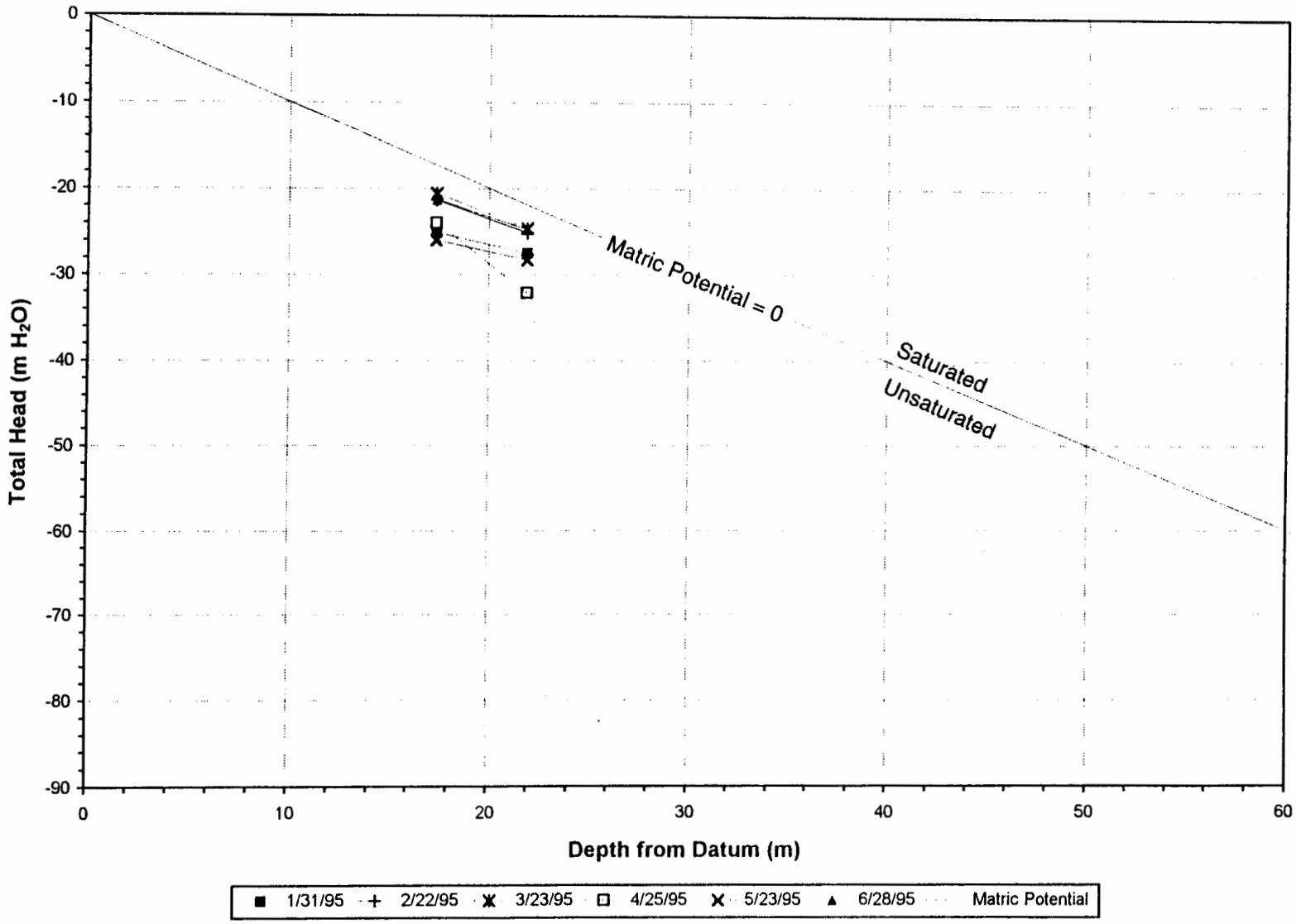

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LP-7 Total Head vs. Depth

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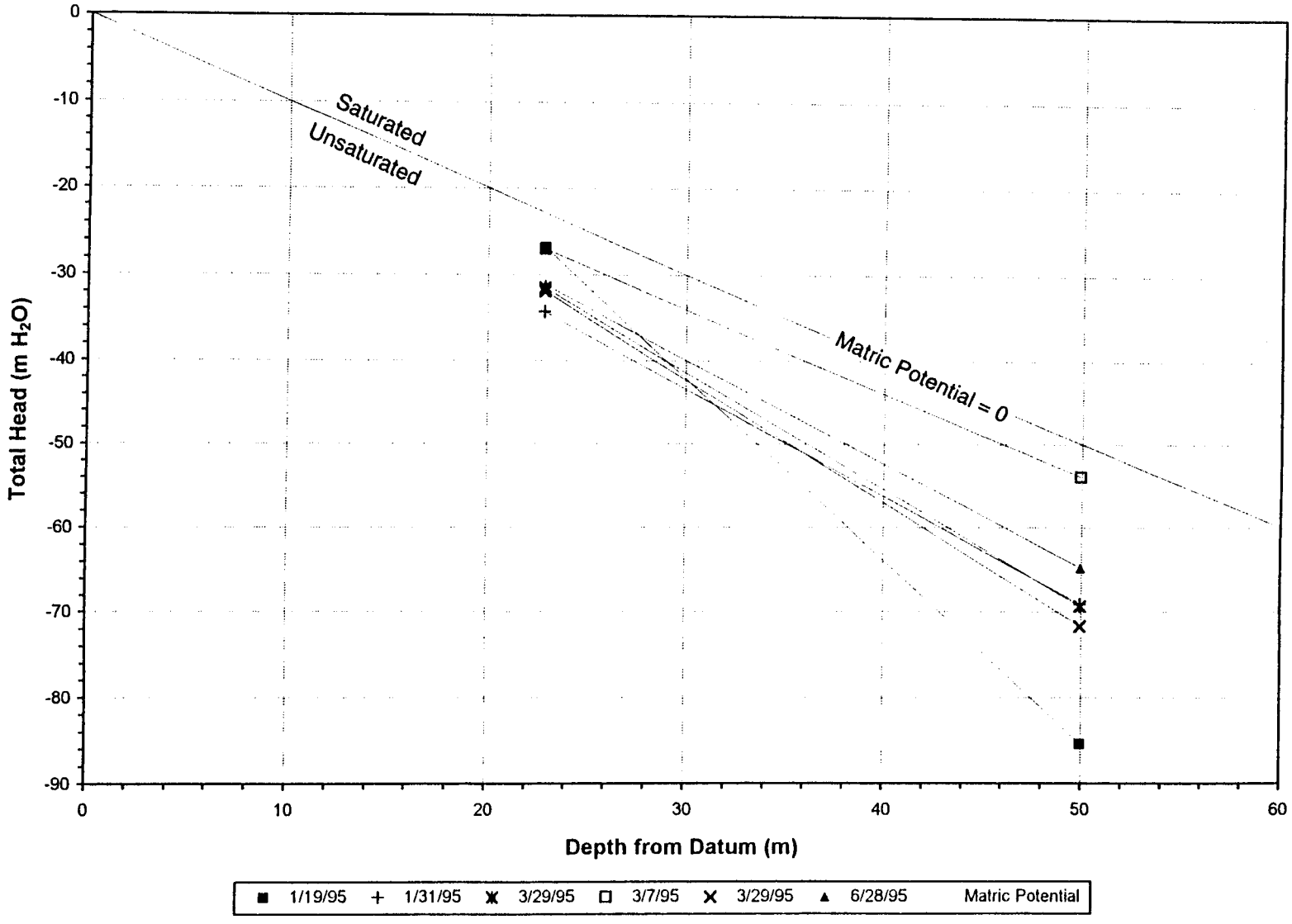
JN 4010

Figure 20



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LPS-2 Total Head vs. Depth

Figure 21

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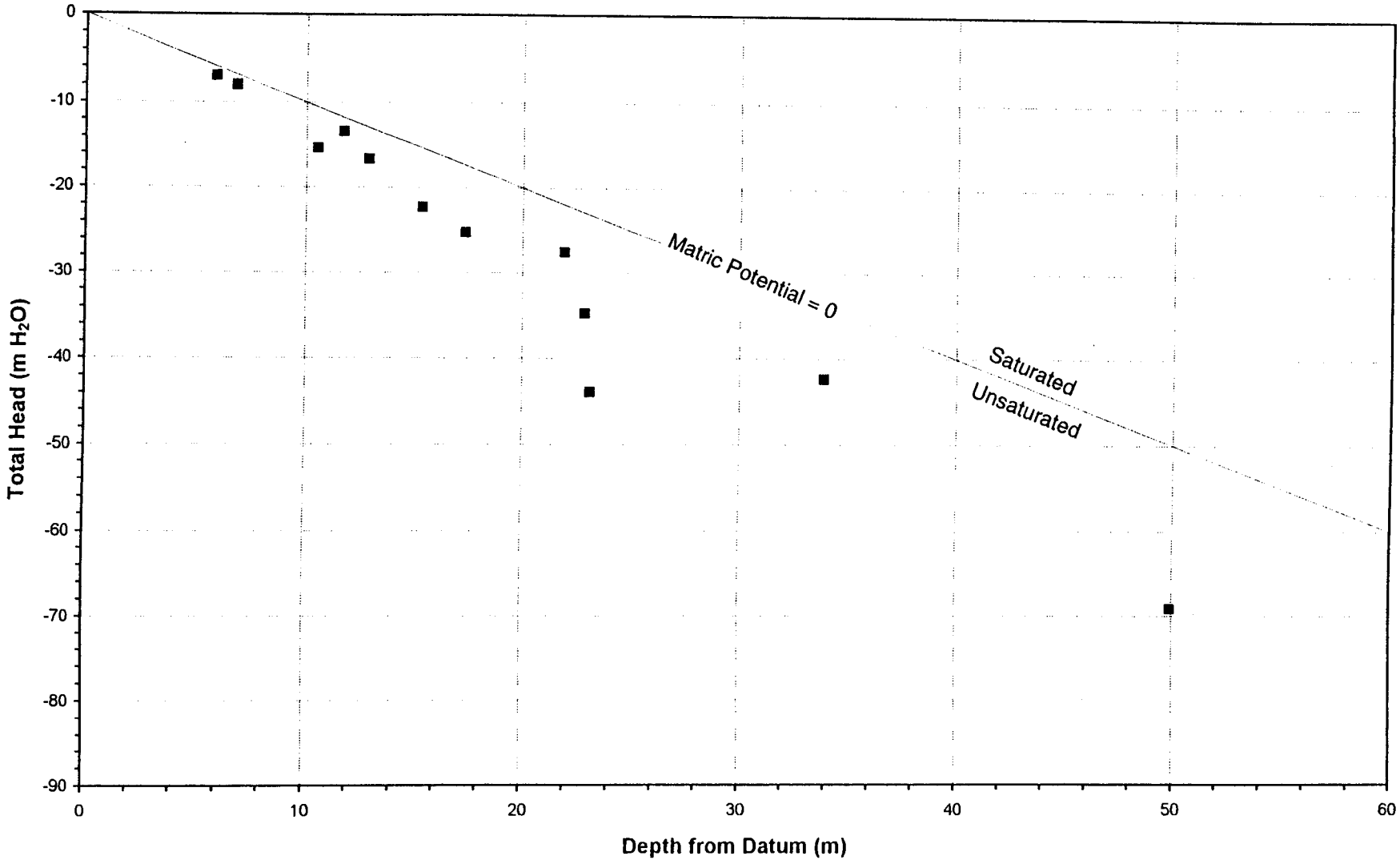
response to neutron count ratio data or, for that matter, precipitation and snowmelt events. Although it is likely that an increased frequency of HDS measurements would be needed to develop such a correlation, the correlation will be required to fully describe the direction of water movement.

Figures 22 and 23 depict total head versus depth for all HDSs on January 31 and June 28, 1995, respectively. Appendix H contains similar total head plots on a monthly basis from January through June 1995. The 0-m H_20 matric potential line is once again plotted to show saturated tuff matric potential with depth. These plots suggest that transient downward moisture movement occurring beneath the landfill and the gradient, while generally greater than 1, approaches unity on a number of occasions. The tuff beneath the perimeter of the landfill was driest in January 1995, wetted significantly during February and March 1995 and has been slowly drying since then. The gradient approaches unity from March through June 1995, suggesting that the soil moisture flux rate beneath the landfill is approximately equal to the unsaturated hydraulic conductivity of the in situ tuff. The soil moisture flux will be addressed more fully during Phase II of this project.

3.5 Soil Temperature Monitoring Program

Downhole temperatures in the volcanic tuff are being monitored at 17 thermocouples and 12 HDSs installed at the site. It is being monitored continuously at 12 thermocouples connected to the data acquisition systems at monitor wells LP-4, LP-7, LP-8, and LPS-2 and on a monthly basis at the HDSs and remaining thermocouples installed in various wells at various depths at the site.

At the monitor wells equipped with data acquisition systems, temperature is monitored continuously at the depths corresponding to the gas ports shown in Table 12. Downhole temperature at the HDSs and remaining thermocouples is measured using a portable 21X datalogger as discussed in Section 2.



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Total Head vs. Depth at TA-73 Landfill
January 31, 1995

Figure 22

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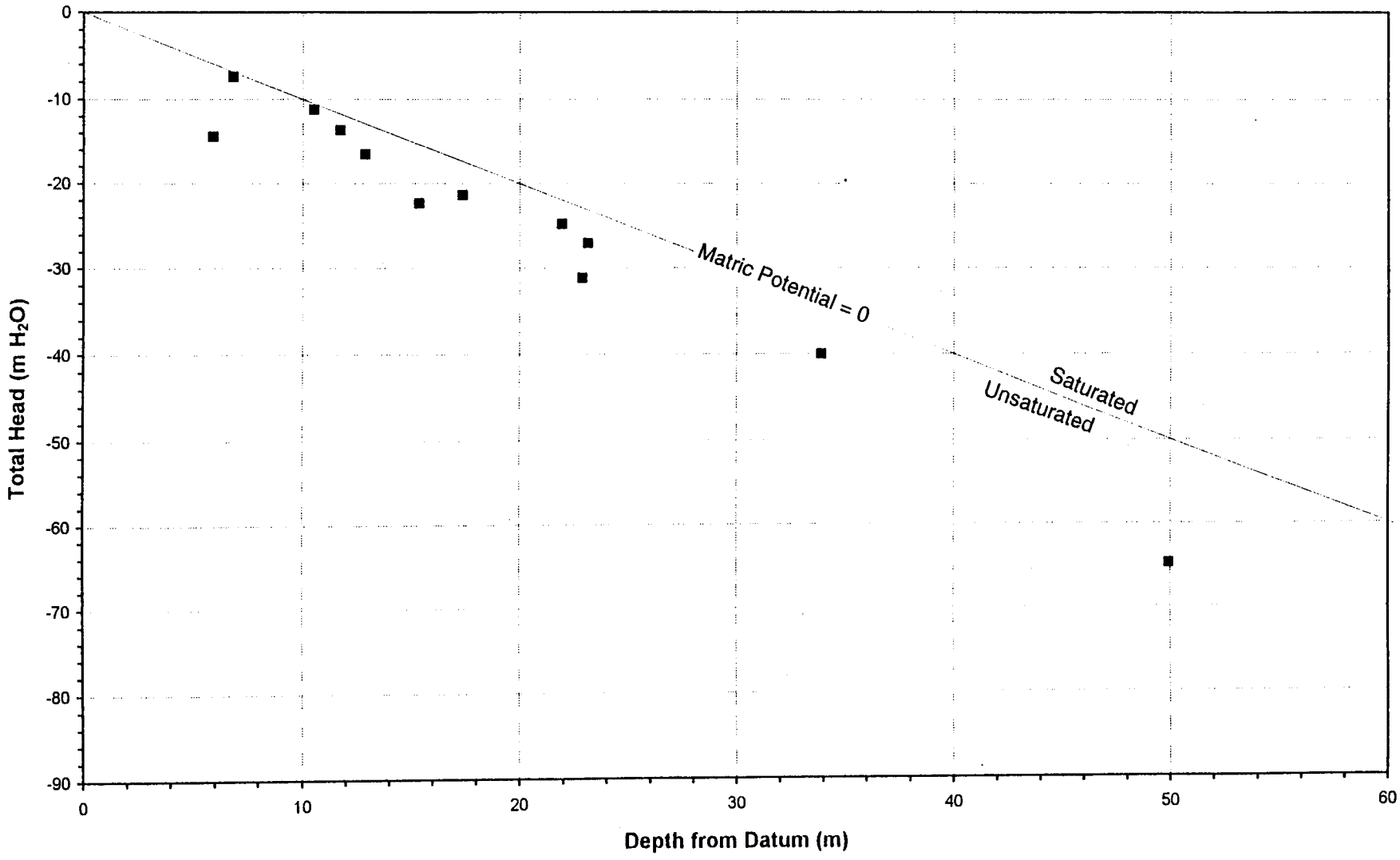

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Total Head vs. Depth at TA-73 Landfill
June 28, 1995

Figure 23

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Table 12. Monitor Well Gas Port Nominal Temperatures

Monitor Well	Soil Gas Port	Depth (ft bgs)	Nominal Temperature (°C)
LPS-2	GP1	161	17.0
	GP2	113	17.4
	GP4	26	15.8
LP-4	GP1	99.3	16.5
	GP2	75.3	16.2
	GP4	13.3	13.4
LP-7	GP1	98.5	27.1
	GP2	27.5	21.3
	GP3	16.0	19.5
LP-8	GP1	91.5	16.8
	GP2	43.5	17.6
	GP3	15.5	13.8

ft bgs = Feet below ground surface

3.5 Soil Temperature Monitoring Preliminary Results

The results of temperature monitoring are presented graphically in Figures 24 through 28. Appendix E contains graphical temperature data for the HDSs and thermocouples currently being monitored. Temperatures measured in all monitor wells, but for LP-1, LP-5 and perhaps LP-6, are significantly greater than expected given the site mean average annual temperature (approximately 10°C) and geothermal gradient (approximately 0.03°C/m).

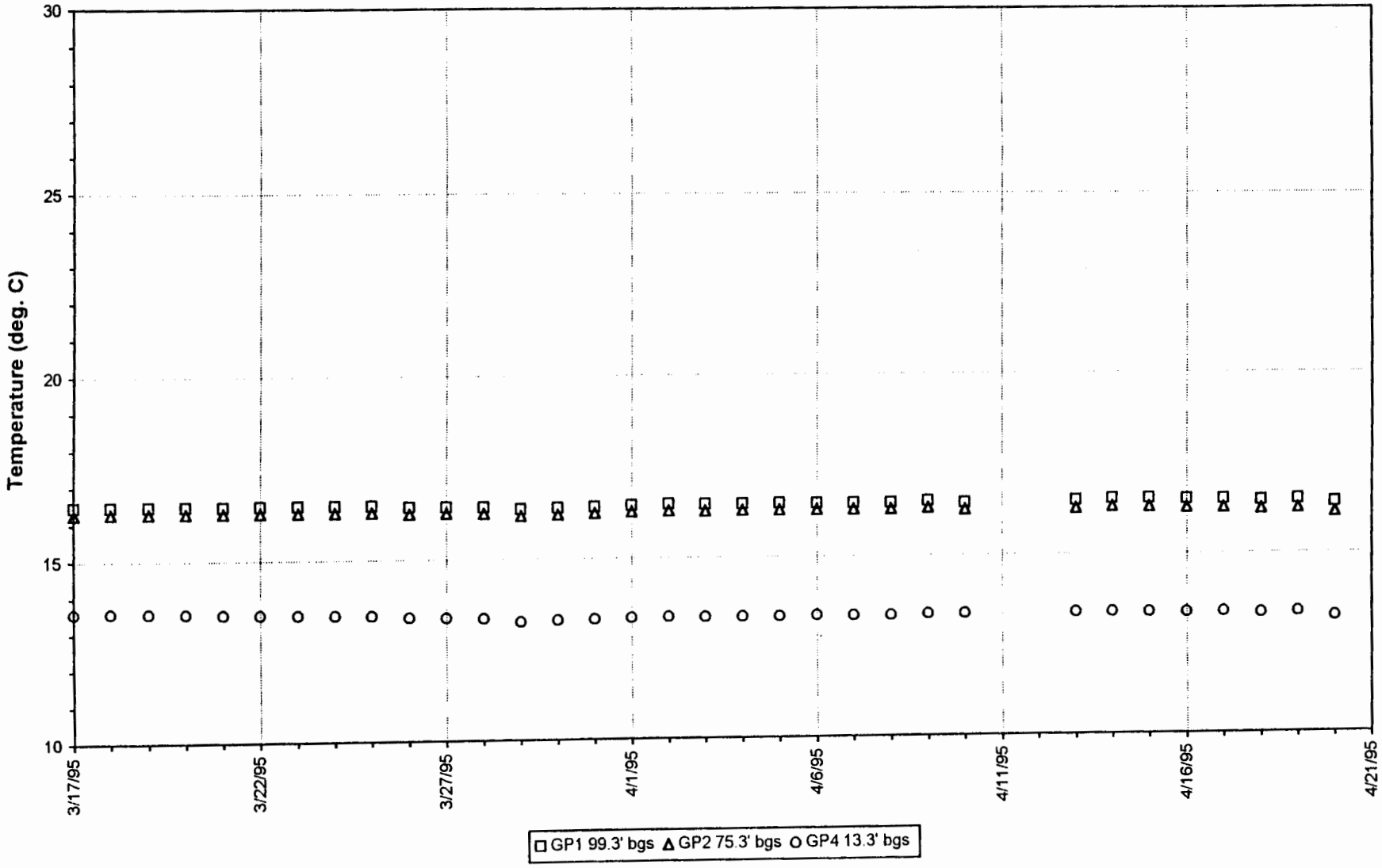
The continuous monitoring plots show daily average temperatures at different depths below surface. Large vertical temperature gradients exist in several of the wells, presumably as a result of subsurface heat generation via exothermic oxidation of biogenic methane.

Temperatures measured at depths greater than approximately 20 feet bgs appear to be relatively constant over the 6-month period of monitoring while those at shallower depths respond to seasonal changes in air temperature. Temperatures over 25°C have been measured consistently in LPS-1 and LP-7 at depths of 57 and 55 feet bgs, respectively. The lowest temperature recorded to date was approximately 10°C in LP-5 at 11 feet bgs during February 1995. Additional monitoring will be needed to fully assess temperature variability at depth through time.

Figures 29 and 30 graphically depict temperature versus depth (from datum) beneath the landfill on January 31 and June 28, 1995. It is readily apparent that a temperature anomaly exists from approximately 10 meters below datum to 50 meters below datum. Large vertical temperature gradients exist but have not yet been quantified. They will be addressed during Phase II of this project.

3.6 Suction Lysimeter Monitoring Program

As described in Section 2, seven suction lysimeters were installed around the TA-73 landfill perimeter in an attempt to collect pore liquid samples. The lysimeters were installed at true depths ranging from 11 to 56 feet bgs in areas where unusually high moisture content was observed in recovered core samples. Monitor wells containing suction lysimeters and the depth of each lysimeter are presented in Table 13.



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Downhole Temperature at LP-4 (Datalogger Results)

Figure 24

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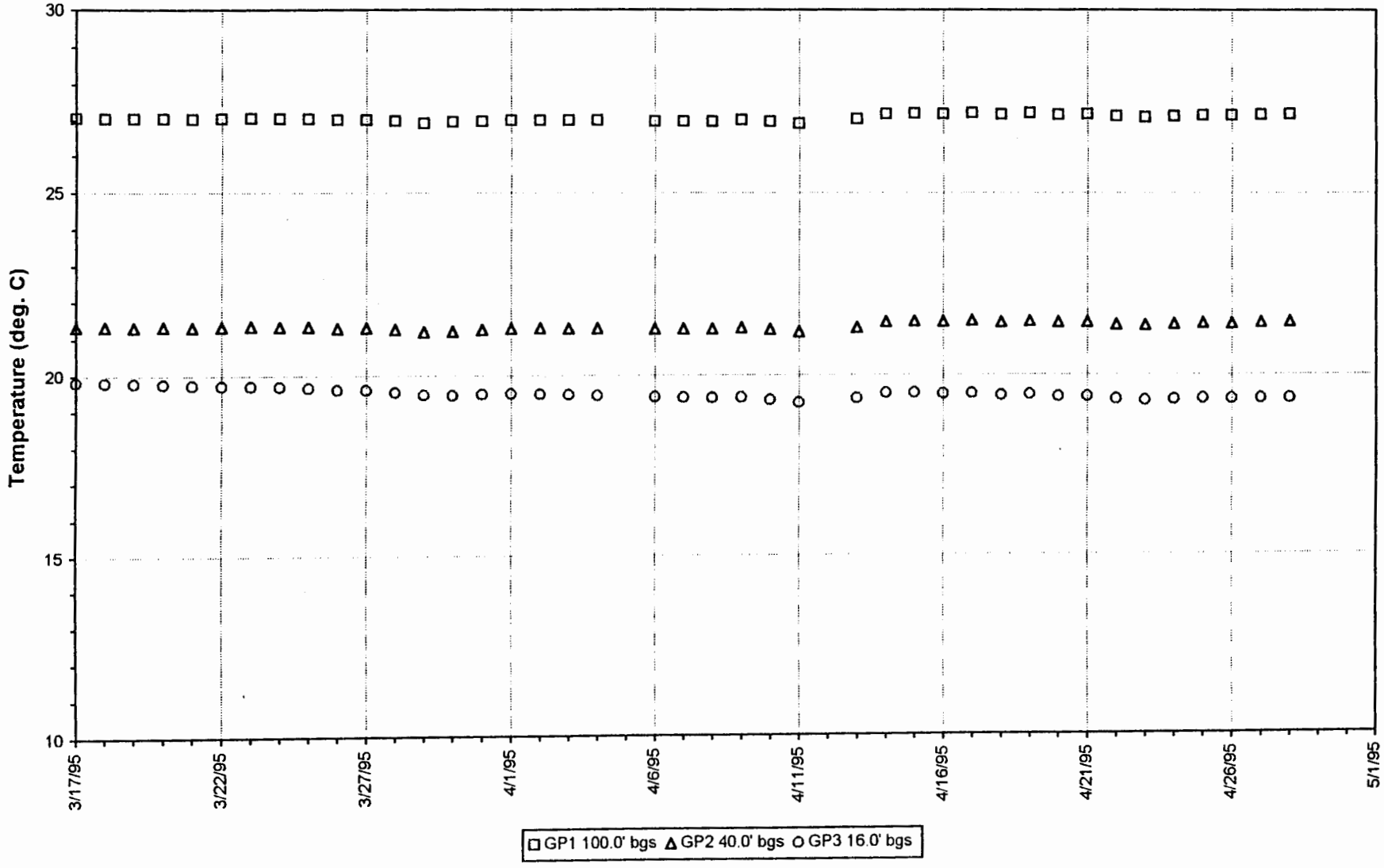

LANL RFI SUPPORT

Downhole Temperature at LP-7 (Datalogger Results)

Figure 25

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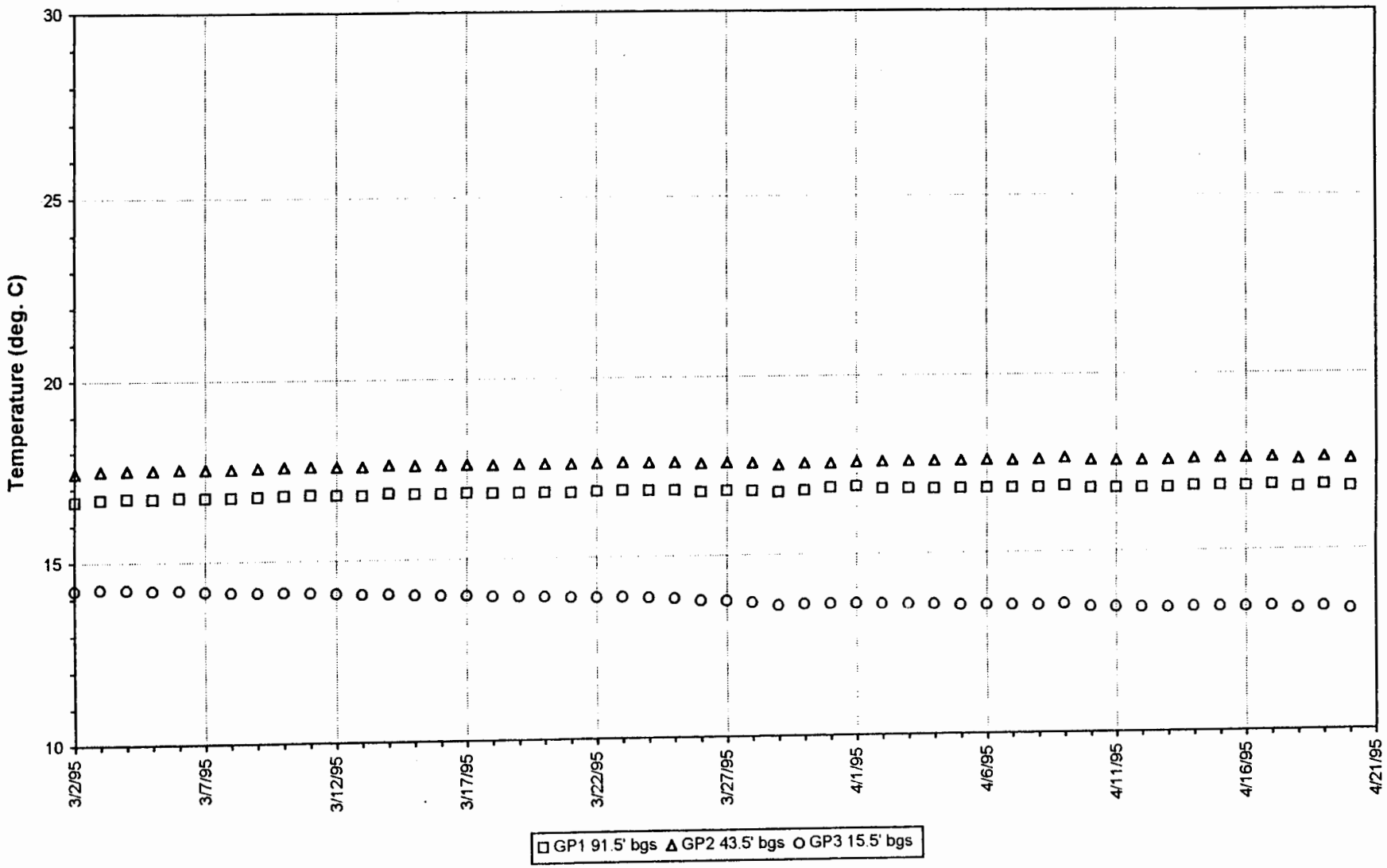

LANL RFI SUPPORT

Downhole Temperature at LP-8 (Datalogger Results)

Figure 26

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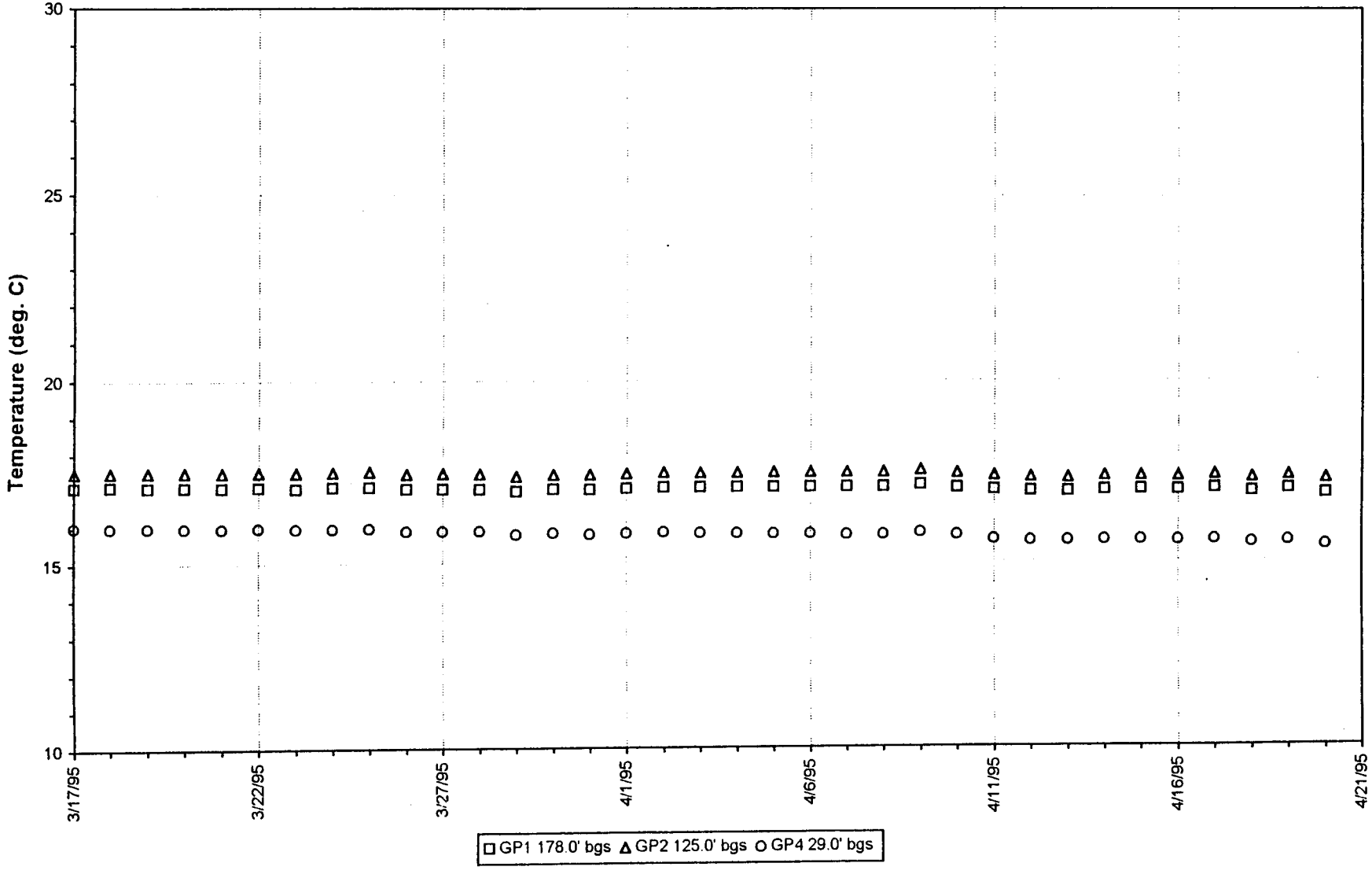

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Downhole Temperature at LPS-2 (Datalogger Results)

Figure 27

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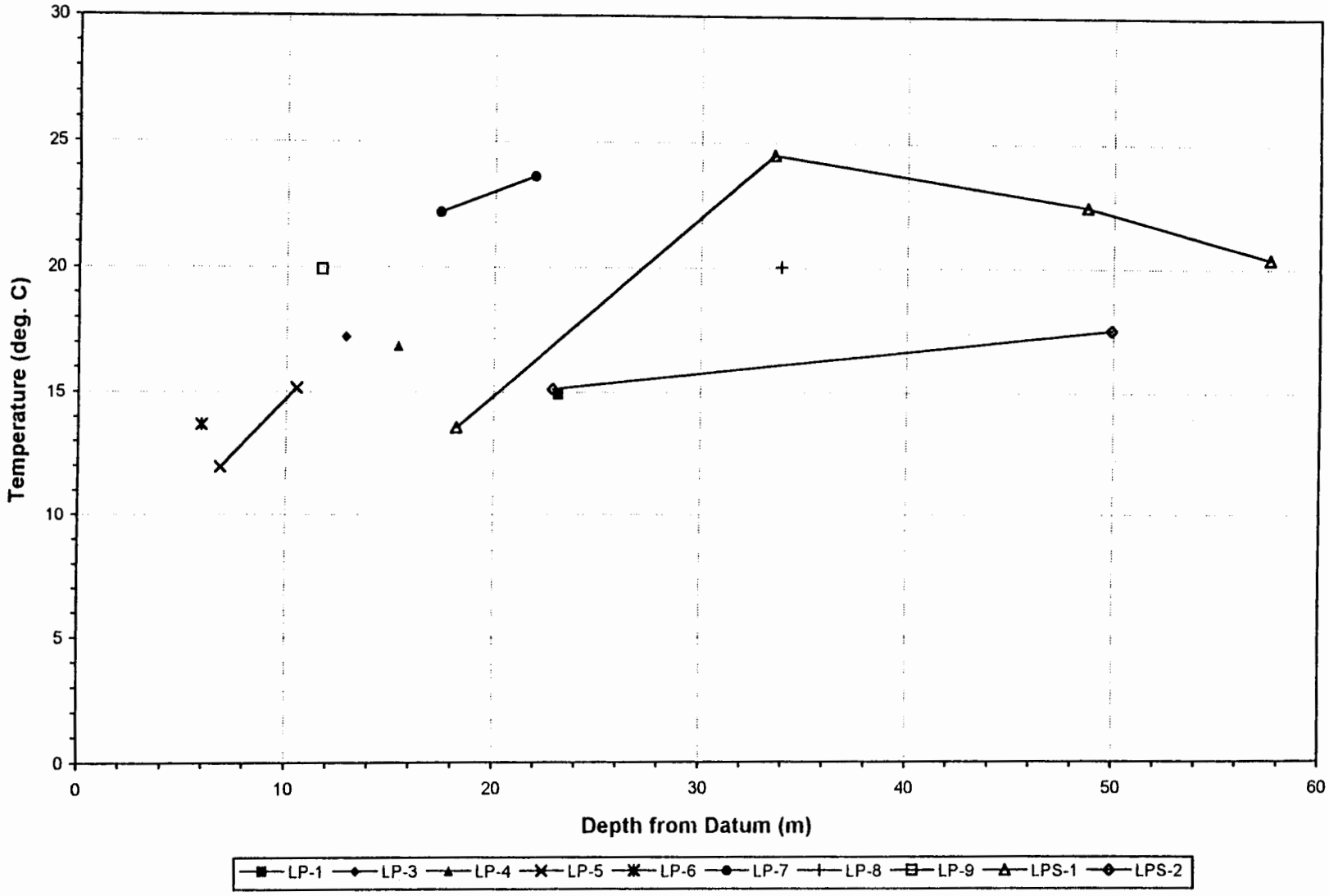

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Temperature Beneath TA-73 Landfill
January 31, 1995

Figure 28

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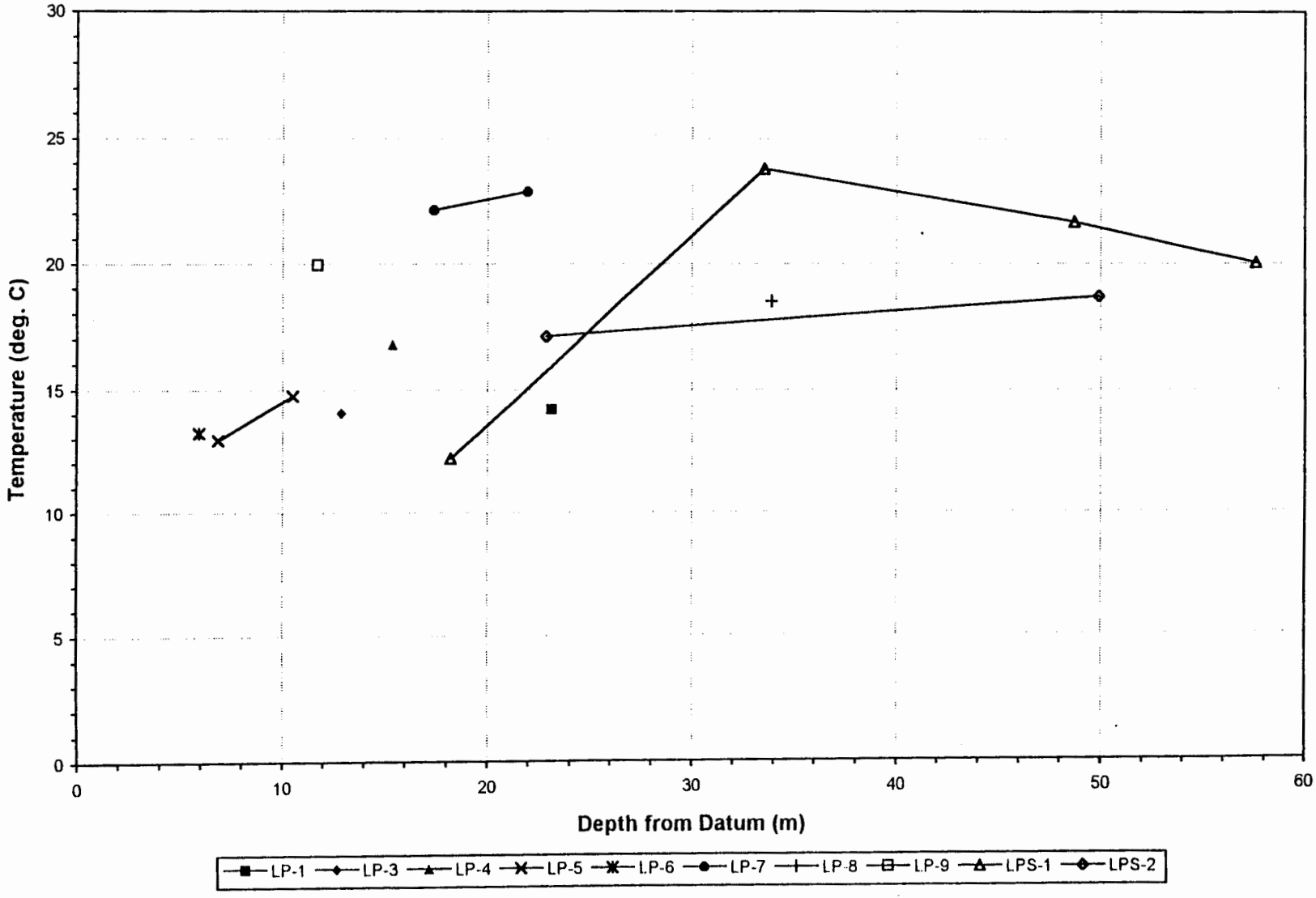

LANL RFI SUPPORT

Temperature Beneath TA-73 Landfill
April 25, 1995

Figure 29

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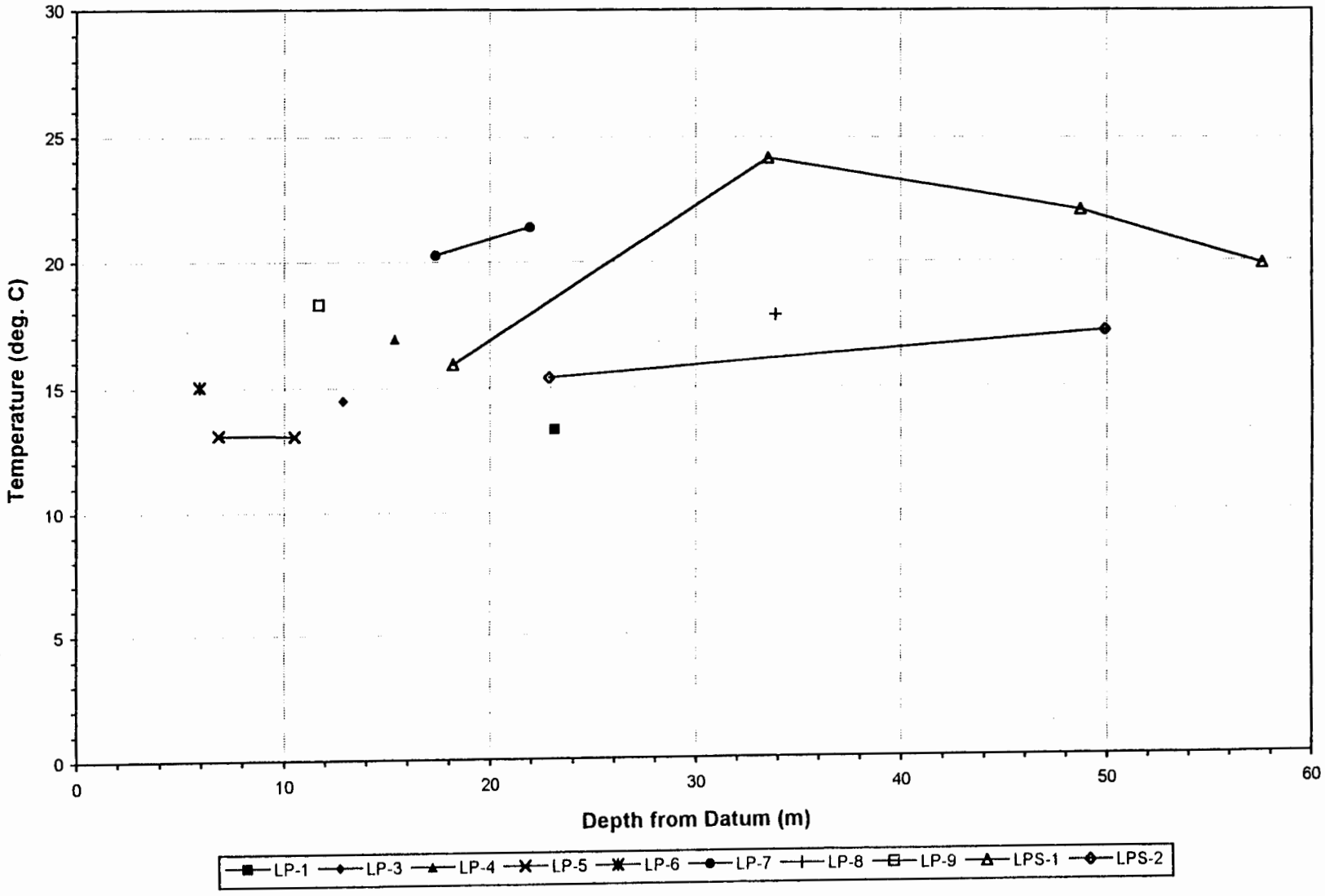

LANL RFI SUPPORT

Temperature Beneath TA-73 Landfill
June 28, 1995

Figure 30

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Table 13. Suction Lysimeter Sampling Log

Monitor Well	Suction Lysimeter Depth (ft bgs)	Approximate Purge Volume (mL)				
		February 1995	March 1995	April 1995	May 1995	Total
LP-3	20.2	0	0	NS	0	0
LP-4	34.3	0	0	40	0	40
LP-5	10.7	500	250	150	80	980
LP-6	11.0	80	0	0	NS	80
LP-7	55.0	200	40	NS	15	255
LP-9	26.0	300	300	150	200	950
LPS-2	62.0	NS	300	NS	0	300

ft bgs = Feet below ground surface
mL = Milliliters
NS = No sample collected

High pressure vacuum lysimeters containing nominal 1-bar ceramic cups were installed at the site. A pressure-vacuum tube and discharge tube extend from the lysimeter to the ground surface. The polyethylene pressure-vacuum tube is alternately used to pull soil water into the lysimeter body through the ceramic cup and to push it to the surface through the Teflon discharge line.

Sampling of the suction lysimeters is performed as follows:

- The heat dissipation sensors are monitored to determine if the field moisture conditions permit sampling of a suction lysimeter

- If the HDS monitoring indicates sufficient moisture, vacuum is applied to the lysimeter in an attempt to collect a pore liquid sample

The following sections describe the suction lysimeter monitoring program in detail, and preliminary results for the first four sampling events are provided.

3.6.1 Suction Lysimeter Cleaning, Testing, and Sampling Methods

Upon receipt from the manufacturer, the suction lysimeters were disassembled and cleaned using a hydrochloric acid solution to remove contaminants. The suction lysimeter parts were then triple rinsed with distilled water. Upon reassembly, distilled water was flushed through each of the lysimeters and a sample collected from one lysimeter for laboratory analysis of VOCs. No VOCs were detected. A copy of the laboratory analysis is included in Appendix C of this report.

After flushing, each suction lysimeter was pressure- and vacuum-tested for leaks. After leak testing, each lysimeter was placed in a separate plastic bag to prevent contamination during storage and transport to the site. Additionally, distilled water containing a conservative tracer was flushed through each suction lysimeter immediately prior to installation to remove trapped air from the porous ceramic and to serve as a final cleaning step.

Applying a vacuum to the suction lysimeter causes pore liquid to move from the surrounding soil into the porous ceramic cup. The rate at which the water sample is collected is dependent upon the matric potential of the hydraulic conductivity relationship of the surrounding soil, the soil wetness, and the magnitude of the applied vacuum. For moist soils, an applied vacuum of between 0.5 and 0.8 bar is generally sufficient to collect a sample in a few hours. Soils that are relatively dry or low hydraulic conductivity soils may require days or weeks to collect a sample of sufficient volume for analytical analysis. For soil matric potentials greater than 0.8 bar, it is unlikely that any sample will be collected.

In order to collect a pore liquid sample, a vacuum is applied to the suction lysimeter cup by connecting the pressure-vacuum line to the vacuum port of the cadet pump used in soil gas sampling. A vacuum of approximately 0.5 bars is drawn. The suction lysimeter is allowed to remain under vacuum for approximately 24 hours before attempting to collect a sample.

The pore liquid sample is collected by attaching the pressure-vacuum tube to the discharge port of a regulated compressed nitrogen cylinder, pressure is applied, and any water collected is purged through the discharge tube. The high pressure-vacuum suction lysimeters require a slow increase of pressure to 9 psi in order to lift the sample from the porous cup to the holding chamber and shut the one-way valve between cup and chamber. Then, sufficient pressure can be applied to lift the water sample to the surface. The water samples are discharged directly to clean collection bottles.

For each pore liquid sample collected, the following information is recorded on the chain-of-custody form: LANL AAA number, time, date, sample location, and requested analyses. Samples are collected for laboratory analysis based upon the liquid volume purged from the lysimeter. To date, the first 40 mL of liquid has been collected for determination of VOCs, the next 125 mL (if sufficient volume is present) for priority pollutant metals, and the remaining volume for bromide and chloride. Once VOC and priority pollutant metal concentrations are established and it is clear that the conservative tracer has been removed, attempts will be made to collect sufficient water for analysis of major ions, semivolatiles, pesticides, and radioactive constituents.

Preliminary results for the first four months of the suction lysimeter monitoring program are discussed below.

3.6.2 Suction Lysimeter Sampling Preliminary Results

Table 13 lists monitor wells that contain suction lysimeters, the depth of each lysimeter, the volume of water recovered during each sampling event from January through May 1995, and the total volume of water produced from each lysimeter. The lysimeters at monitor wells LP-5 and LP-7 have each produced a total of approximately one liter of water. Lesser total volumes have been recovered from the suction lysimeters at LP-4, LP-6, LP-7, and LPS-2. No water has been recovered from the lysimeter at monitor well LP-3 to date, although the HDS measurements suggest that sufficient liquid is present for sampling. It is likely that insufficient contact exists between the suction lysimeter and surrounding backfill tuff to collect a liquid sample. Efforts will continue to recover water from this suction lysimeter.

Table 14 presents bromide and chloride concentrations for samples collected for said analyses during February, March, April, and May 1995. Concentrations were determined by Scott J. Wightman of CST-7 by high precision ion chromatography using a DIONEX Ion Chromatograph. But for the April 1995 sample from monitor well LP-9, bromide concentrations have been less than 10 mg/L and have decreased during subsequent sampling events suggesting that dilution of the tracer is occurring. In addition, high chloride concentrations measured at monitor well LP-9 during February and April 1995 and at LP-5 in May 1995 suggest that some leachate is being collected. No other laboratory analytical data are available at this time for incorporation into this report.

Table 14. Bromide and Chloride Concentrations in Suction Lysimeter Samples

Monitor Well	Concentration (mg/L)							
	February 1995		March 1995		April 1995		May 1995	
	Br^-	Cl^-	Br^-	Cl^-	Br^-	Cl^-	Br^-	Cl^-
LP-5	3.62	19.9	0.281	13.2	1.42	56.2	0.95	250
LP-6	5.15	16.4	NS	NS	NS	NS	NS	NS
LP-7	1.55	34.5	NS	NS	NS	NS	NS	NS
LP-9	3.74	330	1.865	51.7	10.0	277	0.14	46.0
LPS-2	NS	NS	0.736	6.29	NS	NS	NS	NS

NS = No sample collected

4. CONCLUSIONS AND RECOMMENDATIONS

Based upon the preliminary monitoring results presented in this report, the following conclusions have been drawn:

- Stratigraphy adjacent to and underlying the landfill consists of Unit 2 and Unit 3 of the Tshirege member of the Bandelier Tuff. Unit 3 consists of a slightly to moderately indurated tuff that grades into a nonindurated tuff between 40 and 55 feet bgs that extends to a depth of about 95 feet bgs. Unit 2, which underlies Unit 3, consists of slightly to moderately indurated tuff that extends to at least 180 feet bgs.

- Numerous fractures were observed in the core samples of the slightly to moderately indurated tuff. In general, few fractures were observed in core samples of the nonindurated tuff.

- Anomalously high moisture contents detected at depths greater than 30 feet bgs appear to be correlated with the presence of fractures in the volcanic tuff.

- Borehole LP-4 appears to have been drilled along a fractured zone that could serve as a preferential flow path for liquids and gases.

- High concentrations of methane (up to 27 percent) and carbon dioxide (up to 30 percent) exist in soil gas surrounding the landfill perimeter as a result of anaerobic decomposition of refuse and subsequent lateral migration of landfill gas.

- Chlorinated VOCs are present in soil gas surrounding the landfill perimeter at concentrations as high as 36,000 ppbv, with the predominant compounds being, in approximate decreasing order of abundance, cis-1,2-DCE, Freon-22, vinyl chloride, and Freon-12.

- In those samples analyzed to date, soil gas concentrations of chlorinated VOCs show a strong positive correlation with methane concentrations: methane is always present in soil gas containing chlorinated VOCs.

- Preliminary results indicate that concentrations of major gases and VOCs in soil gas at a particular depth remain relatively constant over time.

- Landfill gas consisting of a mixture of carbon dioxide and methane appears to serve as a "carrier gas" for the advective transport of hazardous VOCs, and landfill gas is present to a depth of at least 160 feet, the deepest depth monitored.

- Several of the volatile compounds, such as the Freons and PCE, are primary solvents that apparently were placed directly in the landfill, while others, such as cis-1,2-DCE and vinyl chloride, are biodegradation products of the anaerobic dechlorination of parent solvent compounds such as PCE.

- VOC concentrations in soil gas generally decline with depth below the surface, with the highest concentrations observed in the uppermost soil gas port in each monitor well.

- Soil gas containing significant quantities of landfill gas is predicted to be more dense than ordinary soil air, and thus the potential exists for sinking of dense gas through the vadose zone.

- Both the diffusion (concentration) and advection (density) gradients suggest the possibility for downward migration of landfill gases containing VOCs.

- Barometric pressure fluctuations due to atmospheric tides and synoptic weather systems propagate with only slight attenuation through the vadose zone soil vapor to a depth of at least 160 bgs, suggesting that good connection exists between the landfill soil gas and the atmosphere.

- High subsurface temperatures (up to 27°C) and strong subsurface thermal gradients result from methane oxidation along the anaerobic/aerobic boundary at the perimeter of the landfill gas plume.

- Downhole moisture contents within the tuff remained relatively constant from January through March 1995 in many of the monitor wells. Exceptions include monitor wells LP-4, LP-5, LP-8, and LP-9, where slight increases in moisture content appear to have occurred during this period.

- Matric potential measurements indicate rather wet (less than 1 bar tension) and invariate (±0.5 bar) unsaturated conditions in the Bandelier Tuff in the immediate vicinity of the landfill and/or beneath asphalt paved surfaces. At depth and with increasing distance from the landfill, the tuff becomes drier (generally 1.5 bars tension or greater), and matric potentials become more variable (±1 bar). Matric potential values sitewide decreased (wetted) in response to a major snowmelt event during the last week of January 1995.

- Total hydraulic head plots indicate that unit hydraulic gradient conditions exist in the Bandelier Tuff in the area of the landfill. This condition suggests that the downward soil moisture flux rate is approximately equal to the unsaturated hydraulic conductivity of the tuff at the given matric potential.

- Pore water has been recovered from suction lysimeters installed at depths ranging from 10 to 55 feet bgs. Laboratory results for these samples were not yet available for incorporation in this report.

The above conclusions suggest that further monitoring, field investigations, and closure of the landfill under RCRA (40 CFR Part 264 or Part 265) may be required. To direct these investigations, we offer the following recommendations.

- In order to better characterize the variability of gas-phase contaminant concentrations and the driving forces for liquid- and gas-phase flow, we recommend continued monitoring of the vadose zone instruments, but on a reduced schedule, as follows:

- Reduce the soil gas sampling frequency for laboratory analyses from monthly to quarterly sampling of each soil gas port. However, each soil gas port should be purged on a monthly basis to verify that the major landfill gas concentrations have not changed significantly.

- Conduct neutron access tube monitoring on a quarterly basis instead of monthly, but allow for a higher frequency of neutron access tube and heat dissipation sensor monitoring during snowmelt and summer thunderstorms. The quarterly monitoring will be used to track long-term changes in subsurface moisture content, and the higher-frequency monitoring will be used to assess transient vertical downward moisture movement in response to high-intensity infiltration events.

- Continue monthly monitoring of the heat dissipation sensors to assess changes in the primary driving force for liquid movement (matric potential) and to determine whether sufficient liquid is present for sampling of the suction lysimeters. Sample the suction lysimeters as needed to fully characterize vadose zone water quality.

- Continue to maintain and operate the continuous monitoring system for downhole soil gas pressure and downhole temperature. Conduct spectral analysis of the downhole soil gas pressure data to estimate air permeability of the Bandelier Tuff.

• In order to better characterize maximum gas-phase contaminant concentrations and leachate characteristics for numerical modeling, risk assessment, and design of a landfill cover, we also recommend that the proposed cone penetrometer survey and soil gas flux chamber sampling plans be implemented.

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APPENDIX A

WELL LOGS

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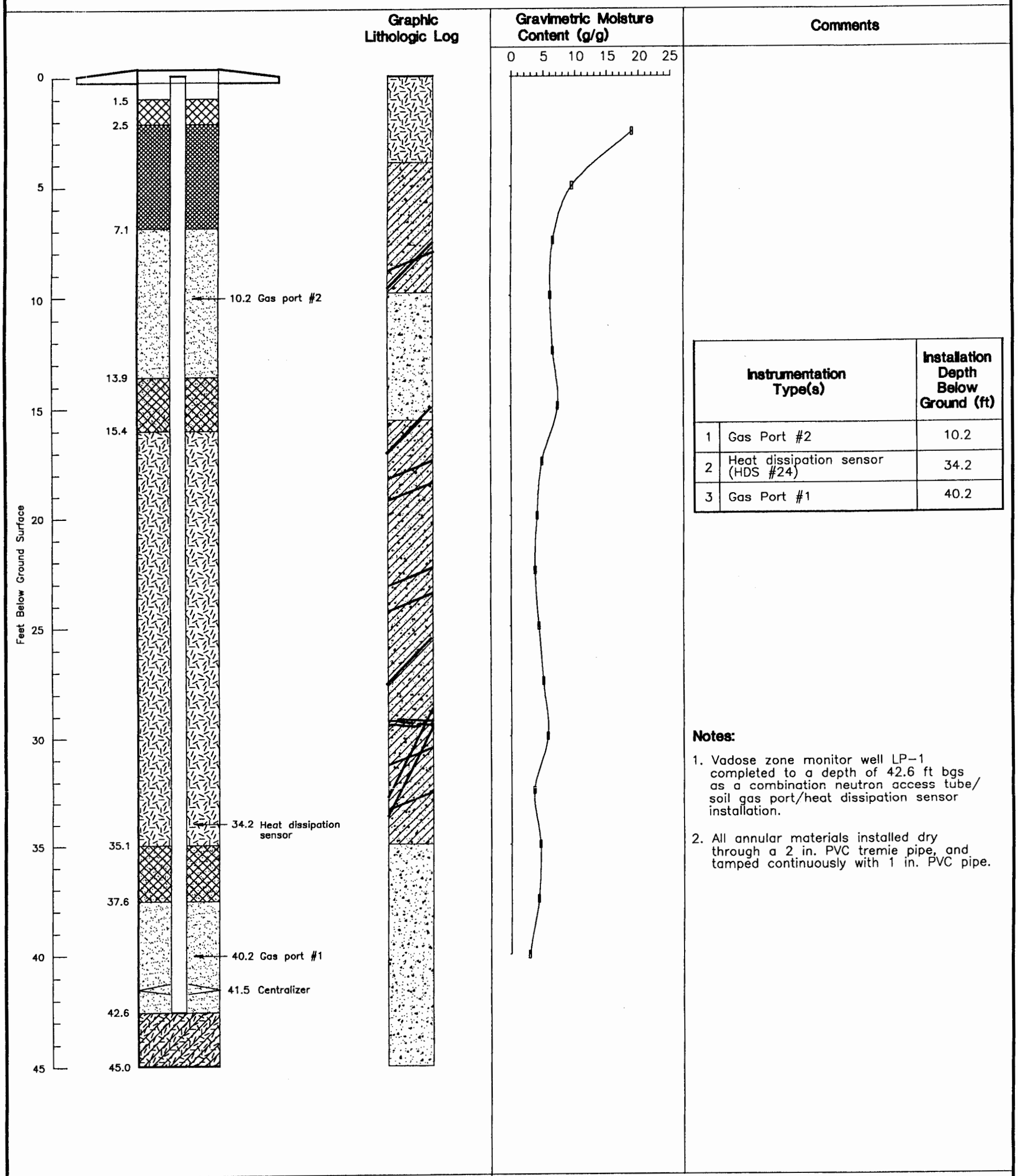

	Instrumentation Type(s)	Installation Depth Below Ground (ft)
1	Gas Port #2	10.2
2	Heat dissipation sensor (HDS #24)	34.2
3	Gas Port #1	40.2

Notes:

1. Vadose zone monitor well LP-1 completed to a depth of 42.6 ft bgs as a combination neutron access tube/ soil gas port/heat dissipation sensor installation.
2. All annular materials installed dry through a 2 in. PVC tremie pipe, and tamped continuously with 1 in. PVC pipe.

Well Construction Symbols

- Bentonite pellets
- 50/50 bentonite and sand
- Bentonite powder (dry)
- 10-20 silica sand
- Slough
- Sieved tuff

Graphic Log Symbols

- Backfill
- Poorly indurated, non-welded tuff
- Partly welded tuff
- Welded, strongly indurated tuff
- Fracture or fault
- Fracture

Hydrologist: KCM, JRF, RSP
Driller: Jim Hale, Layne Environmental Services
Date completed: 10-19-94
Drilling method: Hollow Stem Auger, CME 750
Total borehole depth: 45.0 ft
Borehole diameter: 8-1/4 in.

Sampler Type: 2.5 ft core barrel
Casing diameter: 2.0 in. I.D., 2.4 in. O.D.
Casing length: 42.6 ft
Casing type: SCH 40 PVC, flush threaded
Casing height from ground: flush with grade
Formation of completion: Tshirege Member, Bandelier Tuff

LANL RFI SUPPORT OU-1071, TA-73

Well Log: LP-1

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12-94
JN 4010

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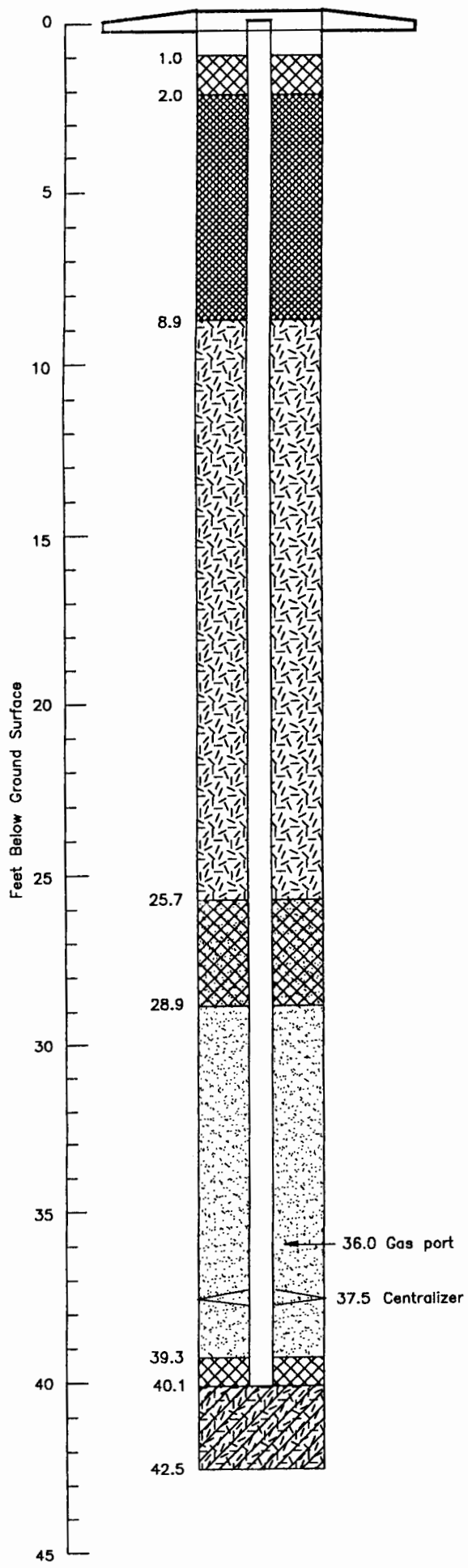
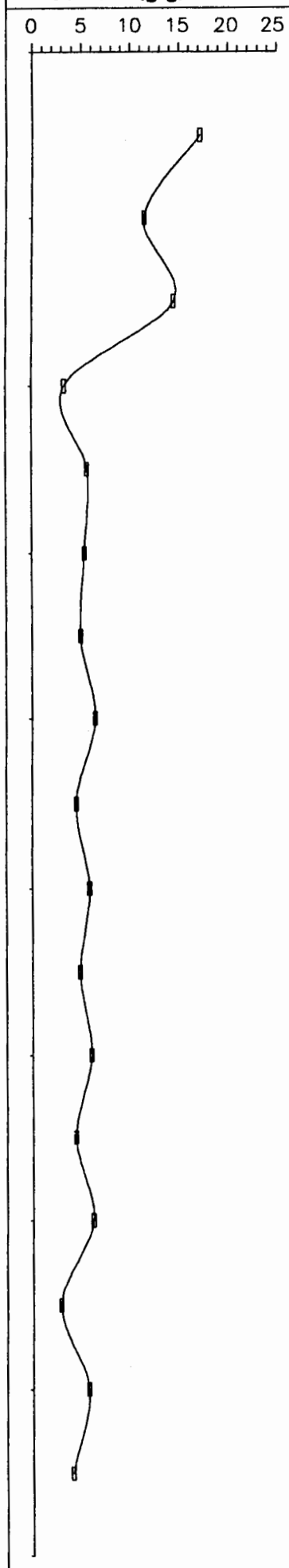


Graphic Lithologic Log

Gravimetric Moisture Content (g/g)



Comments

	Instrumentation Type(s)	Installation Depth Below Ground (ft)
1	Gas Port	35.9

Notes:

1. Vadose zone monitor well LP-2 completed to a depth of 39.3 ft bgs as a combination neutron access tube/ soil gas installation.
2. All backfill materials were emplaced by tremie pipe.

Well Construction Symbols

- Bentonite pellets
- 50/50 bentonite and sand
- Bentonite powder (dry)
- 10-20 silica sand
- Slough
- Sieved tuff

Graphic Log Symbols

- Backfill
- Poorly indurated, non-welded tuff
- Partly welded tuff
- Welded, strongly indurated tuff
- Fracture or fault

Hydrologist: KCM, RSP
Driller: Jim Hale, Layne Environmental Services
Date completed: 10-23-94
Drilling method: Hollow Stem Auger, CME 750
Total borehole depth: 42.5 ft
Borehole diameter: 8-1/4 in.

Sampler Type: 2.5 ft core barrel
Casing diameter: 2.0 in. I.D., 2.4 in. O.D.
Casing length: 39.3 ft
Casing type: SCH 40 PVC, flush threaded
Casing height from ground: flush with grade
Formation of completion: Tshirege Member, Bandelier Tuff

LANL RFI SUPPORT OU-1071, TA-73

Well Log: LP-2

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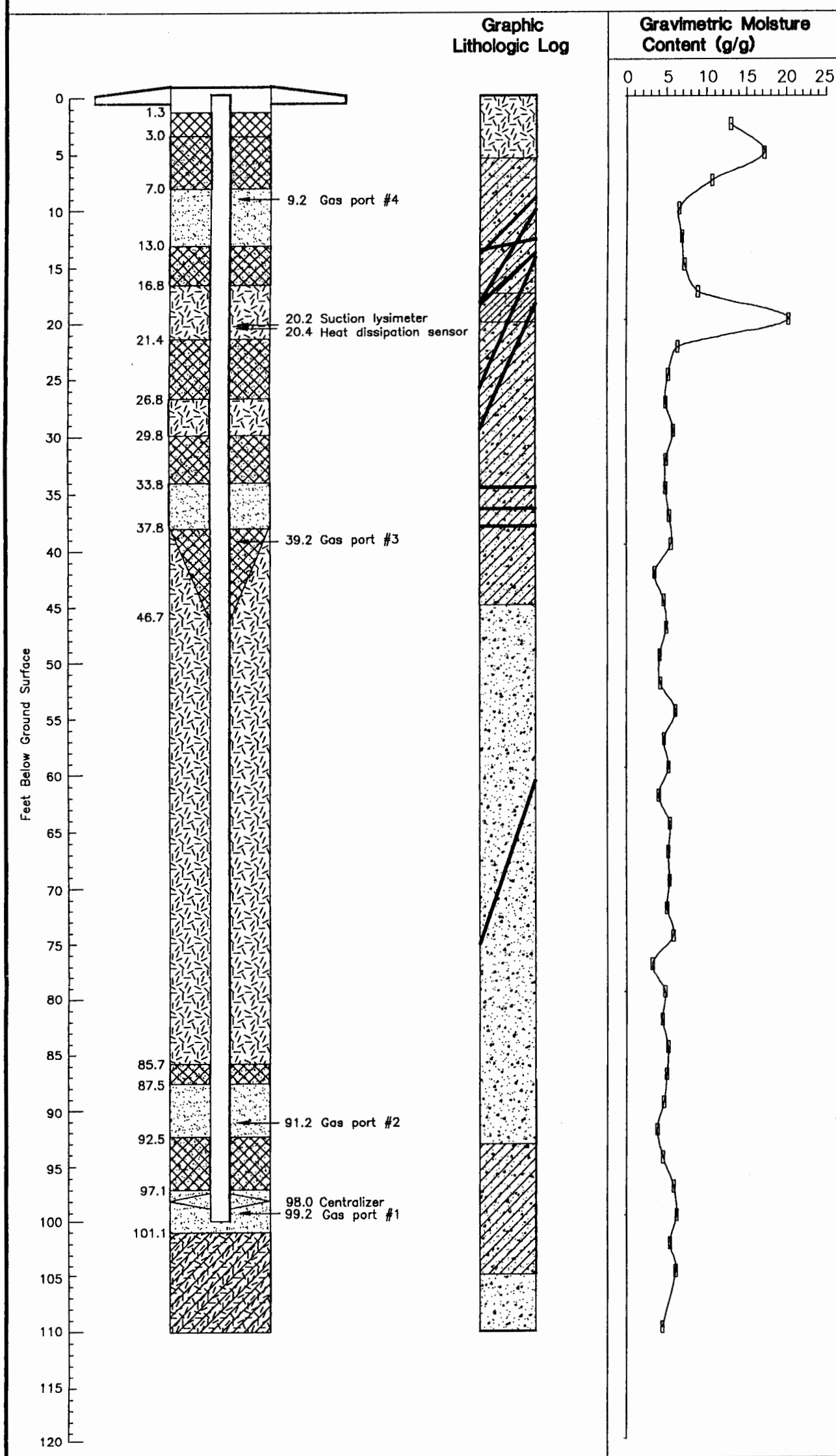


Comments

	Instrumentation Type(s)	Installation Depth Below Ground (ft)
1	Gas port #4	9.2
2	Suction lysimeter (#31)	20.2
3	Heat dissipation sensor (HDS #26)	20.4
4	Gas port #3	39.2
5	Gas port #2	91.2
6	Gas port #1	99.2

Notes:

1. Vadose zone monitor well LP-3 completed to 101 ft bgs as a combination neutron access tube/ multi-port soil gas/suction lysimeter/ heat dissipation sensor installation.
2. Annular materials installed dry through a 2 in. PVC tremie pipe and tamped continuously.
3. Approx. 1/2 gallon of 10 mg/L Br solution was added immediately above the suction lysimeter to facilitate contact of the ceramic cup with the sieved native tuff.

Well Construction Symbols

- Bentonite pellets
- 50/50 bentonite and sand
- Sieved tuff
- 10-20 silica sand
- Slough

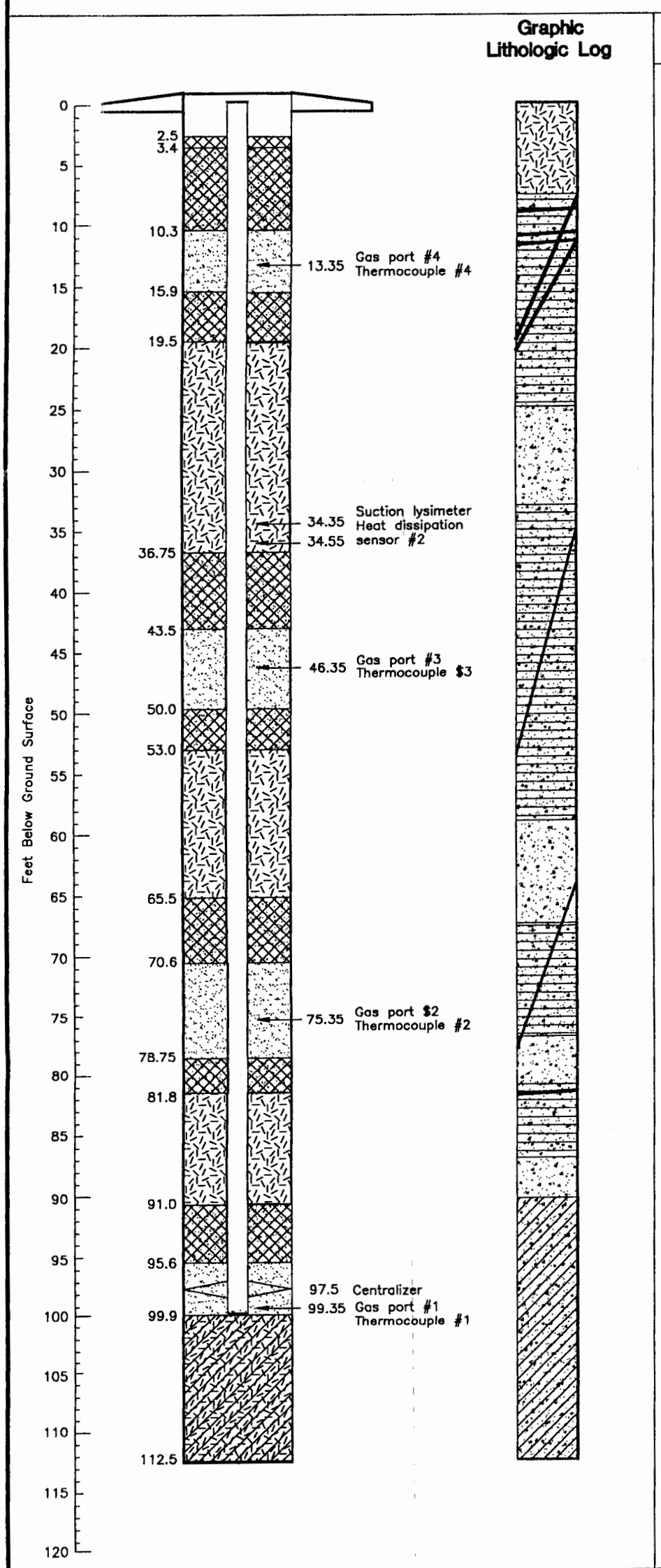
Graphic Log Symbols

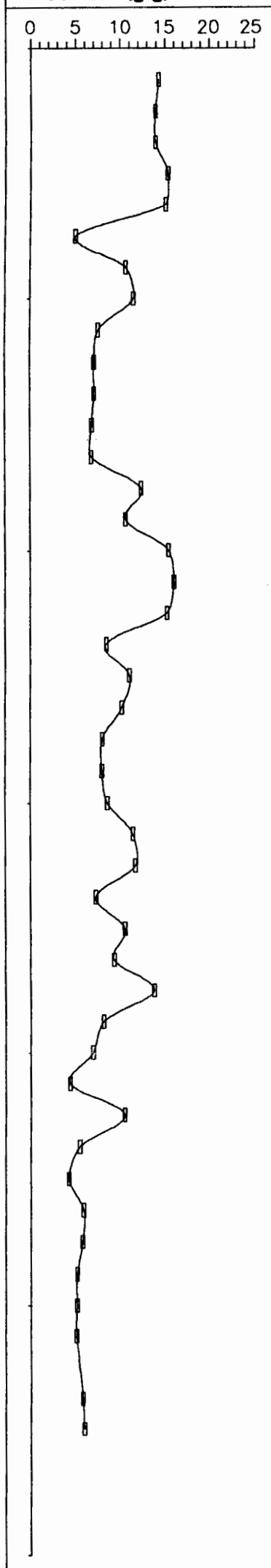
- Backfill
- Poorly indurated, non-welded tuff
- Partly welded tuff
- Welded, strongly indurated tuff
- Fracture or fault

Hydrologist: RSP, LC, JRF
Driller: Jim Hale, Layne Environmental Services
Date completed: 10-22-94
Drilling method: Hollow Stem Auger, CME 750
Total borehole depth: 110.0 ft
Borehole diameter: 8-1/4 in.

Sampler Type: 2.5 ft core barrel
Casing diameter: 2.0 in. I.D., 2.4 in. O.D.
Casing length: 100.1 ft
Casing type: SCH 40 PVC, flush threaded
Casing height from ground: flush with grade
Formation of completion: Tshirege Member, Bandelier Tuff

LANL RFI SUPPORT OU-1071, TA-73
Well Log: LP-3





Comments

	Instrumentation Type(s)	Installation Depth Below Ground (ft)
1	Gas port and thermocouple #4	13.35
2	Suction lysimeter (#30)	34.35
3	Heat dissipation sensor (HDS #31)	34.55
4	Gas port and thermocouple #3	46.35
5	Gas port and thermocouple #2	75.35
6	Gas port and thermocouple #1	99.35

Notes:

1. Vadose zone monitor well LP-4 completed to 99.9 ft bgs as a combination neutron access tube/ multi-port soil gas/suction lysimeter/ heat dissipation sensor/thermocouple installation.
2. All annular materials installed dry through a 2 in. PVC tremie pipe and tamped with a 1-1/2 in. PVC pipe.
3. Approx. 1 gallon 10 mg/L Br solution was added immediately above the suction lysimeter to facilitate contact of the ceramic cup with the seived native tuff.

Well Construction Symbols

- Bentonite pellets
- 50/50 bentonite and sand
- Sieved native tuff backfill
- 10-20 silica sand
- Slough

Graphic Log Symbols

- Backfill
- Poorly indurated, non-welded tuff
- Partly welded tuff
- Welded, strongly indurated tuff
- Fracture or fault
- Weathered tuff: limonite staining yellow-brown in color

Hydrologist: RSP, LMC, KCM, JRL
Driller: Jim Hale, Layne Environmental Services
Date completed: 10-26-94
Drilling method: Hollow Stem Auger, CME 750
Total borehole depth: 112.5 ft
Borehole diameter: 8-1/4 in.

Sampler Type: 2.5 ft core barrel
Casing diameter: 2.0 in. I.D., 2.4 in. O.D.
Casing length: 99.9 ft
Casing type: SCH 40 PVC, flush threaded
Casing height from ground: flush with grade
Formation of completion: Tshirege Member, Bandelier Tuff

LANL RFI SUPPORT OU-1071, TA-73
Well Log: LP-4

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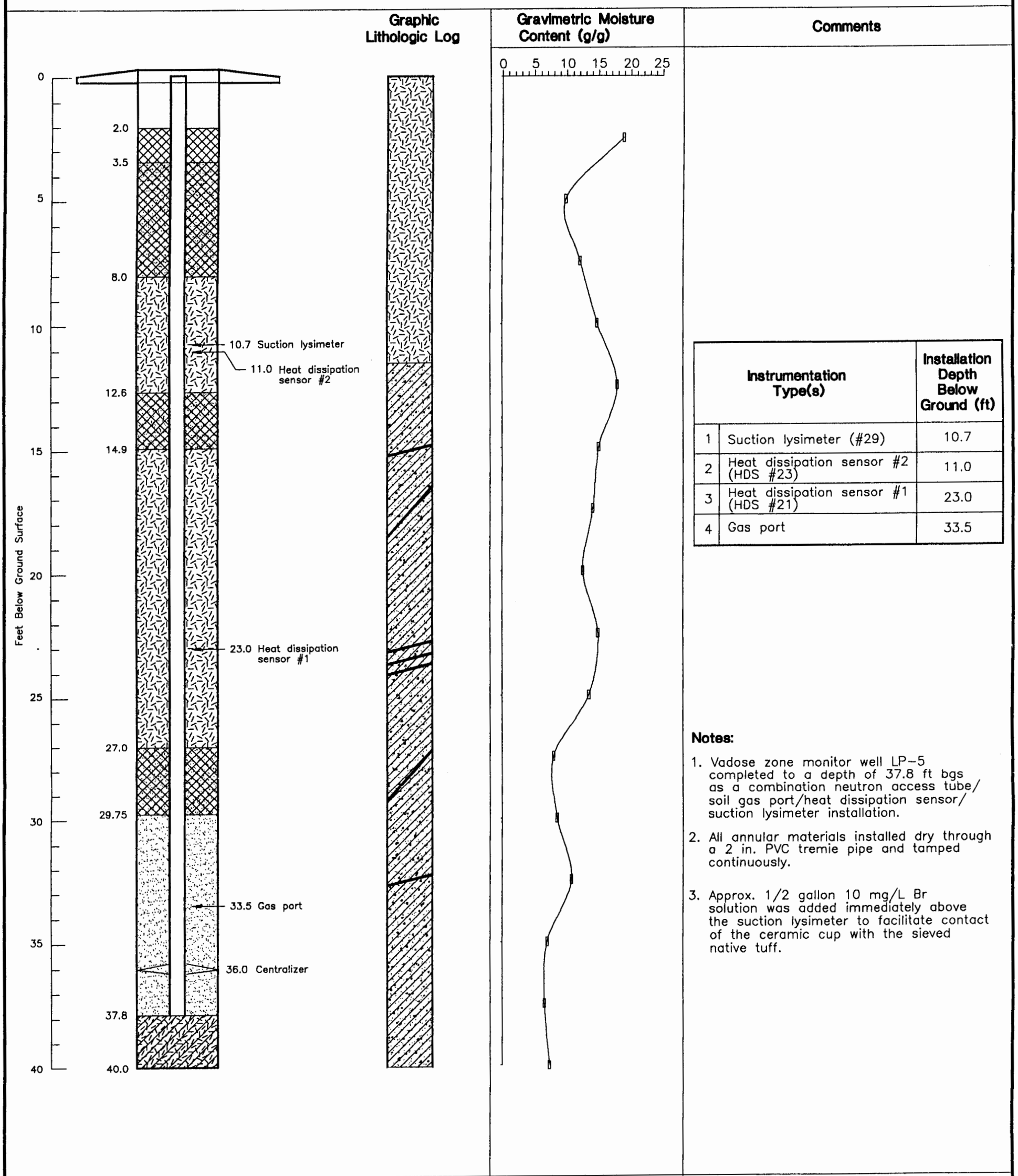

	Instrumentation Type(s)	Installation Depth Below Ground (ft)
1	Suction lysimeter (#29)	10.7
2	Heat dissipation sensor #2 (HDS #23)	11.0
3	Heat dissipation sensor #1 (HDS #21)	23.0
4	Gas port	33.5

Notes:

1. Vadose zone monitor well LP-5 completed to a depth of 37.8 ft bgs as a combination neutron access tube/ soil gas port/heat dissipation sensor/ suction lysimeter installation.
2. All annular materials installed dry through a 2 in. PVC tremie pipe and tamped continuously.
3. Approx. 1/2 gallon 10 mg/L Br solution was added immediately above the suction lysimeter to facilitate contact of the ceramic cup with the sieved native tuff.

Well Construction Symbols

- Bentonite pellets
- 50/50 bentonite and sand
- Sieved tuff
- 10-20 silica sand
- Slough

Graphic Log Symbols

- Backfill
- Poorly indurated, non-welded tuff
- Partly welded tuff
- Welded, strongly indurated tuff
- Fracture or fault

Hydrologist: RCM, JRL, RSP
Driller: Jim Hale, Layne Environmental Services
Date completed: 10-23-94
Drilling method: Hollow Stem Auger, CME 750
Total borehole depth: 40.0 ft
Borehole diameter: 8-1/4 in.

Sampler Type: 2.5 ft core barrel
Casing diameter: 2.0 in. I.D., 2.4 in. O.D.
Casing length: 37.8 ft
Casing type: SCH 40 PVC, flush threaded
Casing height from ground: flush with grade
Formation of completion: Tshirege Member, Bandelier Tuff

LANL RFI SUPPORT OU-1071, TA-73

Well Log: LP-5

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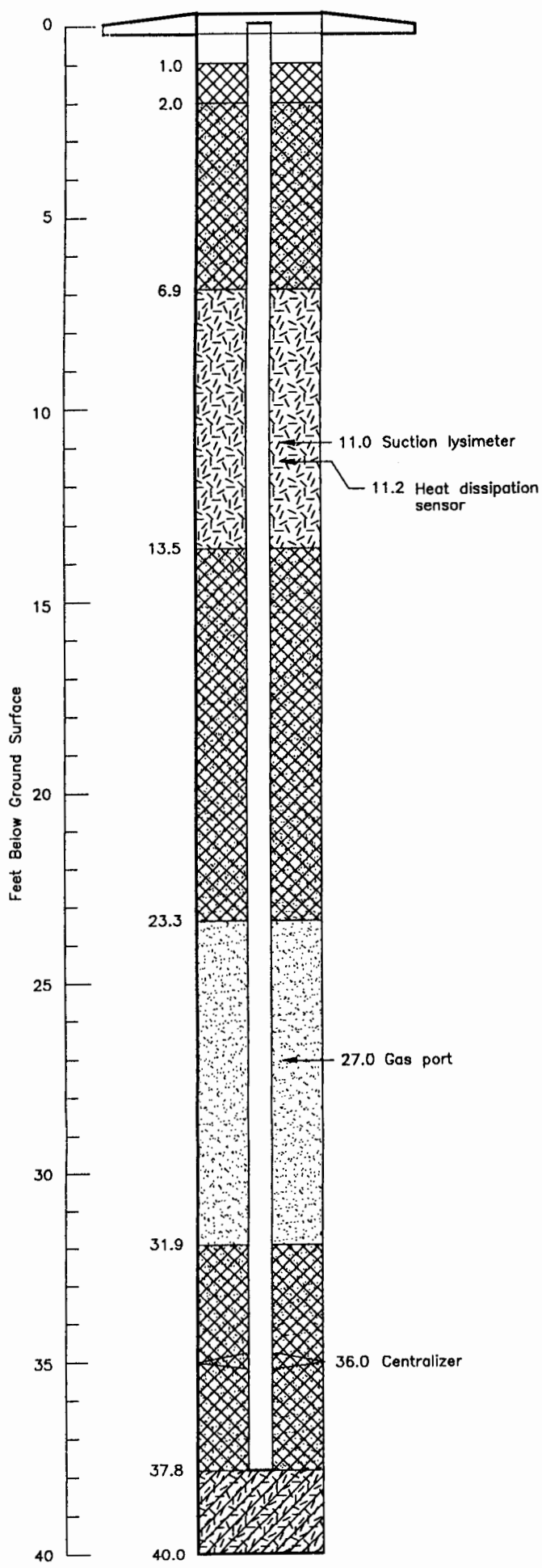

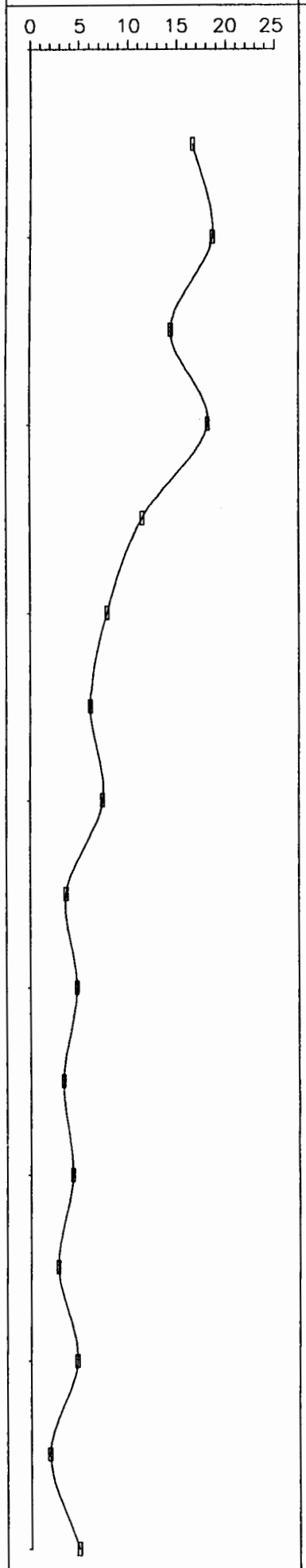

Comments

	Instrumentation Type(s)	Installation Depth Below Ground (ft)
1	Suction lysimeter (#8)	11.0
2	Heat dissipation sensor (HDS #22)	11.2
3	Gas port	27.0

Notes:

1. Vadose zone monitor well LP-6 completed to a depth of 37.8 ft bgs as a combination neutron access tube/ soil gas port/suction lysimeter/ heat dissipation sensor installation.
2. All backfill materials were emplaced by tremie pipe.
3. Approximately 1 gallon of 10 mg/L Br solution was added immediately above the suction lysimeter to facilitate contact of the ceramic cup with the sieved native tuff.

Well Construction Symbols

- Bentonite pellets
- 50/50 bentonite and sand
- Sieved tuff
- 10-20 silica sand
- Slough

Graphic Log Symbols

- Backfill
- Poorly indurated, non-welded tuff
- Partly welded tuff
- Welded, strongly indurated tuff
- Fracture or fault
- Fracture

Hydrologist: KCM, JRL, RSP
Driller: Jim Hale, Layne Environmental Services
Date completed: 10-24-94
Drilling method: Hollow Stem Auger, CME 750
Total borehole depth: 40.0 ft
Borehole diameter: 8-1/4 in.

Sampler Type: 2.5 ft core barrel
Casing diameter: 2.0 in. I.D., 2.4 in. O.D.
Casing length: 37.8 ft
Casing type: SCH 40 PVC, flush threaded
Casing height from ground: flush with grade
Formation of completion: Tshirege Member, Bandelier Tuff

LANL RFI SUPPORT OU-1071, TA-73

Well Log: LP-6

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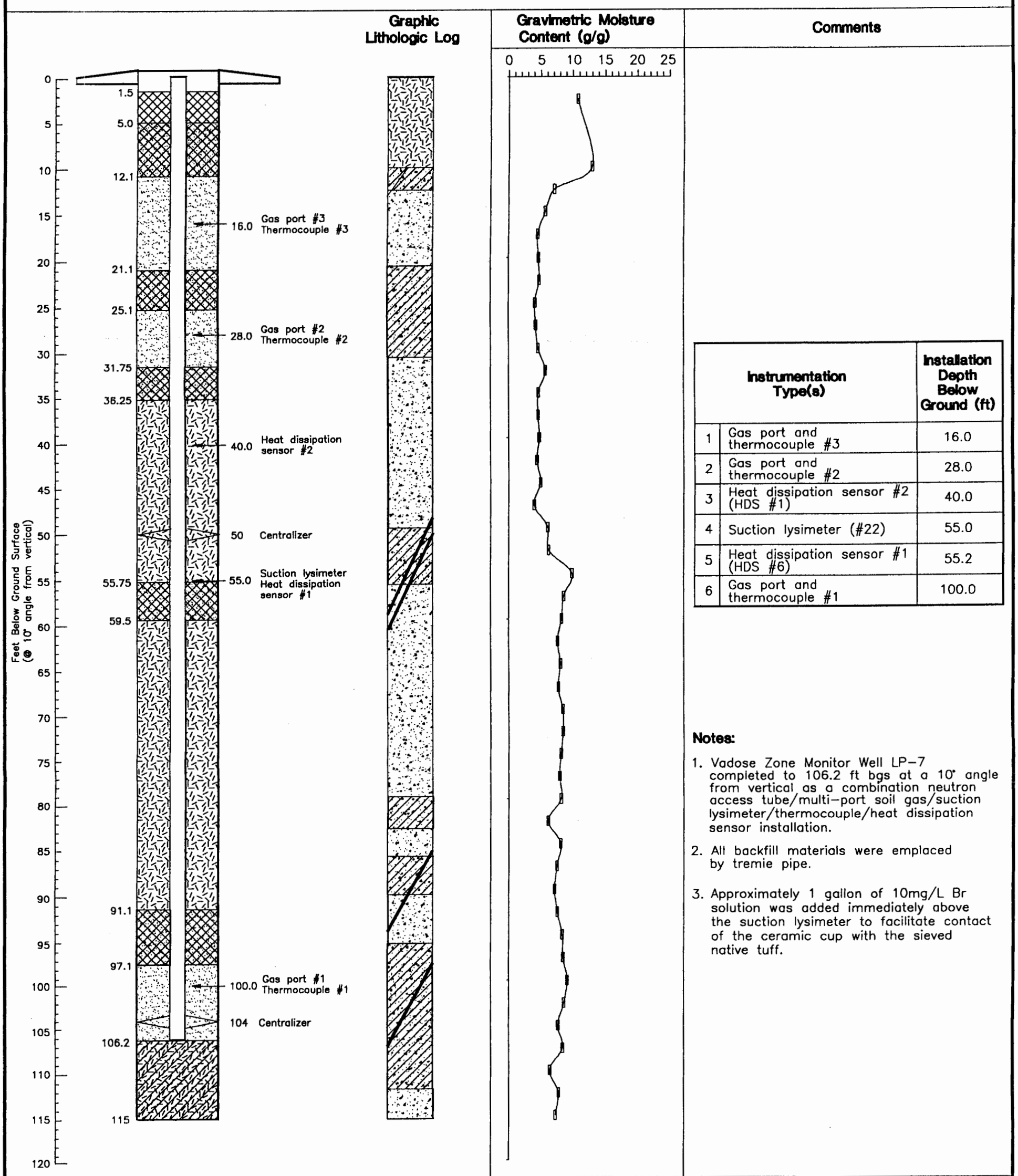

	Instrumentation Type(s)	Installation Depth Below Ground (ft)
1	Gas port and thermocouple #3	16.0
2	Gas port and thermocouple #2	28.0
3	Heat dissipation sensor #2 (HDS #1)	40.0
4	Suction lysimeter (#22)	55.0
5	Heat dissipation sensor #1 (HDS #6)	55.2
6	Gas port and thermocouple #1	100.0

Notes:

1. Vadose Zone Monitor Well LP-7 completed to 106.2 ft bgs at a 10° angle from vertical as a combination neutron access tube/multi-port soil gas/suction lysimeter/thermocouple/heat dissipation sensor installation.
2. All backfill materials were emplaced by tremie pipe.
3. Approximately 1 gallon of 10mg/L Br solution was added immediately above the suction lysimeter to facilitate contact of the ceramic cup with the sieved native tuff.

Well Construction Symbols

- Bentonite pellets
- 50/50 bentonite and sand
- Sieved tuff
- 10-20 silica sand
- Slough

Graphic Log Symbols

- Backfill
- Poorly indurated, non-welded tuff
- Partly welded tuff moderately indurated
- Welded, strongly indurated tuff
- Fracture or fault

Hydrologist: RSP, LC, KCM, MB
Driller: Jim Hale, Layne Environmental Services
Date completed: 10-9-94
Drilling method: Hollow Stem Auger, CME 750
Total borehole depth: 115.0 ft
Borehole diameter: 8-1/4 in.

Sampler Type: 2.5 ft core barrel
Casing diameter: 2.0 in. I.D., 2.4 in. O.D.
Casing length: 106.2ft
Casing type: SCH 40 PVC, flush threaded
Casing height from ground: flush with grade
Formation of completion: Tshirege Member, Bandelier Tuff

LANL RFI SUPPORT OU-1071, TA-73

Well Log: LP-7

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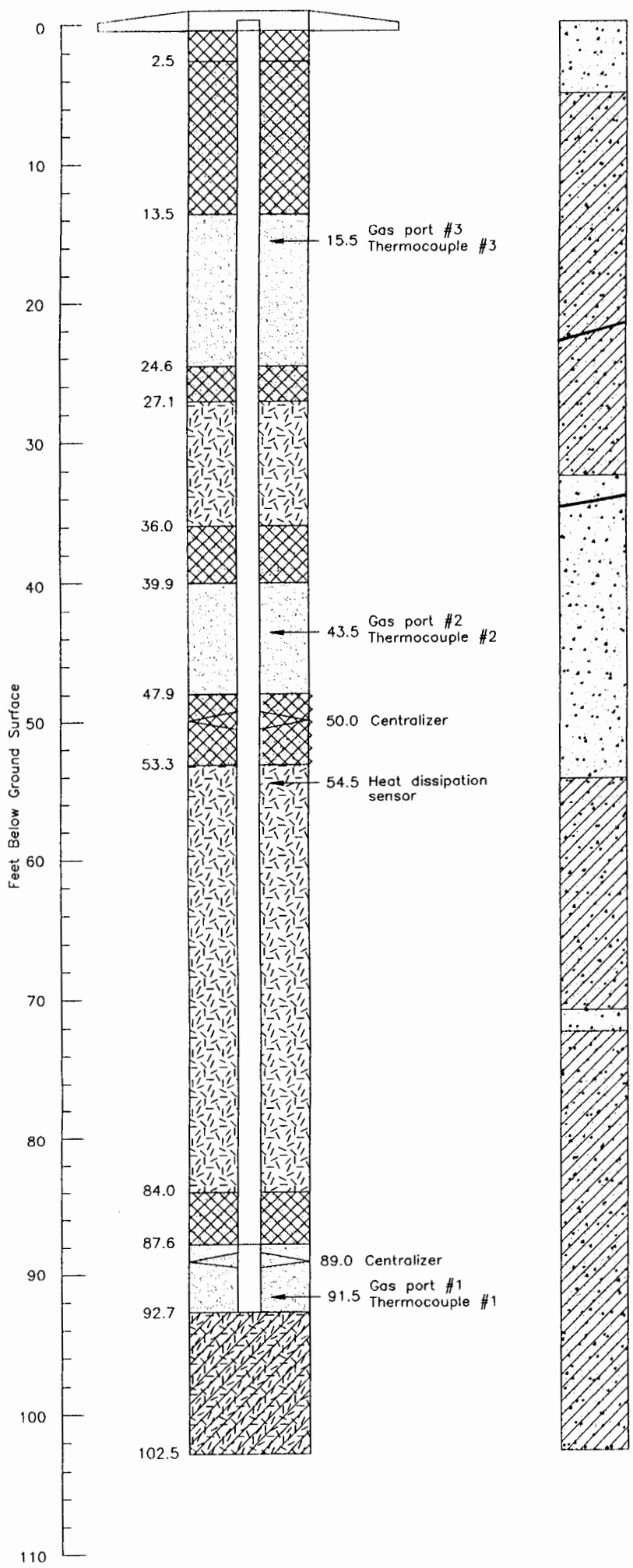

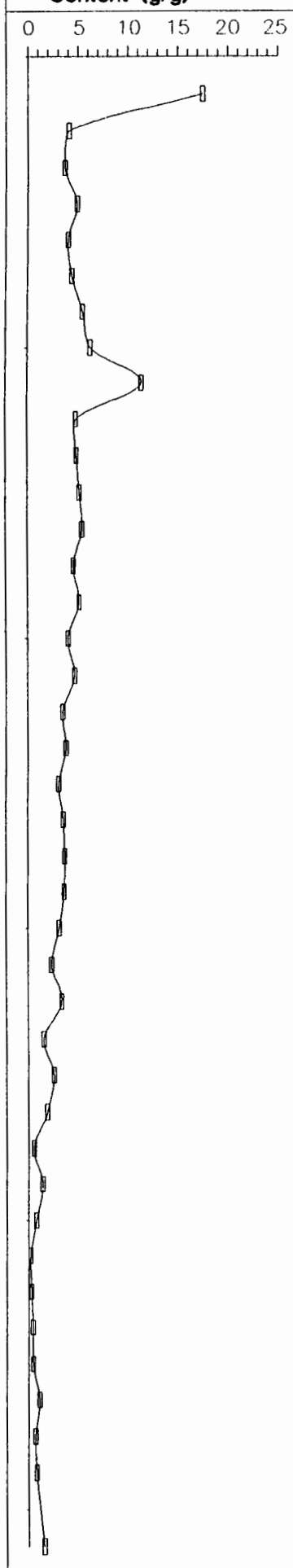

Comments

	Instrumentation Type(s)	Installation Depth Below Ground (ft)
1	Gas port and thermocouple #3	15.5
2	Gas port and thermocouple #2	43.5
3	Heat dissipation sensor (HDS #17)	54.5
4	Gas port and thermocouple #1	91.5

Notes:

1. Vadose zone monitor well LP-8 completed to a depth of 92.7 ft bgs as a combination neutron access tube/ multi-port soil gas/heat dissipation sensor/thermocouple installation.
2. All backfill materials were emplaced by tremie pipe.

Well Construction Symbols

- Bentonite pellets
- 50/50 bentonite and sand
- Sieved tuff
- 10-20 silica sand
- Slough

Graphic Log Symbols

- Backfill
- Poorly indurated, non-welded tuff
- Partly welded tuff moderately indurated
- Welded, strongly indurated tuff
- Fracture or fault

Hydrologist: LC, RSP, KCM, JRL
Driller: Jim Hale, Layne Environmental Services
Date completed: 11-2-94
Drilling method: Hollow Stem Auger, CME 750
Total borehole depth: 102.5 ft
Borehole diameter: 8-1/4 in.

Sampler Type: 2.5 ft core barrel
Casing diameter: 2.0 in. I.D., 2.4 in. O.D.
Casing length: 92.7 ft
Casing type: SCH 40 PVC, flush threaded
Casing height from ground: flush with grade
Formation of completion: Tshirege Member, Bandelier Tuff

LANL RFI SUPPORT OU-1071, TA-73

Well Log: LP-8

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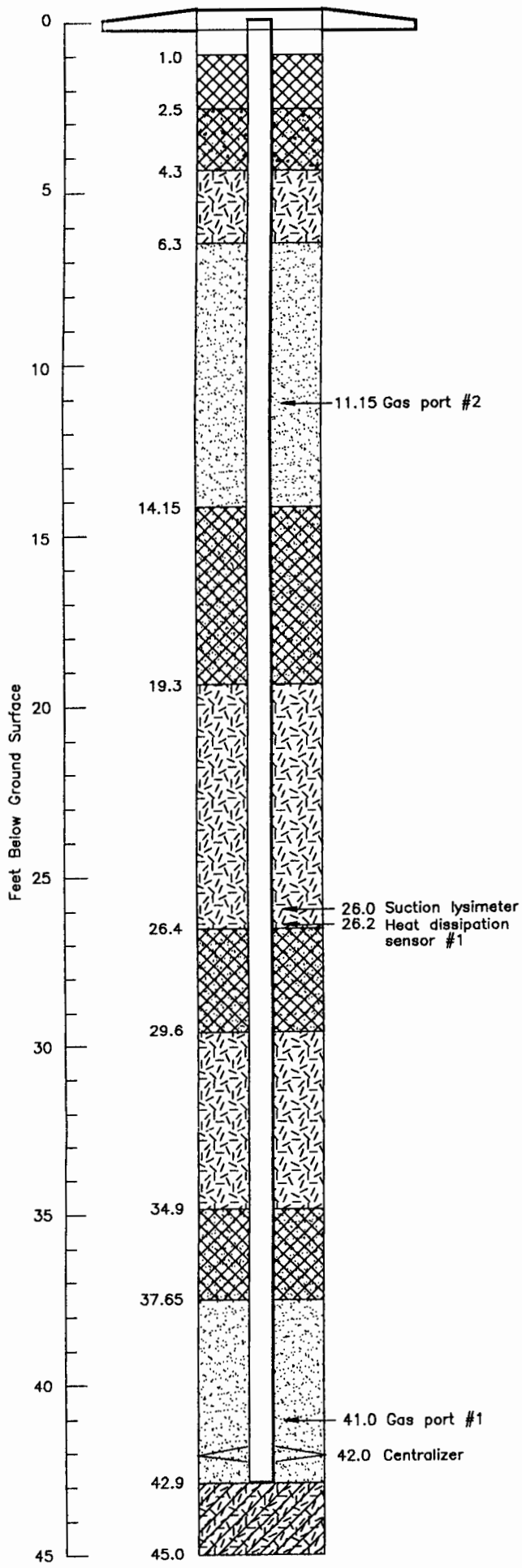

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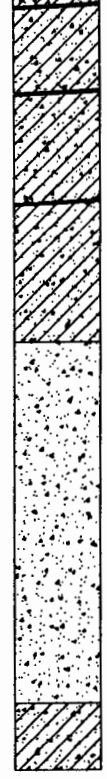
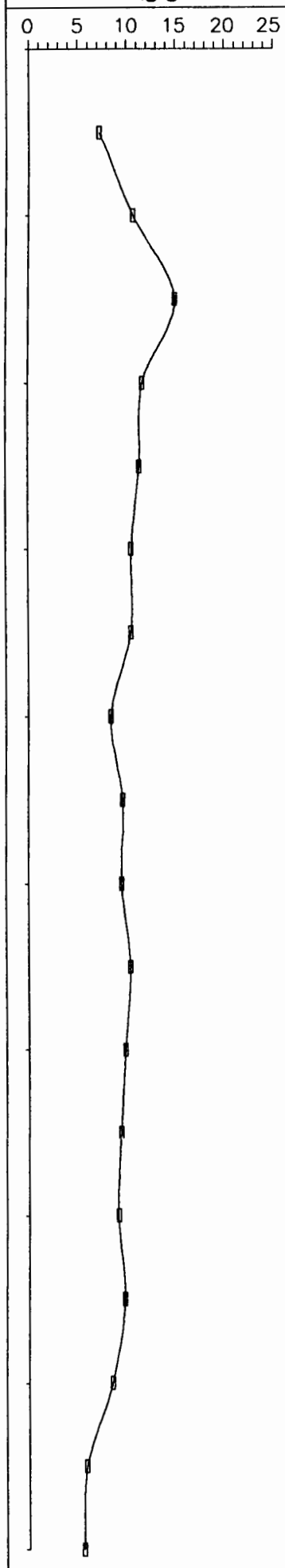


Gravimetric Moisture Content (g/g)



Comments

	Instrumentation Type(s)	Installation Depth Below Ground (ft)
1	Gas port #2	11.15
2	Suction lysimeter (#15)	26.0
3	Heat dissipation sensor (HDS #7)	26.2
4	Gas port #1	41.0

Notes:

1. Vadose zone monitor well LP-9 completed to a depth of 42.9 ft bgs as a combination neutron access tube/ multi-port soil gas/suction lysimeter/ heat dissipation sensor installation.
2. All backfill materials were installed by tremie pipe.
3. Approx. 1 gallon of 10mg/L Br solution was added immediately above the suction lysimeter to facilitate contact of the ceramic cup with the sieved native tuff.

Well Construction Symbols

- Bentonite pellets
- 50/50 bentonite and sand
- Bentonite powder (dry)
- 10-20 silica sand
- Slough
- Sieved tuff

Graphic Log Symbols

- Backfill
- Poorly indurated, non-welded tuff
- Partly welded tuff moderately indurated
- Welded, strongly indurated tuff
- Fracture or fault

Hydrologist: LC, KCM, MB
Driller: Jim Hale, Layne Environmental Services
Date completed: 11-9-94
Drilling method: Hollow Stem Auger, CME 750
Total borehole depth: 45.0
Borehole diameter: 8-1/4 in.

Sampler Type: 2.5 ft core barrel
Casing diameter: 2.0 in. I.D., 2.4 in. O.D.
Casing length: 42.9 ft
Casing type: SCH 40 PVC, flush threaded
Casing height from ground: flush with grade
Formation of completion: Tshirege Member, Bandelier Tuff

LANL RFI SUPPORT OU-1071, TA-73
Well Log: LP-9

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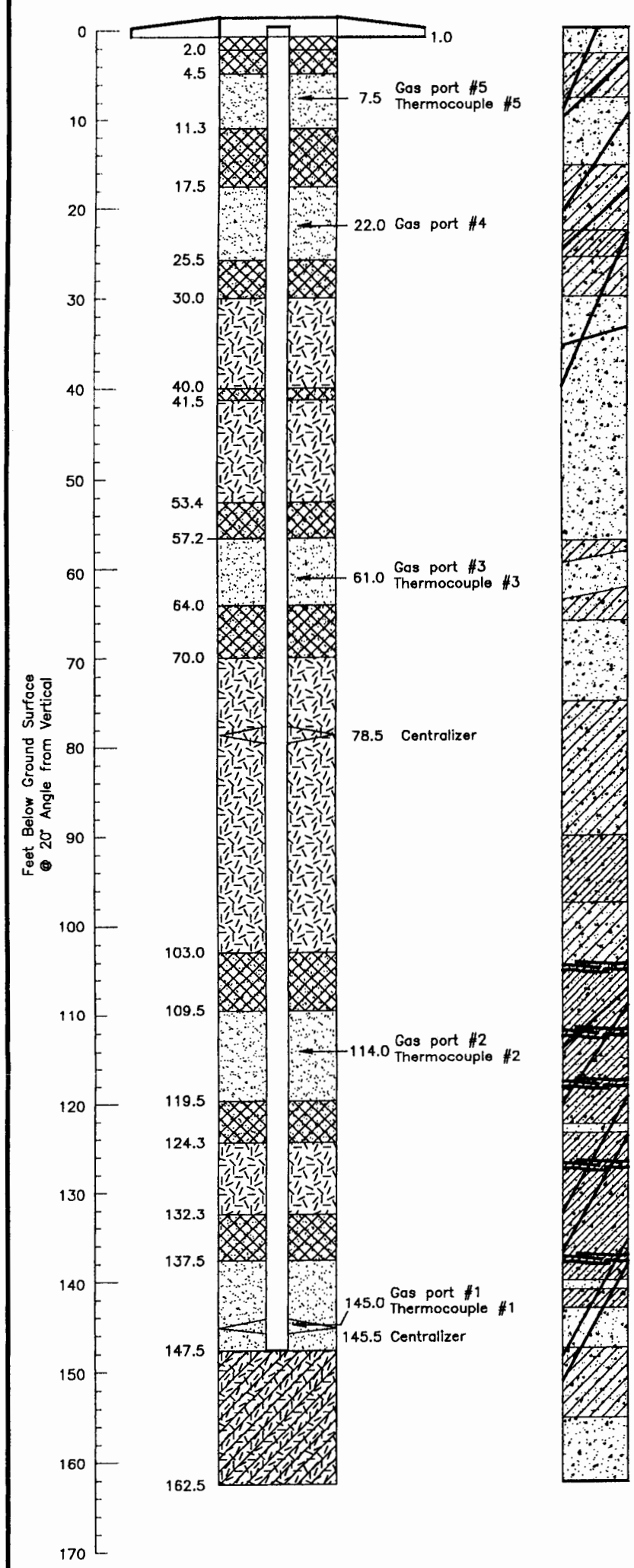

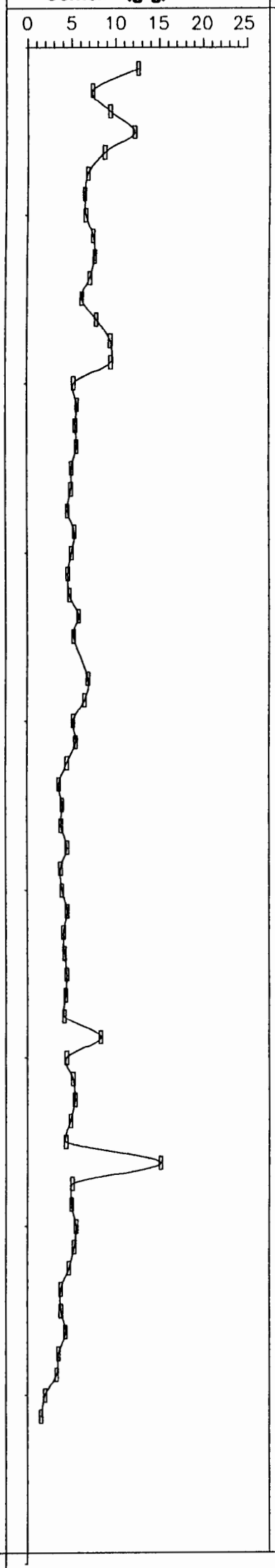

Comments

	Instrumentation Type(s)	Installation Depth Below Ground (ft)
1	Gas port and thermocouple #5	7.5
2	Gas port #4	22.0
3	Gas port and thermocouple #3	61.0
4	Gas port and thermocouple #2	114.0
5	Gas port and thermocouple #1	145.0

Notes:

1. Vadose zone monitor well LPS-1 completed to 147.5 ft at a 20° angle from vertical as a combination neutron access tube/multi-port soil gas/thermocouple installation.
2. All backfill materials were emplaced by tremie pipe.

Well Construction Symbols

- Bentonite pellets
- 50/50 bentonite and sand
- Sieved tuff
- 10-20 silica sand
- Slough

Graphic Log Symbols

- Backfill
- Poorly indurated, non-welded tuff
- Partly welded tuff moderately indurated
- Welded, strongly indurated tuff
- Fracture or fault
- Fracture

Hydrologist: RSP, RCM, JRL, LC
Driller: Jim Hale, Layne Environmental Services
Date completed: 11-6-94
Drilling method: Hollow Stem Auger, CME 750
Total borehole depth: 162.5 ft
Borehole diameter: 8-1/4 in.

Sampler Type: 2.5 ft core barrel
Casing diameter: 2.0 in. I.D., 2.4 in. O.D.
Casing length: 147.5 ft
Casing type: SCH 40 PVC, flush threaded
Casing height from ground: flush with grade
Formation of completion: Tshirege Member, Bandelier Tuff

LANL RFI SUPPORT OU-1071, TA-73

Well Log: LPS-1

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12-94 JN 4010

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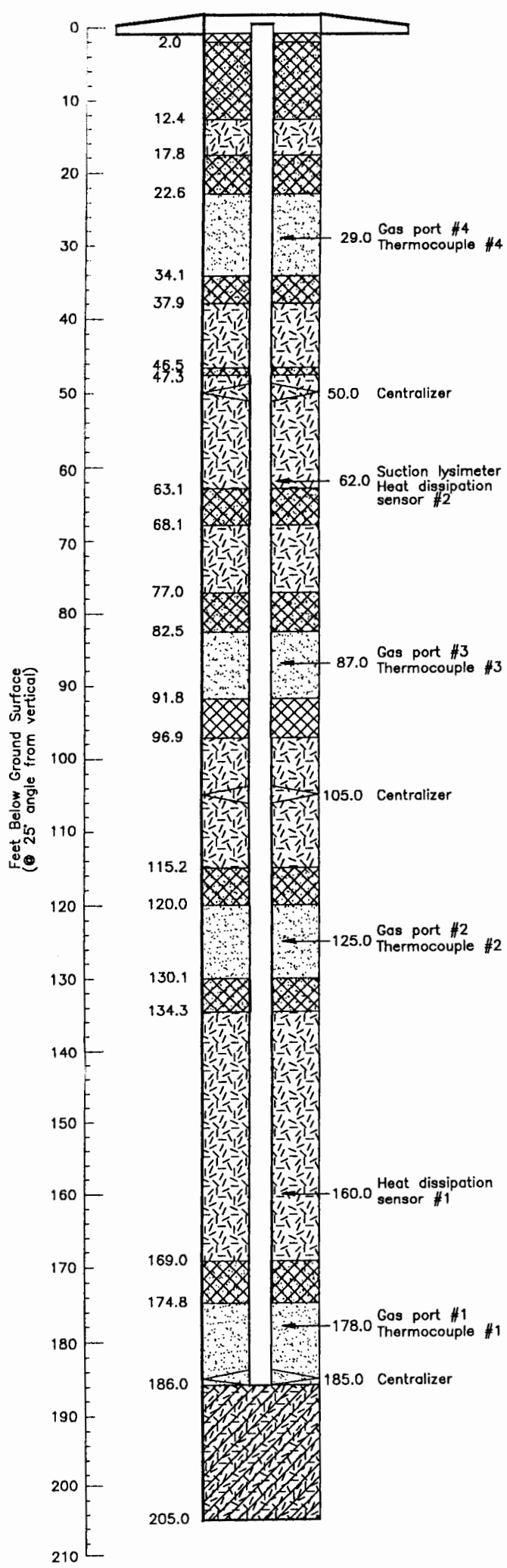
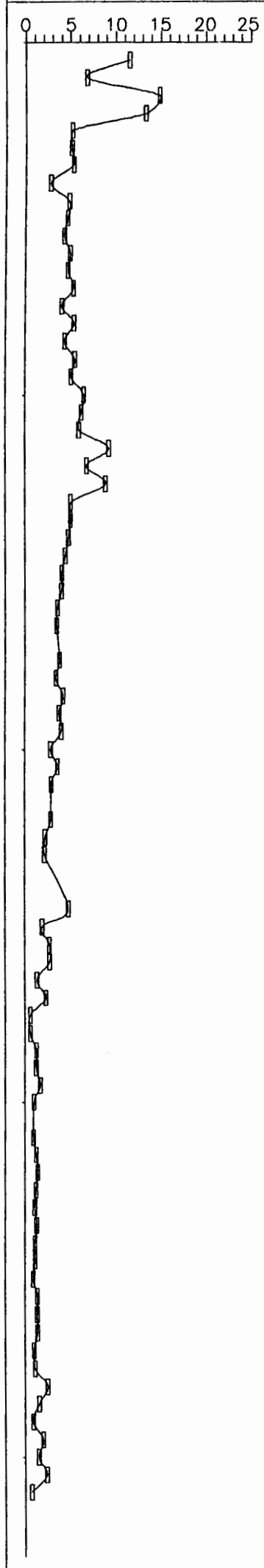


Graphic Lithologic Log



Gravimetric Moisture Content (g/g)

Comments

	Instrumentation Type(s)	Installation Depth Below Ground (ft)
1	Gas port and thermocouple #4	29.0
2	Suction lysimeter (#25)	62.0
3	Heat dissipation sensor #2 (HDS #28)	62.0
4	Gas port and thermocouple #3	87.0
5	Gas port and thermocouple #2	125.0
6	Heat dissipation sensor #1 (HDS #25)	160.0
7	Gas port and thermocouple #1	178.0

Notes:

1. Vadose zone monitor well LPS-2 completed to 186 ft at a 25° angle from vertical with a N45E bearing as a combination neutron access tube/ multi-port soil gas/suction lysimeter/ heat dissipation sensor/thermocouple installation.
2. All backfill materials were emplaced by tremie pipe.
3. Approximately 1 gallon of 10mg/L Br solution was added immediately above the suction lysimeter to facilitate contact of the ceramic cup with the sieved native tuff.

Well Construction Symbols

- Bentonite pellets
- 50/50 bentonite and sand
- Sieved tuff
- 10-20 silica sand
- Slough

Graphic Log Symbols

- Backfill
- Poorly indurated, non-welded tuff
- Partly welded tuff moderately indurated
- Welded, strongly indurated tuff
- Fracture or fault

Hydrologist: RSP, JRL, JRF, MB
Driller: Jim Hale, Layne Environmental Services
Date completed: 11-18-94
Drilling method: Hollow Stem Auger, CME 750
Total borehole depth: 205 ft
Borehole diameter: 8-1/4 in.

Sampler Type: 2.5 ft core barrel
Casing diameter: 2.0 in. I.D., 2.4 in. O.D.
Casing length: 186 ft
Casing type: SCH 40 PVC, flush threaded
Casing height from ground: flush with grade
Formation of completion: Tshirege Member, Bandelier Tuff

LANL RFI SUPPORT OU-1071, TA-73

Well Log: LPS-2

DANIEL B. STEPHENS & ASSOCIATES, INC.
1-95
JN 4010

APPENDIX B

HDS CALIBRATION CURVES

DANIEL B. STEPHENS & ASSOCIATES, INC.

ENVIRONMENTAL SCIENTISTS AND ENGINEERS

INTERNAL MEMORANDUM

TO: Rolf Schmidt-Petersen

DATE: December 9, 1994

FROM: Joe Vinson

SUBJECT: LANL Townsite Heat Dissipation Probes

Please find enclosed the final laboratory data report for laboratory calibration of LANL Townsite head dissipation probes. An invoice for this work will be submitted under separate cover.

All testing results were evaluated subjectively for consistency and reasonableness, and the results appear to be reasonably representative of the material tested. However, DBS&A does not assume any responsibility for interpretations or analyses based on the data enclosed, nor can we guarantee that these data are fully representative of the undisturbed materials at the field site. We recommend that careful evaluation of these laboratory results be made for your particular application.

SUMMARY

The Hydrologic Testing Laboratory at Daniel B. Stephens & Associates, Inc. (DBS&A) has completed laboratory calibration of LANL Townshite head dissipation probes as specified by you. Table 1 gives the results of the specified calibration. A detailed description of each method is available upon request.

Altogether we calibrated the performance of a total of 31 Campbell Scientific heat dissipation probes (Logan, UT) along a series of descending potentials, from saturation to about -5 bars. Our objective, as outlined by Mr. Rolf Schmidt-Petersen, was to describe pulsed differential temperature response of the probes to soil potential, by targeting most of our calibration points within the operational range of typical suction lysimeters, to about -1 bar potential.

Probes were calibrated within a custom 15-bar pressure plate extractor (Soil Moisture Equipment Corp., Santa Barbara, CA) in groups of eight probes per run with seven probes in the fourth and final run (Table 1). We used a well-defined series of preparation steps that were based upon similar calibration work that had been done for another project.

We first measured the length of electrical cable for each probe to the nearest foot. Then, to pneumatically isolate the probe body within the pressure cell, we used 3/16" bore-through thermocouple connectors (Swagelok Co., Solon, OH, p/n SS-300-1-4STBT) with removable nylon ferrules. Outside of the cell the cable leads were wired to a Campbell Scientific 21x datalogger that was used to collect and store raw differential temperature data.

Within the pressure cell the probes were buried within a "cake" of silica flour, our calibration media. On the floor of the cell we used a 5-bar ceramic plate that was caked with about a 1¼-inch thickness of saturated silica flour paste, restrained within the fluted rim of the plate's rubber membrane. Pre-conditioned probes (24 hours of soaking in deionized water at ambient pressure) were fully immersed in the paste. Finally, a second 1-bar plate was positioned, face-down, on top of the "cake." With this arrangement we were able to use two plates for extraction: a 5-bar plate at the lower boundary and a 1-bar plate at the upper. After the -1 bar extraction,

we removed the top plate from the cake and replaced it with a 5-bar plate to complete the extractions.

Differential temperature data for each of the eight probes of a run were recorded by hand from the memory of the datalogger. The probes were never pulsed more than twice per day to reduce heat-induced moisture transfer from the probes to the surrounding matrix. A number of pulse events over a period of days eventually produced stable temperature readings. All of these data were recorded at each pressure step, including the initial "0"-potential, before changing the extraction pressure of the cell.

Stable summary and per-probe temperature readings were fit to 2 parameter least-squares exponential models to predict the potential from observed data (Table 1). Separate models were fit to subsets of data. One model was used to fit data from the first point at which differential temperatures began to change from initial conditions, through the full range of calibration points. A second model was used to fit a more limited range of points, to about -1 bar potential, the range of particular interest in this work.

Overall, the results appear reasonable and internally consistent. However, DBS&A cannot guarantee that these results are representative of the undisturbed materials at the field site, nor can we assume any responsibility for interpretations or analyses based on these data. We recommend that careful evaluation of these laboratory results be made for your particular application.

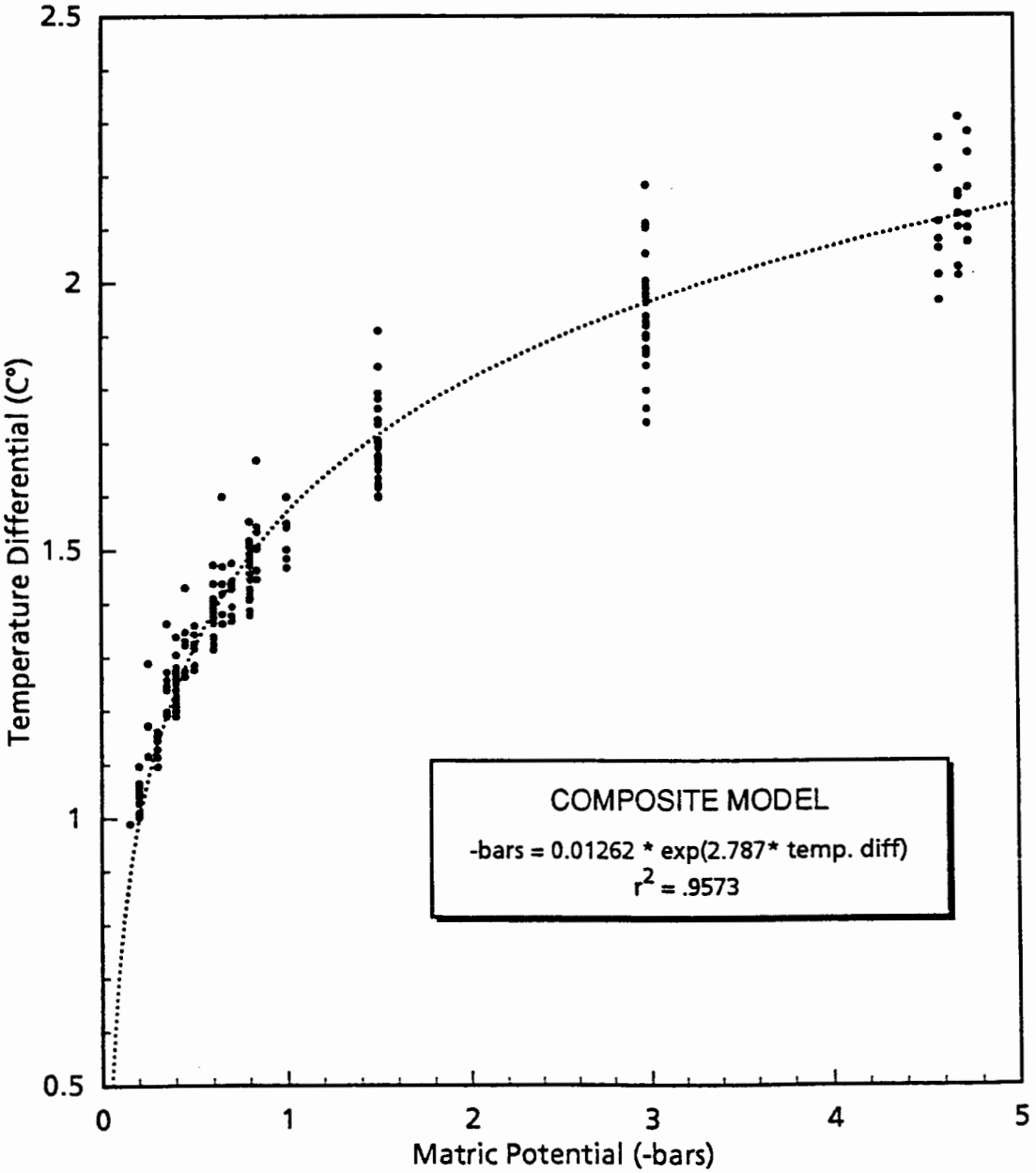
Table 1. Summary of Heat Dissipation Calibration Runs

Run No.	Set-Up Date	End Date	No. of Points	ID No.	Cable Length
1	4/5/94	6/3/94	13	1245	60 feet
				1243	60 feet
				1249	60 feet
				1242	60 feet
				1248	60 feet
				1247	60 feet
				1253	35 feet
				1244	60 feet
2	6/20/94	7/13/94	8	1269	35 feet
				1246	60 feet
				1254	35 feet
				1258	35 feet
				1261	35 feet
				1255	35 feet
				1257	35 feet
				1250	35 feet

Table 1. Summary of Heat Dissipation Calibration Runs (Continued)

Run No.	Set-Up Date	End Date	No. of Points	ID No.	Cable Length
3	7/13/94	8/16/94	8	1241	60 feet
				1240	60 feet
				1267	35 feet
				1251	35 feet
				1256	35 feet
				1252	35 feet
				1265	35 feet
				1259	35 feet
4	8/19/94	9/30/94	9	1260	35 feet
				1264	35 feet
				1263	35 feet
				1262	35 feet
				1266	35 feet
				1268	35 feet
				1270	35 feet

Heat Dissipation Probe Calibration
LANL Townsite / 4848, Composite



Summary of Heat Dissipation Probe Calibration Data

Run Number 1

Equilibrium Differential Temperature Data

Bars	1245	1243	1249	1242	1248	1247	1253	1244
0	0.642	0.683	0.642	0.633	0.658	0.625	0.634	0.625
0.10	0.634	0.667	0.651	0.617	0.642	0.626	0.626	0.617
0.20	1.051	1.059	1.060	1.008	0.634	1.010	1.001	1.059
0.30	1.145	1.161	1.154	1.095	1.128	1.113	1.096	1.153
0.40	1.260	1.276	1.268	1.209	1.251	1.227	1.201	1.267
0.50	1.326	1.342	1.343	1.276	1.317	1.285	1.276	1.359
0.60	1.376	1.384	1.385	1.317	1.376	1.335	1.326	1.409
0.70	1.427	1.443	1.436	1.368	1.435	1.394	1.377	1.476
0.80	1.485	1.492	1.485	1.426	1.476	1.444	1.419	1.517
1.0	1.541	1.541	1.542	1.483	1.549	1.500	1.467	1.598
1.5	1.691	1.690	1.700	1.615	1.698	1.649	1.600	1.781
3.0	1.974	1.981	1.991	1.989	2.056	1.974	1.866	2.113
4.6	2.080	2.063	2.114	2.013	2.212	2.113	1.965	2.270

Least Squares Fitted Parameters

Exponential Model: -bars = a * exp (b * diff. temperature), n = no. obs.

	All points (unshaded)				Points to -1.0 bar			
	n	a	b	r2	a	n	b	r2
1245	11	1.016E-2	2.935	0.9964	7.408E-3	8	3.179	0.9959
1243	11	8.998E-3	3.002	0.9955	6.704E-3	8	3.227	0.9962
1249	11	1.061E-2	2.884	0.9951	6.766E-3	8	3.228	0.9960
1242	11	1.293E-2	2.870	0.9850	7.701E-3	8	3.282	0.9946
1248	10	1.906E-2	2.499	0.9934	1.111E-2	7	2.895	0.9973
1247	11	1.404E-2	2.770	0.9924	8.114E-3	8	3.201	0.9970
1253	11	8.994E-3	3.164	0.9974	7.610E-3	8	3.298	0.9961
1244	11	1.702E-2	2.489	0.9931	1.020E-2	8	2.883	0.9945

Summary of Heat Dissipation Probe Calibration Data

Run Number 2

Equilibrium Differential Temperature Data

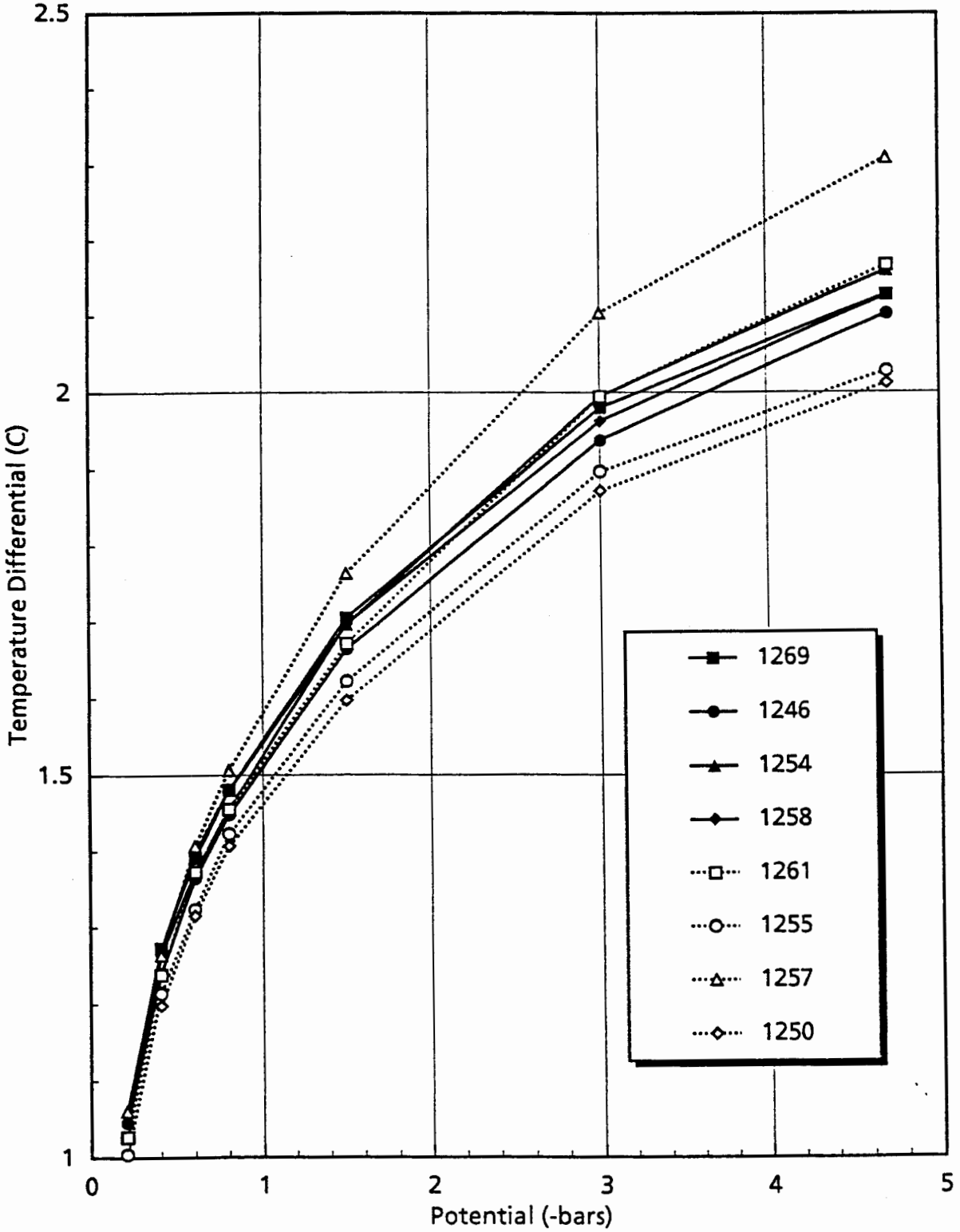
Bars	1269	1246	1254	1258	1261	1255	1257	1250
0	0.692	0.667	0.691	0.666	0.666	0.667	0.708	0.667
0.20	0.664	1.045	1.061	1.045	1.027	1.004	1.061	0.631
0.40	1.273	1.239	1.272	1.264	1.238	1.214	1.264	1.198
0.60	1.391	1.365	1.398	1.373	1.373	1.324	1.407	1.316
0.80	1.481	1.448	1.480	1.456	1.455	1.423	1.506	1.407
1.5	1.705	1.664	1.696	1.697	1.671	1.622	1.763	1.597
3.0	1.980	1.938	1.995	1.963	1.995	1.897	2.104	1.872
4.7	2.128	2.103	2.160	2.127	2.167	2.028	2.309	2.012

Least Squares Fitted Parameters

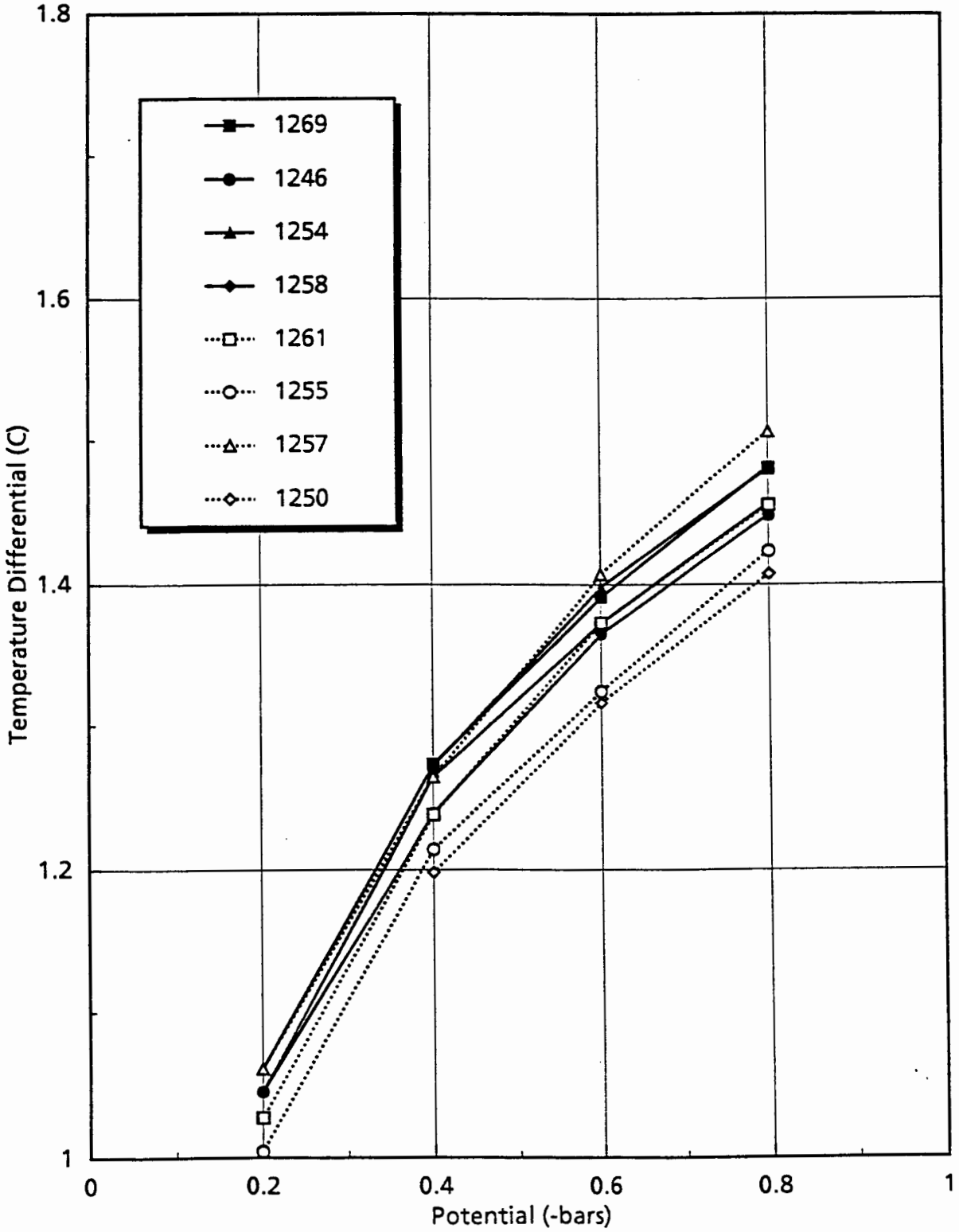
Exponential Model: -bars = a * exp (b * diff. temperature), n = no. obs.

	All points (unshaded)				Points to -0.8 bar			
	n	a	b	r2	n	a	b	r2
1269	6	1.180E-2	2.816	0.9980	3	5.732E-3	3.338	0.9996
1246	7	1.044E-2	2.937	0.9954	4	5.611E-3	3.428	0.9995
1254	7	1.103E-2	2.833	0.9948	4	6.055E-3	3.294	0.9999
1258	7	1.086E-2	2.879	0.9959	4	5.794E-3	3.376	0.9987
1261	7	1.382E-2	2.724	0.9930	4	7.387E-3	3.215	0.9996
1255	7	1.029E-2	3.028	0.9972	4	6.981E-3	3.343	0.9990
1257	7	1.754E-2	2.461	0.9905	4	7.554E-3	3.109	0.9977
1250	6	1.191E-2	2.976	0.9974	3	7.504E-3	3.322	0.9995

Heat Dissipation Probe Calibration
LANL Townsite / 4848, Run No. 2



Heat Dissipation Probe Calibration
LANL Townsite / 4848, Run No. 2
(Potentials to -0.8 bar)



Summary of Heat Dissipation Probe Calibration Data

Run Number 3

Equilibrium Differential Temperature Data

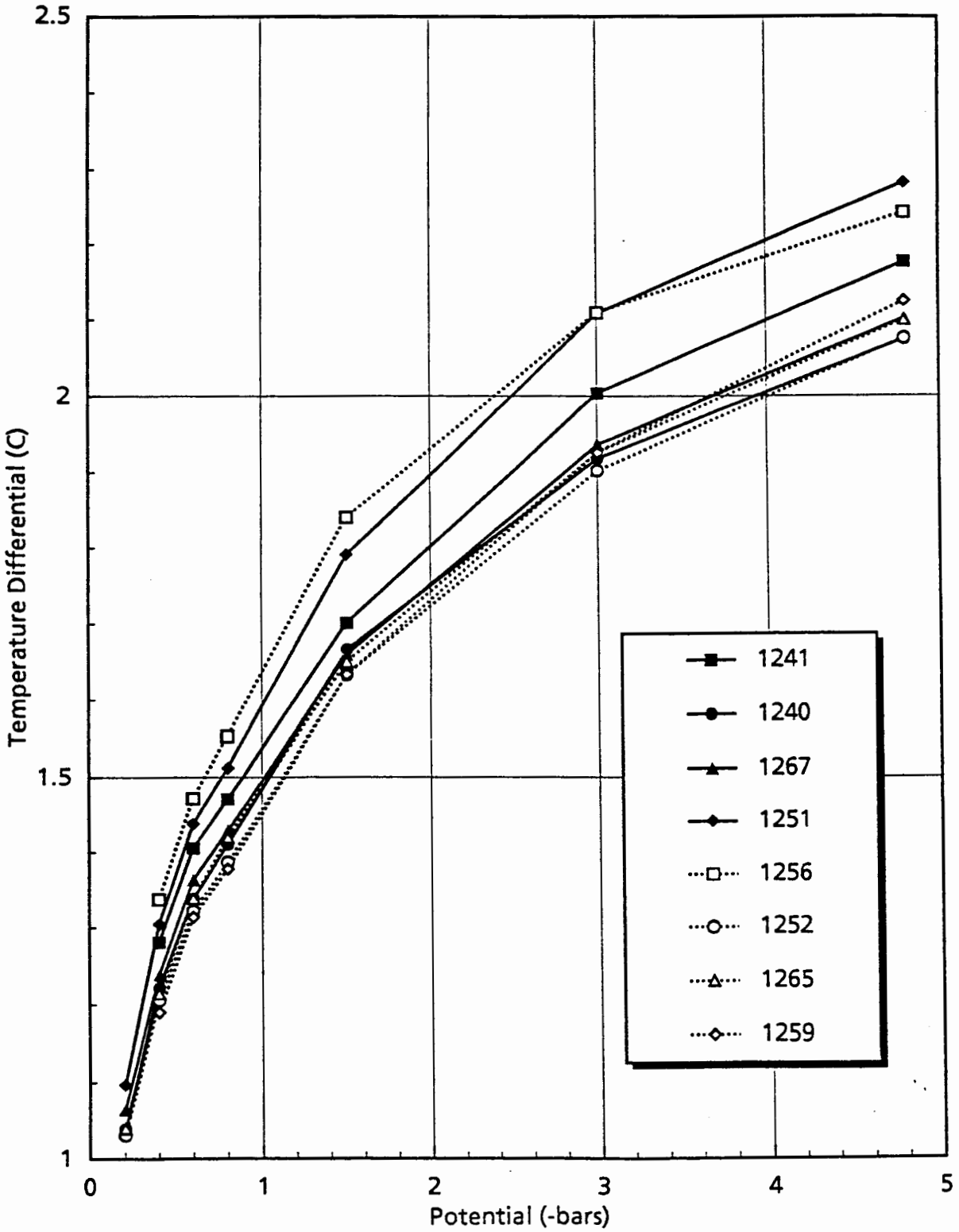
Bars	1241	1240	1267	1251	1256	1252	1265	1259
0	0.700	0.666	0.683	0.674	0.708	0.641	0.658	0.649
0.20	0.708	1.039	1.065	1.097	0.707	1.031	1.040	0.633
0.40	1.281	1.222	1.239	1.305	1.338	1.205	1.214	1.189
0.60	1.406	1.338	1.364	1.438	1.472	1.322	1.339	1.314
0.80	1.471	1.411	1.429	1.512	1.553	1.387	1.420	1.378
1.5	1.701	1.666	1.659	1.791	1.841	1.633	1.650	1.633
3.0	2.004	1.919	1.937	2.109	2.110	1.903	1.927	1.927
4.8	2.176	2.075	2.102	2.282	2.242	2.076	2.100	2.125

Least Squares Fitted Parameters

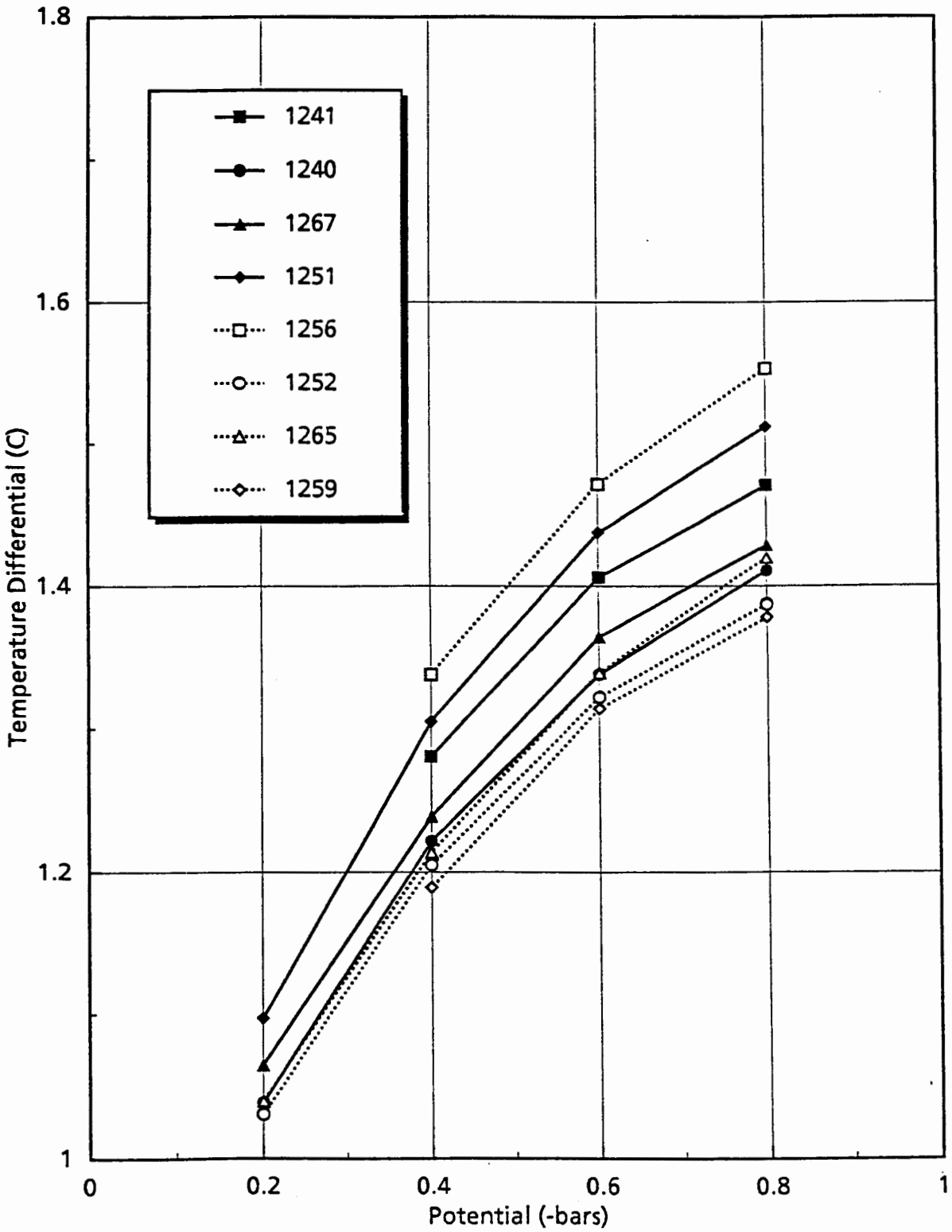
Exponential Model: -bars = a * exp (b * diff. temperature), n = no. obs.

	All points (unshaded)				Points to -0.8 bar			
	n	a	b	r2	n	a	b	r2
1241	6	1.362E-2	2.709	0.9941	3	3.961E-3	3.594	0.9932
1240	7	1.056E-2	2.968	0.9936	4	4.271E-3	3.705	0.9997
1267	7	9.855E-3	2.976	0.9917	4	3.733E-3	3.748	0.9979
1251	7	1.365E-2	2.590	0.9917	4	5.350E-3	3.300	0.9990
1256	6	1.225E-2	2.637	0.9960	3	5.462E-3	3.204	0.9981
1252	7	1.143E-2	2.947	0.9904	4	3.808E-3	3.847	0.9989
1265	7	1.140E-2	2.912	0.9924	4	4.690E-3	3.628	0.9978
1259	6	2.010E-2	2.599	0.9940	3	5.412E-3	3.609	0.9925

Heat Dissipation Probe Calibration
LANL Townsite / 4848, Run No. 3



Heat Dissipation Probe Calibration
LANL Townsite / 4848, Run No. 3
(Potentials to -0.8 bar)



Summary of Heat Dissipation Probe Calibration Data

Run Number 4

Equilibrium Differential Temperature Data

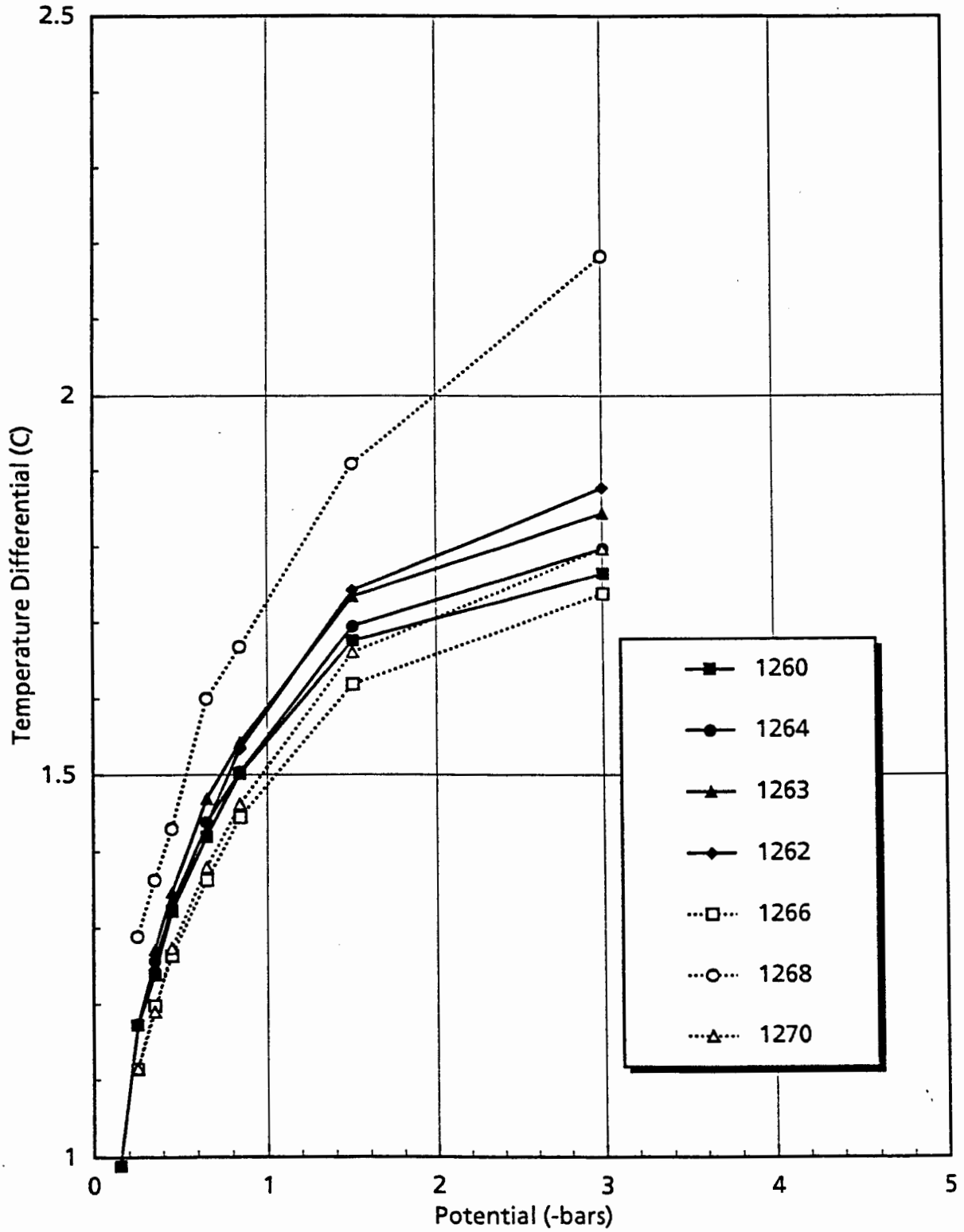
Bars	1260	1264	1263	1262	1266	1268	1270
0	0.707	0.724	0.740	0.707	0.699	0.790	0.666
0.15	0.989	0.699	0.731	0.698	0.682	0.757	0.649
0.25	1.172	1.173	0.724	0.682	1.114	1.289	1.115
0.35	1.239	1.257	1.272	1.246	1.198	1.363	1.190
0.45	1.322	1.323	1.347	1.330	1.264	1.430	1.274
0.65	1.420	1.438	1.469	1.436	1.363	1.600	1.380
0.84	1.502	1.504	1.543	1.534	1.445	1.668	1.462
1.5	1.676	1.695	1.734	1.742	1.619	1.909	1.661
3.0	1.764	1.797	1.844	1.877	1.738	2.183	1.797

Least Squares Fitted Parameters

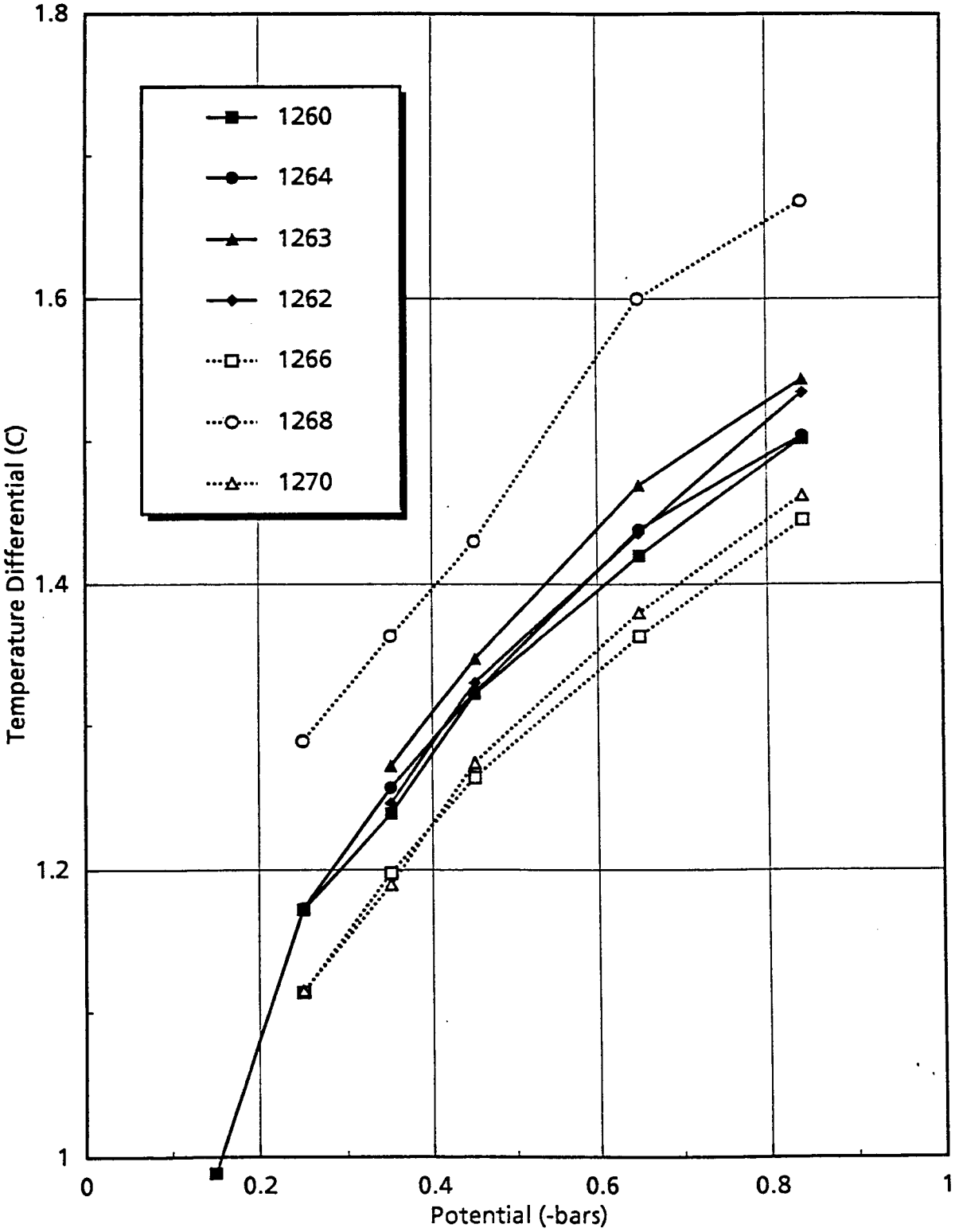
Exponential Model: -bars = a * exp (b * diff. temperature), n = no. obs.

	All points (unshaded)				Points to -0.84 bar			
	n	a	b	r2	n	a	b	r2
1260	7	3.402E-3	3.720	0.9858	5	4.862E-3	3.430	0.9954
1264	7	3.035E-3	3.755	0.9884	5	3.745E-3	3.599	0.9982
1263	6	3.514E-3	3.579	0.9837	4	6.038E-3	3.194	0.9993
1262	6	5.830E-3	3.264	0.9890	4	7.483E-3	3.088	0.9972
1266	7	3.584E-3	3.807	0.9929	5	4.247E-3	3.676	0.9981
1268	7	8.814E-3	2.690	0.9934	5	5.728E-3	2.989	0.9806
1270	7	5.402E-3	3.463	0.9935	5	5.629E-3	3.435	0.9962

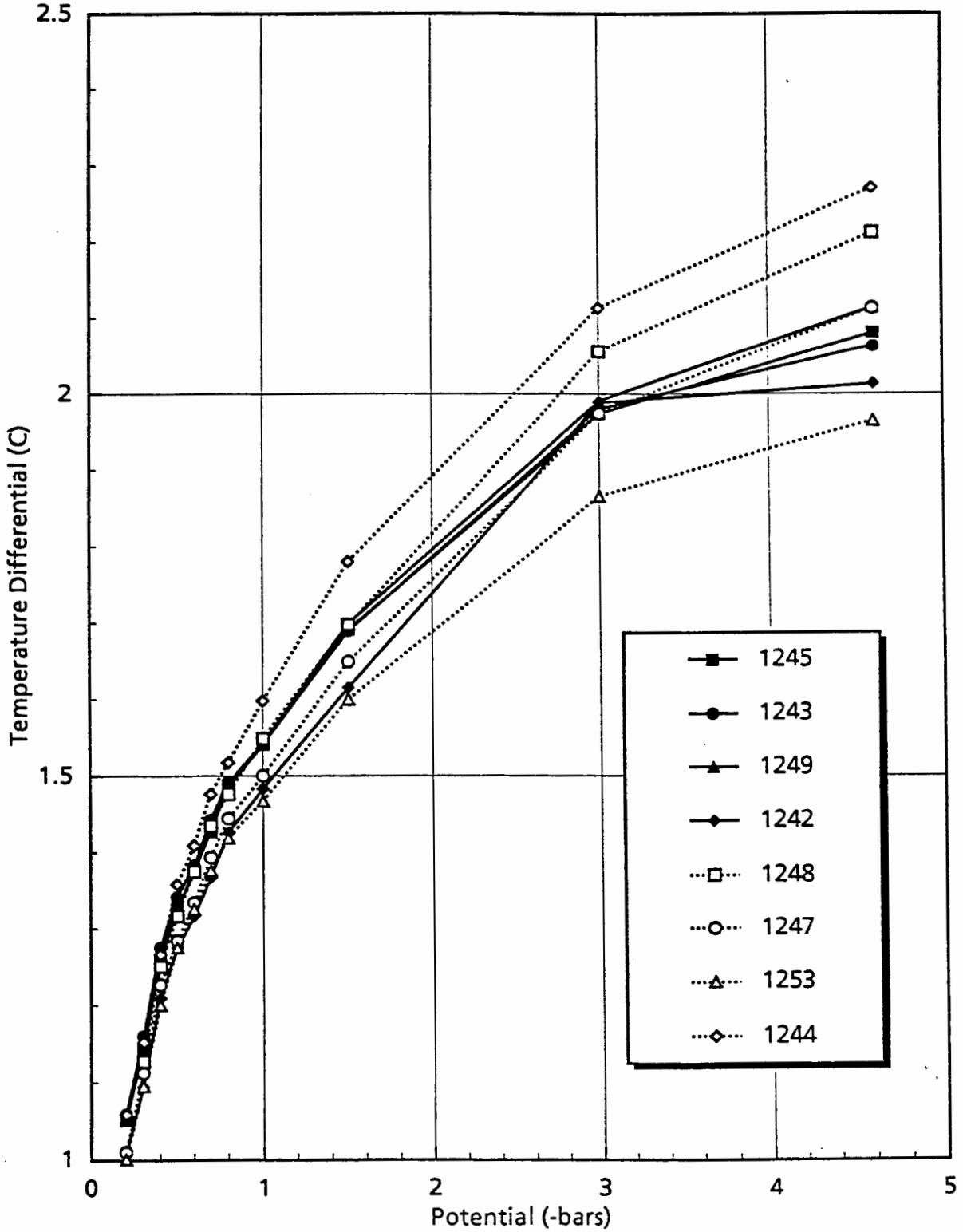
Heat Dissipation Probe Calibration
LANL Townsite / 4848, Run No. 4



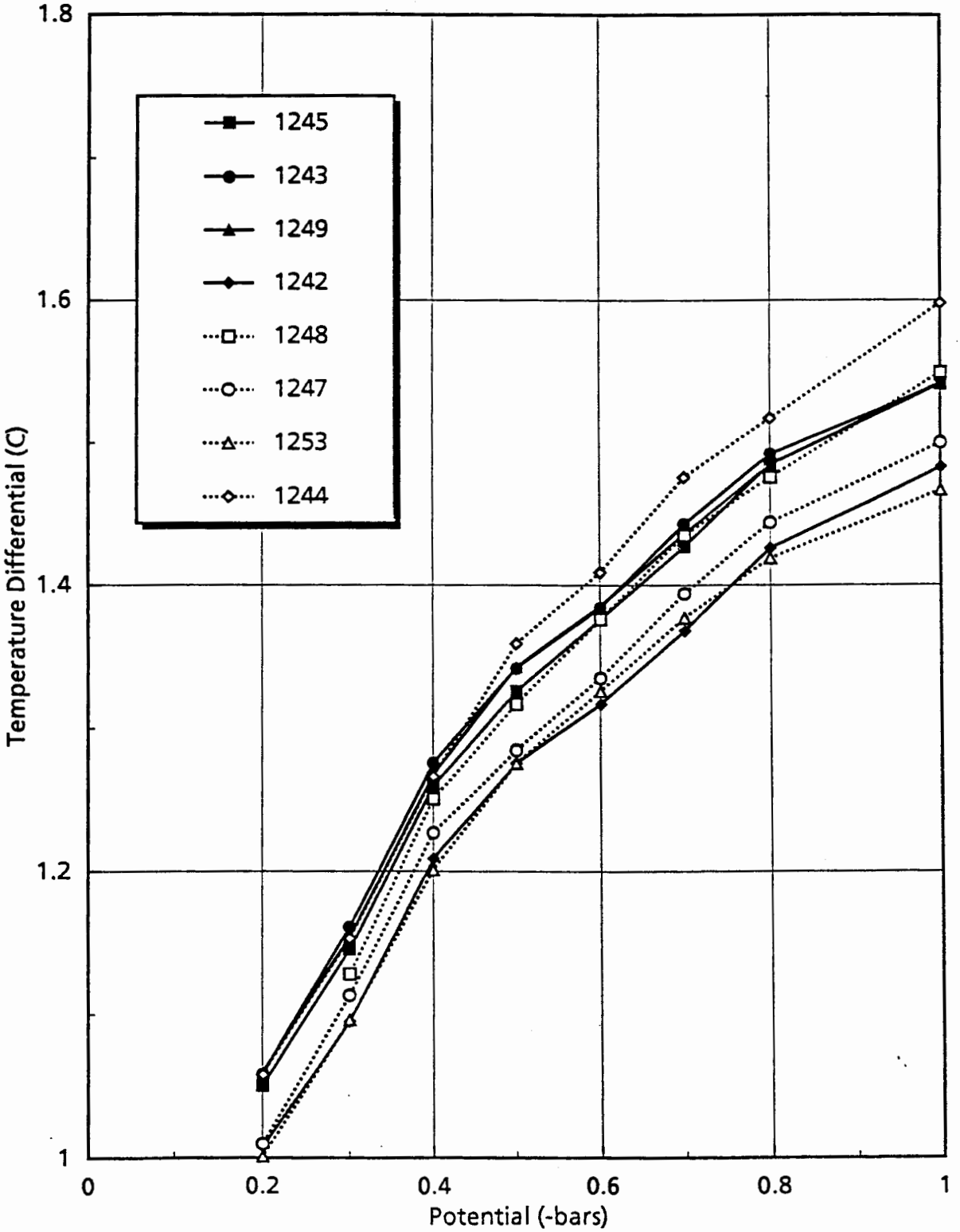
Heat Dissipation Probe Calibration
LANL Townsite / 4848, Run No. 4
(Potentials to -0.84 bar)



Heat Dissipation Probe Calibration
LANL Townsite / 4848, Run No. 1



Heat Dissipation Probe Calibration
LANL Townsite / 4848, Run No. 1
(Potentials to -1 bar)



APPENDIX C

SPECIALTY GAS CERTIFICATE AND LABORATORY QA RESULTS

Hall Environmental Analysis Laboratory

Hall Environmental Analysis Laboratory
2403 San Mateo NE, Suite P-13
Albuquerque, NM 87110

8/30/94

Daniel B. Stephens and Associates, Inc.
6020 Academy NE, Suite 100
Albuquerque, NM 87109

Dear Mr. Rolf Schmidt - Peterson,

Enclosed are the results for the analyses that were requested. These were done according to EPA procedures or the equivalent.

Detection limits are determined by EPA methodology. No determination of compounds below these levels (denoted by the < sign) has been made.

Please don't hesitate to contact me for any additional information or clarifications.

Sincerely,

Scott Hallenbeck 9/2/94

Scott Hallenbeck, Lab Manager

Project: LANL Landfill

Results for sample: Lysimeter 8

Date collected: 8/26/94	Date received: 8/26/94
Date extracted: NA	Date analyzed: 8/29/94
Client: Daniel B. Stephens and Associates, Inc.	
Project Name: LANL Landfill	HEAL #: 9408072-1
Project Manager: Rolf Schmidt - Peterson	Sampled by: JRL
Matrix: Aqueous	

Test: EPA 8010/8020

Analyte:	Units: PPB (UG/L)	Detection Limit
Benzene	nd	0.5
Bromodichloromethane	nd	0.2
Bromoform	nd	1.0
Bromomethane	nd	1.0
Carbon Tetrachloride	nd	0.2
Chlorobenzene	nd	0.2
Chloroethane	nd	0.2
Chloroform	1.9	0.2
Chloromethane	nd	0.2
2-Chloroethylvinyl Ether	nd	1.0
Dibromochloromethane	nd	0.2
1,3-Dichlorobenzene	nd	0.2
1,2-Dichlorobenzene	nd	0.2
1,4-Dichlorobenzene	nd	0.2
Dichlorodifluoromethane	nd	0.2
1,1-Dichloroethane	nd	0.2
1,2-Dichloroethane	nd	0.2
1,1-Dichloroethene	nd	0.2
cis-1,2-Dichloroethene	nd	0.2
trans-1,2-Dichloroethene	nd	0.2
1,2-Dichloropropane	nd	0.2
cis-1,3-Dichloropropene	nd	0.2
trans-1,3-Dichloropropene	nd	0.2
Ethylbenzene	nd	0.2
Dichloromethane	nd	2.0
1,1,2,2-Tetrachloroethane	nd	0.2
Tetrachloroethene (PCE)	nd	0.2
Toluene	nd	0.5
1,1,1-Trichloroethane	nd	0.2
1,1,2-Trichloroethane	nd	0.2
Trichloroethene (TCE)	nd	0.2
Vinyl Chloride	nd	0.2
Xylenes (Total)	nd	0.5
Trichlorofluoromethane	nd	0.2

BFB (Surrogate) Recovery = 89 %
BCM (Surrogate) Recovery = 92 %
Dilution Factor = 1

Results for sample: Trip Blank

Date collected: 8/24/94	Date received: 8/26/94
Date extracted: NA	Date analyzed: 8/29/94
Client: Daniel B. Stephens and Associates, Inc.	
Project Name: LANL Landfill	HEAL #: 9408072-2
Project Manager: Rolf Schmidt - Peterson	Sampled by: JRL
Matrix: Aqueous	

Test: EPA 8010/8020

Analyte:	Units: PPB (UG/L)	Detection Limit
Benzene	nd	0.5
Bromodichloromethane	nd	0.2
Bromoform	nd	1.0
Bromomethane	nd	1.0
Carbon Tetrachloride	nd	0.2
Chlorobenzene	nd	0.2
Chloroethane	nd	0.2
Chloroform	nd	0.2
Chloromethane	nd	0.2
2-Chloroethylvinyl Ether	nd	1.0
Dibromochloromethane	nd	0.2
1,3-Dichlorobenzene	nd	0.2
1,2-Dichlorobenzene	nd	0.2
1,4-Dichlorobenzene	nd	0.2
Dichlorodifluoromethane	nd	0.2
1,1-Dichloroethane	nd	0.2
1,2-Dichloroethane	nd	0.2
1,1-Dichloroethene	nd	0.2
cis-1,2-Dichloroethene	nd	0.2
trans-1,2-Dichloroethene	nd	0.2
1,2-Dichloropropane	nd	0.2
cis-1,3-Dichloropropene	nd	0.2
trans-1,3-Dichloropropene	nd	0.2
Ethylbenzene	nd	0.5
Dichloromethane	nd	2.0
1,1,2,2-Tetrachloroethane	nd	0.2
Tetrachloroethene (PCE)	nd	0.2
Toluene	nd	0.5
1,1,1-Trichloroethane	nd	0.2
1,1,2-Trichloroethane	nd	0.2
Trichloroethene (TCE)	nd	0.2
Vinyl Chloride	nd	0.2
Xylenes (Total)	nd	0.5
Trichlorofluoromethane	nd	0.2

BFB (Surrogate) Recovery = 92 %
BCM (Surrogate) Recovery = 108 %
Dilution Factor = 1

Results for QC: Reagent Blank

Date extracted: NA	Date analyzed: 8/29/94
Client: Daniel B. Stephens and Associates, Inc.	
Project Name: LANL Landfill	HEAL #: RB 8/29
Project Manager: Rolf Schmidt - Peterson	
Matrix: Aqueous	

Test: EPA 8010/8020

Analyte:	Units: PPB (UG/L)	Detection Limit
Benzene	nd	0.5
Bromodichloromethane	nd	0.2
Bromoform	nd	1.0
Bromomethane	nd	1.0
Carbon Tetrachloride	nd	0.2
Chlorobenzene	nd	0.2
Chloroethane	nd	0.2
Chloroform	nd	0.2
Chloromethane	nd	0.2
2-Chloroethylvinyl Ether	nd	1.0
Dibromochloromethane	nd	0.2
1,3-Dichlorobenzene	nd	0.2
1,2-Dichlorobenzene	nd	0.2
1,4-Dichlorobenzene	nd	0.2
Dichlorodifluoromethane	nd	0.2
1,1-Dichloroethane	nd	0.2
1,2-Dichloroethane	nd	0.2
1,1-Dichloroethene	nd	0.2
cis-1,2-Dichloroethene	nd	0.2
trans-1,2-Dichloroethene	nd	0.2
1,2-Dichloropropane	nd	0.2
cis-1,3-Dichloropropene	nd	0.2
trans-1,3-Dichloropropene	nd	0.2
Ethylbenzene	nd	0.5
Dichloromethane	nd	2.0
1,1,2,2-Tetrachloroethane	nd	0.2
Tetrachloroethene (PCE)	nd	0.2
Toluene	nd	0.5
1,1,1-Trichloroethane	nd	0.2
1,1,2-Trichloroethane	nd	0.2
Trichloroethene (TCE)	nd	0.2
Vinyl Chloride	nd	0.2
Xylenes (Total)	nd	0.5
Trichlorofluoromethane	nd	0.2

BFB (Surrogate) Recovery = 98 %
BCM (Surrogate) Recovery = 91 %
Dilution Factor = 1

Results for QC: Blank Spike / Blank Spike Dup

Date extracted: NA	Date analyzed: 8/29/94
Client: Daniel B. Stephens and Associates, Inc.	
Project Name: LANL Landfill	HEAL #: BS/BSD 8/29
Project Manager: Rolf Schmidt - Peterson	
Matrix: Aqueous	Units: PPB (UG/L)

Test: EPA 8010/8020

Compound	Sample Result	Amount Added	Blank Spike	BS %	BS Dup	BSD %	RPD
Chlorobenzene	<0.2	20.0	20.5	103	20.8	104	1
Ethylbenzene	<0.5	20.0	20.6	103	20.7	104	0
1,1-DCE	<0.2	20.0	18.5	93	17.9	90	3
trans-1,2-DCE	<0.2	20.0	18.2	91	19.5	98	7
Carbon tet.	<0.2	20.0	18.4	92	19.9	100	8
1,2-DCA	<0.2	20.0	19.8	99	21.7	109	9
1,2-dichloro-propane	<0.2	20.0	18.3	92	20.2	101	10
1,1,2-TCA	<0.2	20.0	17.2	86	20.1	101	16
PCE	<0.2	20.0	17.7	89	21.2	106	18
1,3-dichloro-benzene	<0.2	20.0	19.6	98	20.0	100	2
1,4-dichloro-benzene	<0.2	20.0	20.2	101	20.2	101	0

Scott Specialty Gases

Shipped From: 6141 EASTON ROAD PO BOX 310
PLUMSTEADVILLE PA 18949-0310
Phone: 215-766-8861 Fax: 215-766-2070

CERTIFICATE OF ANALYSIS

DANIEL B STEPHENS & ASSOC
ATTN: JEFF FORBES
ERM/GOLDER
555 OPPENHEIMER DRIVE
LOS ALAMOS NM 87544

PROJECT #: 01-65459-001
PO#: 12054
ITEM #: 01046676 4EL
DATE: 2/22/95

CYLINDER #: S-IV-EL

ANALYTICAL ACCURACY: +/- 2%

COMPONENT	REQUESTED GAS CONC		ANALYSIS (MOLES)	
CIS 1,2-DICHLOROETHYLENE	10.	PPM	10.6	PPM
1,2-DIBROMOETHANE (EDB)	10.	PPM	10.7	PPM
1,1-DICHLOROETHANE	10.	PPM	10.8	PPM
1,2-DICHLOROETHANE (EDC)	10.	PPM	9.98	PPM
TETRACHLOROETHYLENE	10.	PPM	10.7	PPM
1,1,1-TRICHLOROETHANE	10.	PPM	10.2	PPM
VINYL CHLORIDE	10.	PPM	10.6	PPM
VINYLIDENE CHLORIDE	10.	PPM	10.8	PPM
NITROGEN		BALANCE		BALANCE

ANALYST: Walter Sabitus
WALTER SABITUS

APPENDIX D

ESE LABORATORY CASE NARRATIVES

APPENDIX D
ESE CASE NARRATIVES

This appendix contains case narratives provided by the Environmental Science & Engineering, Inc. (ESE), laboratory in Gainesville, Florida, regarding the February and March 1995 soil gas analyses. The data provided by ESE are currently undergoing data validation at Los Alamos National Laboratory; therefore, all ESE data provided in this report should be considered preliminary.

February 1995

Environmental
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CASE NARRATIVE

Request Numbers: 21386, 21397, 21413, 21416

Analyses: Volatiles - *Method TO14 - Determination of Volatile Organic Compounds (VOCs) in Ambient Air Using SUMMA Passivated Canister Sampling and Gas Chromatographic Analysis.* - EPA, 6/88, Rev. 1.0

Fixed Gasses - *Method 133 - Determination of O_2, N_2, CO_2, and CH_4 (Gas Chromatographic Method)* - Methods of Air Sampling and Analysis, Third Edition, 1989, James P. Lodge, Jr., editor

Thirty-five Summa canisters were received between 2/21/95 and 2/25/95 at ambient temperature and in intact containers with intact custody seals. All samples were accompanied by proper chain of custody documentation. All samples but 95.04043-1 and 95.4044-1 were accompanied by field data sheets.

Although these samples were delivered under four LANL request numbers they are samples of one project and are reported as one deliverable. All samples were requested for the two above mentioned analyses and all samples were analyzed within all established holding times.

Table 1, following, cross references the LANL samples ID numbers, the field ID of the samples and the ESE laboratory ID of the samples. Also listed are the ESE method specific laboratory batch numbers where the data for a given sample can be found. The sample data are summarized for all batches without raw data and ordered by LANL sample ID in section C. Sample Data Summary. The following is a brief discussion of data quality control for each ESE batch:

Volatile Organic Compounds EPA Method TO14 - Batch G59087

The samples were analyzed February 29, 1995 on a Finnigan MAT INCOS 50 GC/MS using a cryofocusing inlet and with a 0.32 mm x 30 M DB-1, 1.0 um film column installed. Initial calibration was performed February 26, 1995 with the analysis of 6 standards ranging from 0.05 to 10.0 PPB concentration. A CCS and a NIST reference samples were analyzed before the run began. The method blank had a positive value of 3.84 PPBV for chloromethane. The NIST reference recoveries ranged from 90.6 - 117.3%. Internal standards were well within limits. All samples were collected in SUMMA canisters and received at a slight vacuum. They were all initially pressurized to give a 1:2 dilution to allow withdrawal of samples for the fixed gasses reported

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elsewhere in this document after the TO14 analyses were completed. All samples in this batch were reported at 1:20 dilution.

Volatile Organic Compounds EPA Method TO14 - Batch G59088

The samples were analyzed March 1, 1995 on a Finnigan MAT INCOS 50 GC/MS using a cryofocusing inlet with a 0.32 mm x 30 M DB-1, 1.0 um film column installed. Initial calibration was performed February 26, 1995 with the analysis of 6 standards ranging from 0.05 to 10.0 PPB concentration. A CCS and a NIST reference samples were analyzed before the run began. The method blank had a positive value of 4.14 PPBV for chloromethane. The NIST reference recoveries ranged from 92.5 - 119.6%. Internal standard areas were all within the limits except sample 95.04043, which failed for low recoveries of bromomethane-d3 and 1,4-difluorobenzene. All samples were collected in SUMMA canisters and received at a slight vacuum. They were all initially pressurized to give a 1:2 dilution to allow withdrawal of samples for the fixed gasses reported elsewhere in this document after the TO14 analyses were completed. Samples in this batch were reported at 1:20 dilution.

Volatile Organic Compounds EPA Method TO14 - Batch G59132

The samples were analyzed within holding time March 2, 1995 on a Finnigan MAT INCOS 50 GC/MS with a 0.32 mm x 30 M DB-1, 1.0 um film column installed.. Initial calibration was performed February 26, 1995 with the analysis of 6 standards ranging from 0.05 to 10.0 PPB concentration. A CCS and a NIST reference samples were analyzed before the run began. The method blank had a positive value of 3.34 PPBV for chloromethane. The NIST reference recoveries ranged from 90.6 - 115.4%. Sample 95.03900 (!LAIR1*7) was analyzed in duplicate and the maximum difference was 12.1%. Internal standard areas were all within the limits. All samples were collected in SUMMA canisters and received at a slight vacuum. They were all initially pressurized to give a 1:2 dilution to allow withdrawal of samples for the fixed gasses reported elsewhere in this document after the TO14 analyses were completed. Samples in this batch were reported at dilutions ranging from 1:20 to 1:1000.

Volatile Organic Compounds EPA Method TO14 - Batch G59133

The samples were analyzed within holding time March 2, 1995 and over midnight to March 3, 1995 on a Finnigan MAT INCOS 50 GC/MS with a 0.32 mm x 30 M DB-1, 1.0 um film column installed. Initial calibration was performed February 26, 1995 with the analysis of 6 standards ranging from 0.05 to 10.0 PPB concentration. A CCS and a NIST reference samples were analyzed before the run began. The method blank had a positive value of 3.58 PPBV for chloromethane. The NIST reference recoveries ranged from 94.3 - 113.5%. Sample 95.03897 (!LAIR1*14) was analyzed in duplicate

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and the maximum difference was 13.4 %. Internal standard areas were all well within the limits. All samples were collected in SUMMA canisters and received at a slight vacuum. They were all initially pressurized to give a 1:2 dilution to allow withdrawal of samples for the fixed gasses reported elsewhere in this document after the TO14 analyses were completed. All samples in this batch were reported at either 1:100 or 1:100 dilution due to the levels of contamination found.

Volatile Organic Compounds EPA Method TO14 - Batch G59186

The samples were analyzed within holding time March 3, 1995 and over midnight to March 4, 1995 on a Finnigan MAT INCOS 50 GC/MS with a 0.32 mm x 30 M DB-1, 1.0 um film column installed. Initial calibration was performed February 26, 1995 with the analysis of 6 standards ranging from 0.05 to 10.0 PPB concentration. A CCS and a NIST reference samples were analyzed before the run began. The method blank had a positive value of 4.94 PPBV for chloromethane. The NIST reference recoveries ranged from 88.7 - 115.1%. Sample 95.04000 (!LAIR1*23) was analyzed in duplicate and the maximum difference was 36.6% for chloromethane. Internal standard areas were all well within the limits. All samples were collected in SUMMA canisters and received at a slight vacuum. They were all initially pressurized to give a 1:2 dilution to allow withdrawal of samples for the fixed gasses reported elsewhere in this document after the TO14 analyses were completed. Samples in this batch were reported at various dilutions due to the levels of contamination.

Fixed Gasses - Batch G59142 (O_2, N_2, CO_2, CH_4)

The samples were analyzed within holding time March 7, 1995 on a Hewlett-Packard model HP5890 II gas chromatograph with a thermal conductivity detector installed. Sample replicates of 95.03889 (!LAIR1*8) and 95.04004 (!LAIR1*27) were analyzed March 15, 1995. The samples were analyzed in accordance with *Method 133 - Determination of O_2, N_2, CO_2, and CH_4 (Gas Chromatographic Method)* of Methods of Air Sampling and Analysis, Third Edition, 1989, James P. Lodge, editor. The column installed in the instrument was a 1/8" X 30' stainless steel packed with Alltech Gas Chrom M/P 100/120 mesh packing material. Initial calibration was performed by single level calibration against a Scott Gas 5 PPB standard and a response factor was determined. An initial calibration verification standard was run before the samples during daily analytical run and continuing calibration standards were run every 10 samples. A standard matrix spike (the Scott Gas standard) was analyzed. Samples 95.03889 (!LAIR1*8) and 95.04004 (!LAIR1*27) were analyzed in duplicate and the maximum difference was 185% for oxygen. Oxygen was somewhat problematic during this analysis due to the high levels of volatile organic contaminants in the samples and scavenging by the analytical column. Analysts's comments for each batch this narrative. All samples were collected in SUMMA canisters and received at a

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slight vacuum. They were all initially pressurized to give a 1:2 dilution for to allow withdrawal of samples for these fixed gas analyses after the TO14 analyses were completed. This was considered during the calculations and the results are reported as percent levels. The raw strip chart data for all fixed gasses and for all ESE batches are provided in chronological order at the end of this ESE batch in the other relevant documents section.

Fixed Gasses - Batch G59167 (O_2, N_2, CO_2, CH_4)

The samples were analyzed within holding time March 8, 1995 on a Hewlett-Packard model HP5890 II gas chromatograph with a thermal conductivity detector installed. Samples 95.04013 (!LAIR1*34) was analyzed March 14, 1995. This sample was omitted during the scheduled analyses and sample 95.04005 (!LAIR1*33) was mistakenly analyzed twice. These samples were analyzed separately for hydrogen and the methane reported here is from that analytical run. The samples were analyzed in accordance with *Method 133 - Determination of O_2, N_2, CO_2, and CH_4 (Gas Chromatographic Method)* of Methods of Air Sampling and Analysis, Third Edition, 1989, James P. Lodge, editor. The column installed in the instrument was a 1/8" X 30' stainless steel packed with Alltech Gas Chrom M/P 100/120 mesh packing material. Initial calibration was performed by single level calibration against a Scott Gas 5 PPB standard and a response factor was determined. An initial calibration verification standard was run before the samples during daily analytical run and continuing calibration standards were run every 10 samples. Two standard matrix spike (the Scott Gas standard) were analyzed. Sample 95.03997 (!LAIR1*33) was analyzed in duplicate and the maximum difference was 8.1%. Oxygen was somewhat problematic during this analysis due to the high levels of volatile organic contaminants in the samples and scavenging by the analytical column. The continuing calibration standards reflected this. Analyst's comments for each batch follow this narrative. All samples were collected in SUMMA canisters and received at a slight vacuum. They were all initially pressurized to give a 1:2 dilution for to allow withdrawal of samples for these fixed gas analyses after the TO14 analyses were completed. This was considered during the calculations and the results are reported as percent levels.

Fixed Gasses - Batch G59388 (H_2)

The samples were analyzed within holding time March 13 and 14, 1995 on a Hewlett-Packard model HP5890 II gas chromatograph with a thermal conductivity detector installed. The samples were analyzed in accordance with *Method 133 - Determination of O_2, N_2, CO_2, and CH_4 (Gas Chromatographic Method)* of Methods of Air Sampling and Analysis, Third Edition, 1989, James P. Lodge, editor. The column installed in the instrument was a 1/8" X 30' stainless steel packed with Alltech Gas Chrom M/P 100/120 mesh packing material. Initial calibration was performed by single level calibration against a Scott Gas 5 PPB standard and a response factor was determined.

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An initial calibration verification standard was run before the samples during daily analytical run and continuing calibration standards were run every 10 samples. Two standard matrix spikes (the Scott Gas standard) were analyzed. All quality control parameters were well within limits. Analyst's comments for each batch follow this narrative. All samples were collected in SUMMA canisters and received at a slight vacuum. They were all initially pressurized to give a 1:2 dilution for to allow withdrawal of samples for these fixed gas analyses after the TO14 analyses were completed. This was considered during the calculations and the results are reported as percent levels.

Fixed Gasses - Batch G58850 (O_2, N_2, CO_2, CH_4)

The samples were analyzed within holding time March 15, 1995 on a Hewlett-Packard model HP5890 II gas chromatograph with a thermal conductivity detector installed. The method blank was analyzed March 1, 1995 and samples 95.03886 (!LAIR1*10) and 95.03894 (!LAIR1*11) were analyzed March 2, 1995. The samples were analyzed in accordance with *Method 133 - Determination of O_2, N_2, CO_2, and CH_4 (Gas Chromatographic Method)* of Methods of Air Sampling and Analysis, Third Edition, 1989, James P. Lodge, editor. The column installed in the instrument was a 1/8" X 30' stainless steel packed with Alltech Gas Chrom M/P 100/120 mesh packing material. Initial calibration was performed by single level calibration against a Scott Gas 5 PPB standard and a response factor was determined. An initial calibration verification standard was run before the samples during daily analytical run and continuing calibration standards were run every 10 samples. Analyst's comments for each batch follow this narrative. All samples were collected in SUMMA canisters and received at a slight vacuum. They were all initially pressurized to give a 1:2 dilution for to allow withdrawal of samples for these fixed gas analyses after the TO14 analyses were completed. This is considered during the calculations and the results are reported as percent levels.

March 29, 1995

ENVIRONMENTAL SCIENCE & ENGINEERING

Edward H. Mansfield
Chemistry Project Manager

file: I:\temp\lanlnarr\21386

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Table 1. Cross Reference of Lab Sample ID, LANL Sample ID and Lab Batch Number

ESE FLD.GRP.	#	LANL SAMPLE ID	COLLECTION DATE	TIME	LANL REQUEST #	LANL C-O-C #	LANL FIELD ID #	SUMMA CANNISTER #	FIXED GASSES LAB BATCH #	TO14 LAB BATCH #
!LAIR1	1	95.03839	02/21/95	12:35	21386	AAC3233	LP-5	GL079	G59142	G59133
!LAIR1	2	95.03840	02/21/95	13:45	21386	AAC3234	LP-1/GP-1	GL106	G58850	G59087
!LAIR1	3	95.03841	02/21/95	14:05	21386	AAC3235	LP-1/GP-2	GL114	G58850	G59087
!LAIR1	4	95.03842	02/21/95	14:55	21386	AAC3236	LP-2	GL061	G58850	G59087
!LAIR1	16	95.03885	02/22/95	09:00	21397	AAC3237	LP-3/GP-1	GL064	G59142	G59133
!LAIR1	10	95.03886	02/22/95	09:35	21397	AAC3238	LP-3/GP-2	GL098	G58850	G59132
!LAIR1	9	95.03887	02/22/95	09:50	21397	AAC3239	LP-3/GP-3	26	G59142	G59132
!LAIR1	20	95.03888	02/22/95	10:05	21397	AAC3240	LP-3/GP-4	GL030	G59142	G59133
!LAIR1	8	95.03889	02/22/95	11:05	21397	AAC3241	LPS-2/GP-1	GL091	G59142	G59133
!LAIR1	12	95.03890	02/22/95	11:20	21397	AAC3242	LPS-2/GP-2	GL006	G58850	G59132
!LAIR1	15	95.03891	02/22/95	11:35	21397	AAC3243	LPS-2/GP-3	GL110	G59142	G59186
!LAIR1	5	95.03892	02/22/95	11:55	21397	AAC3244	LPS-2/GP-4	GL011	G59142	G59186
!LAIR1	13	95.03893	02/22/95	11:55	21397	AAC3245	LPS-2/GP-4	GL059	G59142	G59186
!LAIR1	11	95.03894	02/22/95	13:55	21397	AAC3246	LP-4/GP-1	GL111	G58850	G59132
!LAIR1	19	95.03895	02/22/95	14:10	21397	AAC3247	LP-4/GP-2	22	G59142	G59133
!LAIR1	18	95.03896	02/22/95	14:20	21397	AAC3248	LP-4/GP-3	GL113	G59142	G59133
!LAIR1	14	95.03897	02/22/95	14:35	21397	AAC3249	LP-4/GP-4	GL039	G59142	G59133
!LAIR1	6	95.03898	02/22/95	14:35	21397	AAC3250	LP-4/GP-4	GL014	G59142	G59132
!LAIR1	17	95.03899	02/22/95	15:45	21397	AAC3251	LP-9/GP-1	GL076	G59142	G59133
!LAIR1	7	95.03900	02/22/95	15:55	21397	AAC3252	LP-9/GP-2	GL046	G59142	G59132
!LAIR1	24	95.03993	02/23/95	10:10	21413	AAC3256	LP-7/GP-3	GL083	G59142	G59133
!LAIR1	32	95.03994	02/23/95	16:05	21413	AAC3264	LP-8/GP-2	GL026	G59167	G59088
!LAIR1	21	95.03995	02/23/95	08:30	21413	AAC3253	LP-6/GP-1	GL094	G59142	G59132
!LAIR1	28	95.03996	02/23/95	13:00	21413	AAC3260	LPS-1/GP-3	GL070	G59167	G59088
!LAIR1	33	95.03997	02/23/95	16:15	21413	AAC3265	LP-8/GP-3	GL042	G59167	G59132
!LAIR1	31	95.03998	02/23/95	15:53	21413	AAC3263	LP-8/GP-1	GL058	G59167	G59088
!LAIR1	25	95.03999	02/23/95	10:10	21413	AAC3257	LP-7/GP-3	GL003	G59142	G59186
!LAIR1	23	95.04000	02/23/95	09:50	21413	AAC3255	LP-7/GP-2	GL024	G59142	G59186
!LAIR1	22	95.04001	02/23/95	09:40	21413	AAC3254	LP-7/GP-1	GL060	G59142	G59133
!LAIR1	30	95.04002	02/23/95	13:27	21413	AAC3262	LPS-1/GP-5	GL087	G59167	G59088
!LAIR1	29	95.04003	02/23/95	13:17	21413	AAC3261	LPS-1/GP-4	GL129	G59167	G59088
!LAIR1	27	95.04004	02/23/95	12:30	21413	AAC3259	LPS-1/GP-2	GL044	G59142	G59088
!LAIR1	26	95.04005	02/23/95	12:15	21413	AAC3258	LPS-1/GP-1	GL092	G59142	G59186
!LAIR1	34	95.04043	02/24/95		21416	AAA3269	LP-10	GL072	G59167	G59088
!LAIR1	35	95.04044	02/24/95		21416	AAC3270	LP-11	GL097	G59167	G59186

March 1995

Environmental
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CASE NARRATIVE

Request Numbers: 21682, 21686, 21709

Analyses: Volatiles - *Method TO14 - Determination of Volatile Organic Compounds (VOCs) in Ambient Air Using SUMMA Passivated Canister Sampling and Gas Chromatographic Analysis.* - EPA, 6/88, Rev. 1.0

Fixed Gasses - *Method 133 - Determination of O_2, H_2, N_2, CO_2, and CH_4 (Gas Chromatographic Method)* - Methods of Air Sampling and Analysis, Third Edition, 1989, James P. Lodge, Jr., editor

Thirty-five Summa canisters were received between 3/30/95 and 3/31/95 at ambient temperature and in intact containers with intact custody seals. All samples were accompanied by proper chain of custody documentation.

Although these samples were delivered under three LANL request numbers they are samples of one project and are reported as one deliverable. All samples were requested for the two above mentioned analyses and all samples were analyzed within all established holding times.

All samples were collected in SUMMA canisters and received at a slight vacuum. They were all initially pressurized to give a 1:2 dilution to allow withdrawal of samples for the fixed gasses after the TO14 analyses were completed.

Table 1, following, cross references the LANL samples ID numbers, the field ID of the samples and the ESE laboratory ID of the samples. Also listed are the ESE method specific laboratory batch numbers where the data for a given sample can be found. All samples were analyzed for O_2, N_2, CO_2, and CH_4 in ESE batch G59998 and for H_2 in ESE batch G60215. The sample data are summarized for all batches without raw data and ordered by LANL sample ID in section C. Sample Data Summary. The following is a brief discussion of data quality control for each ESE batch:

Volatile Organic Compounds EPA Method TO14 - Batch G60274

The samples were analyzed April 1, 1995 on a Finnigan MAT INCOS 50 GC/MS using a cryofocusing inlet and with a 0.32 mm x 30 M DB-1, 1.0 um film column installed. Select samples were reanalyzed on April 4, 1995 at higher dilutions to bring the values within the standard curve. The initial calibration was performed March 26, 1995 with the analysis of 6 standards ranging from 0.05 to 10.0 PPB concentration.

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Continuing calibration standards (CCS) and National Institute of Standards & Technology (NIST) reference samples were analyzed before the run began. The method blank had no positive values when run April 1, 1995 but the method blank run April 4, 1995 had positive values for methylene chloride and toluene. The NIST reference recoveries ranged from 86.8 - 136.5%. Sample 95.06302 (LAIR2*8) was analyzed in duplicate and the maximum difference was 6.0%. Internal standards were well within limits. Samples in this batch were reported at 1:20 or 1:100 dilution.

Volatile Organic Compounds EPA Method TO14 - Batch G60276

The samples were analyzed April 2, 1995 on a Finnigan MAT INCOS 50 GC/MS using a cryofocusing inlet with a 0.32 mm x 30 M DB-1, 1.0 um film column installed. Select samples were reaalyzed April 4, 1995. Initial calibration was performed March 26, 1995 with the analysis of 6 standards ranging from 0.05 to 10.0 PPB concentration. CCS and NIST reference samples were analyzed before the run began. The method blank had a positive value of 3.86 PPBV for chloromethane. The NIST reference recoveries ranged from 88.7 - 150%. Sample 95.06296 (LAIR2*27) was analyzed in duplicate and the maximum difference was 4.6%. Internal standard areas were all within the limits. Samples in this batch were reported at 1:20 and 1:100 dilution.

Volatile Organic Compounds EPA Method TO14 - Batch G60370

The samples were analyzed within holding time April 4, 1995 on a Finnigan MAT INCOS 50 GC/MS with a 0.32 mm x 30 M DB-1, 1.0 um film column installed. The initial calibration was performed March 26, 1995 with the analysis of 6 standards ranging from 0.05 to 10.0 PPB concentration. CCS and NIST reference samples were analyzed before the run began. The method blank had a positive value of 17.7 for methylene chloride and 37.9 for toluene. The NIST reference recoveries ranged from 86.8 - 130.8%. Internal standard areas were all well within the limits. The samples in this batch were reported at 1:100, 1:200, 1:1000 and 1:10,000.

Volatile Organic Compounds EPA Method TO14 - Batch G60336

The samples were analyzed within holding time April 11, 1995 on a Finnigan MAT INCOS 50 GC/MS with a 0.32 mm x 30 M DB-1, 1.0 um film column installed. Select samples were reanalyzed at higher dilutions on April 14 and 15, 1995. The initial calibration was performed April 12, 1995 with the analysis of 6 standards ranging from 0.05 to 10.0 PPB concentration. CCS and NIST reference samples were analyzed before the run began. The method blank analyzed 4/11/95 had a positive value of 0.41 for toluene, the method blank analyzed 4/14/95 had a positive value of 17.3 for chloromethane and the method blank analyzed 4/15/95 had a positive value of

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2083 for chloromethane. The actual value found in the run is multiplied by the dilution factor so the actual concentration in the method blank was 0.208 PPBV. The NIST reference recoveries ranged from 83.0 - 103.8%. Sample 95.03600 (LAIR2*30) was analyzed in duplicate and the maximum difference was 5.0%. Internal standard areas were all within the limits. Samples in this batch were reported at dilutions ranging from 1:20 to 1:1000.

Volatile Organic Compounds EPA Method TO14 - Batch G60306

The samples were analyzed within holding time April 13, 1995 on a Finnigan MAT INCOS 50 GC/MS with a 0.32 mm x 30 M DB-1, 1.0 um film column installed. Select samples were reanalyzed at higher dilutions on April 14 and 15, 1995. The initial calibration was performed April 12, 1995 with the analysis of 6 standards ranging from 0.05 to 10.0 PPB concentration. CCS and NIST reference samples were analyzed before the run began. The method blank analyzed 4/13/95 had a positive value of 40 for toluene, 21.8 for chloromethane, 17.9 for methylene chloride and 5.6 for xylene. The method blank analyzed 4/15/95 had a positive value of 20.83 for chloromethane. The actual value found in the run is multiplied by the dilution factor so the actual concentration in the method blank was 0.208 PPBV. The NIST reference recoveries ranged from 88.7 - 113.5%. Sample 95.06482 (LAIR2*35) was analyzed in duplicate and the maximum difference was 10.7%. Internal standard areas were all within the limits. Samples in this batch were reported at dilutions ranging from 1:20 to 1:1000.

Fixed Gasses - Batch G59998 (O_2, N_2, CO_2, CH_4)

The samples were analyzed within holding time March 7, 1995 on a Hewlett-Packard model HP5890 II gas chromatograph with a thermal conductivity detector installed. The column installed in the instrument was a 1/8" X 30' stainless steel packed with Alltech Gas Chrom M/P 100/120 mesh packing material. Initial calibration was performed by a three time one level calibration against a Scott Gas 5 PPB standard and a response factor was determined. An initial calibration verification standard was run before the samples during daily analytical run and continuing calibration standards were run every 10 samples. Sample replicates of 95.06293 (LAIR2*2) and 95.06490 (LAIR2*16) were analyzed with a maximum difference of 2.1%. Standard matrix spikes of various Scott Gas standards were analyzed.

The values for oxygen that are below 2% are probably due to argon. These gasses elute from the column at approximately the same retention time, with oxygen slightly ahead of argon and cannot realistically be separated. Any appreciable level of oxygen, ie; greater than 5%, will mask the contribution of argon and leave a slight inflection in the peak due to the argon. A good illustration of this is the difference between

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samples 95.06478 (LAIR2*9) on pages 1586/1587 and 95.06326 (LAIR2*17) on pages 1590/1591. The concentration of oxygen in sample 95.06326 (*17) is approximately 8% and elutes at 4.55 minutes. The concentration of oxygen listed in 95.06478 (*9) is listed as 1% and elutes at 4.70 minutes. This is most likely argon and not oxygen.

Fixed Gasses - Batch G60215 (H_2)

The samples were analyzed within holding time March 13 and 14, 1995 on a Hewlett-Packard model HP5890 II gas chromatograph with a thermal conductivity detector installed. The column installed in the instrument was a 1/8" X 30' stainless steel packed with Alltech Gas Chrom M/P 100/120 mesh packing material. Initial calibration was performed by three times a single level calibration against a Scott Gas 5 PPB standard and a response factor was determined. An initial calibration verification standard was run before the samples during daily analytical run and continuing calibration standards were run every 10 samples. Standard matrix spikes of various Scott Gas standards were analyzed. All quality control parameters were well within limits.

April 27, 1995

ENVIRONMENTAL SCIENCE & ENGINEERING

Edward H. Mansfield
Chemistry Project Manager

file: I:\temp\lanlnarr\21682.air

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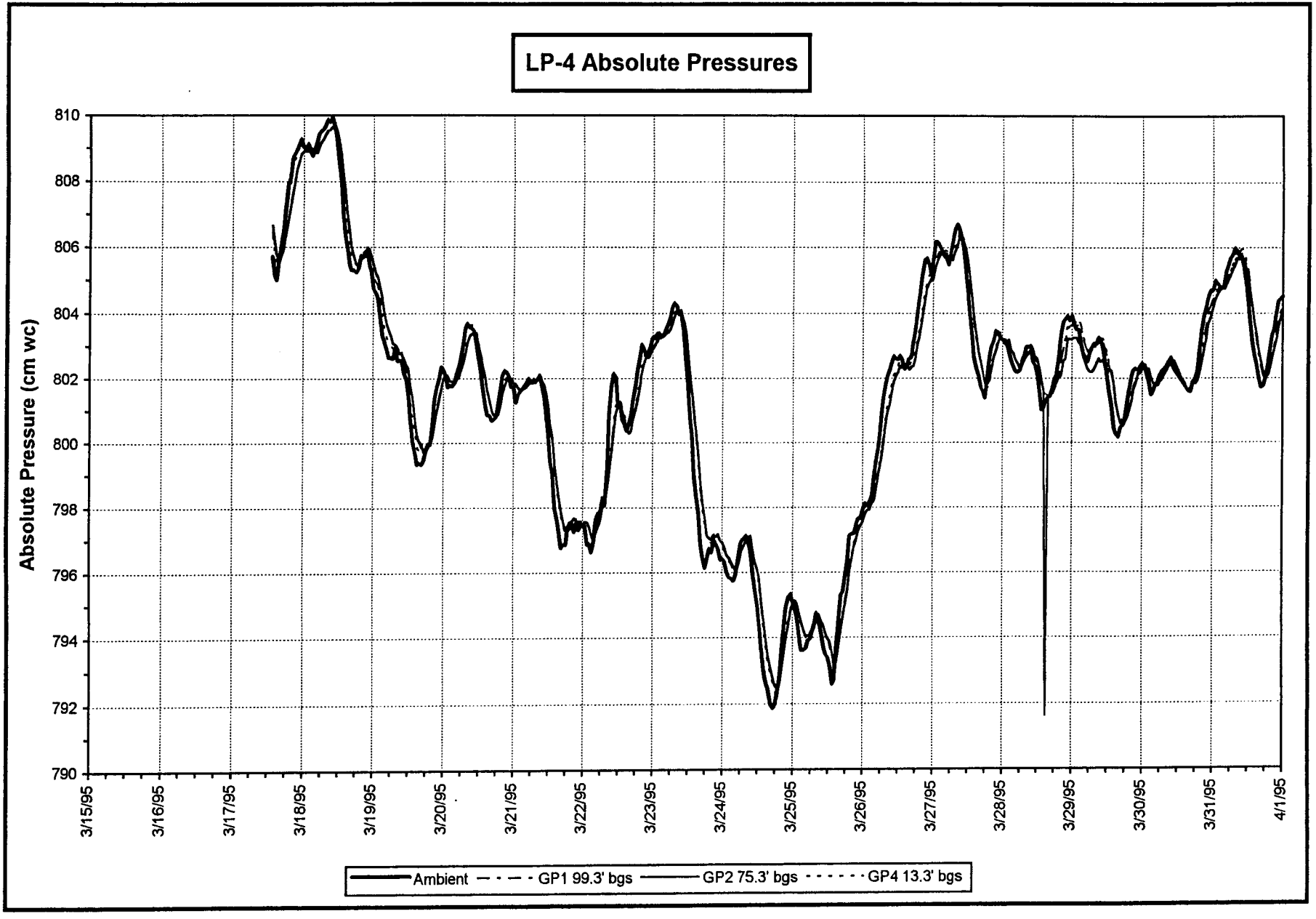
Table 1. Cross Reference of Lab Sample ID, LANL Sample ID and Lab Batch Number

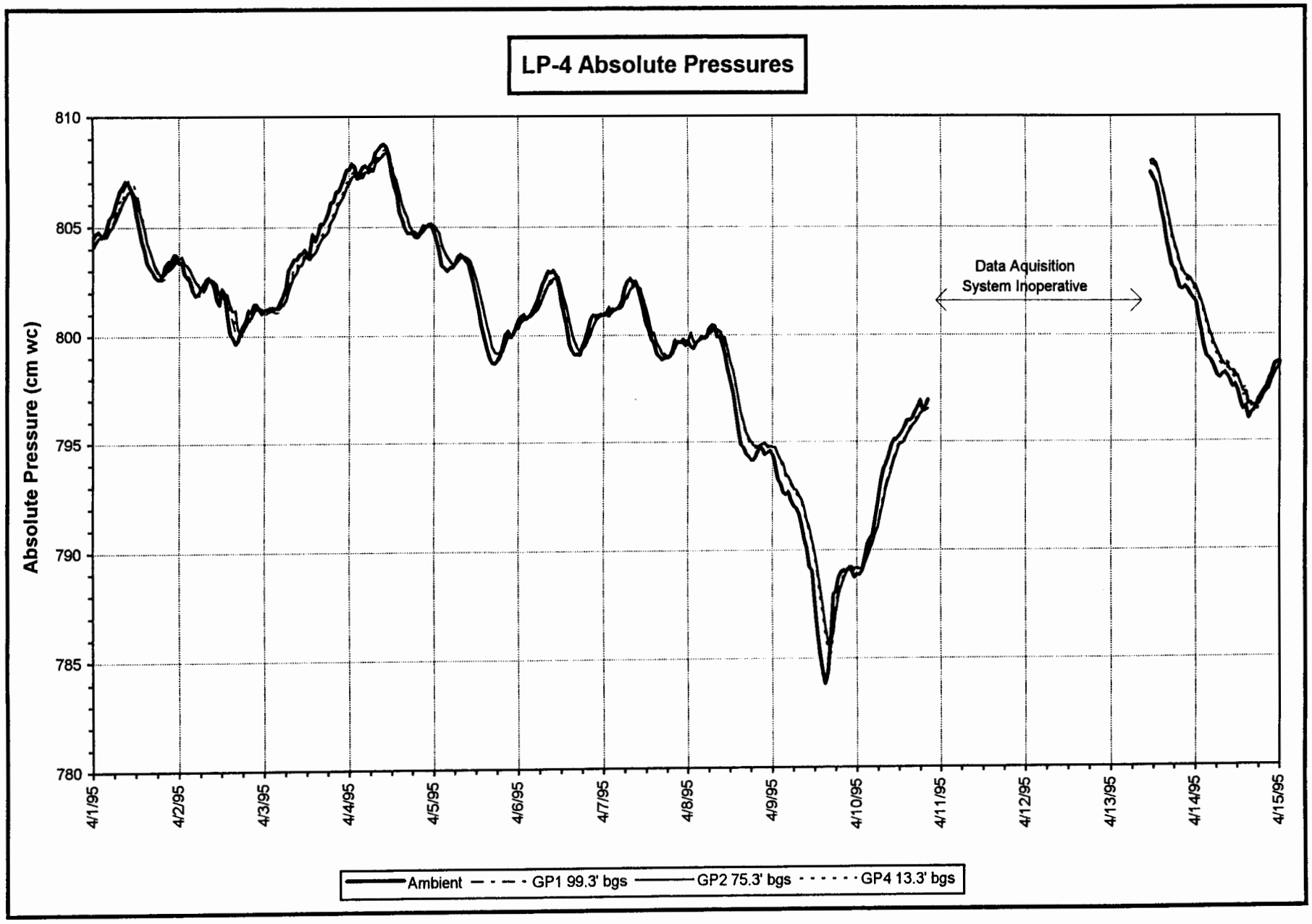
ESE FLD.GRP.	#	LANL SAMPLE ID	COLLECTION DATE	TIME	LANL REQUEST #	LANL C-O-C #	LANL FIELD ID #	SUMMA CANISTER #	FIXED GASSES LAB BATCH #	TO14 LAB BATCH #
LAIR2	26	95.06292	03/27/95	16:03	21682	AAC4146	LPS-1/GP-1	GL042	G59988	G60276
LAIR2	2	95.06293	03/27/95	12:05	21682	AAC4125	LP-1/GP-1	GL097	for all	G60274
LAIR2	33	95.06294	03/27/95	15:17	21682	AAC4143	LP-8/GP-3	GL098	O_2, N_2,	G60276
LAIR2	28	95.06295	03/27/95	16:32	21682	AAC4148	LPS-1/GP-3	GL014	CO_2, CH_4	G60276
LAIR2	27	95.06296	03/27/95	16:18	21682	AAC4147	LPS-1/GP-2	GL087	and	G60276
LAIR2	32	95.06297	03/27/95	15:04	21682	AAC4142	LP-8/GP-2	GL030	G60215	G60276
LAIR2	31	95.06298	03/27/95	14:48	21682	AAC4141	LP-8/GP-1	GL060	for all	G60276
LAIR2	3	95.06299	03/27/95	12:30	21682	AAC4126	LP-1/GP-2	GL070	H_2.	G60274
LAIR2	30	95.06300	03/27/95	17:22	21682	AAC4150	LPS-1/GP-5	GL044		G60336
LAIR2	29	95.06301	03/27/95	16:46	21682	AAC4149	LPS-1/GP-4	GL011		G60306
LAIR2	8	95.06302	03/27/95	13:07	21682	AAC4127	LP-S/GP-1	GL083		G60274
LAIR2	19	95.06318	03/28/95	15:09	21686	AAC4133	LP-4/GP-2	GL111		G60306
LAIR2	21	95.06319	03/28/95	11:02	21686	AAC4137	LP-6/GP-1	26		G60274
LAIR2	1	95.06320	03/28/95	14:15	21686	AAC4136	LP-5/GP-1	GL113		G60274
LAIR2	18	95.06321	03/28/95	15:46	21686	AAC4171	LP-4/GP-3	22		G60306
LAIR2	25	95.06322	03/28/95	15:46	21686	AAC4134	LP-4/GP-4	GL106		G60306
LAIR2	11	95.06323	03/28/95	14:47	21686	AAC4132	LP-4/GP-1	GL026		G60336
LAIR2	7	95.06324	03/28/95	12:17	21686	AAC4145	LP-9/GP-2	GL039		G60274
LAIR2	14	95.06325	03/28/95	16:16	21686	AAC4135	LP-5/GP-5	GL064		G60306
LAIR2	17	95.06326	03/28/95	11:52	21686	AAC4144	LP-9/GP-1	GL046		G60274
LAIR2	9	95.06478	03/29/95	09:49	21709	AAC4130	LP-3/GP-3	GL061		G60336
LAIR2	12	95.06479	03/29/95	11:51	21709	AAC4152	LPS-2/GP-2	GL129		G60336
LAIR2	20	95.06480	03/29/95	10:16	21709	AAC4131	LP-3/GP-4	GL076		G60306
LAIR2	15	95.06481	03/29/95	12:09	21709	AAC4169	LPS-2/GP-3	GL092		G60306
LAIR2	35	95.06482	03/29/95	15:50	21709	AAC4156	LP-11	GL079		G60306
LAIR2	34	95.06483	03/29/95	15:20	21709	AAC4155	LP-10	GL006		G60306
LAIR2	23	95.06484	03/29/95	14:28	21709	AAC4139	LP-7/GP-2	GL055		G60306
LAIR2	22	95.06485	03/29/95	14:12	21709	AAC4138	LP-7/GP-1	GL003		G60274
LAIR2	4	95.06486	03/29/95	16:46	21709	AAC4168	LPS-1/GP-4	GL094		G60336
LAIR2	24	95.06487	03/29/95	14:51	21709	AAC4140	LP-7/GP-3	GL091		G60306
LAIR2	10	95.06488	03/29/95	09:25	21709	AAC4129	LP-3/GP-2	GL059		G60370
LAIR2	5	95.06489	03/29/95	12:09	21709	AAC4153	LPS-2/GP-3	GL114		G60336
LAIR2	16	95.06490	03/29/95	09:12	21709	AAC4128	LP-3/GP-1	GL072		G60274
LAIR2	13	95.06491	03/29/95	12:29	21709	AAC4154	LPS-2/GP-4	GL024		G60336
LAIR2	6	95.06492	03/29/95	11:37	21709	AAC4151	LPS-2/GP-1	GL110		G60274

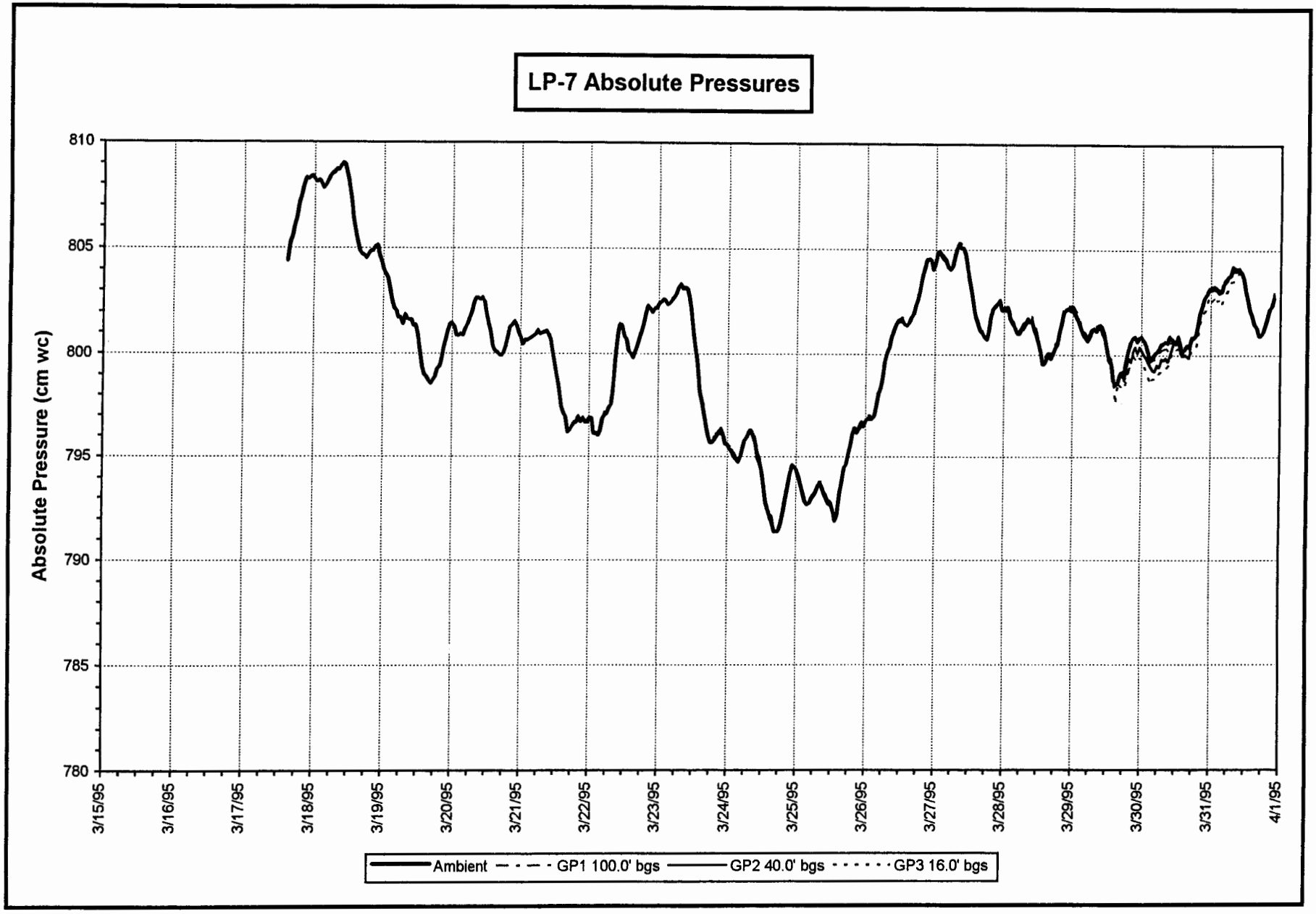
APPENDIX E

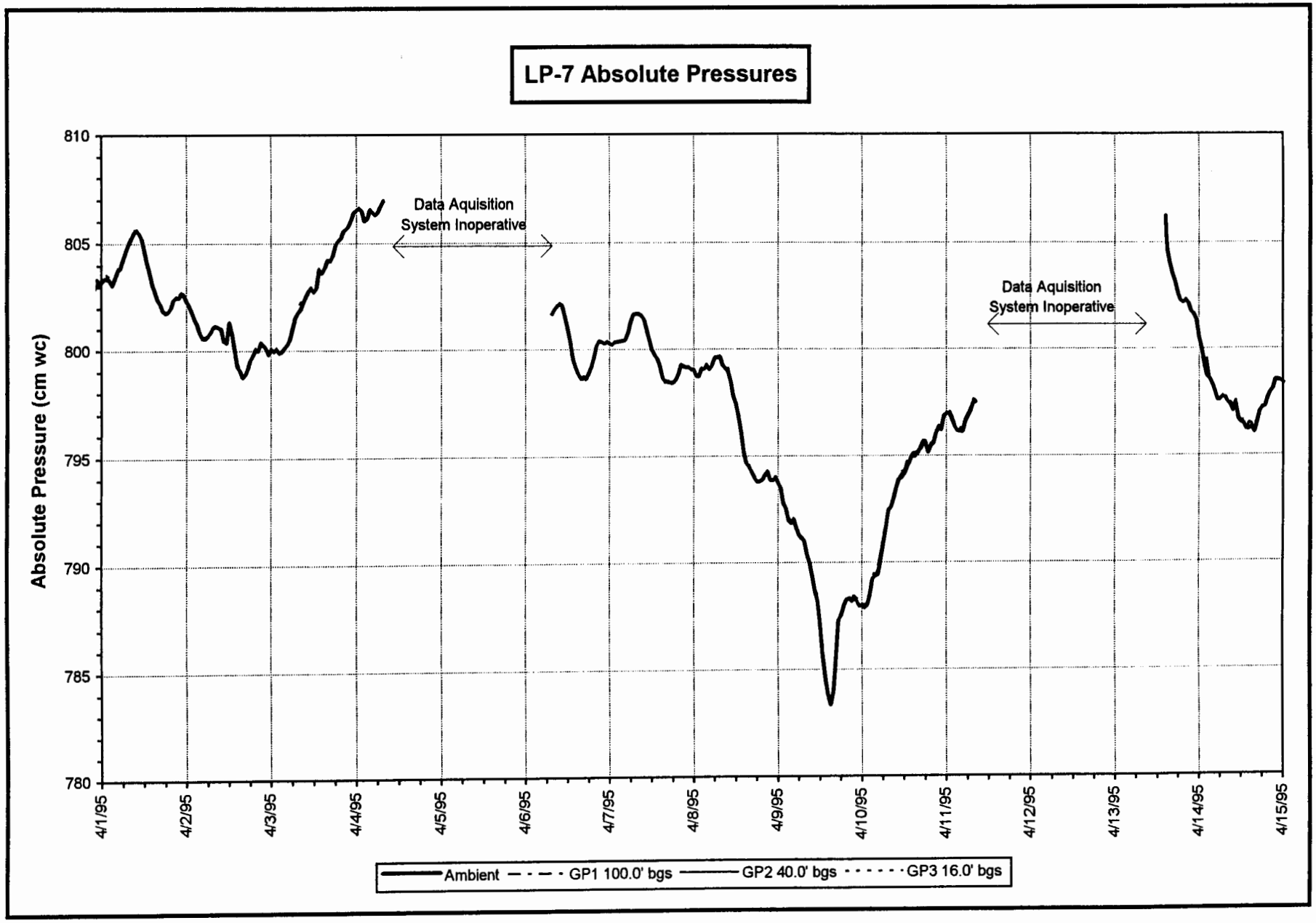
PRESSURE/TEMPERATURE DATA

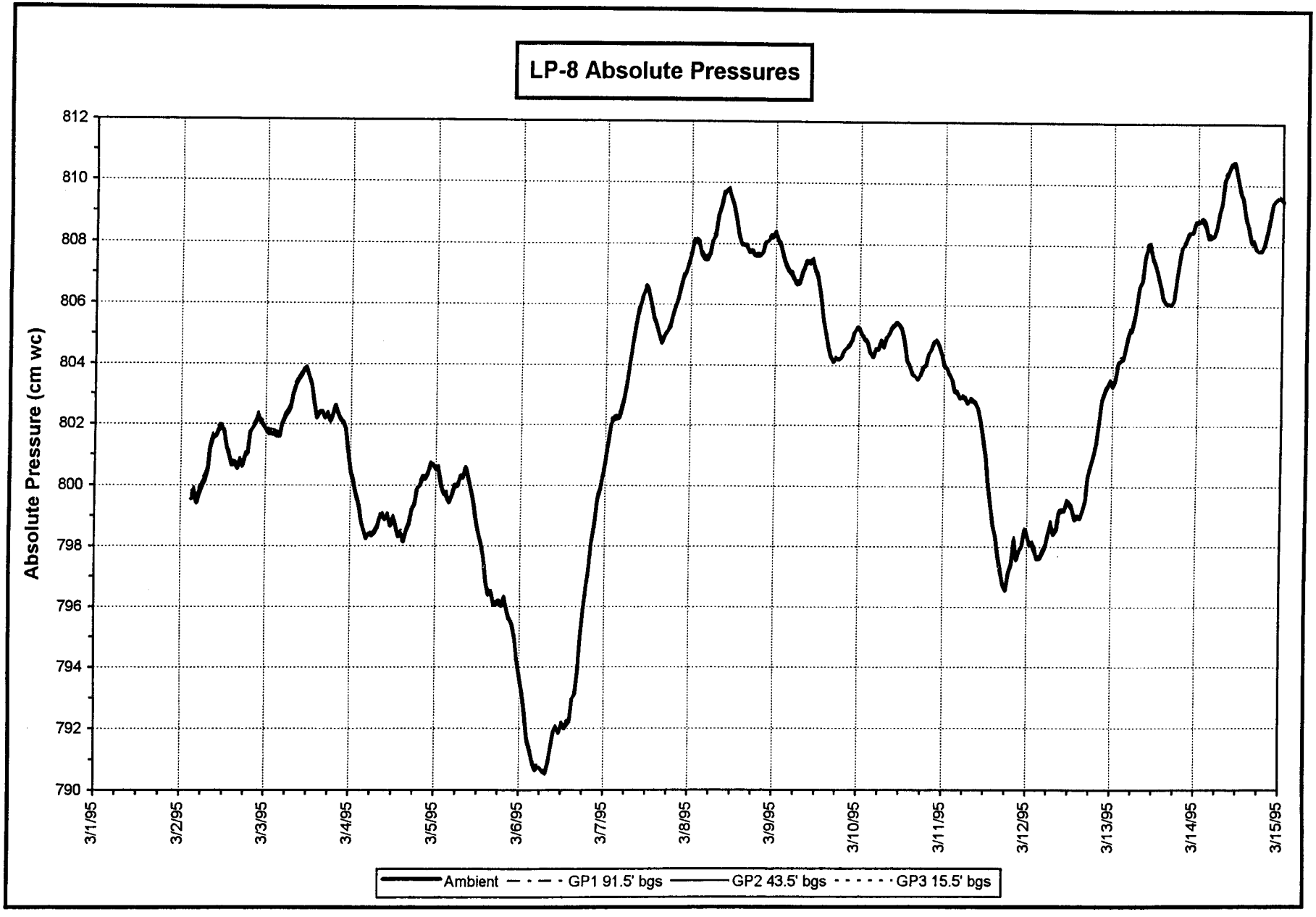
Pressure Data

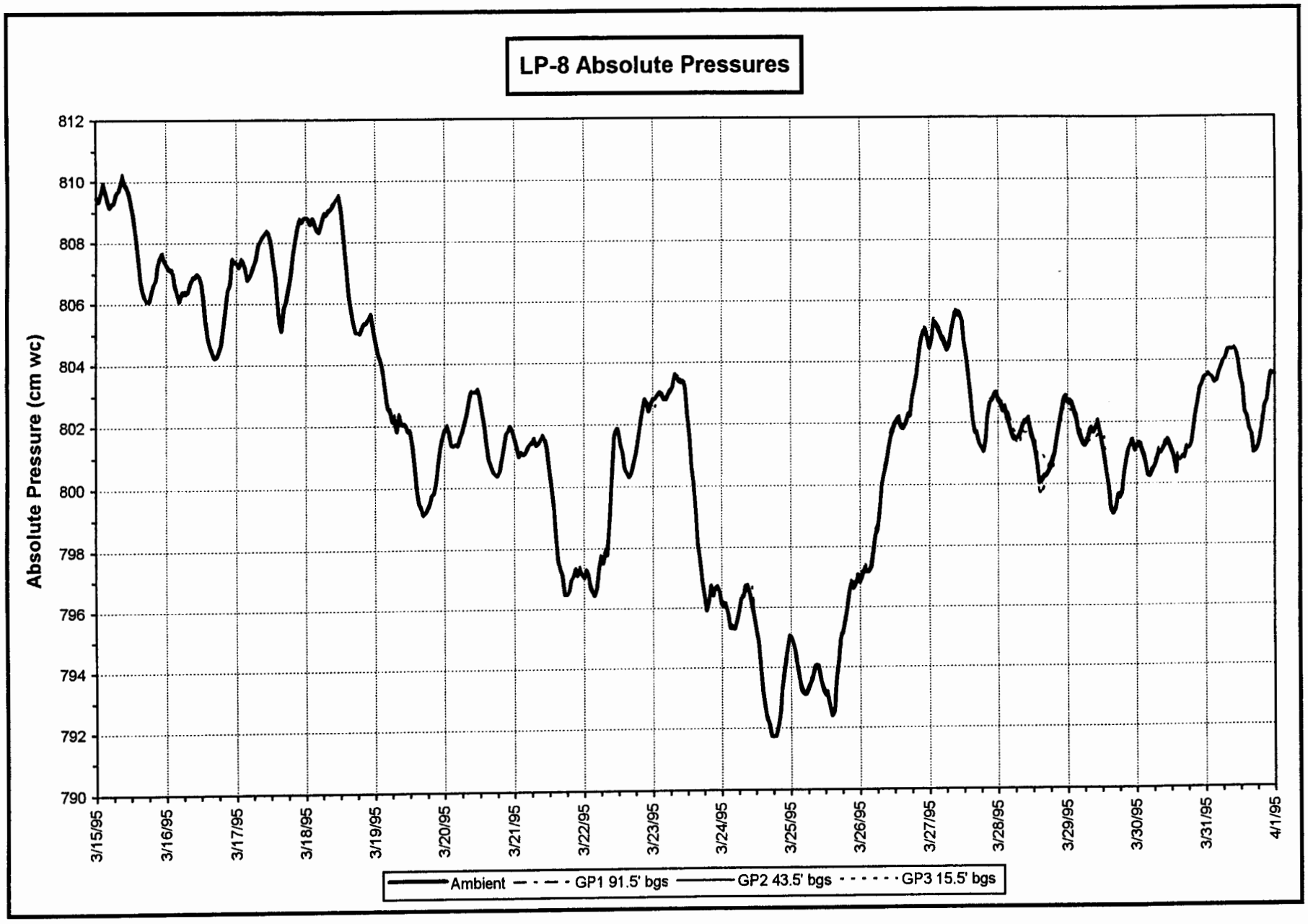

LP-4 Absolute Pressures
Absolute Pressure (cm wc)
810
808
806
804
802
800
798
796
794
792
790
3/15/95
3/16/95
3/17/95
3/18/95
3/19/95
3/20/95
3/21/95
3/22/95
3/23/95
3/24/95
3/25/95
3/26/95
3/27/95
3/28/95
3/29/95
3/30/95
3/31/95
4/1/95
Ambient
GP1 99.3' bgs
GP2 75.3' bgs
GP4 13.3' bgs

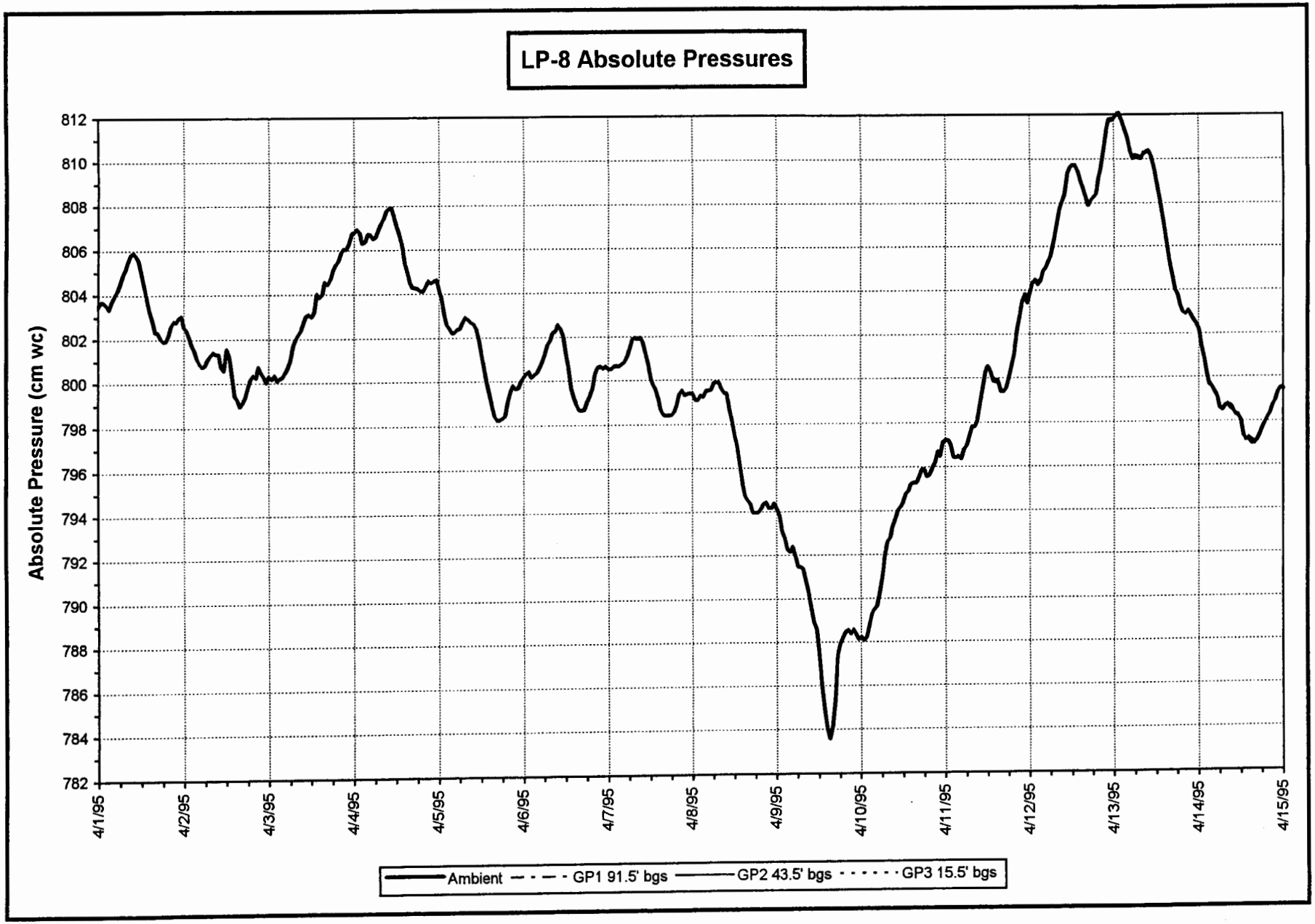

LP-4 Absolute Pressures
Absolute Pressure (cm wc)
810
805
800
795
790
785
780
4/1/95
4/2/95
4/3/95
4/4/95
4/5/95
4/6/95
4/7/95
4/8/95
4/9/95
4/10/95
4/11/95
4/12/95
4/13/95
4/14/95
4/15/95
Data Aquisition
System Inoperative
Ambient
GP1 99.3' bgs
GP2 75.3' bgs
GP4 13.3' bgs

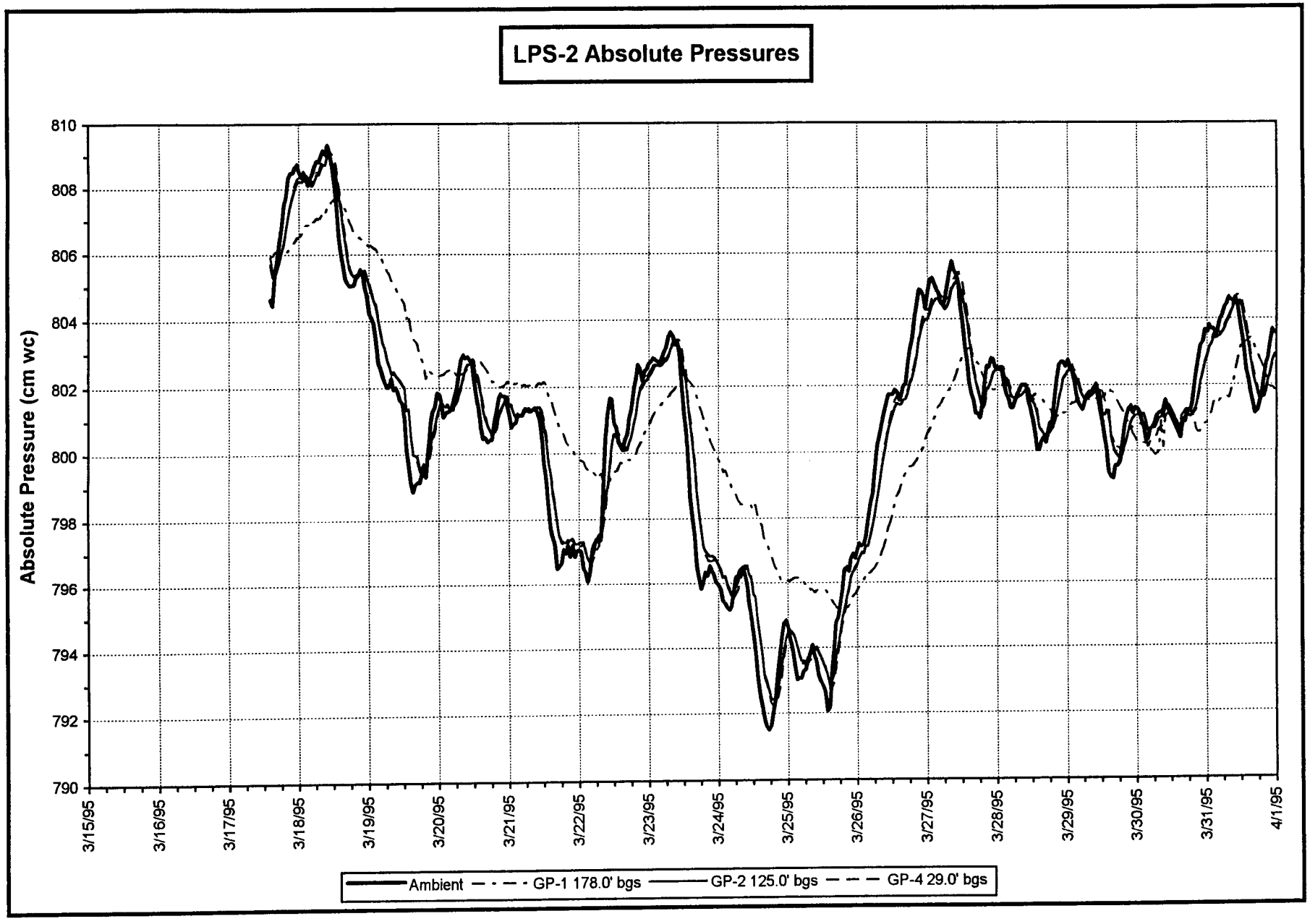

LP-7 Absolute Pressures
Absolute Pressure (cm wc)
810
805
800
795
790
785
780
3/15/95
3/16/95
3/17/95
3/18/95
3/19/95
3/20/95
3/21/95
3/22/95
3/23/95
3/24/95
3/25/95
3/26/95
3/27/95
3/28/95
3/29/95
3/30/95
3/31/95
4/1/95
Ambient
GP1 100.0' bgs
GP2 40.0' bgs
GP3 16.0' bgs

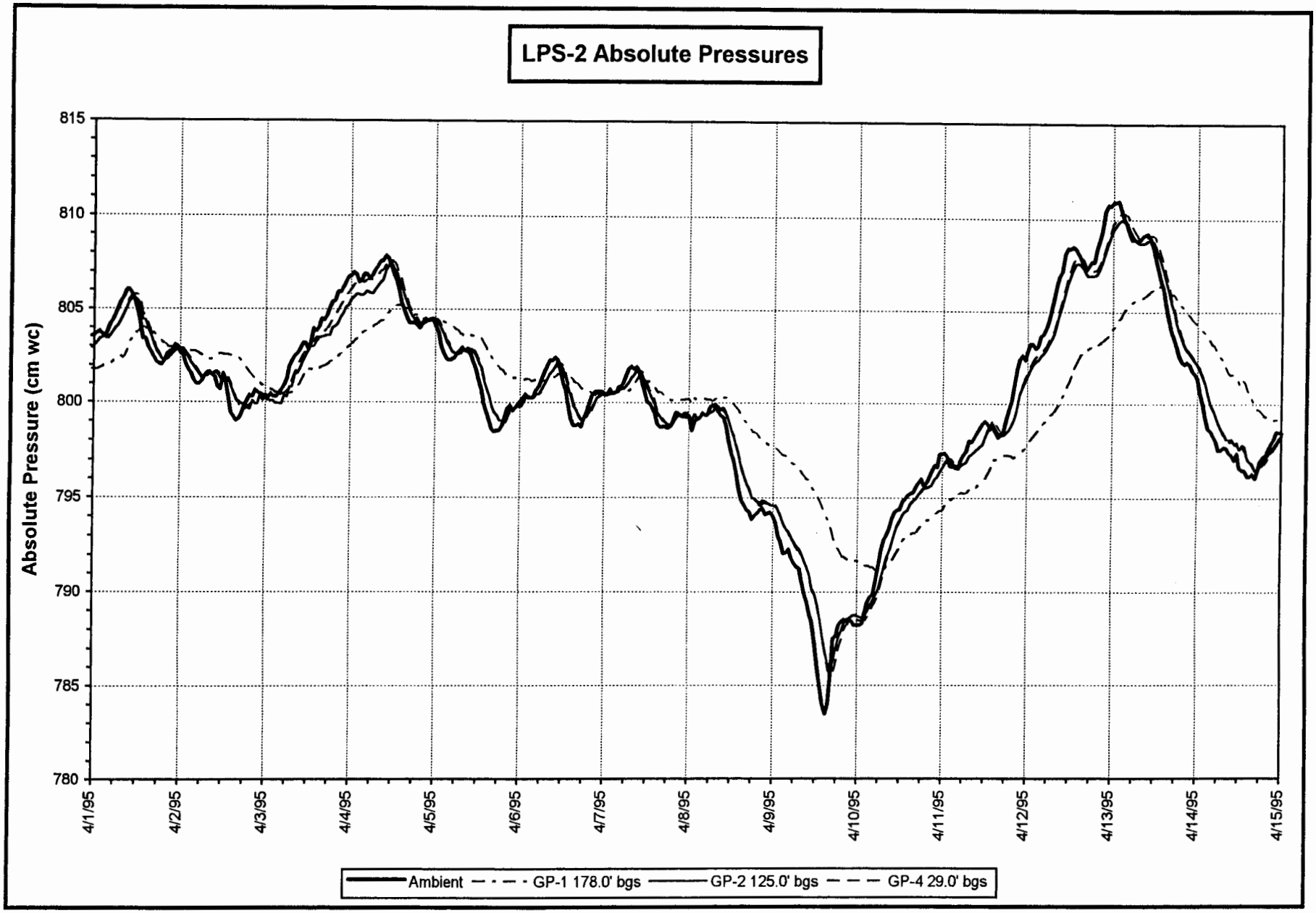

LP-7 Absolute Pressures
Absolute Pressure (cm wc)
810
805
800
795
790
785
780
Data Aquisition System Inoperative
Data Aquisition System Inoperative
4/1/95
4/2/95
4/3/95
4/4/95
4/5/95
4/6/95
4/7/95
4/8/95
4/9/95
4/10/95
4/11/95
4/12/95
4/13/95
4/14/95
4/15/95
Ambient
GP1 100.0' bgs
GP2 40.0' bgs
GP3 16.0' bgs


LP-8 Absolute Pressures
Absolute Pressure (cm wc)
812
810
808
806
804
802
800
798
796
794
792
790
3/1/95
3/2/95
3/3/95
3/4/95
3/5/95
3/6/95
3/7/95
3/8/95
3/9/95
3/10/95
3/11/95
3/12/95
3/13/95
3/14/95
3/15/95
Ambient
GP1 91.5' bgs
GP2 43.5' bgs
GP3 15.5' bgs

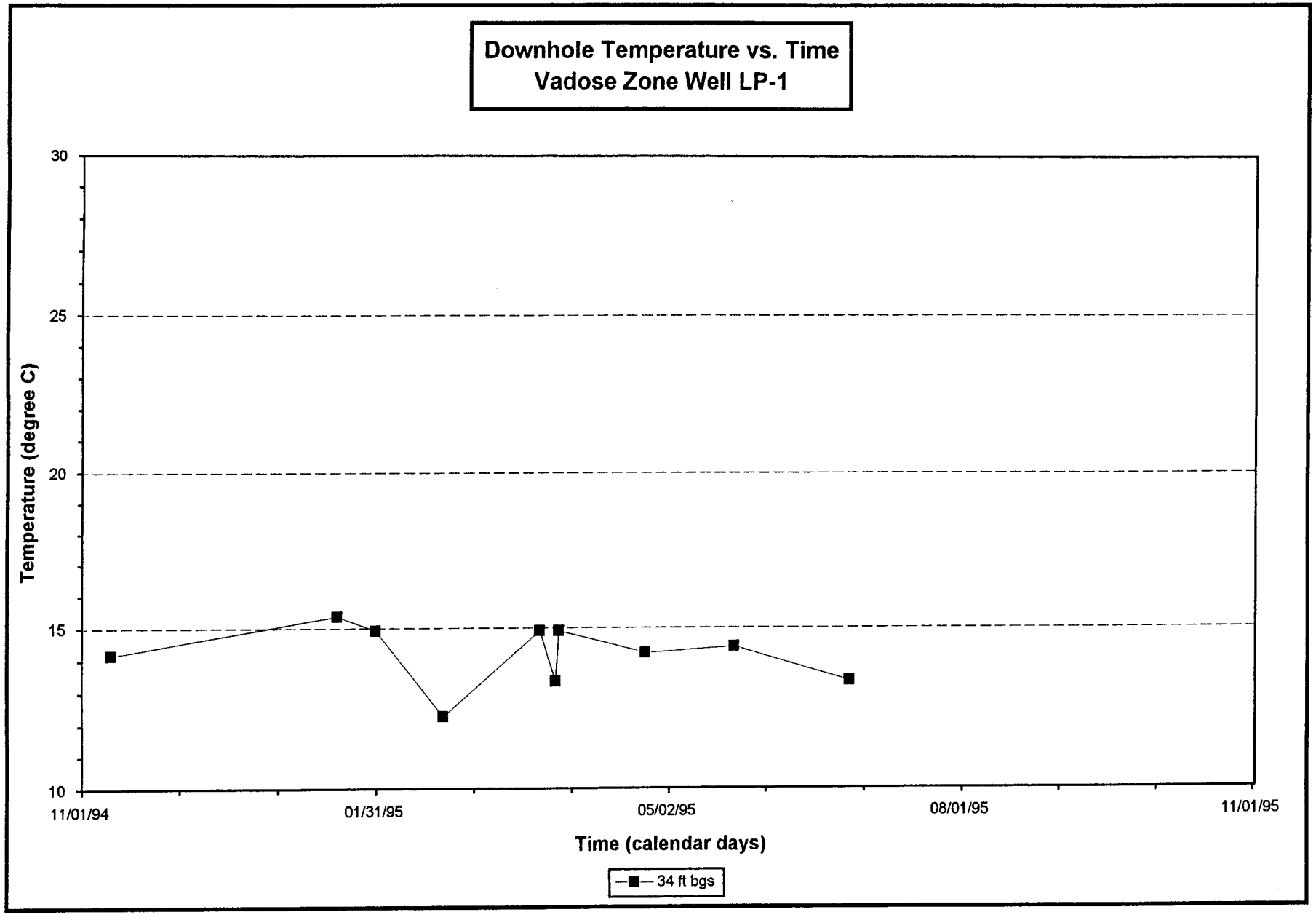

LP-8 Absolute Pressures
Absolute Pressure (cm wc)
812
810
808
806
804
802
800
798
796
794
792
790
3/15/95
3/16/95
3/17/95
3/18/95
3/19/95
3/20/95
3/21/95
3/22/95
3/23/95
3/24/95
3/25/95
3/26/95
3/27/95
3/28/95
3/29/95
3/30/95
3/31/95
4/1/95
Ambient
GP1 91.5' bgs
GP2 43.5' bgs
GP3 15.5' bgs

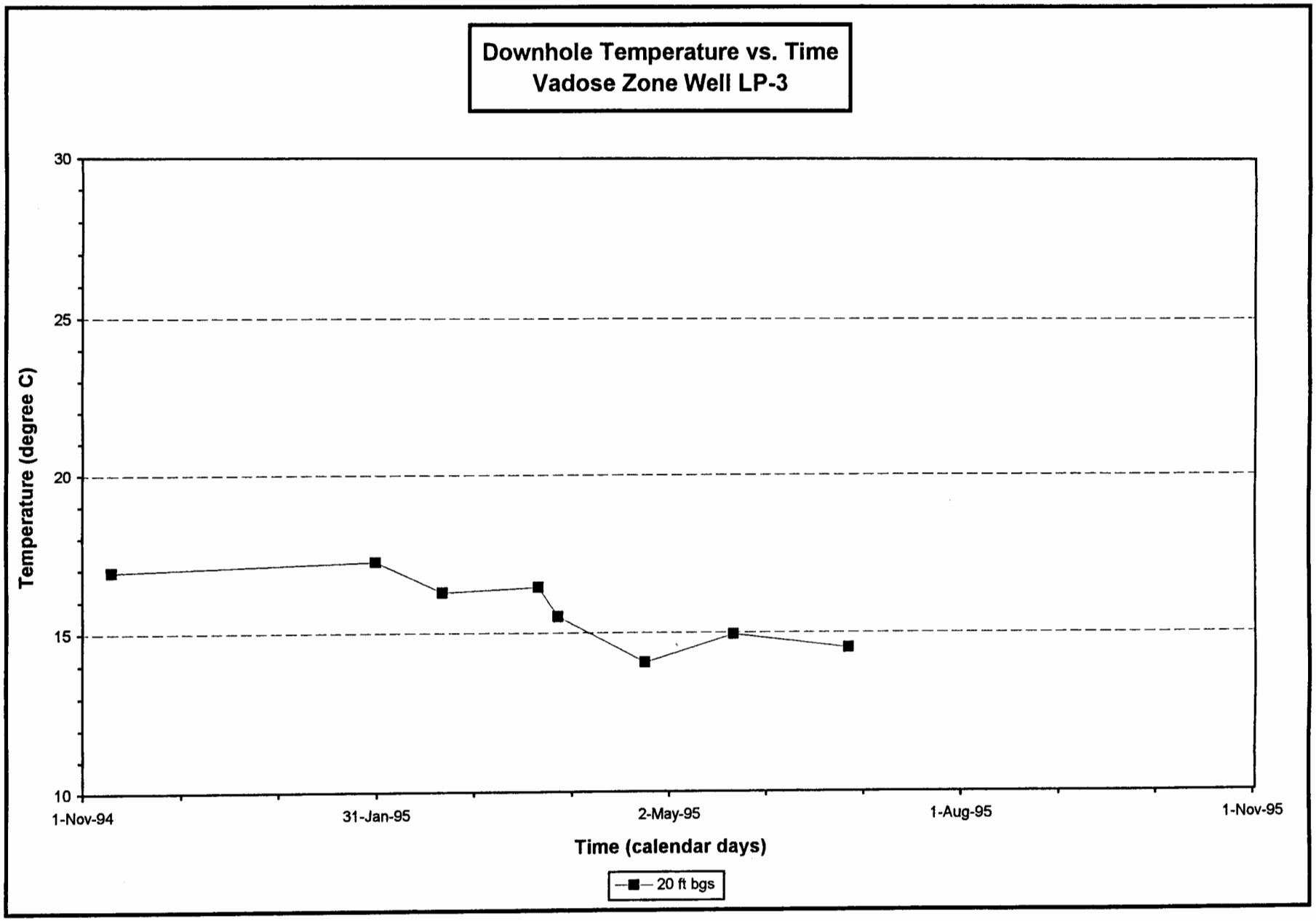

LP-8 Absolute Pressures
Absolute Pressure (cm wc)
812
810
808
806
804
802
800
798
796
794
792
790
788
786
784
782
4/1/95
4/2/95
4/3/95
4/4/95
4/5/95
4/6/95
4/7/95
4/8/95
4/9/95
4/10/95
4/11/95
4/12/95
4/13/95
4/14/95
4/15/95
Ambient
GP1 91.5' bgs
GP2 43.5' bgs
GP3 15.5' bgs

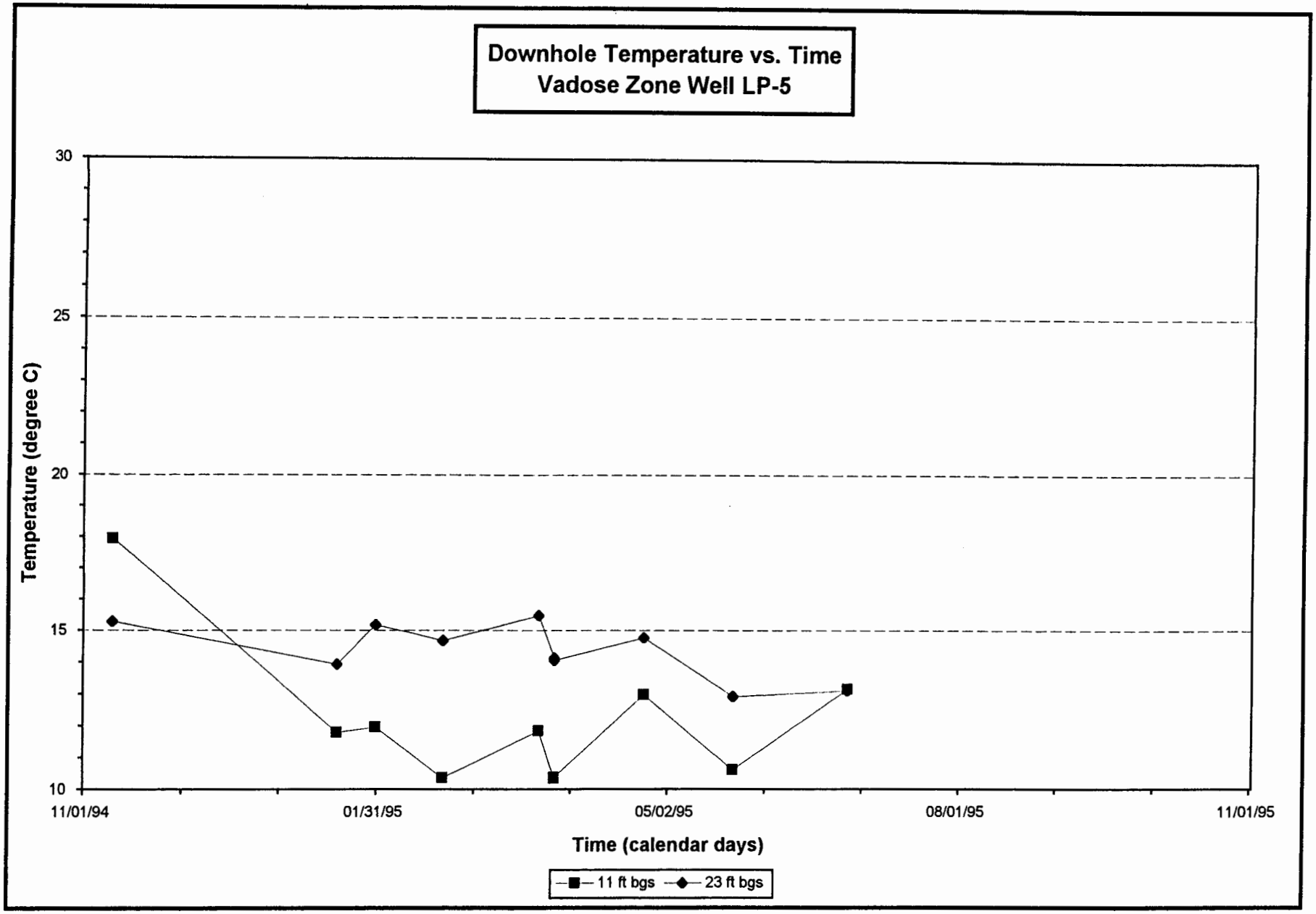

LPS-2 Absolute Pressures
Absolute Pressure (cm wc)
810
808
806
804
802
800
798
796
794
792
790
3/15/95
3/16/95
3/17/95
3/18/95
3/19/95
3/20/95
3/21/95
3/22/95
3/23/95
3/24/95
3/25/95
3/26/95
3/27/95
3/28/95
3/29/95
3/30/95
3/31/95
4/1/95
Ambient
GP-1 178.0' bgs
GP-2 125.0' bgs
GP-4 29.0' bgs

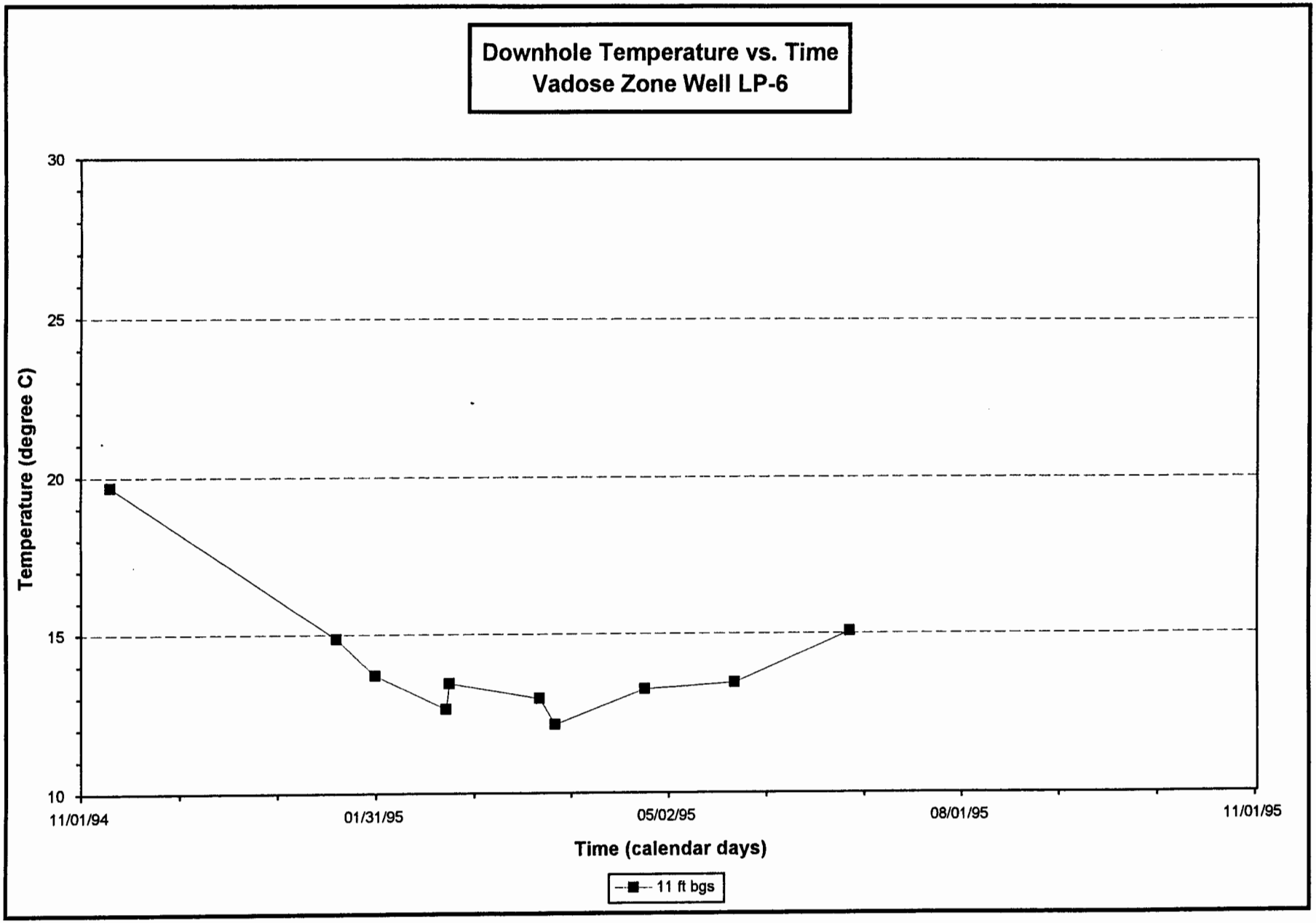

LPS-2 Absolute Pressures
Absolute Pressure (cm wc)
815
810
805
800
795
790
785
780
4/1/95
4/2/95
4/3/95
4/4/95
4/5/95
4/6/95
4/7/95
4/8/95
4/9/95
4/10/95
4/11/95
4/12/95
4/13/95
4/14/95
4/15/95
Ambient
GP-1 178.0' bgs
GP-2 125.0' bgs
GP-4 29.0' bgs

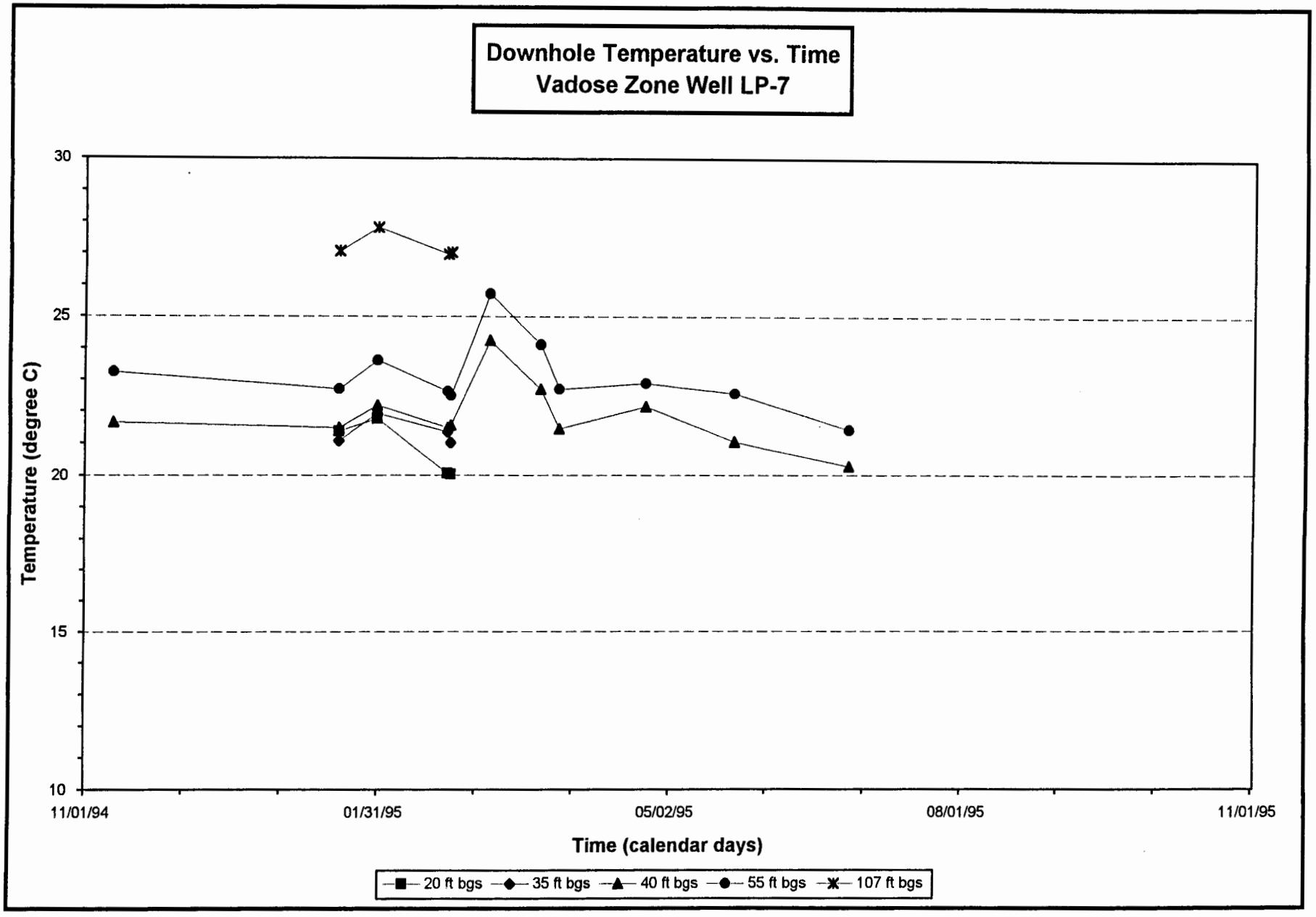
Temperature Data

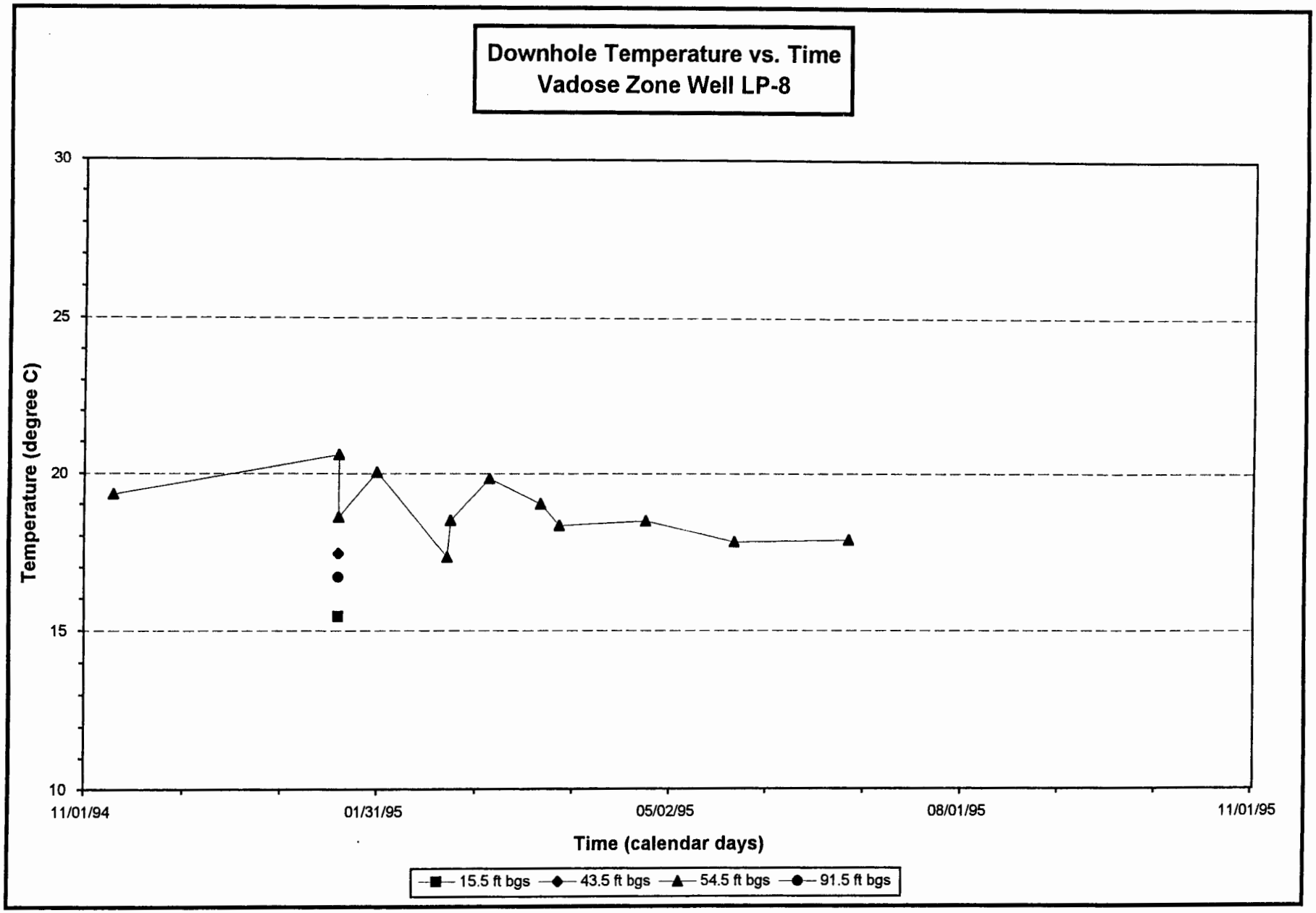

Downhole Temperature vs. Time
Vadose Zone Well LP-1
Temperature (degree C)
30
25
20
15
10
11/01/94
01/31/95
05/02/95
08/01/95
11/01/95
Time (calendar days)
34 ft bgs

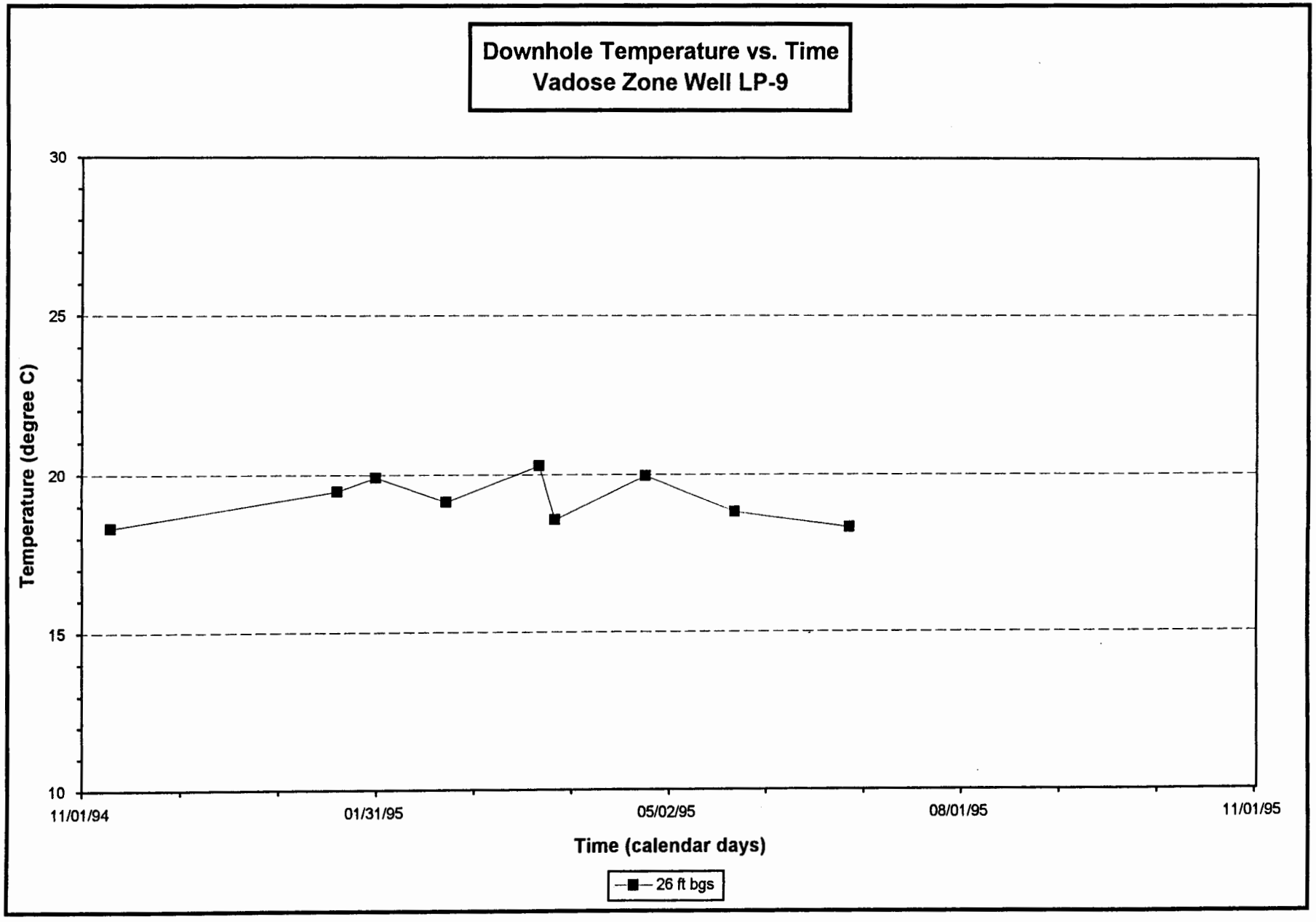

Downhole Temperature vs. Time
Vadose Zone Well LP-3
Temperature (degree C)
30
25
20
15
10
1-Nov-94
31-Jan-95
2-May-95
1-Aug-95
1-Nov-95
Time (calendar days)
20 ft bgs

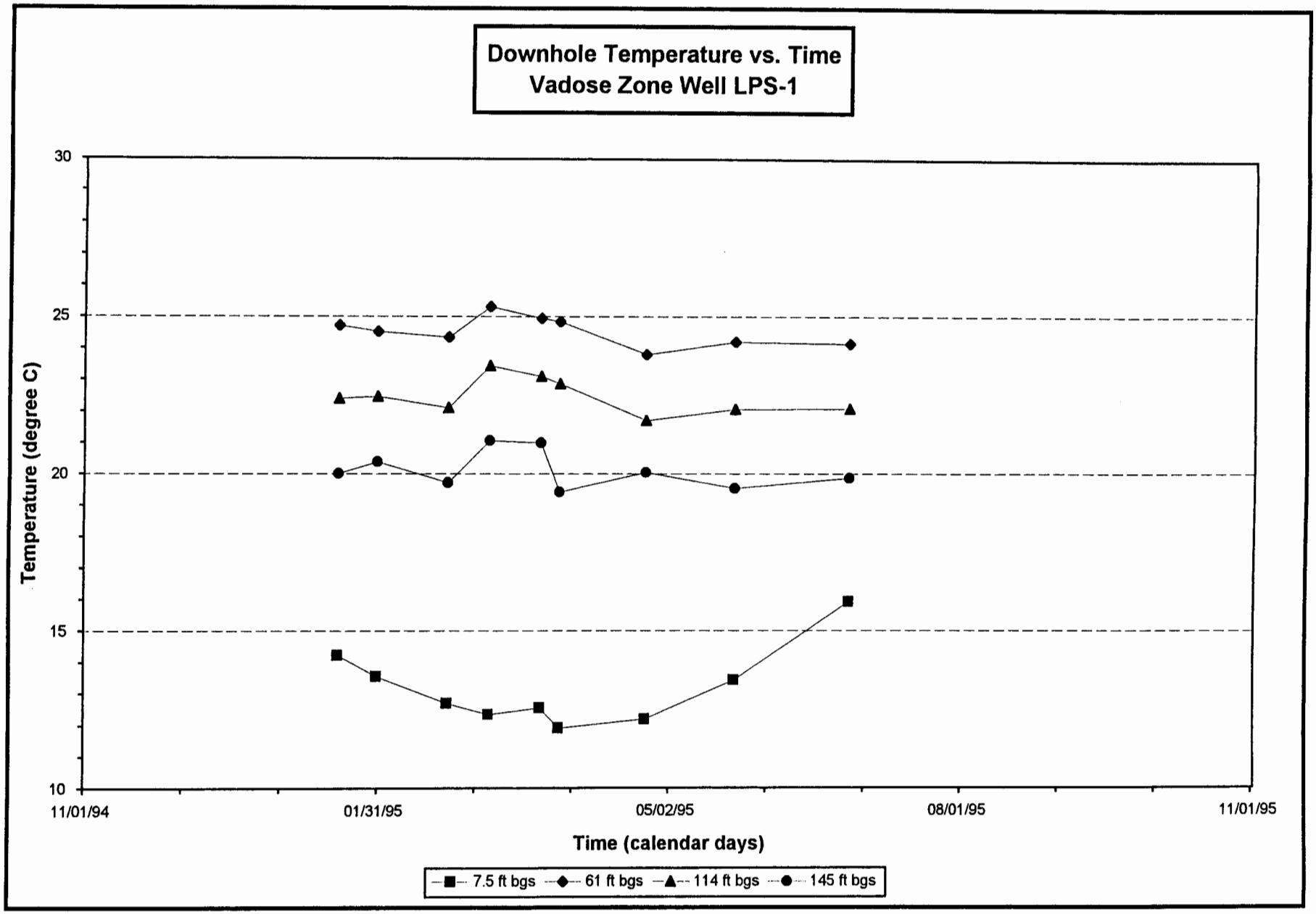

Downhole Temperature vs. Time
Vadose Zone Well LP-5
Temperature (degree C)
30
25
20
15
10
11/01/94
01/31/95
05/02/95
08/01/95
11/01/95
Time (calendar days)
11 ft bgs
23 ft bgs

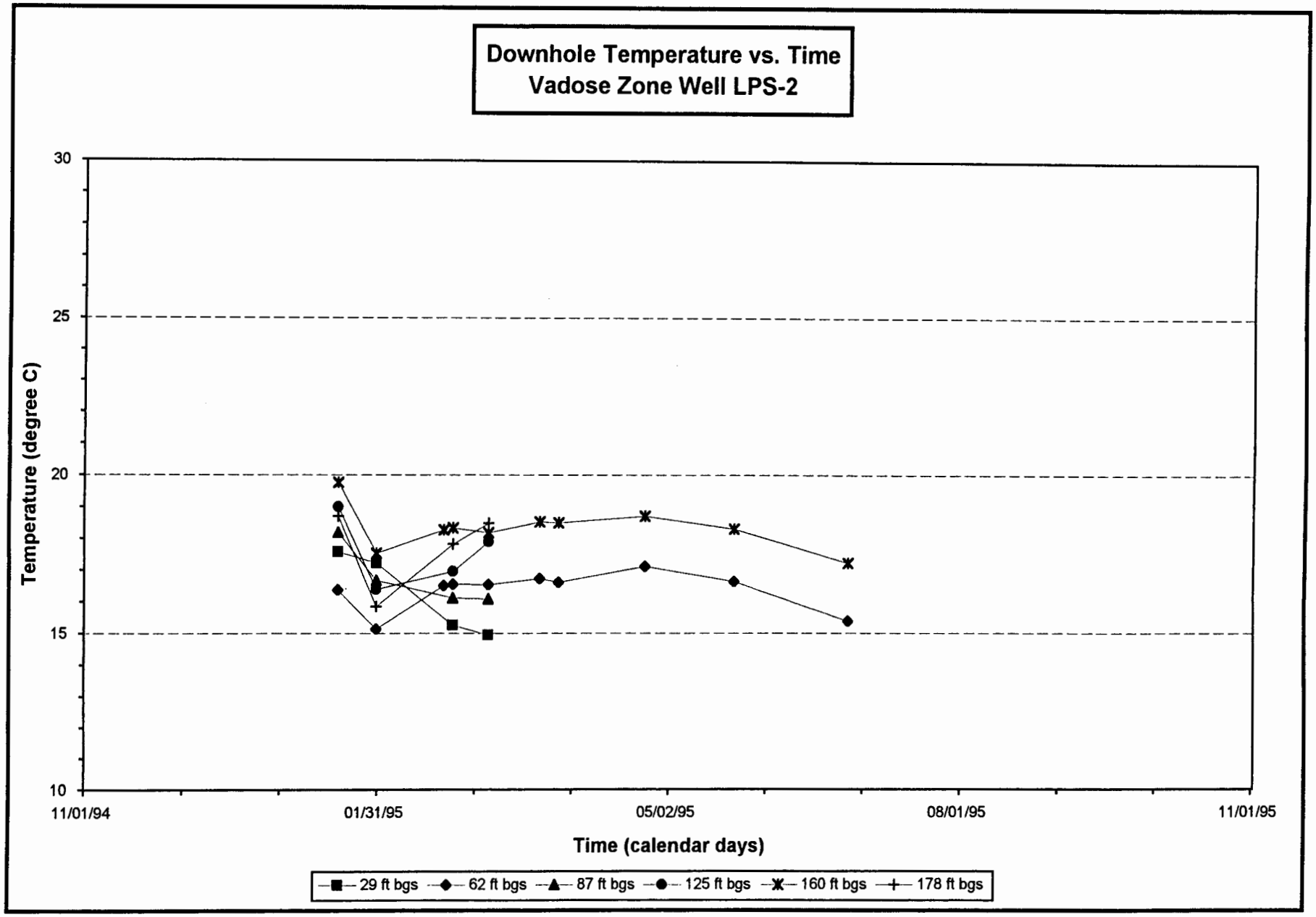

Downhole Temperature vs. Time
Vadose Zone Well LP-6
Temperature (degree C)
30
25
20
15
10
11/01/94
01/31/95
05/02/95
08/01/95
11/01/95
Time (calendar days)
11 ft bgs


Downhole Temperature vs. Time
Vadose Zone Well LP-7
Temperature (degree C)
30
25
20
15
10
11/01/94
01/31/95
05/02/95
08/01/95
11/01/95
Time (calendar days)
20 ft bgs
35 ft bgs
40 ft bgs
55 ft bgs
107 ft bgs


Downhole Temperature vs. Time
Vadose Zone Well LP-8
Temperature (degree C)
30
25
20
15
10
11/01/94
01/31/95
05/02/95
08/01/95
11/01/95
Time (calendar days)
15.5 ft bgs
43.5 ft bgs
54.5 ft bgs
91.5 ft bgs

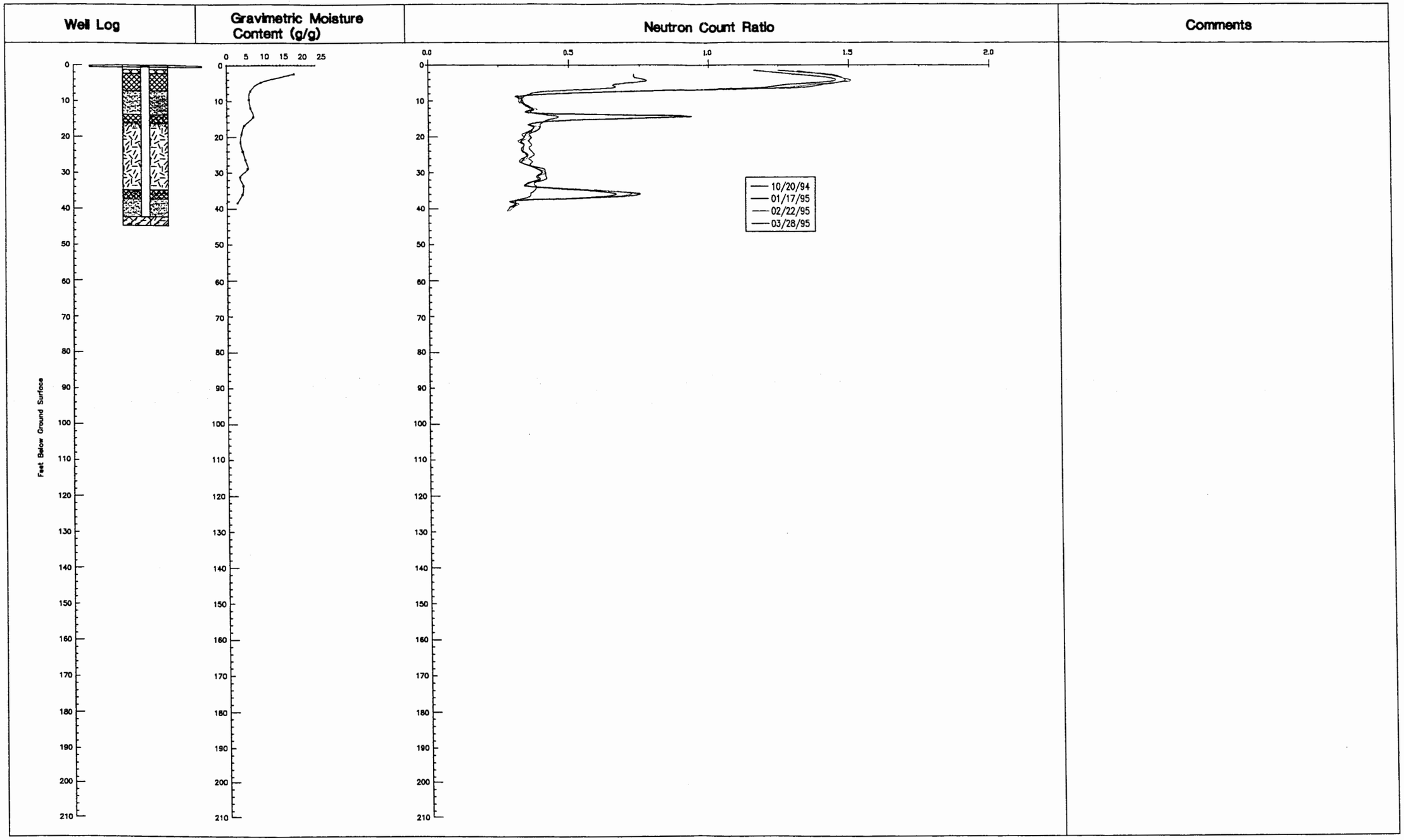

Downhole Temperature vs. Time
Vadose Zone Well LP-9
30
25
20
15
10
Temperature (degree C)
11/01/94
01/31/95
05/02/95
08/01/95
11/01/95
Time (calendar days)
26 ft bgs


Downhole Temperature vs. Time
Vadose Zone Well LPS-1
Temperature (degree C)
30
25
20
15
10
11/01/94
01/31/95
05/02/95
08/01/95
11/01/95
Time (calendar days)
7.5 ft bgs
61 ft bgs
114 ft bgs
145 ft bgs


Downhole Temperature vs. Time
Vadose Zone Well LPS-2
Temperature (degree C)
30
25
20
15
10
11/01/94
01/31/95
05/02/95
08/01/95
11/01/95
Time (calendar days)
29 ft bgs
62 ft bgs
87 ft bgs
125 ft bgs
160 ft bgs
178 ft bgs

APPENDIX F

NEUTRON COUNT RATIO vs. DEPTH



Well Construction Symbols

- Bentonite pellets
- 10–20 silica sand
- Sieved tuff
- 50/50 bentonite and sand
- Slough

Note: The neutron count ratio data was collected utilizing a CPN model 503DR Hydroprobe SN# H38018058

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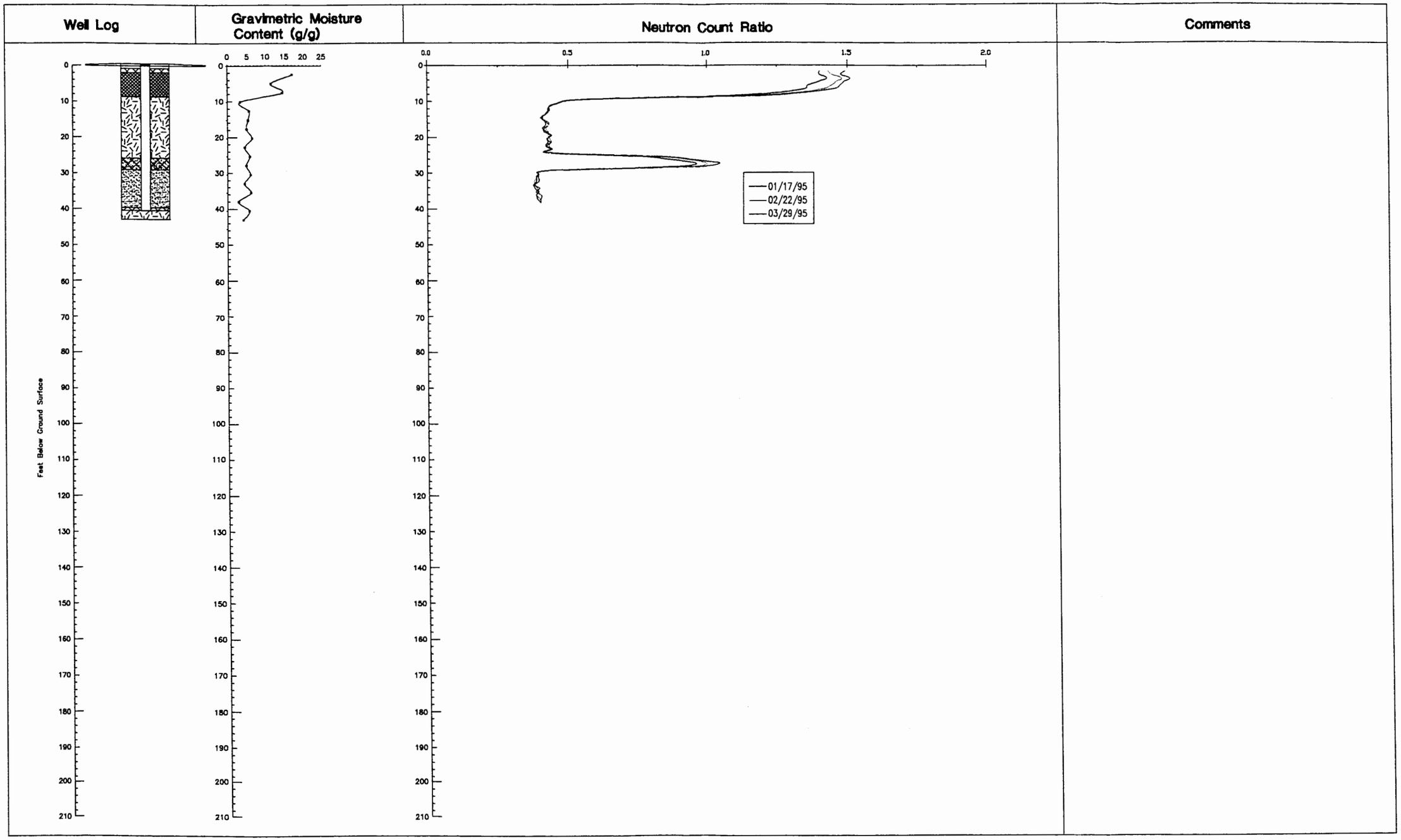
JN 4010

LANL RFI SUPPORT

Netron Count Ratio Measurements in Vadose Zone Well LP-1

M\4010\4010ar.DWG



Well Construction Symbols

- Bentonite pellets
- 10–20 silica sand
- Sieved tuff
- 50/50 bentonite and sand
- Slough

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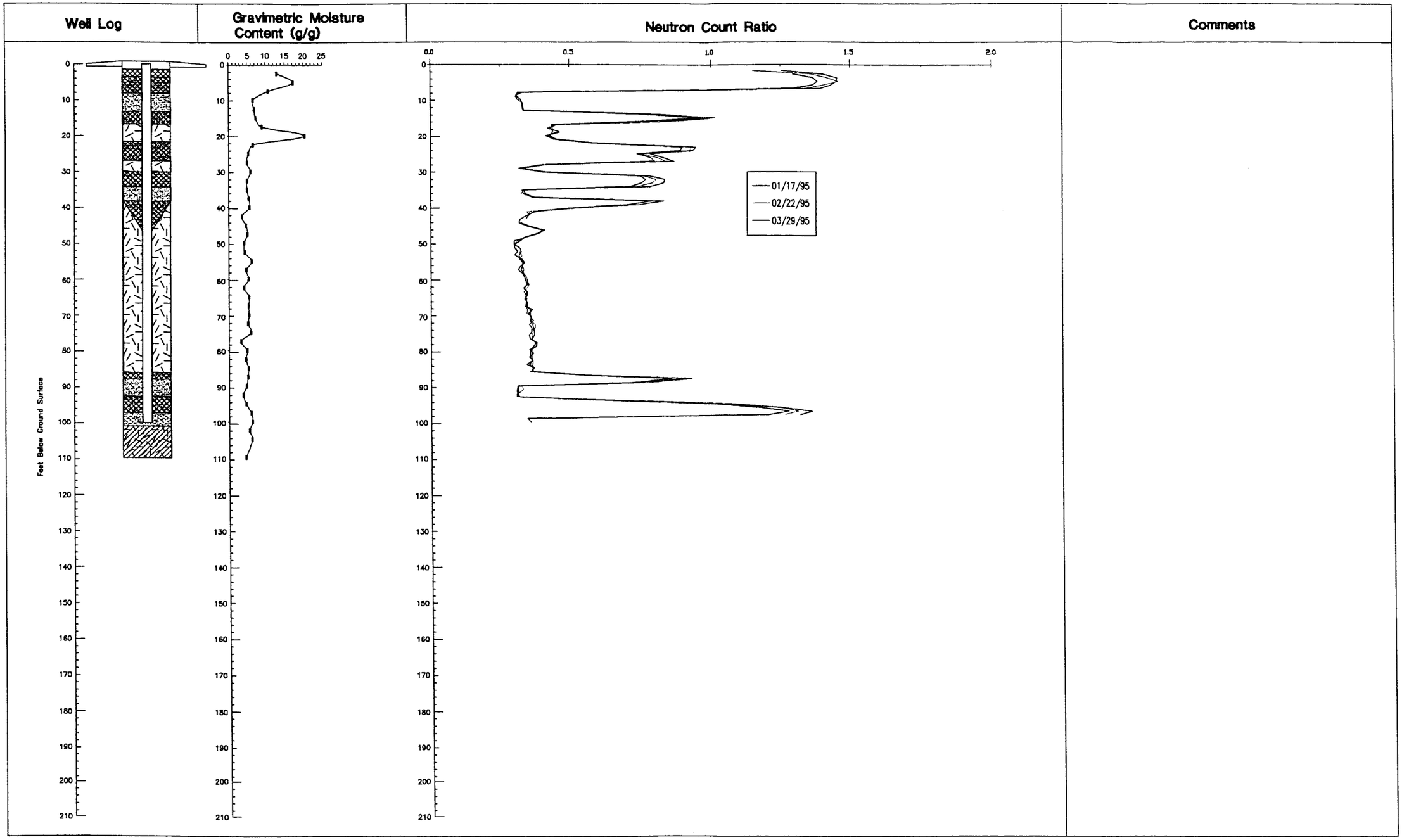
LANL RFI SUPPORT

Neutron Count Ratio Measurements In Vadose Zone Well LP-2

M\4010\4010ZOR.DWG



Well Construction Symbols

- Bentonite pellets
- 50/50 bentonite and sand
- 10–20 silica sand
- Slough
- Sieved tuff

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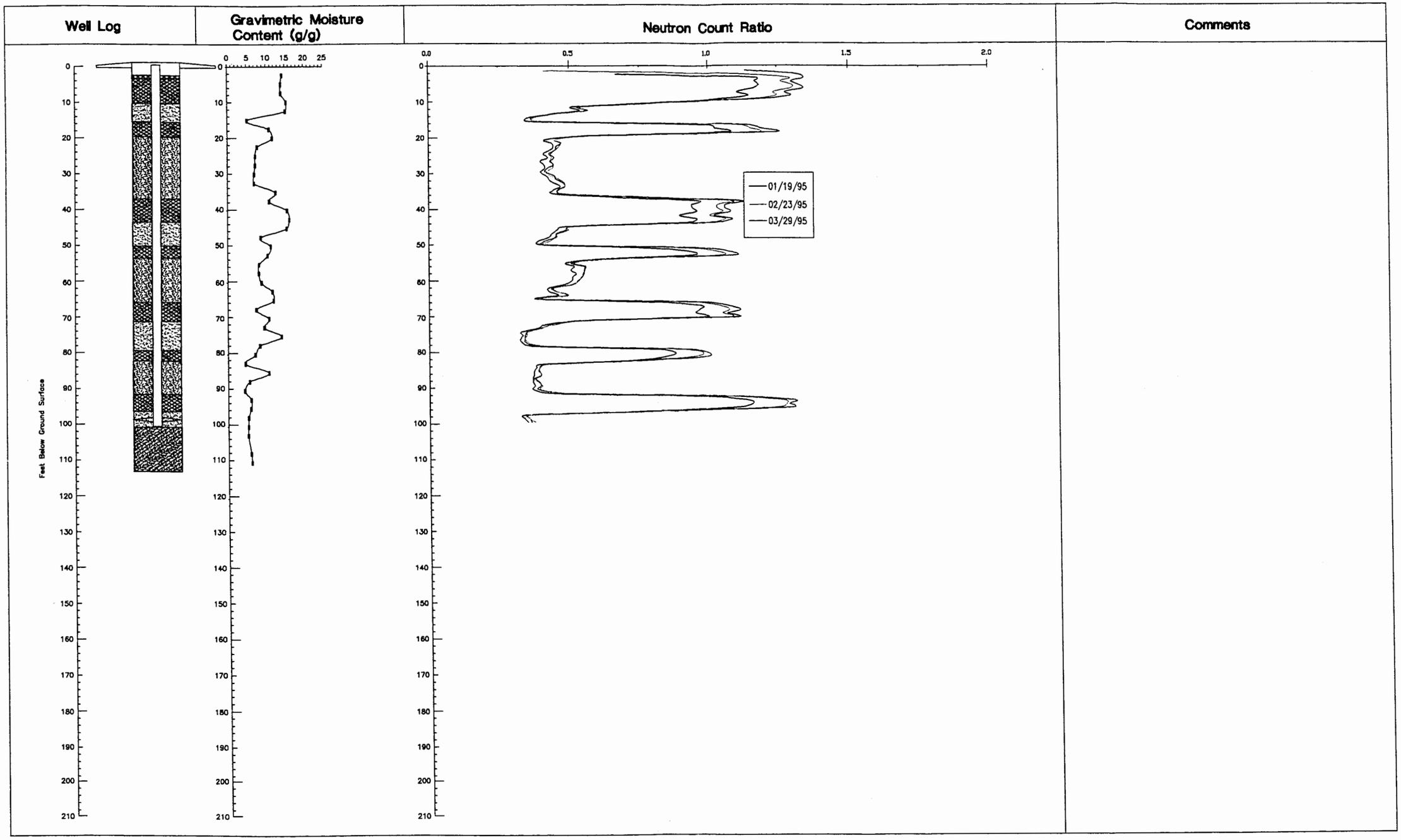
LANL RFI SUPPORT

Neutron Count Ration Measurements in Vadose Zone Well LP-3

M\4010\40102rf.DWG



Well Construction Symbols

- Bentonite pellets
- 10–20 silica sand
- Sieved tuff
- 50/50 bentonite and sand
- Slough

Note: The neutron count ratio data was collected utilizing a CPN model 503DR Hydroprobe SN# H38018058

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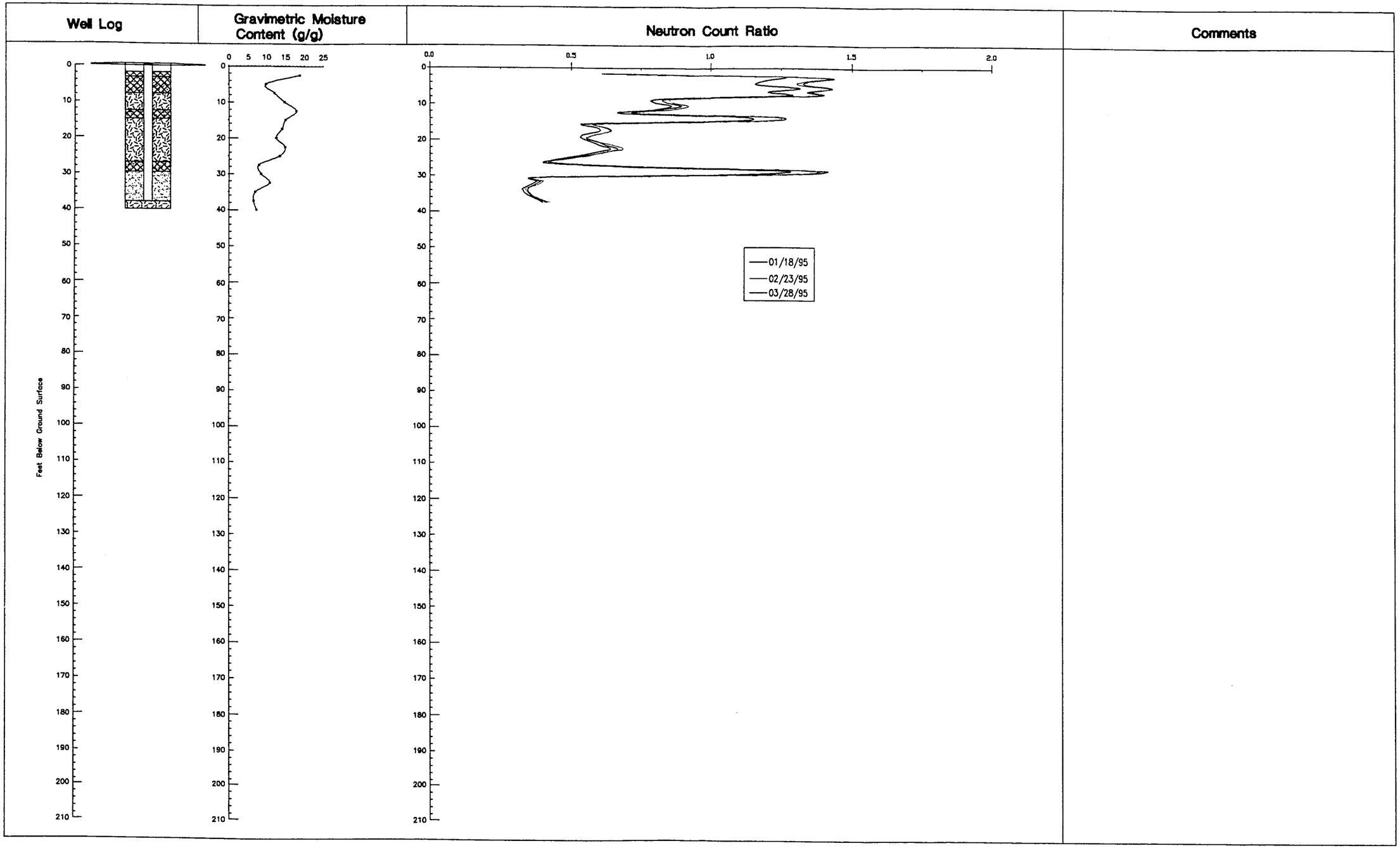
LANL RFI SUPPORT

Neutron Count Ratio Measurements in Vadose Zone Well LP-4



Well Construction Symbols

- Bentonite pellets
- 50/50 bentonite and sand
- 10–20 silica sand
- Slough
- Sieved tuff

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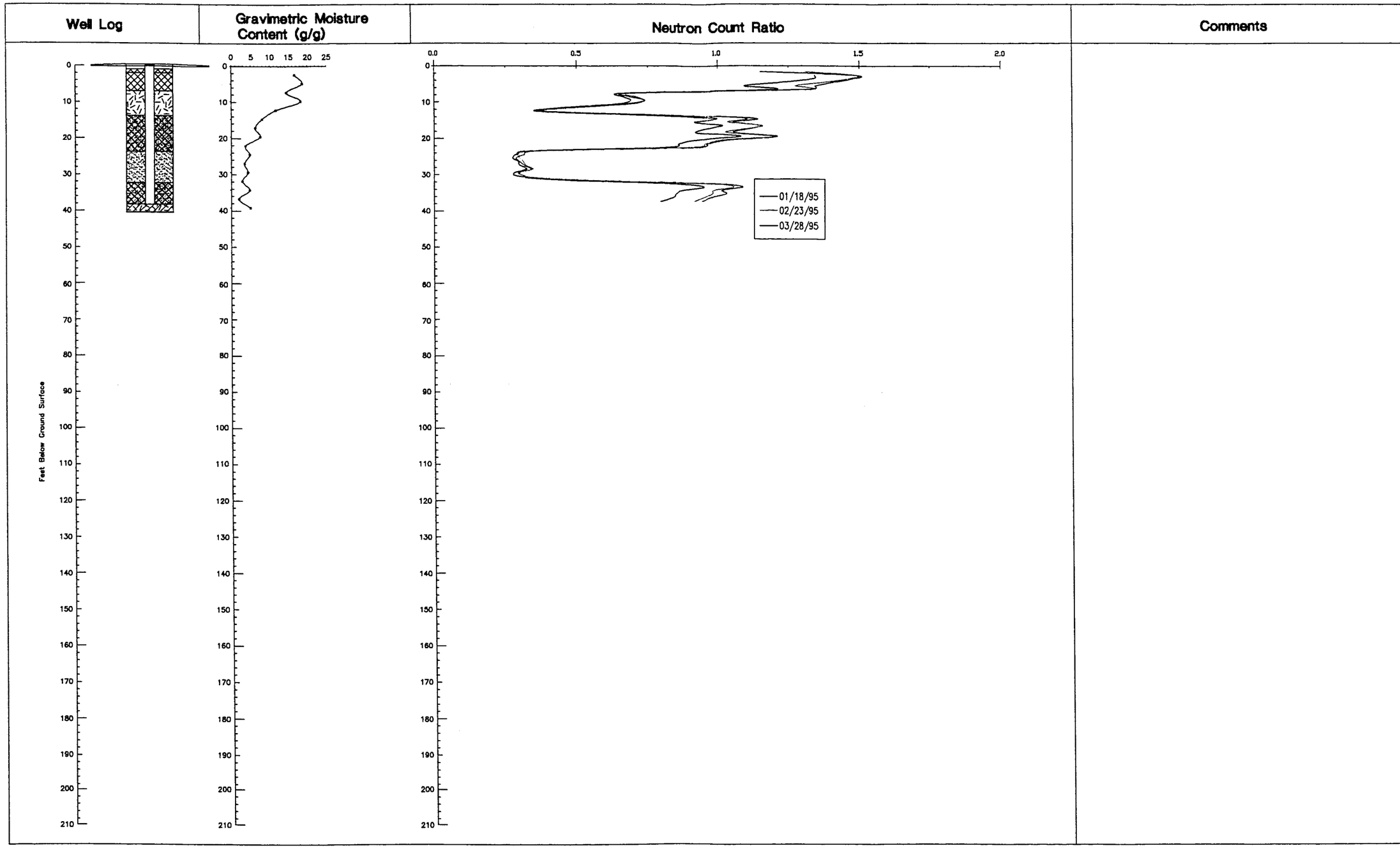
LANL RFI SUPPORT

Neutron Count Ratio Measurements in Vadose Zone Well LP-5

M:\4010\40102.WG



Well Construction Symbols

- Bentonite pellets
- 10–20 silica sand
- Sieved tuff
- 50/50 bentonite and sand
- Slough

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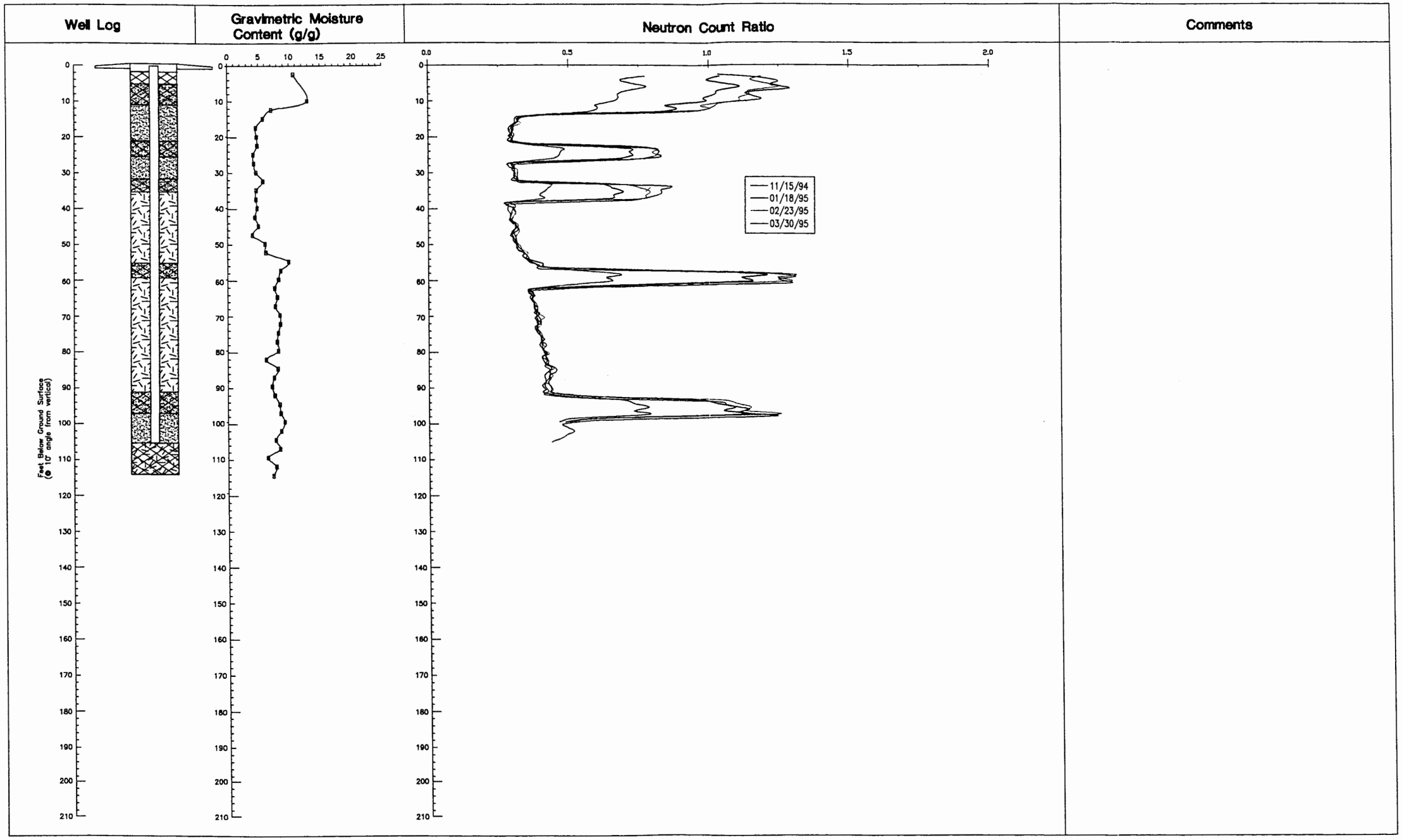
LANL RFI SUPPORT

Neutron Count Ratio Measurements In Vadose Zone Well LP-6

M\4010\401024F.DWG



Well Construction Symbols

- Bentonite pellets
- 50/50 bentonite and sand
- 10–20 silica sand
- Slough
- Sieved tuff

Note: The neutron count ratio data was collected utilizing a CPN model 503DR Hydroprobe SN# H38018058

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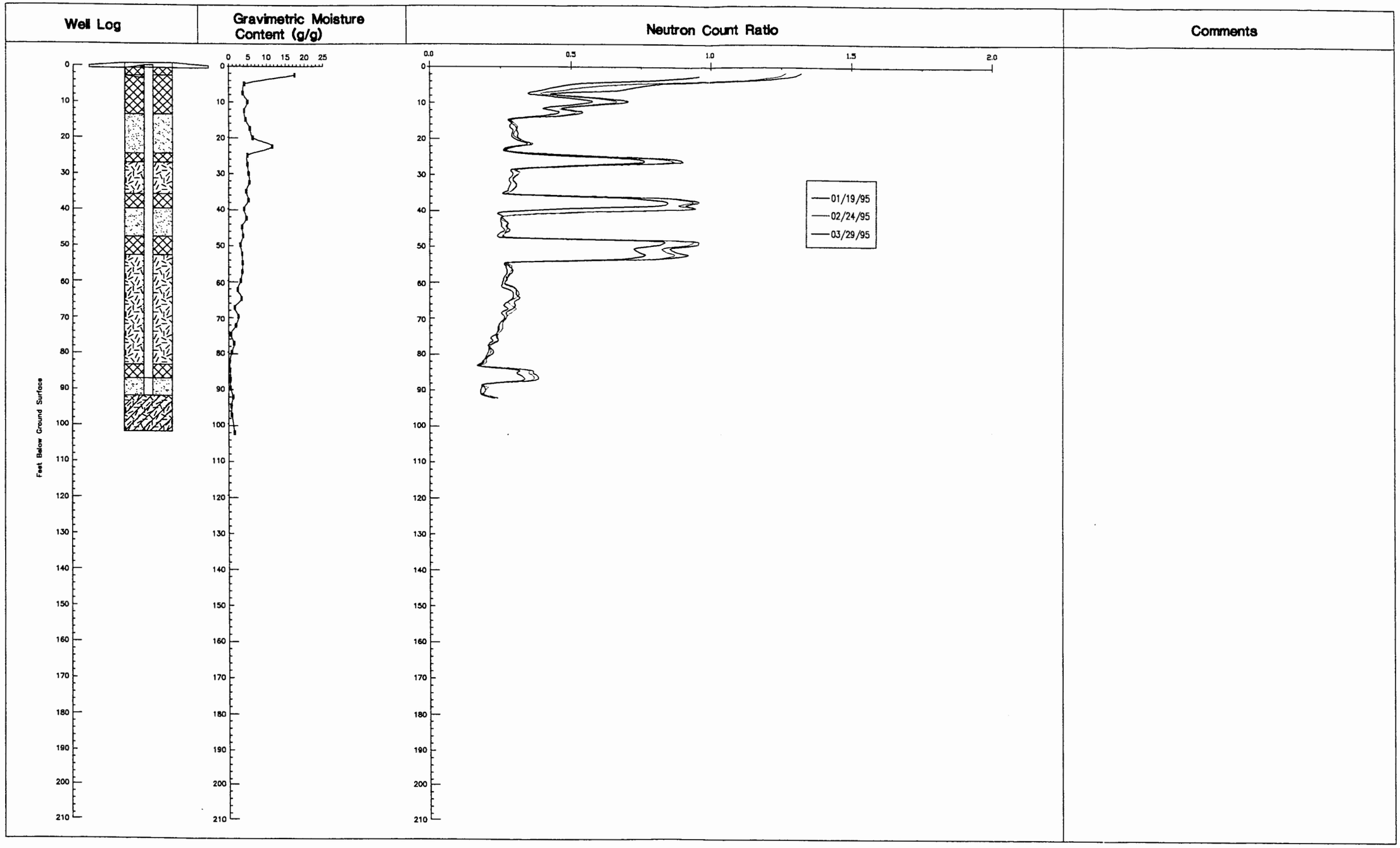
LANL RFI SUPPORT

Neutron Count Ration Measurements in Vadose Zone Well LP-7



Well Construction Symbols

- Bentonite pellets
- 10–20 silica sand
- Sieved tuff
- 50/50 bentonite and sand
- Slough

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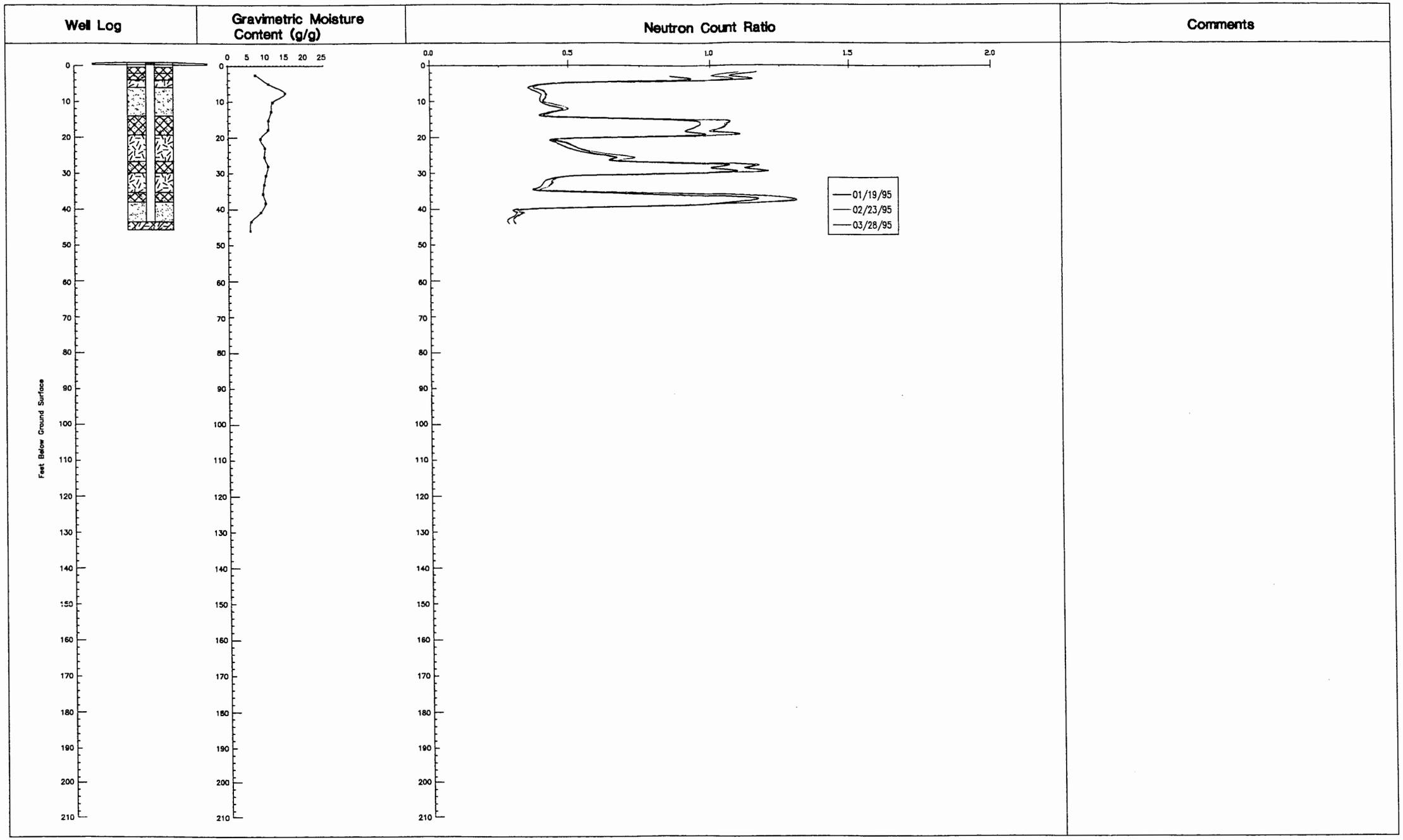
LANL RFI SUPPORT

Neutron Count Ration Measurements in Vadose Zone Well LP-8

M:\4010\401025.DWG



Well Construction Symbols

- Bentonite pellets
- 10-20 silica sand
- Sieved tuff
- 50/50 bentonite and sand
- Slough

Note: The neutron count ratio data was collected utilizing a CPN model 503DR Hydroprobe SN# H38018058

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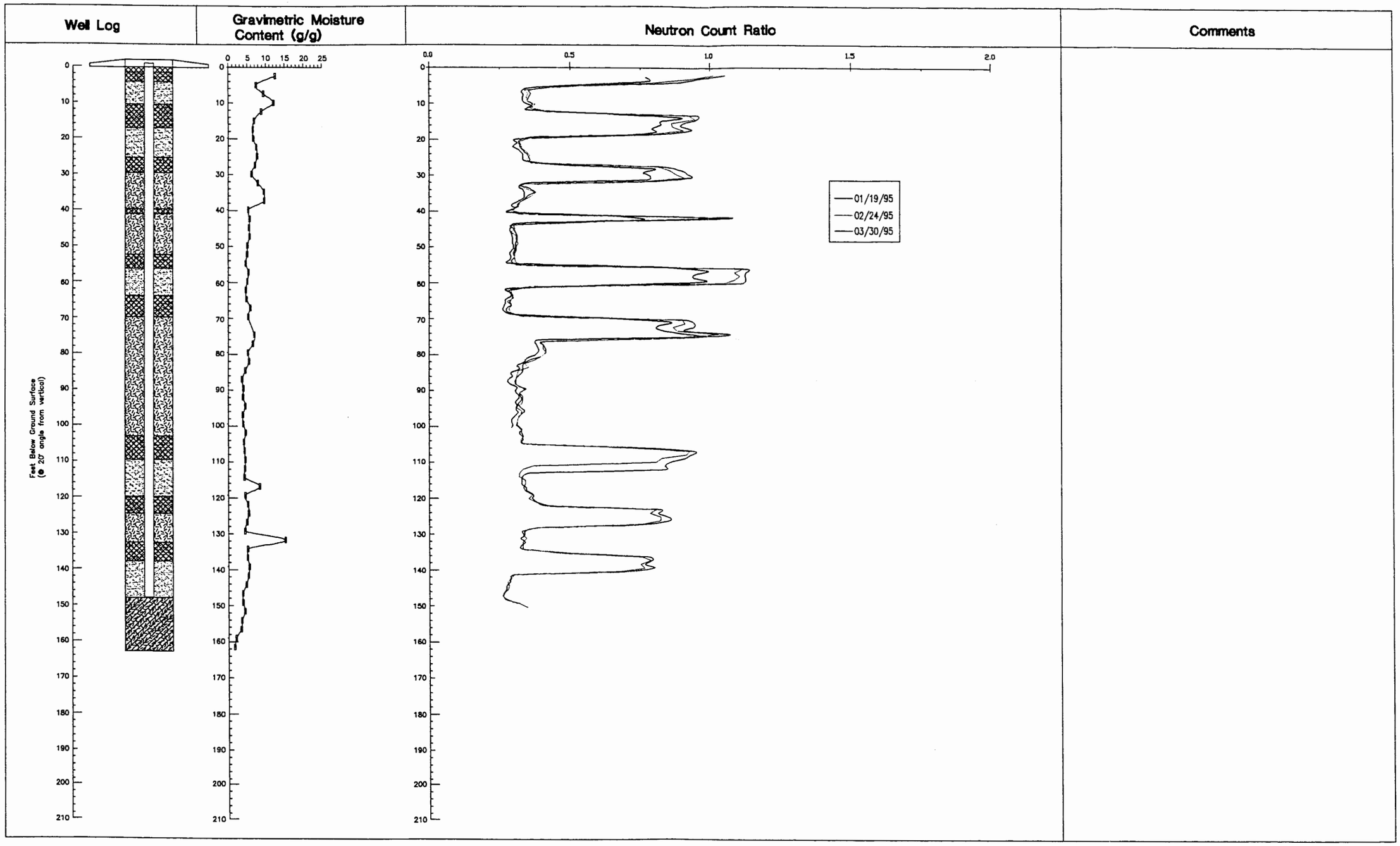
LANL RFI SUPPORT

Neutron Count Ratio Measurements in Vadose Zone Well LP-9

M:\4010\401026.DWG



Well Construction Symbols

- Bentonite pellets
- 50/50 bentonite and sand
- 10–20 silica sand
- Slough
- Sieved tuff

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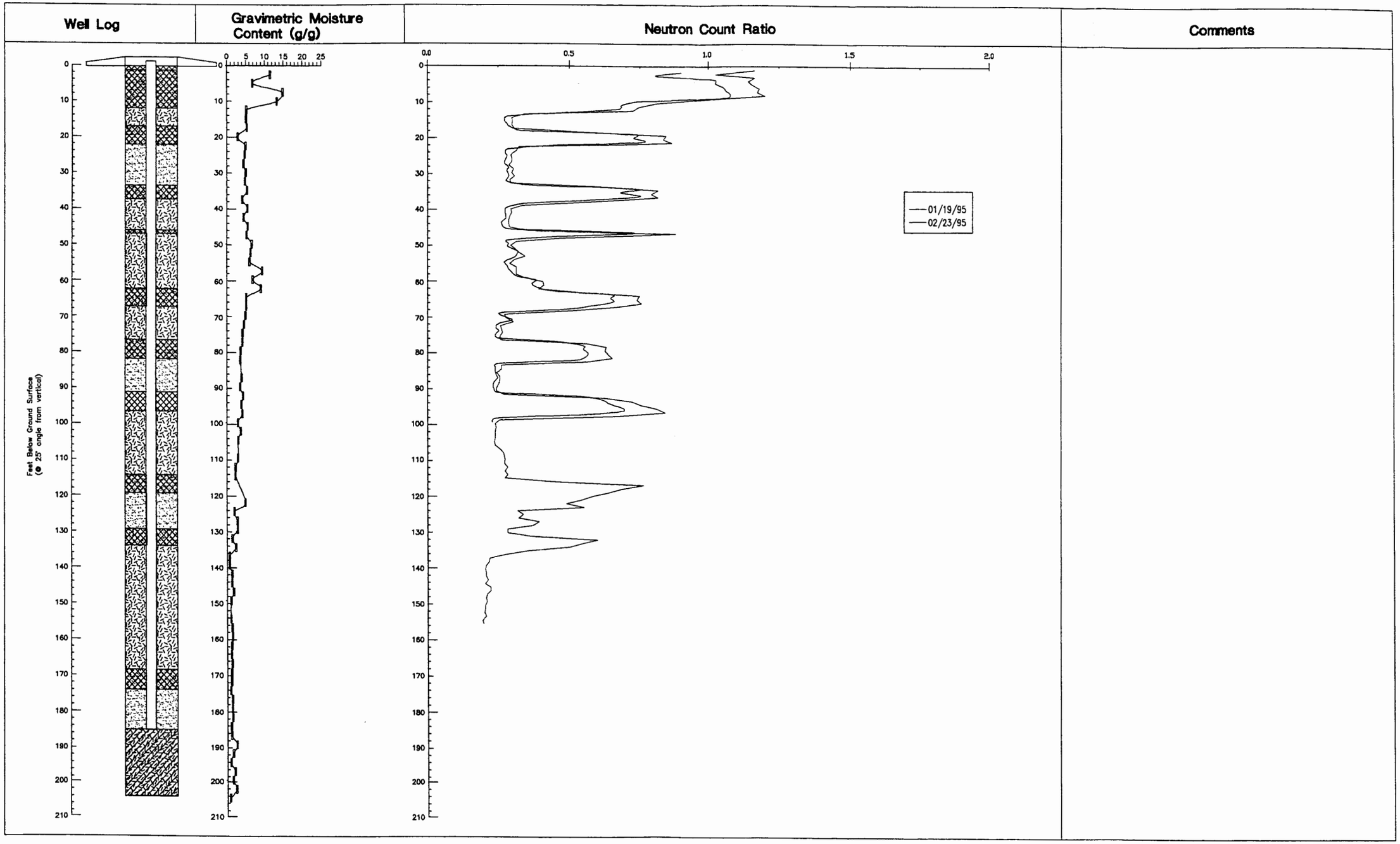
LANL RFI SUPPORT

Neutron Count Ratio Measurements in Vadose Zone Well LPS-1



Well Construction Symbols

- Bentonite pellets
- 10-20 silica sand
- Sieved tuff
- 50/50 bentonite and sand
- Slough

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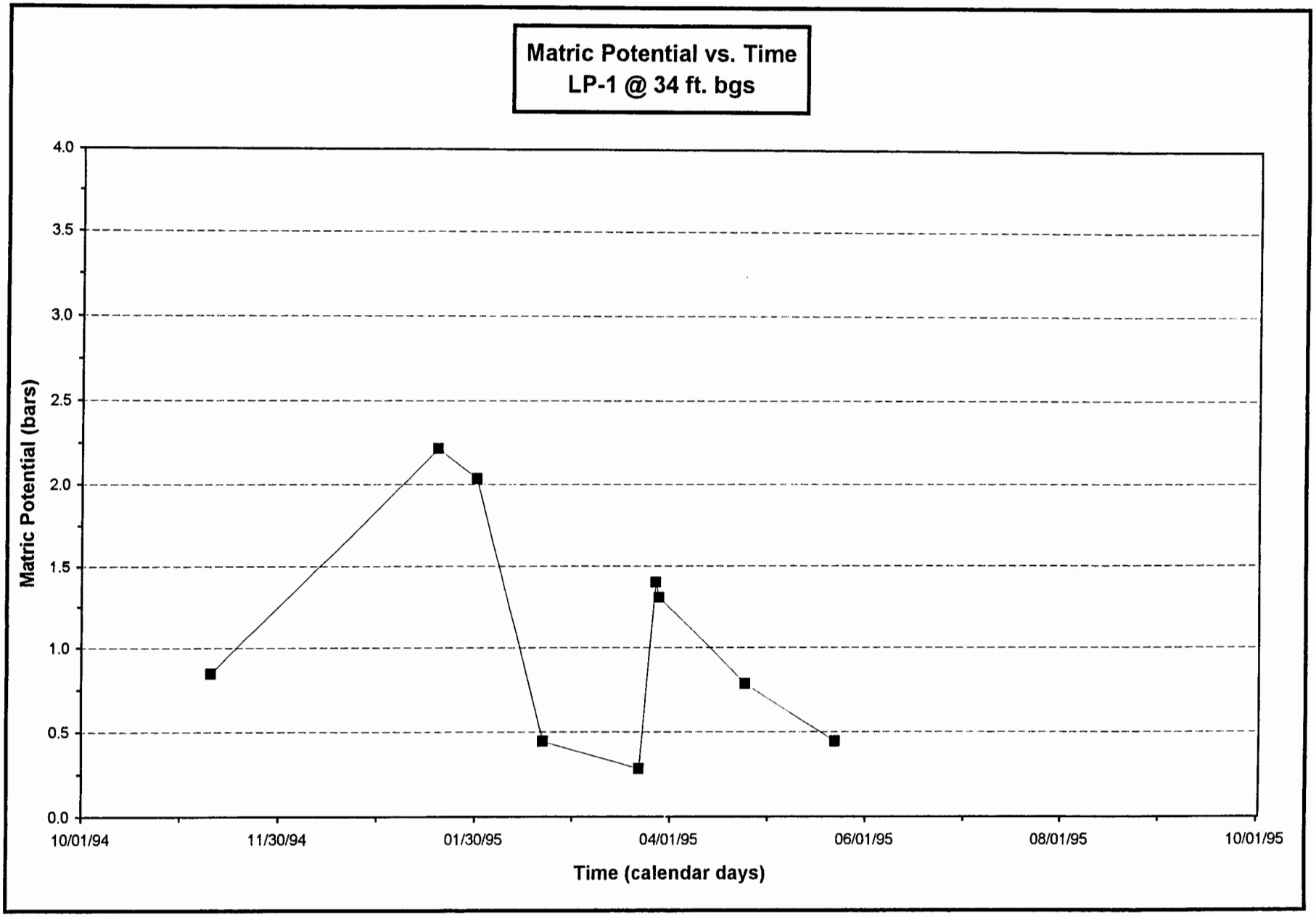
LANL RFI SUPPORT

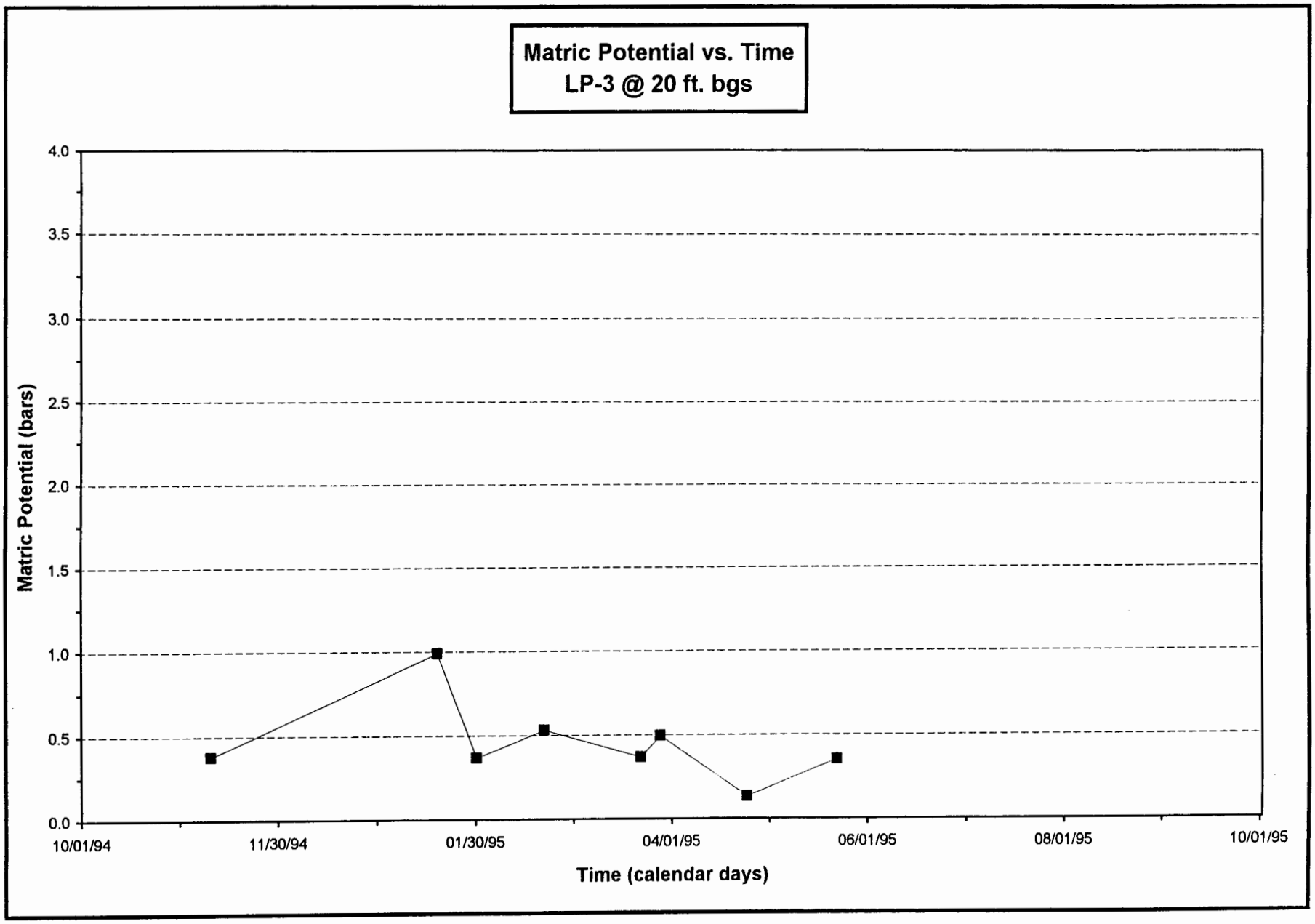
Neutron Count Ratio Measurements in Vadose Zone Well LPS-2

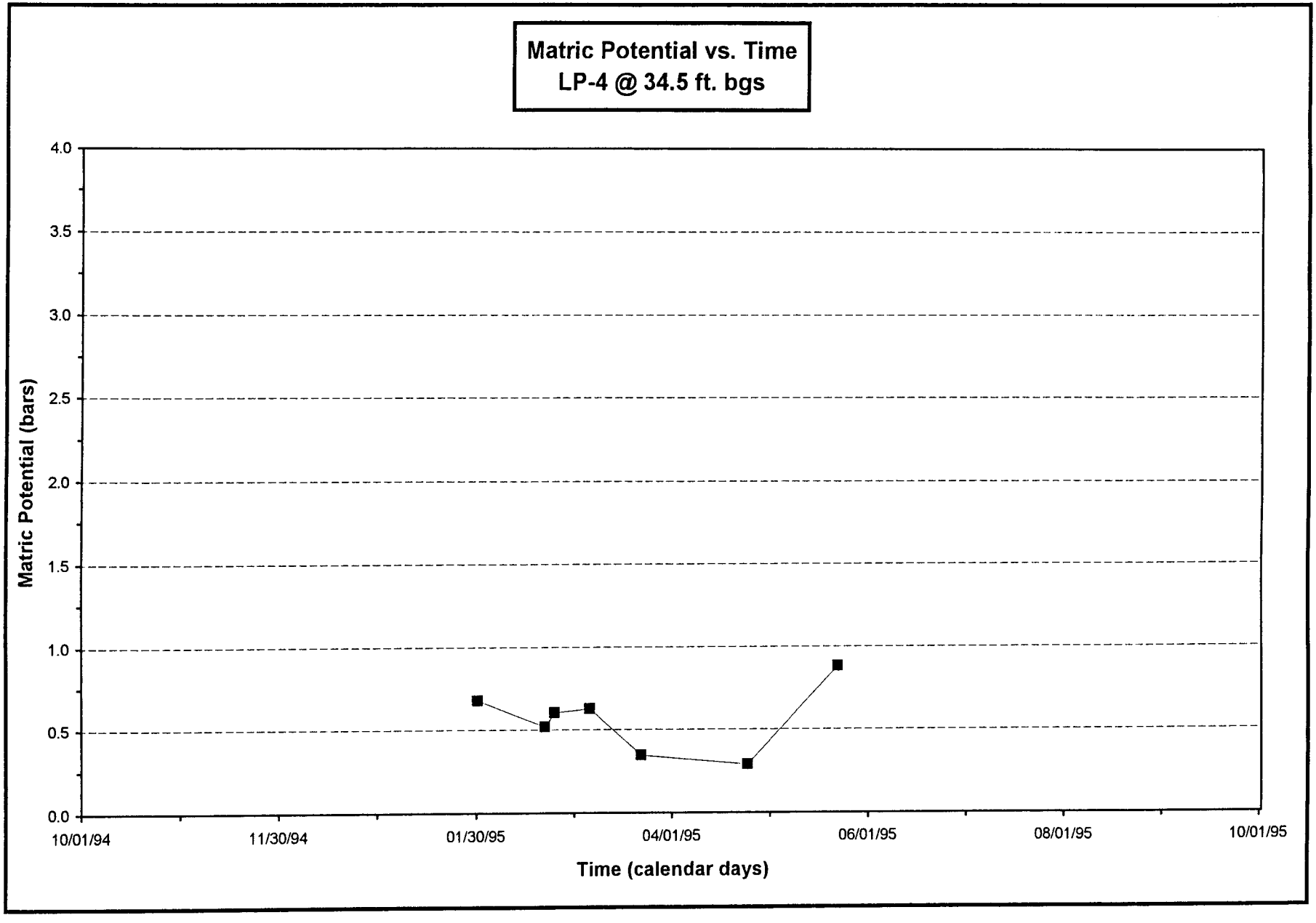
M:\4010\401028F.DWG

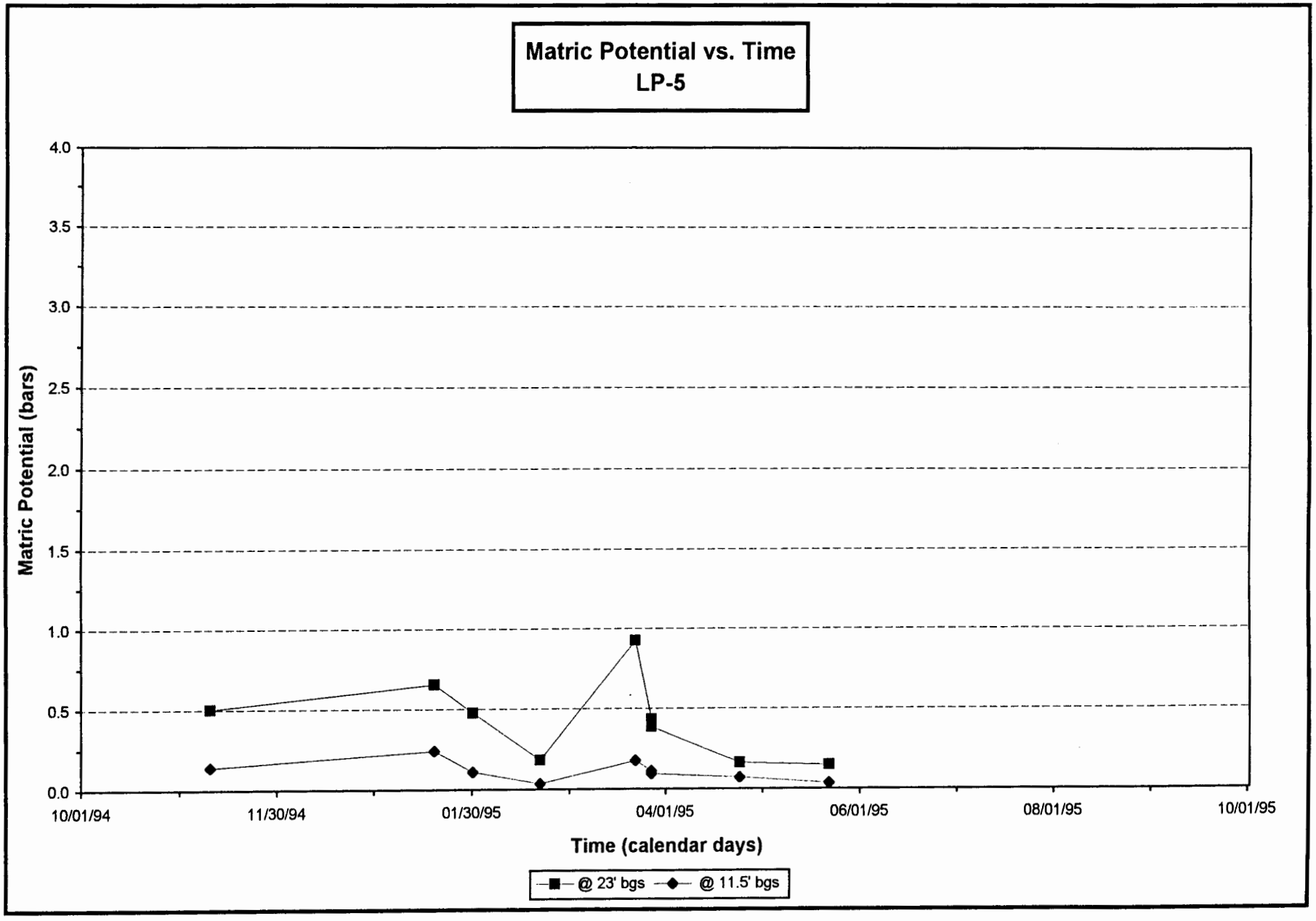
APPENDIX G

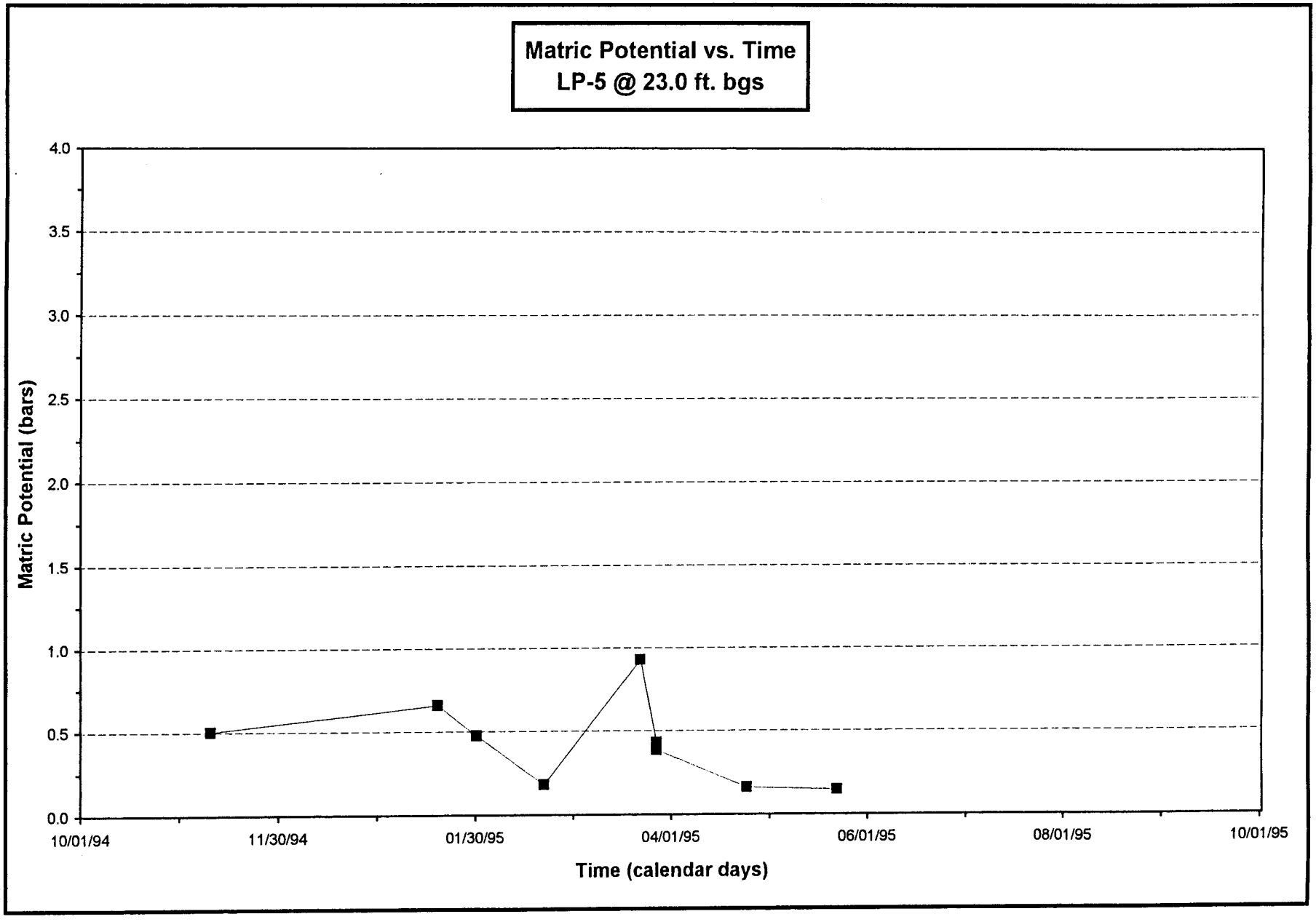
MATRIC POTENTIAL vs. TIME

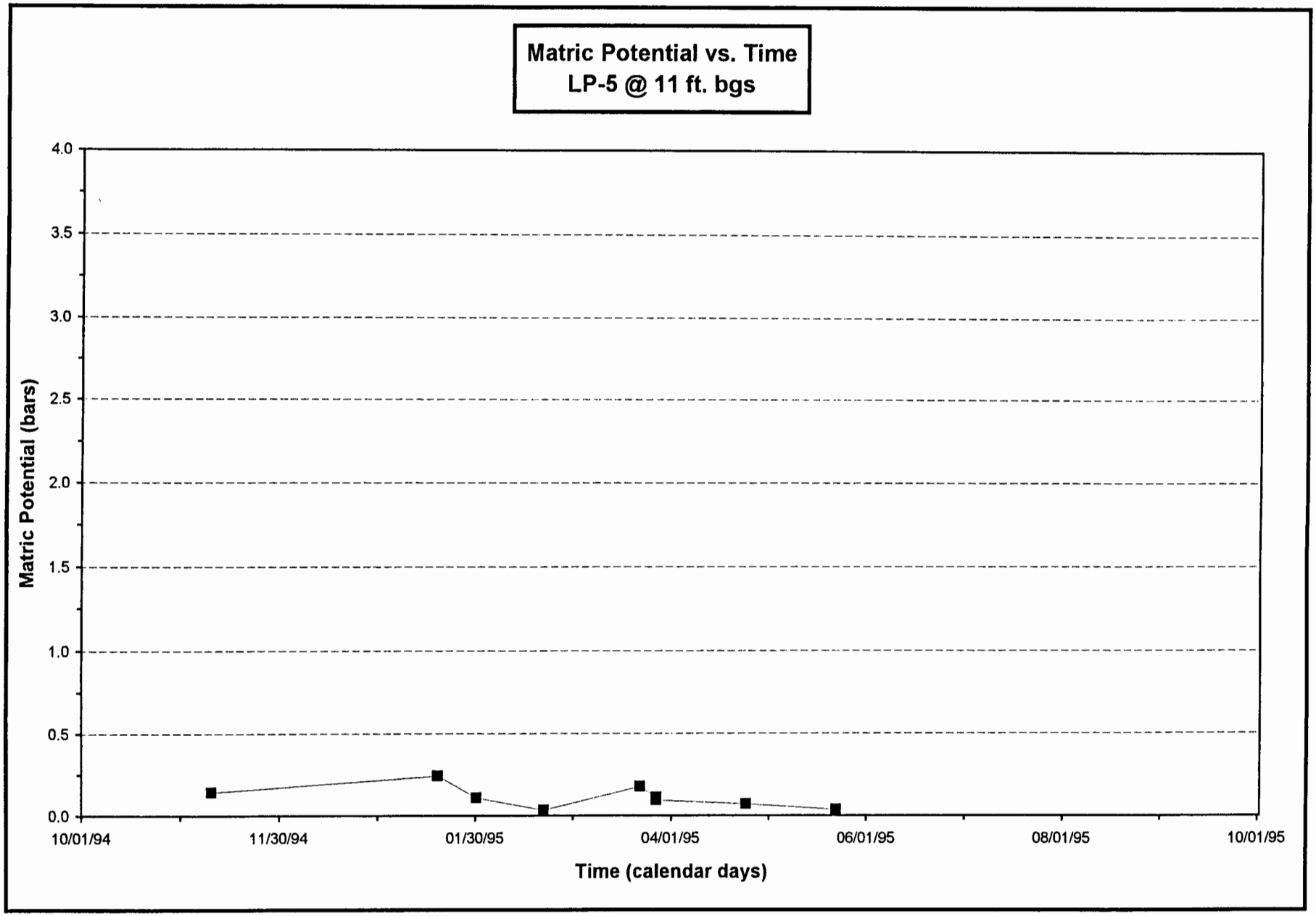

Matric Potential vs. Time
LP-1 @ 34 ft. bgs
Matric Potential (bars)
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
10/01/94
11/30/94
01/30/95
04/01/95
06/01/95
08/01/95
10/01/95
Time (calendar days)

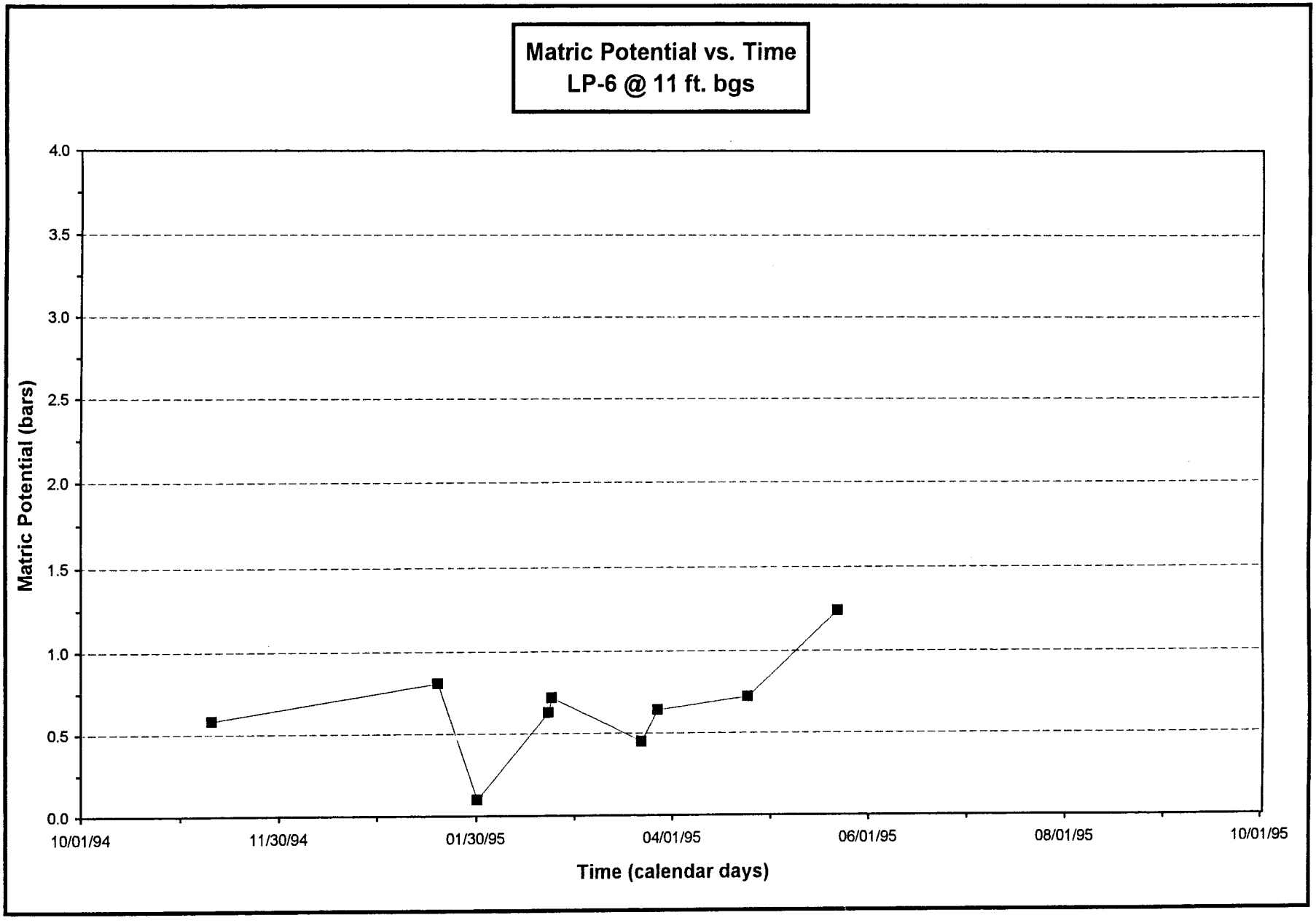

Matric Potential vs. Time
LP-3 @ 20 ft. bgs
Matric Potential (bars)
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
10/01/94
11/30/94
01/30/95
04/01/95
06/01/95
08/01/95
10/01/95
Time (calendar days)

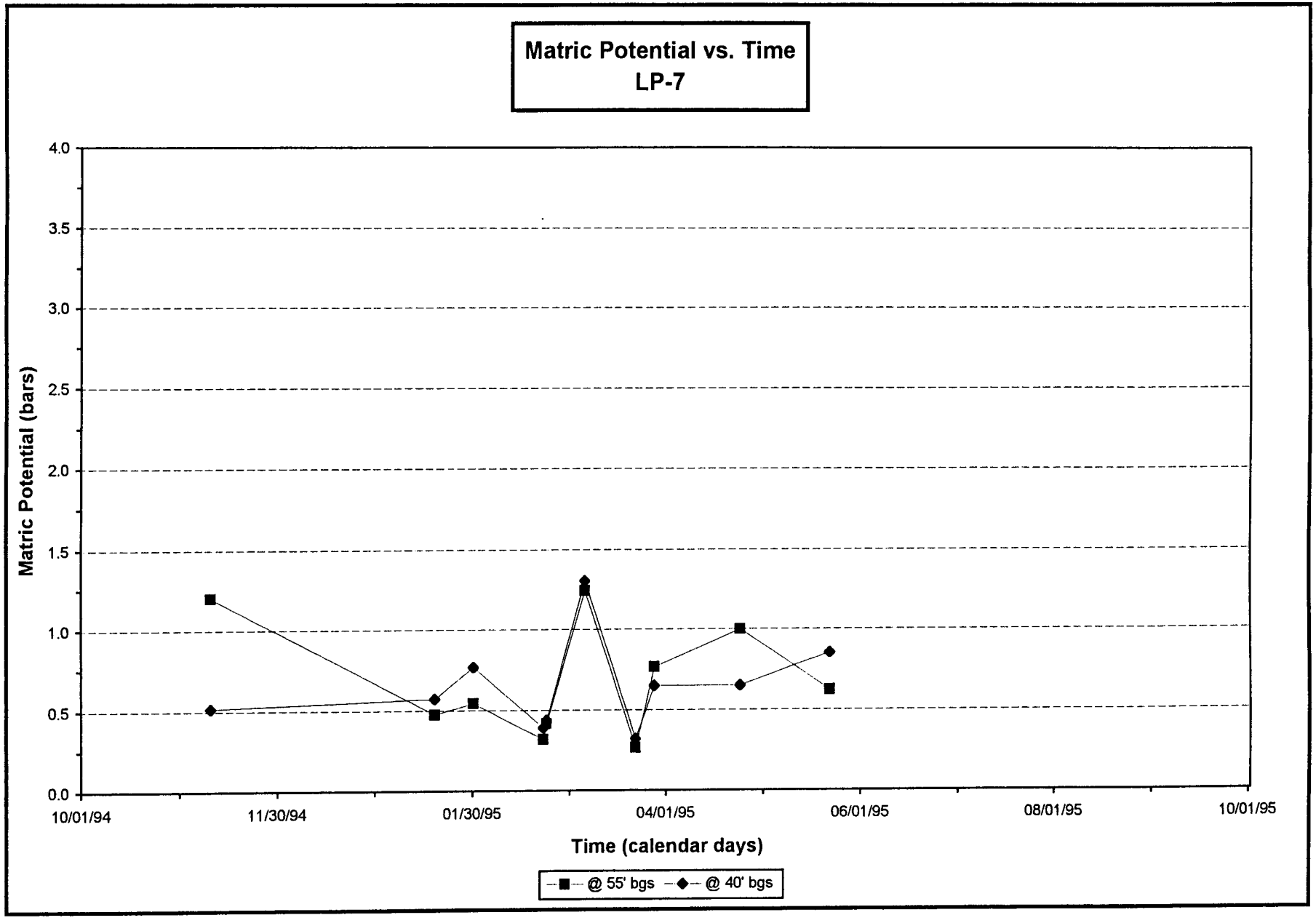

Matric Potential vs. Time
LP-4 @ 34.5 ft. bgs
Matric Potential (bars)
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
10/01/94
11/30/94
01/30/95
04/01/95
06/01/95
08/01/95
10/01/95
Time (calendar days)

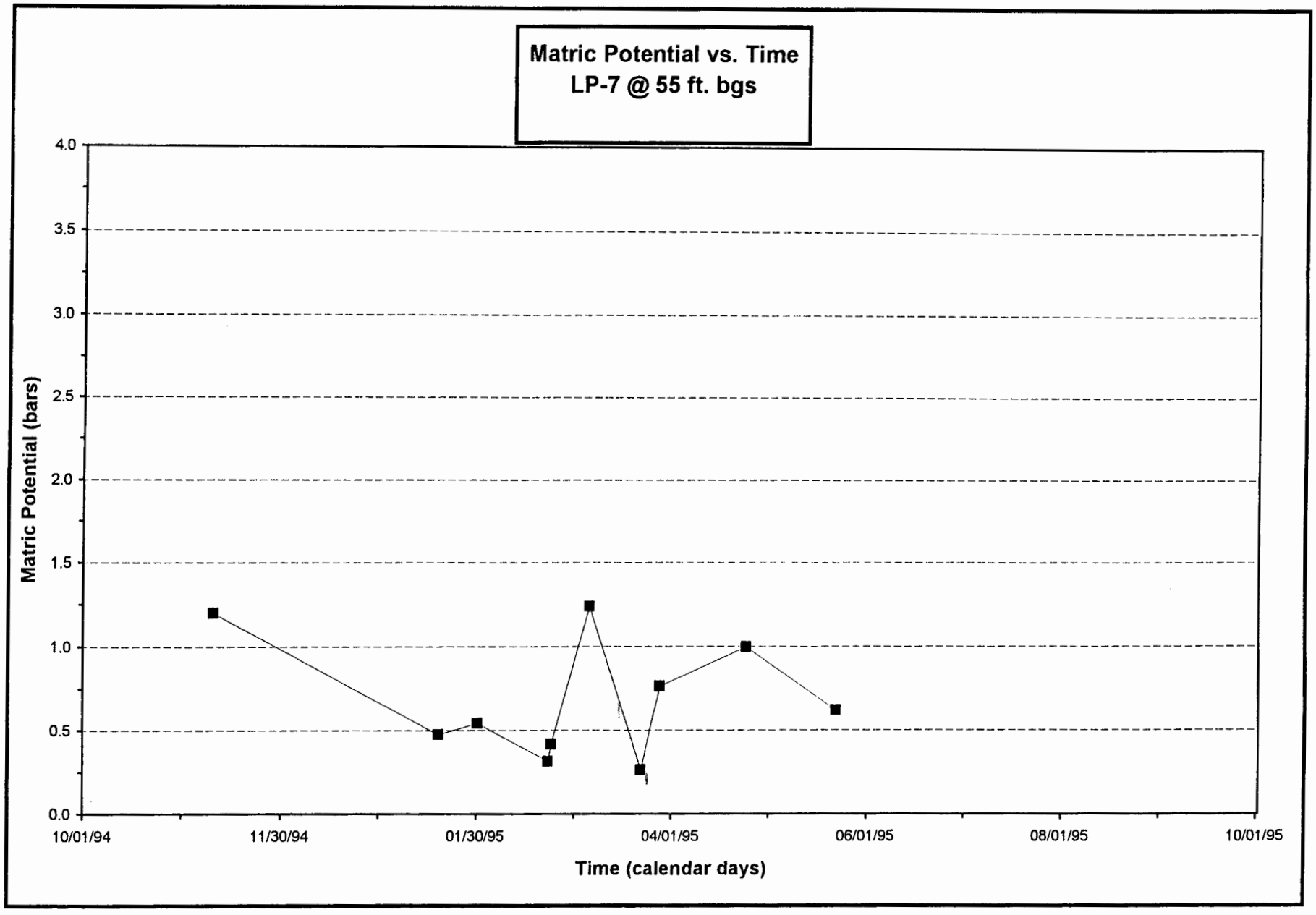

Matric Potential vs. Time
LP-5
Matric Potential (bars)
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
10/01/94
11/30/94
01/30/95
04/01/95
06/01/95
08/01/95
10/01/95
Time (calendar days)
@ 23' bgs
@ 11.5' bgs

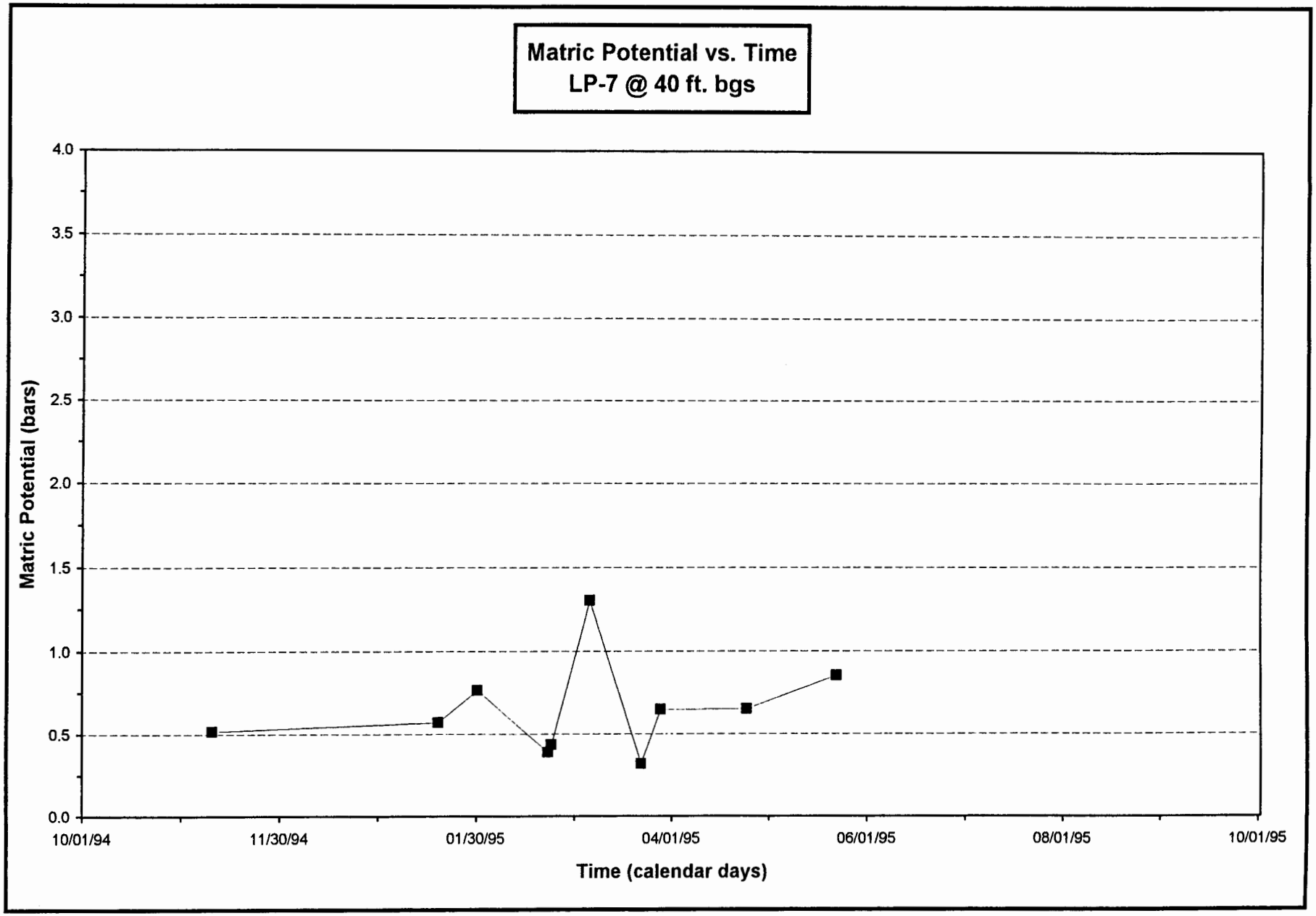

Matric Potential vs. Time
LP-5 @ 23.0 ft. bgs
Matric Potential (bars)
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
10/01/94
11/30/94
01/30/95
04/01/95
06/01/95
08/01/95
10/01/95
Time (calendar days)

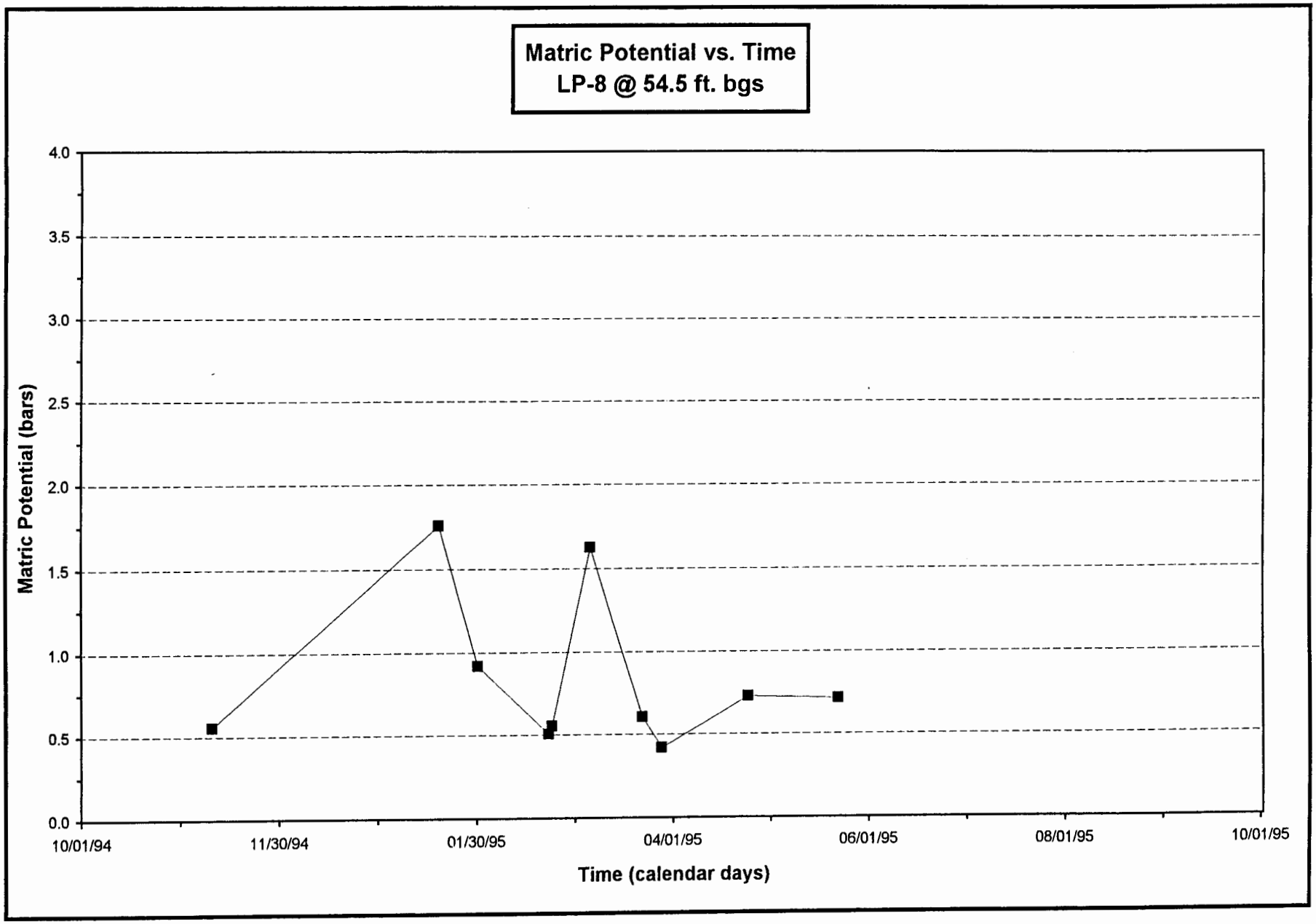

Matric Potential vs. Time
LP-5 @ 11 ft. bgs
Matric Potential (bars)
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
10/01/94
11/30/94
01/30/95
04/01/95
06/01/95
08/01/95
10/01/95
Time (calendar days)

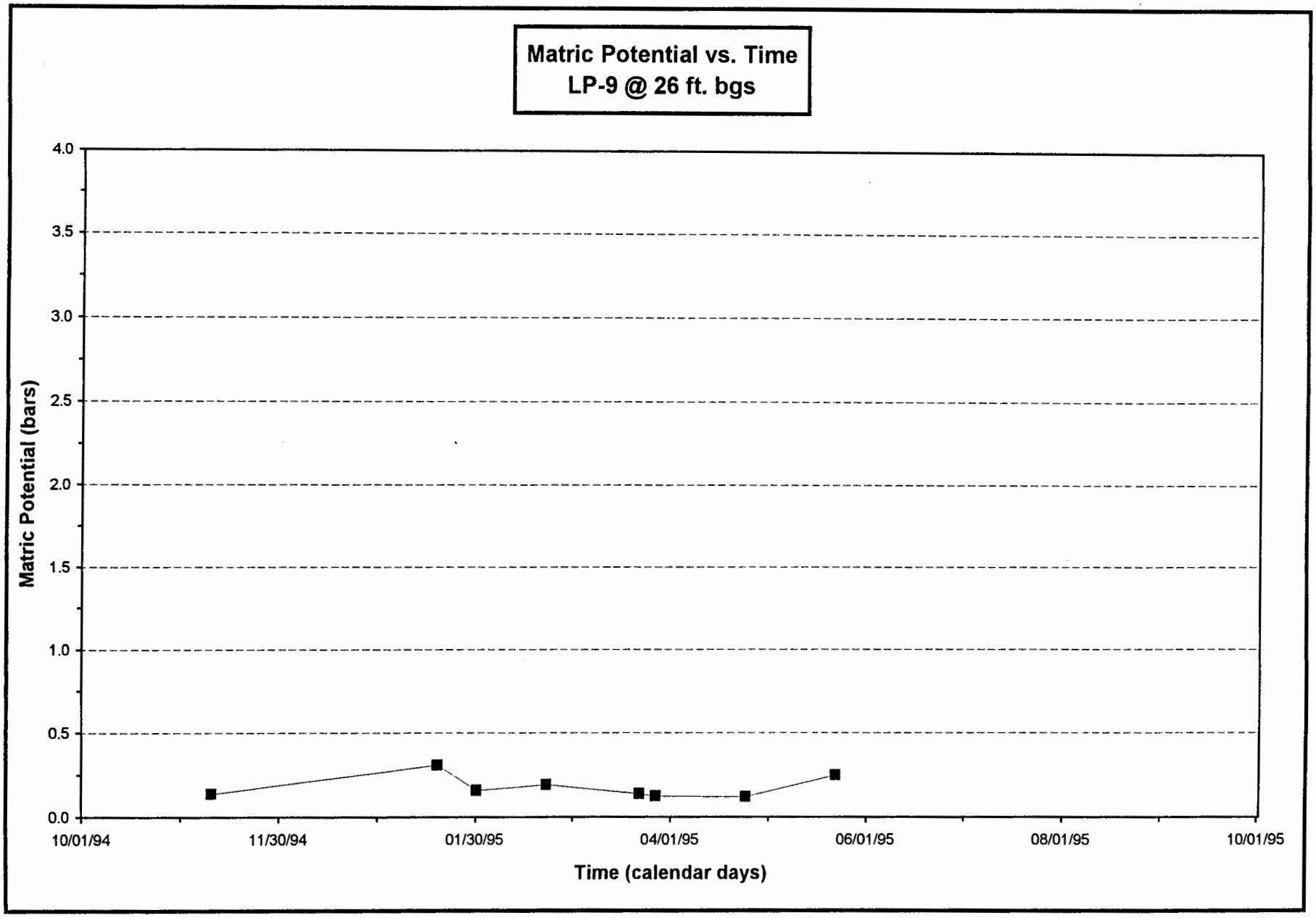

Matric Potential vs. Time
LP-6 @ 11 ft. bgs
Matric Potential (bars)
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
10/01/94
11/30/94
01/30/95
04/01/95
06/01/95
08/01/95
10/01/95
Time (calendar days)

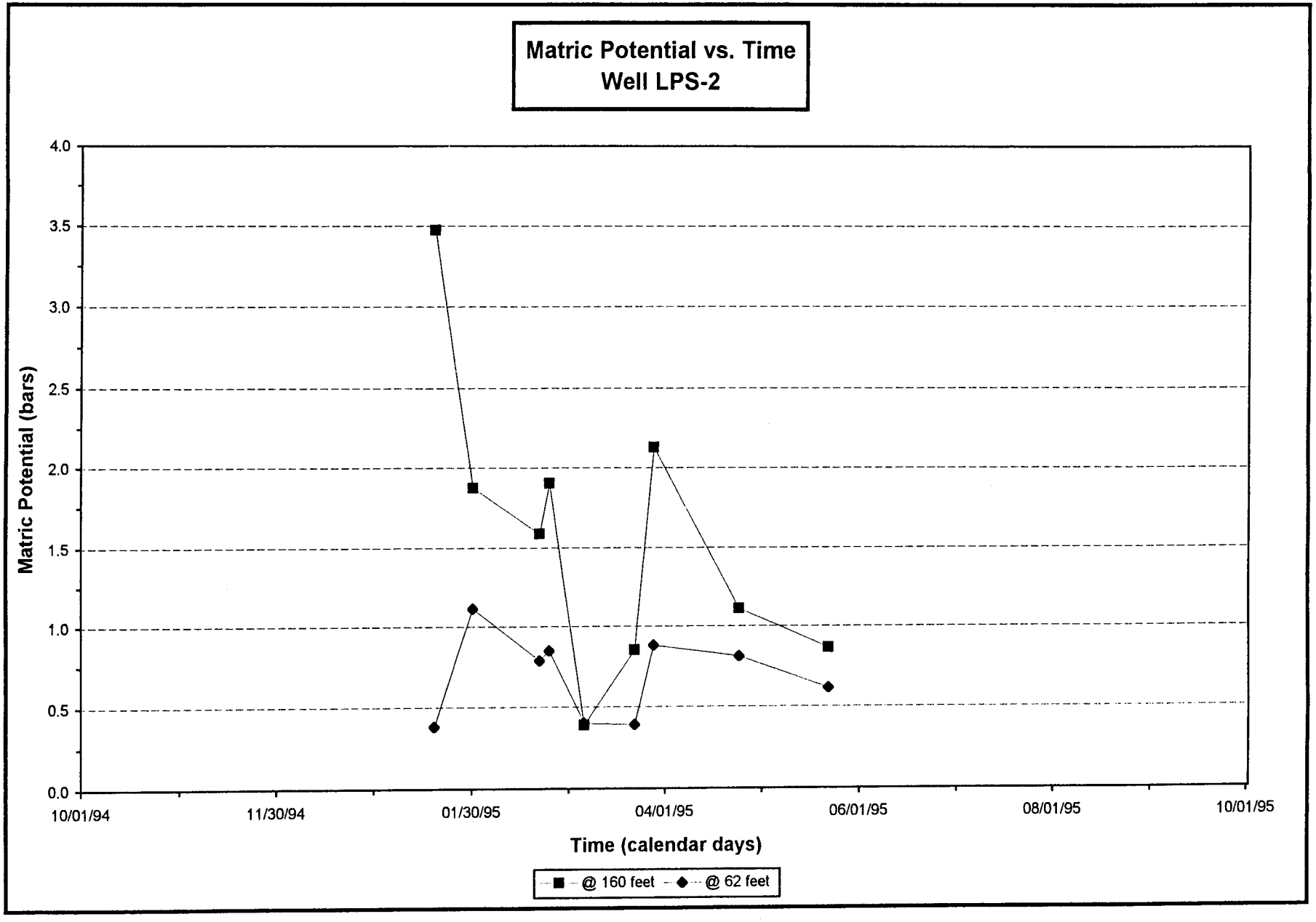

Matric Potential vs. Time
LP-7
Matric Potential (bars)
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
10/01/94
11/30/94
01/30/95
04/01/95
06/01/95
08/01/95
10/01/95
Time (calendar days)
@ 55' bgs
@ 40' bgs

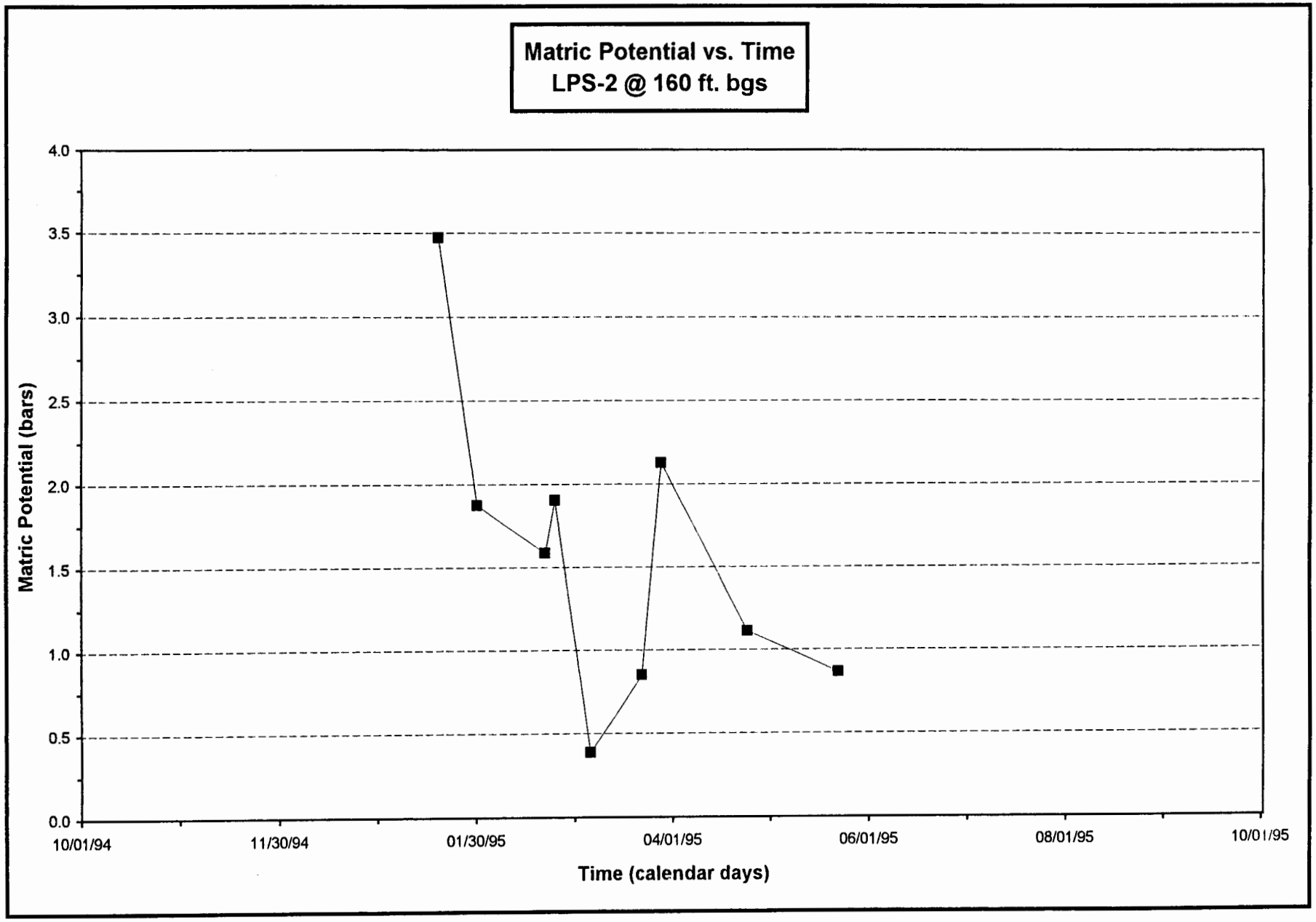

Matric Potential vs. Time
LP-7 @ 55 ft. bgs
Matric Potential (bars)
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
10/01/94
11/30/94
01/30/95
04/01/95
06/01/95
08/01/95
10/01/95
Time (calendar days)

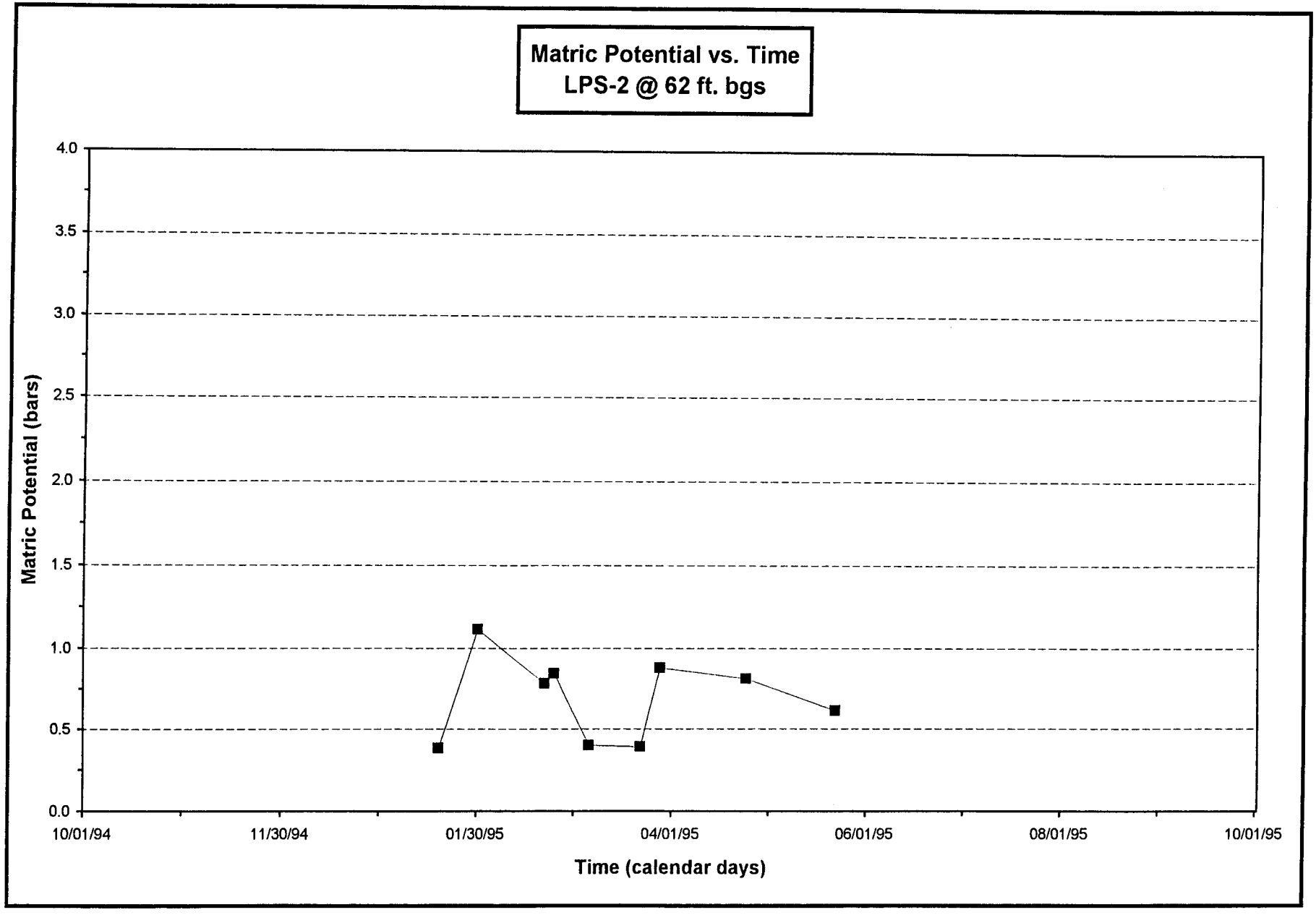

Matric Potential vs. Time
LP-7 @ 40 ft. bgs
Matric Potential (bars)
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
10/01/94
11/30/94
01/30/95
04/01/95
06/01/95
08/01/95
10/01/95
Time (calendar days)


Matric Potential vs. Time
LP-8 @ 54.5 ft. bgs
Matric Potential (bars)
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
10/01/94
11/30/94
01/30/95
04/01/95
06/01/95
08/01/95
10/01/95
Time (calendar days)


Matric Potential vs. Time
LP-9 @ 26 ft. bgs
Matric Potential (bars)
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
10/01/94
11/30/94
01/30/95
04/01/95
06/01/95
08/01/95
10/01/95
Time (calendar days)

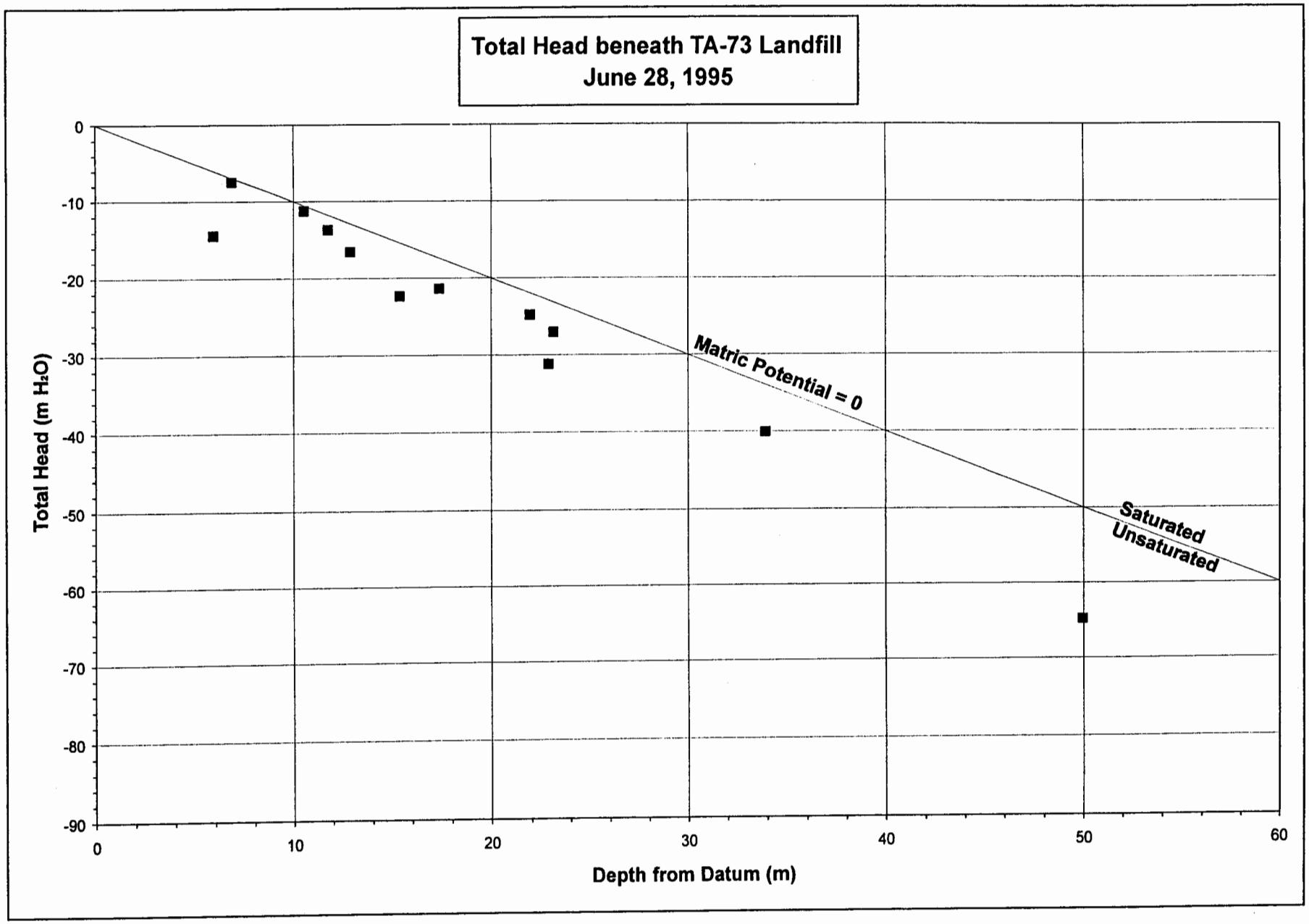

Matric Potential vs. Time
Well LPS-2
Matric Potential (bars)
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
10/01/94
11/30/94
01/30/95
04/01/95
06/01/95
08/01/95
10/01/95
Time (calendar days)
@ 160 feet
@ 62 feet

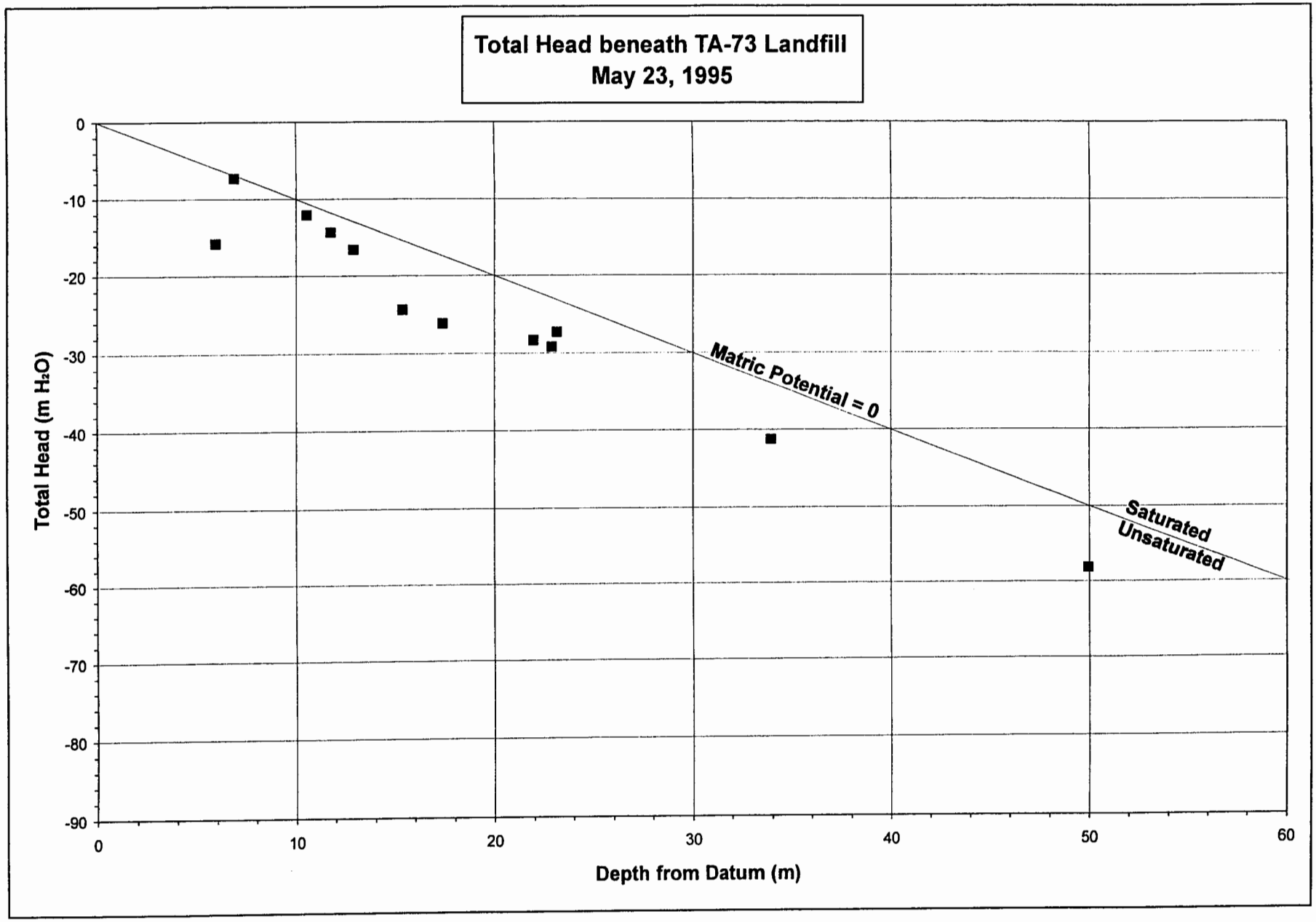

Matric Potential vs. Time
LPS-2 @ 160 ft. bgs
Matric Potential (bars)
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
10/01/94
11/30/94
01/30/95
04/01/95
06/01/95
08/01/95
10/01/95
Time (calendar days)

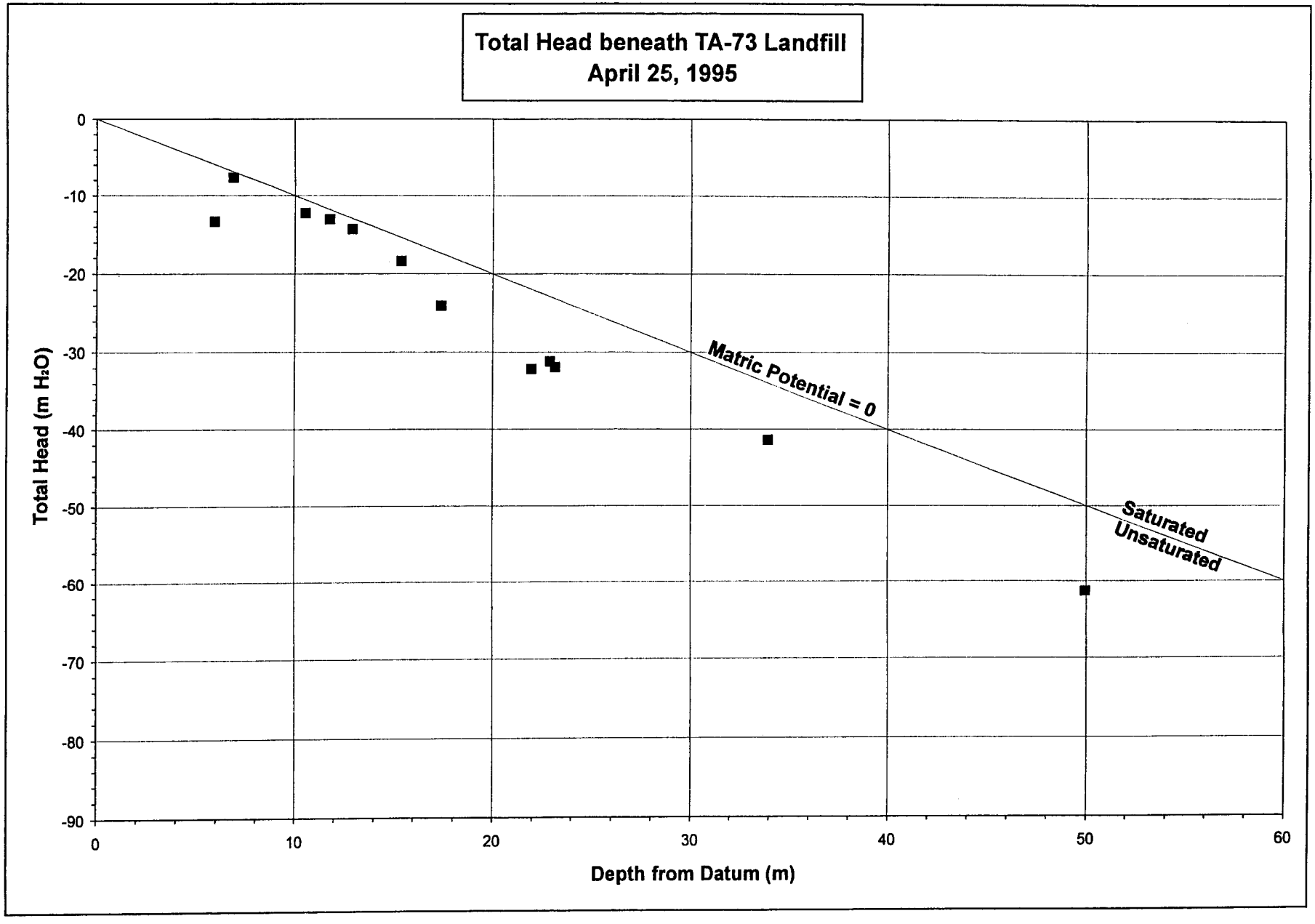

Matric Potential vs. Time
LPS-2 @ 62 ft. bgs
Matric Potential (bars)
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
10/01/94
11/30/94
01/30/95
04/01/95
06/01/95
08/01/95
10/01/95
Time (calendar days)

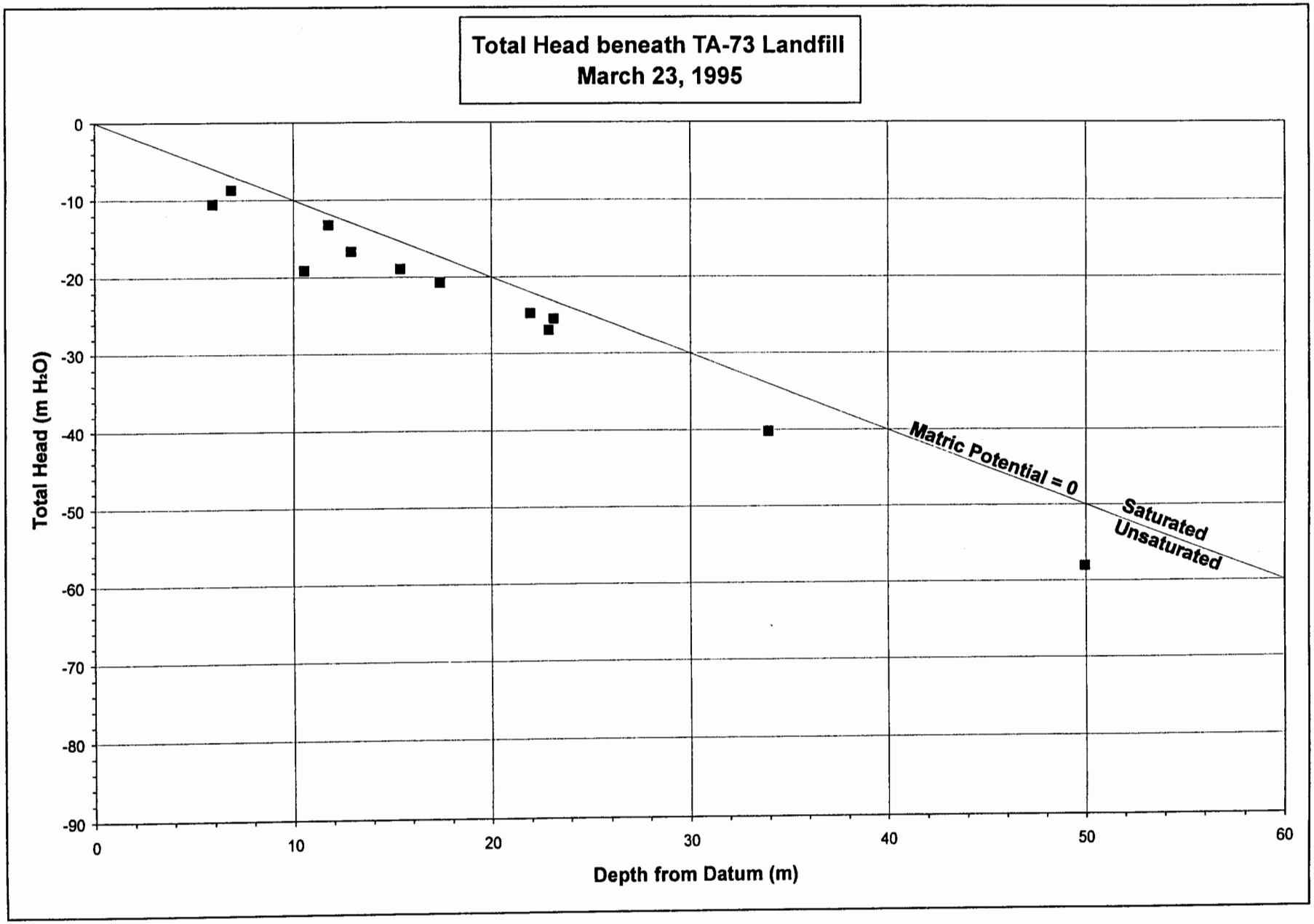
APPENDIX H

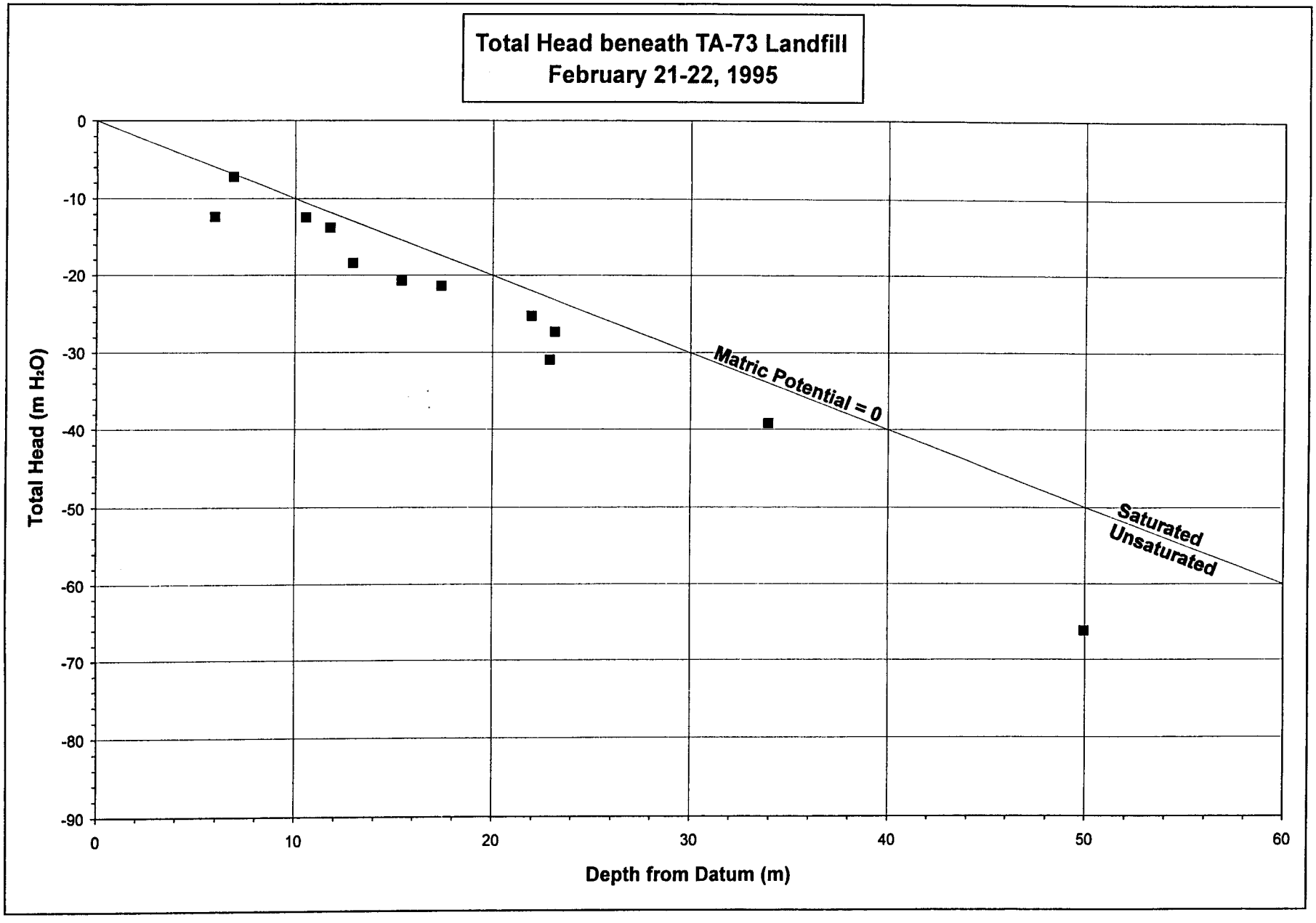
TOTAL HEAD BENEATH TA-73 LANDFILL

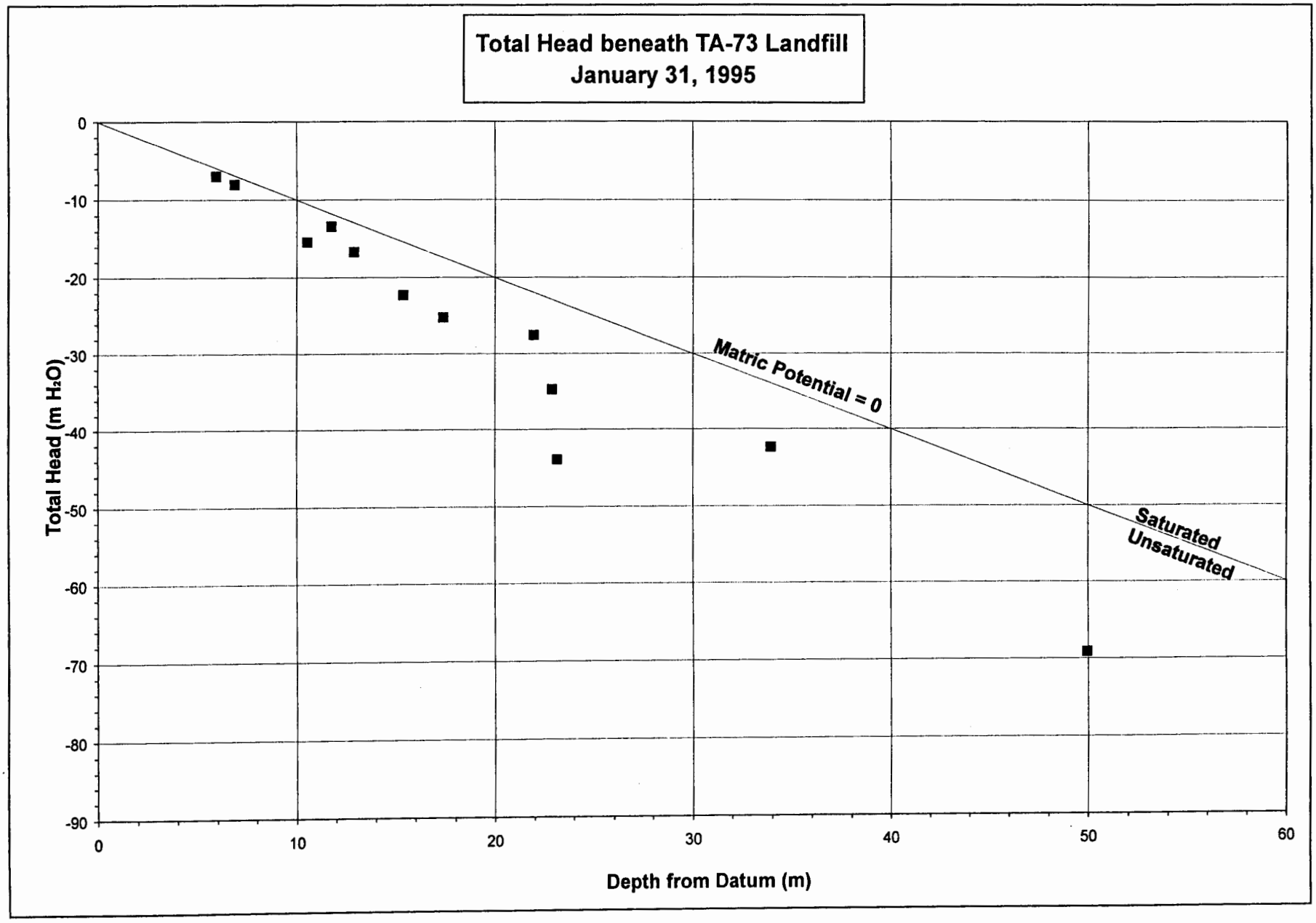

Total Head beneath TA-73 Landfill
June 28, 1995
Total Head (m H2O)
0
-10
-20
-30
-40
-50
-60
-70
-80
-90
0
10
20
30
40
50
60
Depth from Datum (m)
Matric Potential = 0
Saturated
Unsaturated


Total Head beneath TA-73 Landfill
May 23, 1995
Total Head (m H2O)
0
-10
-20
-30
-40
-50
-60
-70
-80
-90
0
10
20
30
40
50
60
Depth from Datum (m)
Matric Potential = 0
Saturated
Unsaturated


Total Head beneath TA-73 Landfill
April 25, 1995
Total Head (m H₂O)
0
-10
-20
-30
-40
-50
-60
-70
-80
-90
0
10
20
30
40
50
60
Depth from Datum (m)
Matric Potential = 0
Saturated
Unsaturated


Total Head beneath TA-73 Landfill
March 23, 1995
Total Head (m H2O)
0
-10
-20
-30
-40
-50
-60
-70
-80
-90
0
10
20
30
40
50
60
Depth from Datum (m)
Matric Potential = 0
Saturated
Unsaturated


Total Head beneath TA-73 Landfill
February 21-22, 1995
Total Head (m H2O)
0
-10
-20
-30
-40
-50
-60
-70
-80
-90
0
10
20
30
40
50
60
Depth from Datum (m)
Matric Potential = 0
Saturated
Unsaturated


Total Head beneath TA-73 Landfill
January 31, 1995
Total Head (m H2O)
0
-10
-20
-30
-40
-50
-60
-70
-80
-90
0
10
20
30
40
50
60
Depth from Datum (m)
Matric Potential = 0
Saturated
Unsaturated