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Department of Energy
Field Office, Albuquerque
Los Alamos Area Office
Los Alamos, New Mexico 87544

AUG 27 1993

TA-16

Ms. Barbara Hoditschek
Permit Program Manager
Hazardous and Radioactive Materials Bureau
New Mexico Environment Department
1190 St. Francis Drive
Santa Fe, New Mexico 87502

TA 16

Dear Ms. Hoditschek:

Enclosed is the Closure and Post-Closure Plan for Technical Area 16, Material Disposal Area P (MDA P). As discussed in meetings with you and your staff, the enclosed plan replaces all previous closure plans for MDA P.

If you have questions, please call me at 665-5027 or ask your staff to call Paul Treat at 665-5808.

Sincerely,

Joseph C. Vozella

Joseph C. Vozella
Chief
Environment, Safety and Health Branch

Enclosure

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Closure and Post-Closure Plan

for

Material Disposal Area P (MDA P)

Los Alamos National Laboratory

Volume 1 of 2

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30 August 1993

Executive Summary

Material Disposal Area P (MDA P) is located within TA-16, a high explosive (HE) development site at the Laboratory. MDA P was operated as a landfill for rubble and debris resulting from burning HE-contaminated equipment, building materials, empty drums and bottles, and trash. Burning took place on sand-covered burning pads, and after the burn, the sand and burned wastes were disposed of in MDA-P. As a result of burning HE waste, levels of barium in the sand exceeded the extraction procedure (EP) toxicity limit, therefore, MDA P was classified as a Resource Conservation and Recovery Act (RCRA) hazardous waste site.

Several closure alternatives were considered for MDA P. These alternatives included containment by immobilization, in-place treatment, removal, and in-place closure. Containment by immobilization and in-place treatment were determined to be infeasible because of the heterogeneous nature of the waste materials and the impossibility of determining the exact location of potential hazardous materials within the disposal area.

Previous studies at MDA P indicate that diverting surface water run-on, protecting against the 100-year flood, constructing a soil and vegetative cover, and stabilizing the landfill slope will eliminate migration of contaminants from MDA P that would have an adverse impact on human health or the environment, thus meeting the requirements of 40 CFR 264, Subpart G. This closure plan includes field investigations to confirm the results of these previous studies. Closure in place is preferred to removal because removal activities could have adverse human health and environmental impacts resulting from releases to the environment of hazardous constituents that are now contained. Removal activities also present a safety risk to workers excavating and transporting materials.

Post-closure requirements include maintaining the cap, protecting against a 100-year flood, controlling surface run-on, and monitoring for 30 years. All of these requirements are practical, are part of the closure strategy, and are described in this closure/post-closure plan. The proposed monitoring activities are consistent with the Laboratory's ongoing environmental surveillance program. All of these activities will be conducted under a post closure permit [40CFR 270.1(c)].

The proposed cap for MDA P is one of soil and vegetative cover. The slope of the eastern portion of the landfill will be reduced with MDA P surface scrap materials and fill to facilitate covering. The slope of the western portion of the landfill has been stable for decades and has a well-established cover of vegetation and soil covered by a rock facing that will be enhanced during closure.

The closure plan includes two phases. Phase 1 will require one to two years to complete and includes:

- Diversion of storm water run-on that now flows onto the landfill from adjacent areas. This water will be redirected to preclude run-on and its infiltration into the Area P landfill.

- An intensive monitoring program to:

  — evaluate the existence of potential contaminants of concern not previously characterized,
  — confirm that surface water runoff and subsurface water movement are not routes of potential significant contaminant migration from MDA P to the Cañon de Valle stream, and
  — determine if MDA P damage from potential earthquakes presents a significant threat to human health and the environment.

If Phase 1 monitoring confirms the absence of significant potential contaminant migration and shows that earthquake damage is not an issue, the following Phase 2 final closure activities will be proposed :

- stabilize the landfill slope,
- improve the base of the landfill slope to withstand a 100-year flood event in the Cañon de Valle stream, and
- complete the landfill capping, utilizing layered soil covering and vegetation.

If Phase 1 monitoring indicates the potential for significant contaminant migration, enhanced closure activities will be proposed. The enhanced closure design could include enhanced cap design, upgradient vadose zone water diversion, or downgradient runoff and vadose zone water collection and treatment. If the enhanced closure design is not adequate to protect human health and the environment, then other closure alternatives will be re-evaluated.

After completion of the Phase 1 investigation, an addendum to this plan will be submitted to the New Mexico Environment Department (NMED) describing the results of the investigation and

proposing the Phase 2 closure design. Implementation of Phase 2 closure activities will require NMED approval.

MDA P CLOSURE AND POST-CLOSURE PLAN
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1.0 Introduction

Closure and post-closure plans for Material Disposal Area P (MDA P) at Technical Area (TA) 16 (Delta H Engineering, Ltd., 1985 and LANL 1988) were prepared by Los Alamos National Laboratory (the Laboratory) and submitted to the New Mexico Environment Department (NMED). However, these closure plans were not approved. In late 1992, the Laboratory requested that NMED allow the MDA P closure to be incorporated in the Resource Conservation and Recovery Act (RCRA) Facility Investigation for TA-16 (S Site) under the Laboratory's Environmental Restoration Program which is being conducted as required under Module VIII of the Laboratory's RCRA permit. This request was denied in a written response from NMED. The response also required that a revised closure and post-closure plan be submitted by August 30, 1993. This closure and post-closure plan is submitted to satisfy that requirement and has been written to meet the regulatory requirements of 40 CFR 264, Subpart G.

Volume 1 of this closure and post-closure plan contains Sections 1.0 through 7.0. Section 2.0 provides a detailed description of the background and history of MDA P including a discussion of previous site studies. Section 3.0 provides an overview of the closure options previously studied and the rationale for this phased closure plan. This section also includes an explanation of the data needs for the final design of the Phase 2 closure elements. Section 4.0 provides a detailed description of proposed closure activities and a schedule of closure activities. Section 5.0 discusses post-closure monitoring and maintenance. Section 6.0 covers cost. Section 7.0 summarizes other closure requirements such as financial assurance and designation of a Laboratory contact person. Volume 2 of the plan provides the complete text of several referenced reports and procedures that are cited throughout the first volume.

2.0 Background and History

2.1 Site Location and Size

MDA P is located within TA-16, a high explosive (HE) development site at the Laboratory. The landfill is situated in the saddle of a short, eastern-trending, narrow mesa. As shown in Fig. 2-1, the saddle is on the southern rim of Cañon de Valle, immediately north of the thermal treatment pad, TA-16-387. Figure 2-2 provides more detail on the topography of MDA P and shows the locations of three cross sections. Figure 2-3 compares the old and new slopes of these cross sections as determined by a pre-landfill survey and a more recent survey (Delta H Engineering, Ltd., 1985 and LANL 1988). The area impacted by the landfill is a half-ellipse, roughly 170 ft north-south and 400 ft east-west; the total surface area encompasses approximately two acres. As illustrated in the cross sections (Fig. 2-3), most of the wastes are located on the steep canyon slope with fill depths ranging from 12 to 14 ft. Although the cross sections indicate that the majority of waste deposition extends 30 to 40 ft south of the mesa rim, visual inspection of the site suggests that waste deposition extends south from the rim as far as 100 to 120 ft up to the fence line shown on Fig. 2-1.

Surface run-on/runoff at the site is currently collected by an unlined drainage ditch located immediately north of and parallel to the fence (see Fig. 2-2). This ditch directs the surface water along the eastern edge of the landfill into the canyon.

2.2 Previous Site Operations

MDA P was operated as a landfill for rubble and debris from the 1950s to approximately 1984. The majority of disposed materials consisted of residues and non-combustible debris resulting from burning HE-contaminated equipment, building materials, empty drums and bottles, and trash. Prior to burning and disposal, HE-contaminated materials were disassembled and cleaned. The wastes and equipment were then taken to the sand-covered burning pads at TA-16 and flashed with combustible materials needed to support destruction (by fire). After the burn, the sand and burned wastes were removed and disposed of over the edge of the slope that forms the canyon wall.

The landfill operation began at the western portion of the canyon rim, gradually progressed toward the east along the narrow mesa, and formed two distinct waste lobes. The western area of the landfill has been leveled and covered with crushed tuff and sandy clay soils from the

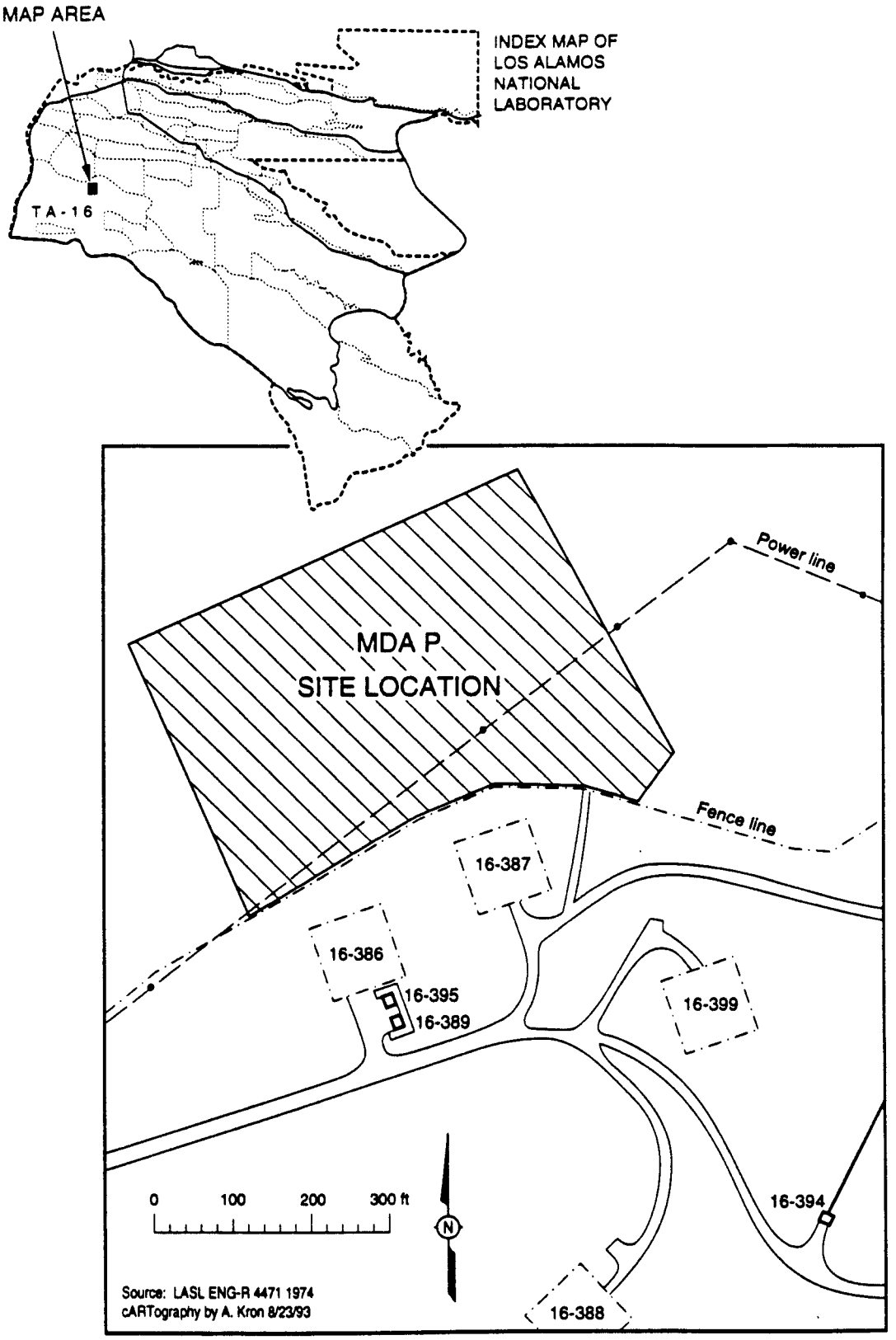


Figure 2-1. MDA P site location map.

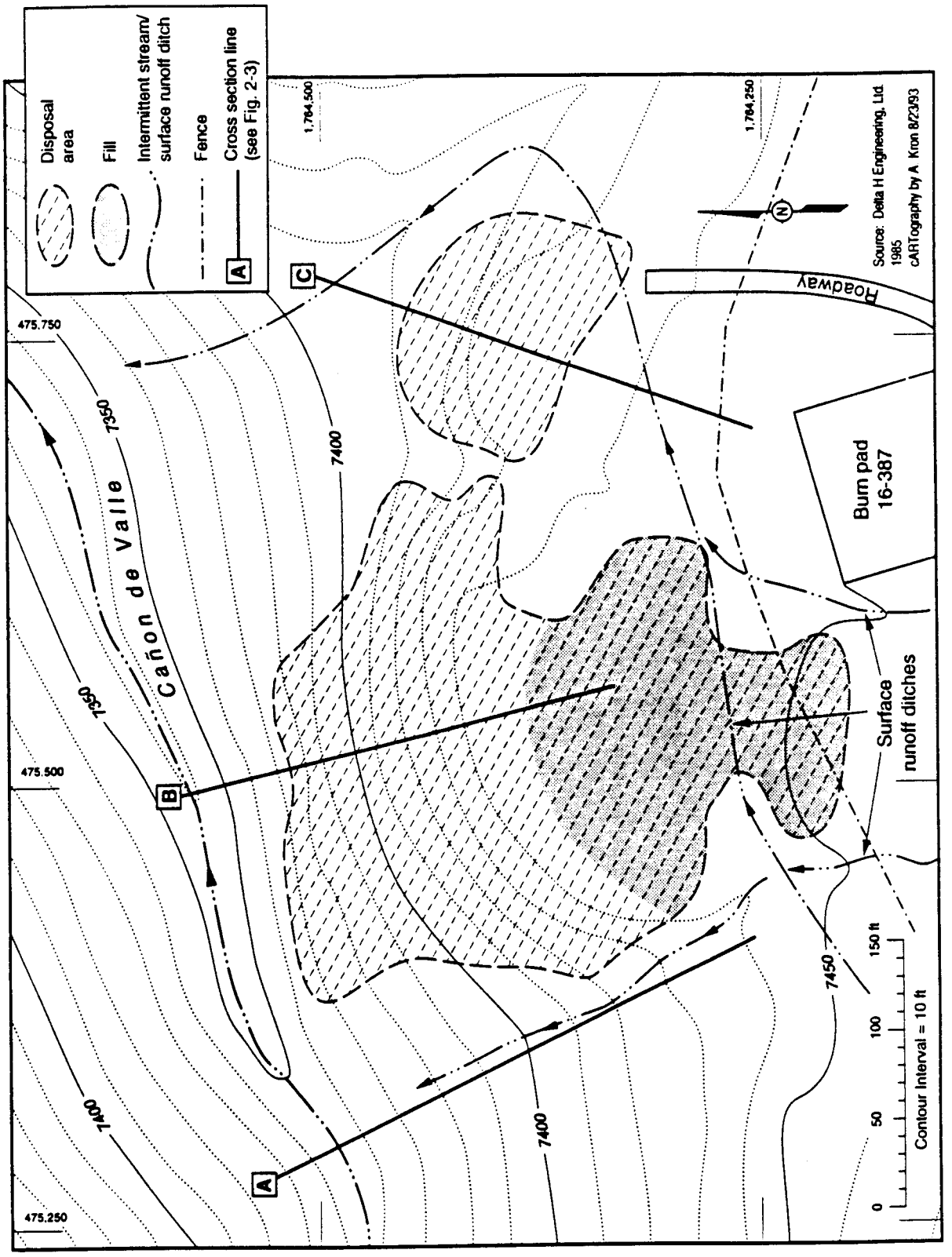


Figure 2-2. MDA P landfill.

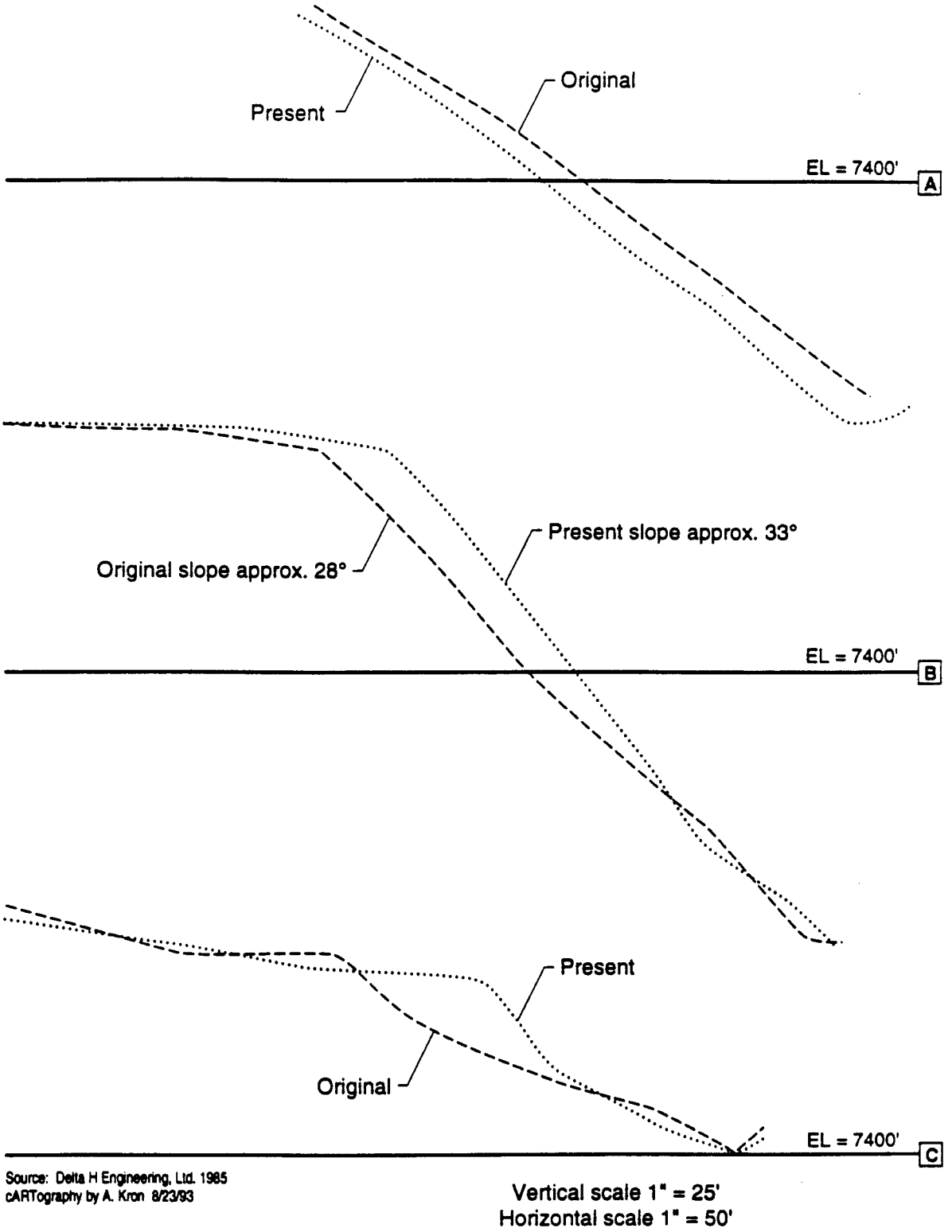


Figure 2-3. MDA P cross sections A, B, and C.

surrounding area; however, wastes such as demolition rubble and pipe remain visible on parts of the north slope face. The eastern area was covered with soil as waste deposition proceeded; however, some wastes remain exposed.

2.3 Waste Description and Inventory

MDA P has received two principal types of wastes. The first consists of waste sand from the burning pad destruction of HE, explosives thermal decomposition residues, and explosives-contaminated equipment. The second type of waste consists of construction or demolition debris. While there are no records documenting the types, quantities, or locations of wastes placed in MDA P, some of the known wastes that have been disposed of include concrete rubble, structural steel, timbers, burning pad sand, burned equipment, and empty solvent cans. Recent visual inspection by ERM/Golder staff resulted in observation of sumps, wastewater filter baskets from HE sumps, concrete blocks, structural steel supports, metal pipe, and a variety of containers projecting from the face of the eastern area of the landfill. The empty containers range in size from small metal cans, glassware, and bottles to 55-gal. drums. The waste inventory has been estimated and reported in several documents (Delta H Engineering, Ltd., 1985 and LANL 1988; IT Corporation 1990; and ERM 1992). Estimates of the total waste volume in MDA P range from 13 000 to 16 000 cu yards. The majority of the material in the landfill is demolition debris from the destruction of World War II buildings located at TA-16.

2.4 General Hydrogeologic Conditions

The Laboratory is located on the Pajarito Plateau on the eastern flank of the Jemez Mountains. This area is dominated by volcanic deposits associated with caldera formation and collapse; these deposits form broad plateaus surrounding the Jemez Mountains. The Pajarito Plateau consists of narrow mesas separated by deep canyons formed by southeast-trending intermittent streams. Beneath a veneer of soils and alluvial deposits, the mesas of the Pajarito Plateau are immediately underlain by the Bandelier Tuff of Pleistocene Age, which is exposed on the canyon walls. Beneath the Bandelier Tuff, a sequence of interstratified sedimentary and volcanic rocks of Miocene to Pleistocene Age occur (LANL 1992). These rock units have been penetrated by water supply wells and have been studied where they outcrop in canyons on the margins of the Pajarito Plateau. These rock units include volcanic rocks of the Paliza Canyon Formation, Tschicoma Formation, and the Cerros del Rio volcanic field, and sedimentary deposits of the Puye Formation, the Totavi Formation, the Cochiti Formation, and the Santa Fe Group. Because the Bandelier Tuff forms the upper surface of the Pajarito Plateau, it is considered the most important

unit at the landfill site. The deposits of Bandelier Tuff are composed of sequential ashfalls and ashflows of rhyolitic tuff that are described as nonwelded, moderately welded, and welded (LANL 1992).

Direct effects of future seismicity at the Laboratory are likely, although quantification of probabilities is not complete at present. Numerous small earthquakes are recorded in the Los Alamos area and northern New Mexico each year. Since establishment of the Laboratory, several earthquakes of Richter scale magnitude 3 to 4 have shaken Los Alamos. Recent work has shown that three major fault segments in Los Alamos County are seismically active. Of these three major faults, the Pajarito Fault is the only one that might affect MDA P (Woodward-Clyde 1993). The Pajarito Fault is approximately 1.24 miles from MDA P. The draft Woodward-Clyde report estimates a peak horizontal acceleration of approximately 0.5 g for a magnitude 7 earthquake (Table 8-4, Woodward-Clyde 1993). This is a worst case event for this fault.

Another fault zone, the Water Canyon Fault zone, has been reported in the vicinity of MDA P (Purtymun 1984). In a recent interview, Jamie Gardner, the principle investigator for seismic studies at the Laboratory (EES-1 Group), stated that "whether the Water Canyon Fault breaks the surface in MDA P is the subject of conflicting views. Field studies, to date, suggest that the Water Canyon Fault does not break the surface in TA-16. Furthermore, the fault is not seen as a seismic source of importance in its ability to generate an earthquake, as it is too short."

The surface of the main aquifer rises westward from the Rio Grande within the Santa Fe Group into the lower part of the Puye Conglomerate beneath the central and western part of the plateau. The water depths below the mesa top range from about 1 200 ft along the western margin of the plateau to about 600 ft at the eastern margin. The main aquifer is separated from the water in the alluvium by 350 to 620 ft of tuff and volcanic sediments. The main aquifer is unconfined in the western part of the plateau and exhibits semiartesian to artesian conditions in the eastern part along the Rio Grande (Purtymun 1984). Available hydrologic data indicate that the major recharge area for the main aquifer is west of the Laboratory, presumably in the Jemez Mountains, although this is still being investigated. The water in the aquifer moves from its major recharge area toward the Rio Grande, where a part is discharged into the river through seeps and springs. The hydraulic gradient of the aquifer averages about 60 to 80 ft/mile within the Puye Conglomerate but increases to 80 to 100 ft/mile along the eastern edge of the plateau as the water in the aquifer enters the less permeable sediments of the Santa Fe Group. The rate of movement of water in the upper section of the aquifer varies, depending on the aquifer materials. Aquifer tests indicate

the movement ranges from 20 ft/year in the Tesuque Formation to 345 ft/year in the more permeable Puye Conglomerate (Purtymun 1984).

MDA P lies near the western margin of the Pajarito Plateau on a short, narrow mesa occupying both the edge of the mesa and the southern wall of the adjacent canyon, Cañon de Valle. To the north of the landfill, the ephemeral stream in Cañon de Valle has cut steep canyon walls into the Bandelier Tuff and drains an area to the west. The canyon walls near MDA P are over 100 ft high and expose moderately welded tuff underlain by welded tuff. The stream flow in Cañon de Valle results from surface runoff (storm water and snow melt), as well as discharge from an NPDES-permitted Laboratory outfall located upstream of MDA P. In the vicinity of the landfill, the canyon has only a thin layer of alluvium of 2 to 7 ft in thickness (Brown et al. 1988) which could contain water from the stream perched on the underlying tuff. This is a common occurrence with water in major stream channels that cross the plateau. However, in Cañon de Valle no such perched water was found in a series of 17 boreholes drilled in the area between the foot of MDA P and the intermittent stream at the canyon bottom (Brown et al. 1988). Subsequent monitoring of several of these boreholes which were constructed as monitoring wells has never shown the presence of groundwater. Cañon de Valle stream water joins a major intermittent stream in Water Canyon approximately two miles to the southeast. Water Canyon, in turn, flows into the Rio Grande approximately six miles to the east in White Rock Canyon.

Some of the hydrologic characteristics of the unsaturated tuff beneath the landfill have been characterized (LANL 1992). Many hydrologic characteristics depend on the degree of welding; the denser the welding, the lower the porosity and hydraulic conductivity. The porosity of moderately welded tuff ranges from 30 to 55% by volume, while that of welded tuff ranges from 15 to 40% by volume. The saturated hydraulic conductivity for moderately welded tuff ranges from 0.1 to 1.7 ft/day (3.53×10^{-5} to 6.00×10^{-4} cm/s); the welded tuff ranges from 0.009 to 0.26 ft/day (3.18×10^{-6} to 9.17×10^{-5} cm/s). The values for porosity and saturated hydraulic conductivity are consistent with the ranges of porosity (34 to 57%) and saturated hydraulic conductivity (2.25×10^{-5} to 5.15×10^{-4} cm/s) of tuff cores recovered at the landfill site and reported by Stephens (1988). However, reported values for volumetric moisture content of tuff are not as consistent; reported values range from 1 to 6% (Purtymun 1984) compared to 18 to 36% (Stephens 1988).

2.5 Regulatory Status

The Laboratory discontinued operation of the MDA P landfill prior to November 8, 1985, and did not seek a RCRA permit for this site. Consequently, the Laboratory was required under the loss of interim status provisions (40 CFR 270.10) to submit a closure and post-closure plan for MDA P.

Pursuant to 40 CFR 265.1(d), a closure and post-closure plan for the MDA P landfill, dated November 25, 1985 (Delta H Engineering, Ltd., 1985), was submitted to the New Mexico Environmental Improvement Division (NMEID). The Laboratory will submit a post-closure permit application. The post-closure permit requires closure under 40 CFR-264, Subpart G, therefore, this closure plan is designed to meet those requirements.

2.6 Previous Site Studies

Previous site investigations and informal studies at MDA P have attempted to establish subsurface geology, monitor groundwater, sample and analyze stream water and sediments, model hydrologic relationships, and monitor the vadose zone. The reports that document some of these site activities, supplemented with other relevant site information/data, are summarized below. Complete references are found in Appendices A through E, Volume 2 of this closure and post-closure plan. A list of studies cited in this plan is included in Table 2-1.

The initial site investigation at MDA P consisted of a drilling and sampling program to characterize the subsurface around the landfill and to monitor groundwater beneath the site (Brown et al. 1988). A copy of this study is contained in Appendix A. During the summer of 1987, a series of 17 boreholes from 9 to 200 ft in depth (numbered P-0 through P-16A) were drilled and logged in the vicinity of the landfill site; borehole locations are shown on Fig. 2-4. Eight boreholes located along the northern perimeter of the disposal area (P-1, and P-3 through P-9) were completed as screened monitoring wells. Four of these wells (P-3, P-4, P-6, and P-8) were designed to monitor water (if present) traveling along the alluvium-tuff horizon; the other four (P-1, P-5, P-7, and P-9) were designed to detect groundwater in the alluvium between the canyon stream and the landfill. Five boreholes were completed as neutron moisture access wells (P-0, P-12A, P-13, P-14, and P-16A), and four boreholes (P-2, P-10, P-11, and P-15) were sealed and closed after lithologic logging. Free-flowing groundwater was not encountered during drilling operations and was never detected in subsequent monitoring in any of the groundwater wells.

TABLE 2-1

PREVIOUS SITE STUDIES

REPORT APPENDIX	SITE STUDY
A	Brown, F., W. D. Purtymun, A. Stoker, and A. Barr, February 1988. "Site Geology and Hydrology of Technical Area 16, Area P," Los Alamos National Laboratory Report LA-11209-MS, and report data addendum, Los Alamos, NM. (Brown et al. 1988)
B	Stephens, D. B. "Final Data Report of Laboratory Analyses of Soil Hydraulic Properties of Welded Tuffs at Los Alamos National Laboratory," prepared for Los Alamos National Laboratory by D. B. Stephens and Associates, Socorro, NM. (Stephens 1988)
C	Nyhan, J. W. "A Hydrologic Modeling Study of Water Balance Relationships at the Area P Landfill in Los Alamos, New Mexico," Los Alamos National Laboratory Report LA-11521-MS, Los Alamos, NM. (Nyhan 1989)
D	McLin, S. G. "Vadose Zone Monitoring Observations at the TA-16 Area P Landfill," (draft report), Solid Waste and Remedial Action Section, Environmental Surveillance Group (HSE-8), Los Alamos National Laboratory, Los Alamos, NM. (McLin 1989)
E	ERM-Program Management Company. "Focused Feasibility Study for Area P Landfill," prepared for Los Alamos National Laboratory, Los Alamos, NM. (ERM 1992)
*	Delta H Engineering, Ltd. "TA-16 Area P Landfill Closure and Post-Closure Plan," prepared for Los Alamos National Laboratory, Santa Fe, NM (1985); modified by Environmental Surveillance Group (HSE-8), Los Alamos National Laboratory, Los Alamos, NM (1988). (Delta H Engineering, Ltd., 1985 and LANL 1988)
*	IT Corporation. "Area P Landfill Closure Alternatives," prepared for Los Alamos National Laboratory, Los Alamos, NM. (IT Corporation 1990)

* not included in this report

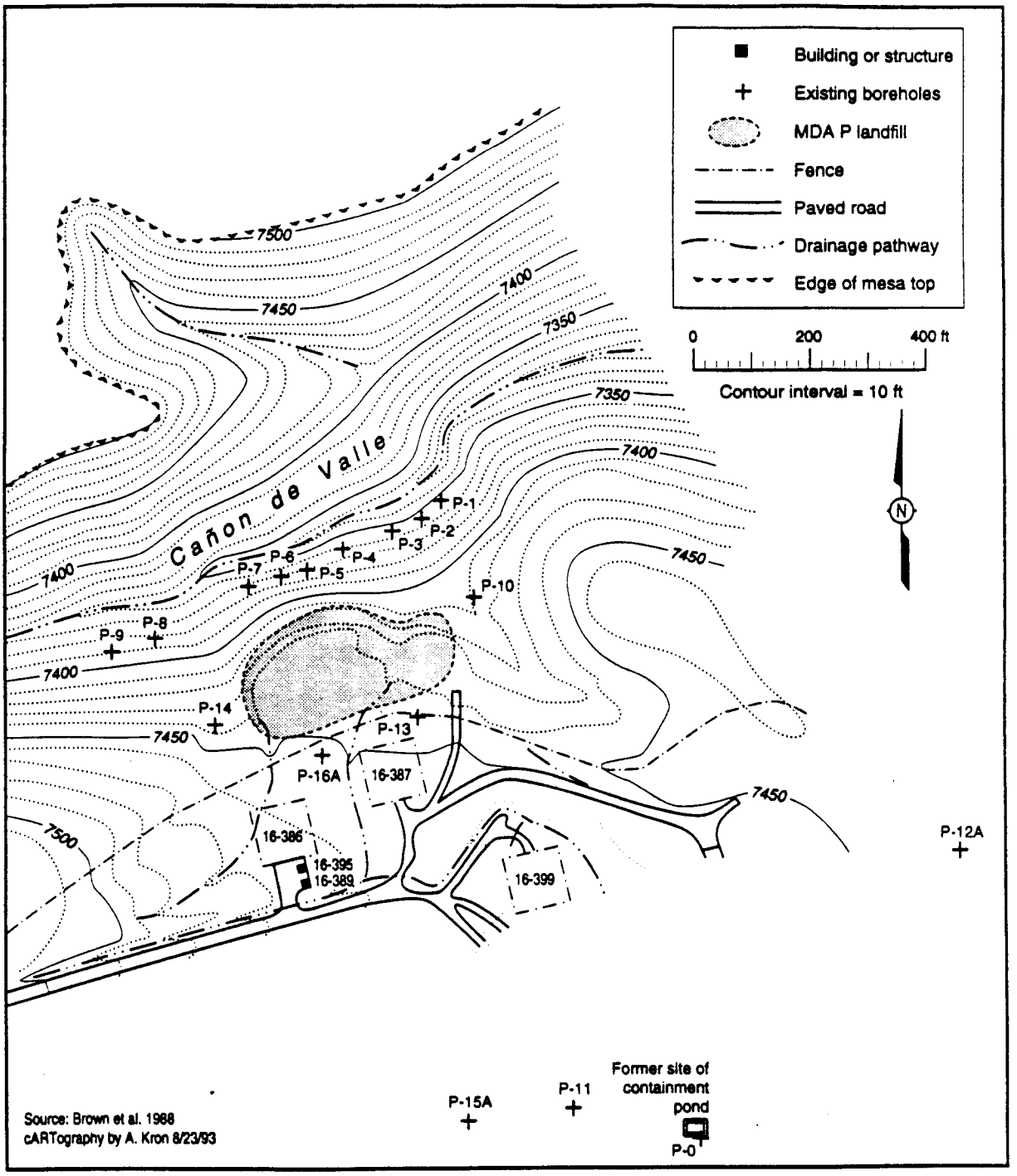


Figure 2-4. Borehole locations, numbered P-0 through P-16A (after Brown et al. 1988).

Continuous auger cuttings were retrieved for lithologic logging and *in-situ* gravimetric moisture analysis. The results for gravimetric moisture contents from sampled borehole cuttings ranged from 1.9 to 24.7%. This range of values is considered low; however, it slightly exceeds the ranges for two technical areas further to the east which are 5 to 11% and 2 to 20% (Abrahams 1963 and Kearl et al. 1986).

One set of continuous core was recovered from borehole P-16A during the investigation in late 1987. From this set of P-16A core the Laboratory analyzed five core samples for metal concentrations and five different core samples for volumetric moisture content. Stephens (1988) analyzed ten different P-16A core samples for saturated hydraulic conductivity, unsaturated hydraulic conductivity, moisture retention, initial moisture content, dry bulk density, and porosity. A copy of the Stephens (1988) laboratory analyses report is contained in Appendix B. The analytical results as a function of depth are summarized on the log for borehole P-16A (shown in Fig. 2-5).

Volumetric moisture content as reported by the Laboratory in the revised closure plan (Delta H Engineering, Ltd., 1985 and LANL 1988) ranged from 5.6 to 16.0%. Volumetric moisture content for the samples analyzed by Stephens (1988) ranged from 18.74 to 36.57%. The differences in the results of these studies raise questions as to the level of moisture in the landfill. Although Stephens specified the methodology utilized for their laboratory moisture measurements, the Laboratory report did not. It is likely, however, that Laboratory measurements were also made by laboratory analysis (not field measurements), although the comparability of the two data sets is unknown.

Laboratory results of hydraulic properties for ten core samples from P-16A generally agree with previously reported data (Stephens 1988) for which saturated hydraulic conductivity ranged from 2.25×10^{-5} to 5.15×10^{-4} cm/s, dry bulk density ranged from 1.25 to 1.80 g/cc, and porosity ranged from 34.6 to 56.2%. As shown in Fig. 2-5, porosity decreased and density increased with the degree of welding in the tuff and, in turn, with depth at the landfill site. Gravimetric moisture content from the laboratory data (a function of both volumetric moisture content and dry bulk density) ranged from 11.17 to 28.30 g/g or % (Stephens 1988). Barium was the only metal identified in the five core samples analyzed for RCRA metal concentrations (by the EP toxicity method). Barium concentrations of 0.07 mg/L and 0.09 mg/L were slightly above the 0.05 mg/L detection level in three core samples; however, these concentrations are considerably below the regulatory threshold of 100 mg/L for EP toxicity (Delta H Engineering, Ltd., 1985 and LANL 1988).

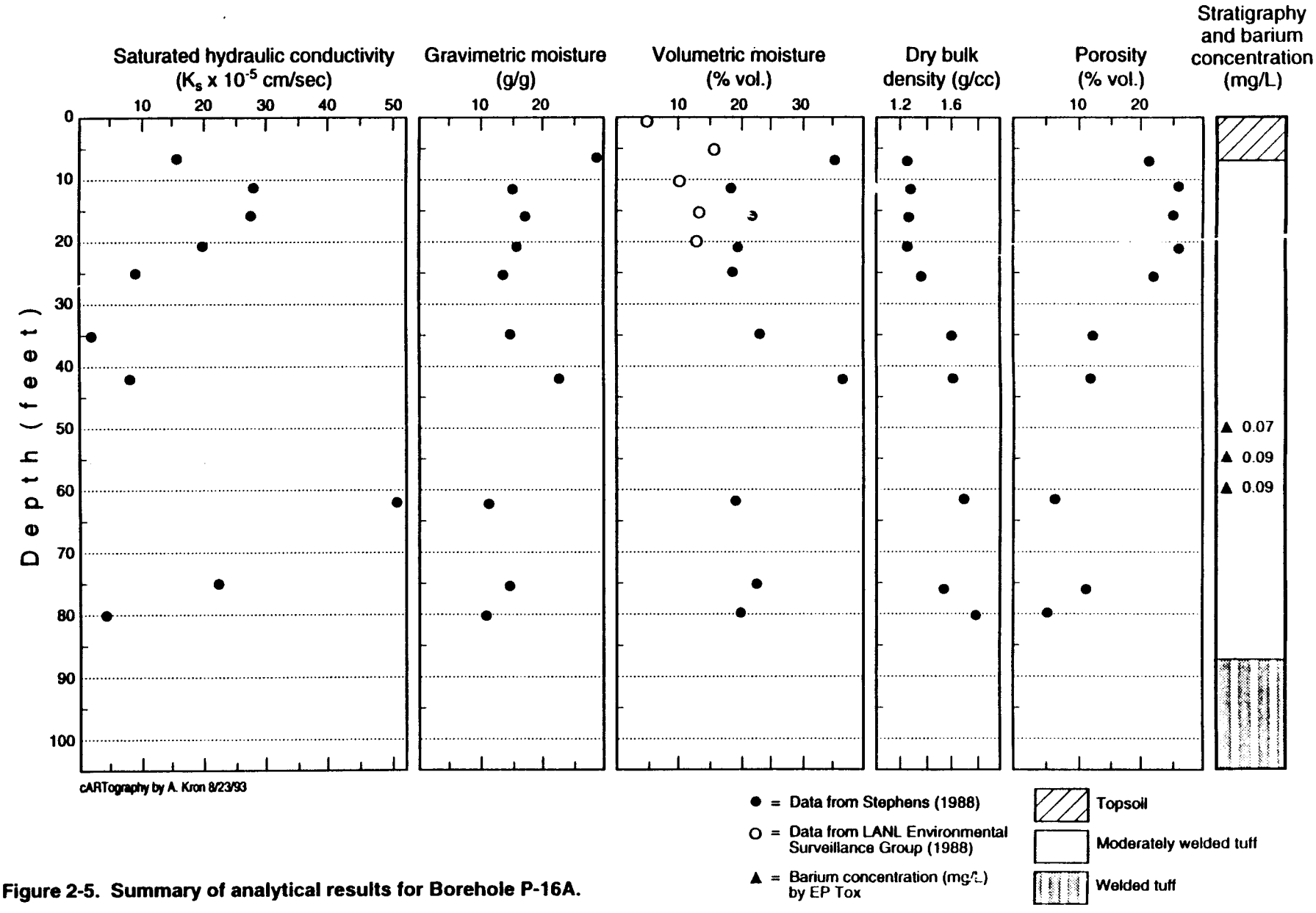
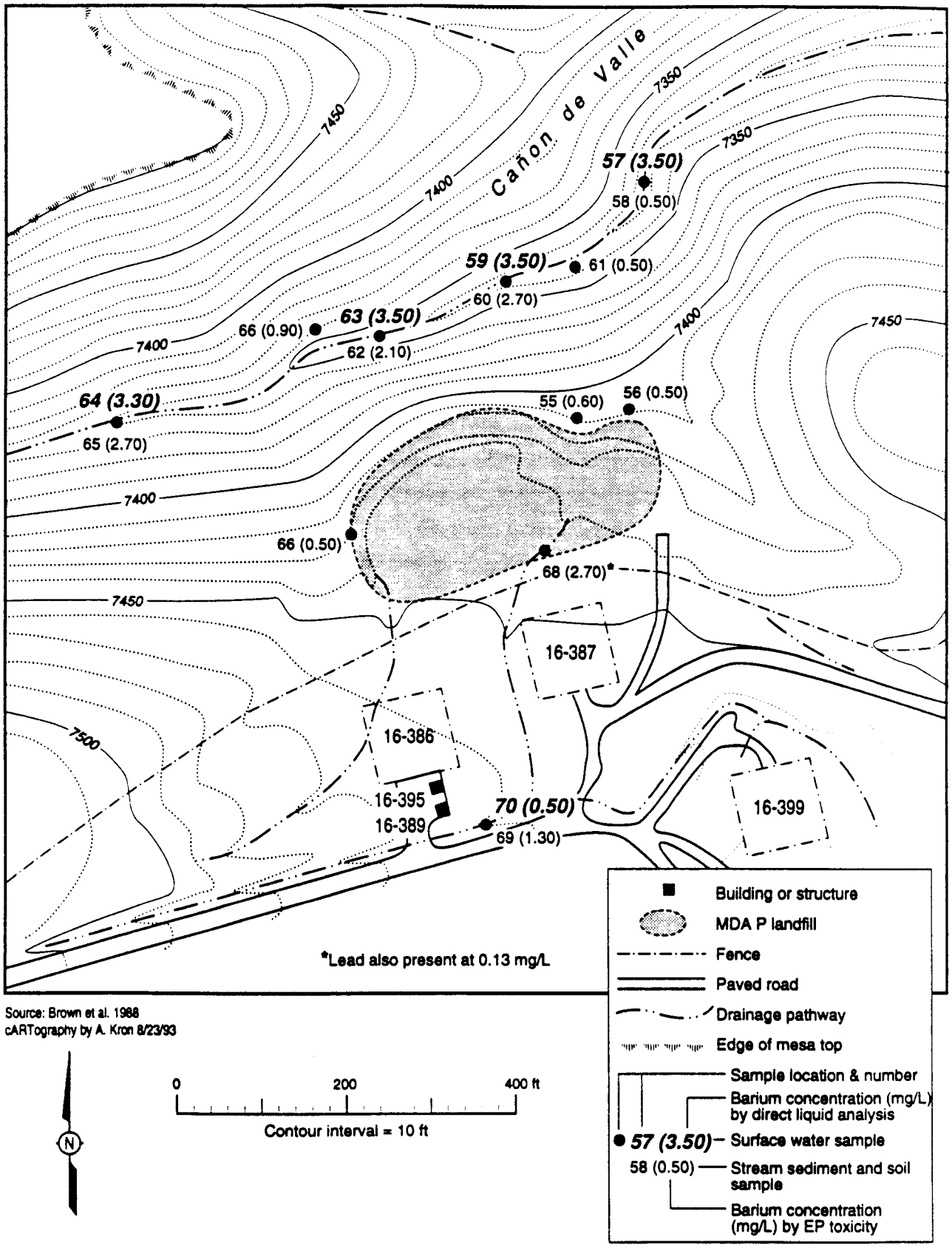


Figure 2-5. Summary of analytical results for Borehole P-16A.

In December 1987, an informal reconnaissance water quality and sediment sampling survey was conducted (Brown et al. 1988) along Cañon de Valle and around the landfill area. The one-day survey consisted of collecting five surface water samples and eleven samples of stream sediments and soils. All samples were analyzed for metal concentrations. Surface water samples were evaluated using direct liquid analysis; stream sediment and soil samples were assessed by the EP toxicity extraction method. It was not specified whether the water samples were filtered or unfiltered. In addition, the analytical methods and sampling procedures were not reported.

Sampling locations and barium results are shown in Fig. 2-6 and a copy of this data is included with Brown et al. (1988) in Appendix A. Two of the eight RCRA metals, barium and lead, were identified. Barium was present in all water, sediment, and soil samples. Barium concentrations in water samples ranged from 0.50 to 3.50 mg/L; the Safe Drinking Water Act maximum contaminant level (MCL) for barium is 1 mg/L. Notably, the barium concentrations in the stream water were similar for samples upstream and downstream of the landfill, potentially indicating that MDA P is not contributing barium to the stream water. When soil samples were subjected to the EP toxicity test, the extract from the media was found to contain barium in all samples and lead in one sample. Barium extract concentrations ranged from 0.50 to 2.70 mg/L (EP toxicity limit for barium is 100 mg/L). The lead concentration in the extract from a sediment sample collected near the southern edge of the landfill was 0.13 mg/L (EP toxicity limit for lead is 5 mg/L). No background samples were taken.

In 1989 Nyhan (Nyhan 1989) examined the water balance relationships at MDA P using the Field Scale Model for Chemicals, Runoff, and Erosion from Agricultural Management Systems (CREAMS) model. A copy of Nyhan's report is included as Appendix C. The CREAMS model was initially developed for modeling field-scale agricultural systems; however, it has since been used in several areas of waste management research, including landfill cover design. The model was used in a preliminary attempt to hydrologically characterize the site and make recommendations regarding its closure. Modeling activities for MDA P had two objectives. First, input parameters were estimated to simulate current landfill conditions for field calibration. Second, after calibration, the model was used to help evaluate closure cover features, such as landfill cover thickness. It is important to note that this study has several limitations. First, the CREAMS model is one-dimensional and evaluates only the vertical transport water process; it does not have the ability to describe two-dimensional unsaturated flow of water through the landfill. Second, the model was only applied to the upper, flat portions of MDA P (the slopes of the landfill were not considered).



Source: Brown et al. 1988
cARTography by A. Kron 8/23/93

Figure 2-6. Sampling locations and analysis results for barium from reconnaissance water quality and sediment sampling survey.

Finally, most model parameters were not based on actual data and in some cases values were used that were known to deviate from actual site conditions.

The only source of hydrologic information available for model input was the volumetric water content from several of the neutron moisture access wells located around MDA P (no information was available within the landfill boundaries). Moisture data were collected at locations P-12A, P-13, and P-16A (shown on Fig. 2-4); moisture data from well P-12A were considered to represent "background" levels whereas moisture data from wells P-13 and P-16A were considered to represent landfill conditions. Sampling results (volumetric moisture content versus depth) are shown in Fig. 2-7. The data show that the wells located adjacent to the landfill (P-13 and P-16A) exhibited elevated levels of volumetric water content relative to the levels at the background location (P-12A). Some of these moisture differences were attributed to the much lower saturated hydraulic conductivity in the underlying tuff than in the crushed tuff; indicating that the underlying tuff is acting as a barrier to vertical soil-water movement. The majority of the large volumetric moisture content differences were attributed to the unlined drainage channel located along the southern border of the landfill, which collects runoff from a large area above the landfill.

To evaluate closure covers, a series of CREAMS simulations were performed by varying the thickness of the landfill cover and the type of vegetation and predicting the amount of potential seepage occurring for both the average and the wettest years. The parameters used in this effort were those of a landfill cover system incorporating a capillary barrier. The simulations showed the influence of vegetative cover in decreasing seepage through the landfill cover by comparing a bare soil surface with 70% gravel cover to a good range grass with 70% gravel cover. Simulation results, showing annual seepage versus cover thickness for both types of landfill covers, are illustrated in Fig. 2-8. Seepage was modeled for a 20-year period from 1968 to 1987 and for the wettest year during that period. The results of this comparison showed that the bare soil/gravel cover consistently produces similar seepage results, regardless of the thickness of the landfill cover. In contrast, the range grass/gravel cover produced average annual seepage that decreased as landfill cover thickness increased. This difference in seepage effects between the two cover designs is a result of enhanced evapotranspiration from the good range grass. Enhanced evapotranspiration results in reduced annual seepage, especially during the plant-growing season.

Regardless of the cover thickness for the good range grass/gravel cover, the amount of annual seepage predicted for the wettest years was about tenfold larger than the average seepage. The

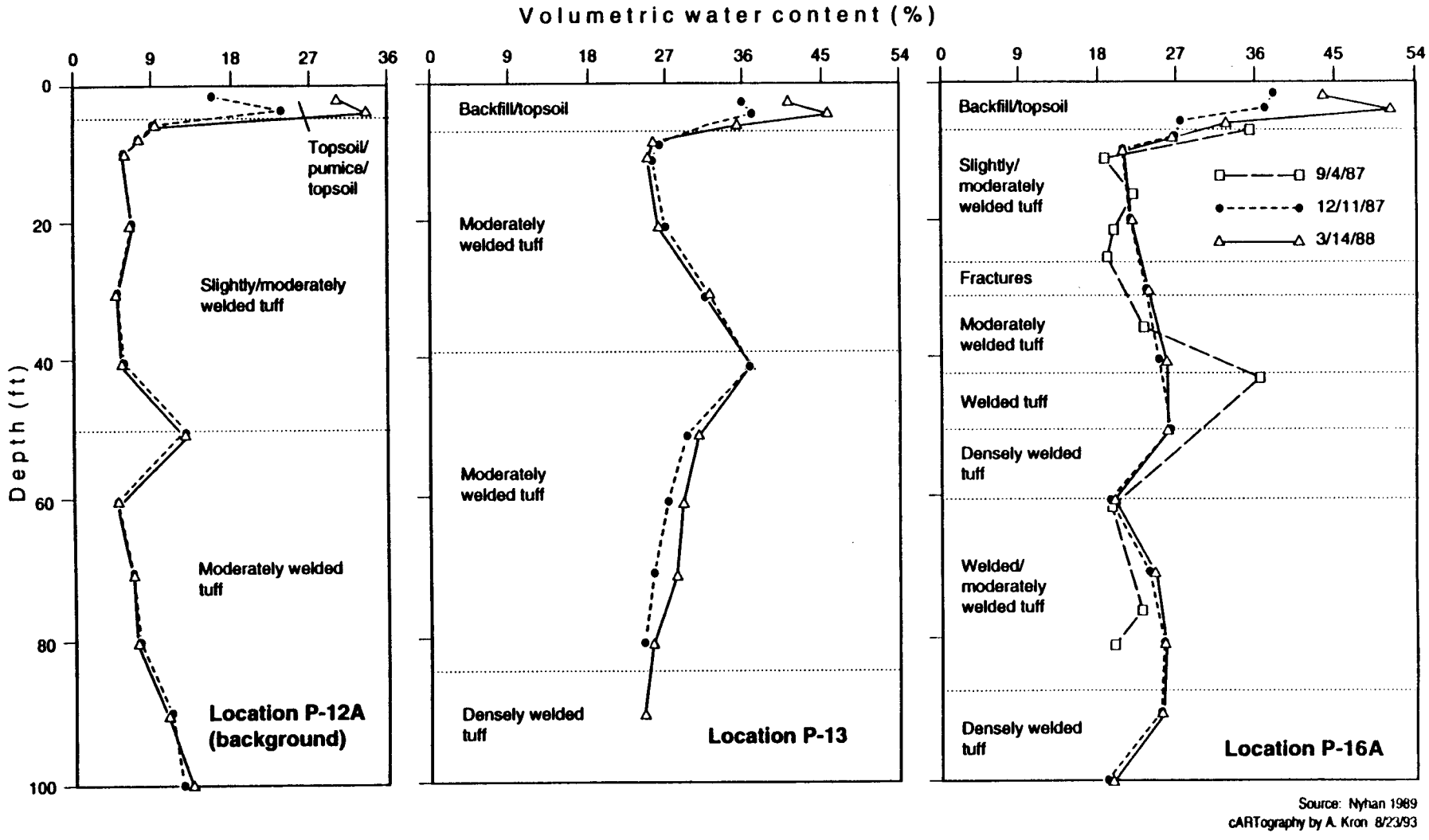
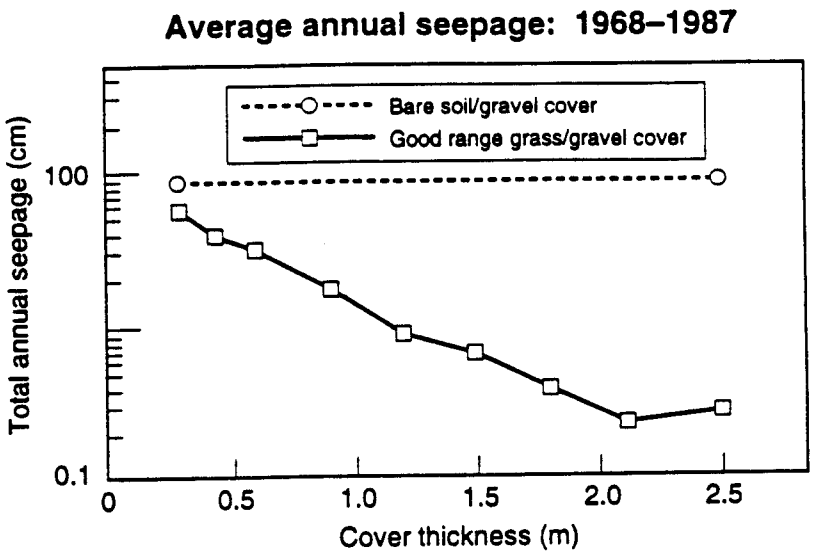


Figure 2-7. Volumetric water content data from sampling locations P-12A, P-13, and P-16A (after Nyhan 1989).



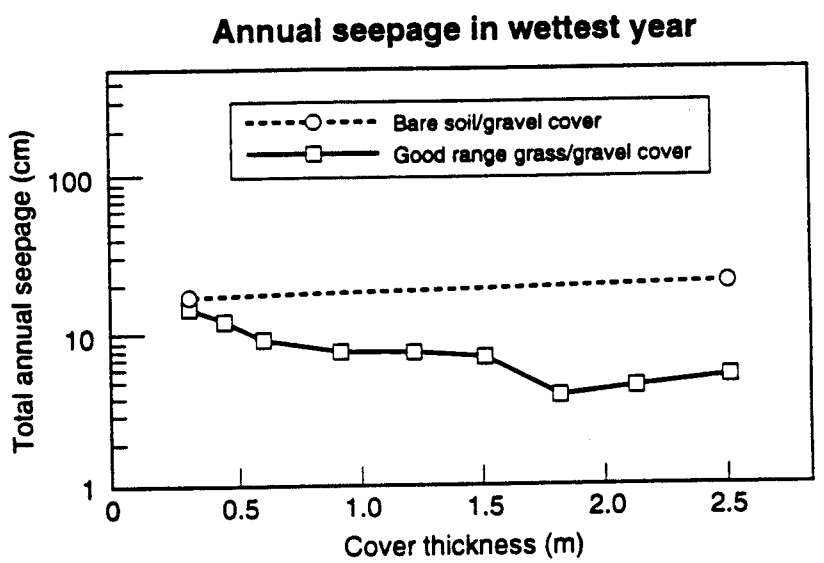


Figure 2-8. Annual seepage results versus cover thickness for bare soil/gravel and good range grass/gravel scenarios (Nyhan 1989).

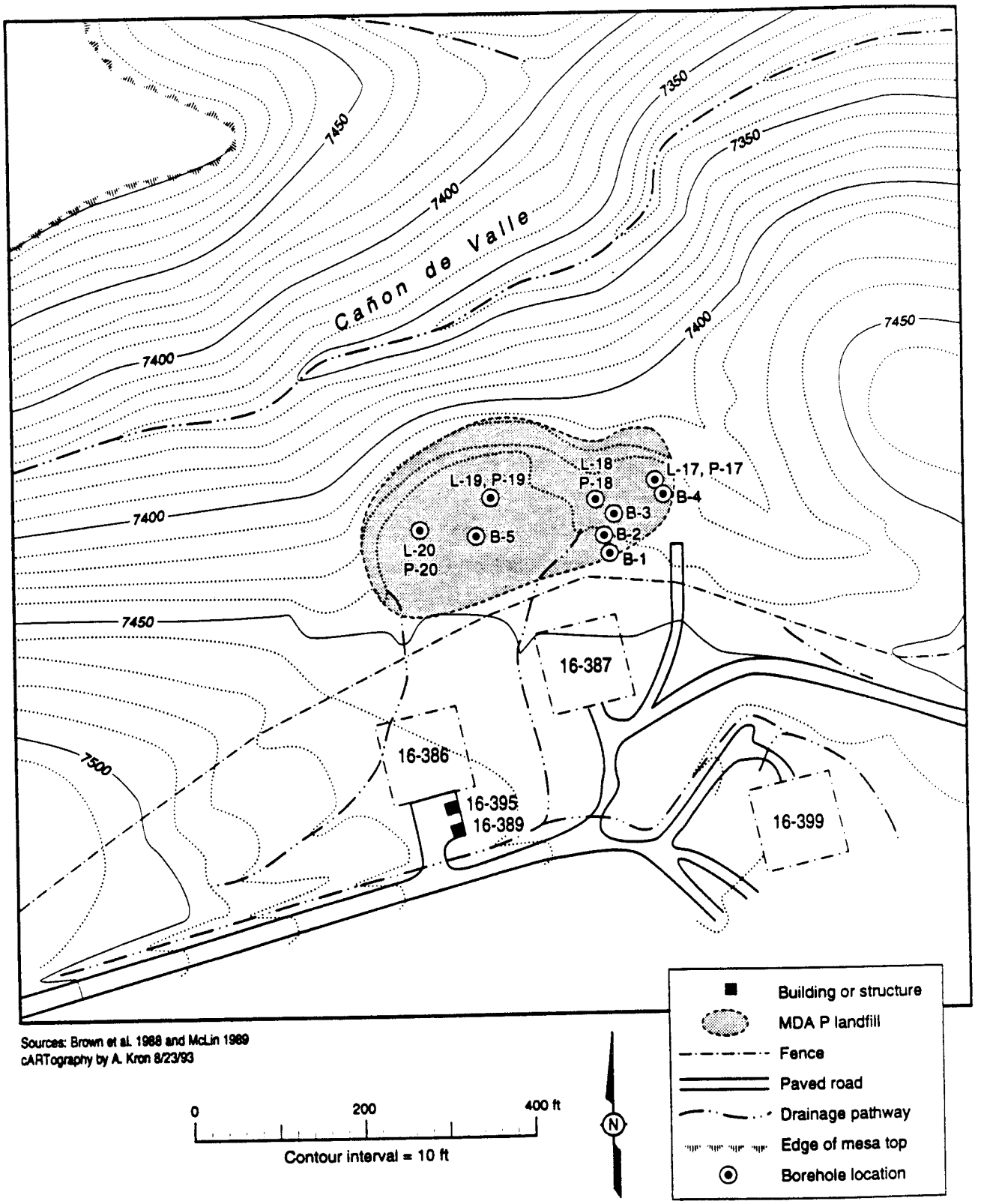
reason for this pattern is that the wettest years are those when snow melt dominates the seepage into the cover; evapotranspiration does not occur during these snow melt periods.

Nyhan's CREAMS study concluded with suggestions regarding both future modeling activities and specific waste management practices for MDA P. Recommendations included relocating the runoff diversion ditch located on the south side of the landfill, collecting borehole soil samples for contaminant assays, collecting neutron moisture gauge data from within the landfill materials, and performing an analysis of flood frequency within the canyon.

In response to these recommendations, 13 boreholes (numbered L-17 through L-20, P-17 through P-20, and B-1 through B-5 on Fig. 2-9) were installed through the waste materials to complete a vadose zone monitoring system at MDA P. Stream samples were also collected during this investigation. A copy of the draft report is included as Appendix D (McLin 1989).

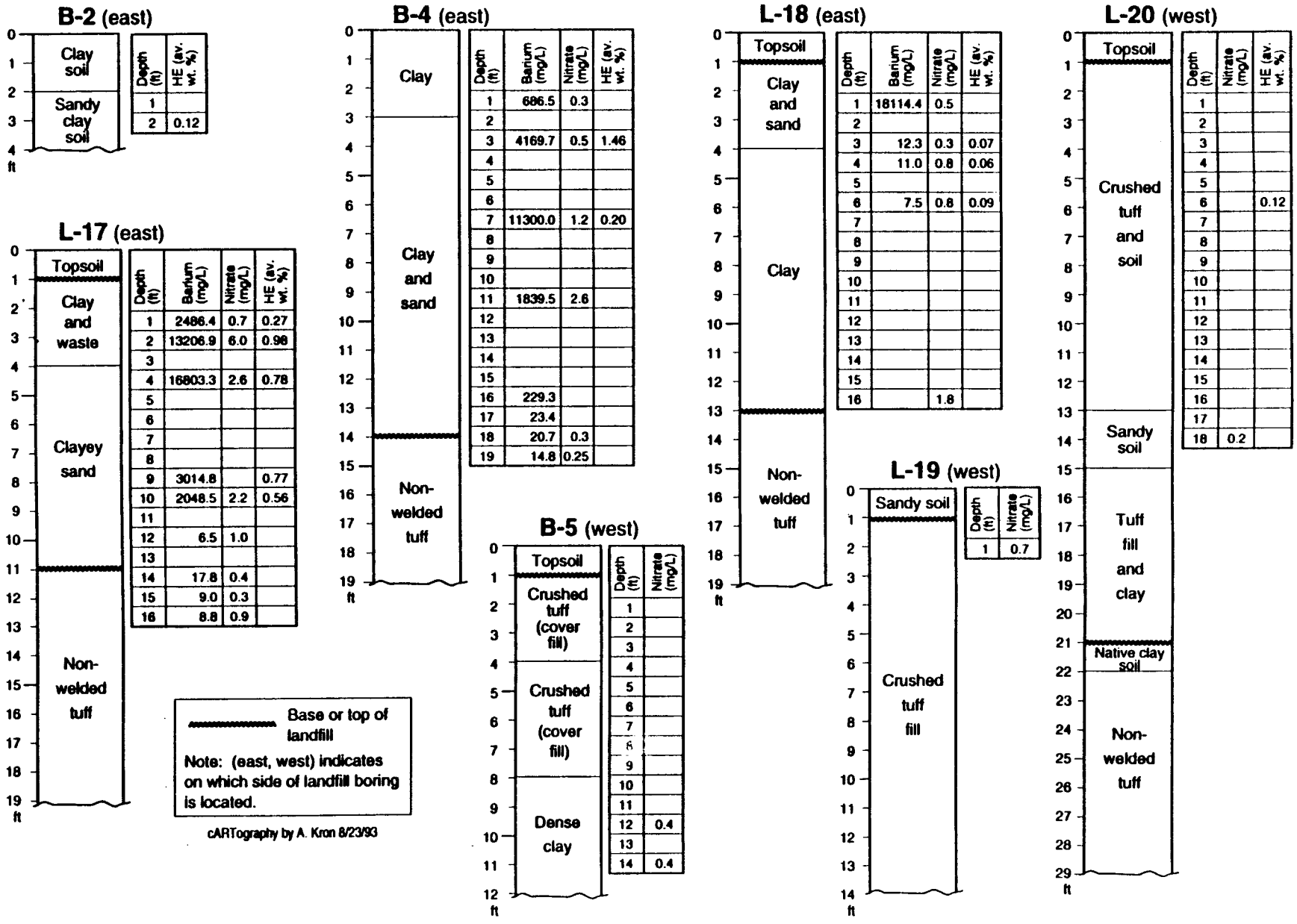
Each of the 13 boreholes penetrated the landfill and into the underlying tuff for a distance of up to 19 ft beneath the landfill/tuff contact. Eight separate wells (L-17 through L-20 and P-17 through P-20) were grouped into four well nests; each well nest consisted of either a single or dual completion pressure-vacuum lysimeter borehole and an adjacent neutron moisture access well. The four lysimeter boreholes (L-17 through L-20) contained a total of seven independent lysimeters located at varying depths in and below the landfill. The neutron access wells (P-17 through P-20) penetrated into the underlying tuff to a maximum depth of 30 ft. Five boreholes (B-1 through B-5) were plugged and abandoned after logging.

Soil and tuff core samples were collected during drilling operations from boreholes B-2, B-4, and B-5, and L-17, L-18, L-19, and L-20. These samples were analyzed for barium by the EP toxicity method, nitrate, and HE content. Results from these chemical analyses that showed detectable results for each borehole are summarized and shown in Fig. 2-10. Barium concentrations from samples taken from the waste materials in the eastern portion of the landfill (Boreholes B-4, L-17, and L-18) were significantly greater than the 100 mg/L regulatory limit; detected levels of the EP toxicity analyses on core sample liquid leachate ranged from 6.5 to 18 114.4 mg/L. EP toxicity barium concentrations were below the reported detection limit of 5.0 mg/L for core samples collected from waste materials in the western portion of the landfill. Barium analyses by EP toxicity were performed on core samples from four borings that penetrated the tuff beneath the landfill (borings B-4, L-17, L-18, and L-20). Two of these borings showed no detectable barium in tuff by EP toxicity beneath the landfill. One boring (L-17) showed very low levels of barium in EP toxicity analyses of tuff decreasing with depth from 17.8 to 6.5 mg/L. Samples were taken at 1, 3,



Sources: Brown et al. 1988 and McLin 1989
cARTography by A. Kron 8/23/93

Figure 2-9. Borehole locations, numbered L-17 through L-20, P-17 through P-20, and B-1 through B-5 (McLin 1989).



B-2 (east)

Depth (ft)	HE (av. wt. %)
1	
2	0.12

B-4 (east)

Depth (ft)	Barium (mg/L)	Nitrate (mg/L)	HE (av. wt. %)
1	686.5	0.3	
2			
3	4169.7	0.5	1.46
4			
5			
6			
7	11300.0	1.2	0.20
8			
9			
10			
11	1839.5	2.6	
12			
13			
14			
15			
16	229.3		
17	23.4		
18	20.7	0.3	
19	14.8	0.25	

L-18 (east)

Depth (ft)	Barium (mg/L)	Nitrate (mg/L)	HE (av. wt. %)
1	18114.4	0.5	
2			
3	12.3	0.3	0.07
4	11.0	0.8	0.06
5			
6	7.5	0.8	0.09
7			
8			
9			
10			
11			
12			
13			
14			
15			
16		1.8	

L-20 (west)

Depth (ft)	Nitrate (mg/L)	HE (av. wt. %)
1		
2		
3		
4		
5		
6		0.12
7		
8		
9		
10		
11		
12		
13		
14		
15		
16		
17		
18	0.2	

L-17 (east)

Depth (ft)	Barium (mg/L)	Nitrate (mg/L)	HE (av. wt. %)
1	2486.4	0.7	0.27
2	13206.9	6.0	0.98
3			
4	16803.3	2.6	0.78
5			
6			
7			
8			
9	3014.8		0.77
10	2048.5	2.2	0.56
11			
12	6.5	1.0	
13			
14	17.8	0.4	
15	9.0	0.3	
16	8.8	0.9	

B-5 (west)

Depth (ft)	Nitrate (mg/L)
1	
2	
3	
4	
5	
6	
7	
8	
9	
10	
11	
12	0.4
13	
14	0.4

L-19 (west)

Depth (ft)	Nitrate (mg/L)
1	0.7

Figure 2-10. Summary of barium, nitrate, and residual high explosive results for six boreholes (data from McLin 1989).

4, and 5 ft beneath the landfill base. Only one boring (B-4) showed barium in EP toxicity analyses greater than 100 mg/L. Four core samples were taken from this boring at depths of 2, 3, 4, and 5 ft beneath the landfill base. The maximum EP toxicity result of 229 mg/L was observed at a depth of 2 ft into tuff. This rapidly decreased to <25 mg/L at 3 ft and continued to decrease to the 5 ft depth. These data show that only very small amounts of leachable barium have entered the tuff beneath the landfill in some areas, and that it is rapidly reduced by the tuff. Nitrate concentrations by EP toxicity analyses of landfill and tuff core samples were at or below 2.6 mg/L. The average residual HE content for core samples tested was below 1.5%, well below the 10% US Army guideline at which contaminated soil is regarded as potentially explosive (Little 1987).

Lysimeters were monitored regularly over a one-year period; however, actual pore water collection was very limited. Four of the seven lysimeters yielded small volumes of water only when sampled during intervals coinciding with heavy precipitation or snow melt and with extended periods of vacuum applied for one week. These four lysimeters were located within the landfill materials; the three remaining lysimeters that did not yield water were located below the landfill/tuff contact. Pore water samples collected from lysimeters were analyzed for barium and nitrate concentrations. Barium concentrations in recovered lysimeter water ranged from 1.1 to 37.8 mg/L, but were generally less than 3 mg/L. Nitrate concentrations were at or below 5.5 mg/L.

Monthly volumetric moisture contents were recorded from individual neutron moisture access wells from March to September 1989 in the five perimeter access wells (P-0, P-12A, P-13, P-14, and P-16A) and the four landfill access wells (P-17 through P-20). Representative results (volumetric moisture versus depth) from wells P-16A, P-18, and P-19 are shown on Fig. 2-11. All wells showed stable moisture distribution with depth (i.e., insignificant differences between minimum and maximum values were recorded at each depth). Neutron moisture access wells that penetrated the landfill (wells P-18 and P-19) showed higher volumetric moisture inventories over depth than the well completed outside the landfill (well P-16A). Additionally, higher moisture inventories were recorded within landfill materials than in the less conductive underlying tuff (wells P-18 and P-19) indicating that landfill moisture inventories resulted from direct precipitation through the existing landfill cover (rather than through the unlined drainage channel). Lastly, western landfill neutron moisture access wells (well P-19) showed similar moisture contents compared to those in the east (well P-18), but higher moisture extended to greater depth. This observation is likely the result of the thicker, clayey fill deposits located on the (covered) western portion of MDA P. The boring logs for B-1, B-3, B-4, and B-5 (contained in Appendix E) for the eastern portion of the landfill show variable cover of 0 to 5 ft.

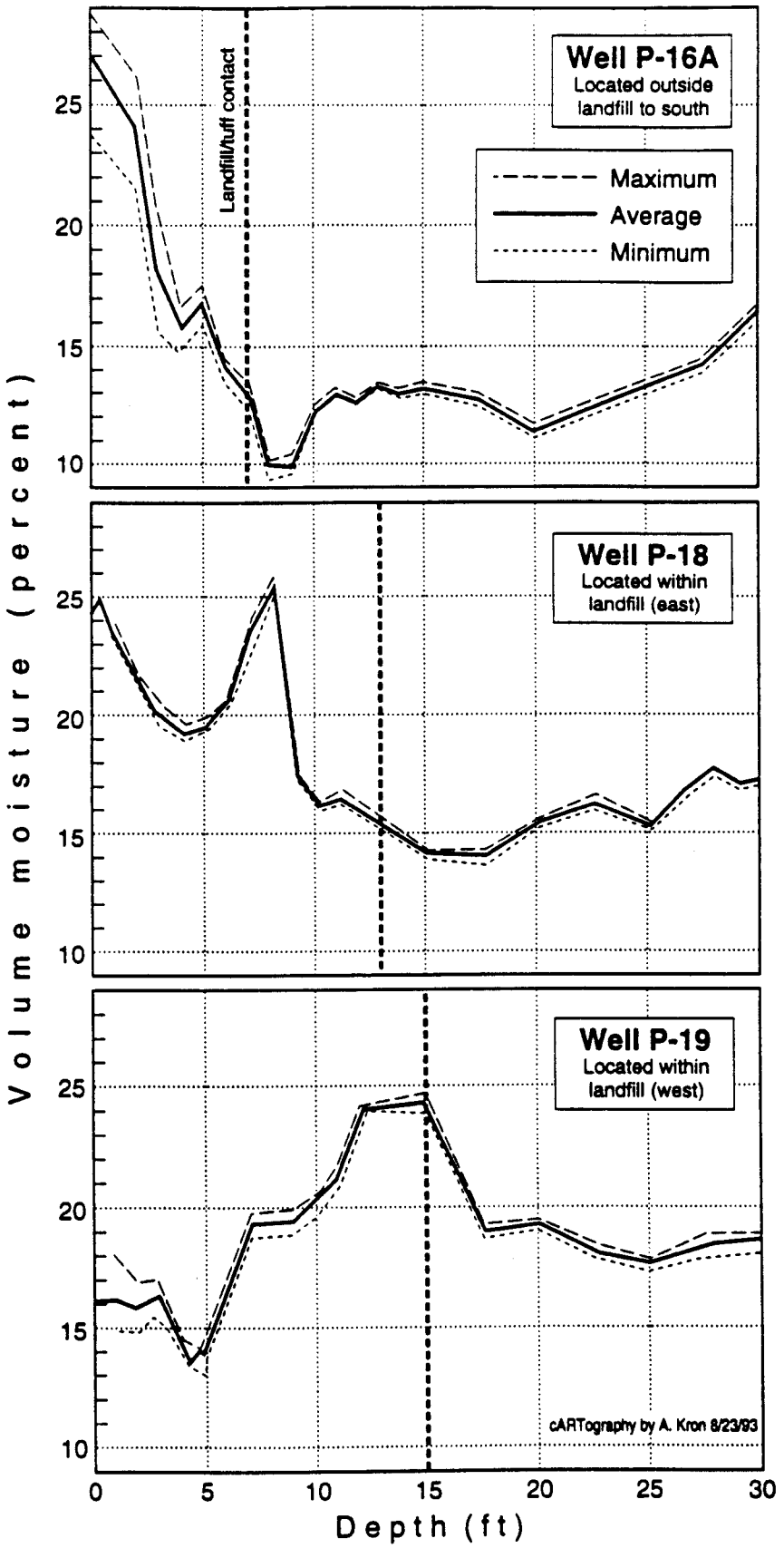
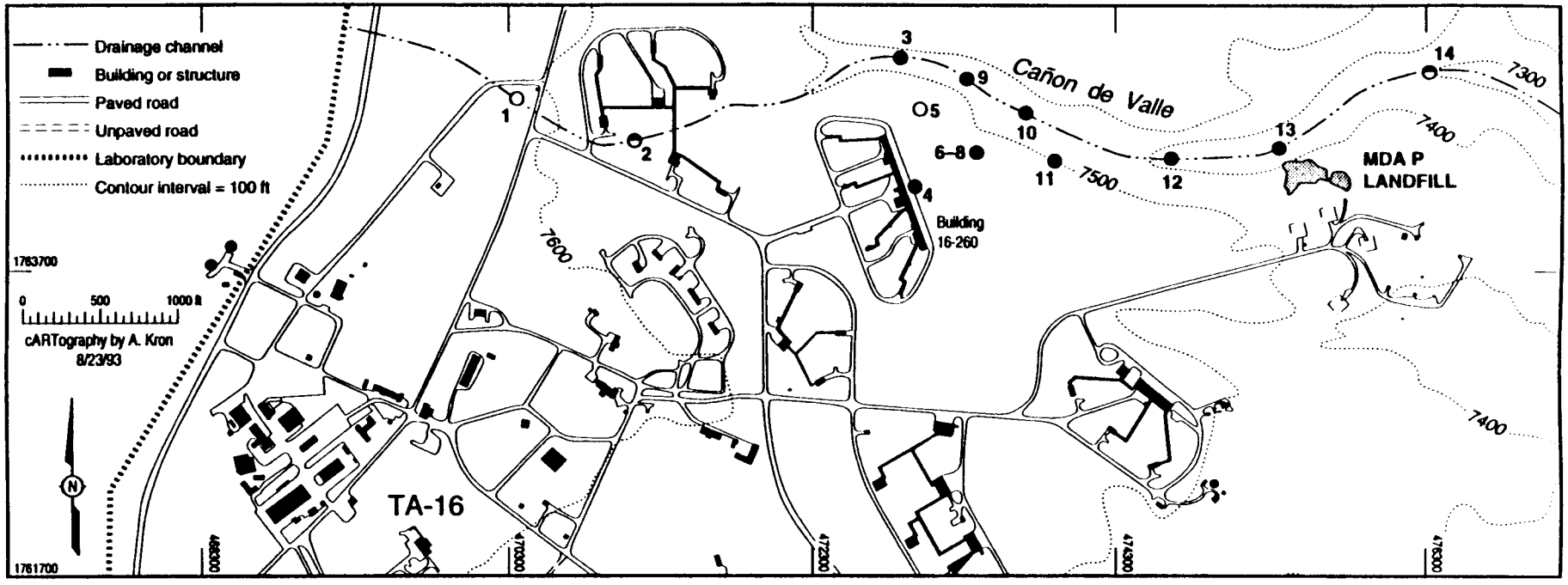


Figure 2-11. Volumetric moisture content versus depth for wells P-16A, P-18, and P-19 (after McLin 1989).

McLin's investigation concluded with a stream sampling survey that was conducted along Cañon de Valle during the fall of 1988. Stream water and sediment samples were collected along the canyon and were analyzed for barium and nitrate. Sampling locations and analyses results are shown on Fig. 2-12. Barium concentrations ranged from 4.4 to 39.9 mg/L for stream water samples and 5.6 to 51.2 mg/L for sediment samples (determined by EP toxicity test procedure). Nitrate concentrations in stream water and sediment samples ranged from 0.2 to 7.7 mg/L. While only one water sample and one sediment sample were collected downstream of MDA P (Station 14), contaminant levels in these samples did not show an increase. This suggests that the barium and nitrate in water and sediment samples originated upstream. The data from Stations 6 through 10 suggest that contamination originates upstream, presumably influenced by a known barium-containing NPDES outfall.



STATION	STATION DESCRIPTION	SEDIMENT SAMPLE RESULTS BARIUM (mg/L)[1]	SEDIMENT SAMPLE RESULTS NITRATE (mg/L)[2]	WATER SAMPLE RESULTS BARIUM (mg/L)[1]	WATER SAMPLE RESULTS NITRATE (mg/L)[2]
1	Channel at State Highway 4	< 5.0	< 0.2	dry	dry
2	Channel below old pond	< 5.0	< 0.3	35.8	< 0.2
3	Channel above Building 16-260	5.6	< 0.2	9.9	0.8
4	Building 16-260 NPDES outfall	< 5.0	< 0.2	4.4	0.8
5	Tributary above outfall	< 5.0	< 0.2	dry	dry
6	Tributary below outfall	6.4	< 0.2	6.4	7.7
7	Tributary below outfall	33.5	< 0.2	38.1	< 0.2
8	Tributary below outfall	51.2	0.3	39.9	2.5
9	Channel below outfall	< 5.0	< 0.2	10.0	0.8
10	Channel below outfall	< 5.0	< 0.2	12.4	0.7
11	Channel below outfall	< 5.0	< 0.2	9.1	0.8
12	Channel below outfall	< 5.0	< 0.2	8.7	0.6
13	Channel above landfill	< 5.0	0.4	9.5	0.6
14	Channel below landfill	< 5.0	NA[3]	9.5	NA[3]

[1] = EP toxicity test procedure
[2] = Total inorganic nitrates
[3] = Not analyzed

Sample location and results:

○ No barium or nitrate detected

◐ Barium detected

● Both barium and nitrate detected

Figure 2-12. Sample location map and barium and nitrate results for Cañon de Valle stream samples (McLin 1989).

3.0 Closure Plan Rationale

Subsection 3.1 reviews the closure options that were evaluated for MDA P and explains why in-place closure was selected. Subsection 3.2 presents an overview of the phased closure plan for MDA P.

3.1 Review of Closure Options

A review of closure options for MDA P was conducted in late 1992 (ERM 1992) and is included as Appendix E. Several closure alternatives were considered including containment by immobilization, in-place treatment, removal, and in-place closure with capping, stabilization, and flood protection. The reasons for rejecting containment by immobilization, treatment technologies, and removal are discussed below.

3.1.1 Containment by Immobilization

The only containment technology, other than capping, that was considered feasible for MDA P was immobilization by stabilization using polymer or grout injection. However, it is questionable if this containment technique could be implemented, either with or without an associated chemical fixation step. The presence of large amounts of concrete rubble, very small to very large pieces of metal wastes of all types (including a demolished truck), and other heterogeneous waste materials makes the introduction of grout or polymer through small borings extremely difficult.

3.1.2 Treatment Technologies

In-situ treatment technologies that were rejected for the waste materials at MDA P included:

- *in-situ* soil flushing for barium;
- *in-situ* bioremediation; and
- downgradient surface water/alluvial water interception and treatment.

These *in-situ* technologies were rejected because of the heterogeneous nature of the waste materials and the impossibility of injecting treatment chemicals or nutrients into all portions of the waste.

Other treatment technologies that were rejected outright as being infeasible for MDA P include:

- vitrification - rejected because of the extensive presence of metal wastes;

- incineration - rejected because of the presence of metals such as barium and lead, which will not be rendered non-hazardous by incineration and could be thermally released; and
- thermal desorption - rejected because it is not appropriate for wastes of low volatility.

Since containment by immobilization and treatment was not considered to be technically feasible for this site, the choice of remediation alternatives was narrowed to removal and in-place closure with capping, stabilization, and flood protection.

3.1.3 Removal

The removal option involves several major issues:

- Although the majority of materials were flashed, the potential remains for undentonated HE in MDA P. Therefore, excavation into MDA P presents worker safety risks. The operating group has estimated that it would take a minimum of a year (possibly longer) to remove materials from MDA P. These removal activities introduce the potential for environmental releases that are not a concern if the landfill is not disturbed.

- All technologies associated with removal would include some form of treatment prior to off-site disposal. The treatments required would involve segregation of RCRA hazardous from non-RCRA hazardous materials and the flashing or other treatment of non-RCRA hazardous materials (non-porous rubble, metal, and other solid objects) to ensure that no HE hazard exists prior to recycling this material. These treatments are both costly, and difficult to implement.

- RCRA hazardous waste materials removed from the landfill will require ultimate disposal in a RCRA-permitted hazardous waste landfill. Off-site disposal of such a large quantity of material presents risks from potential accidents during transport and raises the issue of public concern over transport of hazardous materials.

3.1.4 In-Place Closure

Archival information about site operations indicates that the site waste materials are largely construction rubble and HE-decontaminated equipment; therefore, a source term capable of creating migration of hazardous constituents is not anticipated. Previous site studies (Subsection

2.6) indicate that barium (the likely major RCRA contaminant in MDA P) is probably not migrating from MDA P. Additionally, vertical migration of barium into tuff underneath the landfill is judged, based on previous site studies, to be reduced within 3 ft and therefore poses no risk to groundwater which occurs at over 850 ft below MDA P. Therefore, in-place closure including capping, slope stabilization, and 100-year flood protection, was determined to be as protective of human health and the environment as removal. Phase 1 data will be collected to evaluate this assumption. Because in-place closure does not present the health and safety risks associated with removal, does not have the serious logistical problems of off-site disposal, and provides a more cost-effective solution, it was selected as the best alternative based on the most probable conditions at the site.

3.2 Overview of Phased Closure Plan for MDA P

The strategy for developing the MDA P closure plan is based on the DOE's streamlined approach for environmental restoration (Giante et al. 1993). Components of this approach include:

- Evaluating all remedial alternatives based on probable site conditions.
- Selecting a remedial alternative based on the probable site conditions and planning and designing contingency plans to address reasonable deviations.
- Selecting physical and chemical parameters to be monitored at the waste site to confirm probable site conditions or to detect possible deviations.
- Modifying the remedial action according to prepared contingency plans in response to the occurrence of deviations.

Assumptions about the probable conditions and potential deviations from those conditions at MDA P are summarized in Table 3-1. It should be noted that the probabilities associated with these deviations (Table 3-1) are based on best professional judgment of site conditions after storm water run-on diversion. Run-on diversion is the first step of the closure plan and is proposed for early FY94. Probable conditions are the most likely conditions at the site based on existing information. Deviations are those conditions that will cause re-evaluation of the closure plan.

Based on existing information and best professional judgment, the following conditions are considered probable for MDA P:

- There is no current or future potential for an adverse impact on human health or the environment from contaminants migrating from the landfill to the stream in Cañon de Valle (the major exposure route); and
- The site has acceptable earthquake potential conditions.

The condition of no adverse impact on human health or the environment is based on archival information about disposal activities at MDA P and the previous site studies (Section 2.0). The

TABLE 3-1

PROBABLE CONDITIONS FOR MDA P AND POTENTIAL DEVIATIONS

MEDIA TO BE EVALUATED	PROBABLE CONDITIONS	POTENTIAL DEVIATIONS	PROBABILITY OF DEVIATION OCCURRENCE	ALTERNATIVE ACTION PLAN
Surface soil (at toe of landfill) and sediment in stream and drainages	No current or potential adverse impact on stream water	Stream water adversely impacted and: - current closure doesn't control - enhanced closure doesn't control	- Low - Very Low	- Mitigation measures list* - Re-evaluate closure options
Stream water from - storm events - non-storm	No current or potential adverse impact from landfill	COCs from landfill in the stream > regulatory limits/risk limits - current closure doesn't control - enhanced closure doesn't control	- Low - Very Low	- Mitigation measures list* - Re-evaluate closure options
Seeps	No seeps	High water volume and/or a current or potential adverse impact on stream water - current closure doesn't control - enhanced closure doesn't control	- Very Low - Very Low	- Mitigation measures list* - Re-evaluate closure options
Faults	No fault within 200' of landfill with Holocene displacement (40 CFR 264.18a)	Fault w/in 200' of landfill w/ Holocene displacement - current & enhanced closure doesn't control	- Very Low	- Re-evaluate closure options

* Mitigation measures list:
1) Enhanced cap
2) Vadose water diversion, and
3) Downgradient water treatment

acceptable earthquake fault conditions are based on the Laboratory's ongoing seismic hazard evaluation study, which states that TA-16's most probable peak horizontal acceleration (a design criteria) for sites such as MDA P ranges from 0.1 g force to 0.14 g force with a specific annual exceedance probability of 2×10^{-3} to 1×10^{-3}. This means that the probability each year for an

earthquake with a horizontal force greater than 0.1g is less than 2 in 1 000 (Woodward-Clyde 1993). As stated previously, data will be collected in the Phase 1 investigation to evaluate probable conditions and the closure plan will be modified if there are deviations from those probable conditions.

The potential deviations, which will trigger re-evaluation of the current Phase 2 closure plan (Table 3-1), are:

- The stream water is or could be adversely impacted by contaminants from MDA P to such an extent that:
  - (1) the current closure design will not mitigate the problem, but an enhanced in-place closure design will mitigate the problem (judged to have a low probability), or
  - (2) the enhanced in-place closure design will not mitigate the problem (judged to have a very low probability).
- MDA P has unacceptable fault conditions (judged to have low probability).

If the current design is found to be inadequate, the alternative action is an enhanced closure design based on the results of the Phase 1 investigation. This enhanced design will be proposed as an addendum to this closure and post-closure plan and will be subject to NMED approval. If the enhanced design is also found to be inadequate, the alternative action is to re-evaluate the closure options in light of the site conditions revealed by the Phase 1 investigation.

To implement this streamlined approach, the MDA P closure will be accomplished in two phases. Phase 1 will include diversion of storm water run-on that now flows onto the landfill from adjacent portions of TA-16. This water will be redirected and channeled to preclude run-on infiltration into the MDA P landfill. The run-on control is described in more detail in Subsection 4.1.1.

Phase 1 will also include a 1- to 2-year field data collection program to evaluate the assumptions about probable site conditions. The data collection is designed to test the assumption that the landfill presently does not contribute unacceptable levels of contaminants to the stream. Additional data are needed because existing data are not conclusive. For example, the existing barium data for the stream sediment and soils, while they support the assumption of no significant migration, are inconclusive because they represent a single point in time and do not reflect seasonal variation or precipitation effects. Previous studies have considerable uncertainty because the methods of sampling and analysis were not specified and quality control data are not available. Contaminant characterization was incomplete in the previous studies since samples

were not evaluated for beryllium, high explosives, and depleted uranium. In addition, soil samples were not collected in the area between the landfill toe and the stream, nor were studies to identify and sample seeps conducted.

Another source of uncertainty in the site conditions is the differences between the reported moisture content in the Stephens (1988) and Los Alamos (LANL 1988) studies as explained in Section 2.6. Differences in the soil moisture measurements on core samples from the same boring indicate that the moisture content of the landfill materials and the possible source of this moisture are not adequately characterized. Specifically, the respective percentage of moisture that may be entering the landfill materials from infiltration of surface precipitation; or that entering from storm water run-on infiltration, is not understood. The Phase 1 sampling activities in combination with the control of run-on are designed to eliminate the uncertainty of the contribution of precipitation infiltration versus the contribution of run-on to moisture content in the landfill.

At the conclusion of the Phase 1 investigation an addendum to this closure plan will be submitted describing the Phase 1 investigation and proposing the Phase 2 closure design. The Laboratory will not proceed with the Phase 2 activities until the NMED has approved this addendum. Should the results of the field investigation confirm the probable condition that there is little or no potential for migration of barium or other contaminants of concern (COCs), or that any deviation from this assumption is mitigated by the current closure plan, then the addendum to this plan will propose the following closure design for Phase 2 implementation:

- Stabilize the landfill slope;
- Improve the base of the landfill slope to withstand the 100-year flood event in Cañon de Valle; and
- Cap the landfill using layered soil covering and vegetation.

The details of this design are presented in Subsection 4.2 of this report.

If the Phase 1 investigation shows that the deviations from the probable conditions cannot be mitigated by the current Phase 2 closure design but an enhanced design will protect human health and the environment, then the addendum will provide the Phase 1 results and propose an enhanced design. This enhanced design will be based on the new understanding of the site conditions and could include one or more of the following elements:

- enhanced cap, additional protective layers in the cover;
- upgradient vadose zone water diversion; and
- downgradient surface water runoff collection and treatment.

If the Phase 1 investigation shows that the site conditions pose a threat to human health or the environment that cannot be mitigated by in-place closure, then the closure options will be re-evaluated based on this new understanding of the site conditions. The addendum will provide the results of the Phase 1 investigation and propose a new Phase 2 closure plan.

4.0 Closure Procedures

This section provides a detailed description of Phase 1 closure activities including surface water run-on control (Subsection 4.1.1) and Phase 1 data collection (Subsection 4.1.2). Subsection 4.2 describes the proposed Phase 2 activities, Subsection 4.3 describes closure certification, Subsection 4.4 discusses survey requirements, and Subsection 4.5 presents the site closure schedule.

4.1 Phase 1 Activities

4.1.1 Surface Water Run-on Control

Existing drainages for surface water runoff around MDA P are shown in Fig. 4-1. Existing drainage around MDA P flows in an unlined drainage channel that varies in depth from 2 to 5 ft from the western portion to the eastern portion of the site. Approximately 3 acres of surface drainage area are located immediately uphill of MDA P in the vicinity of burning pads TA-16-386 and TA-16-387. The unlined channel also accepts drainage that flows down the sides of the road entering TA-16 from the west. This drainage runs in channels along the north and south sides of the road. This road is steep and slopes from the west to the east as it descends from the mesa top. An area approximately 250 ft in width and 2 000 ft long, or approximately 12 acres, drains into the drainage channel on the north side of the road. Based on a walkover inspection of the drainage channels in the area, the runoff travels from the northern side of the access road to TA-16 and flows in a culvert under the access drive to burning pad TA-16-386.

Based on historical records, it is known that in the 1980s, the current drainage channel was built to divert drainage that formerly flowed over the eastern face of MDA P, and drainage that formerly flowed from the west side of the site in a culvert under the access drive to burning pad TA-16-386. Drainage from the west formerly flowed into a culvert under the access drive to pad TA-16-387, followed the north side of the access drive to pad TA-16-399, and flowed to the south side of the mesa. Although drainage was improved in the 1980s so that run-on does not flow over the face of MDA P, the drainage channel is still very close to the edge of the waste disposal area and can cross over the top of the waste materials.

The planned changes for surface run-on control during Phase 1 closure activities are also shown in Fig. 4-1. The 15-acre drainage area will be reduced to approximately 3 acres by redirecting the drainage ditch along the TA-16 access road so that it flows to the south of the mesa as originally

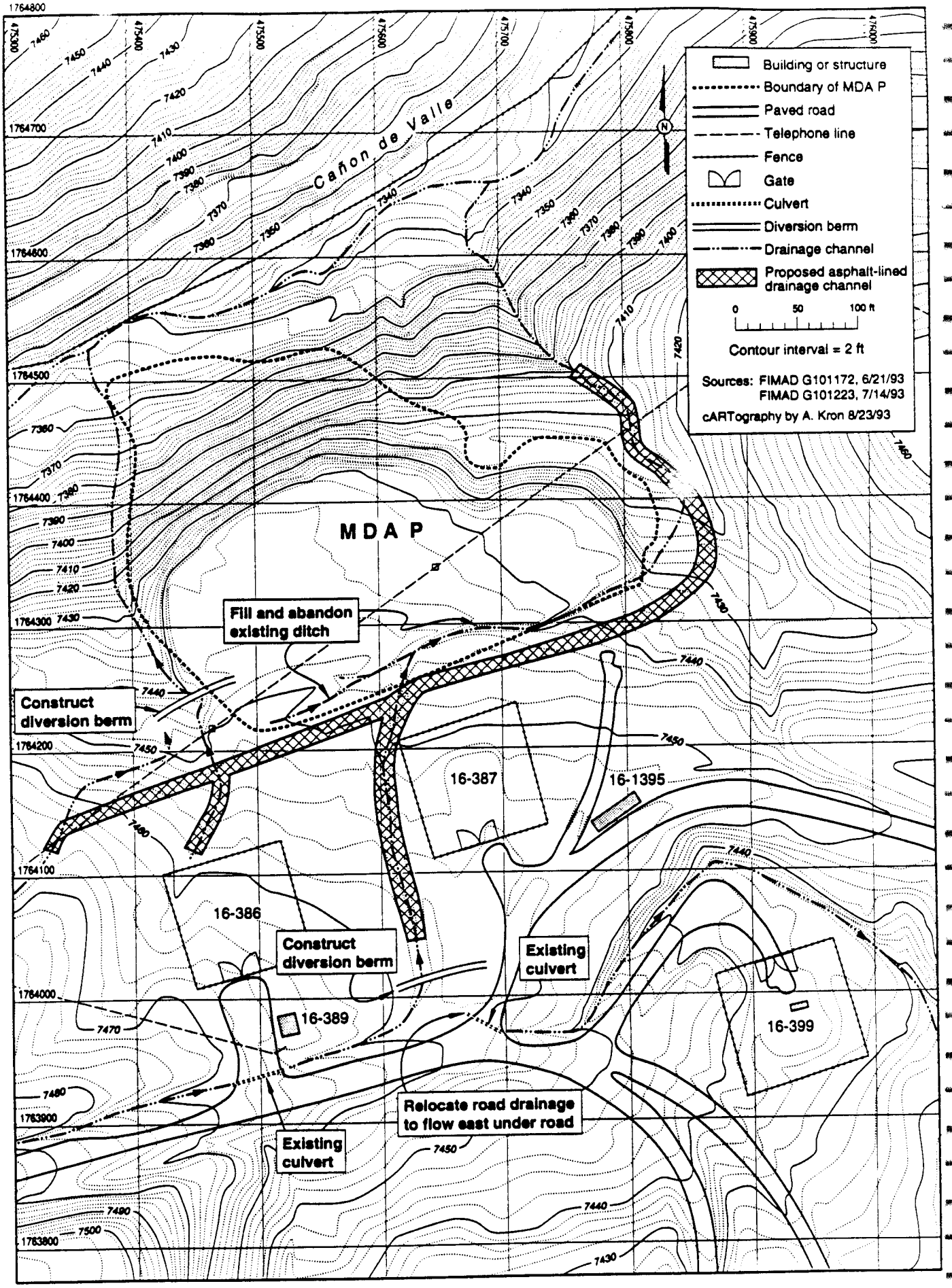


Figure 4-1. Existing site surface water run-on and Phase 1 modifications.

constructed. The drainage channel that runs immediately south of MDA P will be relocated to increase the distance between the drainage channel and the waste materials. The current location of this drainage channel is approximately 30 ft north of burning pad TA-16-387 and also slightly north of the fence that surrounds the burning pad area (Fig. 2-2). This drainage channel will be relocated south of the fence or approximately 40 ft north of burning pad TA-16-387, and will be lined with asphalt to prevent water infiltration under MDA P. The two burn pads have interim status and are not part of MDA P.

A redirected runoff area of approximately 3 acres in the vicinity of burning pads TA-16-386 and TA-16-387 will flow through the lined channel after the Phase 1 run-on construction is complete. As this construction is extremely important for eliminating moisture from the waste materials contained in MDA P, the Laboratory proposes to complete this drainage alteration in the fall of 1993 on an expedited basis. Final engineering design details such as channel cross sections, and actual construction of the improvements will be performed by existing Laboratory contract operations staff without the need to complete formal external plans and specifications or advertise for competitive bids. This action will expedite the completion of this element of the Phase 1 closure.

4.1.2 Phase 1 Data Collection

The goal of the Phase 1 investigation is to provide adequate information to evaluate the efficacy of the current Phase 2 closure design, and to provide information for an enhanced closure design, if necessary. If, after evaluation of the Phase 1 data, it is determined that unacceptable uncertainties remain about the efficacy of in-place closure, then closure options will be re-evaluated.

4.1.2.1 Data Quality Objectives (DQO) Process and Assumptions

Products of the DQO process that have been followed in the development of this Phase 1 investigation for MDA P are described in the following subsections (EPA 1991). The DQO process starts with a statement of the problem and the decision that needs to be addressed. The next steps of the DQO process indicate the required data needs to support the decision and define the spatial and temporal domain of the decision. The decision rule states the decision in terms of a statistical hypothesis test. The final design includes a specification of acceptable limits on uncertainty. In this closure plan the Phase 1 sampling plans for stream water and sediments

are based on best professional judgment of numbers of samples rather than on quantified levels of decision uncertainties.

Each of the DQO process steps applied in developing the sampling plan are described in the following subsections. The problem statement (Subsection 4.1.2.2) provides an overview of the issues that must be resolved before a final decision can be made as to efficacy of in-place closure. The decision is presented in Subsection 4.1.2.3. The data needs are described in Subsection 4.1.2.4, and the decision domain is presented in Subsection 4.1.2.5. Subsection 4.1.2.5 provides the qualitative decision rules.

An important premise of the Phase 1 investigation is that current and future risks to human health and the environment from migration of contaminants from MDA P will be determined by: evaluating current levels of contamination in the stream and by evaluating the impact of seeps and drainages on stream water quality.The logic behind this premise is that after 40 years of operation, it is reasonable to assume that there will be evidence of contaminant migration to the stream if migration is a current or potential problem. This premise will be evaluated throughout the post-closure period (Subsection 5.3).

The efficacy of the current Phase 2 closure elements to mitigate potential risks from MDA P depends on the following assumptions about the site conditions after Phase 1 run-on diversion:

1) MDA P is not contributing contaminants to the stream within Cañon de Valle at a level that presents a current or future unacceptable risk to human health or exceeds regulatory levels, and
2) damage to MDA P from earthquakes is not a concern.

Phase 1 data will be provided to test these two assumptions.

4.1.2.2 Problem Statement

The primary objective of the Phase 1 data collection is to determine if there are COCs migrating from the landfill to the stream. Table 4-1 lists the potential contaminants of concern (PCOCs) and their screening action levels (SALs). SALs for water are maximum concentration limits (MCLs) where they exist. For constituents that do not have MCLs, risk-based levels derived from Subpart S guidance are used. VOCs are not listed in Table 4-1; however, samples will be analyzed for VOCs to determine if these constituents are present. SALs for VOCs are documented in Appendix J of

TABLE 4-1

POTENTIAL CONTAMINANTS OF CONCERN
AND THEIR SCREENING ACTION LEVELS (SALS)

CONTAMINANT	REGULATORY LIMIT/WATER CRITERIA (µg/L)	SOIL SAL (mg/kg)	WATER SAL (µg/L)
Barium nitrate (soluble barium)	2 000[a]	5 600	1 000
1,3-DNB (dinitrobenzene)	NA	8	3.5
2,4-DNT (dinitrotoluene)	0.17[b]	1	0.17
2,6-DNT (dinitrotoluene)	0.0068[b]	1	0.0068
DPA (diphenylyamine)	NA	2 000	880
HMX (cyclotetramethylenetetranitramine)	400	4 000	400
PETN (pentaerythritolletranitrate)	NA	1 600	700
RDX (trimethylenetrinitramine)	2	64	2
Tetryl (n-methyl-N,2,4,6 tetranitrobenzeneamine)	NA	800	350
1,3,5-TNB (trinitrobenzene)	NA	4	1.8
2,4,6-TNT (trinitrotoluene)	2	40	2
Nitrobenzene	-	40	18
2-Nitrotoluene	-	800	350
3-Nitrotoluene	-	800	350
4-Nitrotoluene	-	800	350
Beryllium	NA	0.16	0.0081
Lead	50	500	50
Depleted uranium	NA	58.6(pCi/g)	Not calculated
Nitrate (as N)[a]	10 000	130 000	10 000

[a] Drinking Water Regulations and Health Advisory Tables maximum contaminant level (MCL) (May 1993).

[b] Drinking Water Health Advisory for Adults; USACETHMA, CETHA-TS-CR-90067 (August 1990).

NA = Not Available

the Installation Work Plan (LANL 1992) for the Los Alamos Environmental Restoration Program. Appendix J of the IWP has been updated in draft (LANL 1993a). A copy of the draft Appendix J is provided in Volume 2, Appendix F, of this closure and post-closure plan.

Even though the source of the perennial stream in this part of Cañon de Valle is an NPDES permitted outfall and is not a drinking water source, SALs will be used to identify COCs.

The other issue that must be addressed at MDA P is the potential risk from an earthquake. The 40 CFR 264.18 (a) requirement for siting a waste disposal facility is that it is greater than 200 ft from a fault that shows displacement in the Holocene Period. Investigations will be coordinated

with the Laboratory's ongoing studies of earthquake fault areas to determine if this condition is met.

4.1.2.3 Decisions

The primary issue addressed by the Phase 1 data is to determine if MDA P is contributing COCs to the stream. This issue has three main components, identifying COCs in seeps and the stream; determining if the COCs in the stream water or sediments are from MDA P; and evaluating transport of COCs from MDA P through seeps and drainages. These three main components have the following decision statements.

Identifying COCs

IF, for each PCOC, it is determined that the concentration in the stream water or sediments is greater than its corresponding water SAL or soil SAL,
THEN the constituent is a COC.
ELSE the constituent is not a COC.

IF, for each PCOC, it is determined that the concentration in the drainage runoff is greater than the water SAL or the concentration in drainage sediments is greater than the soil SAL,
THEN, the constituent is a COC.
ELSE the constituent is not a COC.

IF, for each PCOC, it is determined that the concentration in the seeps is greater than the water SAL,
THEN the constituent is a COC.
ELSE the constituent is not a COC.

Determining if COCs are from MDA P:

IF, for each COC, it is determined that its concentration in the stream water (or sediments) below MDA P is greater than the levels above MDA P,
THEN MDA P is contributing this COC to the stream.
ELSE MDA P is not contributing significant amounts of this COC to the stream.

Determining transport of COCs to stream:

> **IF** contaminant transport calculations indicate the potential for significant migration of COCs from the MDA P drainages and seeps to the stream,
> **THEN** MDA P has the potential for significant migration of COCs to the stream.
> **ELSE** MDA P does not have the potential for significant migration of COCs to the stream.

The other decision is to determine if fault zones that show displacement within Holocene time are located within 200 ft of MDA P. A seismic investigation for faults within 200 ft of MDA P will be undertaken as part of Phase 1 studies to provide information needed for final design of the Phase 2 closure plan. DQOs were not used to develop the sampling approach for this decision as this sampling will use the approach developed by the Laboratory's seismic studies group. This sampling approach is described in Subsection 4.1.4.2.

The remainder of the DQO process products are focused on the issue of contaminant migration, since DQOs were used to develop the Phase 1 sampling plan to study potential migration of contaminants from MDA P.

4.1.2.4 Data Needs

The following data will be necessary to resolve the decisions specified in Subsection 4.1.2.3. During Phase 1, drainage areas and seeps will be identified. Then samples will be collected and measured to determine concentrations of PCOCs (Table 4-1) in stream water and stream sediment, seeps, drainage runoff, and sediment. VOC analyses will be performed on water samples from seeps and on soil sediment and stream sediment samples. VOC analyses will not be done on stream water samples since they will have volatilized from the stream water.

4.1.2.5 Decision Domain

The spatial decision domain includes the following:

- sediments and water runoff in drainage channels in the surface runoff area between the toe of the landfill and the Cañon de Valle stream;
- seeps (if they are found within 200 ft of the landfill); and
- stream water and sediments in Cañon de Valle, upstream and downstream of the landfill.

The temporal domain includes three seasonal periods: the spring snow runoff period, the summer thunderstorm period, and the fall low-flow period.

Another component of the decision domain is precipitation level. In each seasonal period, samples will be collected after a storm event and after a period of no precipitation (non-storm event). The storm event is defined as one with precipitation greater than 0.5 in. The non-storm event is defined as one with five consecutive days with cumulative precipitation less than 0.1 in.

4.1.2.6 Decision Rules

The decision rule formulates the decisions in terms of the data collected to support the decision. For example, decision rules for identifying COCs are stated in terms of the maximum observed concentration of each PCOC in a sample:

> **IF** the maximum concentration of any PCOC in the stream water or sediment sample is greater than its corresponding water SAL or soil SAL,
> **THEN** the constituent is a COC.
> **ELSE** the constituent is not a COC.
>
> **IF** the maximum concentration of any PCOC in the drainage runoff sample is greater than its water SAL or the associated sediment concentration in the sample is greater than its soil SAL,
> **THEN** the constituent is a COC.
> **ELSE** the constituent is not a COC.
>
> **IF** the maximum concentration of any PCOC in any seep sample is greater than its water SAL,
> **THEN** the constituent is a COC.
> **ELSE** the constituent is not a COC.

Some adjustments will be made to these decision rules to account for PCOCs for which SALs are less than the Laboratory normal range of background in this area, or if several PCOCs exhibit concentrations that are close to SALs without actually exceeding them. Subsection 4.1.4 and Appendix J of the Los Alamos IWP (LANL 1993a) (see Volume 2, Appendix F, of this document) provide details of the effect of these adjustments on the decision rule.

To determine if COCs in the stream are from MDA P, comparisons of data from samples collected above MDA P will be compared with samples collected below MDA P. These comparisons will be based on statistical tests of differences between the means of the samples. The appropriate tests (parametric or non parametric) will be determined after the data is collected.

> **IF**, for any COC, statistical analysis shows that mean of the of the samples below MDA P is significantly greater than the mean of the samples above MDA P,
> **THEN** MDA P is contributing this COC to the stream.
> **ELSE** MDA P is not contributing significant amounts of this COC to the stream.

The decision rule to determine if MDA P is contributing COCs to the stream through surface water runoff or seeps requires transport models to determine if the volume and concentration of COC(s) are sufficient to make the stream water quality unacceptable.

> **IF**, for any COC, the transport model indicates that MDA P contributes COCs to the stream that could increase stream levels above MCLs,
> **THEN** MDA P is contributing this COC to the stream.
> **ELSE** MDA P is not contributing significant amounts of this COC to the stream.

The Phase 1 data will be evaluated after the first year of sampling. If data are inconclusive, then sampling will continue for at most one more year. The sampling design for the second year of data collection will be based on the first year's results. After completion of the Phase 1 investigation, the Laboratory will develop an addendum to this plan describing the results of the Phase 1 investigation and proposing the final Phase 2 closure design for NMED approval. As stated previously, the proposed Phase 2 closure design will remain unchanged in the addendum if the Phase 1 data indicate that MDA P is not contributing significant levels of contamination to the stream and earthquake damage is not an important issue. However, if the Phase 1 data indicate that contaminant migration cannot be satisfactorily mitigated by the existing Phase 2 closure design or earthquake damage presents a threat to human health and the environment, the addendum will propose appropriate modifications to the Phase 2 closure elements for NMED approval.

4.1.3 Phase 1 Sampling and Analysis Approach

The sampling and analysis plans described in these subsections have been developed using professional judgment as to the number of samples rather than basing the number of samples on quantified decision uncertainties. If, when these data are evaluated uncertainties are

unacceptably large, additional data will be collected. Acceptable uncertainties will be determined by NMED.

4.1.3.1 Radiation Screening

Radiation screening is necessary for health and safety purposes and to help select samples for radionuclide analysis. The area between the landfill and Cañon de Valle stream, and a 100-ft zone above and below MDA P boundaries, will be screened for gross gamma activity using a 10-ft grid. This gross gamma screening will detect depleted uranium if present. Areas detected above background during the surface screening will be flagged in the field and their positions documented. A surface soil sample representing 0 to 6-in. depth will be collected from the flagged locations and submitted for gamma spectroscopy analysis.

4.1.3.2 Drainages and Seeps

Samples of storm water runoff and sediment will be obtained from four drainage locations, R1 through R4 (Fig. 4-2), following one storm event and one non-storm event in each of three seasonal periods for a total of six samples per year per site. A duplicate sample will be collected at R4 for each event for a total of 36 sediment samples and 36 water samples. Samples will be analyzed for the PCOCs listed in Table 4-1 and VOCs.

Additionally, three background runoff channel locations for soil sediment (B1, B2, and B-3) will be selected for sampling for comparison to these data. One of these locations (B-1) will be a minimum of 500 ft west (or up canyon) of MDA P in similar terrain, and the other two locations (B2 and B-3) will be a minimum of 500 ft east (or down canyon) of MDA P. These samples will be collected at the same time the MDA P samples are collected and will be useful to discriminate between MDA P effects and those from other TA-16 activities.

Vadose zone seeps, should they occur, will be sampled in the area defined by MDA P. It is not known if seeps will be found, but two seeps located up canyon of MDA P were identified during a recent canyon reconnaissance. During the establishment of the sampling stations described in Subsection 4.1.3, a complete walkover survey of the area will be conducted to search for seeps. This will be performed at least twice after periods of heavy precipitation in the area between the landfill and the stream. If seeps are found, samples will be collected. Samples will be analyzed for the PCOCs listed in Table 4-1 and VOCs.

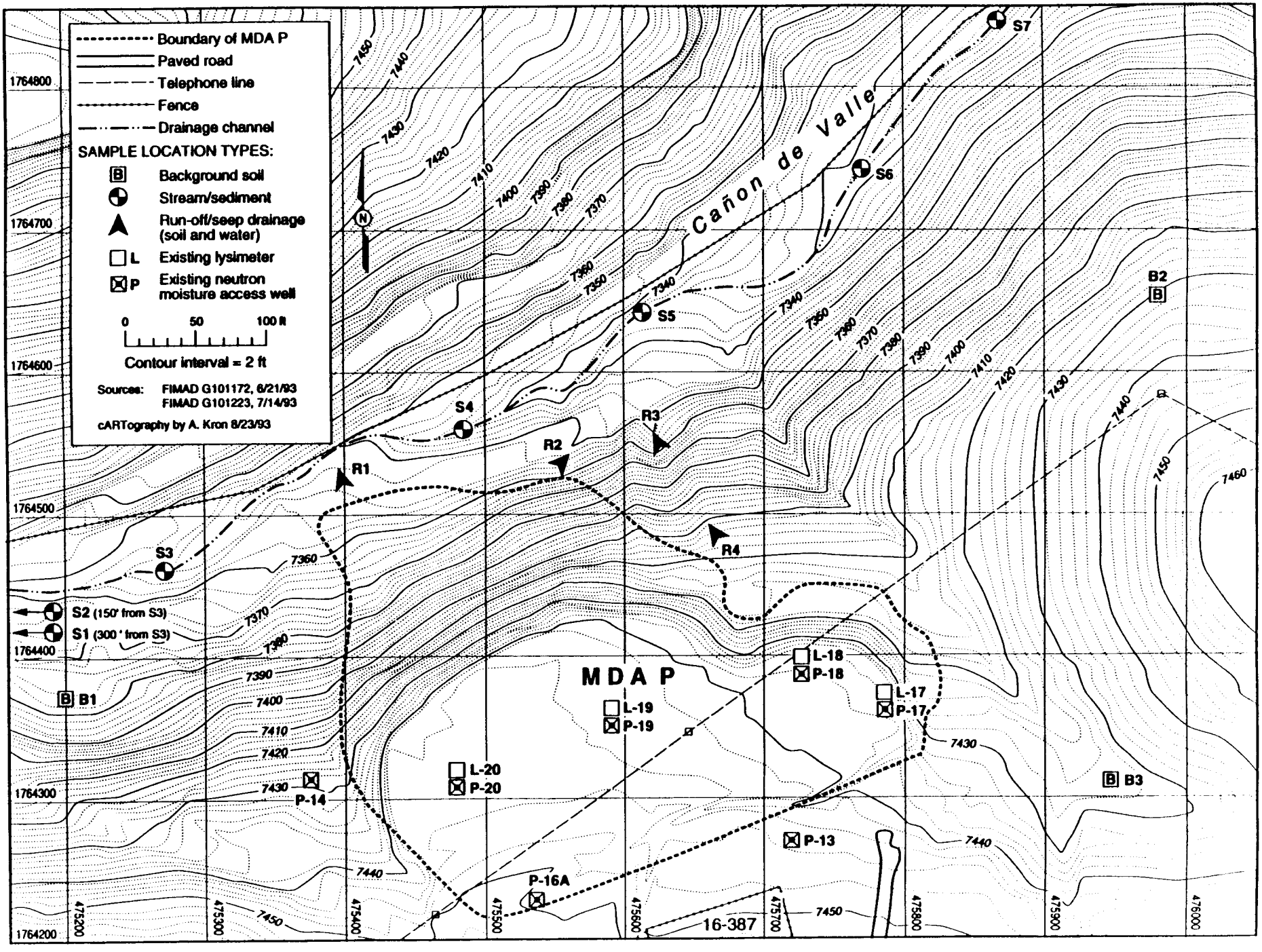


Figure 4-2. Phase 1 closure field design data collection sampling locations.

4.1.3.3 Stream Water

The Cañon de Valle stream will be sampled in seven locations during the same three seasonal periods. Figure 4-2 shows approximate sampling locations. Three samples will be located upstream of the landfill. The first sample will be located approximately 100 ft west of the location where the surface water drainage flows down the western side of the landfill and enters the Cañon de Valle stream (S3); the second (S2) an additional 150 ft upstream; and, the third (S1) 300 ft upstream of S3. The fourth location will be in the stream across from the mid area of the western portion of MDA P (S4). The fifth location will be across from the eastern portion of MDA P (S5), and the sixth location will be approximately 100 ft downstream from the confluence of the surface water run-on drainage that flows around the eastern side of the MDA P landfill (S6). The seventh (S7) will be approximately 150 ft downstream of S6. Six samples per year of surface water and stream sediment from each of these seven locations (total 42 water samples, 42 sediment samples) will be collected during the same storm and non-storm events for which soil and surface water runoff samples are collected. Upstream sources of barium, which discharge into the Cañon de Valle stream, are known to exist. Those will be accounted for by the sampling locations upstream of MDA P. Also, these upstream sources will be independently investigated during the RCRA field investigation of Operable Unit 1082.

Stream water samples will be 24-hour composite time-integrated samples initiated during the onset of the storm event and continuing for approximately 24 hours. Flow will be estimated at each location of sampling to enable interpretation of the data on a flow-proportional basis. Both filtered and unfiltered samples will be analyzed to differentiate between dissolved and particulate contamination.

One duplicate stream water and sediment sample will be collected at location S6 to evaluate the variability component owing to the sampling method. Stream water samples will be analyzed for all PCOCs listed in Table 4-1. Initially, only three sediment sampling locations (S3, S4, and S5) will have VOC analyses. If VOCs are detected in these samples, all sediment sampling locations will be evaluated during the next sampling event.

Quality control and quality assurance samples will be taken according to specifications in the SOPs and the Environmental Restoration Quality Program Plan and Quality Assurance Project Plan (LANL 1993b).

4.1.4 Other Sampling Specifications

4.1.4.1 Soil Moisture

Moisture measurements will be taken six times per year in each of the four existing neutron moisture access wells installed within the MDA P area. The locations of the moisture access wells are shown in Fig. 4-2. These measurements will provide data to study the correlation of landfill moisture variations with seasons and storm events, and to help understand discrepancies in past moisture data. These data will provide information to evaluate the effectiveness of the surface water diversion and will provide a baseline for the post-closure monitoring described in Subsection 5.3. Understanding moisture variation will also assist in developing an enhanced Phase 2 design, in case the current proposed design is found to be inadequate.

4.1.4.2 Fault Analysis

A field investigation of fault zones located within 200 ft of MDA P will be conducted during the Phase 1 investigation. This 200-ft distance is drawn from the siting requirement for new landfills as the most appropriate area for investigation around MDA P. This field fault mapping will be coordinated with the Laboratory's ongoing fault and seismic analysis efforts under the Environmental Restoration Program seismic hazards program and will be conducted in accordance with LANL-ER-SOP-03.09 Revision 0 Geologic Mapping of Bedrock Units. In particular, this fault mapping study will determine if the Water Canyon fault exists within 200 ft of MDA P). If faults are determined to exist within 200 ft of MDA P, a detailed analysis of the seismic hazards of closure in place will be performed. This information will be included in the addendum to be submitted to NMED at the end of Phase 1.

4.1.5 Analytical Methods

Analytical parameters and test methods are shown in Table 4-2. Table 4-3 summarizes the number of samples to be taken at each location.

4.1.6 Sampling Methods, Handling, and Documentation

Los Alamos Environmental Restoration Program standard operating procedures will be followed for all sampling and analysis. These include at minimum the SOPs shown in Table 4-4.

TABLE 4-2

ANALYTICAL PARAMETERS AND TEST METHODS FOR POTENTIAL CONTAMINANTS OF CONCERN (PCOCs)

PARAMETERS	METHOD-SOIL/SEDIMENT	METHOD-WATER
Barium	EPA SW 846 Method 6010	EPA SW 846 Method 6010
Lead	EPA SW 846 Method 6010	EPA SW 846 Method 6010
Beryllium	EPA SW 846 Method 6010	EPA SW 846 Method 6010
Nitrate	EPA 300.0 by Ion Chromotography	EPA 300.0 by Ion Chromotography
Volatile Organics	EPA SW 846 Method 8240	EPA SW 846 Method 8240
Gamma scan	ER Field Procedures	
Gamma Spectroscopy*	Gamma Spectroscopy	
High Explosives**	USATHAMA by High Performance Liquid Chromatography or SW 846 Method 8330	USATHAMA by High Performance Liquid Chromatography or SW 846 Method 8330

* These analyses will only be performed if positive results are obtained at any locations in the surface screening of the landfill area and area between the landfill and Cañon de Valle stream.

** Includes HMX; RDX; 1,3-DNB; 1,3,5-TNB; 2,4-DNT; 2,6-DNT; 2,4,6-TNT; Tetryl; DPA; Nitrobenzene; 2 through 4 Nitrotoluene; PETN

TABLE 4-3

SUMMARY OF PHASE 1 WATER AND SEDIMENT SAMPLES

SAMPLE STATION	# WATER SAMPLES/YR	#WATER FIELD DUPLICATE/YR	TOTAL	# SEDIMENT SAMPLES/YR	#SEDIMENT FIELD DUPLICATE/YR	TOTAL
S1	6		6	6		6
S2	6		6	6		6
S3	6		6	6		6
S4	6		6	6		
S5	6		6	6		6
S6	6	6	12	6	6	12
S7	6		6	6		6
B1				6		6
B2				6		6
B3				6		6
R1	6		6			
R2	6		6			
R3	6		6			
R4	6	6	12	6	6	12

Note: All samples (except stream water and four sediment locations) to be analyzed for all PCOCs including barium, VOCs, nitrate, beryllium, lead, and HE. Stream water samples will be analyzed on filtered and unfiltered portions for all PCOCs except VOCs.

S1 through S7: stream water and sediment.
B1 through B3: background runoff channel sediments.
R1 through R4: landfill runoff channel water and sediments.

TABLE 4-4

ENVIRONMENTAL RESTORATION PROGRAM
STANDARD OPERATING PROCEDURES (SOPs)

SOP	TITLE	NOTES
01.02,R0	Sample containers & preservation	Applies to all laboratory samples
01.04,R1	Sample control & field documentation	Applies to all laboratory samples
01.05,R0	Field quality control samples	Field quality control samples
03.06,R0	Fracture characterization	
03.09,R0	Geologic mapping of bedrock units	
06.03,R0	Sampling for volatile organics	
06.10,R0	Hand auger & thin-wall tube samples	Soil samples
06.09,R0	Spade and scoop method for collection of soil samples	
06.13,R0	Surface water sampling	Applies to all water samples
06.14,R0	Sediment material collection	Applies to all sediment samples

Copies of these standard procedures are included in Volume 2, Appendix G, of this plan. In addition to these SOPs, all operating division health and safety requirements will be incorporated into the field activities. All sampling will be governed by the Environmental Restoration Quality Program Plan and Quality Assurance Project Plan (LANL 1993b). The analyte list will be constant for the first 12 months of sampling including all of the PCOCs previously listed in Table 4-1. In addition to the Table 4-1 PCOCs, VOC concentrations will be determined in all seep, drainage sediment and water, and in three stream sediment samples. The second year of sampling (if needed) will focus on those constituents identified as COCs in one or more sampling events in the first year.

4.2 Phase 2 Activities

4.2.1 Final Design and Construction

4.2.1.1 Landfill Slope Stabilization

The slope of the eastern portion of the landfill will be stabilized by extending the cover of that portion of the landfill to include the entire slope. Extraneous surface waste materials from the top and the foot of the slope of the western portion of the landfill will be collected and used as fill on the slope of the eastern portion of the landfill. Additional clean fill will be used to cover this waste material and to decrease the slope of the eastern portion of the landfill to approximately a 3H:1V slope. Some degree of grading of the top of the slope will be necessary to accomplish this objective. Once the slope of the entire eastern portion of the landfill is reduced to a 3H:1V slope,

the entire horizontal and sloped area of the eastern portion of the area will be covered with the cap design system discussed in Subsection 4.2.1.3. Engineering material specifications will be provided in the addendum proposing the final cap design.

The slope of the western portion of the landfill will not be modified (See Fig. 2-3). The slope is believed to be stable owing to the length of time of the landfill has been in place without slumping or failure (approximately 40 years) and, owing to the nature of the waste materials which contain numerous structures, pipes, racks, and long pieces of metal. These materials in the waste provide tensile strength to the waste materials and have enhanced the overall stability of the western portion of the landfill. The existing surface of the slope is vegetated and partially covered with rock. Because of the steepness of the slope and the presence of well-established vegetation and rock, it is believed that very little infiltration occurs on the slope of the western portion of the landfill. To enhance the surface evaporation and erosion resistance, additional rock facing will be placed on approximately 50% of the western slope of the landfill. Six to 12-in. diameter cobbles will be placed between existing rock covering and vegetation.

4.2.1.2 Flood Protection

As outlined in 40 CFR 270.14-11(iii) [NMHWMR-7, Part IX, Section 270.14-11(iii)], MDA P must be protected from washout during 100-year precipitation event and flood conditions. In order to address the abnormally high water elevations and velocities associated with this 100-year event within the closure plan, the floodplain elevations along Cañon de Valle near MDA P were evaluated.

The 100-year floodplain elevations within the boundaries of the Laboratory have recently been defined and reported by McLin (1992). The Corps of Engineer's computer-based Flood Hydrograph Package (HEC-1 and HEC-2) was used to perform floodplain hydrology simulations. The Flood Hydrograph model (HEC-1) was used to generate 100-year, 6-hour storm event hydrographs at selected channel locations (situated at 250-ft channel segment intervals) within each major watershed. The hydrograph peaks predicted by HEC-1, along with stream channel geometry and watershed basin characteristics, were then input to HEC-2 to compute 100-year floodplain elevations. Detailed maps of 100-year floodplain elevations were generated for 11 watersheds at the Laboratory, including the Water Canyon Watershed (of which the Cañon de Valle tributary is a part).

The floodplain elevations produced for Cañon de Valle from HEC-1 and HEC-2 simulations showed some obvious inaccuracies (i.e., in some instances floodplains were not located in the canyon basin). These inaccuracies are due to the broad interpretations of model input parameters; stream channel geometry information was based on general topographic features (from 7.5" quadrangle maps) and channel segments were evaluated at 250-ft intervals. In order to correct for variations in topography within these 250-ft intervals, the 100-year floodplains along the canyon have been adjusted; floodplains have been centered (based on elevation) within the canyon while maintaining computer-simulated floodplain widths. This adjustment produced a consistent fit with the canyon topography at MDA P. Several adjustments of floodplain centering all resulted in the same maximum flood elevations for MDA P.

Figure 4-3 shows these adjusted 100-year floodplain elevations in Cañon de Valle with respect to MDA P. The floodplain extends up onto the landfill toe on the western portion of MDA P to a maximum elevation of 7 358 ft; the floodplain is located at a considerable distance from the eastern portion of MDA P. In order to reinforce the western portion of the landfill and protect it from washout during a 100-year storm event, gabions (approximately 3.5 ft x 3.5 ft) will be placed on the toe of the slope. The gabions will extend to an elevation of 7 360 ft, approximately 2 ft above the currently projected 100-year flooodplain elevation. Figure 4-3 shows the extent of the area that will receive gabion reinforcement/protection; a distance of approximately 150 ft along the northwestern face of the landfill toe will require protection. Maximum height of gabions will be approximately 6 ft at the lowest portion of the landfill toe (elevation 7 354 ft).

4.2.1.3 Cap Design

The regulatory cover system requirements for RCRA closure under 40 CFR 264.310 (NMHWMR-7, Part IV, 264.310) are based on performance and include the following:

- Provide long-term minimization of migration of liquids through the closed landfill.
- Function with minimum maintenance.
- Promote drainage and minimize erosion or abrasion of the cover.
- Accommodate settlement and subsidence so that the cover's integrity is maintained.
- Have a permeability less than or equal to the permeability of any bottom liner system or natural subsoils present.

In order to meet the intent of the RCRA regulations for conservative cases (e.g., humid regions with high concentrations of mobile chemicals), EPA technical guidance documents (EPA 1985 and EPA 1989) outline a general RCRA cap design. Also within these guidance documents, EPA

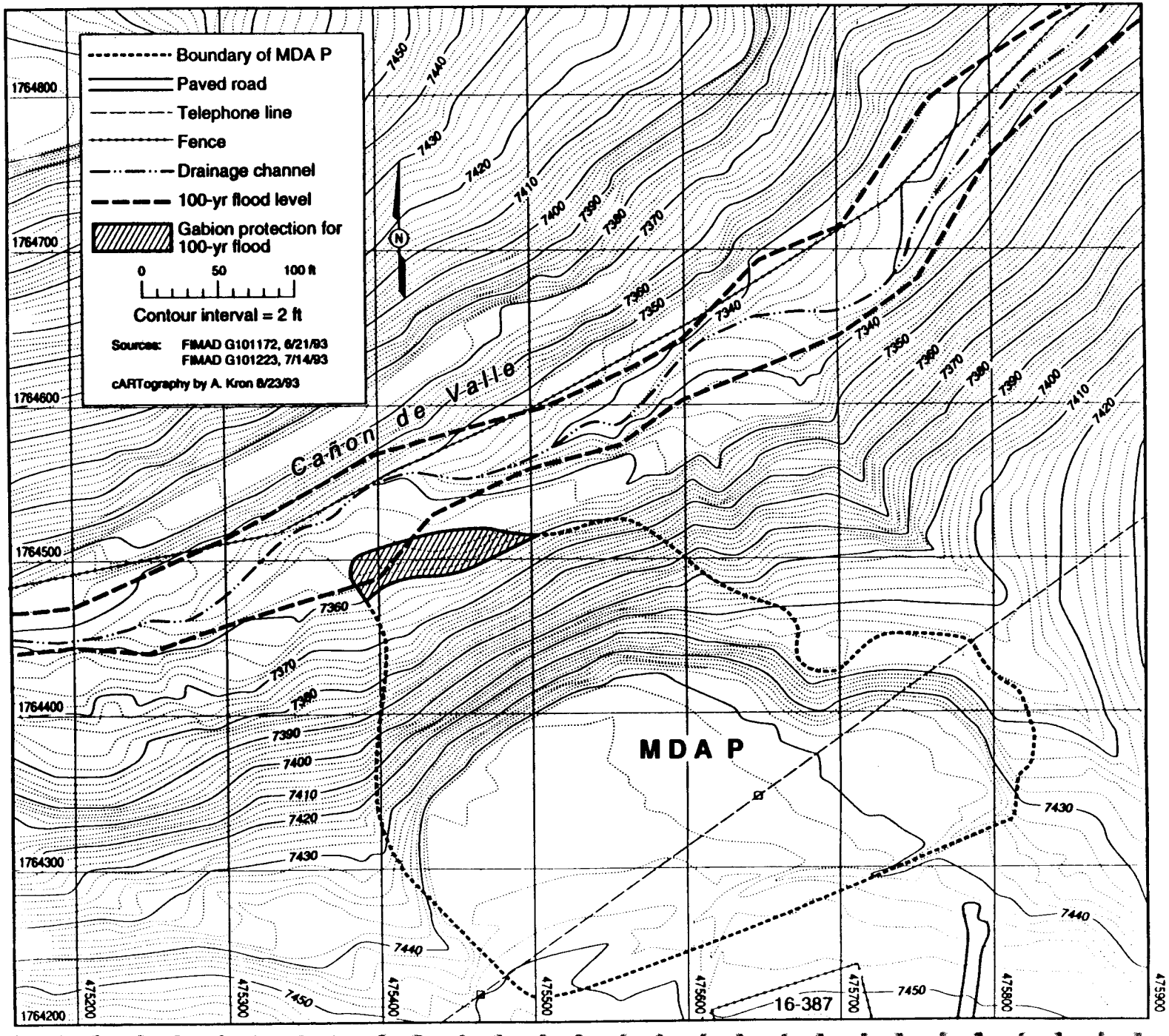


Figure 3. Location of the 100-year flood plain.

acknowledges that alternative site-specific final cover designs based upon the technical evaluation of different site conditions can be appropriate (particularly in arid regions). Depending on site-specific conditions and upon the determination that the alternative design adequately fulfills the regulatory requirements listed above, alternative designs consisting of fewer layers or optional layers can be applicable. For instance, a gravel-armored top surface component might serve to compensate for a naturally reduced vegetation coverage and the erosion control that it provides. In summary, both the underlying regulations and implementing guidance allow exceptions to the standard designs.

Based upon the history and site-specific conditions of MDA P (semi-arid climate, deep groundwater, minimal infiltration, type of waste materials), a clay or soil cap can satisfy the above-listed regulatory requirements for the final cover of MDA P. These types of landfill caps have been extensively studied at the Laboratory (Nyhan and Barnes 1989 and LANL 1991). Additional background on this capping technology is included in Volume 2, Appendix H, of this plan (Nyhan et al. 1993 and LANL 1986). Fig. 4-4 shows the extent of the coverage of this cap at MDA P. The components of the cover system proposed for MDA P are shown on Fig. 4-5 and are listed below (from top to bottom):

- 2.0 ft of uncompacted clay loam topsoil with a 70% coverage of gravel mulch and a well-maintained vegetative cover and unpaved mulch.
- 2.5 ft of fine sand.
- geotextile filter fabric.
- 1.0 ft of gravel.

In a semi-arid environment such as Los Alamos, the cover system proposed above has features suitable for successful performance .

- The cover system as a whole is made of natural materials. There is less uncertainty over the long-term performance of any of the cover elements, than there would be if geomembranes were used.
- The vegetative layer (with gravel surface mulch) removes significant moisture from the cover system by evapotranspiration. The vegetation and gravel reduce erosion and soil loss as well.
- The topsoil layer, suggested as a clay loam soil, serves as a rooting medium for the vegetation, but also provides a zone for moisture retention of precipitation that has infiltrated the cover system. In dry periods, this moisture is available for subsequent uptake and evapotranspiration by vegetation.

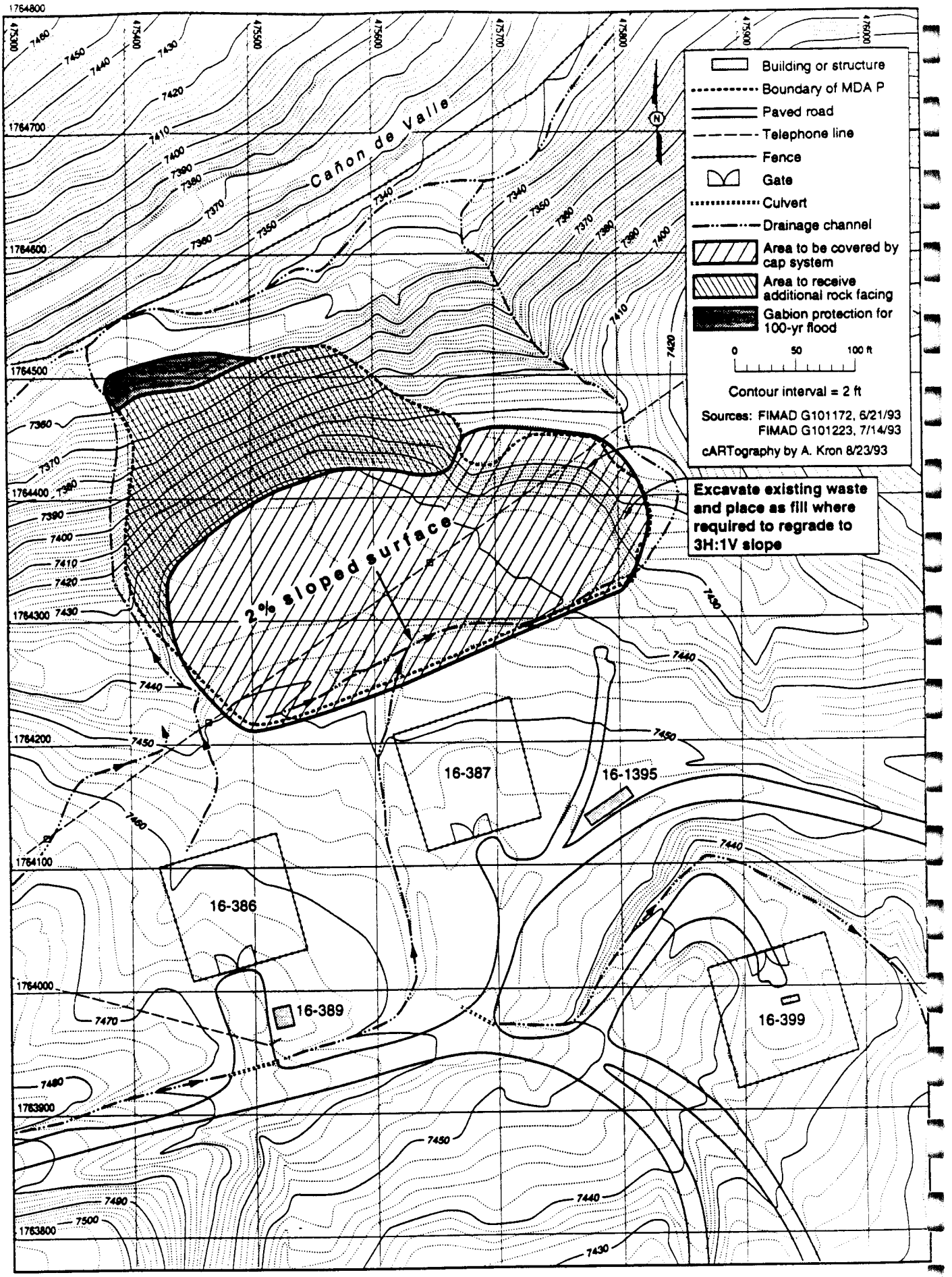


Figure 4-4. Extent of cap area.

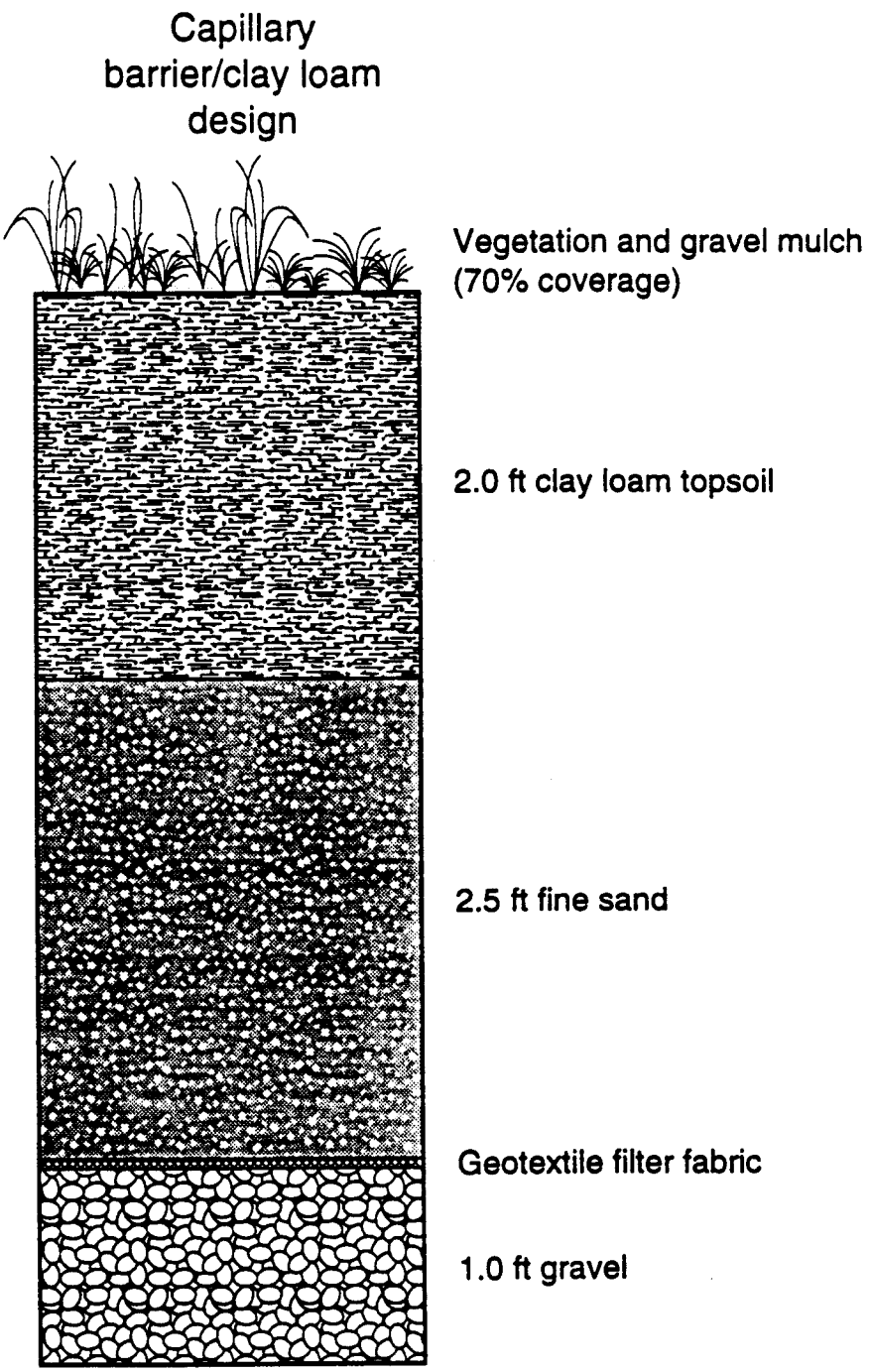


Figure 4-5. Cross section of cover design.

- The fine sand serves as a capillary break above the underlying gravel. Moisture entering this layer will be held within the sand by capillary tension. Lateral transmission of the moisture is favored. This is another pathway to remove infiltrated moisture from the cover system, and thereby prevent infiltration.
- A filter fabric is specified to provide a distinct interface between the fine sand and the underlying gravel. A capillary break will perform best if a sharp contrast in hydraulic conductivity can be maintained between the layers.
- A gravel layer provides lateral drainage within the cover, and is the final lateral drainage layer for any infiltrating moisture.

The cover design described above is similar to the RCRA guidance in that it uses vegetation, a topsoil layer, and lateral drainage layers. It is different from the RCRA guidance in that a capillary break is provided instead of a low permeability layer, or layers. The capillary break design offers equal or better performance, and in the long term will avoid design life questions concerning geomembranes or desiccative cracking in clay cover systems.

This designed cap will be installed on the top flat portions of both the eastern and western portions of MDA P, as well as on the reconstructed/regraded 3H:1V slope of the eastern portion. The western slope is considered stable and the only cap work required is placement of flat armor rock over approximately 50% of the slope face area. These flat rocks will not disturb the established vegetative cover and will help reduce infiltration and provide protection against runoff erosion on the slope. A detailed description of erosion control measures and the vegetative cover will be provided in the addendum.

Figure 4-6 shows a typical cross section through each part of the closed landfill as each part will be configured at the completion of closure activities. (It should be noted that the vertical scale is exaggerated by a factor of 2.5 causing the slope to appear much steeper than it is.) The cover areas across the top parts of MDA P are designed with slopes of 2% (minimum) to promote surface drainage. Surface runoff from the flat parts of the closed facility will primarily drain southward into the re-routed asphalt-line drainage channel that will also collect potential run-on from upgradient drainage areas.

The amount of settlement in the landfill and its impact on the cover will be negligible. Waste and backfill materials will be sufficiently compacted under earthwork equipment as part of the slope

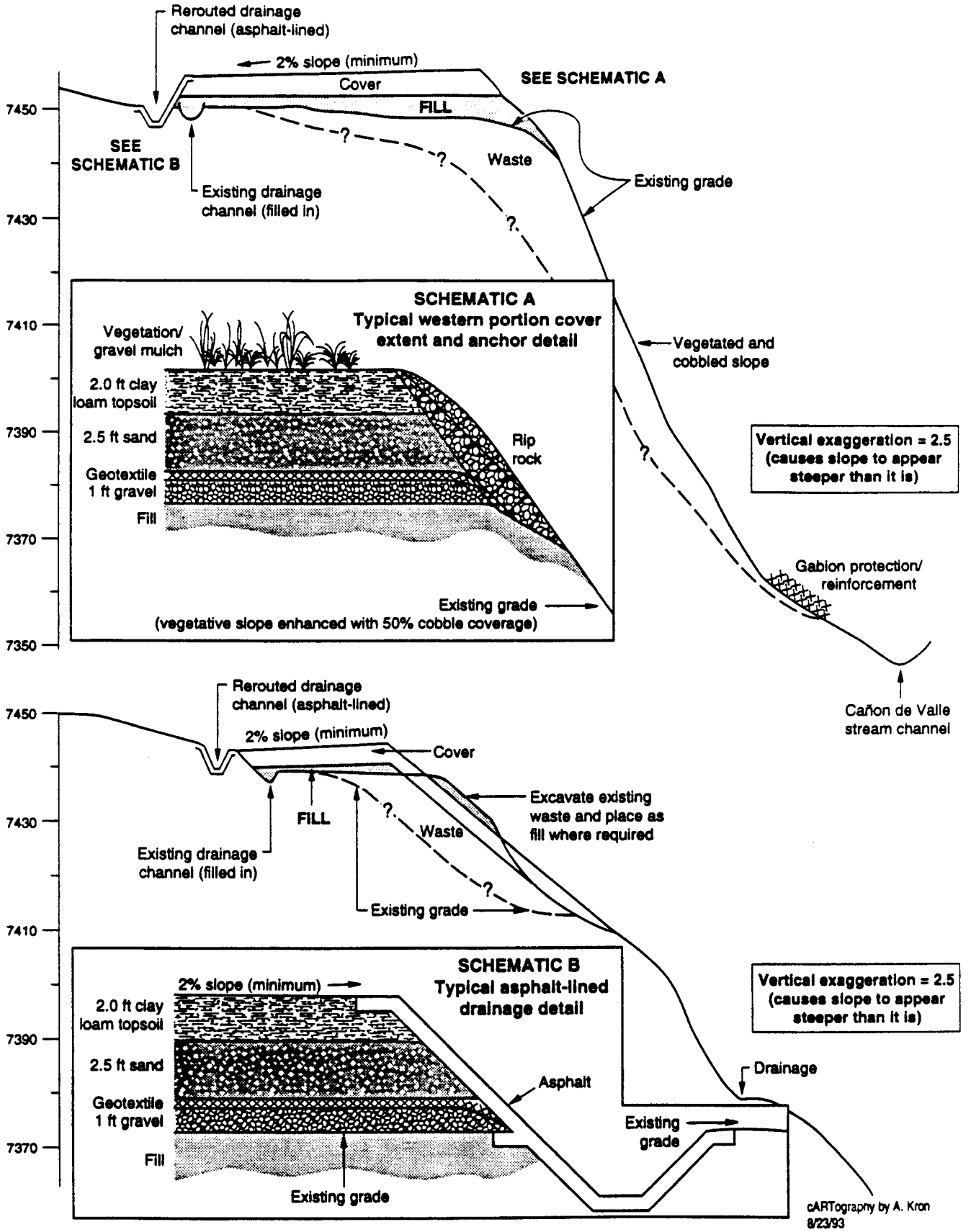


Figure 4-6. Typical cross section through west landfill (top) and typical cross section through east landfill (bottom).

regrading/reconstruction process on the eastern portion of MDA P. Waste areas not impacted by this process are considered stable at this point during the 40-year lifetime of the landfill.

4.2.2 Closure Plan Addendum and Final Report

After completion of Phase 1 activities, an addendum to the closure plan will be submitted describing the results and proposing the final Phase 2 closure design. NMED approval of this addendum will be required before proceeding with the Phase 2 closure.

Upon completion of both Phase 1 and Phase 2 closure activities, the Laboratory will submit a final closure report to NMED. The report will document the final closure and contain, at a minimum, the following:

1. A certification of closure (described in Subsection 4.3.)
2. A tabular summary of all sampling results showing:
   a. the datum reported,
   b. the detection limit for each datum sample analysis batch,
   c. a measure of analytical precision (e.g., uncertainty, range, variance),
   d. identification of analytical procedure, and
   e. identification of analytical laboratory.
3. A quality assurance/quality control statement on the adequacy of the analytical analyses and the decontamination effort.
4. The location of the file of supporting documentation including:
   a. field logbooks,
   b. laboratory sample analysis reports,
   c. the quality assurance/quality control documentation, and
   d. chain-of-custody records.
5. A description of any variances from the approved closure plan.

4.3 Closure Certification

In accordance with 40 CFR 264.115 (NMHWMR-7, Part VI, Section 264.115), a certification of closure will be prepared within 60 days of completion of the final closure activities described in this plan. This certification will be completed (after review of field activities and site inspection report records) by an independent, registered professional engineer and the facility owner and operator (or authorized representative). The certification will verify that closure activities were conducted in accordance with the approved closure plan. The final closure certification and

closure completion notification, signed by both parties, will then be submitted by registered mail to the NMED.

4.4 Survey Plat

Benchmarks will be installed in the vicinity of MDA P during the closure process and will serve as permanent locators for the facility. A survey plat indicating the location and dimensions of MDA P, as well as the closure construction with respect to these permanently surveyed benchmarks, will be prepared and certified by a professional land surveyor (as outlined in 40 CFR 264.116 and NMHWMR-7, Section VI, Part 265.116). This plat will be completed and submitted to the local land use authority and the NMED no later than submission of the certification of closure.

4.5 Closure Schedule

Figure 4-7 shows the schedule for the implementation for Phase 1 and Phase 2 closure elements. The closure regulations require the Laboratory to initiate closure within 90 days of closure plan approval and to complete final closure activities within 180 days after approval of the closure plan, unless a longer period has been approved.

An extension of the 180 day time frame for completion is requested. Subsections 4.1 and 4.2 (Phase 1 and 2 closure) and Fig. 4-7 (closure schedule) demonstrate that the final closure activities may, of necessity, take longer than 180 days after approval of the closure plan.

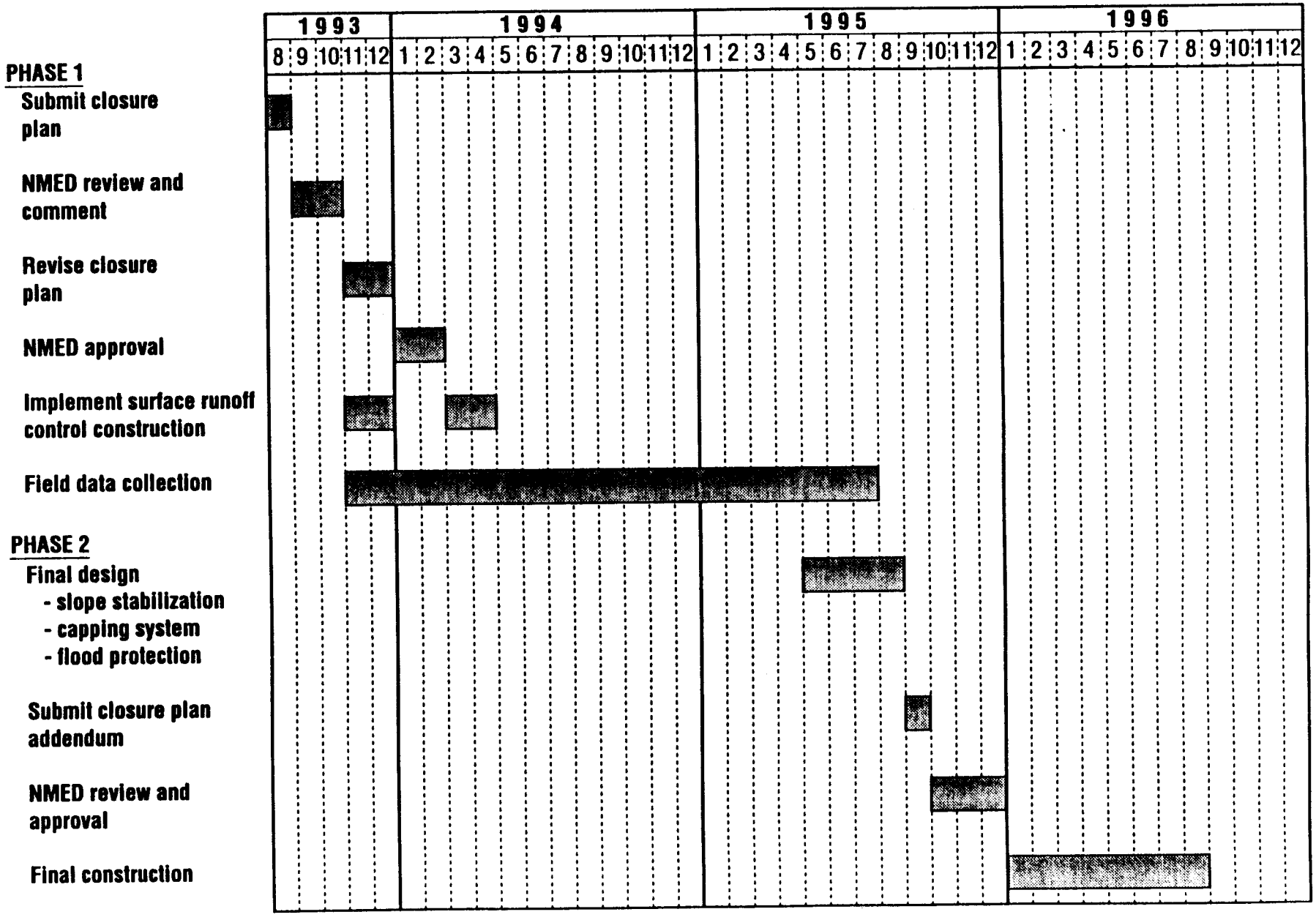


Figure 4-7. Phased construction schedule for the MDA P closure plan implem

5.0 Post-Closure Care

Upon completion of the closure activities outlined in Section 4.0, the Laboratory will conduct post-closure inspection, maintenance, and monitoring activities as described herein. Post-closure surveillance for MDA P is scheduled for a period of 30 years, as required by 40 CFR 264.117(a)(1) [(NMHWMR-7, Past VI, Section 264.117 (a)(1)]. Post-closure will be conducted as specified in the post-closure permit.

5.1 Inspections

The purpose of site inspections is to verify the performance of the cover system, to identify any maintenance needs, and to monitor fluctuations in water quality and volume. The landfill area will be inspected monthly for the duration of the post-closure period. Inspection frequency may be reduced to once per quarter if the previous three-month period produces minimal cover system deterioration. All inspection activities will be documented.

General inspection of the landfill area will include the following:

- Cover integrity (vegetation, erosion, subsidence, etc.)
- Run-on/runoff control (drainage slope and channel conditions, etc.)
- Condition of survey benchmarks.
- Condition of monitoring wells (caps, locks, bumpers, etc.).

5.2 Maintenance

General maintenance activities of the landfill site will include the following:

- Maintenance of established benchmarks near the closure area.
- Addition of soil (or riprap) to eroded areas.
- Maintenance of the asphalt-lined drainage ditch, including cleanup of accumulated debris and sediments that may block flow of run-on/runoff water.
- Re-vegetation of bare areas exposed due to erosion or construction.

Documented inspections will serve to identify areas requiring additional, specific maintenance.

5.3 Monitoring

The Laboratory has determined that the groundwater monitoring requirements under 40 CFR Part 264 Subpart F (NMHWMR-7, Part VI, Section 264 Subpart F) are waived for the site as allowed under 40 CFR 264.90 (c) [NMHWMR-7, Part VI, Section 264.90(c)]. This determination has been made based on the demonstrated absence of groundwater in sufficient quantities to sample in monitoring wells installed around MDA P. Subsection 2.6 of this plan describes details about the unsuccessful efforts to obtain groundwater samples from these monitoring wells.

Post-closure monitoring will include sampling of neutron moisture access wells (for moisture content versus depth) as described in Phase 1 sampling, Subsection 4.1.4. This monitoring will continue on a quarterly basis, for a period of one year following final closure. If only insignificant fluctuations in moisture content are reported during this one year period, moisture monitoring will be reduced to once a year. Post-closure monitoring of the Cañon de Valle stream water will also be conducted at least once per year at locations determined to provide the most information based on Phase 1 results. Details of the post-closure stream monitoring will be proposed in the addendum to this closure plan. This monitoring will allow ongoing evaluation of the effectiveness of final closure. After five years of stream water monitoring, the need for continued stream monitoring will be evaluated based on an evaluation of the post-closure monitoring data.

6.0 Cost Estimates

Cost estimates for closure activities and post-closure care are not required because federal facilities are exempt from the requirements outlined in Subpart H - Financial Requirements of 40 CFR 265.140 (c) [NMHWMR-7, Part VI, Section 265.140 (c)].

7.0 Other Closure Requirements

7.1 Financial Assurance

Documentation of financial assurance for closure activities and post-closure care is not required because federal facilities are exempt from the requirements outlined in Subpart H - Financial Requirements of 40 CFR 264.140 (c) [NMHWMR-7, Part VI, Section 264.140(c)].

7.2 Contact Person

Upon approval of this closure plan, the NMED and the Laboratory will communicate in writing with the respective contact person(s) to coordinate activities and communications between the parties under the plan. NMED and the Laboratory will provide timely written notification of any changes in the designation of contact persons during the term of this plan. The Laboratory will provide a minimum of ten days advance notice to the NMED through the NMED contact person(s), of any construction, sampling, or other activities.

7.3 Facility Access and Cooperation

The Laboratory will provide reasonable access to its facility upon request to authorized representatives of the NMED for the purpose of monitoring, sampling, and observing activities carried out under this plan. NMED representatives shall comply with established Laboratory safety and security practices.

The Laboratory and the NMED representative will cooperate to the fullest extent possible in the reporting and exchange of data developed under this plan. Copies in the Laboratory's possession of sampling results and analyses and other relevant technical data generated by the parties or their agents or contractors under this plan, including raw data, field notes, laboratory bench sheets, and reports will be exchanged as soon as practicable. If the Laboratory contracts with an

analytical laboratory to perform work and the State of New Mexico requests from the Laboratory copies of raw data, field notes, or laboratory bench sheets generated for the Laboratory, the Laboratory shall indicate that it has no objection to such documents being provided to the State.

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Closure and Post-Closure Plan

for

Material Disposal Area P (MDA P)

Los Alamos National Laboratory

Volume 2 of 2

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30 August 1993

VOLUME 2

APPENDICES

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Appendix B	Final Data Report of Laboratory Analyses of Soil Hydraulic Properties of Welded Tuffs at Los Alamos National Laboratory
Appendix C	A Hydrologic Modeling Study of Water Balance Relationships at the Area P Landfill in Los Alamos, New Mexico
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Appendix E	Focused Feasibility Study for Area P Landfill
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APPENDIX A

Appendix D: Geology and In-Situ Moisture Content of Technical Area 16 Area P.

Fred Brown

(extracted from Brown et al., 1987)

I. REGIONAL GEOLOGY

The regional geology of Los Alamos has been previously reported in detail (i.e., Smith and Bailey, 1966; Purtymun, 1974; Gardner and Goff, 1986). In summary, Los Alamos National Laboratory is located on the eastern flank of the Jemez Mountains, an area dominated by volcanic deposits associated with the formation and collapse of the Valle and Toledo Calderas. Eruptive activity culminated with the deposition of a large volume (about 400 km^3) of Quaternary Bandelier Tuff, a rhyolitic tuff ranging in thickness from 30 to 1000 ft. The Bandelier Tuff is composed of a series of ashfall and ashflow tuffs (ignimbrites) unconformably resting on Chino Mesa Basalt and Puye Conglomerate of the Santa Fe Group. Depth to the main aquifer in the vicinity of Area P is about 1230 ft (Purtymun, 1984). See Figure D1.

Deposits of Bandelier Tuff form broad plateaus that encircle the Jemez Mountains and dip gently away from the Valle

Caldera. The plateau on the eastern side of the Jemez Mountains, the Pajarito Plateau, consists of a series of east to southeast trending mesas separated by deeply incised canyons. The Bandelier Tuff itself consists of upper (Tshirege) and lower (Otowi) members, each containing a prominent ashfall bed at the base. Generally, the upper (Tshirege) member is the more densely welded of the two, and welding tends to increase with proximity to caldera sources (Bailey et al. 1969; Gardner et al., 1986).

The Bandelier Tuff dips 2 to 5 degrees towards the east. Four fault zones have been recognized in the Pajarito Plateau: the Pajarito, Water Canyon, Guaje Mt., and Rendija Canyon Fault Zones (Dransfield and Gardner, 1985). The Water Canyon Fault Zone, which extends through TA-16, trends roughly north to northeast, with about 30 to 100 ft of down-to-the-east displacement. Approximately 10 to 15 ft of displacement can be seen in the subsurface adjacent to Area-P, with little-or-no surface expression apparent.

II. GEOLOGY OF AREA P

Area P lies near the eastern margin of the Jemez Mountains, in the saddle of a short east-west trending mesa. The Water Canyon Fault Zone cuts through the tuff approximately 500 ft to the east. To the north the Canon de Valle has cut through the fault scarp, draining an area on the west of the Sierra

de los Valles flanks. To the south is a small unnamed canyon containing intermittent discharge from local outfalls. The main technical centers of TA-16 are located west of Area P (See Figure D2).

The mesa is capped by approximately 800 ft of Bandelier Tuff (Purtymun, 1968). Five distinct units, composed of groups of ashflows, have been recognized in the Tshirege Member of the Bandelier Tuff (Griggs, 1964; Smith and Bailey, 1966), of which two units were encountered during drilling operations at Area P (Brown, 1987). In addition, scattered outcrops of El Cajete Pumice occur in the area.

In order to establish the subsurface geology of Area P a series of 17 boreholes (numbered P-0 through P-16) was drilled in the summer of 1987. Drilling was done with a CME-55 rotary drilling rig and four-inch conventional auger. Continuous auger cuttings were retrieved for moisture analysis, and one set of continuous core was recovered using six-inch hollow stem auger and split spoon core barrels.

Borehole logging of lithology was done on the basis of four characteristics: (1) color (Goddard et al., 1984), (2) degree of welding, (3) shape and abundance of pumice lapilli, and (4) distribution of lithic fragments. Four distinct types of welding were recognized during drilling operations:

1. Non-welded: high porosity, low cohesion of glassy fragments and crumbly texture. In core samples this can be recognized by disaggregation and little or no flattening of pumice lapilli.

2. Moderately welded: less porosity, moderate cohesion, brittle texture and slight deformation of glassy fragments. In core samples this texture crumbles easily in the hand and contains some noticeably flattened pumice lapilli.

3. Welded: low porosity, good cohesion, brittle texture and noticeable deformation of glassy fragments. This texture normally requires a hammer to break, and the majority of pumice fragments are noticeably flattened.

4. Densely welded: texture noticeably impedes or halts drilling; little or no penetration; poor core recovery.

Two major lithologic units have been recognized at Area P (person. comm., W. Purtymun, 1987). Unit 3, the uppermost unit encountered during drilling operations, consists of four individual ashflows that appear to have cooled as a single unit. These ashflows are herein designated as Subunits 3a, 3b, 3c and 3d (bottom to top). Unit 3 rests conformably above Unit 2, the lowermost unit encountered. In

the vicinity of Area P dip is negligible, and the units are essentially horizontal and of uniform thickness.

Subunit 3a consists of a welded dark yellowish brown tuff, with rare pumice lapilli (slightly flattened), and abundant pebble sized red porphyritic latite and grey rhyolite lithic fragments. The contact between Subunit 3a and Unit 2 tends to be densely welded. East of the Water Canyon Fault this unit appears to be non-welded.

Subunit 3b consists of a welded pale yellowish brown tuff, with common grey and red pumice lapilli, (noticeably flattened), and rare pebble sized rhyolite lithic fragments. This unit weathers to a dark brown, and contains abundant clayey pumice lapilli to the north-west.

Subunit 3c consists of a moderately welded brownish grey to yellowish brown tuff, with common grey pumice lapilli (noticeably flattened), and rare pebble sized rhyolite lithic fragments. Clay filled vertical fractures are common throughout this subunit. The contact between 3c and 3d tends to be densely welded.

Subunit 3d outcrops along the higher rim of the saddle, and consists of a moderately welded yellowish brown tuff, with rare pebble sized rhyolite lithic fragments and common

grey pumice lapilli. Subunit 3d is overlain by scattered deposits of El Cajete Pumice.

Locally, Unit 2 consists of a welded to densely welded tuff, light grey to pinkish grey in color, with common pumice lapilli and pebble sized rhyolite fragments. Due to dense welding the drill bit was only able to penetrate the upper 5 to 10 ft of Unit 2. See Figure D3.

III. IN-SITU MOISTURE CONTENT

Hydrologic characteristics of tuff depend primarily on the degree of welding, with porosity and hydraulic conductivity decreasing as the degree of welding increases. At Los Alamos, saturated hydraulic conductivity for a moderately welded tuff ranges from 0.1 to 1.7 ft/day, and for a welded tuff ranges from 0.009 to 0.26 ft/day (Abeele et al., 1981). Samples of tuff recovered during drilling operations at Area P were not saturated.

Gravimetric moisture determinations were conducted to obtain a direct measurement of in-situ water content of the tuff. Samples were taken from drill cuttings every 5 or 10 ft, and moisture determinations were made by weighing samples immediately after collection and after oven-drying 24 hrs at 105 degrees C.

Although gravimetric moisture determinations are relatively easy to perform, care must be taken to insure that the heat produced by drilling does not bias the samples collected. In the few cases where drill cuttings were noticeably warm to the touch, or water vapor was noticed coming from the borehole, samples were not collected for analysis. Care was also taken to maintain the drying oven at 105 degrees C to ensure that no structural water was driven off.

Table D1 provides a summary of gravimetric data collected for Unit 3, and indicates a low overall moisture content for Area P. Although a range of 1.9 to 24.7% is considered low, this value slightly exceeds the gravimetric moisture content determined for technical areas further to the east (5-11% for TA-33, Abrahams 1963; 2-20% for TA-54; Kearl et al., 1986). This increase may be due to increased rainfall at TA-16 caused by orographic effects adjacent to the Jemez Mountains.

Unit	Mean (%)	STD	Range (%)
3d	5.2	3.6	2.2-17.7
3c	6.1	3.5	1.9-24.7
3b	5.7	2.1	2.3-11.4
3a	3.8	1.4	2.3-5.8
Total Unit	5.8	3.0	1.9-24.7

Table D1: Average Gravimetric Moisture Content. STD = Standard Deviation.

The energy relationship with moisture content for the Tshirege Member of the Bandelier Tuff was worked out for volumetric moisture content by Abrahams (1963). Volumetric values can be converted to gravimetric values by using the average bulk density of the tuff. Repeated neutron and gamma probe calibration runs have established an average bulk density for the Tshirege Member of 1.4 g/cm^3. In addition, the density of ten random samples was obtained after drying by weighing crushed tuff of a known volume. Average density for the ten samples was 1.47 g/cm^3, with a standard deviation of 0.12.

TA-16 Area P lies in the vadose zone of the Bandelier Tuff, a zone defined by Everett et al. (1984) as existing beneath the topsoil and above the water table, in which moisture in pore spaces coexists with air or in which geological materials are unsaturated. Based on the results of Abrahams (1963), saturation of the Tshirege Member of the Bandelier Tuff, and thus groundwater, occurs when gravimetric moisture content is about 29%. When moisture content is below 7% there is no movement of water; between 7 to 21% moisture is redistributed by diffusion; between 21 to 29% moisture distribution is by gravity and capillarity, and above 29% movement is by gravity drainage (Figure D4). From Table D1 it can be seen that the primary mechanism for moisture

distribution at Area P is diffusion. There is no evidence for the existence of groundwater at Area P.

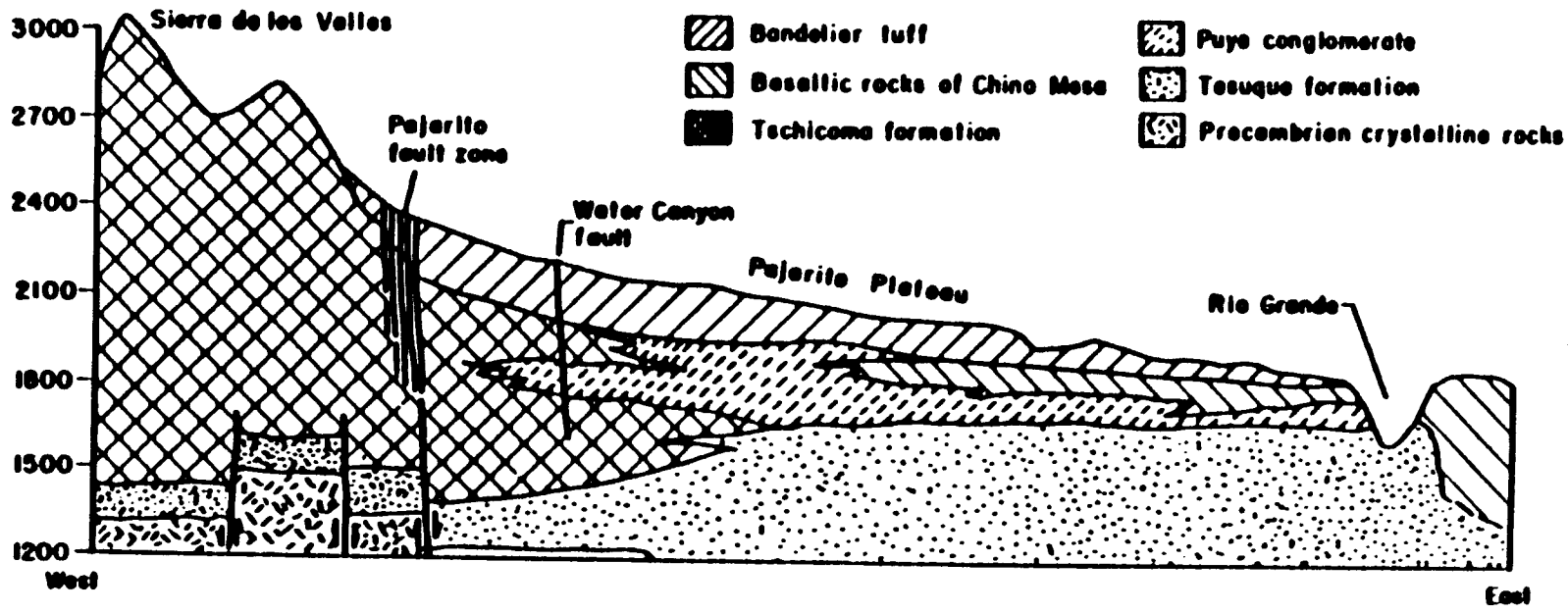


Figure D1. Geologic cross section through the Pajarito Plateau.

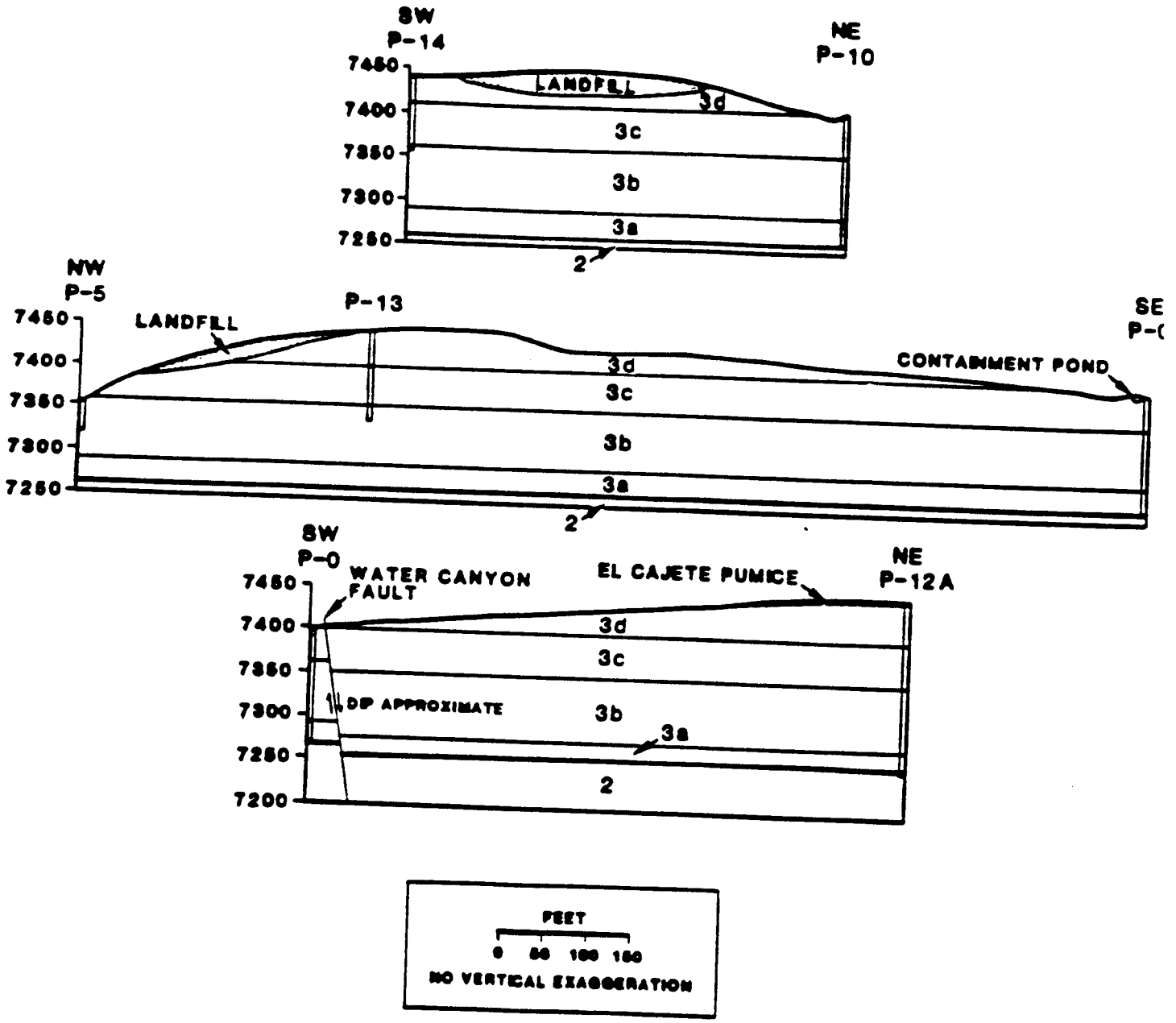


Figure D3. Geologic cross sections through Area P. Section lines are shown in Figure D2.

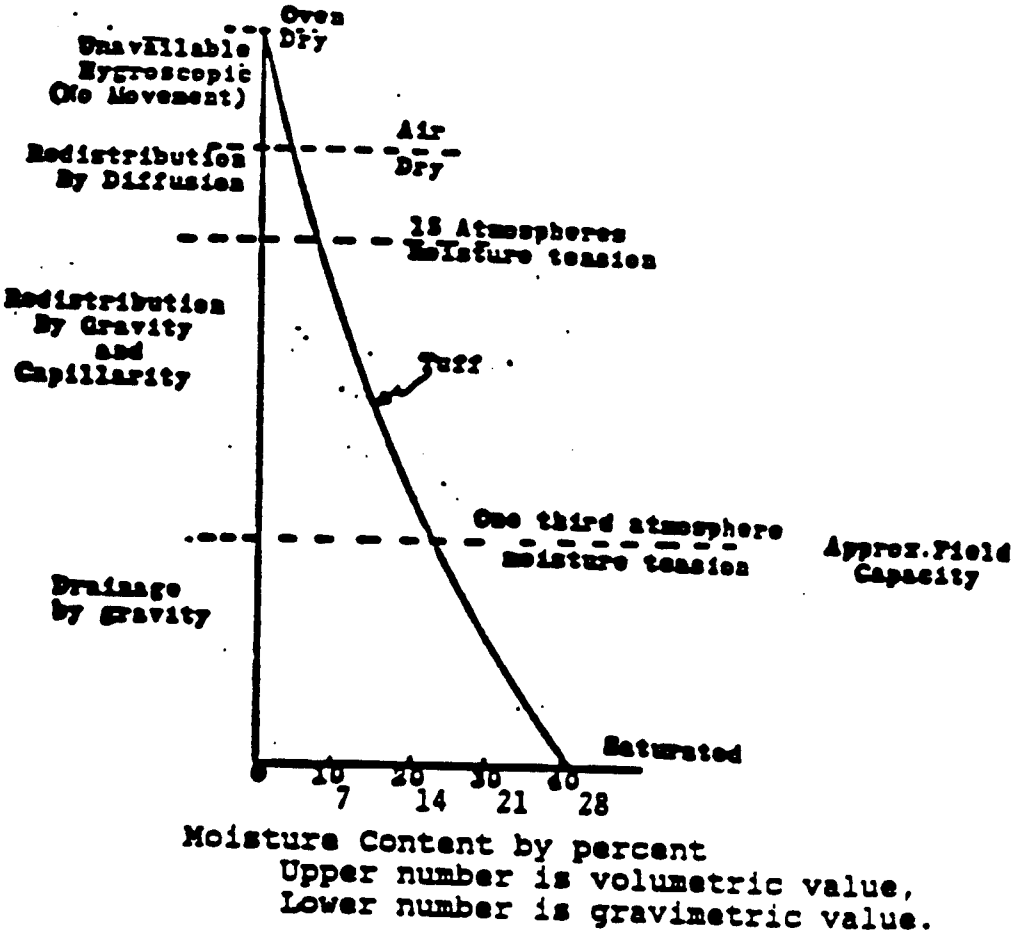
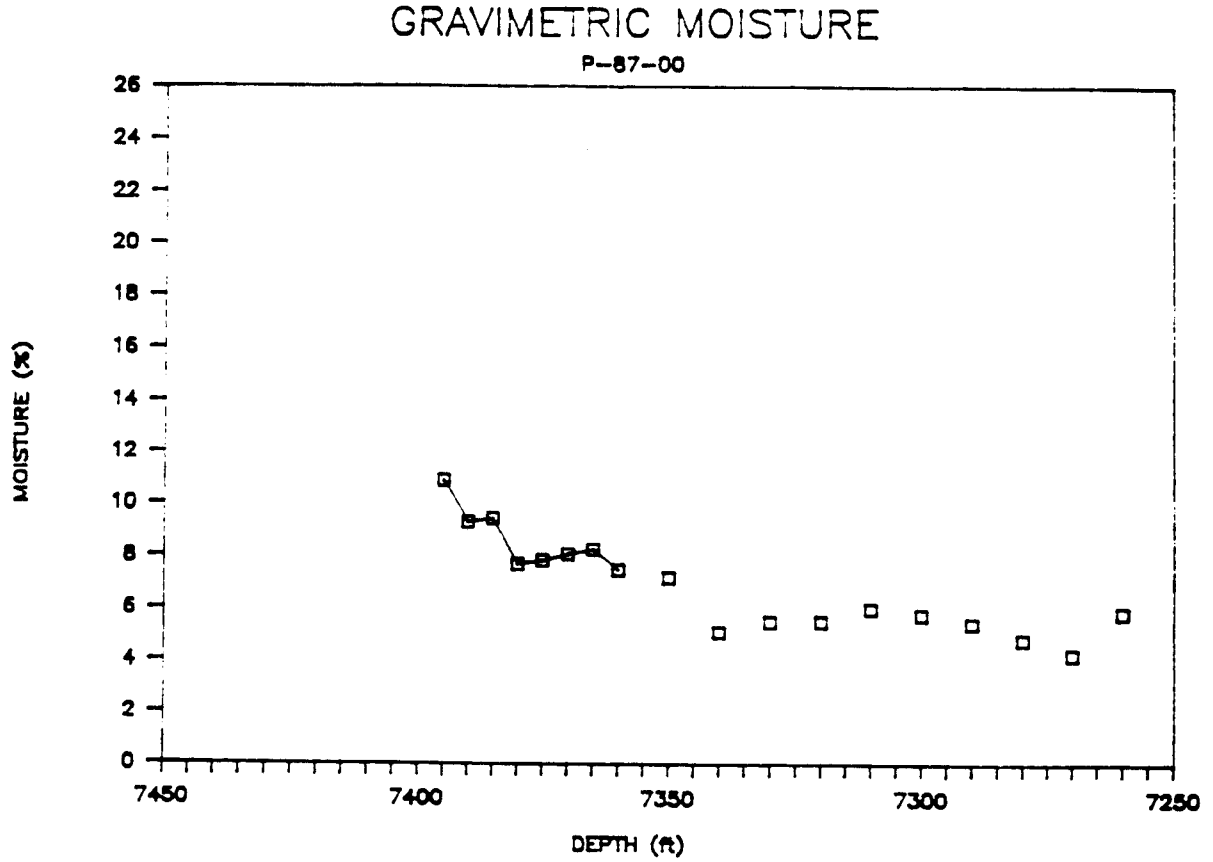
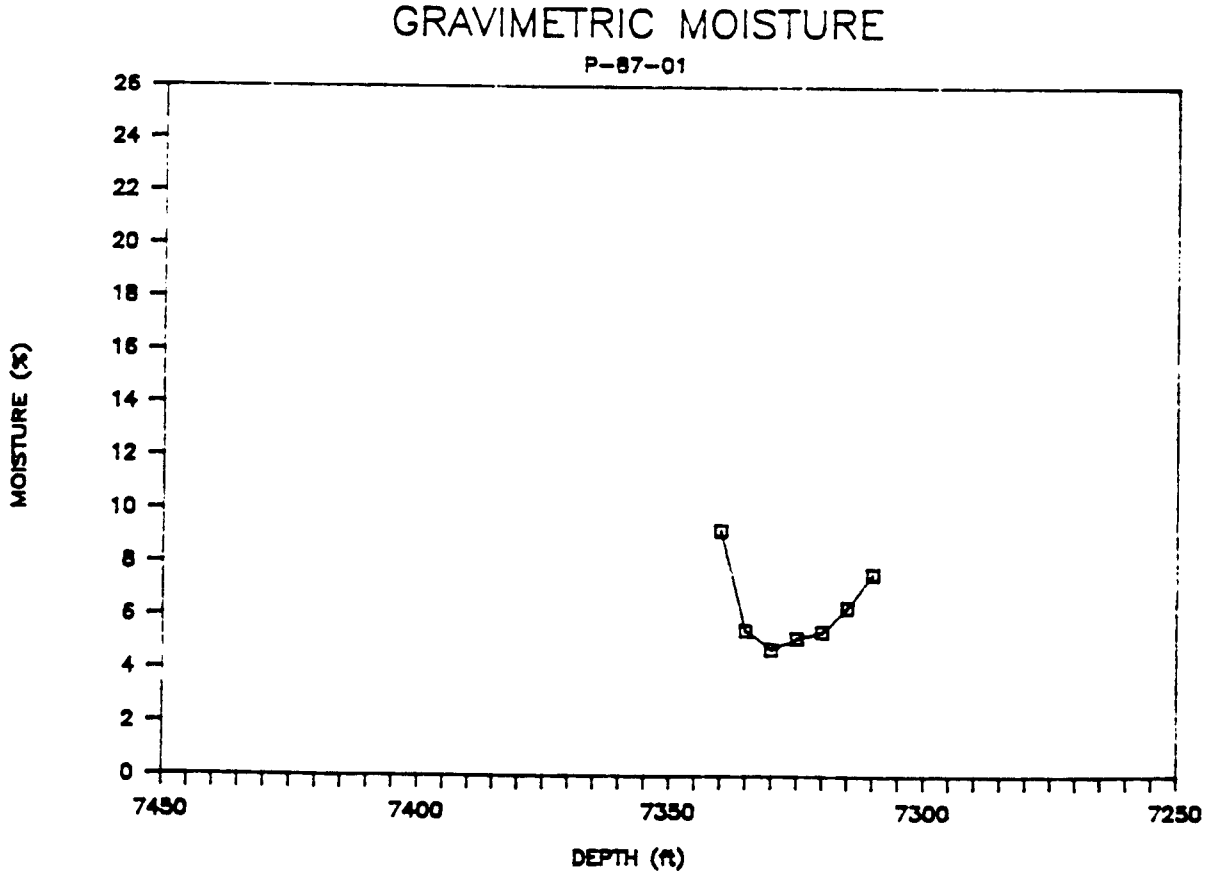
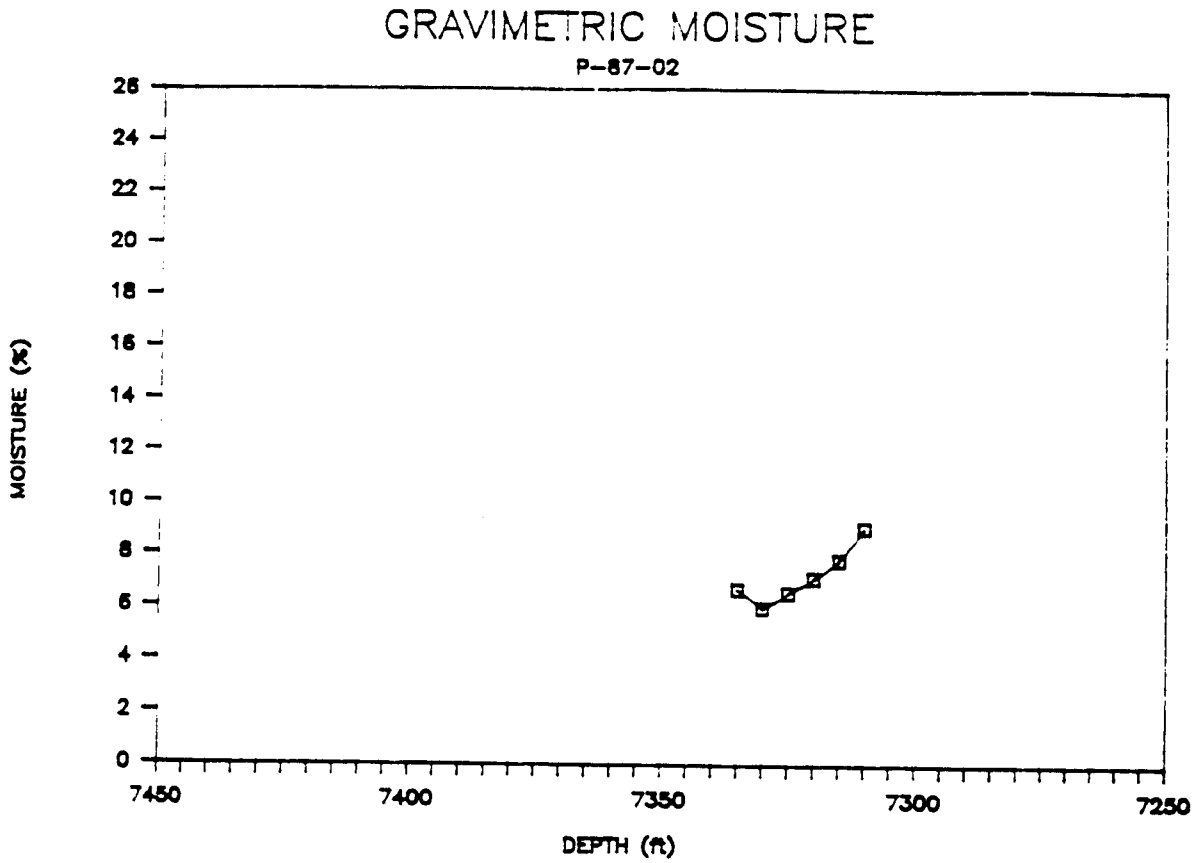
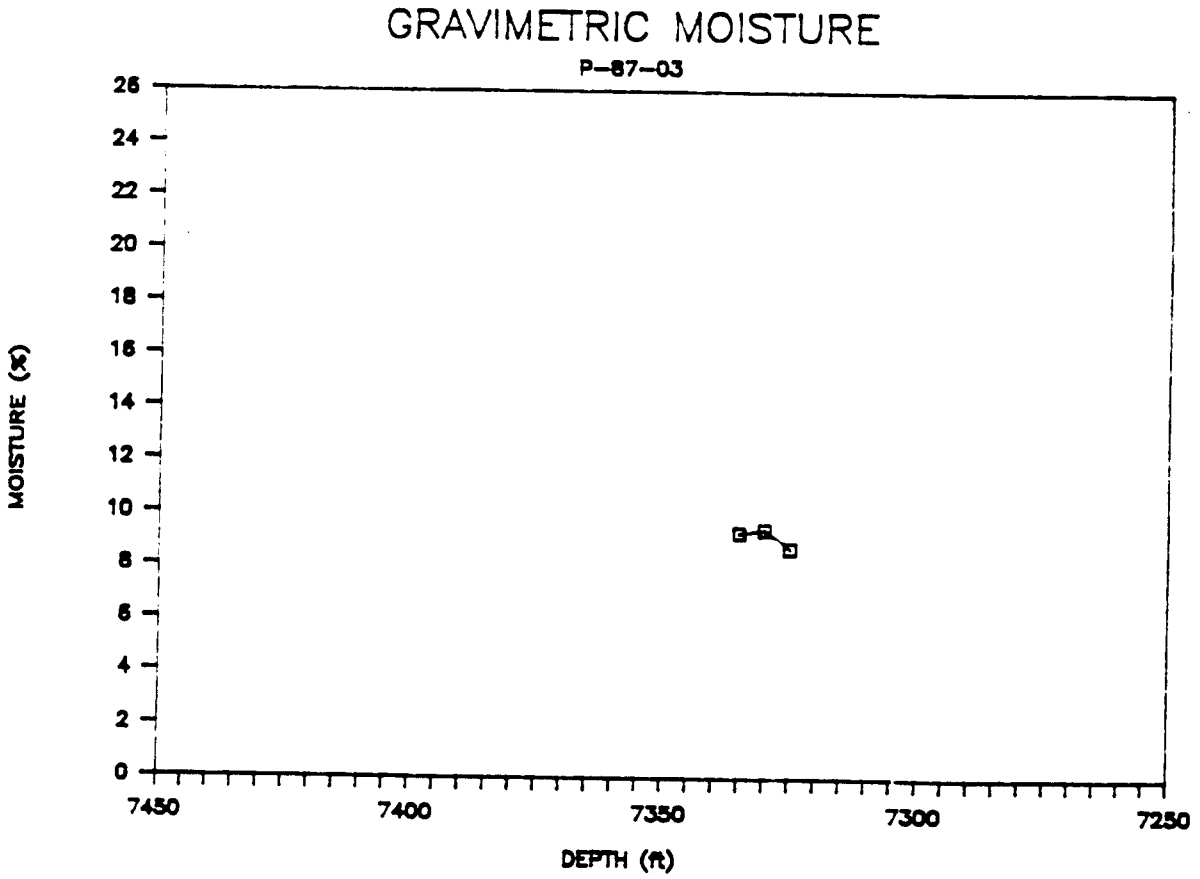


Figure D4. Energy relationship with moisture content of Bandelier Tuff (modified from Abrahams, 1963).


GRAVIMETRIC MOISTURE
P-87-00
MOISTURE (%)
26
24
22
20
18
16
14
12
10
8
6
4
2
0
7450
7400
7350
7300
7250
DEPTH (ft)


GRAVIMETRIC MOISTURE
P-87-01
MOISTURE (%)
26
24
22
20
18
16
14
12
10
8
6
4
2
0
7450
7400
7350
7300
7250
DEPTH (ft)


GRAVIMETRIC MOISTURE
P-87-02
MOISTURE (%)
26
24
22
20
18
16
14
12
10
8
6
4
2
0
7450
7400
7350
7300
7250
DEPTH (ft)


GRAVIMETRIC MOISTURE
P-87-03
MOISTURE (%)
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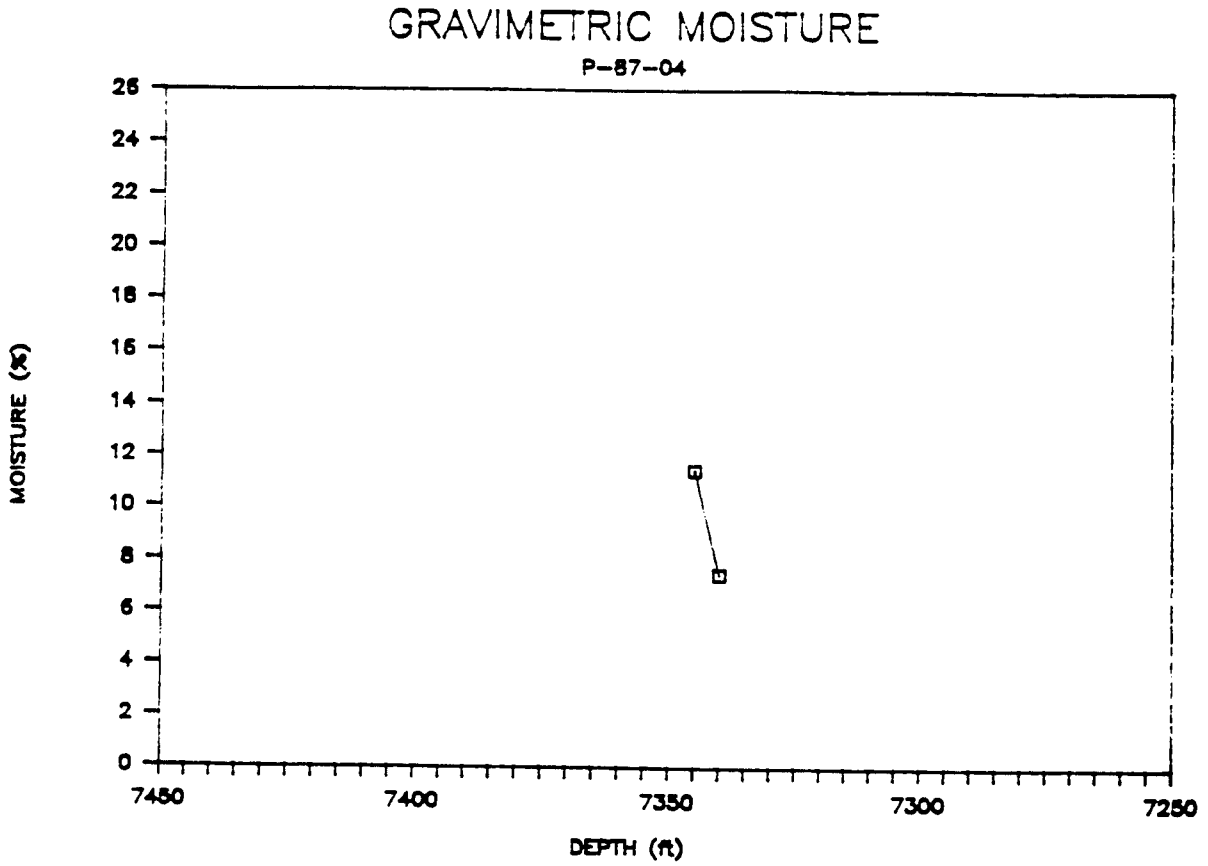
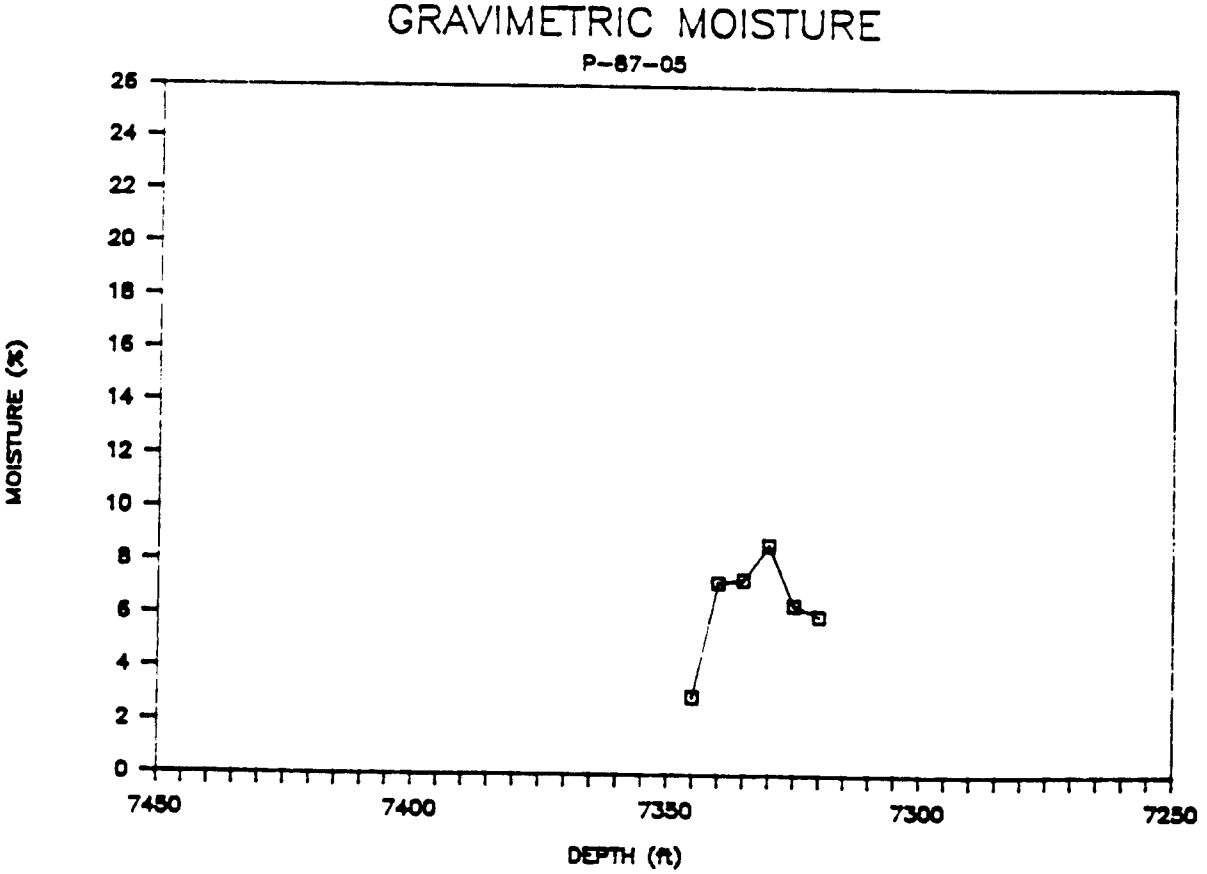
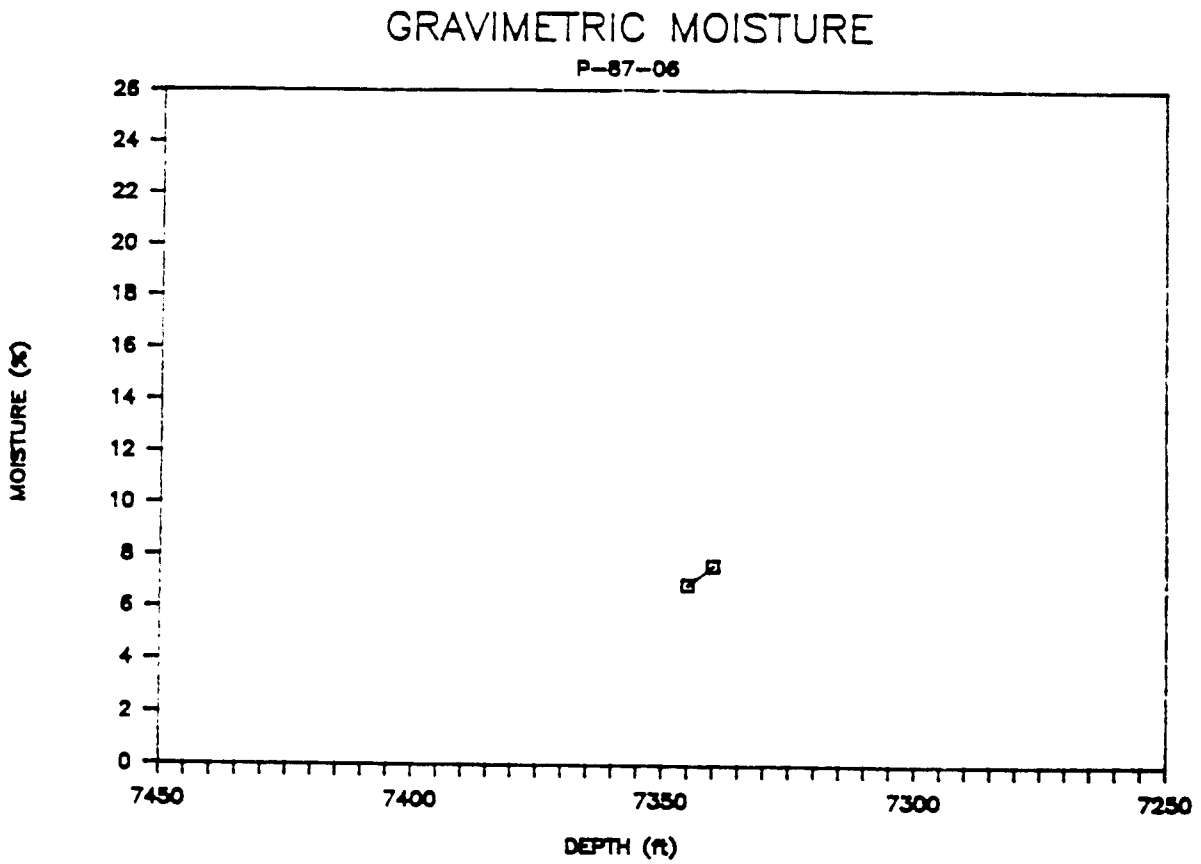
24
22
20
18
16
14
12
10
8
6
4
2
0
7450
7400
7350
7300
7250
DEPTH (ft)


GRAVIMETRIC MOISTURE
P-87-04
MOISTURE (%)
26
24
22
20
18
16
14
12
10
8
6
4
2
0
7450
7400
7350
7300
7250
DEPTH (ft)


GRAVIMETRIC MOISTURE
P-87-05
MOISTURE (%)
26
24
22
20
18
16
14
12
10
8
6
4
2
0
7450
7400
7350
7300
7250
DEPTH (ft)


GRAVIMETRIC MOISTURE
P-87-06
MOISTURE (%)
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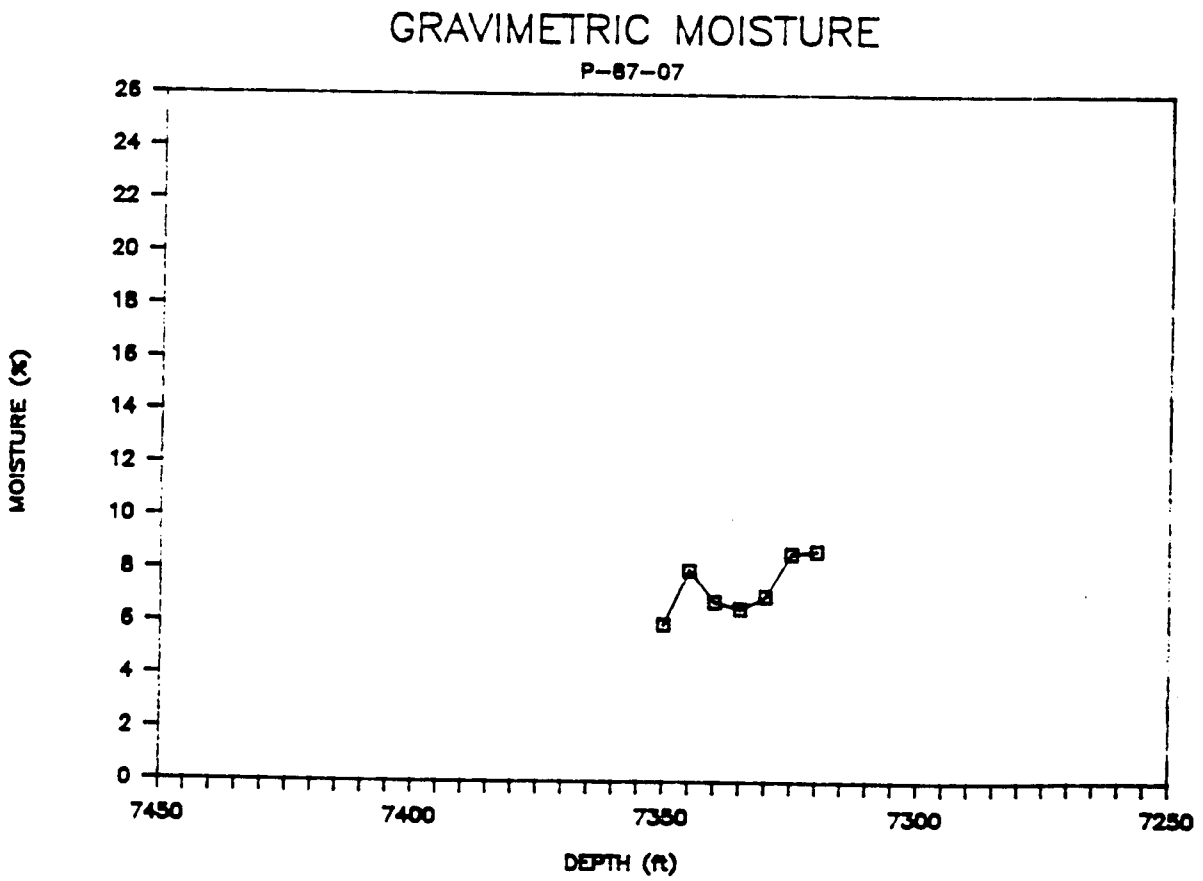
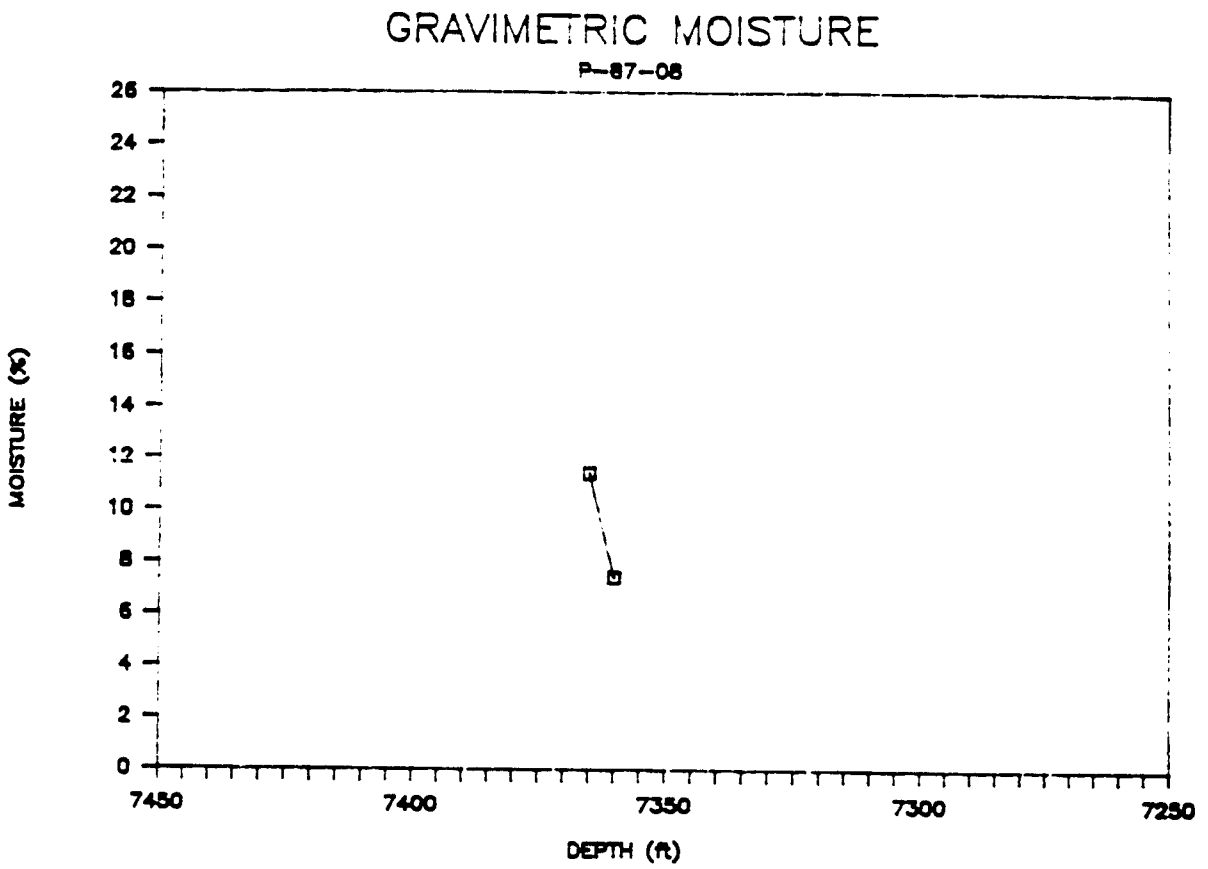
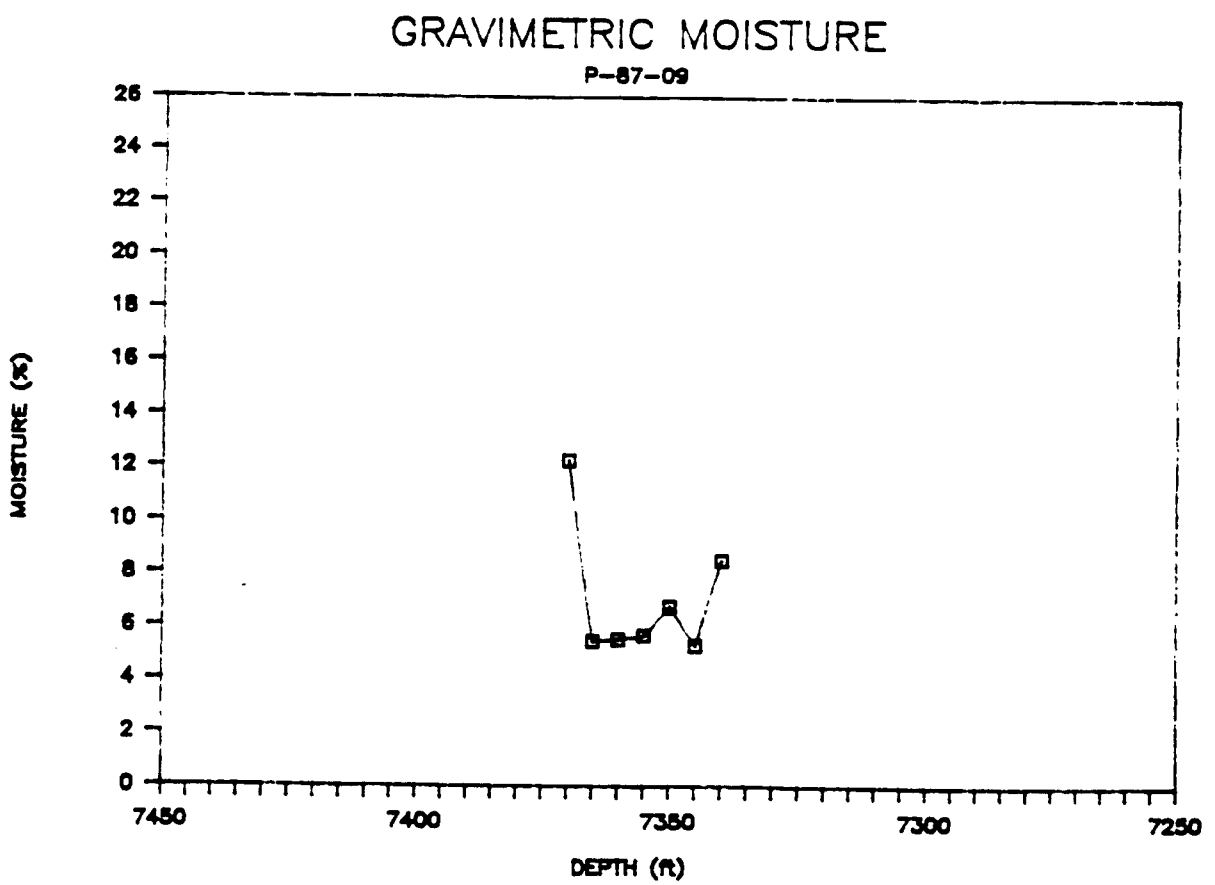
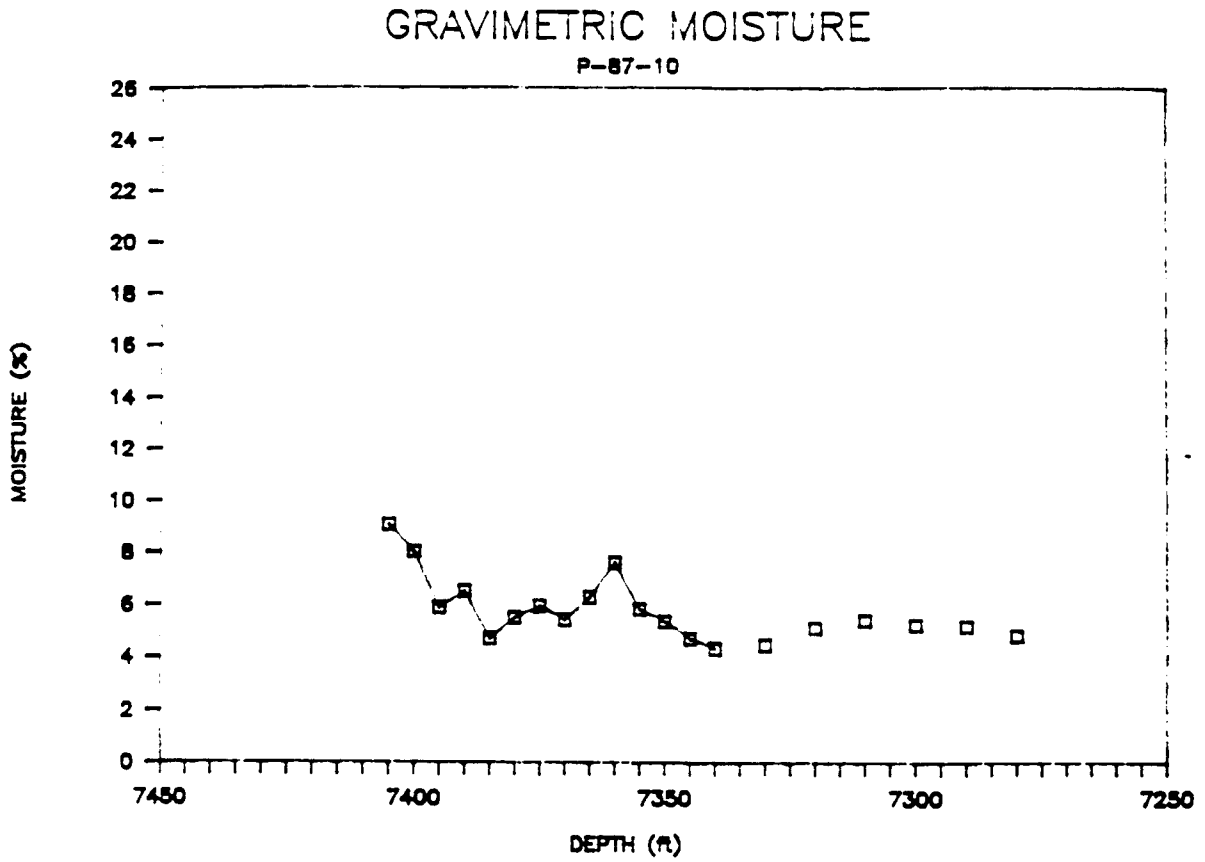
24
22
20
18
16
14
12
10
8
6
4
2
0
7450
7400
7350
7300
7250
DEPTH (ft)


GRAVIMETRIC MOISTURE
P-87-07
MOISTURE (%)
26
24
22
20
18
16
14
12
10
8
6
4
2
0
7450
7400
7350
7300
7250
DEPTH (ft)


GRAVIMETRIC MOISTURE
P-87-08
MOISTURE (%)
26
24
22
20
18
16
14
12
10
8
6
4
2
0
7450
7400
7350
7300
7250
DEPTH (ft)


GRAVIMETRIC MOISTURE
P-87-09
MOISTURE (%)
26
24
22
20
18
16
14
12
10
8
6
4
2
0
7450
7400
7350
7300
7250
DEPTH (ft)


GRAVIMETRIC MOISTURE
P-87-10
MOISTURE (%)
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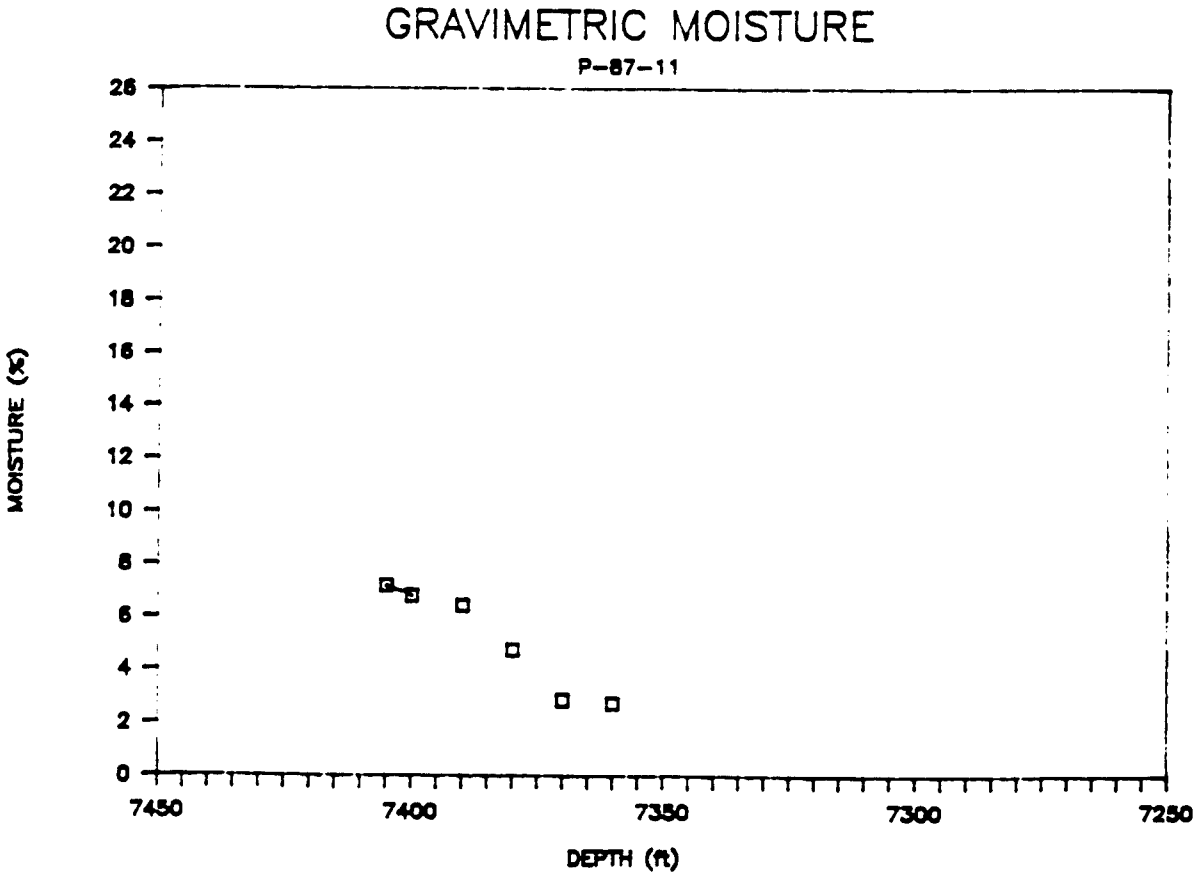
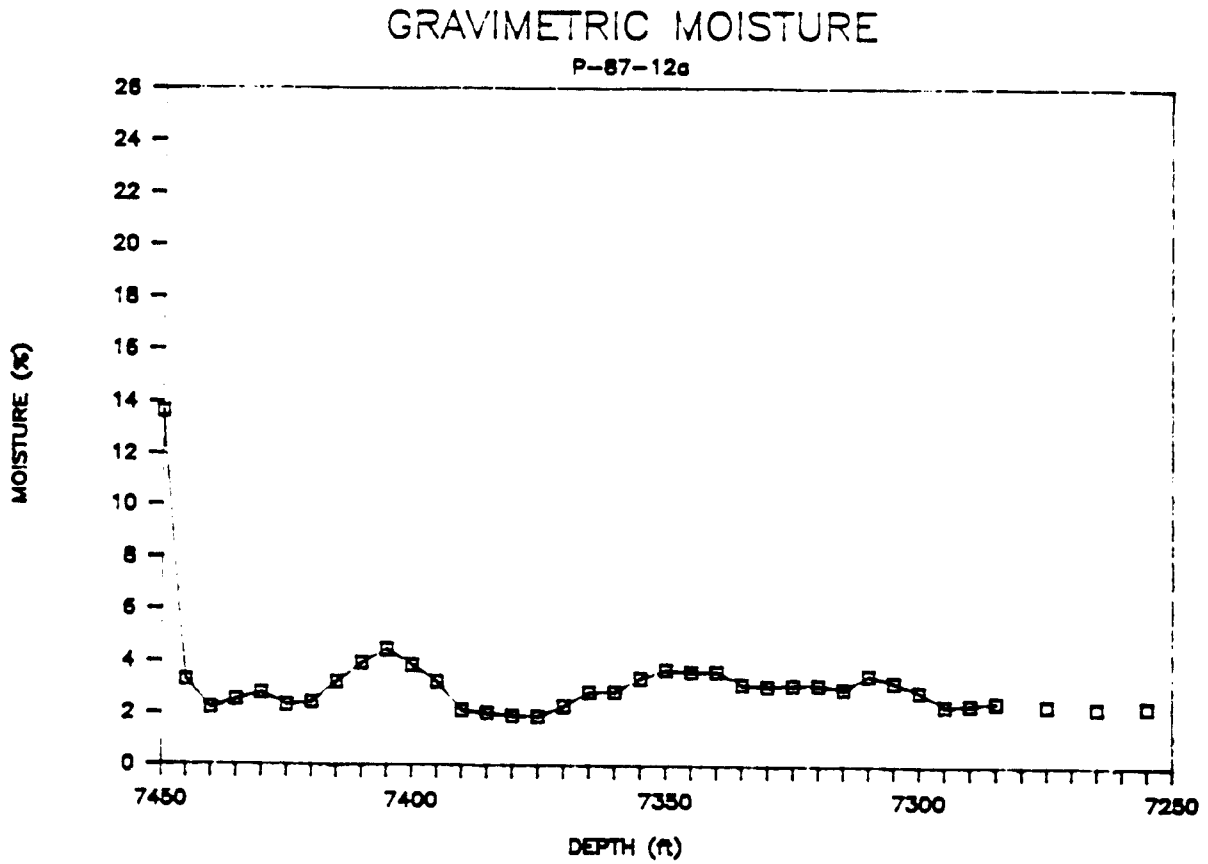
24
22
20
18
16
14
12
10
8
6
4
2
0
7450
7400
7350
7300
7250
DEPTH (ft)


GRAVIMETRIC MOISTURE
P-87-11
MOISTURE (%)
26
24
22
20
18
16
14
12
10
8
6
4
2
0
7450
7400
7350
7300
7250
DEPTH (ft)


GRAVIMETRIC MOISTURE
P-87-12a
MOISTURE (%)
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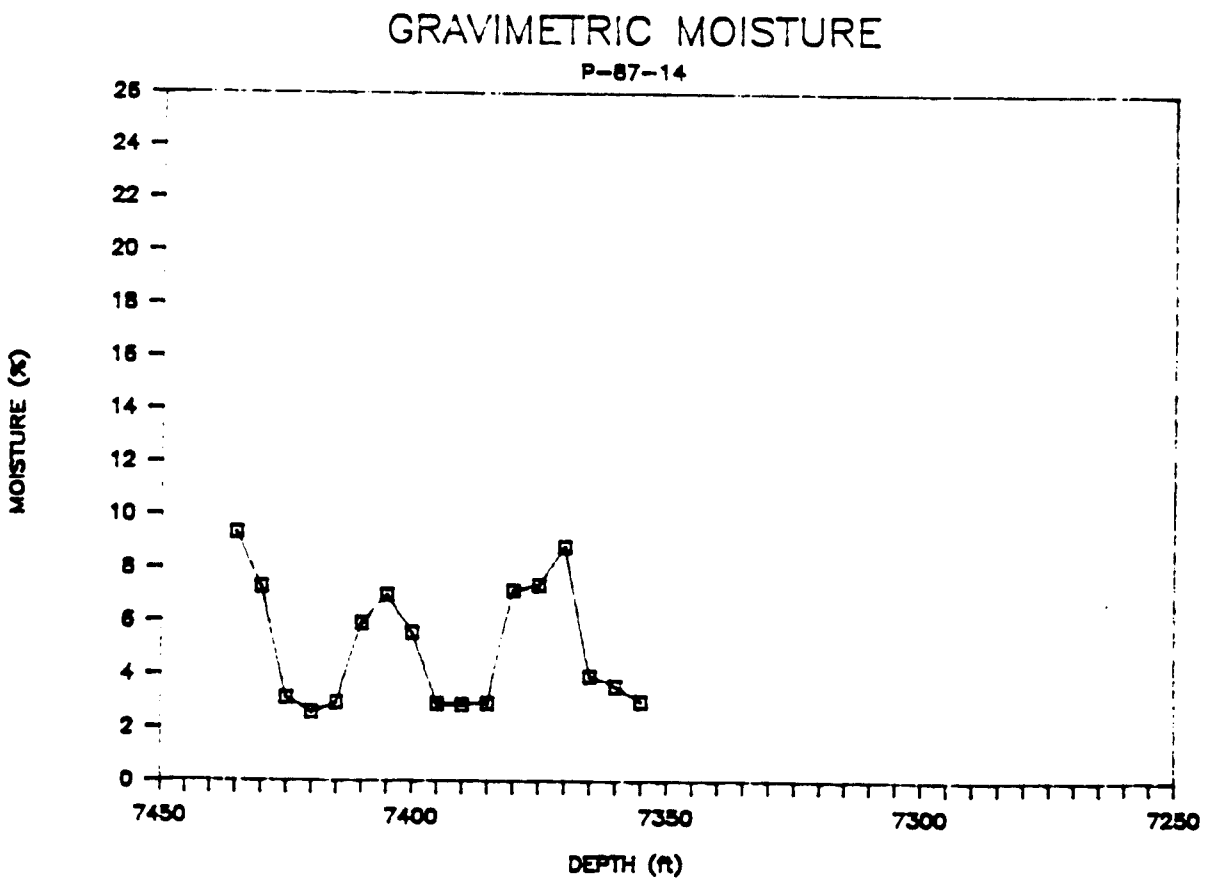
24
22
20
18
16
14
12
10
8
6
4
2
0
7450
7400
7350
7300
7250
DEPTH (ft)


GRAVIMETRIC MOISTURE
P-87-14
MOISTURE (%)
26
24
22
20
18
16
14
12
10
8
6
4
2
0
7450
7400
7350
7300
7250
DEPTH (ft)

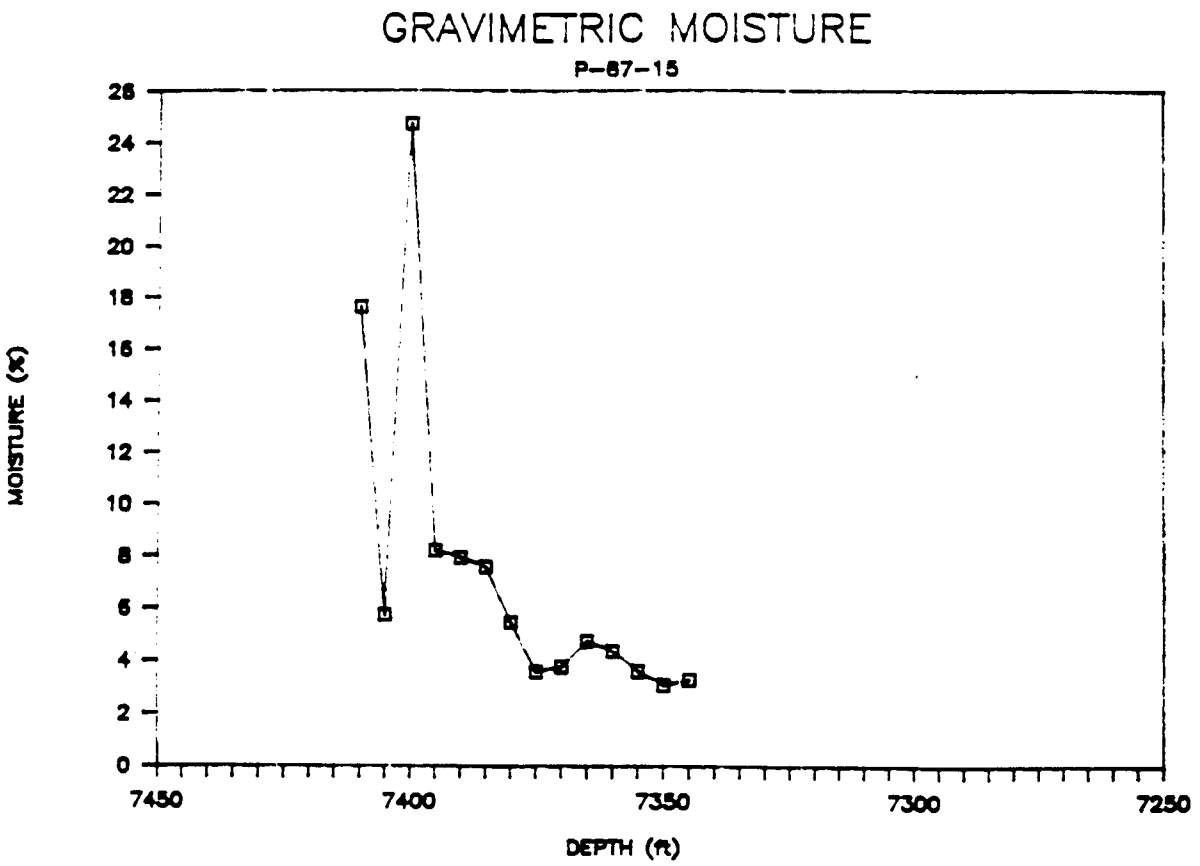

GRAVIMETRIC MOISTURE
P-87-15
MOISTURE (%)
0
2
4
6
8
10
12
14
16
18
20
22
24
26
7450
7400
7350
7300
7250
DEPTH (ft)

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TABLE D-3
TARGET VOLATILE AND SEMI-VOLATILE ORGANIC COMPOUND
INDENTIFICATION LIST FOR WELL P-16 CORE SAMPLES

Compound Name	CAS Number
Acetone	67641
Benzene	71432
Bromodichloromethane	75274
Bromoform	75252
Bromomethane (methyl bromide)	74839
2-Butanone (methyl ethyl ketone)	78933
Carbon Disulfide	75150
Carbon Tetrachloride	56235
Chlorobenzene	108907
Chloroethane	75003
Chloroform	67663
Chloromethane (methyl chloride)	74873
1,2-Dichlorobenzene	95501
1,3-Dichlorobenzene	541731
1,4-Dichlorobenzene	106467
1,1-Dichloroethane (ethylidene dichloride)	75343
1,2-Dichloroethane	107062
1,2-Dichloroethene	540590
1,1-Dichloroethylene	75354
1,2-Dichloropropane (propylene dichloride)	78875
cis-1,3-Dichloropropene	10061015
trans-1,3-Dichloropropene	10061026
Ethyl Benzene	100414
Naphthalene	91023
Methylene Chloride	75092
4-Methyl-2-Pentanone	108101
Styrene	100425
1,1,2,2-Tetrachloroethane	79345
Tetrachloroethene	127184
Toluene	108883
1,1,2-Trichloroethane	79005
1,1,1-Trichloroethane (methyl chloroform)	71556
Trichloroethene	79016
Trichloroflouromethane	75694
Vinyl Acetate	108054
Vinyl Chloride (chloroethene)	75014
Xylenes	133027

NOTE: All of the above compounds were at concentrations below GC/MS detection limits. Sample date was 9-10-87.

TABLE D-2
DATA FROM DRILLING CORES RECOVERED AT WELL P-16A

RESULTS OF HEAVY METALS ANALYSES:

EPA EXTRACT CONCENTRATIONS (in milligrams/liter)

PARAMETER	CORE DEPTHS (in feet) 10	50	55	60	81	UNCERTANITY (mg/l)
Arsenic	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05
Barium	<0.05	0.07	0.09	0.09	<0.05	<0.05
Cadmium	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Chromium	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05
Lead	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05
Mercury	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02
Selenium	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Silver	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05

VOLUMETRIC MOISTURE CONTENT OF CORE LOGS RECOVERED FROM WELL P-16A

Depth	% Moisture
0.5 ft	5.6 %
5.5 ft	16.0 %
10.5 ft	10.1 %
15.5 ft	13.8 %
20.5 ft	13.1 %

AVERAGE GRAVIMETRIC MOISTURE CONTENT (%) FROM FIFTEEN DIFFERENT CORE LOGS AT TA-16 AREA P LANDFILL

GEOLOGIC UNIT	MEAN MOISTURE (%)	STD	RANGE (%)
3 d	5.2	3.6	2.2 - 17.7
3 c	6.1	3.5	1.9 - 24.7
3 b	5.7	2.1	2.3 - 11.4
3 a	3.8	1.4	2.3 - 5.8
Total for Unit	5.8	3.0	1.9 - 24.7

Notes: (1) See Figure D-3 for Geologic Unit Cross Section
(2) STD = standard deviation.

TABLE D-4. RECONNAISSANCE WATER QUALITY AND SEDIMENT SAMPLING
LOS ALAMOS NATIONAL LABORATORY - TA-16 AREA P LANDFILL
SEE ATTACHED MAP FOR SAMPLE LOCATIONS

STATION ID : TA-16 AREA P - CANON DE VALLE
SAMPLE TYPE: SURFACE WATER SAMPLES - CANON DE VALLE
SAMPLE DATE: DECEMBER 7, 1987
LABORATORY : LANL HSE-9 LABORATORY (ANALYSES ON 12-15-87)

	PARAMETER CONCENTRATION ===> (all units in mg/l)							
SAMPLE NO.	As	Ba	Cd	Cr	Pb	Hg	Se	Ag
57	< 0.05	3.50	< 0.01	< 0.05	< 0.05	< 0.001	< 0.01	< 0.05
59	< 0.05	3.50	< 0.01	< 0.05	< 0.05	< 0.001	< 0.01	< 0.05
63	< 0.05	3.50	< 0.01	< 0.05	< 0.05	< 0.001	< 0.01	< 0.05
64	< 0.05	3.30	< 0.01	< 0.05	< 0.05	< 0.001	< 0.01	< 0.05
70	< 0.05	.50	< 0.01	< 0.05	< 0.05	< 0.001	< 0.01	< 0.05
UNCERTAINITY	0.05	0.05	0.01	0.05	0.05	0.001	0.01	0.05

SAMPLE NO.	SAMPLE DESCRIPTION ==>
57	DOWNSTREAM SURFACE WATER SAMPLE
59	SURFACE WATER NORTH OF LANDFILL
63	SURFACE WATER NORTH OF LANDFILL
64	UPSTREAM SURFACE WATER SAMPLE
70	SNOWMELT IN INFLOW DRAINAGE CHANNEL

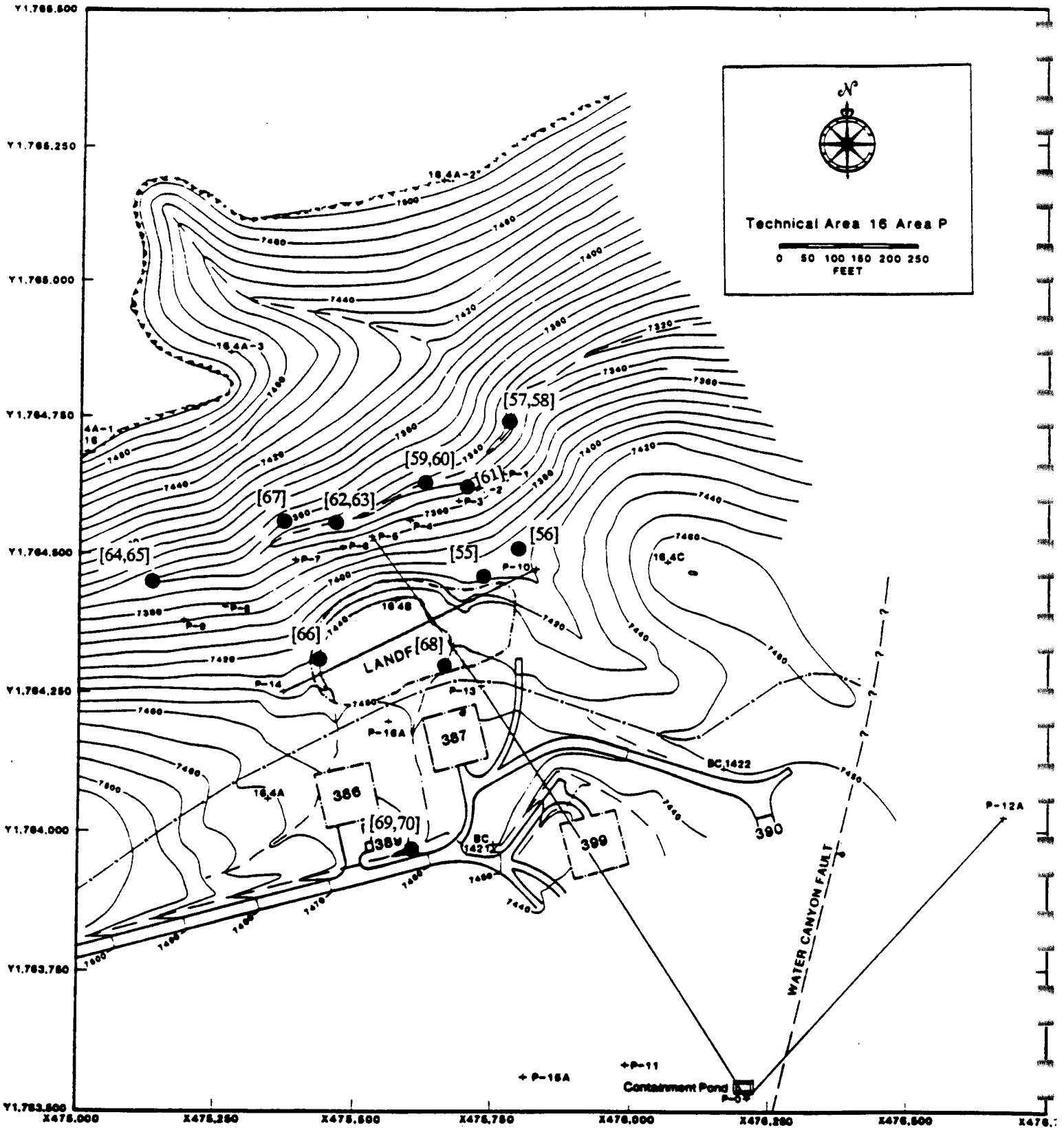
TABLE D-4. RECONNAISSANCE WATER QUALITY AND SEDIMENT SAMPLING
LOS ALAMOS NATIONAL LABORATORY - TA-16 AREA P LANDFILL
SEE ATTACHED MAP FOR SAMPLE LOCATIONS

STATION ID : TA-16 AREA P - CANON DE VALLE
SAMPLE TYPE: STREAM SEDIMENTS & SOIL SAMPLES - EPA WATER EXTRACT
SAMPLE DATE: DECEMBER 7, 1987
LABORATORY : LANL HSE-9 LABORATORY (ANALYSES ON 12-15-87)

PARAMETER CONCENTRATION ===> (all units in mg/l)

SAMPLE NO.	As	Ba	Cd	Cr	Pb	Hg	Se	Ag
55	< 0.05	.60	< 0.01	< 0.05	< 0.05	< 0.001	< 0.01	< 0.05
56	< 0.05	.50	< 0.01	< 0.05	< 0.05	< 0.001	< 0.01	< 0.05
58	< 0.05	.50	< 0.01	< 0.05	< 0.05	< 0.001	< 0.01	< 0.05
60	< 0.05	2.70	< 0.01	< 0.05	< 0.05	< 0.001	< 0.01	< 0.05
61	< 0.05	.50	< 0.01	< 0.05	< 0.05	< 0.001	< 0.01	< 0.05
62	< 0.05	2.10	< 0.01	< 0.05	< 0.05	< 0.001	< 0.01	< 0.05
65	< 0.05	2.70	< 0.01	< 0.05	< 0.05	< 0.001	< 0.01	< 0.05
66	< 0.05	.50	< 0.01	< 0.05	< 0.05	< 0.001	< 0.01	< 0.05
67	< 0.05	.90	< 0.01	< 0.05	< 0.05	< 0.001	< 0.01	< 0.05
68	< 0.05	2.70	< 0.01	< 0.05	.13	< 0.001	< 0.01	< 0.05
69	< 0.05	1.30	< 0.01	< 0.05	< 0.05	< 0.001	< 0.01	< 0.05
UNCERTAINITY	0.05	0.05	0.01	0.05	0.05	0.001	0.01	0.05

SAMPLE NO.	SAMPLE DESCRIPTION ==>
55	LANDFILL EROSION SOIL SEDIMENTS
56	BACKGROUND EROSION SOIL SEDIMENTS
58	DOWNSTREAM SURFACE CHANNEL SEDIMENTS
60	SURFACE CHANNEL SEDIMENTS NORTH OF LANDFILL
61	SURFACE CHANNEL SEDIMENTS NORTH OF LANDFILL
62	SURFACE CHANNEL SEDIMENTS NORTH OF LANDFILL
65	UPSTREAM SURFACE CHANNEL SEDIMENTS (NORTHWEST)
66	DRAINAGE CHANNEL SEDIMENTS WEST OF LANDFILL
67	DRAINAGE CHANNEL SEDIMENTS AT CANON DE VALLE
68	DRAINAGE CHANNEL SEDIMENTS SOUTH OF LANDFILL
69	INFLOW DRAINAGE CHANNEL SEDIMENTS


Technical Area 16 Area P
0 50 100 150 200 250
FEET
N
Y1,765,500
Y1,765,250
Y1,765,000
Y1,764,750
Y1,764,500
Y1,764,250
Y1,764,000
Y1,763,750
Y1,763,500
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X475,250
X475,500
X475,750
X476,000
X476,250
X476,500
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[69,70]
LANDF
387
386
388
399
390
BC,1422
BC 1421
16,4A-2
16,4A-3
16,4A
16,4B
16,4C
4A-1
16
P-1
P-2
P-3
P-4
P-5
P-6
P-7
P-8
P-9
P-10
P-11
P-12A
P-13
P-14
P-15A
P-16A
P-0
Containment Pond
WATER CANYON FAULT

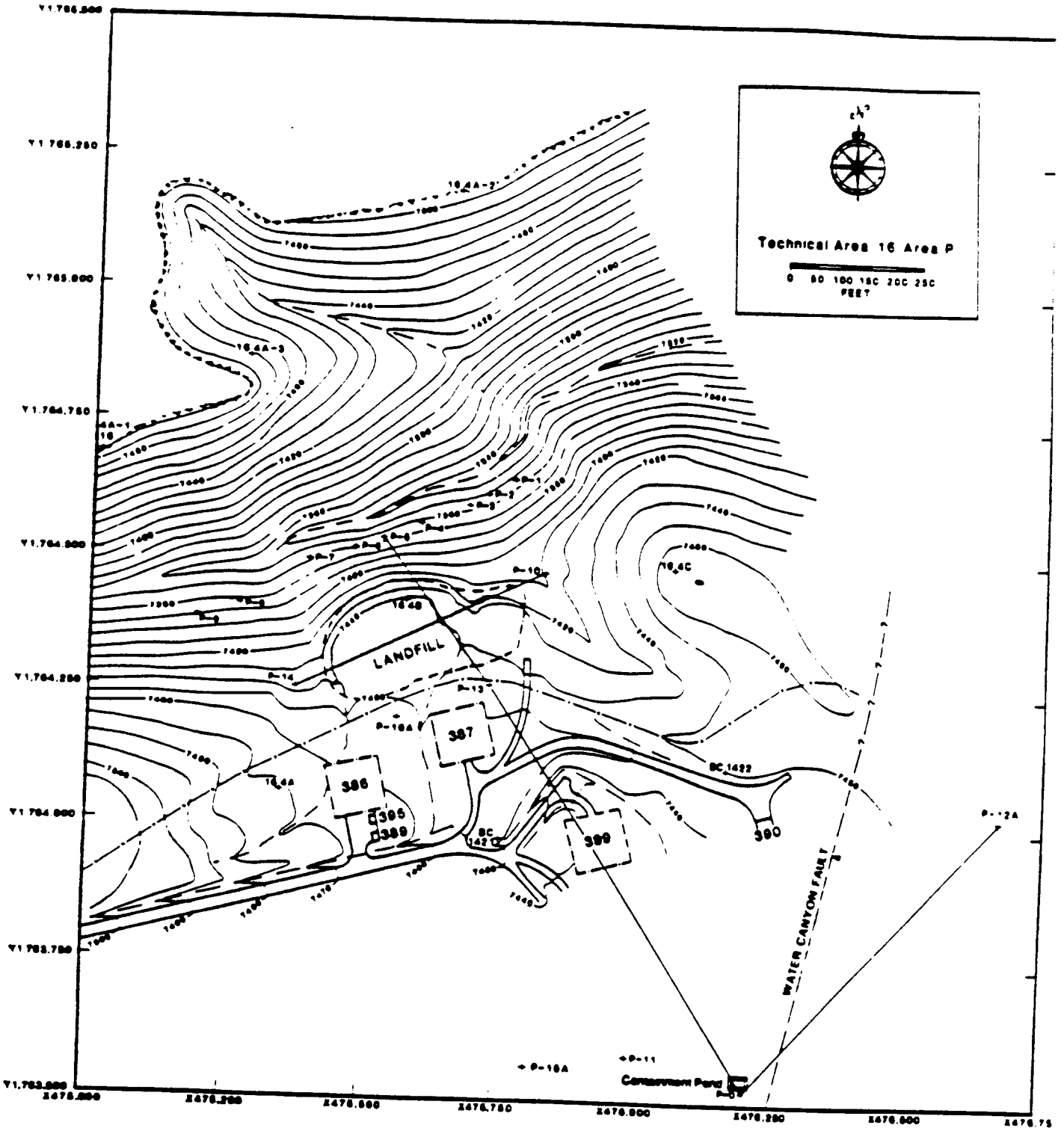

Figure D2. Site map of Technical Area 16 Area P. Boreholes are numbered P-0 through P-16A, and marked with crosses.

BOREHOLE: P-87-00
GEOLOGIST: Fred Brown
DATE DRILLED: 21 JULY 1987
ELEVATION: 7399 ft
LOCATION: 476215,1763523
TOTAL DEPTH: 135 ft
DISPOSITION: Aluminum Casing

DEPTH	DESCRIPTION
0-3	Fill/Top Soil (sandy loam)
3-40	Unit 3c. Light brownish grey tuff Moderately welded Rare rhyolite lithic fragments Common grey pumice lapilli
40	Contact is strongly welded
40-110	Unit 3b. Pale yellowish brown tuff Moderately welded Rare rhyolite fragments Abundant grey pumice lapilli Fracture noted at 45 ft
110	Contact is strongly welded
110-135	Unit 3a. Dark yellowish brown tuff Welded Abundant rhyolite/latite lithic fragments Rare pumice lapilli
135	Unit 2. Densely welded tuff halts drilling

WELL COMPLETION DIAGRAM

P-87-00
(ALUMINUM)

```
                T|  |<--------- 0
                T|  | TOP SOIL
                T|  |<--------- 3
                T|  |
                T|  | TUFF (3c)
                T|  |
                T|  |<--------- 40
                T|  |
                T|  |
                T|  | TUFF (3b)
                T|  |
                T|  |
                T|  |
                T|  |<--------- 110
120 --------->T|  |
                 |X| TUFF (3a)
                 |X|
                  - <--------- 135
```

SCREEN	=
CAVED-IN	X
BACKFILLED TUFF	T
CEMENT	C
BENTONITE	B
SILICA SAND	S

(NOT TO SCALE)

BOREHOLE: P-87-01
GEOLOGIST: Fred Brown
DATE DRILLED: 29 JULY 1987
ELEVATION: 7344 ft
LOCATION: 475756,1764645
TOTAL DEPTH: 35 ft
DISPOSITION: PVC Casing

DEPTH	DESCRIPTION
0-4	Top Soil (sandy loam)
5-10	Unit 3b. Dark yellowish brown tuff Welded Rare rhyolite lithic fragments Rare pumice lapilli
10-35	Unit 3b. Pale yellowish brown tuff Moderately welded Rare rhyolite lithic fragments Rare pumice lapilli

WELL COMPLETION DIAGRAM

P-87-01
(PVC)

```
                C|  |<--------- 0
                C|  | TOP SOIL
                C|  |<--------- 4
                C|  |
13 --------->C|  |
                B|  |
15 --------->B|  |
                S|=|
                S|=|
                S|=| TUFF (3b)
                S|=|
                S|=|
                S|=|
                S|=|
                S|=|
                S|=|
                  - <--------- 35
```

SCREEN	=
CAVED-IN	X
BACKFILLED TUFF	T
CEMENT	C
BENTONITE	B
SILICA SAND	S

(NOT TO SCALE)

BOREHOLE: P-87-02
GEOLOGIST: Fred Brown
DATE DRILLED: 23 JULY 1987
ELEVATION: 7341 ft
LOCATION: 475708, 1764617
TOTAL DEPTH: 10 ft
DISPOSITION: Filled In

DEPTH	DESCRIPTION
0-3	Top Soil (sandy loam)
3-10	Unit 3b. Dark yellowish brown tuff Moderately welded Rare rhyolite lithic fragments Rare pumice lapilli

BOREHOLE: P-87-02
GEOLOGIST: Fred Brown
DATE DRILLED: 23 JULY 1987
ELEVATION: 7341 ft
LOCATION: 475708, 1764617
TOTAL DEPTH: 10 ft
DISPOSITION: Filled In

DEPTH	DESCRIPTION
0-3	Top Soil (sandy loam)
3-10	Unit 3b. Dark yellowish brown tuff Moderately welded Rare rhyolite lithic fragments Rare pumice lapilli

BOREHOLE: P-87-03
GEOLOGIST: Fred Brown
DATE DRILLED: 23 JULY 1987
ELEVATION: 7342 ft
LOCATION: 475676, 1764596
TOTAL DEPTH: 9 ft
DISPOSITION: Teflon Casing

DEPTH	DESCRIPTION
0-3	Top Soil, boulders and cobbles
3-9	Unit 3b. Dark yellowish brown tuff Moderately welded Rare rhyolite lithic fragments Rare pumice lapilli

WELL COMPLETION DIAGRAM

P-87-03
(TEFLON)

```
                C|  |<---------- 0
1 ---------->C|  |
                B|  | TOP SOIL
2 ---------->B|  |
                S|=|
                S|=|
                S|=|<---------- 3
                S|=|
                S|=|
                S|=|
                S|=|
                S|=| TUFF (3b)
                S|=|
                S|=|
7 ---------->S|=|
                |X|
                |X|
                 - <---------- 9
```

SCREEN	=
CAVED-IN	X
BACKFILLED TUFF	T
CEMENT	C
BENTONITE	B
SILICA SAND	S

(NOT TO SCALE)

BOREHOLE: P-87-04
GEOLOGIST: Fred Brown
DATE DRILLED: 28 JULY 1987
ELEVATION: 7348 ft
LOCATION: 475588, 1764562
TOTAL DEPTH: 10 ft
DISPOSITION: Teflon Casing

DEPTH	DESCRIPTION
0-4	Top Soil (sandy loam)
4-10	Unit 3b. Dark yellowish brown tuff Welded Rare rhyolite lithic fragments Rare pumice lapilli

WELL COMPLETION DIAGRAM

P-87-04
(TEFLON)

```
                C|  |<---------- 0
1 ---------->C|  |
                B|  |  TOP SOIL
3 ---------->B|  |
                S|=|
                S|=|
                S|=|<---------- 4
                S|=|
                S|=|
                S|=|
                S|=|
                S|=|  TUFF (3b)
                S|=|
                S|=|
8 ---------->S|=|
                |X|
                |X|
                 - <---------- 10
```

SCREEN	=
CAVED-IN	X
BACKFILLED TUFF	T
CEMENT	C
BENTONITE	B
SILICA SAND	S

(NOT TO SCALE)

BOREHOLE: P-87-05
GEOLOGIST: Fred Brown
DATE DRILLED: 29 JULY 1987
ELEVATION: 7353 ft
LOCATION: 475520, 1764532
TOTAL DEPTH: 35 ft
DISPOSITION: PVC Casing

DEPTH	DESCRIPTION
0-3	Top Soil (sandy loam)
3-15	Unit 3b. Dark yellowish brown tuff Welded Rare rhyolite lithic fragments Rare pumice lapilli
15-35	Unit 3b. Orange pink tuff Moderately welded Rare rhyolite lithic fragments Rare grey pumice lapilli

WELL COMPLETION DIAGRAM

P-87-05
(PVC)

```
                C|  |<--------- 0
                C|  | TOP SOIL
                C|  |<--------- 3
                C|  |
13 --------->C|  |
                B|  |
15 --------->B|  |
                S|=|
                S|=|
                S|=| TUFF (3b)
                S|=|
                S|=|
                S|=|
                S|=|
                S|=|
                S|=|
                S|=|
                  - <--------- 35
```

SCREEN	=
CAVED-IN	X
BACKFILLED TUFF	T
CEMENT	C
BENTONITE	B
SILICA SAND	S

(NOT TO SCALE)

BOREHOLE: P-87-06
GEOLOGIST: Fred Brown
DATE DRILLED: 28 JULY 1987
ELEVATION: 7352 ft
LOCATION: 475467, 1764514
TOTAL DEPTH: 10 ft
DISPOSITION: Teflon Casing

DEPTH	DESCRIPTION
0-4	Top Soil (sandy loam)
4-10	Unit 3b. Pale yellowish brown tuff Welded Rare rhyolite lithic fragments Rare pumice lapilli

WELL COMPLETION DIAGRAM

P-87-06
(TEFLON)

```
                C|  |<--------- 0
1 --------->C|  |
                B|  |
2 --------->B|  |  TOP SOIL
                S|=|
                S|=|
                S|=|<--------- 4
                S|=|
                S|=|
                S|=|
                S|=|
                S|=|  TUFF (3b)
                S|=|
                S|=|
7 --------->S|=|
                |X|
                |X|
                 - <--------- 10
```

SCREEN	=
CAVED-IN	X
BACKFILLED TUFF	T
CEMENT	C
BENTONITE	B
SILICA SAND	S

(NOT TO SCALE)

BOREHOLE: P-87-07
GEOLOGIST: Fred Brown
DATE DRILLED: 29 JULY 1987
ELEVATION: 7356
LOCATION: 475381, 1764491
TOTAL DEPTH: 35 ft
DISPOSITION: PVC Casing

DEPTH	DESCRIPTION
0-2	Top Soil (sandy loam)
2-5	Unit 3b. Pale yellowish brown tuff Welded Rare rhyolite lithic fragments Rare pumice lapilli
5-6	Weathered dark reddish brown clay
6-35	Unit 3b. Pale yellowish brown tuff Moderately welded Common rhyolite lithic fragments Rare pumice lapilli

WELL COMPLETION DIAGRAM

P-87-07
(PVC)

```
                C|  |<--------- 0
                C|  | TOP SOIL
                C|  |<--------- 2
                C|  |
13 --------->C|  |
                B|  |
15 --------->B|  |
                S|=|
                S|=|
                S|=| TUFF (3b)
                S|=|
                S|=|
                S|=|
                S|=|
                S|=|
                S|=|
                S|=|
                  - <--------- 35
```

SCREEN	=
CAVED-IN	X
BACKFILLED TUFF	T
CEMENT	C
BENTONITE	B
SILICA SAND	S

(NOT TO SCALE)

BOREHOLE: P-87-08
GEOLOGIST: Fred Brown
DATE DRILLED: 28 JULY 1987
ELEVATION: 7370 ft
LOCATION: 475257, 1764405
TOTAL DEPTH: 10 ft
DISPOSITION: Teflon Casing

DEPTH	DESCRIPTION
0-3	Top Soil (sandy loam)
3-10	Unit 3c. Dark yellowish brown tuff Welded Rare rhyolite lithic fragments Rare pumice lapilli

WELL COMPLETION DIAGRAM

P-87-08
(TEFLON)

```
                C|  |<--------- 0
1 --------->C|  |
                B|  |  TOP SOIL
2 --------->B|  |
                S|=|
                S|=|
                S|=|<--------- 3
                S|=|
                S|=|
                S|=|
                S|=|
                S|=|  TUFF (3c)
                S|=|
                S|=|
7 --------->S|=|
                |X|
                |X|
                 - <--------- 10
```

SCREEN	=
CAVED-IN	X
BACKFILLED TUFF	T
CEMENT	C
BENTONITE	B
SILICA SAND	S

(NOT TO SCALE)

BOREHOLE: P-87-09
GEOLOGIST: Fred Brown
DATE DRILLED: 29 JULY 1987
ELEVATION: 7376 ft
LOCATION: 475183, 1764381
TOTAL DEPTH: 35 ft
DISPOSITION: PVC Casing

DEPTH	DESCRIPTION
0-3	Top Soil (sandy loam)
3-15	Unit 3c. Moderate brown tuff Moderately welded Rare rhyolite lithic fragments Common grey pumice lapilli
15-33	Unit 3b. Greyish brown tuff Welded Abundant rhyolite/latite lithic fragments Common red-brown pumice lapilli
33-35	Unit 3b. Pale brown tuff and clay Moderately welded Rare rhyolite lithic fragments Abundant clayey pumice lapilli

WELL COMPLETION DIAGRAM

P-87-09
(PVC)

```
                C| |<--------- 0
                C| | TOP SOIL
                C| |<--------- 3
                C| |
13 --------->C| | TUFF (3c)
                B| |
15 --------->B| |<--------- 15
                S|=|
                S|=|
                S|=|
                S|=|
                S|=| TUFF (3b)
                S|=|
                S|=|
                S|=|
                S|=|
                S|=|
                  - <--------- 35
```

SCREEN	=
CAVED-IN	X
BACKFILLED TUFF	T
CEMENT	C
BENTONITE	B
SILICA SAND	S

(NOT TO SCALE)

WELL COMPLETION DIAGRAM

P-87-10
(UNCASED)

```
<--------- 0
 TOP SOIL
<--------- 3

 TUFF (3c)

<--------- 50

 TUFF (3b)

<--------- 120

 TUFF (3a)

<--------- 150
```

SCREEN	=
CAVED-IN	X
BACKFILLED TUFF	T
CEMENT	C
BENTONITE	B
SILICA SAND	S

(NOT TO SCALE)

BOREHOLE: P-87-11
GEOLOGIST: Fred Brown
DATE DRILLED: 27 AUGUST 1987
ELEVATION: 7409 ft
LOCATION: 475991, 1763584
TOTAL DEPTH: 70 ft
DISPOSITION: Uncased

DEPTH	DESCRIPTION
0-2	Top Soil (sandy loam)
2-35	Unit 3c. Dark yellowish brown tuff Moderately welded Rare rhyolite lithic fragments Common red pumice lapilli
35-45	Unit 3c. Pale yellowish brown tuff Slightly welded Rare rhyolite lithic fragments Rare pumice lapilli
45-50	Unit 3c. Dark yellowish brown tuff Moderately welded Rare rhyolite lithic fragments Rare pumice lapilli
50-70	Unit 3b. Pale yellowish brown tuff Densely welded Rare rhyolite lithic fragments Rare pumice lapilli

BOREHOLE: P-87-12A
GEOLOGIST: Fred Brown
DATE DRILLED: 26 August 1987
ELEVATION: 7448 ft
LOCATION: 476664, 1764036
TOTAL DEPTH: 200 ft
DISPOSITION: Aluminum Casing

DEPTH	DESCRIPTION
0-1	El Cajete Pumice
1-3	Pumice/Top Soil (sandy loam)
3-5	Clay
5-50	Unit 3d. Greyish pink tuff Slightly welded Rare rhyolite lithic fragments Rare pumice lapilli
50	Contact moderately welded Abundant brown pumice lapilli
50-102	Unit 3c. Light brown tuff Moderately welded Rare rhyolite lithic fragments Rare pumice lapilli
102	Contact moderately welded Abundant rhyolite/latite lithic fragments Common grey pumice lapilli
102-173	Unit 3b. Pale yellowish brown tuff Slightly welded Rare rhyolite lithic fragments Common reddish pumice lapilli
173	Contact slightly welded Abundant rhyolite lithic fragments Rare pumice lapilli
173-195	Unit 3a. Pale yellowish brown tuff Non-welded Abundant rhyolite/latite lithic fragments Rare pumice lapilli
195-200	Unit 2. Dark yellowish brown tuff Densely welded Abundant rhyolite lithic fragments Rare pumice lapilli

WELL COMPLETION DIAGRAM

P-87-12A
(ALUMINUM)

```
                 T|  |<--------- 0
                 T|  | TOP SOIL
                 T|  |<--------- 3
                 T|  | TUFF (3d)
                 T|  |
                 T|  |<--------- 50
                 T|  |
                 T|  | TUFF (3C)
                 T|  |
                 T|  |<--------- 102
                 T|  |
171 --------->T|  | TUFF (3b)
                 |X|
                 |X|<--------- 173
                 |X| TUFF (3a)
                 |X|<--------- 195
                 |X| TUFF (2)
                  - <--------- 200
```

SCREEN	=
CAVED-IN	X
BACKFILLED TUFF	T
CEMENT	C
BENTONITE	B
SILICA SAND	S

(NOT TO SCALE)

BOREHOLE: P-86-13
GEOLOGIST: William Purtymun
DATE DRILLED: 3 OCTOBER 1986
ELEVATION: 7445 ft
LOCATION: 475720, 1764264
TOTAL DEPTH: 103 ft
DISPOSITION: Aluminum Casing

DEPTH	DESCRIPTION
0-38	Unit 3d. Light brown tuff Moderately welded Rare rhyolite/latite lithic fragments Rare pumice lapilli
38	Contact strongly welded Common rhyolite/latite lithic fragments
38-84	Unit 3c. Grey tuff Moderately welded Rare rhyolite lithic fragments Rare pumice lapilli
84-103	Unit 3b. Light grey tuff Moderately welded Rare rhyolite lithic fragments Rare pumice lapilli

WELL COMPLETION DIAGRAM

P-87-13
(ALUMINUM)

```
                T|  |<--------- 0
                T|  |
                T|  |
                T|  | TUFF (3d)
                T|  |
                T|  |
                T|  |<--------- 38
                T|  |
                T|  |
                T|  | TUFF (3c)
                T|  |
                T|  |
                T|  |<--------- 84
92 --------->T|  |
                 |X| TUFF (3b)
                 |X|
                 |X|
                  - <--------- 103
```

SCREEN	=
CAVED-IN	X
BACKFILLED TUFF	T
CEMENT	C
BENTONITE	B
SILICA SAND	S

(NOT TO SCALE)

BOREHOLE: P-87-14
GEOLOGIST: Fred Brown
DATE DRILLED: 28 AUGUST 1987
ELEVATION: 7437 ft
LOCATION: 475365, 1764251
TOTAL DEPTH: 85 ft
DISPOSITION: Aluminum Casing

DEPTH	DESCRIPTION
0-4	Fill/Top Soil (sandy loam)
4-30	Unit 3d. Pale yellowish brown tuff Moderately welded Rare rhyolite lithic fragments Common grey pumice lapilli
30	Contact is strongly welded Abundant rhyolite lithic fragments Common grey pumice lapilli
30-35	Unit 3c. Pale yellowish brown tuff Moderately welded Rare rhyolite lithic fragments Rare pumice lapilli
35-75	Unit 3c. Dark yellowish brown tuff and clay Welded Rare rhyolite lithic fragments Abundant clayey pumice lapilli
75-85	Unit 3b. Pale yellowish brown pumice Densely welded Rare rhyolite lithic fragments Common grey pumice lapilli

WELL COMPLETION DIAGRAM

P-87-14
(ALUMINUM)

```
                T|  |<--------- 0
                T|  | TOP SOIL
                T|  |<--------- 4
                T|  |
                T|  | TUFF (3d)
                T|  |
                T|  |<--------- 30
                T|  |
                T|  |
                T|  |
                T|  | TUFF (3c)
                T|  |
                T|  |
                T|  |
79 --------->T|  |<--------- 75
                |X| TUFF (3b)
                |X|
                - <--------- 85
```

SCREEN	=
CAVED-IN	X
BACKFILLED TUFF	T
CEMENT	C
BENTONITE	B
SILICA SAND	S

(NOT TO SCALE)

BOREHOLE: P-87-15
GEOLOGIST: Fred Brown
DATE DRILLED: 27 AUGUST 1987
ELEVATION: 7413 ft
LOCATION: 475803, 1763520
TOTAL DEPTH: 70 ft
DISPOSITION: Uncased

DEPTH	DESCRIPTION
0-1	El Cajete Pumice
1-3	Pumice/Top Soil (sandy loam)
3-4	Dark yellowish brown clay
4-40	Unit 3c. Dark yellowish brown tuff Moderately welded Rare rhyolite lithic fragments Common red-grey pumice lapilli
40-50	Unit 3c. Pale yellowish brown tuff Slightly welded Rare rhyolite lithic fragments Rare pumice lapilli
50-55	Unit 3c. Dark yellowish brown tuff Moderately welded Rare rhyolite lithic fragments Common red-grey pumice lapilli
55-70	Unit 3b. Dark yellowish brown tuff Densely welded Rare rhyolite lithic fragments Rare pumice lapilli

BOREHOLE: P-87-16A
GEOLOGIST: Fred Brown
DATE DRILLED: 4 SEPTEMBER 1987
ELEVATION: 7452 ft
LOCATION: 475550, 1764200
TOTAL DEPTH: 105 ft
DISPOSITION: Aluminum Casing

DEPTH	DESCRIPTION
0-5	Fill/Dark Brown Clay
5-7	Top Soil (sandy loam)
7-15	Unit 3d. Pale yellowish brown tuff Slightly welded Rare rhyolite lithic fragments Rare pumice lapilli Vertical fracture at 9-12 ft
15-26	Unit 3d. Greyish orange pink tuff Moderately welded Rare rhyolite lithic fragments Oxidation halo surrounds rhyolite lithic fragments Rare brown pumice lapilli Vertical fracture 19-22 ft
26-31	Extensive clay-filled vertical fractures
31-42	Unit 3d. Greyish orange pink tuff Moderately welded Common oxidized rhyolite lithic fragments Common grey pumice lapilli
42-46	Unit 3c. Pale red tuff Welded Common oxidized rhyolite lithic fragments Common grey pumice lapilli Clay-filled vertical fracture (width to .5 in)
46-50	Unit 3c. Pale yellowish brown tuff Welded Common oxidized rhyolite lithic fragments Common grey pumice lapilli
50-60	Densly welded, no core recovered
60-68	Unit 3c. Greyish red tuff Welded Rare rhyolite lithic fragments Common large (to 2 in) pumice lapilli

68-74	Unit 3c. Pale brown tuff Moderately welded Rare rhyolite lithic fragments Rare clayey pumice lapilli
74-81	Unit 3c. Pale yellowish brown tuff Moderately welded Rare rhyolite lithic fragments Rare pumice lapilli Clay-filled vertical fracture (width to .75 in)
81-87	Unit 3c. Pale yellowish brown tuff Welded Rare rhyolite lithic fragments Rare pumice lapilli
87-105	Unit 3b. Densly welded, no core recovered

WELL COMPLETION DIAGRAM

P-87-16A
(ALUMINUM)

```
                T|  |<--------- 0
                T|  | TOP SOIL
                T|  |<--------- 7
                T|  |
                T|  | TUFF (3d)
                T|  |
                T|  |
                T|  |<-------- 42
                T|  |
                T|  |
                T|  | TUFF (3c)
                T|  |
                T|  |
                T|  |<--------- 87
8 --------->T|  |
                 |X| TUFF (3b)
                 |X|
                  - <--------- 105
```

SCREEN	=
CAVED-IN	X
BACKFILLED TUFF	T
CEMENT	C
BENTONITE	B
SILICA SAND	S

(NOT TO SCALE)

APPENDIX B

DANIEL B. STEPHENS & ASSOCIATES, INC.
CONSULTANTS IN GROUND-WATER HYDROLOGY

• GROUND-WATER CONTAMINATION • UNSATURATED ZONE INVESTIGATIONS • WATER SUPPLY DEVELOPMENT •

January 5, 1988

Mr. Fred Brown
Hydrogeologist
Los Alamos National Laboratory
Group HSE-8
Los Alamos, NM 87545

Subject: Results of Testing for Hydraulic Properties of Welded Tuff

Dear Mr. Brown:

Please find enclosed the final data report on laboratory analyses for hydraulic properties of 10 cores of welded tuff. This report constitutes completion of the analyses requested.

We are continuing our own in-house research on unsaturated hydraulic conductivity using the additional cores that you provided us. I will report to you the results of the investigation when they have been completed.

We would like to point out that the porosity values we have reported are those computed from degree of saturation to water, and therefore represent the effective porosity to that fluid.

Daniel B. Stephens & Associates, Inc. cannot verify that samples are representative of the formation from which they were collected, and we do not assume any responsibility for interpretations or analyses based on this data.

We are very grateful to provide this service to Los Alamos National Laboratory. Please do not hesitate to call us if you have any questions.

Sincerely yours,

Daniel B. Stephens & Associates, Inc.

Warren B. Cox
Laboratory Manager

WBC:bdf
Enclosure

P.O. BOX 740 SOCORRO, NEW MEXICO 87801 (505) 835-3162

DANIEL B. STEPHENS & ASSOCIATES, INC.

CONSULTANTS IN GROUND-WATER HYDROLOGY SOCORRO, NEW MEXICO

FINAL DATA REPORT ON LABORATORY ANALYSES OF SOIL HYDRAULIC PROPERTIES OF WELDED TUFFS AT LOS ALAMOS NATIONAL LABORATORY

PREPARED FOR

LOS ALAMOS NATIONAL LABORATORY

JANUARY, 1988

Final Data Report on Laboratory Analyses

Of

Soil Hydraulic Properties

Of

Welded Tuffs

At

Los Alamos National Laboratory

Prepared For

Los Alamos National Laboratory

January, 1988

DANIEL B. STEPHENS & ASSOCIATES, INC.

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2. Unit Conventions

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SCOPE OF WORK

Scope of Work

Daniel B. Stephens & Associates, Inc. (DBS) was requested by Los Alamos National Laboratory of Los Alamos, New Mexico, to perform laboratory analyses for properties of soil, as outlined in written communication of September 9, 1987. The scope of work included the following laboratory tests on 10 cores:

1. Sample Preparation
2. Saturated Hydraulic Conductivity
3. Moisture Retention (main drainage curve), Hanging Column Method, 2 points
4. Moisture Retention (main drainage curve), Pressure Plate Method, 4 points
5. Initial Moisture Content, Bulk Density and Porosity
6. Unsaturated Hydraulic Conductivity

In execution of the foregoing request, DBS has performed the work as summarized below and in Table 1.

The cores of welded tuff were cut by hand to fit soil retaining rings in which all tests were performed. Descriptions of the sample characteristics are presented in Table 3. Laboratory analyses to determine the hydraulic properties of the ten samples are summarized in Tables 4-7. The sample reference numbers were taken as those marked on the outside of each individual sample bag.

Included in this data report are summary tables, graphs where presentation in this form was required, and raw laboratory data. The Principles and Methods section describes the basic principles of the analyses and methods of calculation. All calculation results are expressed in metric units according to Table 2.

Table 1. Summary of Tests Performed

Sample Number	Hydraulic Conductivity		Moisture Retention		Initial Moisture Content	Porosity	Dry Bulk Density
	Saturated	Unsaturated	Hanging Column	Pressure Plate			
7-8	X	X	X	X	X	X	X
11-12	X	X	X	X	X	X	X
16-17	X	X	X	X	X	X	X
21-22	X	X	X	X	X	X	X
25-26	X	X	X	X	X	X	X
35-36	X	X	X	X	X	X	X
42-43	X	X	X	X	X	X	X
61-62	X	X	X	X	X	X	X
75-76	X	X	X	X	X	X	X
80-81	X	X	X	X	X	X	X

Table 2. Unit Conventions

Hydraulic Conductivity: cm/sec

Moisture Content: % volume

Bulk Density: g/cc

Porosity: dimensionless (cm^3/cm^3)

Note: Unless otherwise stated, lengths are in units of centimeters, and masses are in units of grams.

SAMPLE CHARACTERISTICS

Table 3. Summary of Sample Characteristics

Sample No.	Depth (ft)	Color	Texture	Comments
7-8	Unknown	Reddish Brown	Volcanic Ash	Contained Olivine Crystals
11-12	Unknown	Reddish Brown	Volcanic Ash	Contained Olivine Crystals
16-17	Unknown	Reddish Brown	Volcanic Ash	Contained Olivine Crystals
21-22	Unknown	Reddish Brown	Volcanic Ash	Contained Olivine Crystals
25-26	Unknown	Reddish Brown	Volcanic Ash	Contained Olivine Crystals
35-36	Unknown	Reddish Brown	Volcanic Ash	Contained Olivine Crystals
42-43	Unknown	Reddish Brown	Volcanic Ash	Contained Olivine Crystals
61-62	Unknown	Reddish Brown	Volcanic Ash	Contained Olivine Crystals
75-76	Unknown	Reddish Brown	Volcanic Ash	Contained Olivine Crystals and a small area of clay at one end
80-81	Unknown	Reddish Brown	Volcanic Ash	Contained Olivine Crystals

SATURATED HYDRAULIC CONDUCTIVITY

Table 4. Summary of Saturated Hydraulic Conductivity Tests

Sample No.	K_s (cm/sec)
7-8	1.58E-04
11-12	2.84E-04
16-17	2.78E-04
21-22	2.00E-04
25-26	9.18E-05
35-36	2.25E-05
42-43	8.57E-05
61-62	5.15E-04
75-76	2.28E-04
80-81	4.41E-05

FALLING HEAD TEST DATA

JOB NAME: Los Alamos
JOB NUMBER: 87-L-070
SAMPLE NUMBER: 7-8
RING NUMBER: 14
DEPTH: unknown
TYPE OF WATER USED: 0.01N CaCl2 SOLUTION
SAMPLE X-SECTION AREA: 22.060 (sq. cm)
STANDPIPE X-SECTION AREA: 0.785 (sq. cm)
SAMPLE LENGTH: 3.0 (cm)

DATE (1987)	TIME (DAY)	DEL T (SEC)	TEMP (C)	RESERVOIR HEAD(CM)	SAMPLE HEAD(CM)	K SAT (CM/SEC)	K SAT @ 20 C (CM/SEC)
TEST # 1:							
11/5	0.00		19.0	0.0	70.5		
11/5	0.00	705	19.0	0.0	24.8	1.58E-04	1.61E-04
TEST # 2:							
11/5	0.00		19.0	0.0	70.5		
11/5	0.00	590	19.0	0.0	30.4	1.52E-04	1.55E-04

AVERAGE K SAT: 1.58E-04 (CM/SEC)

COMMENTS:

LABORATORY ANALYSIS BY: S. Stoller
CALCULATIONS MADE BY: S. Stoller
CHECKED BY: W. Cox

FALLING HEAD TEST DATA

JOB NAME: Los Alamos
JOB NUMBER: 87-L-070
SAMPLE NUMBER: 11-12
RING NUMBER: 22
DEPTH: unknown
TYPE OF WATER USED: 0.01N CaCl2 SOLUTION
SAMPLE X-SECTION AREA: 22.060 (sq. cm)
STANDPIPE X-SECTION AREA: 0.785 (sq. cm)
SAMPLE LENGTH: 3.0 (cm)

DATE (1987)	TIME (DAY)	DEL T (SEC)	TEMP (C)	RESERVOIR HEAD(CM)	SAMPLE HEAD(CM)	K SAT (CM/SEC)	K SAT @ 20 C (CM/SEC)
TEST # 1:							
11/10	839:33		15.0	0.0	74.6		
11/10	845:39	423	15.0	0.0	29.4	2.35E-04	2.59E-04
TEST # 2:							
11/10	854:11		15.0	0.0	74.6		
11/10	900:20	369	15.0	0.0	28.3	2.80E-04	3.09E-04

AVERAGE K SAT: 2.84E-04 (CM/SEC)

COMMENTS:

LABORATORY ANALYSIS BY: S. Stoller
CALCULATIONS MADE BY: S. Stoller
CHECKED BY: W. Cox

FALLING HEAD TEST DATA

JOB NAME: Los Alamos
JOB NUMBER: 87-L-070
SAMPLE NUMBER: 16-17
RING NUMBER: 2
DEPTH: unknown
TYPE OF WATER USED: 0.01N CaCl2 SOLUTION
SAMPLE X-SECTION AREA: 22.060 (sq. cm)
STANDPIPE X-SECTION AREA: 0.785 (sq. cm)
SAMPLE LENGTH: 3.0 (cm)

DATE (1987)	TIME (DAY)	DEL T (SEC)	TEMP (C)	RESERVOIR HEAD(CM)	SAMPLE HEAD(CM)	K SAT (CM/SEC)	K SAT @ 20 C (CM/SEC)
TEST # 1:							
11/5	0.00		19.0	0.0	69.8		
11/5	0.00	302	19.0	0.0	32.7	2.68E-04	2.73E-04
TEST # 2:							
11/5	0.00		19.0	0.0	69.8		
11/5	0.00	276	19.0	0.0	34.0	2.78E-04	2.83E-04

AVERAGE K SAT: 2.78E-04 (CM/SEC)

COMMENTS:

LABORATORY ANALYSIS BY: S. Stoller
CALCULATIONS MADE BY: S. Stoller
CHECKED BY: W. Cox

FALLING HEAD TEST DATA

JOB NAME: Los Alamos
JOB NUMBER: 87-L-070
SAMPLE NUMBER: 21-22
RING NUMBER: F
DEPTH: unknown
TYPE OF WATER USED: 0.01N CaCl2 SOLUTION
SAMPLE X-SECTION AREA: 22.060 (sq. cm)
STANDPIPE X-SECTION AREA: 0.785 (sq. cm)
SAMPLE LENGTH: 3.0 (cm)

DATE (1987)	TIME (DAY)	DEL T (SEC)	TEMP (C)	RESERVOIR HEAD(CM)	SAMPLE HEAD(CM)	K SAT (CM/SEC)	K SAT @ 20 C (CM/SEC)
TEST # 1:							
11/5	0.00		19.0	0.0	76.1		
11/5	0.00	364	19.0	0.0	38.7	1.98E-04	2.02E-04
TEST # 2:							
11/5	0.00		19.0	0.0	76.1		
11/5	0.00	497	19.0	0.0	30.7	1.95E-04	1.99E-04

AVERAGE K SAT: 2.00E-04 (CM/SEC)

COMMENTS:

LABORATORY ANALYSIS BY: S. Stoller
CALCULATIONS MADE BY: S. Stoller
CHECKED BY: W. Cox

FALLING HEAD TEST DATA

JOB NAME: Los Alamos
JOB NUMBER: 87-L-070
SAMPLE NUMBER: 25-26
RING NUMBER: C
DEPTH: unknown
TYPE OF WATER USED: 0.01N CaCl2 SOLUTION
SAMPLE X-SECTION AREA: 22.060 (sq. cm)
STANDPIPE X-SECTION AREA: 0.785 (sq. cm)
SAMPLE LENGTH: 3.0 (cm)

DATE (1987)	TIME (DAY)	DEL T (SEC)	TEMP (C)	RESERVOIR HEAD(CM)	SAMPLE HEAD(CM)	K SAT (CM/SEC)	K SAT @ 20 C (CM/SEC)
TEST # 1:							
11/5	0.00		19.0	0.0	76.5		
11/5	0.00	1116	19.0	0.0	29.6	9.08E-05	9.25E-05
TEST # 2:							
11/5	0.00		19.0	0.0	76.5		
11/5	0.00	736	19.0	0.0	41.3	8.94E-05	9.11E-05

AVERAGE K SAT: 9.18E-05 (CM/SEC)

COMMENTS:

LABORATORY ANALYSIS BY: S. Stoller
CALCULATIONS MADE BY: S. Stoller
CHECKED BY: W. Cox

FALLING HEAD TEST DATA

JOB NAME: Los Alamos
JOB NUMBER: 87-L-070
SAMPLE NUMBER: 35-36
RING NUMBER: G
DEPTH: unknown
TYPE OF WATER USED: 0.01N CaCl2 SOLUTION
SAMPLE X-SECTION AREA: 22.060 (sq. cm)
STANDPIPE X-SECTION AREA: 0.785 (sq. cm)
SAMPLE LENGTH: 3.0 (cm)

DATE (1987)	TIME (DAY)	DEL T (SEC)	TEMP (C)	RESERVOIR HEAD(CM)	SAMPLE HEAD(CM)	K SAT (CM/SEC)	K SAT @ 20 C (CM/SEC)
TEST # 1:							
11/10	845:16		15.0	0.0	70.7		
11/10	941:03	3347	15.0	0.0	36.9	2.07E-05	2.29E-05
TEST # 2:							
11/10	942:22		15.0	0.0	70.7		
11/10	1110:48	5306	15.0	0.0	26.1	2.00E-05	2.21E-05

AVERAGE K SAT: 2.25E-05 (CM/SEC)

COMMENTS:

LABORATORY ANALYSIS BY: S. Stoller
CALCULATIONS MADE BY: S. Stoller
CHECKED BY: W. Cox

FALLING HEAD TEST DATA

JOB NAME: Los Alamos
JOB NUMBER: 87-L-070
SAMPLE NUMBER: 42-43
RING NUMBER: 4
DEPTH: unknown
TYPE OF WATER USED: 0.01N CaCl2 SOLUTION
SAMPLE X-SECTION AREA: 22.060 (sq. cm)
STANDPIPE X-SECTION AREA: 0.785 (sq. cm)
SAMPLE LENGTH: 3.0 (cm)

DATE (1987)	TIME (DAY)	DEL T (SEC)	TEMP (C)	RESERVOIR HEAD(CM)	SAMPLE HEAD(CM)	K SAT (CM/SEC)	K SAT @ 20 C (CM/SEC)
TEST # 1:							
11/10	841:17		15.0	0.0	76.5		
11/10	904:42	1405	15.0	0.0	29.6	7.21E-05	7.96E-05
TEST # 2:							
11/10	905:46		15.0	0.0	76.5		
11/10	923:33	1067	15.0	0.0	33.3	8.32E-05	9.18E-05

AVERAGE K SAT: 8.57E-05 (CM/SEC)

COMMENTS:

LABORATORY ANALYSIS BY: S. Stoller
CALCULATIONS MADE BY: S. Stoller
CHECKED BY: W. Cox

FALLING HEAD TEST DATA

JOB NAME: Los Alamos
JOB NUMBER: 87-L-070
SAMPLE NUMBER: 61-62
RING NUMBER: A4
DEPTH: unknown
TYPE OF WATER USED: 0.01N CaCl2 SOLUTION
SAMPLE X-SECTION AREA: 22.060 (sq. cm)
STANDPIPE X-SECTION AREA: 0.785 (sq. cm)
SAMPLE LENGTH: 3.0 (cm)

DATE (1987)	TIME (DAY)	DEL T (SEC)	TEMP (C)	RESERVOIR HEAD(CM)	SAMPLE HEAD(CM)	K SAT (CM/SEC)	K SAT @ 20 C (CM/SEC)
TEST # 1:							
11/10	840:53		15.0	0.0	79.8		
11/10	844:18	265	15.0	0.0	28.8	4.11E-04	4.53E-04
TEST # 2:							
11/10	855:36		15.0	0.0	79.8		
11/10	859:14	218	15.0	0.0	27.4	5.23E-04	5.78E-04

AVERAGE K SAT: 5.15E-04 (CM/SEC)

COMMENTS:

LABORATORY ANALYSIS BY: S. Stoller
CALCULATIONS MADE BY: S. Stoller
CHECKED BY: W. Cox

FALLING HEAD TEST DATA

JOB NAME: Los Alamos
JOB NUMBER: 87-L-070
SAMPLE NUMBER: 75-76
RING NUMBER: 19
DEPTH: unknown
TYPE OF WATER USED: 0.01N CaCl2 SOLUTION
SAMPLE X-SECTION AREA: 22.060 (sq. cm)
STANDPIPE X-SECTION AREA: 0.785 (sq. cm)
SAMPLE LENGTH: 3.0 (cm)

DATE (1987)	TIME (DAY)	DEL T (SEC)	TEMP (C)	RESERVOIR HEAD(CM)	SAMPLE HEAD(CM)	K SAT (CM/SEC)	K SAT @ 20 C (CM/SEC)
TEST # 1:							
11/10	840:27		15.0	0.0	76.1		
11/10	849:03	576	15.0	0.0	26.8	1.93E-04	2.13E-04
TEST # 2:							
11/10	855:03		15.0	0.0	76.1		
11/10	903:29	506	15.0	0.0	26.8	2.20E-04	2.43E-04

AVERAGE K SAT: 2.28E-04 (CM/SEC)

COMMENTS:

LABORATORY ANALYSIS BY: S. Stoller
CALCULATIONS MADE BY: S. Stoller
CHECKED BY: W. Cox

FALLING HEAD TEST DATA

JOB NAME: Los Alamos
JOB NUMBER: 87-L-070
SAMPLE NUMBER: 80-81
RING NUMBER: 18
DEPTH: unknown
TYPE OF WATER USED: 0.01N CaCl2 SOLUTION
SAMPLE X-SECTION AREA: 22.060 (sq. cm)
STANDPIPE X-SECTION AREA: 0.785 (sq. cm)
SAMPLE LENGTH: 3.0 (cm)

DATE (1987)	TIME (DAY)	DEL T (SEC)	TEMP (C)	RESERVOIR HEAD(CM)	SAMPLE HEAD(CM)	K SAT (CM/SEC)	K SAT @ 20 C (CM/SEC)
TEST # 1:							
11/10	840:02		15.0	0.0	74.9		
11/10	921:11	2469	15.0	0.0	27.4	4.35E-05	4.80E-05
TEST # 2:							
11/10	923:49		15.0	0.0	74.0		
11/10	1015:03	3074	15.0	0.0	25.9	3.65E-05	4.02E-05

AVERAGE K SAT: 4.41E-05 (CM/SEC)

COMMENTS:

LABORATORY ANALYSIS BY: S. Stoller
CALCULATIONS MADE BY: S. Stoller
CHECKED BY: W. Cox

MOISTURE RETENTION

Table 5. Summary of Moisture Retention Characteristics

Sample No.	Pressure Head (cm of water)	Moisture Content (cm^3/cm^3)
7-8	-0.0	51.8
	-100.0	49.4
	-195.0	49.0
	-1019.8	15.0
	-3059.4	13.9
	-5099.0	12.5
	-15297.0	8.3
11-12	-0.0	56.1
	-98.0	53.3
	-198.0	52.7
	-1019.8	37.6
	-3059.4	29.3
	-5099.0	26.1
	-15297.0	19.9
16-17	-0.0	54.9
	-101.0	53.6
	-199.0	52.9
	-1019.8	42.2
	-3059.4	29.2
	-5099.0	26.0
	-15297.0	20.4
21-22	-0.0	56.2
	-97.0	56.1
	-1019.8	28.1
	-3059.4	22.8
	-5099.0	19.5
	-15297.0	12.4
25-26	-0.0	52.0
	-98.5	51.4
	-1019.8	23.3
	-3059.4	21.3
	-5099.0	16.6
	-15297.0	10.0

Table 5. Summary of Moisture Retention Characteristics (continued)

Sample No.	Pressure Head (cm of water)	Moisture Content (% vol)
35-36	-0.0	42.8
	-205.0	41.4
	-1019.8	30.2
	-3059.4	14.2
	-5099.0	13.4
	-15297.0	9.4
42-43	-0.0	42.3
	-100.5	42.3
	-209.0	42.2
	-1019.8	33.5
	-3059.4	30.5
	-5099.0	28.9
	-15297.0	22.8
61-62	-0.0	36.4
	-95.5	34.8
	-202.0	32.6
	-1019.8	19.3
	-3059.4	11.2
	-5099.0	10.4
	-15297.0	7.9
75-76	-0.0	41.6
	-95.0	37.9
	-199.0	33.1
	-1019.8	24.0
	-3059.4	12.5
	-5099.0	11.6
	-15297.0	8.3
80-81	-0.0	34.6
	-1019.8	27.5
	-3059.4	18.3
	-5099.0	17.1
	-15297.0	10.7

MOISTURE RETENTION DATA - HANGING COLUMN
(PORE SIZE DISTRIBUTION)

JOB NAME: LOS ALAMOS
JOB NUMBER: 87-L-070
SAMPLE NUMBER: 7-8
RING NUMBER: 14
DEPTH: unknown
SAMPLE VOLUME: 66.18 (cc)
SATURATED WEIGHT AT 0 CM TENSION
(WITH CAP AND RING): 189.1 (g)
TARE RING: 72.1 (g)
TARE CAP: 0.0 (g)
DRY WEIGHT OF SAMPLE: 82.7 (g)
SATURATED MOISTURE CONTENT: 51.8 (% vol)
INITIAL VOLUME OF WATER IN SAMPLE: 34.3 (cc)

DATE (1987)	TIME	SUCTION (CM)	BURET VOL (CC)	CHANGE VOL (CC)	CHANGES VOL (CC)	MOISTURE CONTENT(% VOL) DRYING	WETTING
11/23	1025	0.0	37.1	--	--	51.8	0.0
11/25	800	100.0	35.5	1.6	1.6	49.4	0.0
11/30	810	195.0	35.2	0.3	1.9	49.0	0.0

COMMENTS:

LABORATORY ANALYSIS PERFORMED BY: S. Stoller
CALCULATION MADE BY: S. Stoller
CHECKED BY: W. Cox

MOISTURE RETENTION DATA - 15 BAR PRESSURE PLATE
(PORE SIZE DISTRIBUTION)

JOB NAME: LOS ALAMOS
JOB NUMBER: 87-L-070
SAMPLE NUMBER: 7-8
RING NUMBER: 14
DEPTH: unknown
SAMPLE VOLUME: 66.18 (cc)
SATURATED WEIGHT AT 0 CM TENSION
(WITH CAP AND RING): 189.1 (g)
TARE RING: 72.1 (g)
TARE CAP: 0.0 (g)
DRY WEIGHT OF SAMPLE: 82.7 (g)
SATURATED MOISTURE CONTENT: 51.8 (% vol)
INITIAL VOLUME OF WATER IN SAMPLE: 30.1 (cc)
WEIGHT FROM HANGING COLUMN, W/O CAP: 184.9 (g)
FINAL TENSION ON HANGING COLUMN: 195.0 (cm)

DATE (1987)	TIME	PRESSURE (BAR)	WEIGHT W/RING(G)	CHANGE WT (G)	CHANGES WT (G)	MOISTURE CONTENT (% VOL)
11/30	845	0.0	184.9	--	--	--
12/2	735	1.0	164.7	20.2	20.2	15.0
12/6	830	3.0	164.0	0.7	20.9	13.9
12/8	840	5.0	163.1	0.9	21.8	12.5
12/13	1655	15.0	160.3	2.8	24.6	8.3

COMMENTS:

LABORATORY ANALYSIS PERFORMED BY: S. Stoller
CALCULATION MADE BY: S. Stoller
CHECKED BY: W. Cox

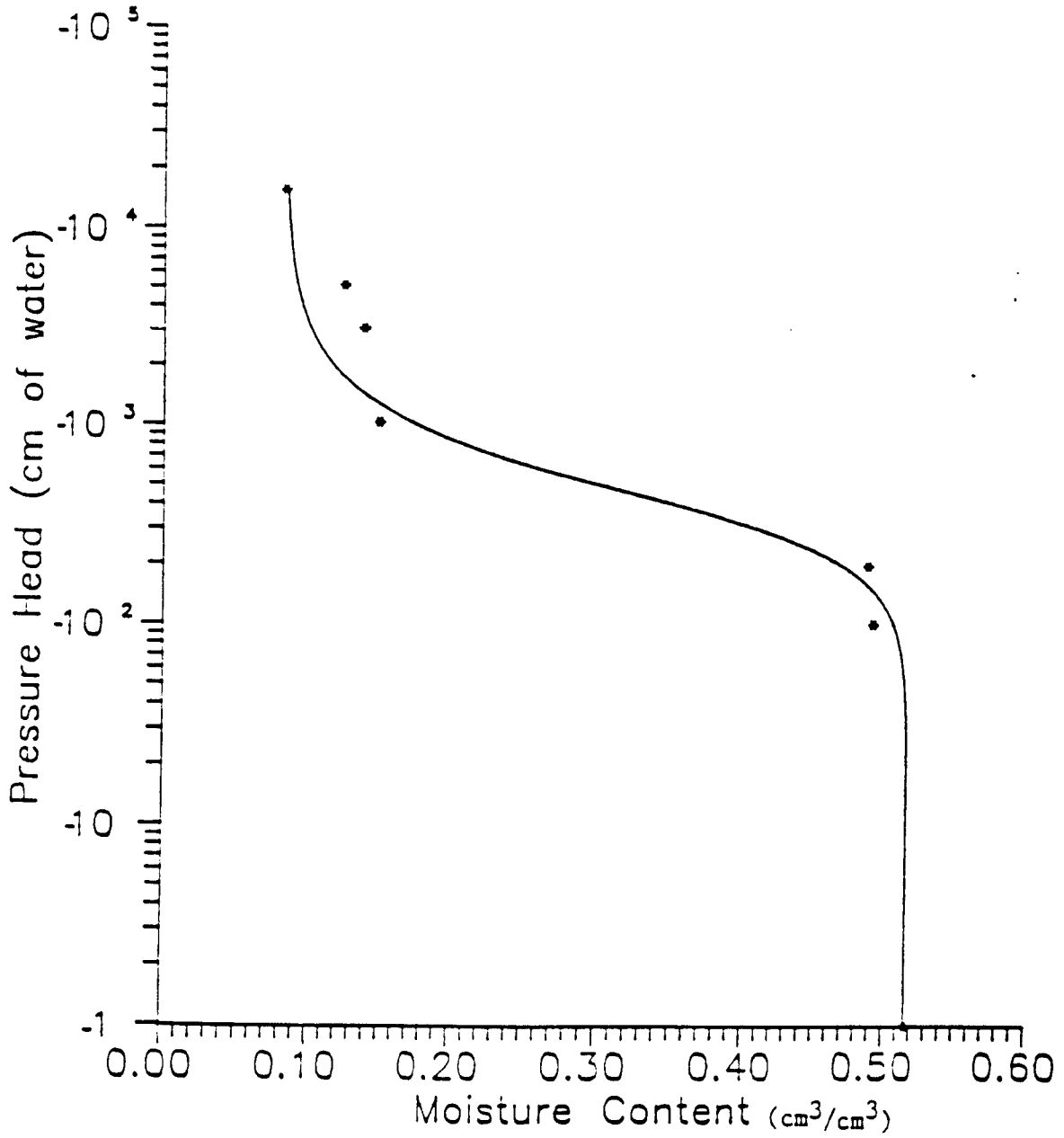


FIGURE NUMBER:	Pressure Head (cm of water) vs. Moisture Content (cm^3/cm^3), Sample No. 7-8.				DANIEL B. STEPHENS & ASSOCIATES, INC.
FOR:	PROJECT NO:	DATE:	PLOTTED BY:	CHECKED BY:	
Los Alamos	87-L-070	1/4/88	SLS	WBC	

MOISTURE RETENTION DATA - HANGING COLUMN
(PORE SIZE DISTRIBUTION)

JOB NAME: LOS ALAMOS
JOB NUMBER: 87-L-070
SAMPLE NUMBER: 11-12
RING NUMBER: 22
DEPTH: unknown
SAMPLE VOLUME: 66.18 (cc)
SATURATED WEIGHT AT 0 CM TENSION
(WITH CAP AND RING): 193.6 (g)
TARE RING: 73.3 (g)
TARE CAP: 0.0 (g)
DRY WEIGHT OF SAMPLE: 83.2 (g)
SATURATED MOISTURE CONTENT: 56.1 (% vol)
INITIAL VOLUME OF WATER IN SAMPLE: 37.1 (cc)

DATE (1987)	TIME	SUCTION (CM)	BURET VOL (CC)	CHANGE VOL (CC)	CHANGES VOL (CC)	MOISTURE CONTENT(% VOL) DRYING	WETTING
11/23	1025	0.0	36.4	--	--	56.1	0.0
11/25	800	98.0	34.6	1.8	1.8	53.3	0.0
11/30	810	198.0	34.2	0.4	2.2	52.7	0.0

COMMENTS:

LABORATORY ANALYSIS PERFORMED BY: S. Stoller
CALCULATION MADE BY: S. Stoller
CHECKED BY: W. Cox

MOISTURE RETENTION DATA - 15 BAR PRESSURE PLATE
(PORE SIZE DISTRIBUTION)

JOB NAME: LOS ALAMOS
JOB NUMBER: 87-L-070
SAMPLE NUMBER: 11-12
RING NUMBER: ZZ
DEPTH: unknown
SAMPLE VOLUME: 66.18 (cc)
SATURATED WEIGHT AT 0 CM TENSION
(WITH CAP AND RING): 193.6 (g)
TARE RING: 73.3 (g)
TARE CAP: 0.0 (g)
DRY WEIGHT OF SAMPLE: 83.2 (g)
SATURATED MOISTURE CONTENT: 56.1 (% vol)
INITIAL VOLUME OF WATER IN SAMPLE: 32.6 (cc)
WEIGHT FROM HANGING COLUMN, W/O CAP: 189.1 (g)
FINAL TENSION ON HANGING COLUMN: 198.0 (cm)

DATE (1987)	TIME	PRESSURE (BAR)	WEIGHT W/RING(G)	CHANGE WT (G)	CHANGES WT (G)	MOISTURE CONTENT (% VOL)
11/30	845	0.0	189.1	--	--	--
12/2	740	1.0	181.4	7.7	7.7	37.6
12/6	830	3.0	175.9	5.5	13.2	29.3
12/8	840	5.0	173.8	2.1	15.3	26.1
12/13	1700	15.0	169.7	4.1	19.4	19.9

COMMENTS:

LABORATORY ANALYSIS PERFORMED BY: S. Stoller
CALCULATION MADE BY: S. Stoller
CHECKED BY: W. Cox

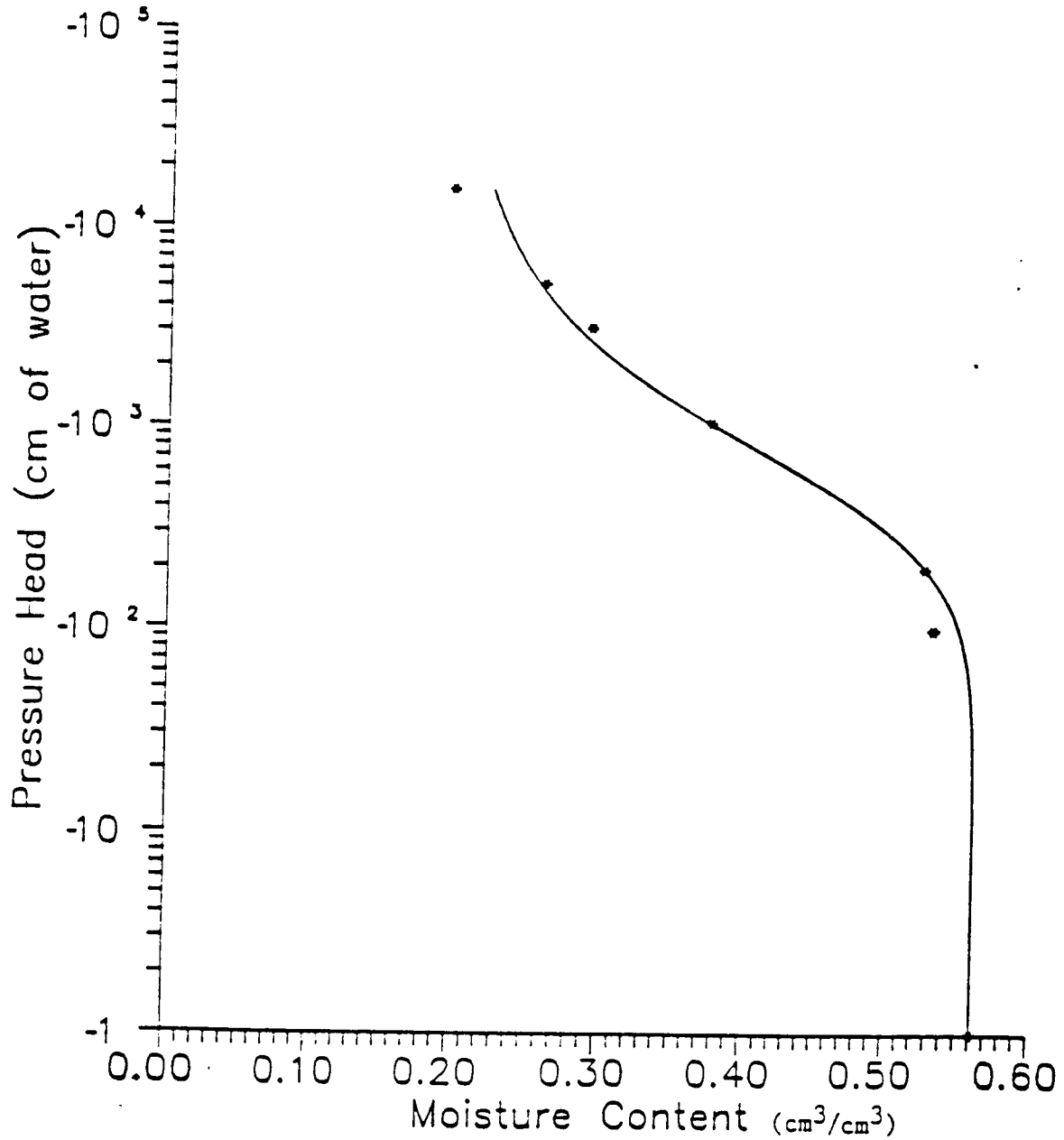


FIGURE NUMBER:	Pressure Head (cm of water) vs. Moisture Content (cm^3/cm^3), Sample No. 11-12				DANIEL B. STEPHENS & ASSOCIATES, INC.
FOR: Los Alamos	PROJECT NO 87-L-070	DATE: 1/4/88	PLOTTED BY: SLS	CHECKED BY: WBC	

MOISTURE RETENTION DATA - HANGING COLUMN
(PORE SIZE DISTRIBUTION)

JOB NAME: LOS ALAMOS
JOB NUMBER: 87-L-070
SAMPLE NUMBER: 16-17
RING NUMBER: 2
DEPTH: unknown
SAMPLE VOLUME: 66.18 (cc)
SATURATED WEIGHT AT 0 CM TENSION
(WITH CAP AND RING): 193.6 (g)
TARE RING: 73.1 (g)
TARE CAP: 0.0 (g)
DRY WEIGHT OF SAMPLE: 84.2 (g)
SATURATED MOISTURE CONTENT: 54.9 (% vol)
INITIAL VOLUME OF WATER IN SAMPLE: 36.3 (cc)

DATE (1987)	TIME	SUCTION (CM)	BURET VOL (CC)	CHANGE VOL (CC)	CHANGES VOL (CC)	MOISTURE CONTENT(% VOL) DRYING	WETTING
11/23	1025	0.0	33.7	--	--	54.9	0.0
11/25	800	101.0	32.9	0.8	0.8	53.6	0.0
11/30	810	199.0	32.4	0.5	1.3	52.9	0.0

COMMENTS:

LABORATORY ANALYSIS PERFORMED BY: S. Stoller
CALCULATION MADE BY: S. Stoller
CHECKED BY: W. Cox

MOISTURE RETENTION DATA - 15 BAR PRESSURE PLATE
(PORE SIZE DISTRIBUTION)

JOB NAME: LOS ALAMOS
JOB NUMBER: 87-L-070
SAMPLE NUMBER: 16-17
RING NUMBER: 2
DEPTH: unknown
SAMPLE VOLUME: 66.18 (cc)
SATURATED WEIGHT AT 0 CM TENSION
(WITH CAP AND RING): 193.6 (g)
TARE RING: 73.1 (g)
TARE CAP: 0.0 (g)
DRY WEIGHT OF SAMPLE: 84.2 (g)
SATURATED MOISTURE CONTENT: 54.9 (% vol)
INITIAL VOLUME OF WATER IN SAMPLE: 33.4 (cc)
WEIGHT FROM HANGING COLUMN, W/O CAP: 190.7 (g)
FINAL TENSION ON HANGING COLUMN: 199.0 (cm)

DATE (1987)	TIME	PRESSURE (BAR)	WEIGHT W/RING(G)	CHANGE WT (G)	CHANGES WT (G)	MOISTURE CONTENT (% VOL)
11/30	845	0.0	190.7	--	--	--
12/2	740	1.0	185.2	5.5	5.5	42.2
12/6	830	3.0	176.6	8.6	14.1	29.2
12/8	840	5.0	174.5	2.1	16.2	26.0
12/13	1700	15.0	170.8	3.7	19.9	20.4

COMMENTS:

LABORATORY ANALYSIS PERFORMED BY: S. Stoller
CALCULATION MADE BY: S. Stoller
CHECKED BY: W. Cox

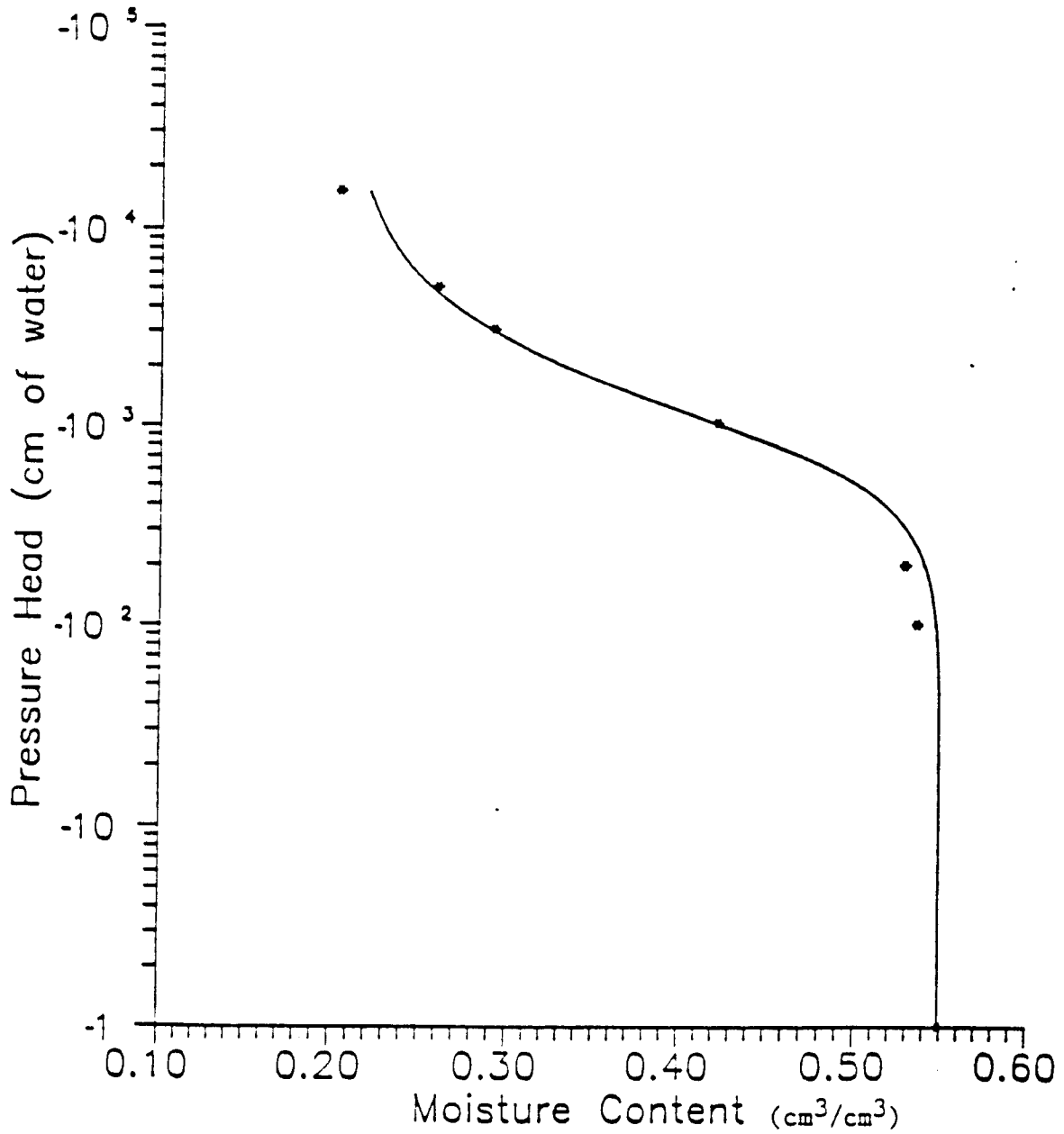


FIGURE NUMBER:	Pressure Head (cm of water) vs. Moisture Content (cm^3/cm^3), Sample No. 16-17				DANIEL B. STEPHENS & ASSOCIATES, INC.
FOR: Los Alamos	PROJECT NO: 87-L-070	DATE: 1/4/88	PLOTTED BY: SLS	CHECKED BY: WBC	

MOISTURE RETENTION DATA - HANGING COLUMN
(PORE SIZE DISTRIBUTION)

JOB NAME: LOS ALAMOS
JOB NUMBER: 87-L-070
SAMPLE NUMBER: 21-22
RING NUMBER: F
DEPTH: unknown
SAMPLE VOLUME: 66.18 (cc)
SATURATED WEIGHT AT 0 CM TENSION
(WITH CAP AND RING): 194.0 (g)
TARE RING: 73.8 (g)
TARE CAP: 0.0 (g)
DRY WEIGHT OF SAMPLE: 83.0 (g)
SATURATED MOISTURE CONTENT: 56.2 (% vol)
INITIAL VOLUME OF WATER IN SAMPLE: 37.2 (cc)

DATE (1987)	TIME	SUCTION (CM)	BURET VOL (CC)	CHANGE VOL (CC)	CHANGES VOL (CC)	MOISTURE CONTENT(% VOL) DRYING	WETTING
11/23	1025	0.0	34.5	--	--	56.2	0.0
11/25	800	97.0	34.4	0.1	0.1	56.1	0.0
11/30	810	198.0	37.6	-3.2	-3.1	60.9	0.0

COMMENTS:

LABORATORY ANALYSIS PERFORMED BY: S. Stoller
CALCULATION MADE BY: S. Stoller
CHECKED BY: W. Cox

MOISTURE RETENTION DATA - 15 BAR PRESSURE PLATE
(PORE SIZE DISTRIBUTION)

JOB NAME: LOS ALAMOS
JOB NUMBER: 87-L-070
SAMPLE NUMBER: 21-22
RING NUMBER: F
DEPTH: unknown
SAMPLE VOLUME: 66.18 (cc)
SATURATED WEIGHT AT 0 CM TENSION (WITH CAP AND RING): 194.0 (g)
TARE RING: 73.8 (g)
TARE CAP: 0.0 (g)
DRY WEIGHT OF SAMPLE: 83.0 (g)
SATURATED MOISTURE CONTENT: 56.2 (% vol)
INITIAL VOLUME OF WATER IN SAMPLE: 32.7 (cc)
WEIGHT FROM HANGING COLUMN, W/O CAP: 189.5 (g)
FINAL TENSION ON HANGING COLUMN: 198.0 (cm)

DATE (1987)	TIME	PRESSURE (BAR)	WEIGHT W/RING(G)	CHANGE WT (G)	CHANGES WT (G)	MOISTURE CONTENT (% VOL)
11/30	845	0.0	189.5	--	--	--
12/2	740	1.0	175.4	14.1	14.1	28.1
12/6	830	3.0	171.9	3.5	17.6	22.8
12/8	840	5.0	169.7	2.2	19.8	19.5
12/13	1710	15.0	165.0	4.7	24.5	12.4

COMMENTS:

LABORATORY ANALYSIS PERFORMED BY: S. Stoller
CALCULATION MADE BY: S. Stoller
CHECKED BY: W. Cox

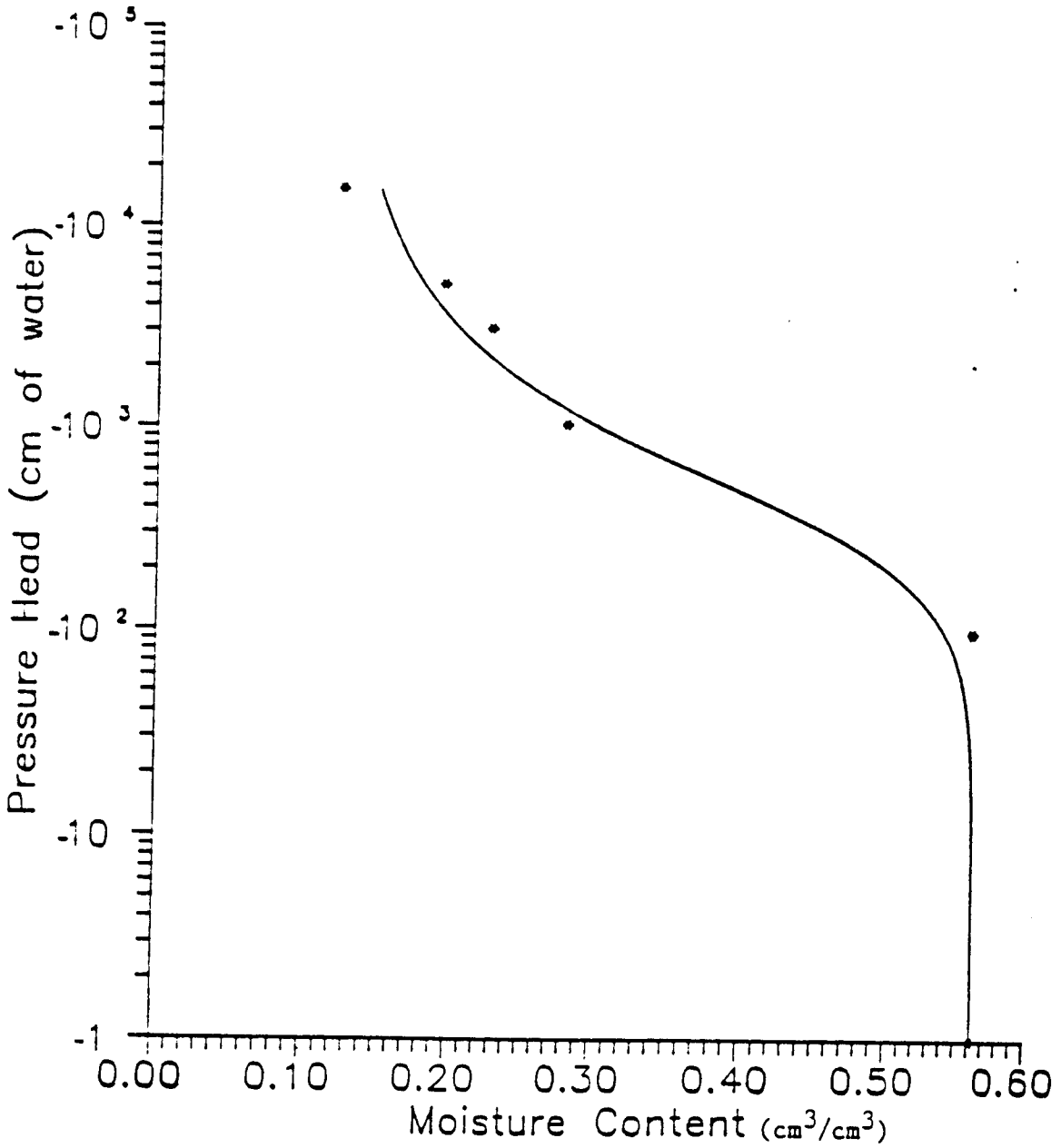


FIGURE NUMBER:	Pressure Head (cm of water) vs. Moisture Content (cm^3/cm^3), Sample No. 21-22				DANIEL B. STEPHENS & ASSOCIATES, INC.
FOR: Los Alamos	PROJECT NO: 87-L-070	DATE: 1/4/88	PLOTTED BY: SLS	CHECKED BY: WBC	

MOISTURE RETENTION DATA - HANGING COLUMN
(PORE SIZE DISTRIBUTION)

JOB NAME: LOS ALAMOS
JOB NUMBER: 87-L-070
SAMPLE NUMBER: 25-26
RING NUMBER: C
DEPTH: unknown
SAMPLE VOLUME: 66.18 (cc)
SATURATED WEIGHT AT 0 CM TENSION
(WITH CAP AND RING): 198.3 (g)
TARE RING: 72.8 (g)
TARE CAP: 0.0 (g)
DRY WEIGHT OF SAMPLE: 91.1 (g)
SATURATED MOISTURE CONTENT: 52.0 (% vol)
INITIAL VOLUME OF WATER IN SAMPLE: 34.4 (cc)

DATE (1987)	TIME	SUCTION (CM)	BURET VOL (CC)	CHANGE VOL (CC)	CHANGES VOL (CC)	MOISTURE CONTENT(% VOL) DRYING	WETTING
11/23	1025	0.0	35.6	--	--	52.0	0.0
11/25	800	98.5	35.2	0.4	0.4	51.4	0.0
11/30	810	203.0	36.5	-1.3	-0.9	53.3	0.0

COMMENTS:

LABORATORY ANALYSIS PERFORMED BY: S. Stoller
CALCULATION MADE BY: S. Stoller
CHECKED BY: W. Cox

MOISTURE RETENTION DATA - 15 BAR PRESSURE PLATE
(PORE SIZE DISTRIBUTION)

JOB NAME: LOS ALAMOS
JOB NUMBER: 87-L-070
SAMPLE NUMBER: 25-26
RING NUMBER: C
DEPTH: unknown
SAMPLE VOLUME: 66.18 (cc)
SATURATED WEIGHT AT 0 CM TENSION
(WITH CAP AND RING): 198.3 (g)
TARE RING: 72.8 (g)
TARE CAP: 0.0 (g)
DRY WEIGHT OF SAMPLE: 91.1 (g)
SATURATED MOISTURE CONTENT: 52.0 (% vol)
INITIAL VOLUME OF WATER IN SAMPLE: 30.9 (cc)
WEIGHT FROM HANGING COLUMN, W/O CAP: 194.8 (g)
FINAL TENSION ON HANGING COLUMN: 203.0 (cm)

DATE (1987)	TIME	PRESSURE (BAR)	WEIGHT W/RING(G)	CHANGE WT (G)	CHANGES WT (G)	MOISTURE CONTENT (% VOL)
11/30	845	0.0	194.8	--	--	--
12/2	740	1.0	179.3	15.5	15.5	23.3
12/6	830	3.0	178.0	1.3	16.8	21.3
12/8	840	5.0	174.9	3.1	19.9	16.6
12/13	1710	15.0	170.5	4.4	24.3	10.0

COMMENTS:

LABORATORY ANALYSIS PERFORMED BY: S. Stoller
CALCULATION MADE BY: S. Stoller
CHECKED BY: W. Cox

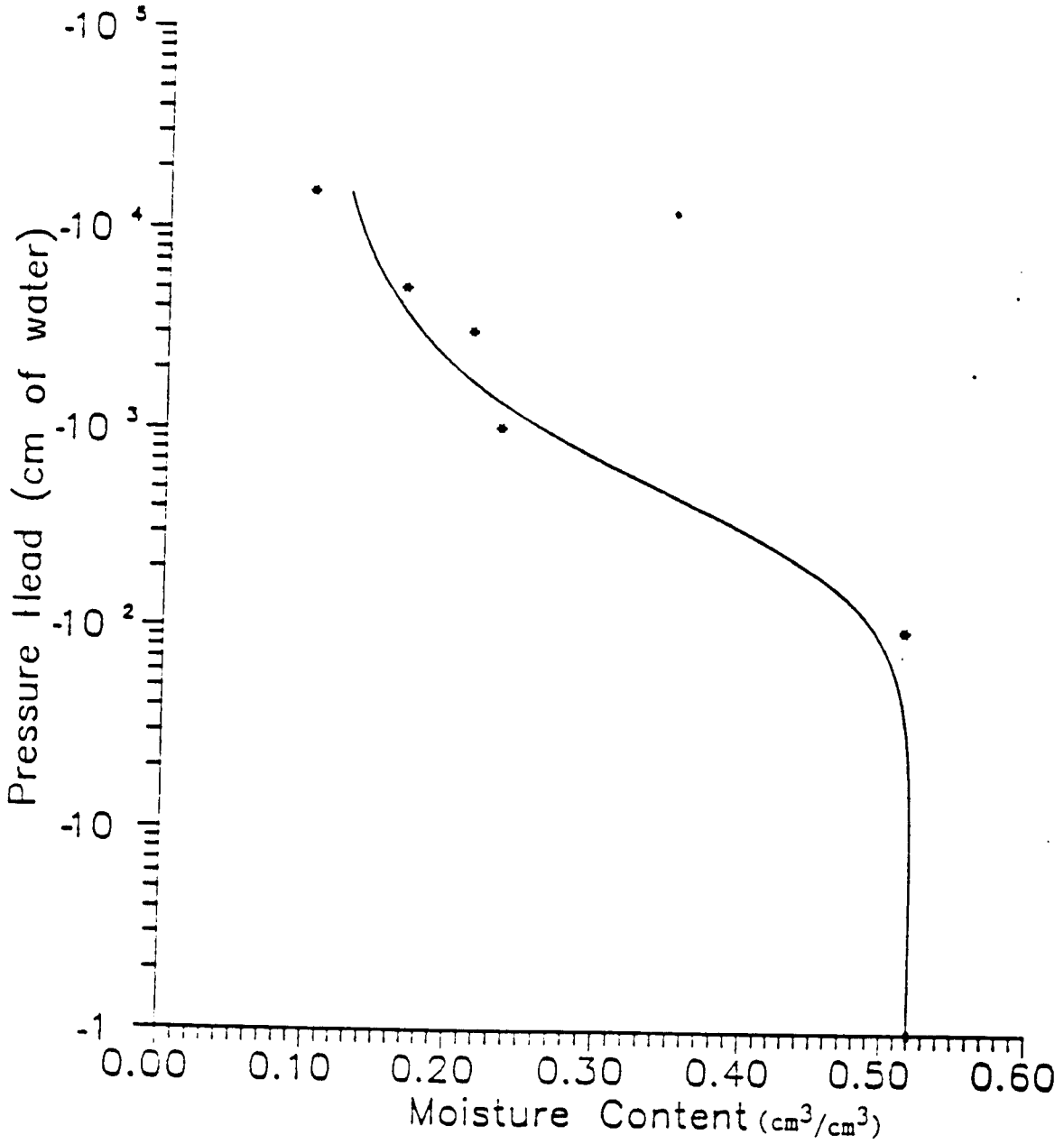


FIGURE NUMBER:	Pressure Head (cm of water) vs. Moisture Content (cm^3/cm^3), Sample No. 25-26				DANIEL B. STEPHENS & ASSOCIATES, INC.
FOR: Los Alamos	PROJECT NO: 87-L-070	DATE: 1/4/88	PLOTTED BY: SLS	CHECKED BY: WBC	

MOISTURE RETENTION DATA - HANGING COLUMN
(PORE SIZE DISTRIBUTION)

JOB NAME: LOS ALAMOS
JOB NUMBER: 87-L-070
SAMPLE NUMBER: 35-36
RING NUMBER: G
DEPTH: unknown
SAMPLE VOLUME: 66.18 (cc)
SATURATED WEIGHT AT 0 CM TENSION
(WITH CAP AND RING): 208.4 (g)
TARE RING: 73.3 (g)
TARE CAP: 0.0 (g)
DRY WEIGHT OF SAMPLE: 106.8 (g)
SATURATED MOISTURE CONTENT: 42.8 (% vol)
INITIAL VOLUME OF WATER IN SAMPLE: 28.3 (cc)

DATE (1987)	TIME	SUCTION (CM)	BURET VOL (CC)	CHANGE VOL (CC)	CHANGES VOL (CC)	MOISTURE CONTENT(% VOL) DRYING	WETTING
11/24	1120	0.0	33.0	--	--	42.8	0.0
11/28	1125	96.0	32.1	0.9	0.9	41.4	0.0
11/30	810	205.0	32.1	0.0	0.9	41.4	0.0

COMMENTS:

LABORATORY ANALYSIS PERFORMED BY: S. Stoller
CALCULATION MADE BY: S. Stoller
CHECKED BY: W. Cox

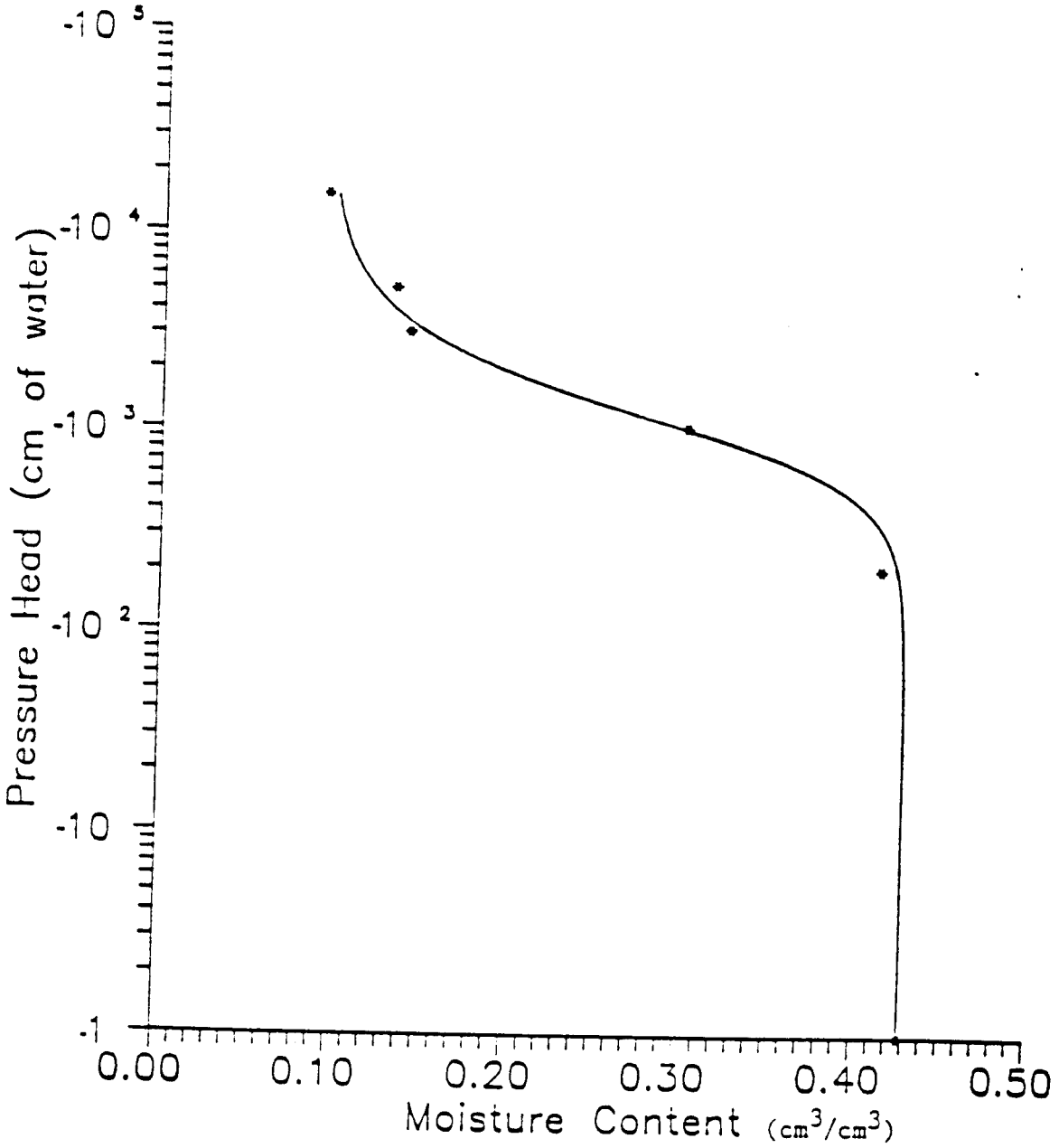


FIGURE NUMBER	Pressure Head (cm of water) vs. Moisture Content (cm^3/cm^3), Sample No. 35-36				DANIEL B. STEPHENS & ASSOCIATES, INC.
FOR: Los Alamos	PROJECT NO 87-L-070	DATE: 1/4/88	PLOTTED BY: SLS	CHECKED BY: WBC	

MOISTURE RETENTION DATA - 15 BAR PRESSURE PLATE
(PORE SIZE DISTRIBUTION)

JOB NAME: LOS ALAMOS
JOB NUMBER: 87-L-070
SAMPLE NUMBER: 35-36
RING NUMBER: G
DEPTH: unknown
SAMPLE VOLUME: 66.18 (cc)
SATURATED WEIGHT AT 0 CM TENSION
(WITH CAP AND RING): 208.4 (g)
TARE RING: 73.3 (g)
TARE CAP: 0.0 (g)
DRY WEIGHT OF SAMPLE: 106.8 (g)
SATURATED MOISTURE CONTENT: 42.8 (% vol)
INITIAL VOLUME OF WATER IN SAMPLE: 27.0 (cc)
WEIGHT FROM HANGING COLUMN, W/O CAP: 207.1 (g)
FINAL TENSION ON HANGING COLUMN: 205.0 (cm)

DATE (1987)	TIME	PRESSURE (BAR)	WEIGHT W/RING(G)	CHANGE WT (G)	CHANGES WT (G)	MOISTURE CONTENT (% VOL)
11/30	845	0.0	207.1	--	--	--
12/2	740	1.0	200.1	7.0	7.0	30.2
12/6	830	3.0	189.5	10.6	17.6	14.2
12/8	840	5.0	189.0	0.5	18.1	13.4
12/13	1715	15.0	186.3	2.7	20.8	9.4

COMMENTS:

LABORATORY ANALYSIS PERFORMED BY: S. Stoller
CALCULATION MADE BY: S. Stoller
CHECKED BY: W. Cox

MOISTURE RETENTION DATA - HANGING COLUMN
(PORE SIZE DISTRIBUTION)

JOB NAME: LOS ALAMOS
JOB NUMBER: 87-L-070
SAMPLE NUMBER: 42-43
RING NUMBER: 4
DEPTH: unknown
SAMPLE VOLUME: 66.18 (cc)
SATURATED WEIGHT AT 0 CM TENSION
(WITH CAP AND RING): 208.0 (g)
TARE RING: 72.6 (g)
TARE CAP: 0.0 (g)
DRY WEIGHT OF SAMPLE: 107.4 (g)
SATURATED MOISTURE CONTENT: 42.3 (% vol)
INITIAL VOLUME OF WATER IN SAMPLE: 28.0 (cc)

DATE (1987)	TIME	SUCTION (CM)	BURET VOL (CC)	CHANGE VOL (CC)	CHANGES VOL (CC)	MOISTURE CONTENT(% VOL) DRYING	WETTING
11/24	1120	0.0	32.7	--	--	42.3	0.0
11/28	1125	100.5	32.7	0.0	0.0	42.3	0.0
11/30	810	209.0	32.6	0.1	0.1	42.2	0.0

COMMENTS:

LABORATORY ANALYSIS PERFORMED BY: S. Stoller
CALCULATION MADE BY: S. Stoller
CHECKED BY: W. Cox

MOISTURE RETENTION DATA - 15 BAR PRESSURE PLATE
(PORE SIZE DISTRIBUTION)

JOB NAME: LOS ALAMOS
JOB NUMBER: 87-L-070
SAMPLE NUMBER: 42-43
RING NUMBER: 4
DEPTH: unknown
SAMPLE VOLUME: 66.18 (cc)
SATURATED WEIGHT AT 0 CM TENSION
(WITH CAP AND RING): 208.0 (g)
TARE RING: 72.6 (g)
TARE CAP: 0.0 (g)
DRY WEIGHT OF SAMPLE: 107.4 (g)
SATURATED MOISTURE CONTENT: 42.3 (% vol)
INITIAL VOLUME OF WATER IN SAMPLE: 26.4 (cc)
WEIGHT FROM HANGING COLUMN, W/O CAP: 206.4 (g)
FINAL TENSION ON HANGING COLUMN: 209.0 (cm)

DATE (1987)	TIME	PRESSURE (BAR)	WEIGHT W/RING(G)	CHANGE WT (G)	CHANGES WT (G)	MOISTURE CONTENT (% VOL)
11/30	845	0.0	206.4	--	--	--
12/2	740	1.0	202.2	4.2	4.2	33.5
12/6	830	3.0	200.2	2.0	6.2	30.5
12/8	840	5.0	199.1	1.1	7.3	28.9
12/13	1720	15.0	195.1	4.0	11.3	22.8

COMMENTS:

LABORATORY ANALYSIS PERFORMED BY: S. Stoller
CALCULATION MADE BY: S. Stoller
CHECKED BY: W. Cox

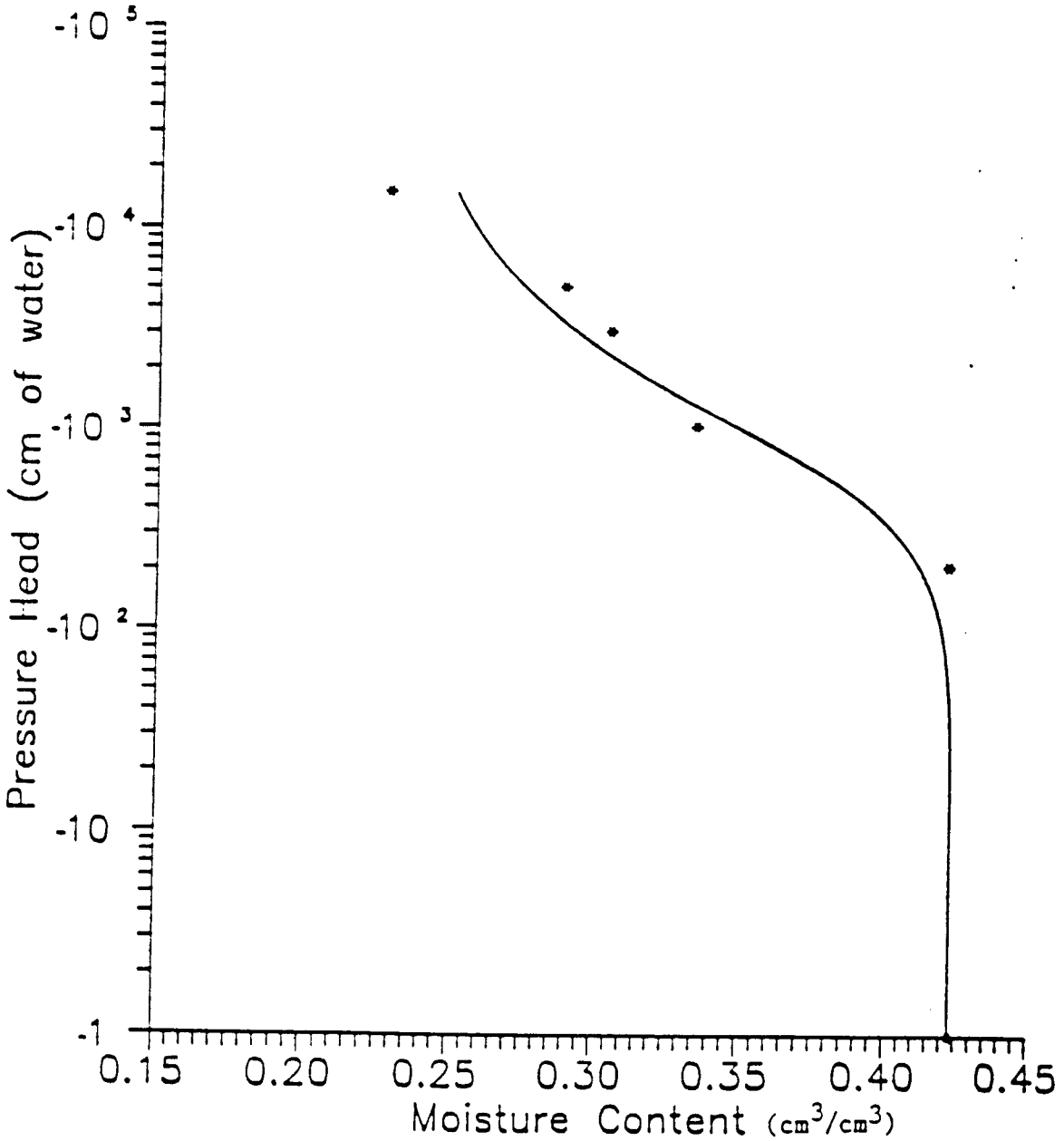


FIGURE NUMBER:	Pressure Head (cm of water) vs. Moisture Content (cm^3/cm^3), Sample No. 42-43				DANIEL B. STEPHENS & ASSOCIATES, INC.
FOR: Los Alamos	PROJECT NO: 87-L-070	DATE: 1/4/88	PLOTTED BY: SLS	CHECKED BY: WBC	

MOISTURE RETENTION DATA - HANGING COLUMN
(PORE SIZE DISTRIBUTION)

JOB NAME: LOS ALAMOS
JOB NUMBER: 87-L-070
SAMPLE NUMBER: 61-62
RING NUMBER: A4
DEPTH: unknown
SAMPLE VOLUME: 66.18 (cc)
SATURATED WEIGHT AT 0 CM TENSION
(WITH CAP AND RING): 210.1 (g)
TARE RING: 73.4 (g)
TARE CAP: 0.0 (g)
DRY WEIGHT OF SAMPLE: 112.6 (g)
SATURATED MOISTURE CONTENT: 36.4 (% vol)
INITIAL VOLUME OF WATER IN SAMPLE: 24.1 (cc)

DATE (1987)	TIME	SUCTION (CM)	BURET VOL (CC)	CHANGE VOL (CC)	CHANGES VOL (CC)	MOISTURE CONTENT(% VOL) DRYING	WETTING
11/24	1120	0.0	36.1	--	--	36.4	0.0
11/28	1125	95.5	35.0	1.1	1.1	34.8	0.0
11/30	810	202.0	33.6	1.4	2.5	32.6	0.0

COMMENTS:

LABORATORY ANALYSIS PERFORMED BY: S. Stoller
CALCULATION MADE BY: S. Stoller
CHECKED BY: W. Cox

MOISTURE RETENTION DATA - 15 BAR PRESSURE PLATE
(PORE SIZE DISTRIBUTION)

JOB NAME:	LOS ALAMOS
JOB NUMBER:	87-L-070
SAMPLE NUMBER:	61-62
RING NUMBER:	A4
DEPTH:	unknown
SAMPLE VOLUME:	66.18 (cc)
SATURATED WEIGHT AT 0 CM TENSION (WITH CAP AND RING):	210.1 (g)
TARE RING:	73.4 (g)
TARE CAP:	0.0 (g)
DRY WEIGHT OF SAMPLE:	112.6 (g)
SATURATED MOISTURE CONTENT:	36.4 (% vol)
INITIAL VOLUME OF WATER IN SAMPLE:	20.8 (cc)
WEIGHT FROM HANGING COLUMN, W/O CAP:	206.8 (g)
FINAL TENSION ON HANGING COLUMN:	202.0 (cm)

DATE (1987)	TIME	PRESSURE (BAR)	WEIGHT W/RING(G)	CHANGE WT (G)	CHANGES WT (G)	MOISTURE CONTENT (% VOL)
11/30	845	0.0	206.8	--	--	--
12/2	740	1.0	198.8	8.0	8.0	19.3
12/6	830	3.0	193.4	5.4	13.4	11.2
12/8	840	5.0	192.9	0.5	13.9	10.4
12/13	1720	15.0	191.2	1.7	15.6	7.9

COMMENTS:

LABORATORY ANALYSIS PERFORMED BY: S. Stoller
CALCULATION MADE BY: S. Stoller
CHECKED BY: W. Cox

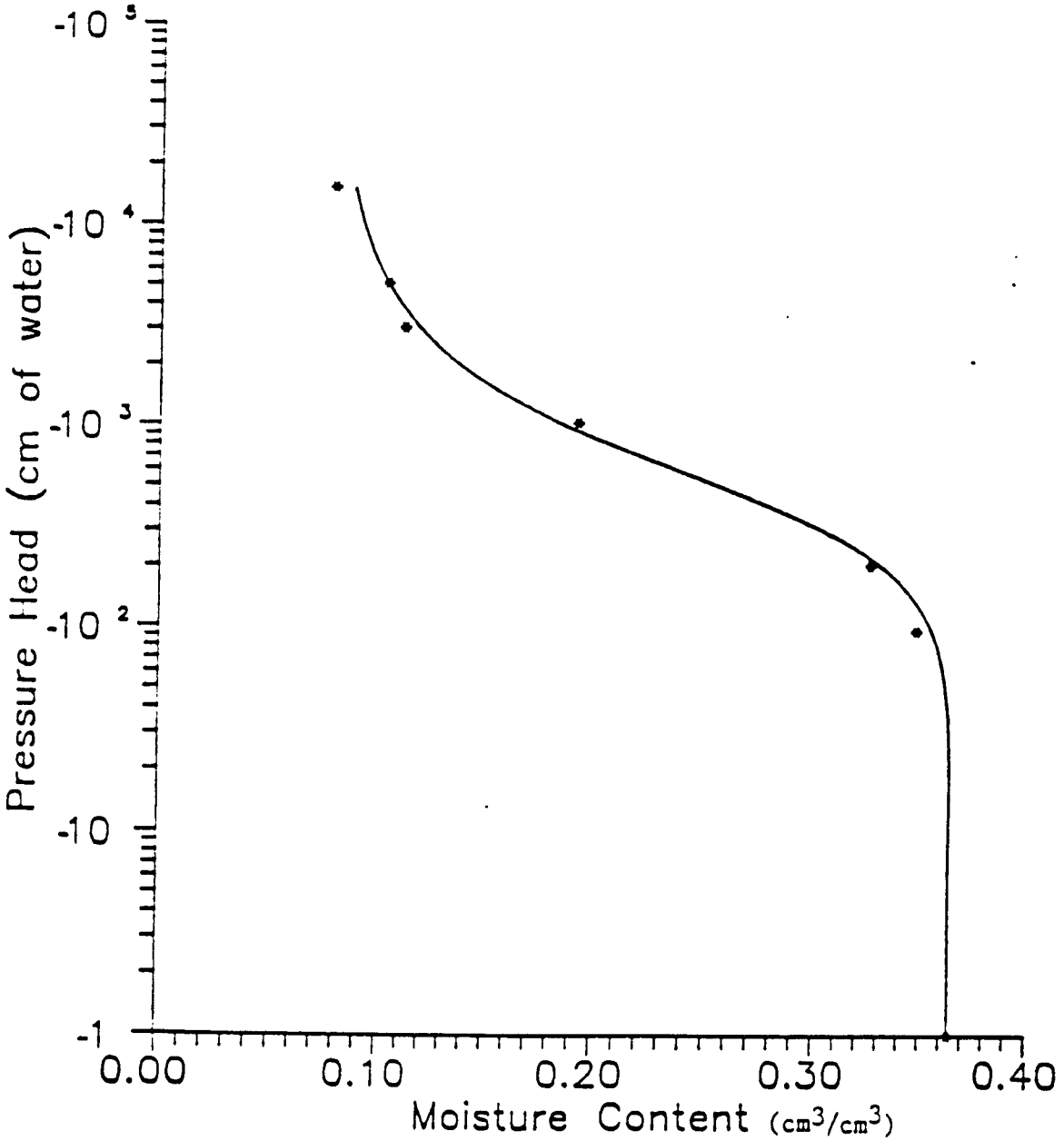


FIGURE NUMBER:	Pressure Head (cm of water) vs. Moisture Content (cm^3/cm^3), Sample No. 61-62				DANIEL B. STEPHENS & ASSOCIATES, INC.
FOR: Los Alamos	PROJECT NO: 87-L-070	DATE: 1/4/88	PLOTTED BY: SLS	CHECKED BY: WBC	

MOISTURE RETENTION DATA - HANGING COLUMN
(PORE SIZE DISTRIBUTION)

JOB NAME: LOS ALAMOS
JOB NUMBER: 87-L-070
SAMPLE NUMBER: 75-76
RING NUMBER: 19
DEPTH: unknown
SAMPLE VOLUME: 66.18 (cc)
SATURATED WEIGHT AT 0 CM TENSION
(WITH CAP AND RING): 204.5 (g)
TARE RING: 73.4 (g)
TARE CAP: 0.0 (g)
DRY WEIGHT OF SAMPLE: 103.6 (g)
SATURATED MOISTURE CONTENT: 41.6 (% vol)
INITIAL VOLUME OF WATER IN SAMPLE: 27.5 (cc)

DATE (1987)	TIME	SUCTION (CM)	BURET VOL (CC)	CHANGE VOL (CC)	CHANGES VOL (CC)	MOISTURE CONTENT(% VOL) DRYING	WETTING
11/24	1120	0.0	34.4	--	--	41.6	0.0
11/28	1125	95.0	32.0	2.4	2.4	37.9	0.0
11/30	810	199.0	28.8	3.2	5.6	33.1	0.0

COMMENTS:

LABORATORY ANALYSIS PERFORMED BY: S. Stoller
CALCULATION MADE BY: S. Stoller
CHECKED BY: W. Cox

MOISTURE RETENTION DATA - 15 BAR PRESSURE PLATE
(PORE SIZE DISTRIBUTION)

JOB NAME: LOS ALAMOS
JOB NUMBER: 87-L-070
SAMPLE NUMBER: 75-76
RING NUMBER: 19
DEPTH: unknown
SAMPLE VOLUME: 66.18 (cc)
SATURATED WEIGHT AT 0 CM TENSION
(WITH CAP AND RING): 204.5 (g)
TARE RING: 73.4 (g)
TARE CAP: 0.0 (g)
DRY WEIGHT OF SAMPLE: 103.6 (g)
SATURATED MOISTURE CONTENT: 41.6 (% vol)
INITIAL VOLUME OF WATER IN SAMPLE: 21.9 (cc)
WEIGHT FROM HANGING COLUMN, W/O CAP: 198.9 (g)
FINAL TENSION ON HANGING COLUMN: 199.0 (cm)

DATE (1987)	TIME	PRESSURE (BAR)	WEIGHT W/RING(G)	CHANGE WT (G)	CHANGES WT (G)	MOISTURE CONTENT (% VOL)
11/30	845	0.0	198.9	--	--	--
12/2	740	1.0	192.9	6.0	6.0	24.0
12/6	830	3.0	185.3	7.6	13.6	12.5
12/8	840	5.0	184.7	0.6	14.2	11.6
12/13	1725	15.0	182.5	2.2	16.4	8.3

COMMENTS:

LABORATORY ANALYSIS PERFORMED BY: S. Stoller
CALCULATION MADE BY: S. Stoller
CHECKED BY: W. Cox

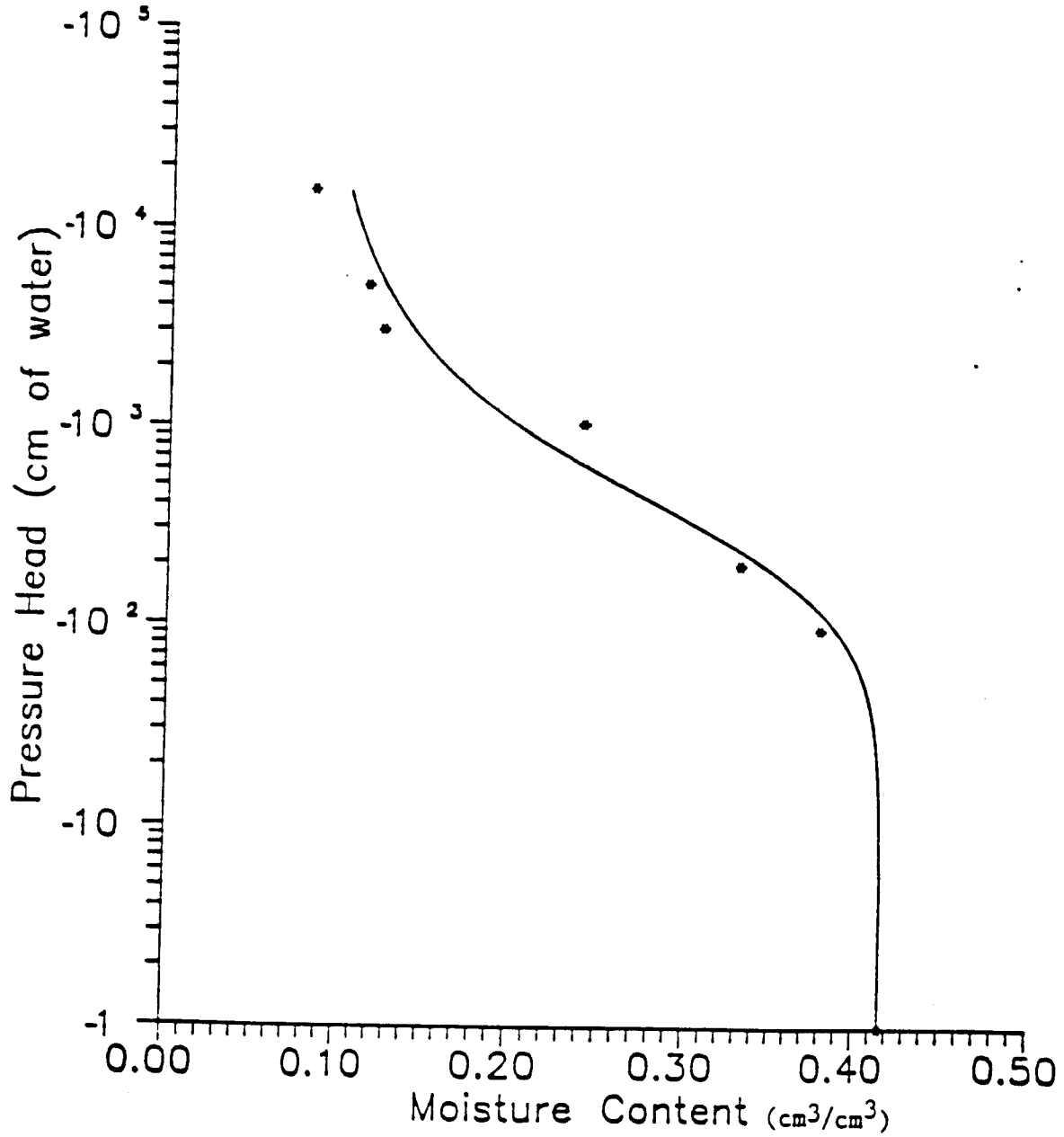


FIGURE NUMBER:	Pressure Head (cm of water) vs. Moisture Content (cm^3/cm^3), Sample No. 75-76				DANIEL B. STEPHENS & ASSOCIATES, INC.
FOR: Los Alamos	PROJECT NO: 87-L-070	DATE: 1/4/88	PLOTTED BY: SLS	CHECKED BY: WBC	

MOISTURE RETENTION DATA - HANGING COLUMN
(PORE SIZE DISTRIBUTION)

JOB NAME: LOS ALAMOS
JOB NUMBER: 87-L-070
SAMPLE NUMBER: 80-81
RING NUMBER: 18
DEPTH: unknown
SAMPLE VOLUME: 66.18 (cc)
SATURATED WEIGHT AT 0 CM TENSION
(WITH CAP AND RING): 215.1 (g)
TARE RING: 73.1 (g)
TARE CAP: 0.0 (g)
DRY WEIGHT OF SAMPLE: 119.1 (g)
SATURATED MOISTURE CONTENT: 34.6 (% vol)
INITIAL VOLUME OF WATER IN SAMPLE: 22.9 (cc)

DATE (1987)	TIME	SUCTION (CM)	BURET VOL (CC)	CHANGE VOL (CC)	CHANGES VOL (CC)	MOISTURE CONTENT(% VOL) DRYING	WETTING
11/24	1120	0.0	34.0	--	--	34.6	0.0
11/28	1125	98.5	34.1	-0.1	-0.1	34.8	0.0
11/30	810	205.0	38.1	-4.0	-4.1	40.8	0.0

COMMENTS:

LABORATORY ANALYSIS PERFORMED BY: S. Stoller
CALCULATION MADE BY: S. Stoller
CHECKED BY: W. Cox

MOISTURE RETENTION DATA - 15 BAR PRESSURE PLATE
(PORE SIZE DISTRIBUTION)

JOB NAME: LOS ALAMOS
JOB NUMBER: 87-L-070
SAMPLE NUMBER: 50-81
RING NUMBER: 18
DEPTH: unknown
SAMPLE VOLUME: 66.18 (cc)
SATURATED WEIGHT AT 0 CM TENSION
(WITH CAP AND RING): 215.1 (g)
TARE RING: 73.1 (g)
TARE CAP: 0.0 (g)
DRY WEIGHT OF SAMPLE: 119.1 (g)
SATURATED MOISTURE CONTENT: 34.6 (% vol)
INITIAL VOLUME OF WATER IN SAMPLE: 21.4 (cc)
WEIGHT FROM HANGING COLUMN, W/O CAP: 213.6 (g)
FINAL TENSION ON HANGING COLUMN: 205.0 (cm)

DATE (1987)	TIME	PRESSURE (BAR)	WEIGHT W/RING(G)	CHANGE WT (G)	CHANGES WT (G)	MOISTURE CONTENT (% VOL)
11/30	845	0.0	213.6	--	--	--
12/2	740	1.0	210.4	3.2	3.2	27.5
12/6	630	3.0	204.3	6.1	9.3	18.3
12/8	840	5.0	203.5	0.8	10.1	17.1
12/13	1725	15.0	199.3	4.2	14.3	10.7

COMMENTS:

LABORATORY ANALYSIS PERFORMED BY: S. Stoller
CALCULATION MADE BY: S. Stoller
CHECKED BY: W. Cox

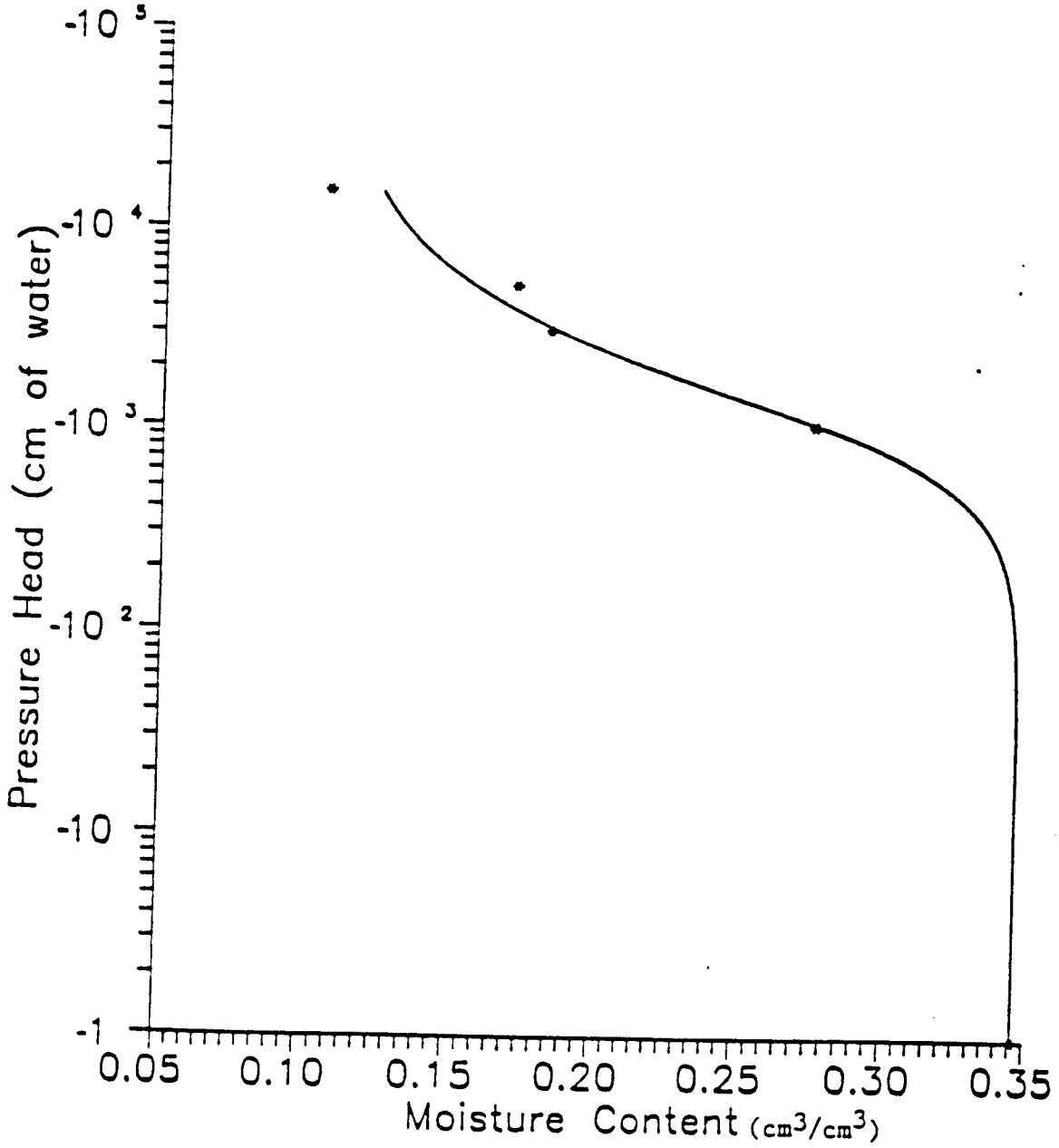


FIGURE NUMBER:	Pressure Head (cm of water) vs. Moisture Content (cm^3/cm^3), Sample No. 80-81				DANIEL B. STEPHENS & ASSOCIATES, INC.
FOR: Los Alamos	PROJECT NO: 87-L-070	DATE: 1/4/88	PLOTTED BY: SLS	CHECKED BY: WBC	

INITIAL MOISTURE CONTENT, DRY BULK DENSITY AND POROSITY

Table 6. Summary of Initial Moisture Content, Dry Bulk Density and Porosity

Sample No.	Initial Moisture Content Gravimetric (g/g)	Initial Moisture Content Volumetric (cm^3/cm^3)	Dry Bulk Density (g/cc)	Porosity* (% vol)
7-8	28.30	35.36	1.25	51.8
11-12	14.90	18.74	1.26	56.1
16-17	17.46	22.21	1.27	54.9
21-22	15.90	19.95	1.25	56.2
25-26	13.94	19.19	1.38	52.0
35-36	14.51	23.42	1.61	42.8
42-43	22.53	36.57	1.62	42.3
61-62	11.55	19.64	1.70	36.4
75-76	14.77	23.12	1.57	41.6
80-81	11.17	20.10	1.80	34.6

*Taken as saturated moisture content

DATA FOR INITIAL MOISTURE CONTENT,
BULK DENSITY, AND POROSITY

JOB NAME: LOS ALAMOS
JOB NUMBER: 87-L-070
SAMPLE NUMBER: 11-12
RING NUMBER: 22
DEPTH: unknown

FIELD WEIGHT OF SAMPLE (W/CAP AND RING): 168.9 (g)
TARE WEIGHT, RING: 73.3 (g)
TARE WEIGHT, PAN: 0.0 (g)
SAMPLE VOLUME: 66.18 (cc)
DATE AND TIME INTO OVEN: 12/13/87 1700
DATE AND TIME OUT OF OVEN: 12/17/87 940

DRY WEIGHT OF SAMPLE: 83.2 (g)
DRY BULK DENSITY: 1.26 (g/cc)
PARTICLE DENSITY: 2.65 (g/cc)
(METHOD: ASSUME MEAN PARTICLE DENSITY = 2.65 g/cc)

CALCULATED POROSITY: 52.56 (% vol)

INITIAL MOISTURE CONTENT (VOLUMETRIC): 18.74 (% vol)

INITIAL MOISTURE CONTENT (GRAVIMETRIC): 14.90 (%)

COMMENTS:

LABORATORY ANALYSIS PERFORMED BY: S. Stoller
CALCULATIONS MADE BY: S. Stoller
CHECKED BY: W. Cox

DATA FOR INITIAL MOISTURE CONTENT,
BULK DENSITY, AND POROSITY

JOB NAME: LOS ALAMOS
JOB NUMBER: 87-L-070
SAMPLE NUMBER: 16-17
RING NUMBER: 2
DEPTH: unknown

FIELD WEIGHT OF SAMPLE (W/CAP AND RING): 172.0 (g)
TARE WEIGHT, RING: 73.1 (g)
TARE WEIGHT, PAN: 0.0 (g)
SAMPLE VOLUME: 66.18 (cc)
DATE AND TIME INTO OVEN: 12/13/87 1700
DATE AND TIME OUT OF OVEN: 12/17/87 940

DRY WEIGHT OF SAMPLE: 84.2 (g)
DRY BULK DENSITY: 1.27 (g/cc)
PARTICLE DENSITY: 2.65 (g/cc)
(METHOD: ASSUME MEAN PARTICLE DENSITY = 2.65 g/cc)

CALCULATED POROSITY: 51.99 (% vol)

INITIAL MOISTURE CONTENT (VOLUMETRIC): 22.21 (% vol)

INITIAL MOISTURE CONTENT (GRAVIMETRIC): 17.46 (%)

COMMENTS:

LABORATORY ANALYSIS PERFORMED BY: S. Stoller
CALCULATIONS MADE BY: S. Stoller
CHECKED BY: W. Cox

DATA FOR INITIAL MOISTURE CONTENT,
BULK DENSITY, AND POROSITY

JOB NAME: LOS ALAMOS
JOB NUMBER: 87-L-070
SAMPLE NUMBER: 21-22
RING NUMBER: F
DEPTH: unknown

FIELD WIEGHT OF SAMPLE (W/CAP AND RING): 170.0 (g)
TARE WEIGHT, RING: 73.8 (g)
TARE WEIGHT, PAN: 0.0 (g)
SAMPLE VOLUME: 66.18 (cc)
DATE AND TIME INTO OVEN: 12/13/87 1700
DATE AND TIME OUT OF OVEN: 12/17/87 940

DRY WEIGHT OF SAMPLE: 83.0 (g)
DRY BULK DENSITY: 1.25 (g/cc)
PARTICLE DENSITY: 2.65 (g/cc)
(METHOD: ASSUME MEAN PARTICLE DENSITY = 2.65 g/cc)

CALCULATED POROSITY: 52.67 (% vol)

INITIAL MOISTURE CONTENT (VOLUMETRIC): 19.95 (% vol)

INITIAL MOISTURE CONTENT (GRAVIMETRIC): 15.90 (%)

COMMENTS:

LABORATORY ANALYSIS PERFORMED BY: S. Stoller
CALCULATIONS MADE BY: S. Stoller
CHECKED BY: J. Cox

DATA FOR INITIAL MOISTURE CONTENT,
BULK DENSITY, AND POROSITY

JOB NAME: LOS ALAMOS
JOB NUMBER: 87-L-070
SAMPLE NUMBER: 25-26
RING NUMBER: C
DEPTH: unknown

FIELD WEIGHT OF SAMPLE (W/CAP AND RING): 176.6 (g)
TARE WEIGHT, RING: 72.8 (g)
TARE WEIGHT, PAN: 0.0 (g)
SAMPLE VOLUME: 66.18 (cc)
DATE AND TIME INTO OVEN: 12/13/87 1700
DATE AND TIME OUT OF OVEN: 12/17/87 940

DRY WEIGHT OF SAMPLE: 91.1 (g)
DRY BULK DENSITY: 1.38 (g/cc)
PARTICLE DENSITY: 2.65 (g/cc)
(METHOD: ASSUME MEAN PARTICLE DENSITY = 2.65 g/cc)

CALCULATED POROSITY: 48.05 (% vol)

INITIAL MOISTURE CONTENT (VOLUMETRIC): 19.19 (% vol)

INITIAL MOISTURE CONTENT (GRAVIMETRIC): 13.94 (%)

COMMENTS:

LABORATORY ANALYSIS PERFORMED BY: S. Stoller
CALCULATIONS MADE BY: S. Stoller
CHECKED BY: J. Cox

DATA FOR INITIAL MOISTURE CONTENT,
BULK DENSITY, AND POROSITY

JOB NAME: LOS ALAMOS
JOB NUMBER: 87-L-070
SAMPLE NUMBER: 35-36
RING NUMBER: G
DEPTH: Unknown

FIELD WEIGHT OF SAMPLE (W/CAP AND RING): 195.6 (g)
TARE WEIGHT, RING: 73.3 (g)
TARE WEIGHT, PAN: 0.0 (g)
SAMPLE VOLUME: 66.18 (cc)
DATE AND TIME INTO OVEN: 12/13/87 1700
DATE AND TIME OUT OF OVEN: 12/17/87 940

DRY WEIGHT OF SAMPLE: 106.8 (g)
DRY BULK DENSITY: 1.61 (g/cc)
PARTICLE DENSITY: 2.65 (g/cc)
(METHOD: ASSUME MEAN PARTICLE DENSITY = 2.65 g/cc)

CALCULATED POROSITY: 39.10 (% vol)

INITIAL MOISTURE CONTENT (VOLUMETRIC): 23.42 (% vol)

INITIAL MOISTURE CONTENT (GRAVIMETRIC): 14.51 (%)

COMMENTS:

LABORATORY ANALYSIS PERFORMED BY: S. Stoller
CALCULATIONS MADE BY: S. Stoller
CHECKED BY: W. Cox

DATA FOR INITIAL MOISTURE CONTENT,
BULK DENSITY, AND POROSITY

JOB NAME: LOS ALAMOS
JOB NUMBER: 87-L-070
SAMPLE NUMBER: 42-43
RING NUMBER: 4
DEPTH: unknown

FIELD WIEGHT OF SAMPLE (W/CAP AND RING): 204.2 (g)
TARE WEIGHT, RING: 72.6 (g)
TARE WEIGHT, PAN: 0.0 (g)
SAMPLE VOLUME: 66.18 (cc)
DATE AND TIME INTO OVEN: 12/13/87 1700
DATE AND TIME OUT OF OVEN: 12/17/87 940

DRY WEIGHT OF SAMPLE: 107.4 (g)
DRY BULK DENSITY: 1.62 (g/cc)
PARTICLE DENSITY: 2.65 (g/cc)
(METHOD: ASSUME MEAN PARTICLE DENSITY = 2.65 g/cc)

CALCULATED POROSITY: 38.76 (% vol)

INITIAL MOISTURE CONTENT (VOLUMETRIC): 36.57 (% vol)

INITIAL MOISTURE CONTENT (GRAVIMETRIC): 22.53 (%)

COMMENTS:

LABORATORY ANALYSIS PERFORMED BY: S. Stoller
CALCULATIONS MADE BY: S. Stoller
CHECKED BY: J. Cox

DATA FOR INITIAL MOISTURE CONTENT,
BULK DENSITY, AND POROSITY

JOB NAME: LOS ALAMOS
JOB NUMBER: 87-L-070
SAMPLE NUMBER: 61-62
RING NUMBER: A4
DEPTH: unknown

FIELD WIEGHT OF SAMPLE (W/CAP AND RING): 199.0 (g)
TARE WEIGHT, RING: 73.4 (g)
TARE WEIGHT, PAN: 0.0 (g)
SAMPLE VOLUME: 66.18 (cc)
DATE AND TIME INTO OVEN: 12/13/87 1700
DATE AND TIME OUT OF OVEN: 12/17/87 940

DRY WEIGHT OF SAMPLE: 112.6 (g)
DRY BULK DENSITY: 1.70 (g/cc)
PARTICLE DENSITY: 2.65 (g/cc)
(METHOD: ASSUME MEAN PARTICLE DENSITY = 2.65 g/cc)

CALCULATED POROSITY: 35.80 (% vol)

INITIAL MOISTURE CONTENT (VOLUMETRIC): 19.64 (% vol)

INITIAL MOISTURE CONTENT (GRAVIMETRIC): 11.55 (%)

COMMENTS:

LABORATORY ANALYSIS PERFORMED BY: S. Stoller
CALCULATIONS MADE BY: S. Stoller
CHECKED BY: W. Cox

DATA FOR INITIAL MOISTURE CONTENT,
BULK DENSITY, AND POROSITY

JOB NAME: LOS ALAMOS
JOB NUMBER: 87-L-070
SAMPLE NUMBER: 75-76
RING NUMBER: 19
DEPTH: unknown

FIELD WIEGHT OF SAMPLE (W/CAP AND RING): 192.3 (g)
TARE WEIGHT, RING: 73.4 (g)
TARE WEIGHT, PAN: 0.0 (g)
SAMPLE VOLUME: 66.18 (cc)
DATE AND TIME INTO OVEN: 12/13/87 1700
DATE AND TIME OUT OF OVEN: 12/17/87 940

DRY WEIGHT OF SAMPLE: 103.6 (g)
DRY BULK DENSITY: 1.57 (g/cc)
PARTICLE DENSITY: 2.65 (g/cc)
(METHOD: ASSUME MEAN PARTICLE DENSITY = 2.65 g/cc)

CALCULATED POROSITY: 40.93 (% vol)

INITIAL MOISTURE CONTENT (VOLUMETRIC): 23.12 (% vol)

INITIAL MOISTURE CONTENT (GRAVIMETRIC): 14.77 (%)

COMMENTS:

LABORATORY ANALYSIS PERFORMED BY: S. Stoller
CALCULATIONS MADE BY: S. Stoller
CHECKED BY: W. Cox

DATA FOR INITIAL MOISTURE CONTENT,
BULK DENSITY, AND POROSITY

JOB NAME: LOS ALAMOS
JOB NUMBER: 87-L-070
SAMPLE NUMBER: 80-81
RING NUMBER: 18
DEPTH: unknown

FIELD WIEGHT OF SAMPLE (W/CAP AND RING): 205.5 (g)
TARE WEIGHT, RING: 73.1 (g)
TARE WEIGHT, PAN: 0.0 (g)
SAMPLE VOLUME: 66.18 (cc)
DATE AND TIME INTO OVEN: 12/13/87 1700
DATE AND TIME OUT OF OVEN: 12/17/87 940

DRY WEIGHT OF SAMPLE: 119.1 (g)
DRY BULK DENSITY: 1.80 (g/cc)
PARTICLE DENSITY: 2.65 (g/cc)
(METHOD: ASSUME MEAN PARTICLE DENSITY = 2.65 g/cc)

CALCULATED POROSITY: 32.09 (% vol)

INITIAL MOISTURE CONTENT (VOLUMETRIC): 20.10 (% vol)

INITIAL MOISTURE CONTENT (GRAVIMETRIC): 11.17 (%)

COMMENTS:

LABORATORY ANALYSIS PERFORMED BY: S. Stoller
CALCULATIONS MADE BY: S. Stoller
CHECKED BY: W. Cox

UNSATURATED HYDRAULIC PROPERTIES

Table 7. Summary of Parameters for Calculating Unsaturated Hydraulic Conductivity

Sample No.	α (cm^{-1})	N (dimension-less)	θ_r (cm^3/cm^3)	θ_s (cm^3/cm^3)	K_s (cm/sec)
7-8	0.00272	2.49734	0.083	0.518	1.58E-04
11-12	0.00231	1.73884	0.199	0.561	2.84E-04
16-17	0.00119	2.04731	0.204	0.549	2.78E-04
21-22	0.00313	1.73941	0.124	0.562	2.00E-04
25-26	0.00371	1.69308	0.100	0.520	9.18E-05
35-36	0.00108	2.44961	0.094	0.428	2.25E-05
42-43	0.00164	1.66466	0.228	0.423	8.57E-05
61-62	0.00263	1.93720	0.079	0.364	5.15E-04
75-76	0.00452	1.65070	0.083	0.416	2.28E-04
80-81	0.00098	1.96205	0.107	0.346	4.41E-05

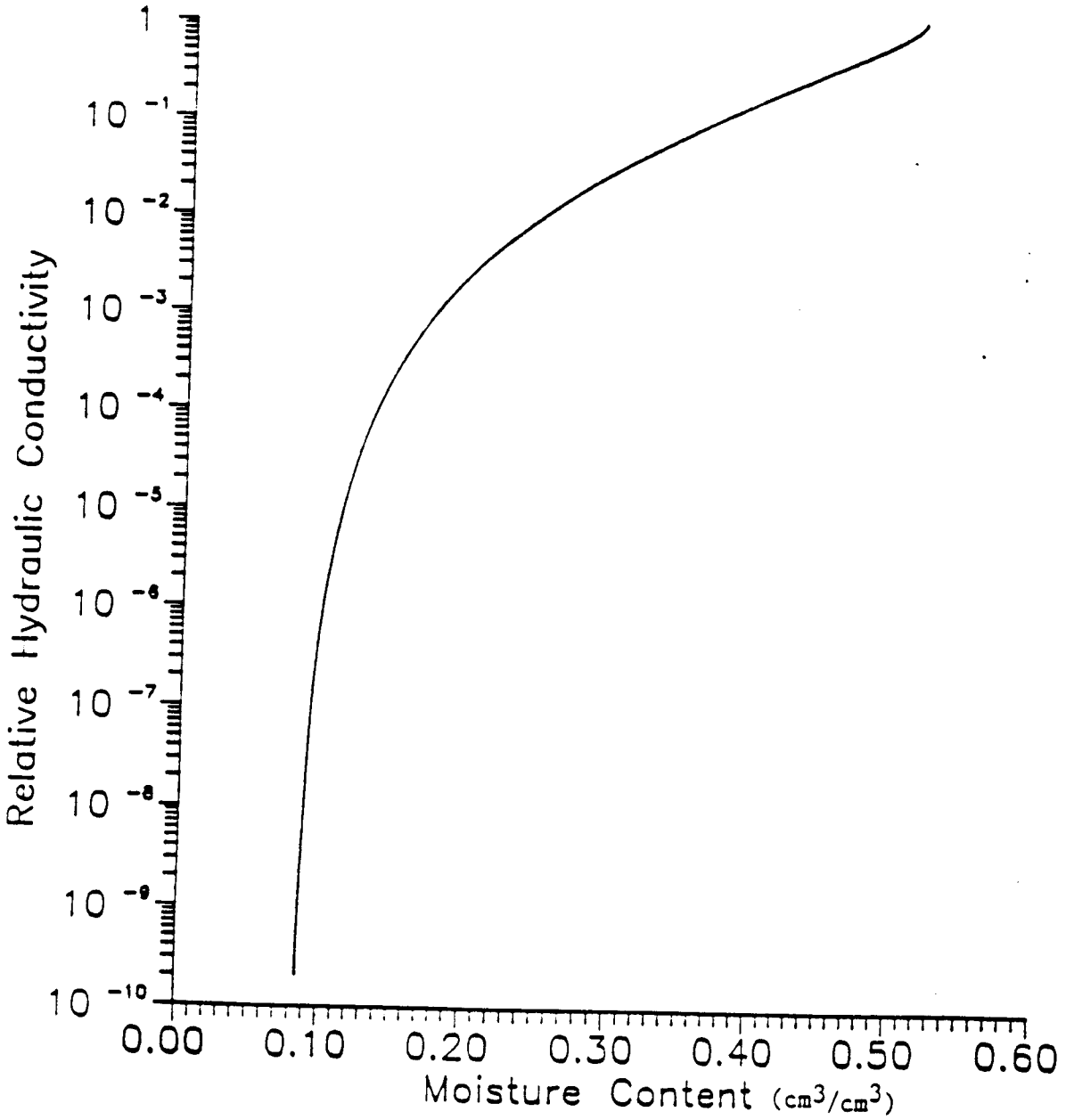


FIGURE NUMBER:	Relative Hydraulic Conductivity vs. Moisture Content (cm^3/cm^3), Sample No. 7-8				DANIEL B. STEPHENS & ASSOCIATES, INC.
FOR: Los Alamos	PROJECT NO: 87-L-070	DATE: 1/4/88	PLOTTED BY: SLS	CHECKED BY: WBC	

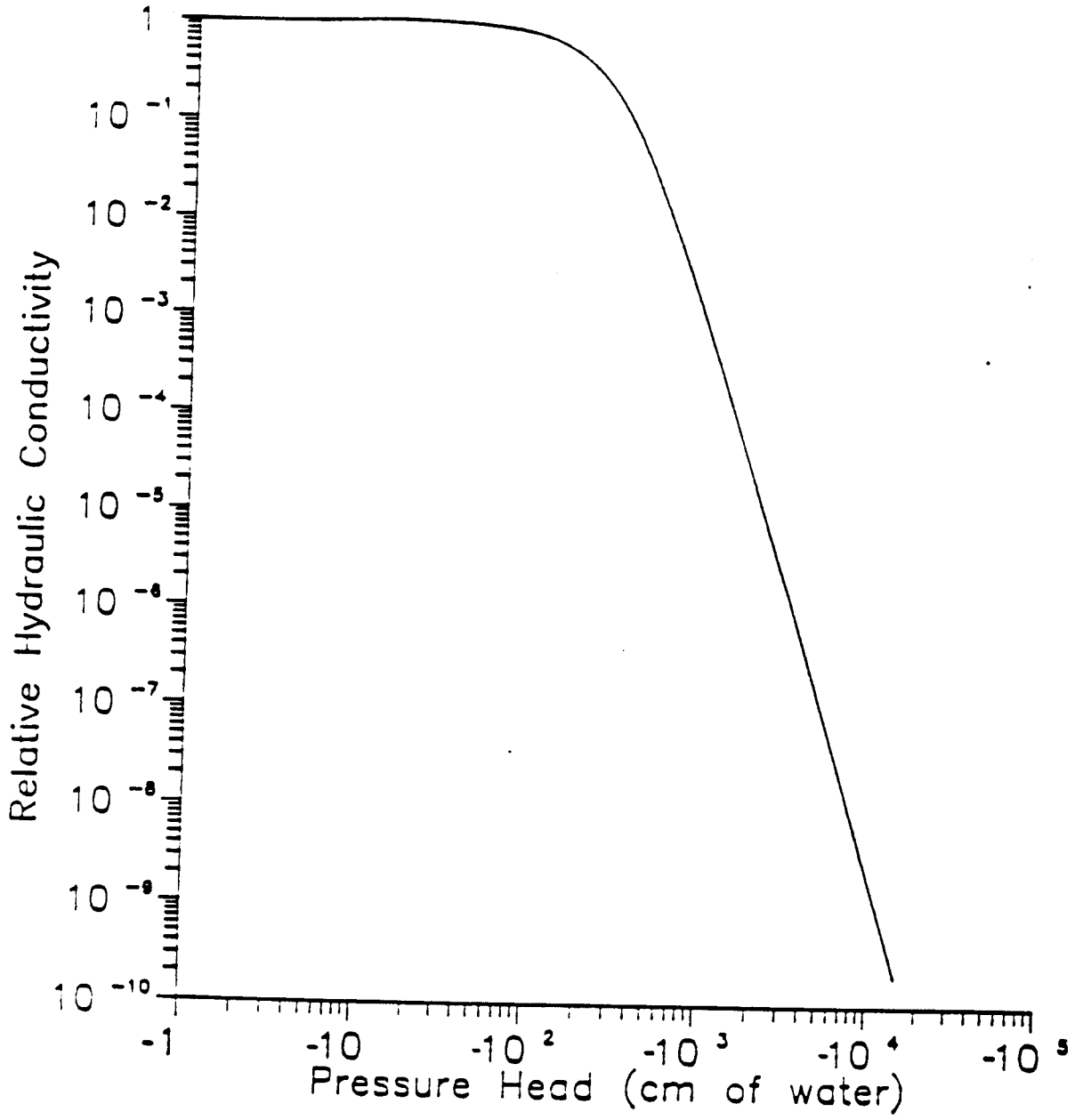


FIGURE NUMBER:	Relative Hydraulic Conductivity vs. Pressure Head (cm of water), Sample No.7-8				DANIEL B. STEPHENS & ASSOCIATES, INC.
FOR: Los Alamos	PROJECT NO. 87-L-070	DATE: 1/4/88	PLOTTED BY: SLS	CHECKED BY: WBC	

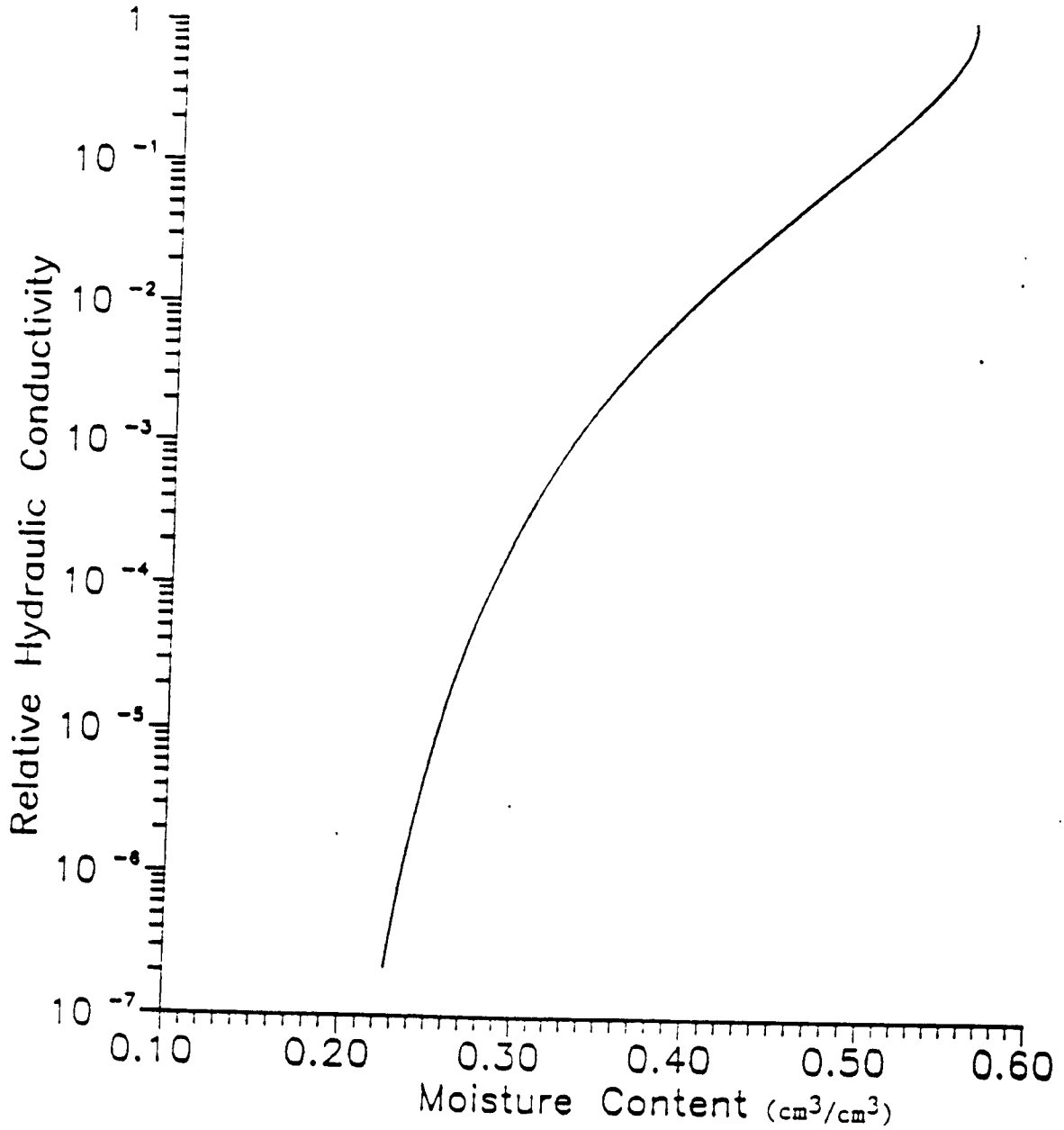


FIGURE NUMBER	Relative Hydraulic Conductivity vs. Moisture Content (cm^3/cm^3), Sample No. 11-12				
FOR: Los Alamos	PROJECT NO: 87-L-070	DATE: 1/4/88	PLOTTED BY: SLS	CHECKED BY: WBC	DANIEL B. STEPHENS & ASSOCIATES, INC.

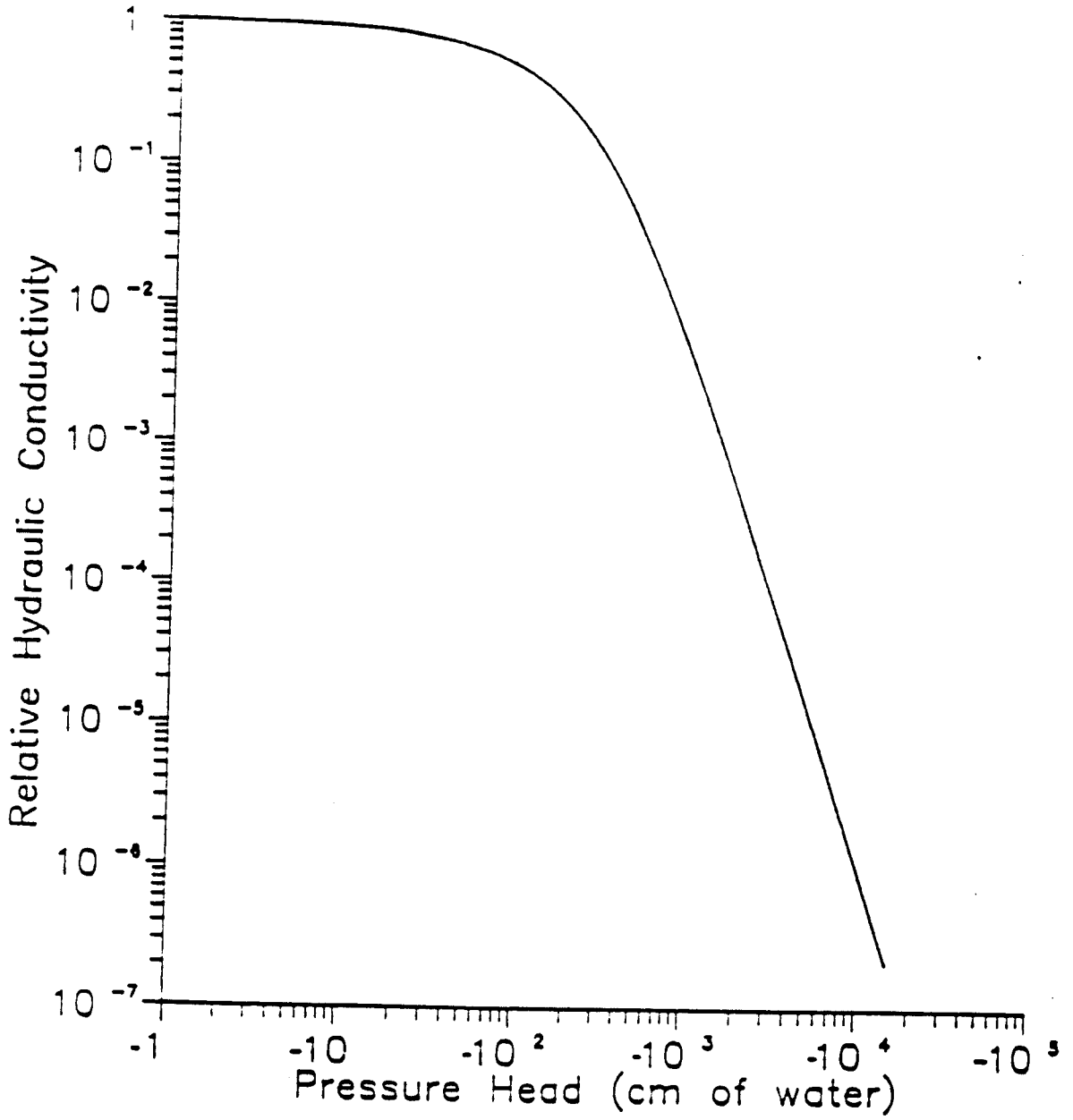


FIGURE NUMBER	Relative Hydraulic Conductivity vs. Pressure Head (cm of water), Sample No. 11-12				DANIEL B. STEPHENS & ASSOCIATES, INC.
FOR: Los Alamos	PROJECT NO: 87-L-070	DATE: 1/4/88	PLOTTED BY: SLS	CHECKED BY: WBC	

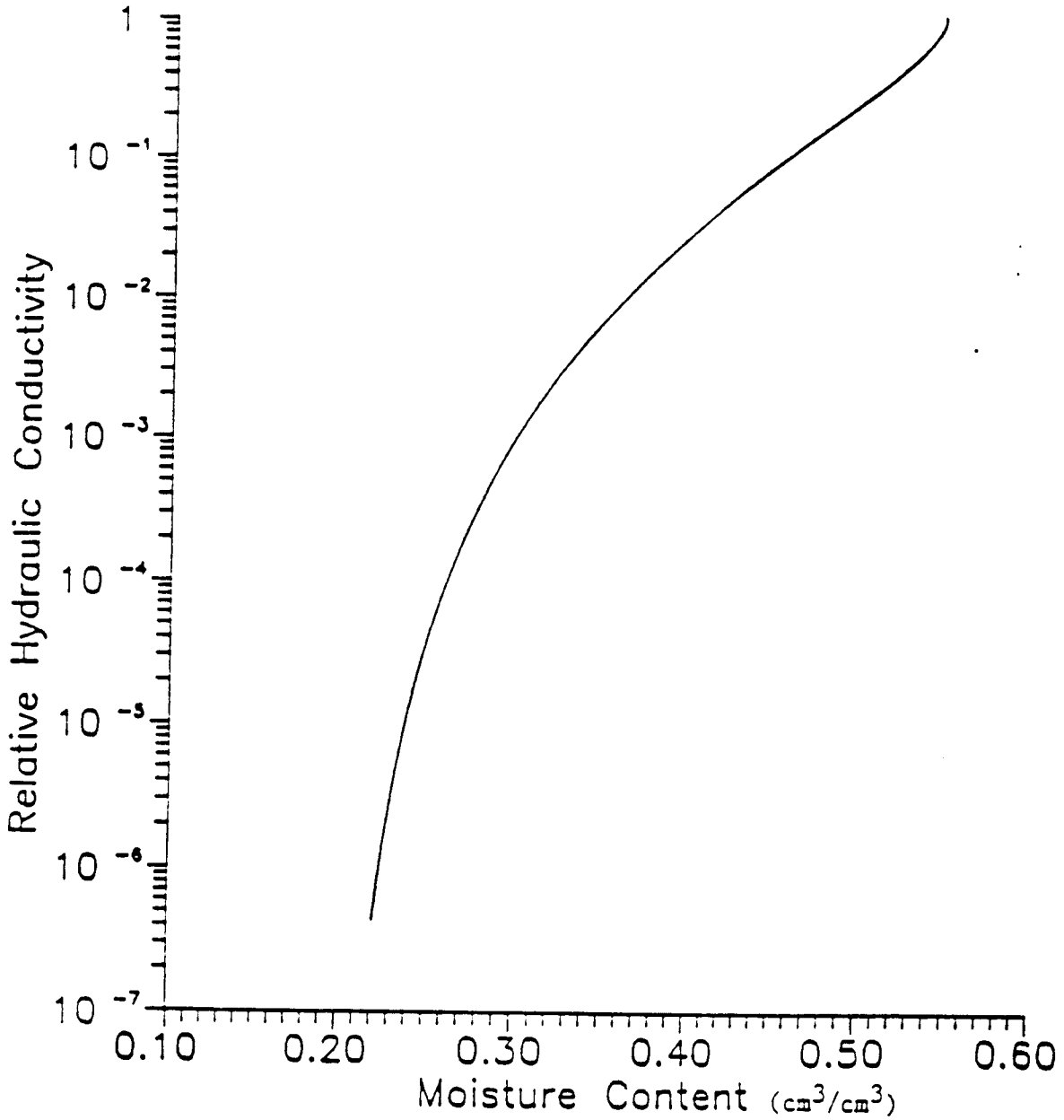


FIGURE NUMBER:	Relative Hydraulic Conductivity vs. Moisture Content (cm^3/cm^3), Sample No. 16-17				DANIEL B. STEPHENS & ASSOCIATES, INC.
FOR: Los Alamos	PROJECT NO: 87-L-070	DATE: 1/4/88	PLOTTED BY: SLS	CHECKED BY: WBC	

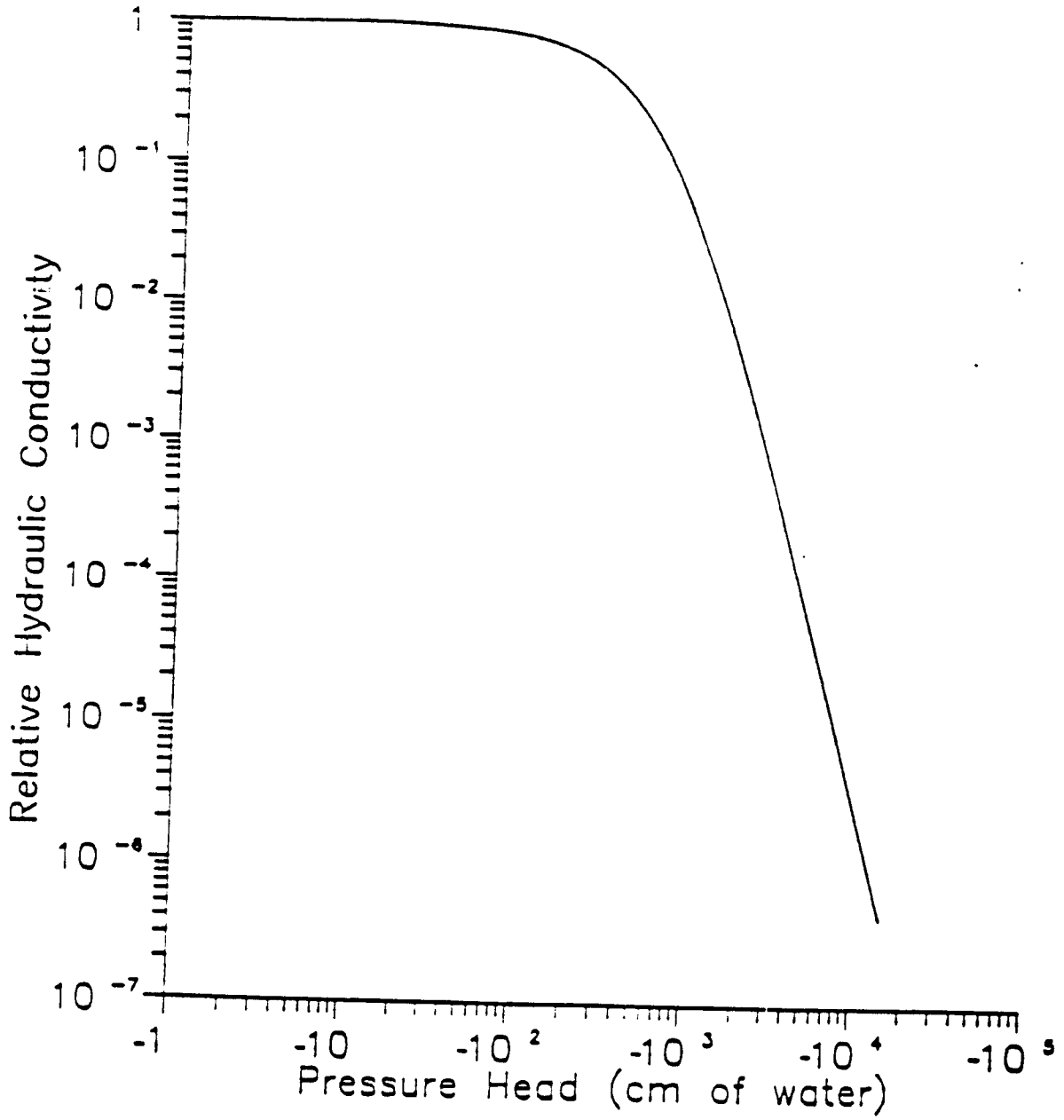


FIGURE NUMBER	Relative Hydraulic Conductivity vs. Pressure Head (cm of water), Sample No. 16-17				DANIEL B. STEPHENS & ASSOCIATES, INC.
FOR: Los Alamos	PROJECT NO: 87-L-070	DATE: 1/4/88	PLOTTED BY: SLS	CHECKED BY: WBC	

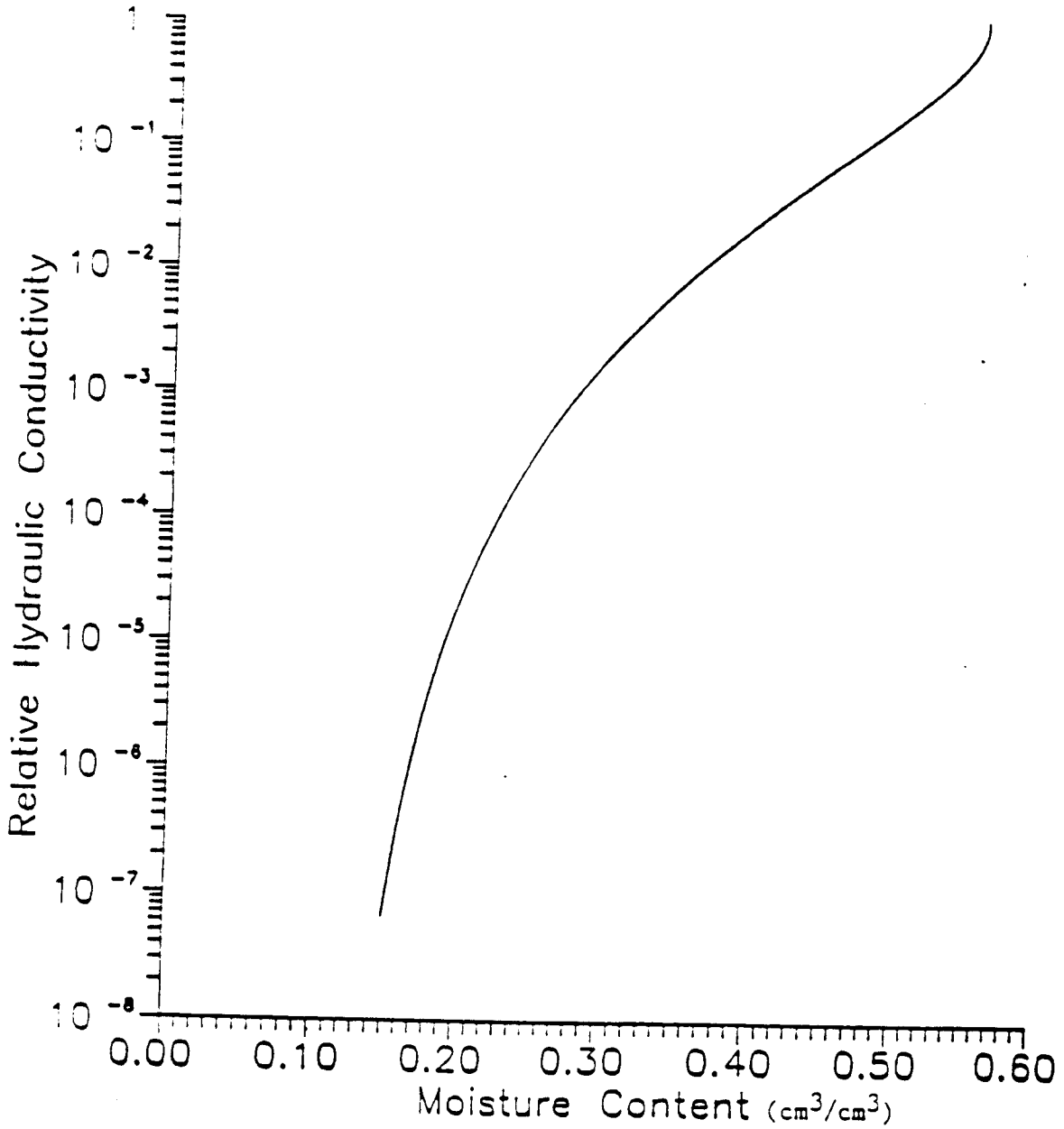


FIGURE NUMBER:	Relative Hydraulic Conductivity vs. Moisture Content (cm^3/cm^3), Sample No. 21-22				DANIEL B. STEPHENS & ASSOCIATES, INC.
FOR: Los Alamos	PROJECT NO: 87-L-070	DATE: 1/4/88	PLOTTED BY: SLS	CHECKED BY: WBC	

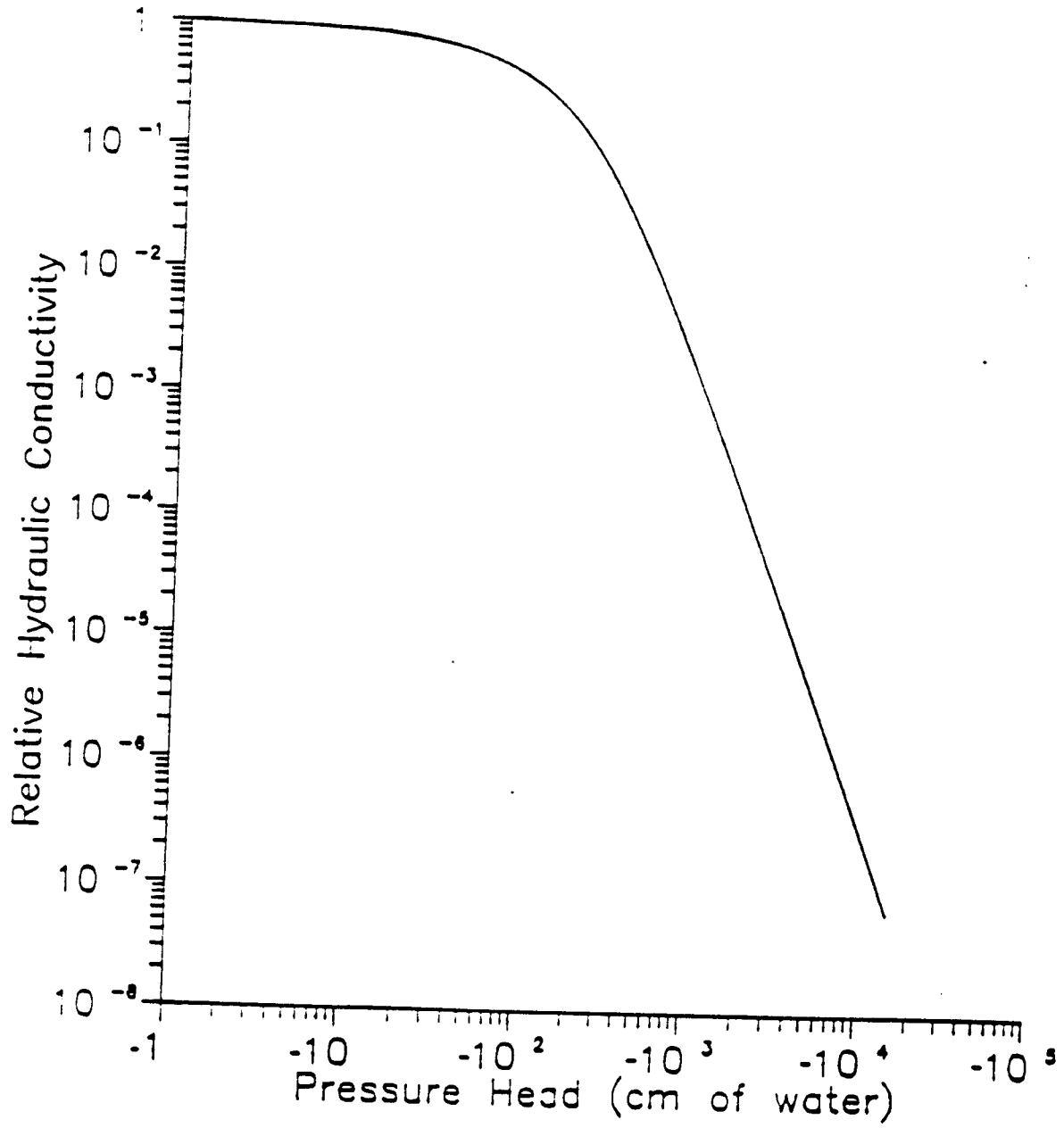


FIGURE NUMBER	Relative Hydraulic Conductivity vs. Pressure Head (cm of water), Sample No. 21-22				
FOR: Los Alamos	PROJECT NO: 87-L-070	DATE: 1/4/88	PLOTTED BY: SLS	CHECKED BY: WBC	DANIEL B. STEPHENS & ASSOCIATES, INC.

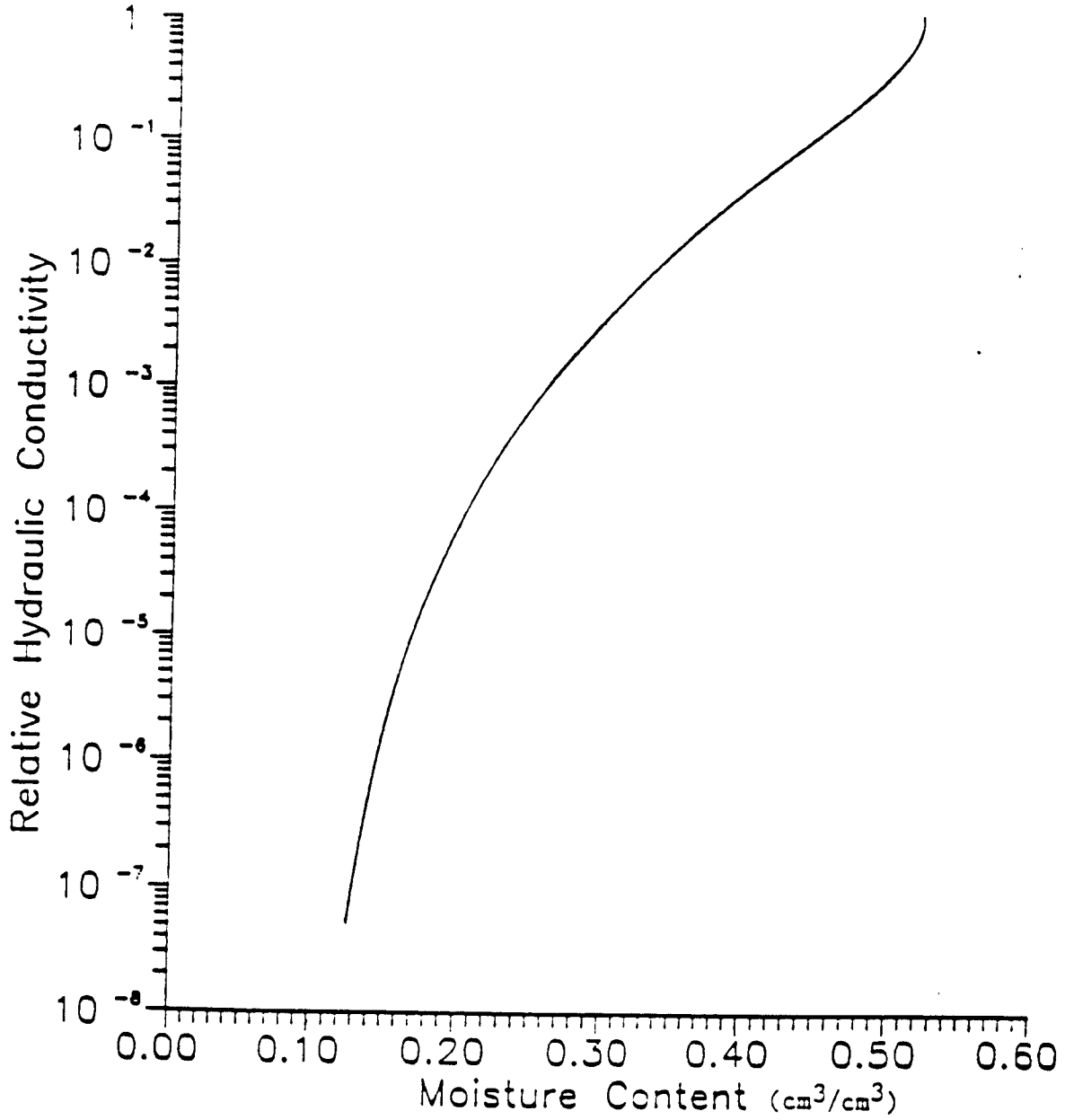


FIGURE NUMBER:	Relative Hydraulic Conductivity vs. Moisture Content (cm^3/cm^3), Sample No. 25-26				DANIEL B. STEPHENS & ASSOCIATES, INC.
FOR: Los Alamos	PROJECT NO: 87-L-070	DATE: 1/4/88	PLOTTED BY: SLS	CHECKED BY: WBC	

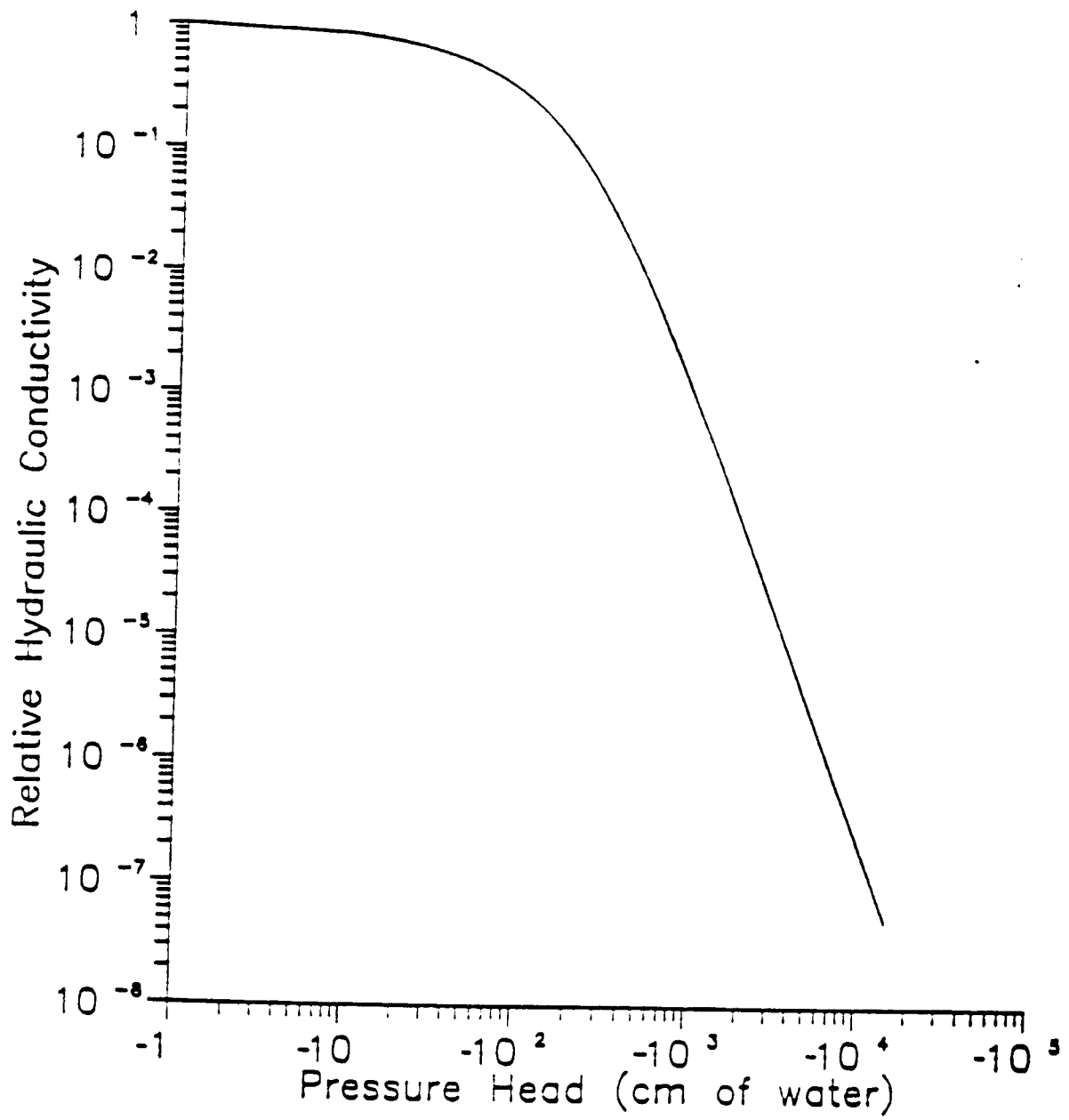


FIGURE NUMBER:	Relative Hydraulic Conductivity vs. Pressure Head (cm of water), Sample No. 25-26				DANIEL B. STEPHENS & ASSOCIATES, INC.
FOR: Los Alamos	PROJECT NO: 87-L-070	DATE: 1/4/88	PLOTTED BY: SLS	CHECKED BY: WBC	

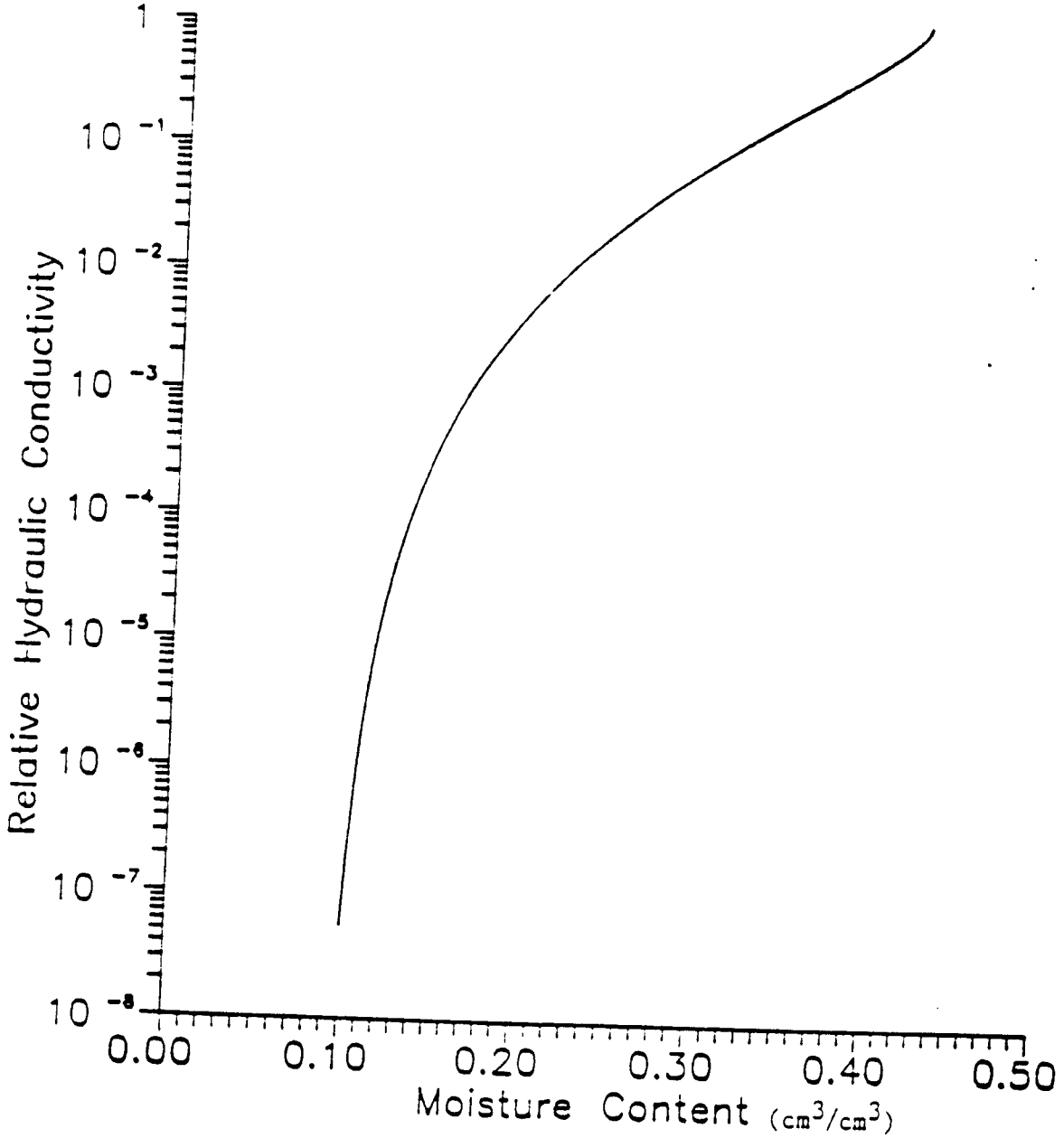


FIGURE NUMBER:	Relative Hydraulic Conductivity vs. Moisture Content (cm^3/cm^3), Sample No. 35-36				DANIEL B. STEPHENS & ASSOCIATES, INC.
FOR: Los Alamos	PROJECT NO: 87-L-070	DATE: 1/4/88	PLOTTED BY: SLS	CHECKED BY: WBC	

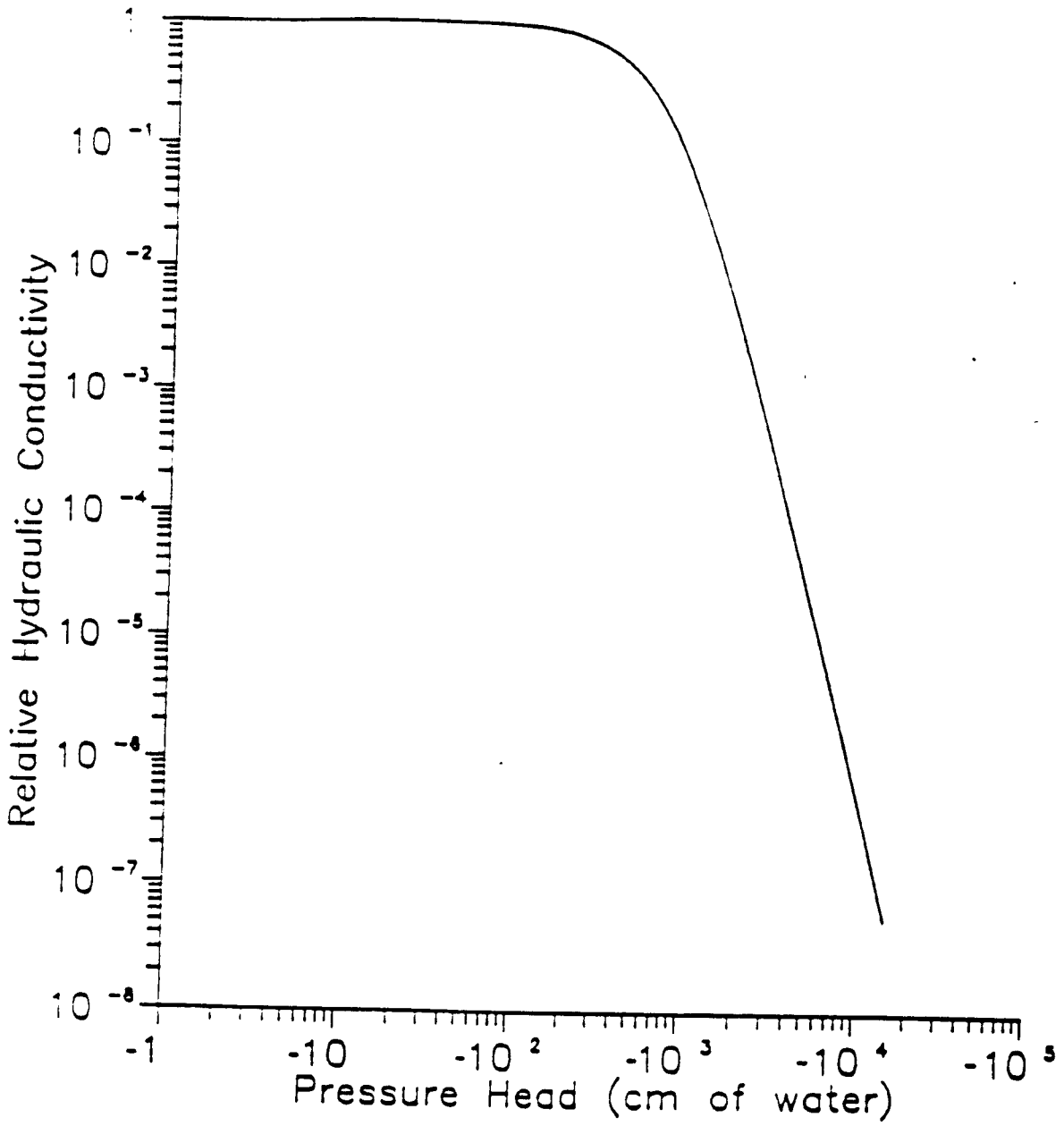


FIGURE NUMBER	Relative Hydraulic Conductivity vs. Pressure Head (cm of water), Sample No. 35-36				DANIEL B. STEPHENS & ASSOCIATES, INC.
FOR: Los Alamos	PROJECT NO: 87-L-070	DATE: 1/4/88	PLOTTED BY: SLS	CHECKED BY: WBC	

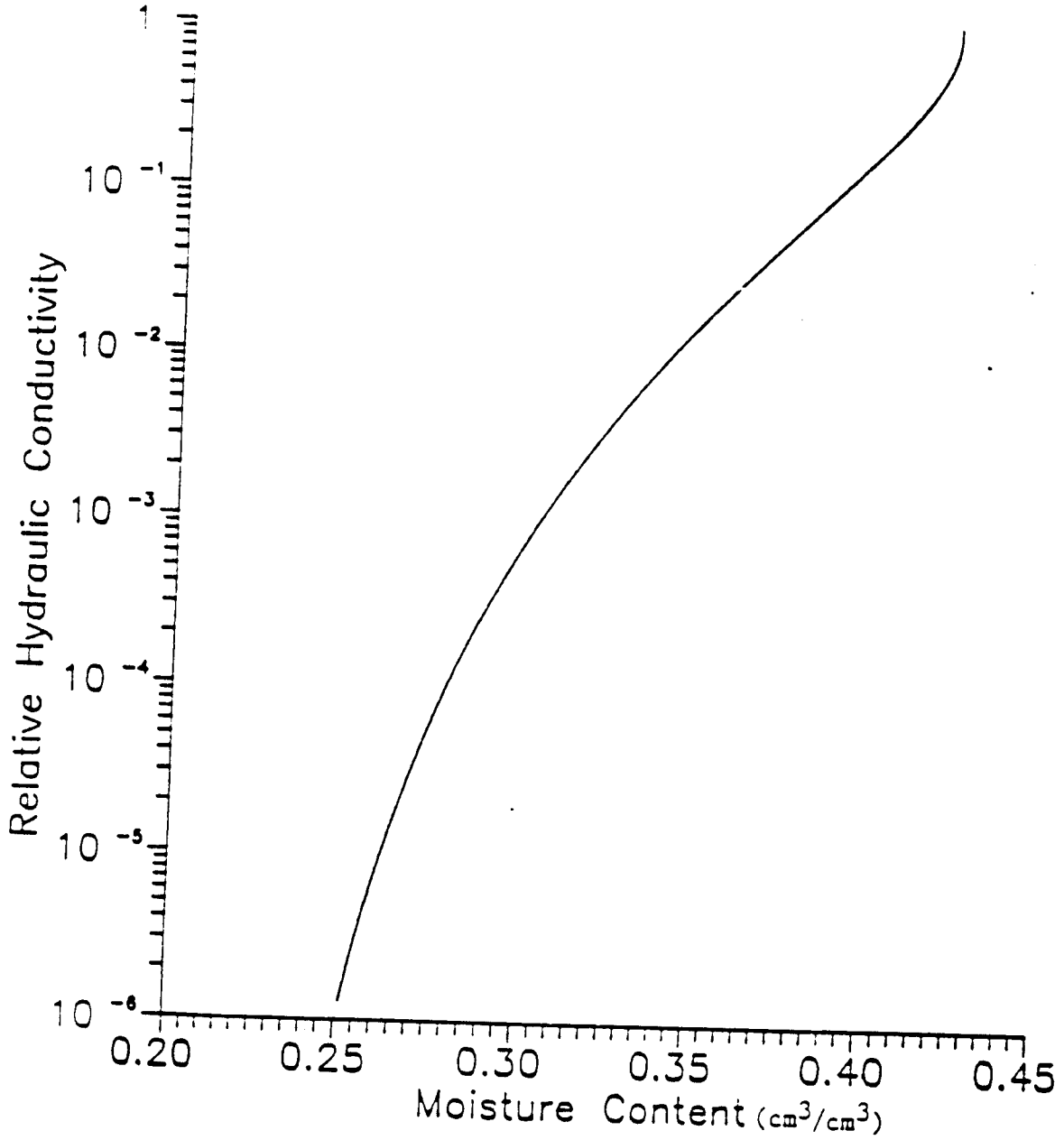


FIGURE NUMBER:	Relative Hydraulic Conductivity vs. Moisture Content (cm^3/cm^3), Sample No. 42-43				DANIEL B. STEPHENS & ASSOCIATES, INC.
FOR: Los Alamos	PROJECT NO: 87-L-070	DATE: 1/4/88	PLOTTED BY: SLS	CHECKED BY: WBC	

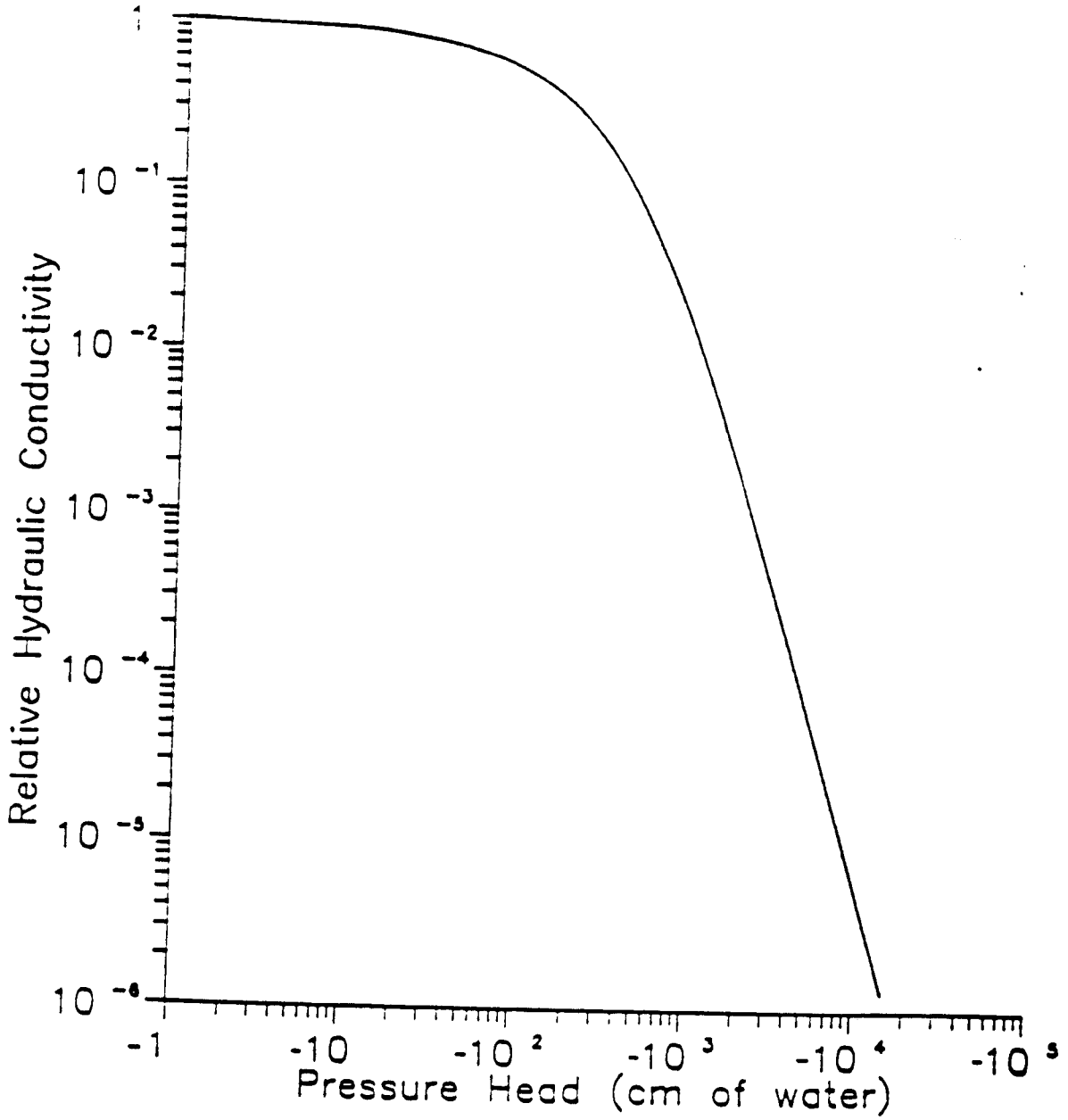


FIGURE NUMBER	Relative Hydraulic Conductivity vs. Pressure Head (cm of water), Sample No. 42-43				DANIEL B. STEPHENS & ASSOCIATES, INC.
FOR: Los Alamos	PROJECT NO: 87-L-070	DATE: 1/4/88	PLOTTED BY: SLS	CHECKED BY: WBC	

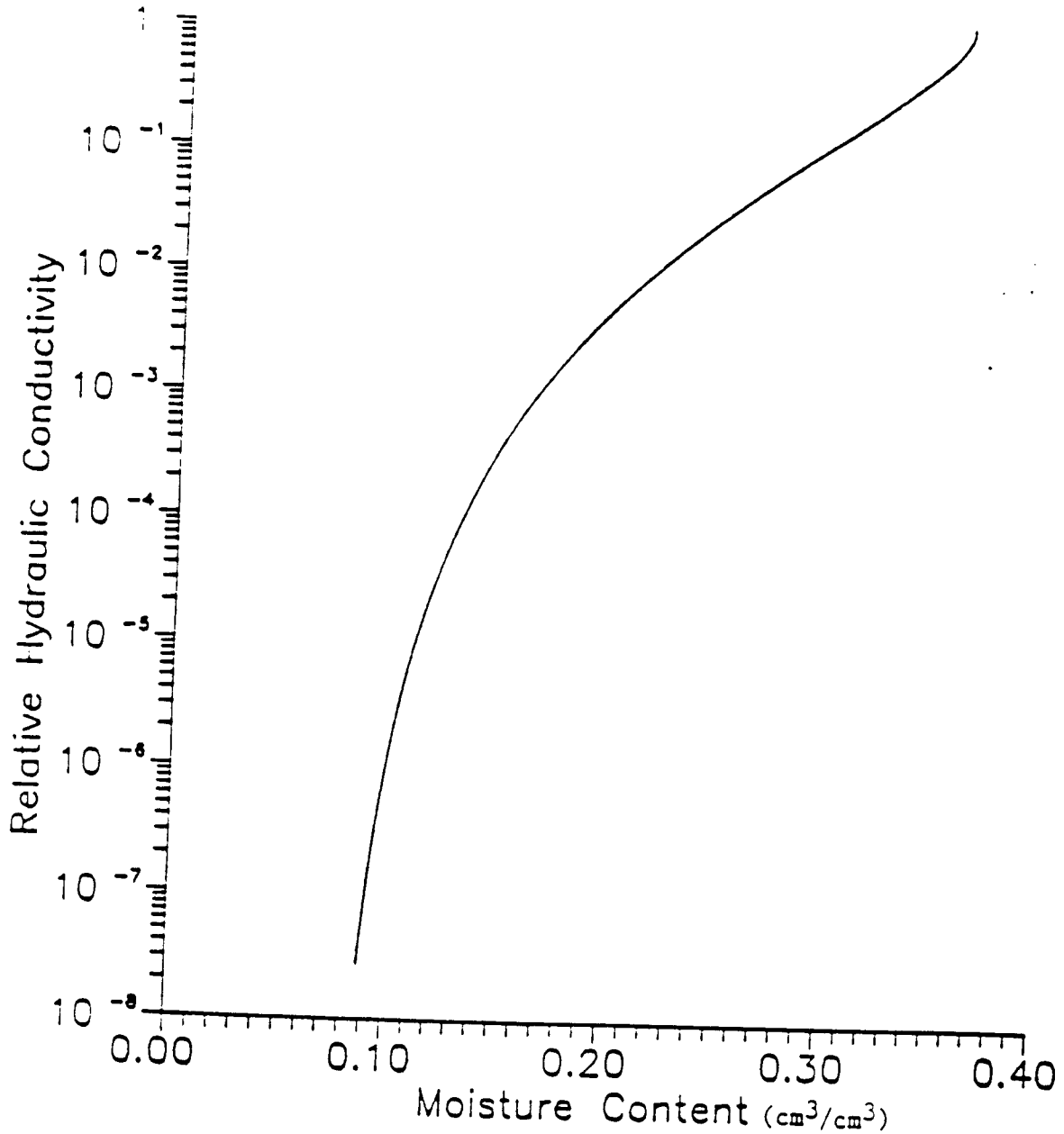


FIGURE NUMBER	Relative Hydraulic Conductivity vs. Moisture Content (cm^3/cm^3), Sample No. 61-62				DANIEL B. STEPHENS & ASSOCIATES, INC.
FOR: Los Alamos	PROJECT NO: 87-L-070	DATE: 1/4/88	PLOTTED BY: SLS	CHECKED BY: WBC	

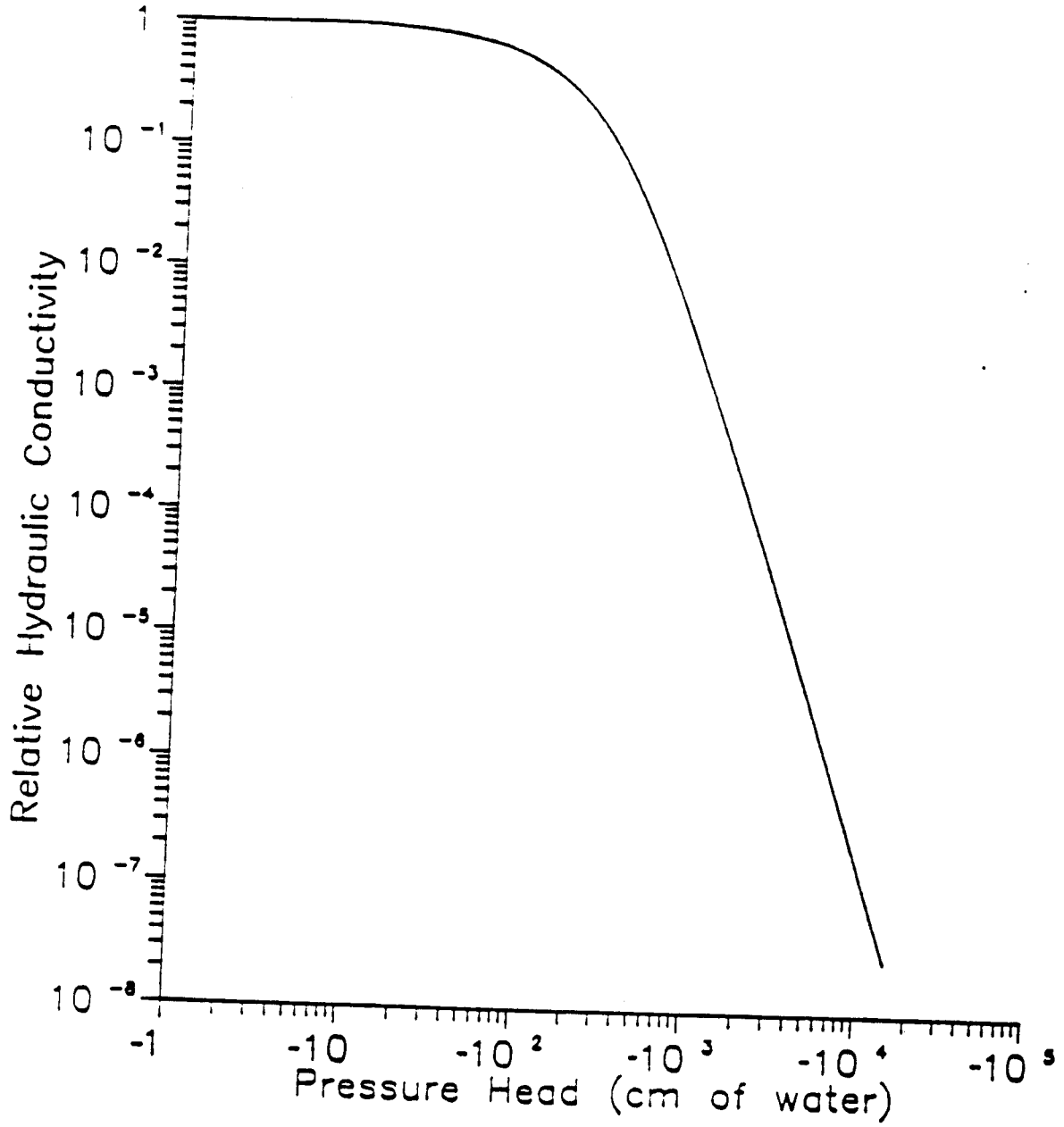


FIGURE NUMBER	Relative Hydraulic Conductivity vs. Pressure Head (cm of water), Sample No. 61-62				DANIEL B. STEPHENS & ASSOCIATES, INC.
FOR: Los Alamos	PROJECT NO: 87-L-070	DATE: 1/4/88	PLOTTED BY: SLS	CHECKED BY: WBC	

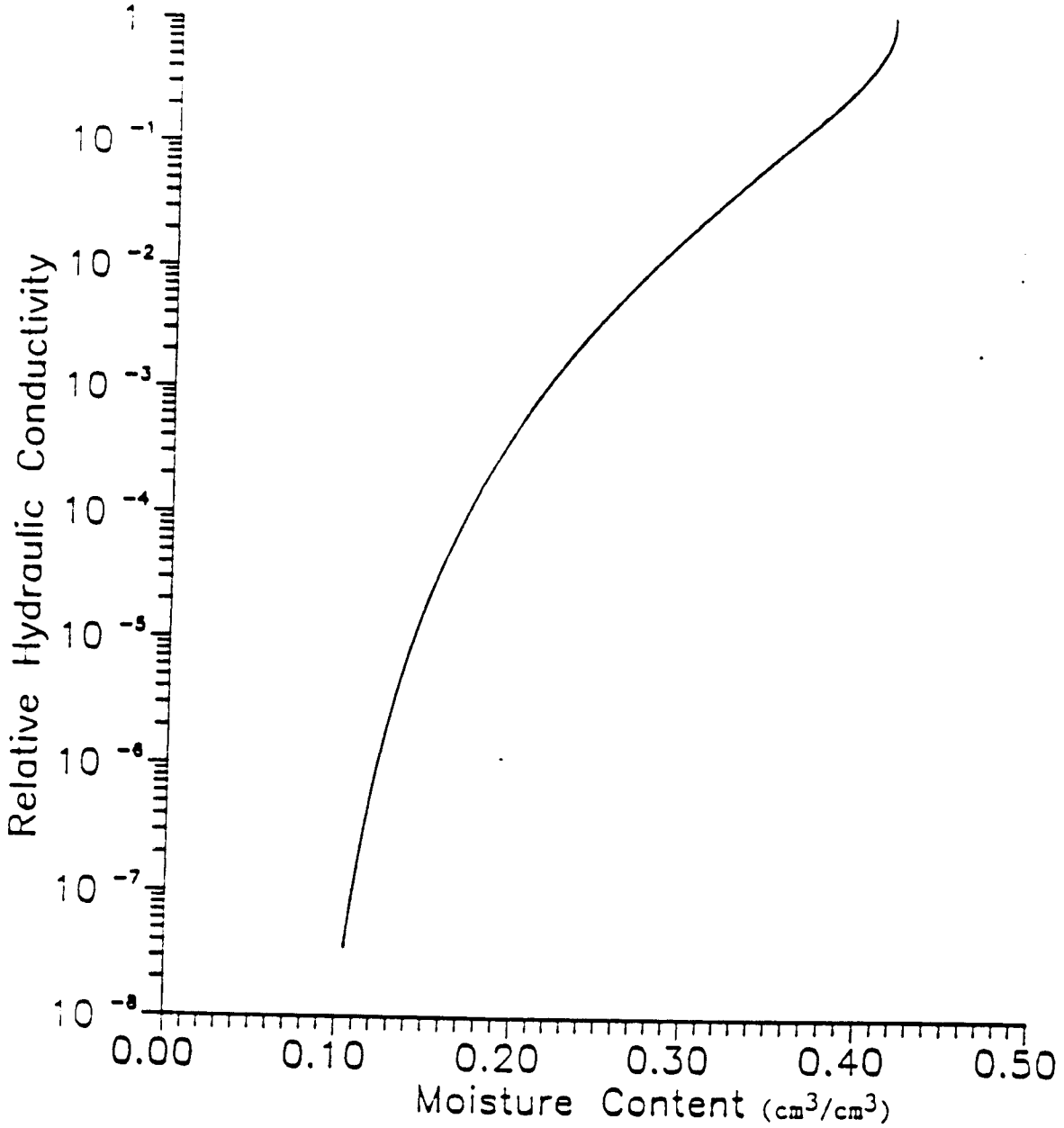


FIGURE NUMBER	Relative Hydraulic Conductivity vs. Moisture Content (cm^3/cm^3), Sample No. 61-62				DANIEL B. STEPHENS & ASSOCIATES, INC.
FOR: Los Alamos	PROJECT NO: 87-L-070	DATE: 1/4/88	PLOTTED BY: SLS	CHECKED BY: WBC	

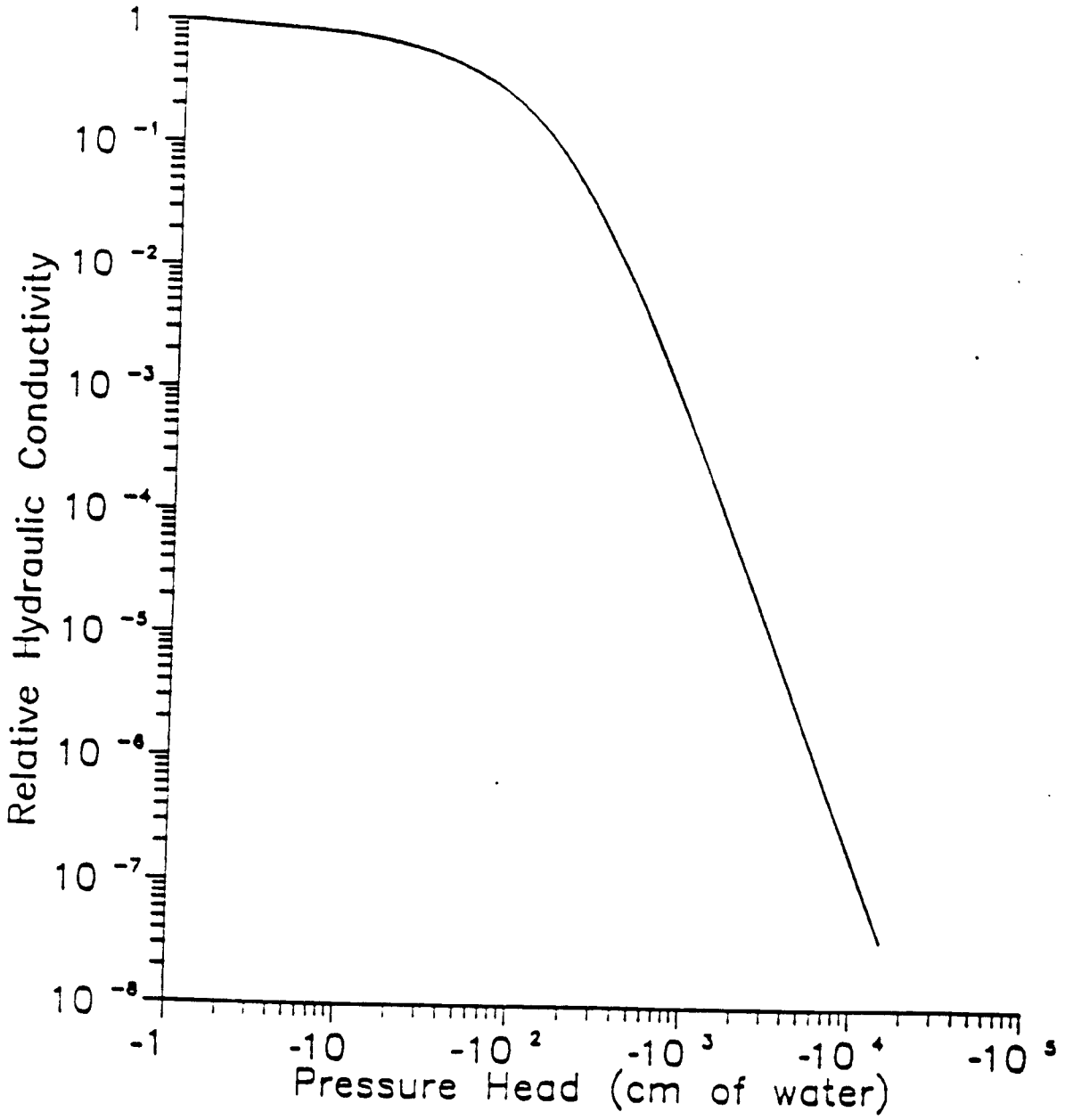


FIGURE NUMBER	Relative Hydraulic Conductivity vs. Pressure Head (cm of water), Sample No. 75-76				DANIEL B. STEPHENS & ASSOCIATES, INC.
FOR: Los Alamos	PROJECT NO: 87-L-070	DATE: 1/4/88	PLOTTED BY: SLS	CHECKED BY: WBC	

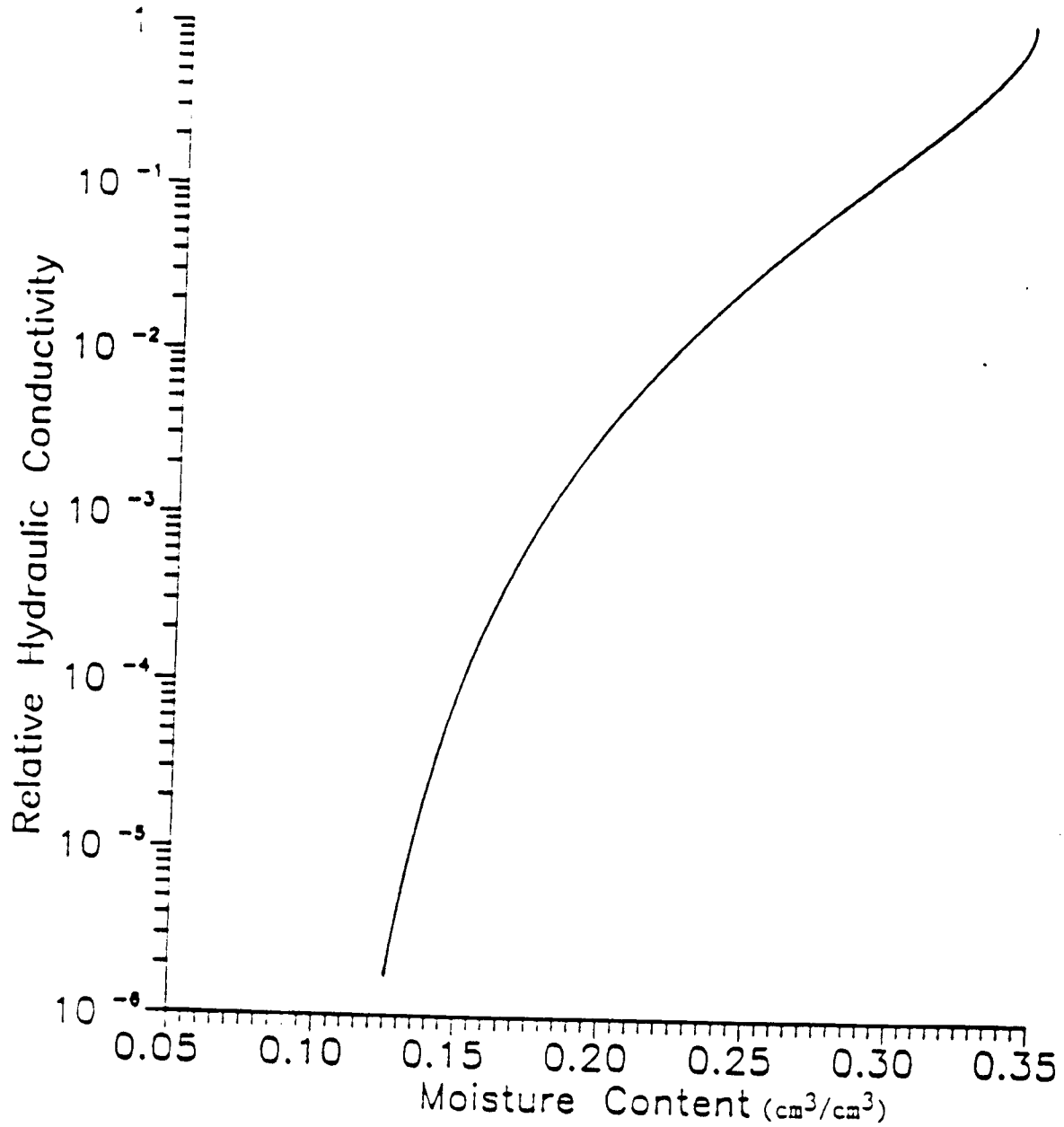


FIGURE NUMBER	Relative Hydraulic Conductivity vs. Moisture Content (cm^3/cm^3), Sample NO. 80-81				DANIEL B. STEPHENS & ASSOCIATES, INC.
FOR: Los Alamos	PROJECT NO: 87-L-070	DATE: 1/4/88	PLOTTED BY: SLS	CHECKED BY: WBC	

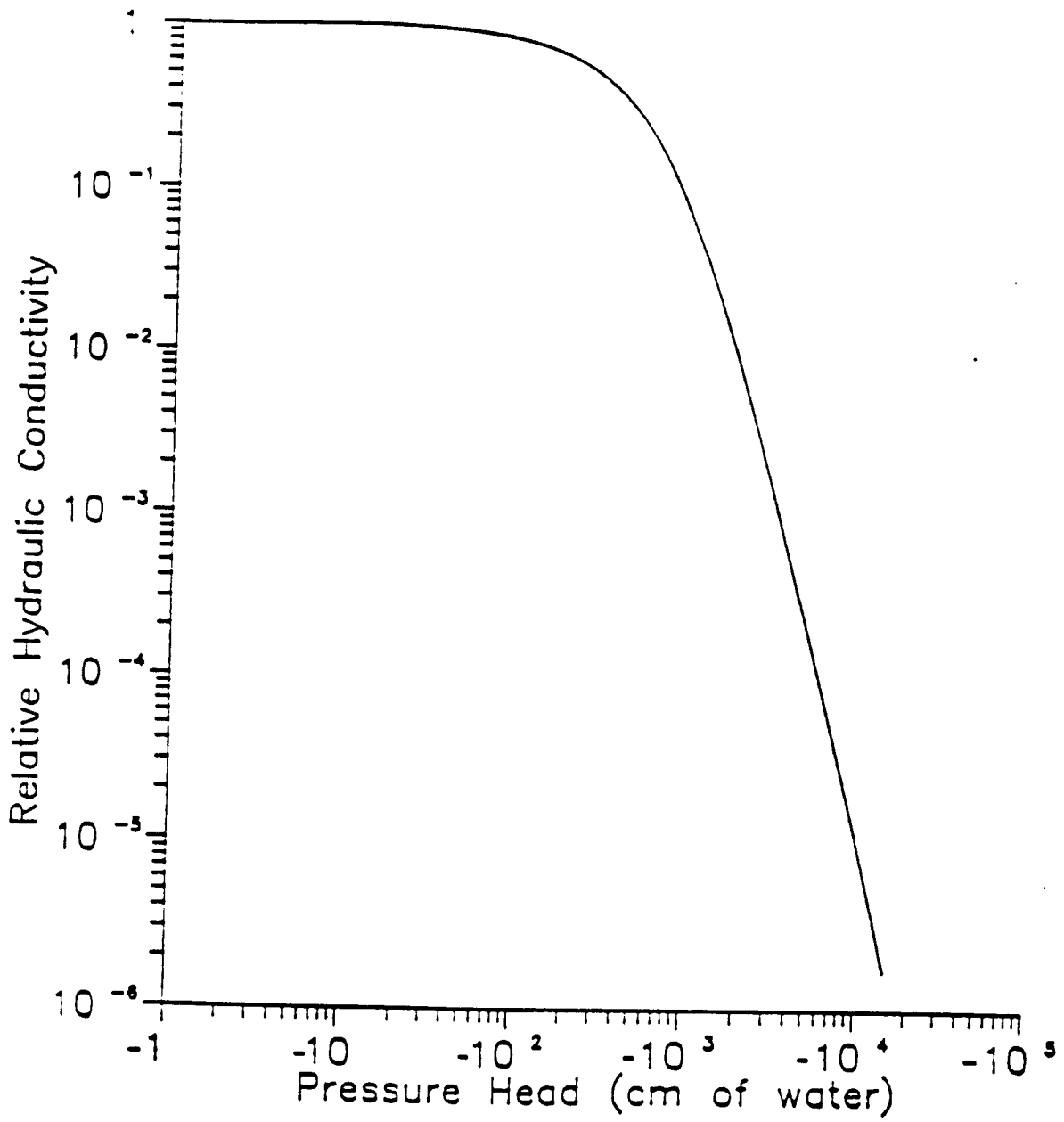


FIGURE NUMBER	Relative Hydraulic Conductivity vs. Pressure Head (cm of water), Sample No. 80-81				DANIEL B. STEPHENS & ASSOCIATES, INC.
FOR: Los Alamos	PROJECT NO. 87-L-070	DATE: 1/4/88	PLOTTED BY: SLS	CHECKED BY: WBC	

PRINCIPLES AND METHODS

MOISTURE RETENTION - PRESSURE PLATE

Principle

The operation of the pressure plate moisture extractor requires maintaining a pressure difference between the liquid phase of the water in the soil and water on the opposite side of a porous plate which supports the soil sample. The sample and porous plate are sealed in a rigid container so that positive gas pressure applied above the plate causes flow to occur across the plate (Figure B-4). The porous ceramic plate is supported by a fine mesh screen which also provides a passage way for the extracted solution. The water beneath the plate is open to the atmosphere through the outflow tube. The illustration in Figure B-5 shows a magnified view of soil particles in contact with the plate inside the pressure plate extractor during an extraction run.

As soon as air pressure inside the chamber is raised above atmospheric pressure, the higher pressure inside the chamber forces excess water through the microscopic pores in the plate. Air, however, will not flow through the pores of the plate, because the plate remains saturated due to its high air-entry pressure. When the pressure in the chamber increases, water leaves the sample until the tension of the water

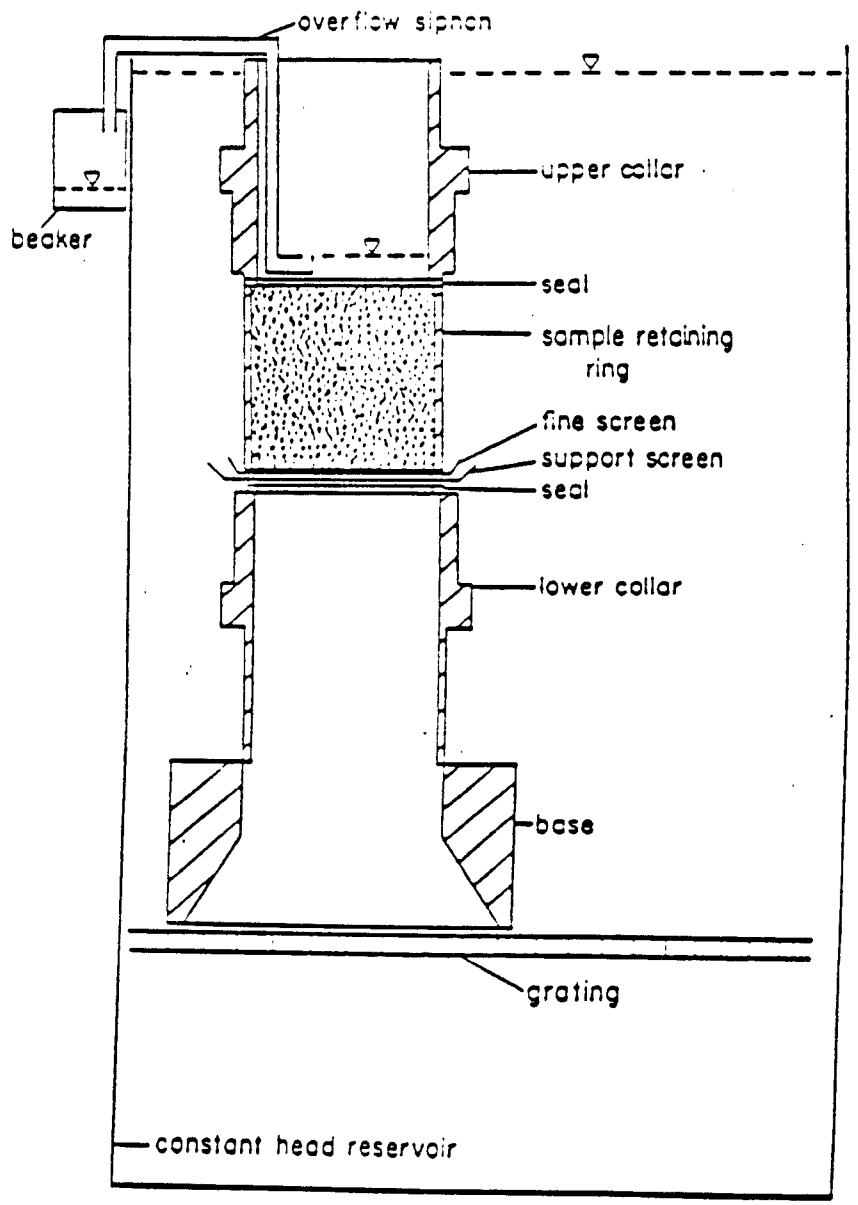


Figure B-1. Constant Head Permeameter

Falling head. A soil sample of length L and cross sectional area, A, is placed in a sample holder which has a standpipe with cross-sectional area, a. A head of H_1, is established in the standpipe above the sample, then the water level is allowed to fall to H_2 in time t. Figure B-2 is a diagram of the apparatus used. A falling head system is best suited to samples with conductivities less than 10^{-4} cm/sec. The hydraulic conductivity, is then defined as:

$$K = (a \times L/A \times t) \ \ln (H_1/H_2)(V_T/V_{20}) \qquad (2)$$

Procedures:

Constant head. Cylinders containing the soil sample are covered on both ends with loose fitting caps and placed in a shallow pan containing de-aired water. The samples are allowed to wet slowly from below for 24 hours. The samples are removed from the pan, and two screens are placed over one end; a very stiff one of coarse mesh for support and a fine one of either 80 to 100 mesh to prevent any sample from being washed out. The cylinder, with screens attached, is then clamped into the sample retainer and placed in the permeameter. The level of the water in the permeameter reservoir is then slowly raised over a period of hours. When the level in the reservoir reaches to within a few centimeters above the top of the sample, a siphon is placed in the sample retainer assembly to remove water from above

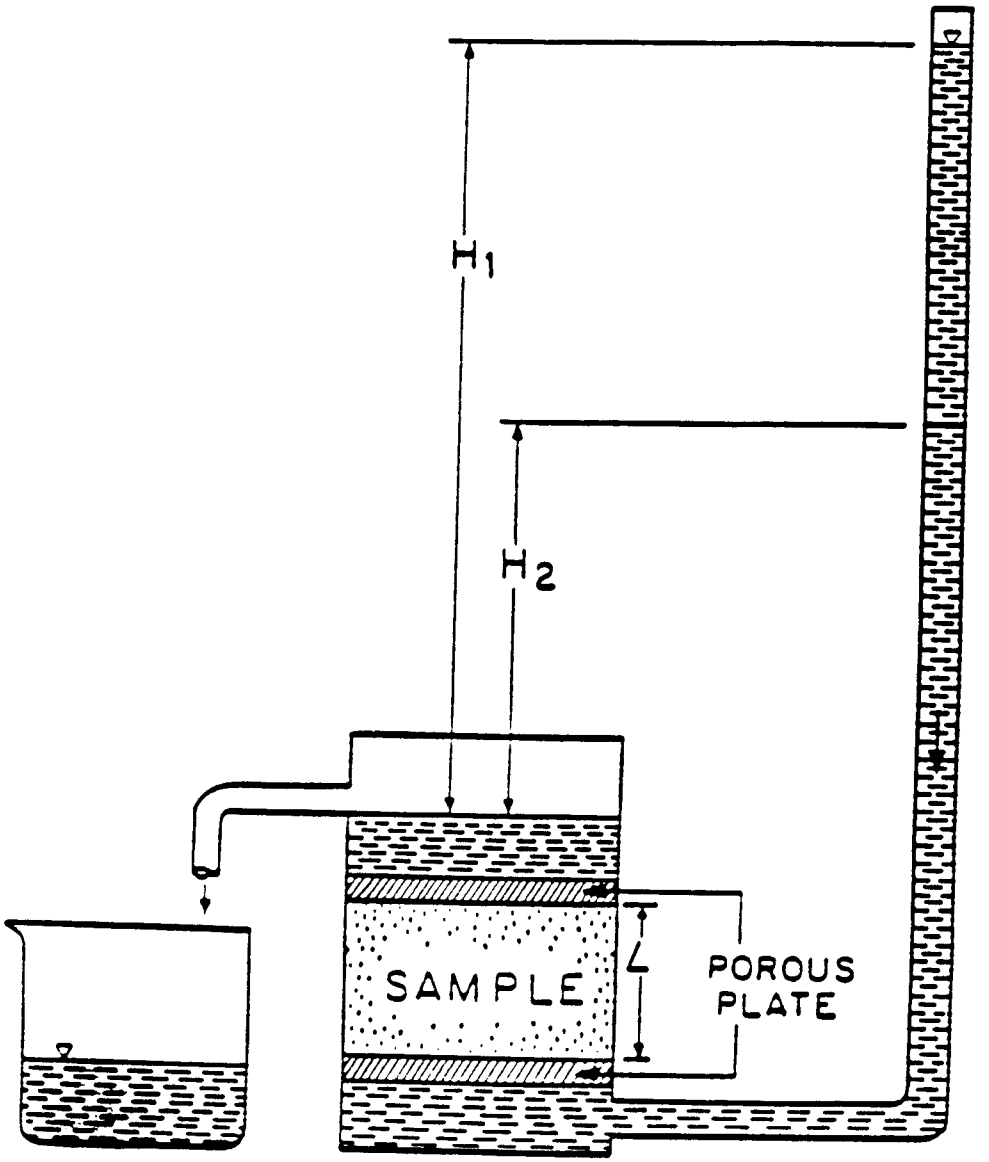


Figure B-2. Falling Head Permeameter

the sample. Water flows upward through the sample due to the hydraulic head difference across the sample. Periodic measurements of discharge and the head difference across the sample are made, and the hydraulic conductivity is calculated. A correction to 20 C is then applied for differences in kinematic viscosity. Measurement continues until the calculated hydraulic conductivity value stabilizes.

Falling head. Saturation of the sample is obtained by the same procedures described under constant head test. Screens are also attached as outlined under constant head test. The ring with screens is then placed in the falling head sample retainer and set in a constant head reservoir. Water is added to the standpipe and the difference between the water level in the standpipe and that in the constant head reservoir are recorded over time. The water level in the standpipe is allowed to fall, while the fluid level in the lower level is constant. After a period of time the difference in water levels between that in the standpipe and that in the constant head reservoir are measured and the elapsed time noted. Correction is applied for kinematic viscosity.

Calculations:

Experimental values are substituted into the appropriate equation as outlined under methods.

MOISTURE RETENTION - HANGING COLUMN

(PORE SIZE DISTRIBUTION)

Principle

Use of pore size distribution as a soil characteristic is based upon acceptance of the capillary model. This model is described by:

$$h' = 2 \cos \gamma / \rho g r \qquad (3)$$

where h' is the height to which a liquid will rise in a clean capillary tube of radius r, γ is the surface tension of the liquid, ρ is its density, and g is acceleration due to gravity. If water is extracted from an initially saturated sample of soil by a tension equal to h', the volume of water extracted is equal to the volume of pores having an effective radius greater than the radius, r. As the tension applied to the sample increases, additional water drains from progressively smaller pores.

Method

The key component of the apparatus for measuring the retention of moisture at different pressure heads or pore size distribution is a fritted glass porous plate that conducts water, but when wet the plate is impermeable to air. The fritted glass

plates have an air-entry pressure of about 300 to 400 cm of water. These plates are affixed in a glass funnel which is connected to a buret with stopcock by means of flexible tubing. A diagram of the apparatus is shown in Figure 3. A soil sample is placed on the plate and tension, h' is applied to the sample by positioning the fluid level in the buret at different levels below the center of the sample. Water flows out of the sample into the buret until equilibrium is achieved. The tension is again increased or decreased to obtain another state of equilibrium between moisture held by capillary forces in the sample and the applied tension.

Laboratory Procedure

Air is first removed from the porous plate by allowing de-aired water to pass continuously through it for 24 hours. The funnel with porous plate and the buret are supported on vertical rods by means of clamps. A saturated sample within its sample ring is then placed on the porous plate, making certain that good hydraulic contact is established between the soil particles and the plate. With the stopcock of the buret closed, the initial level of the water in the buret is recorded.

The buret is then lowered a small increment to about 10 to 15 cm below the center of the soil sample. When the stopcock is opened, the soil may begin to desaturate, and the drainage will flow into the buret. When drainage has ceased, the stopcock is

SATURATED HYDRAULIC CONDUCTIVITY

Method

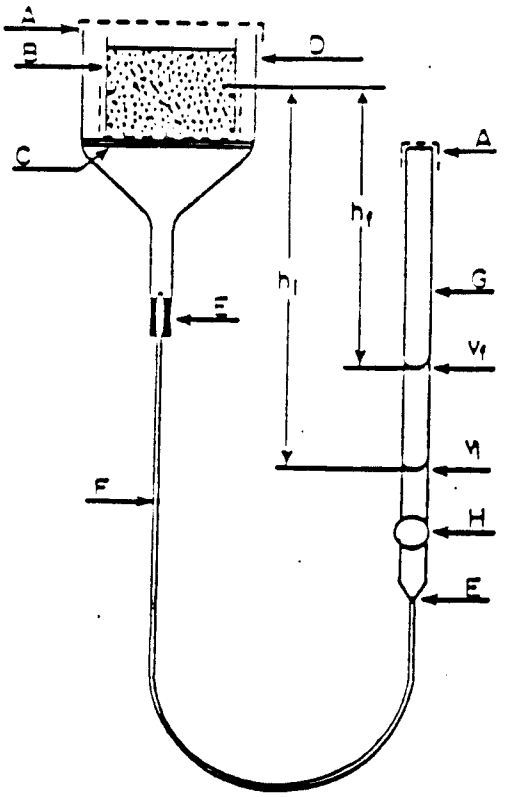
The saturated hydraulic conductivity of a soil sample can be measured in two types of laboratory apparatus: a constant head permeameter or a falling head permeameter.

Constant head. The hydraulic conductivity K is defined here as the ratio of q, the volume flux of water passing through a unit cross sectional area of soil per unit time, and ($\Delta h/L$) or gradient of hydraulic head in the direction of flow, corrected to 20°C:

$$K = (q/[\Delta h/L])(V_T/V_{20}) \qquad (1)$$

where $V_{20,T}$ is the kinematic viscosity at 20°C and observed temperature, T.

A soil sample of length, L, and cross-sectional area, A, is placed in a sample holder which prevents any loss of soil or change in volume and establishes laminar unidirectional flow through the sample. A constant head differential, Δh, is then set up across the sample and maintained. Periodic readings of volumetric outflow are taken until stable values for conductivity, K are obtained. Temperature of the fluid is measured with a thermometer. Figure B-1 is a diagram of the apparatus used. A constant head system is best suited to samples with conductivities greater than 10^{-4} cm/sec.



A Aluminum foil covers
B Sample in cylinder
C Fritted glass porous plate (part of D)
D Büchner funnel with porous plate
E Joints must be secure
F Flexible tubing
G Burette, least division not more than 0.1% sample volume
H Stopcock of burette
h_i cm of water suction, initial
h_f cm of water suction, final
v_i Burette reading, initial
v_f Burette reading, final

Figure B-3. Hanging Column Apparatus

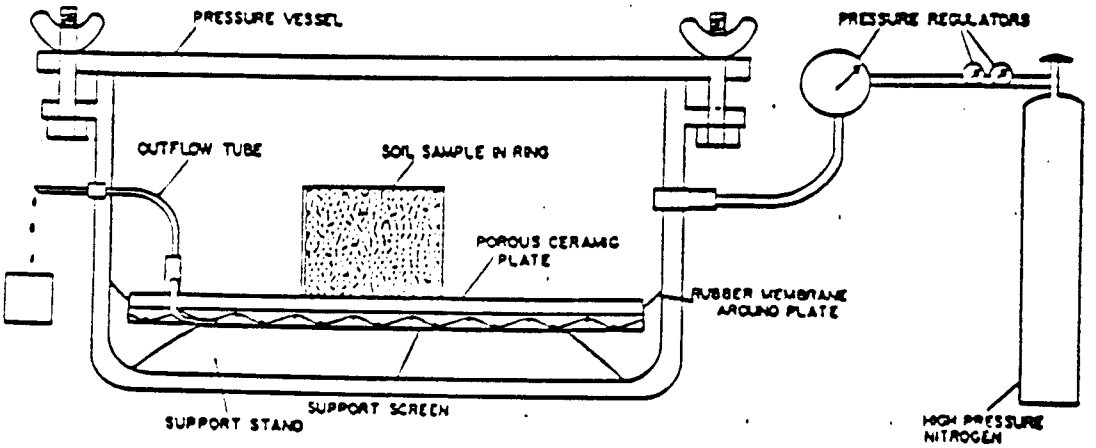


Figure B-4. Pressure Plate Extractor

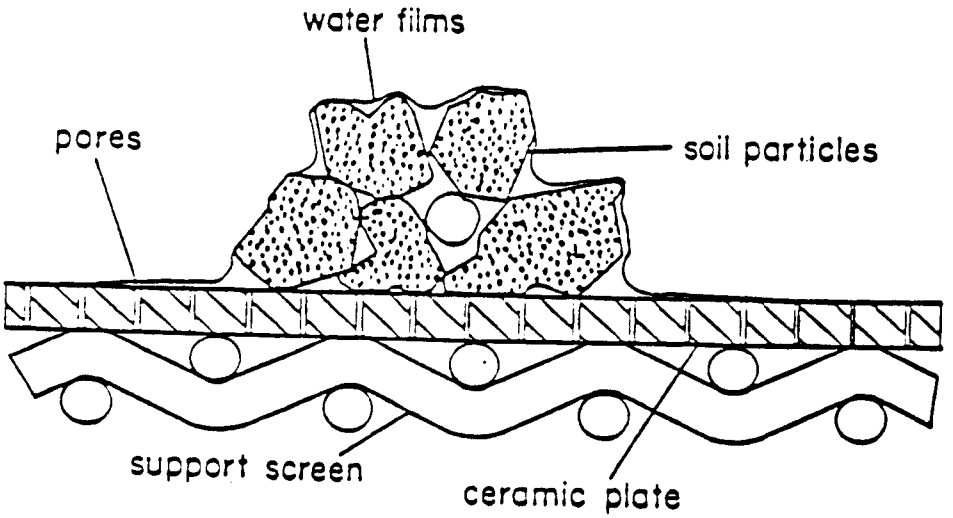


Figure B-5. Magnified View of Soil Particles

closed and we record the water level in the buret and the vertical distance from the bottom of the meniscus of the water in the buret to the middle of the soil sample. The procedure is repeated in a stepwise manner until the maximum tension desired is reached. A reversal of the process is used to gather data on the wetting behavior of the sample.

Calculation

Saturated moisture content , θ_{sat} , (volume percent) is determined as follows:

$$\theta sat = [M\ sat - M\ dry]/[V_T \times \rho_w] \times 100 \quad (\%\ vol) \quad (4)$$

where M sat = mass of sample saturated, M dry = mass of sample, oven dried to a constant weight, V_T = volume of the sample, ρ_w = density of the water at temp when saturated mass was determined. The quantity $[M\ sat - M\ dry]/\rho_w$ is the volume, in cubic centimeters, of water initially contained in the sample volume. The drainage is subtracted from the initial volume of water and then divided by the sample volume to arrive at the moisture content in percent volume at the given value of tension.

$$[V_i - V_D]/V_T \times 100 = \theta_{h'} \quad (\%\ vol) \quad (5)$$

where V = volume of water initial, V_D = cumulative volume drained from sample, V_T = volume of sample, $\theta_{h'}$ = moisture content at the tension value h'. This gives then a paired set of values of tension, or pressure head, versus volumetric moisture content.

due to capillary and adsorptive forces is in equilibrium with the applied pressure.

Method

Moisture retention is obtained using a pressure plate extractor (Soil Moisture Inc., Santa Barbara, CA, Model 1500), with 1, 3 and 15 bar ceramic plates. Pressure is provided by high pressure nitrogen from cylinders.

Laboratory Procedure

The porous ceramic plate is placed is a shallow pan with deaired distilled water and allowed to stand overnight. The plate is then removed from the pan and placed in the extractor. De-aired distilled water is poured over the plate to the limit allowed by the rubber skirt, which generally just submerges the plate. The pressure plate is sealed and pressure brought to 50% of the plates maximum rated pressure. This pressure is maintained until outflow ceases. The extractor is opened and any excess water around the plate is removed.

The soil samples in their sample rings are then placed on the plate, making certain good hydraulic contact is established. The extractor is then sealed and the pressure brought to the level desired. The pressure is maintained until outflow ceases. The extractor is then opened and the samples weighed quickly on an electronic top-loading balance. Subsequently, the samples are

returned to the extractor, and the pressure is increased to the next increment.

Calculations

The decrease in mass of water in the sample during a period of applied pressure is converted to an equivalent decrease in volume of water according to:

$$V_w = \Delta m/\rho_T \qquad \text{(cc)} \qquad (6)$$

where Δm = change in mass of soil sample (g), ρ_T = density of water at temperature of experiment (g/cc), V_w = equivalent volume of water (cc).

Volumes of water calculated from equation 6 are then used to determine the moisture content at that pressure:

$$\theta_p = (V_i - \Sigma\Delta V_w)/V_T \times 100 \qquad \text{(\% vol)} \qquad (7)$$

where θ_p = moisture content at pressure p (% vol), V_i = initial volume of water in sample (cc), $\Sigma\Delta V_w$ = cumulative water volume change (cc), V_T = total volume of the sample (cc).

INITIAL MOISTURE CONTENT

Method

Core method, with oven drying.

Laboratory Procedure

The field weight of the soil sample is determined as soon as possible after the sample is removed from the packing container. The tare of the ring which holds the sample, as well as the mass of the caps for the ends of the ring, are determined. The volume of soil in the sample ring is also calculated. After all specified analyses have been performed on the sample, the sample is removed from its ring and spread in an aluminum pan. When necessary, soil aggregates are broken up by motar and pestal. Care is taken not to change the natural particle size distribution. The sample is placed in a convection oven at 110° C for at least 24 hours until dried to a constant weight.

Calculations

The initial moisture content is determined on a percent volume basis according to:

$$\theta_i = [M_i - M_f]/[V_T \times \rho] \times 100 \quad (\%vol) \qquad (8)$$

where θ_i = initial moisture content (% vol), M_i = initial mass of soil only (g), M_f = final mass of soil only (g), V_T = total

BULK DENSITY

Method

Core method, with oven drying.

Laboratory Procedure

The volume of the soil sample is determined from sample geometry measurements, and the sample is dried in the oven at 110 C until no additional mass loss occurs.

Calculations

$$\rho_b = M_D/V_T \qquad (g/cc) \qquad (9)$$

where ρ_b = dry bulk density (g/cc), M_D = mass of oven dried soil sample (g), V_T = total volume of soil sample (cc).

POROSITY

Method

Calculated from bulk density and measured or assumed values of particle density.

Laboratory Procedure

Bulk density, ρ_b, is determined by oven drying, as described in the section outlining the bulk density determination. For this series of analyses particle density, ρ_s, is assumed to be 2.65 g/cc.

Calculation

$$n = [1 - (\rho_b/\rho_s)] \times 100 \qquad \text{(percent)} \qquad (10)$$

UNSATURATED HYDRAULIC CONDUCTIVITY

Method

Mualem (1976) described the theoretical basis for a procedure used to estimate unsaturated hydraulic conductivity from the soil-water release curve according to the following equations;

$$K_r = S_e^{\frac{1}{2}}\left[\int_0^{S_e} 1/h(x)dx / \int_0^1 1/h(x)\ dx\right]^2 \qquad (11)$$

where K_r = relative hydraulic conductivity, $h = h(S_e)$ is the negative pressure head, given here as a function of dimensionless moisture content:

$$S_e = \theta - \theta_r \ / \ \theta_s - \theta_r \qquad (12)$$

where subscripts s and r indicate saturated and residual values of the soil moisture (θ). The expression relating dimensionless moisture content to the pressure head, and thus the soil moisture release curve is given by:

$$S_e = [\ 1/1+(\alpha h)^n]^m \qquad m = 1 - 1/n \qquad (13)$$

where α, and n are obtained by a non-linear least squares numerical procedure applied to measured moisture retention data using the technique developed by Van Genuchten (1978).

Laboratory procedure

The data input to the computer model of Van Genuchten (1978)

consists of the saturated moisture content, residual moisture content and values of observed pressure head versus moisture content. The residual moisture content is taken to be the moisture content at -15 bars. The paired values of observed pressure head and moisture content are obtained as described under the procedures for determining moisture retention by the hanging column and pressure plate methods. Saturated moisture content is determined through gravimetric measurements and sample geometry.

References

Mualem, Y., 1976, A New Model for Predicating the Hydraulic Conductivity of Unsaturated Porous Media, Water Resources Research, vol. 12, no. 3, p. 513-522.

Van Genuchten, R., 1978, Calculating the Unsaturated Hydraulic Conductivity With a New Closed-Form Analytical Model, Research Report No. 78-WR-08, Princeton University, Department of Civil Engineering, September 1978, 65pp.

APPENDIX C

LA-11521-MS

Los Alamos Environmental Restoration Records Processing Facility

ER Record I.D.# 0006890

A Hydrologic Modeling Study of Water Balance Relationships at the Area P Landfill in Los Alamos, New Mexico

Los Alamos National Laboratory is operated by the University of California for the United States Department of Energy under contract W-7405-ENG-36

Photocomposition by Wendy Rowley, Group IS-11
Manuscript prepared by Sylvia Gonzales, Group HSE-12

This work was supported by the U.S. Department of Energy, Office of Energy Research.

This report was submitted on January 6, 1989.

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LA-11521-MS

UC-402
Issued: March 1989

A Hydrologic Modeling Study of Water Balance Relationships at the Area P Landfill in Los Alamos, New Mexico

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A HYDROLOGIC MODELING STUDY OF WATER BALANCE RELATIONSHIPS AT THE AREA P LANDFILL IN LOS ALAMOS, NEW MEXICO

by

John W. Nyhan

ABSTRACT

The water balance relationships of the Area P landfill in Los Alamos were studied in a preliminary attempt to hydrologically characterize and successfully close this shallow land burial site. The current Resource Conservation and Recovery Act status of the site is discussed, and plans to reach site closure are presented along with the waste use history and description of the site. The precipitation and temperature at the Area P landfill are evaluated and soil volumetric water content data collected at the site are presented, along with calculations of water inventories in the backfill and underlying tuff. The results of hydrologic modeling studies are then presented for various scenarios at the landfill, for both those with and without a final closure cover. A final set of design recommendations is presented relative to improving the final approved closure plan for this landfill.

I. INTRODUCTION

Although shallow land burial (SLB) of wastes began with early civilizations, recently developed rules and regulations require the ability to model hydrologic processes on SLB systems used for the disposal of wastes, such as Waste Disposal Area P at Los Alamos. An important part of hydrologic models for SLB systems is the surface water balance. This balance is an accounting (or budgeting) of water from the soil through its entire profile to the plant rooting depth, an accounting that includes input, output, and storage terms. Precipitation is the input to the system, whereas outputs are net surface runoff, evaporation and transpiration losses, and net subsurface flow. The subsurface flow can be either lateral or vertical; the vertical downward flow below the root zone is often called deep seepage or percolation. Changes in soil water content account for gains in or losses of water stored in the soil profile (see Fig. 1).

Trench covers that isolate wastes at SLB facilities are subject to the interactive factors of a dynamic system, which includes water dynamics. Failure of the trench cap can cause excessive soil erosion, plant and animal intrusion into the waste, and percolation of infiltrated water into the waste ultimately allowing mobilization and transport of chemical wastes. Such failures emphasize the importance of water management at SLB facilities; these failures have been summarized by Nyhan (1989).

Migration barriers are used in SLB facilities to slow or stop the movement of water and contaminants, and are a single component embedded in a complex environmental system (Lane and Nyhan 1984). Migration barrier (moisture, or capillary, barrier) performance is very much a function of interactive processes operating to control water dynamics at SLB facilities. Traditional engineering solutions, which do not include analyses of these interactive factors, have already led to numerous SLB failures. Future designs that ignore the interactive factors controlling the performance of SLB facilities are likely to reproduce many of the failures of the past, including losing the integrity of migration barriers.

However, strictly speaking, with or without a migration barrier in the SLB profile, the current state of the art is that adequate data do not exist from carefully instrumented, large-scale field experiments on the movement of water and contaminants under unsaturated conditions to enable a site operator to define and

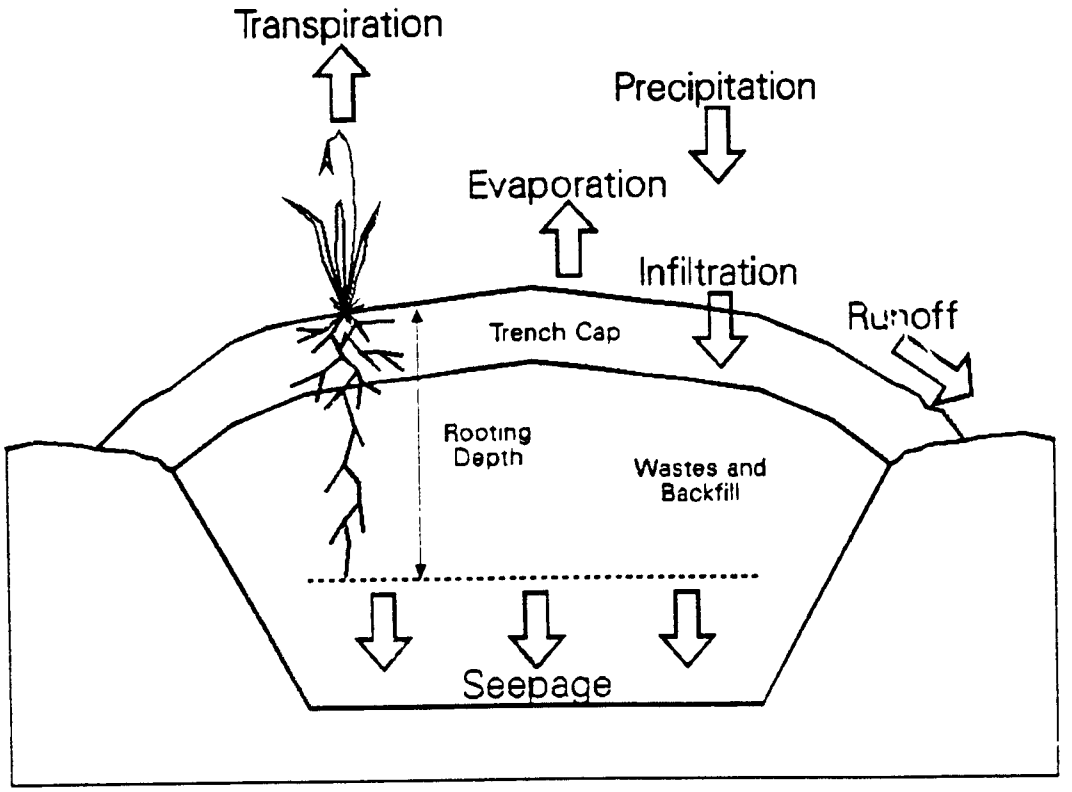

Fig. 1. Hydrology of SLB of waste materials.

engineer suitable barriers to prevent the migration of waste materials out of an SLB facility. Without these data, current modeling capabilities are inadequate for engineers to use to properly design and evaluate the long-term performance of migration barriers.

In spite of the latter observation, our approach has been to gather a limited amount of hydrologic field data and to calibrate a model at small field scale, making the assumption that we can eventually extrapolate to a field scale as large as Waste Disposal Area P. Using these field data, infiltration and percolation through the soil to the plant rooting depth are both the upper boundary and initial conditions for subsurface water flow and contaminant transport calculations. However, because water management can in fact vary the potential subsurface water flux by orders of magnitude, SLB designs should include analysis of surface and near-surface water dynamics to calculate a water balance and the upper boundary conditions for subsequent subsurface flow calculations. Thus, water balance relationships must be taken into account if SLB sites are to be hydrologically characterized and successfully closed out.

A. Performance Requirements for Closure of Burial Sites

Site-closure performance requirements are criteria set before closure of the facility, by which the acceptability of the site for closure is to be judged. Performance requirements may be written either in the form of prescriptive requirements or performance objectives. The prescriptive requirement demands specific technical design features. Use of prescriptive requirements permits more straightforward regulation of a greater number of sites. Performance objectives mandate a level of performance without stipulating how that performance should be attained. Use of performance objectives, such as maximum exposure to radioactivity at levels that are below measurable limits, requires significant technical substantiation by site

operators to show that closure designs will meet intended performance objectives. Performance objectives allow actions to be tailored to site-specific conditions, but do not preclude adoption of prescriptive requirements.

Because the Department of Energy (DOE) Order 5820.2 contains only general requirements for site closure, other pertinent regulations should be reviewed in the development of site-specific performance requirements, such as those published by the Nuclear Regulatory Commission (NRC), the Environmental Protection Agency (EPA), and the New Mexico Environmental Improvement Division (EID). Specific performance requirements found in present regulations 10 Code of Federal Regulations (CFR) 61 (US NRC 1982), 40 CFR 265 (US EPA 1980), and 50 CFR 191 (US EPA 1985) for closure of disposal sites containing low level wastes (LLW), transuranic (TRU) wastes or hazardous wastes are shown in Table I. Regulations for disposal of LLW and TRU are based both on site selection and design requirements stipulated under these requirements, and are based on a site containing only one waste type.

Obviously, it is the intent of the postclosure requirements (Table I) to limit the exposure of the general public to radioactive and hazardous wastes for time periods ranging from 30 to 10,000 yr. However, the hydrologic model used in the current study was developed using the results of about only 40 yr of field research. Clearly, we cannot wait 10,000 yr before using the water balance relationships in this model to evaluate SLB site designs—we need to make our best estimate based on the field data currently available at Los Alamos.

These same types of considerations also apply to the performance of moisture barriers (Pertusa 1980). Based on a study of liner materials used in various SLB configurations, liner service life (as a moisture barrier) and cost have been estimated (Fig. 2). Life expectancies for liners to be used to retain radioactive waste solutions were also estimated for some liner materials. Past experience indicates that synthetic liners, in general, have an expected life of around 25 yr. Although some research is under way in several DOE laboratories to determine the long-term effects of different chemicals and leachates on synthetic liners, these experiments have been in progress for less than 8 yr. This is far too short a time to provide data on long-term stability needed for disposal of wastes. Although synthetic liners may provide a short-term solution to containment of wastes, they do not at present provide a cost-effective containment even for the short run. The conclusion from this study and others is that moisture barriers constructed of clay and clay admixtures (Abeele 1984b, Abeele 1986a and 1986b, Abeele *et al.* 1986) offer the most inexpensive barrier for a given containment time of the waste.

B. Role of the Hydrologic Model Employing Water Balance Considerations

Water balance at an SLB facility, as conceptualized in Fig. 1, is a paradigm for interactive factors, especially surface and near-surface water balance dynamics, that control the performance of SLB facilities. If we restrict our attention to net rates and amounts and consider one-dimensional movement of water in the soil profile, then we have the following simplified water balance equation:

$$\frac{ds}{dt} = P - Q - ET - L \quad , \tag{1}$$

where

$\frac{ds}{dt}$ = time ratio of change in soil moisture,
P = precipitation,
Q = runoff,
ET = evapotranspiration,
L = seepage or percolation, and
t = time.

Applying this equation to the plant rooting depth within the closure cover at Waste Disposal Area P illustrates that the rate of change in soil moisture with time (ds/dt) is equal to the difference between input (P) and output (Q, ET, and L).

The CREAMS model (a Field Scale Model for Chemicals, Runoff, and Erosion from Agricultural Management Systems) was initially developed and intended for modeling field-scale agricultural systems

TABLE I. Postclosure Requirements for Disposal of LLW, TRU, and Hazardous Waste (US NRC 1982; US EPA 1980; US EPA 1985)

Statute	Sites Governed	Postclosure Performance Objectives
Doe Order 5820.2 Chapter III[a]	DOE low-level waste disposal sites.	– Annual dose limit of 500 mrem to any member of the general public; doses must be maintained at levels as low as reasonably achievable. (Operational limit only. No DOE-wide limits exist for closure.)
10 CFR 61[b]	Commerical sites for shallow-land disposal of low-level waste.	– Annual dose to any member of the general public not to exceed 25 mrem to whole body, 75 mrem to thyroid, 25 mrem to any other organ. – Protection of individuals from inadvertent intrusion. – Long-term stability of site (500 yr). – 100-yr maximum institutional control period. – Buffer zone.
40 CFR 191[c]	Sites developed for management and disposal of spent nuclear fuel, high-level and transuranic radioactive wastes.	– Long-term stability of site (10,000 yr). – Meet release limits for specific radionuclides (191.13). – Annual dose to any member of the general public not to exceed 25 mrems to whole body, 75 mrem to thyroid, 25 mrems to any other organ, for 1000 yrs after (undisturbed) disposal. – Meet specific ground water protection requirements for 1000 yr disposal (undisturbed).
40 CFR 265[d]	Hazardous waste facilities.	– Minimize need for further maintenance of hazardous waste constituents, leachate, contaiminated rainfall, or waste composition products to the ground or surface waters or the atmosphere.

[a]Radioactive waste management, management of low-level waste, currently replaced by DOE Order 5820.2A.
[b]Licensing requirements for land disposal of radioactive waste.
[c]Environmental standards for the management and disposal of spent nuclear fuel and high-level and transuranic radioactive wastes.
[d]Interim status standards for owners and operators of hazardous waste treatment, storage, and disposal facilities.

(Knisel 1980) using the water balance approach. The model has since been used in several areas of waste management research in semiarid climates, including erosion studies (Nyhan and Lane 1982), water balance and primary production of desert shrubs (Lane *et al.* 1984), and landfill cover design (Hakonson *et al.* 1982, Nyhan *et al.* 1984). CREAMS has been tested in a limited way with respect to percolation of water below a surface rooting zone, but not in any detail with respect to the effects of native plant cover on soil water storage.

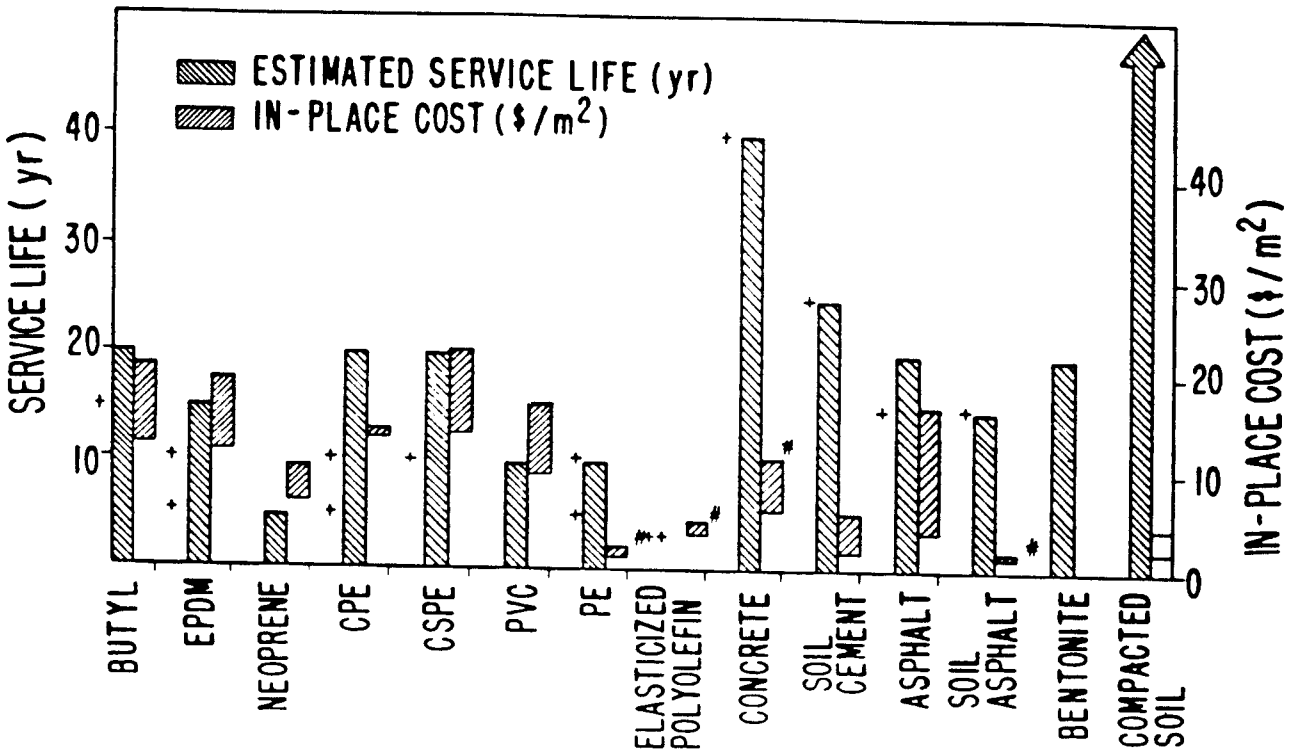

Fig. 2. Comparison of expected service life vs in-place cost (1976). Unless noted, service life estimate is for water-retaining structures. A + is the radwaste estimate; ++ means no estimate is available (because the liner was invented in 1975). Cost estimate includes excavation, installation, backfilling, compaction, and seeding (glacial till). A # means the cost does not include construction of subgrade or earth cover (Pertusa 1980).

In the present study, CREAMS was used in the daily rainfall/runoff mode to obtain a complete water budget (estimates of runoff, evapotranspiration, percolation, and soil water storage or water content in the soil column to the depth of the rooting zone) on each day that there was a precipitation event using the water balance equation. Monthly and annual water budgets are also obtained. The model is one-dimensional, calculating the process of vertical transport of water in the soil column using a seven-layer representation of the profile from the surface extending through the rooting zone of the vegetative cover. Initial responses to precipitation are calculated on a daily time-step using a modification of the Soil Conservation Service (SCS) curve number model (Knisel 1980).

C. Scope and Limitations of the Study

This report deals only with the hydrologic component of the CREAMS model and was applied only to the consideration of the upper, flat portions of Waste Disposal Area P. The erosion component of CREAMS is actually driven by the hydrologic component of CREAMS, and it could be used in the future to evaluate the site for soil erosion losses over time. However, our attention was limited to the daily rainfall/runoff model discussed earlier, which was only applied to a configuration we had field and modeling experience with, and not to the steep slopes at the northern edge of Area P.

The CREAMS model is a widely known and accepted model used in waste management. However, research scientists, users, and program administrators should not regard the CREAMS model as an absolutely accurate and final representation of hydrologic processes in the surface and near-surface areas of SLB facilities. Instead, the CREAMS model is one step in continuing efforts to understand and improve models of the water balance and associated technology for surface-water management.

With these limitations in mind, the Resource Conservation and Recovery Act (RCRA) status of the Area P landfill is first discussed, and two proposed prototype closure plans for the area are described. Several phases of the hydrologic modeling activities at Waste Disposal Area P are then presented, starting with a description of the waste use history of the site. An evaluation of the backfill moisture data previously collected at the site is presented, followed by an evaluation of the precipitation and air temperature input terms to be used in the modeling activities. The results of the hydrologic modeling studies are then presented for various scenarios with the Area P landfill as it exists today, with and without a final approved closure cover. A final set of design recommendations is presented relative to improving the final approved closure of this landfill.

II. CURRENT STATUS OF AREA P LANDFILL

Harold Valencia's (DOE) letter (2/3/88) to Mike Burkhart (EID) best sums up the current RCRA status of Waste Disposal Area P:

> The Department of Energy (DOE) did not choose to continue operation of the Technical Area (TA) 16 Area P landfill at Los Alamos National Laboratory (LANL) after November 8, 1985. Therefore, DOE did not apply for a Resource Conservation and Recovery Act (RCRA) permit at this site Consequently, DOE was required under the loss of interim status provisions (40 CFR 270.10) to submit a Closure and Post-Closure Plan for this landfill. Pursuant to the DOE Closure and Post-Closure Plan dated November 25, 1985, for the Area P landfill reflected interim status standards for such activities. DOE recognizes, however, that upon receiving a RCRA operating permit, Area P post-closure (and possibly closure) activities will be subject to permitting standards (*i.e.*, 40 CFR 264) rather than interim status standards (*i.e.*, 40 CFR 265).
>
> Under separate cover, the amendments are submitted with the intent that the Area P landfill fully comply with both standards. Equally important however, is the collection of a consistent and reliable water quality data base from which critical decisions concerning potential statistically significant changes in individual water quality parameters can be made. Thus, the proposed ground-water quality monitoring program for Area P has been modified to reflect sufficient flexibility so that DOE will comply with both 40 CFR 265 and 264 requirements, even though only a single regulatory standard will be in effect at any given time.

Currently, an approved final site closure plan for the Area P landfill does not exist. However, the water balance modeling presented later in this report was performed in support of a ground water waiver which the Laboratory is demonstrating for this landfill.

The first attempt at a closure plan for Waste Disposal Area P was submitted to the Laboratory in November 1985 (Delta H Engineering, Ltd. 1985). At that time the west (retired) portion and the east (active) portion of the landfill were proposed to be closed separately. Briefly, the only closure activity proposed for the west portion of the landfill was to leave the existing cover of vegetation on the surface, the reasoning being that this land area would pose less of a risk to human health and the environment. The closure proposed for the east portion of the landfill involved its stabilization with a thick concrete blanket installed on a reinforcing steel base set on a layer of gravel.

An approved final site-closure plan still did not exist for the Area P landfill in 1986, but another prototype plan is presented in Fig. 3 just to show an example of another closure plan considered by Laboratory personnel for this site. The cover consists of a 3-ft-thick soil layer underlain by subsequent layers of a geotextile, a high density polyethylene (HDPE) drainage net, and a 40-mil HDPE liner. All of these cover components are proposed to be emplaced over the current landfill at Los Alamos, after adding compacted soil layers to level out the preexisting land surface.

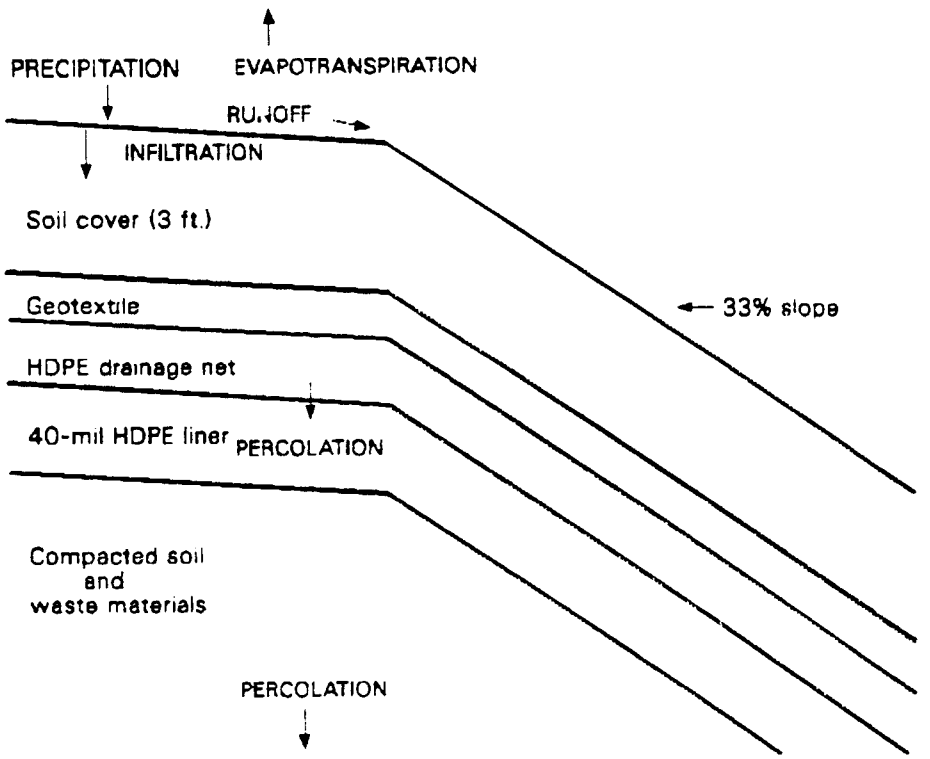

Fig. 3. One prototype closure plan for Waste Disposal Area P.

III. SITE DESCRIPTION AND WASTE USE HISTORY OF THE AREA P LANDFILL

Waste Disposal Area P (Figs. 4 and 5) is located in a saddle of a short, eastern-trending, narrow mesa. The saddle is near the south rim of Cañon de Valle, just north of the TA-16 thermal treatment area's pad number 387. Figure 6 shows the results of a recent land survey conducted to characterize Waste Disposal Area P compared with a prelandfill survey to determine the area influenced by the landfill (Delta H Engineering, Ltd. 1985). The general area impacted is a half-ellipse, roughly 170 ft (north/south) by 400 ft (east/west). Within this area are two areas of fill, one to the west and the second to the east. The estimated landfill volume is 13,000 yd^3. Landfilling progressed from west to east. The west portion was closed by leveling the landfill and covering the soil. The leveling overflowed the rim in the northwest quadrant of Waste Disposal Area P, as witnessed by the elevation changes determined by the survey. As shown in the cross sections, large quantities of the wastes are located on the steep canyon slope. The landfill depth at the rim is 12 to 14 ft, thinning both to the south and down the slope to the north. While there is a disturbance back to the 7450 ft elevation, much of the elevation change is only 1 ft and is probably the result of leveling the site, not of waste burial. The cross section indicates that deposition of wastes reaches only 30 to 40 ft back from the rim, and extends down the slope. Large items, such as blocks of foundation concrete and pieces of structural steel, did roll to the canyon floor. A few empty cans were also found on the canyon floor.

The west portion of the landfill has revegetated with grasses, wild rose, wormwood, and oak brush. There are occasional protrusions of concrete rubble, pipe, and steel, which aid in binding the mass. However, the east landfill area was the most recently active portion of the site. Fill has progressed from south to north with cover soil being spread as the fill advanced. Wastes on the north face are exposed.

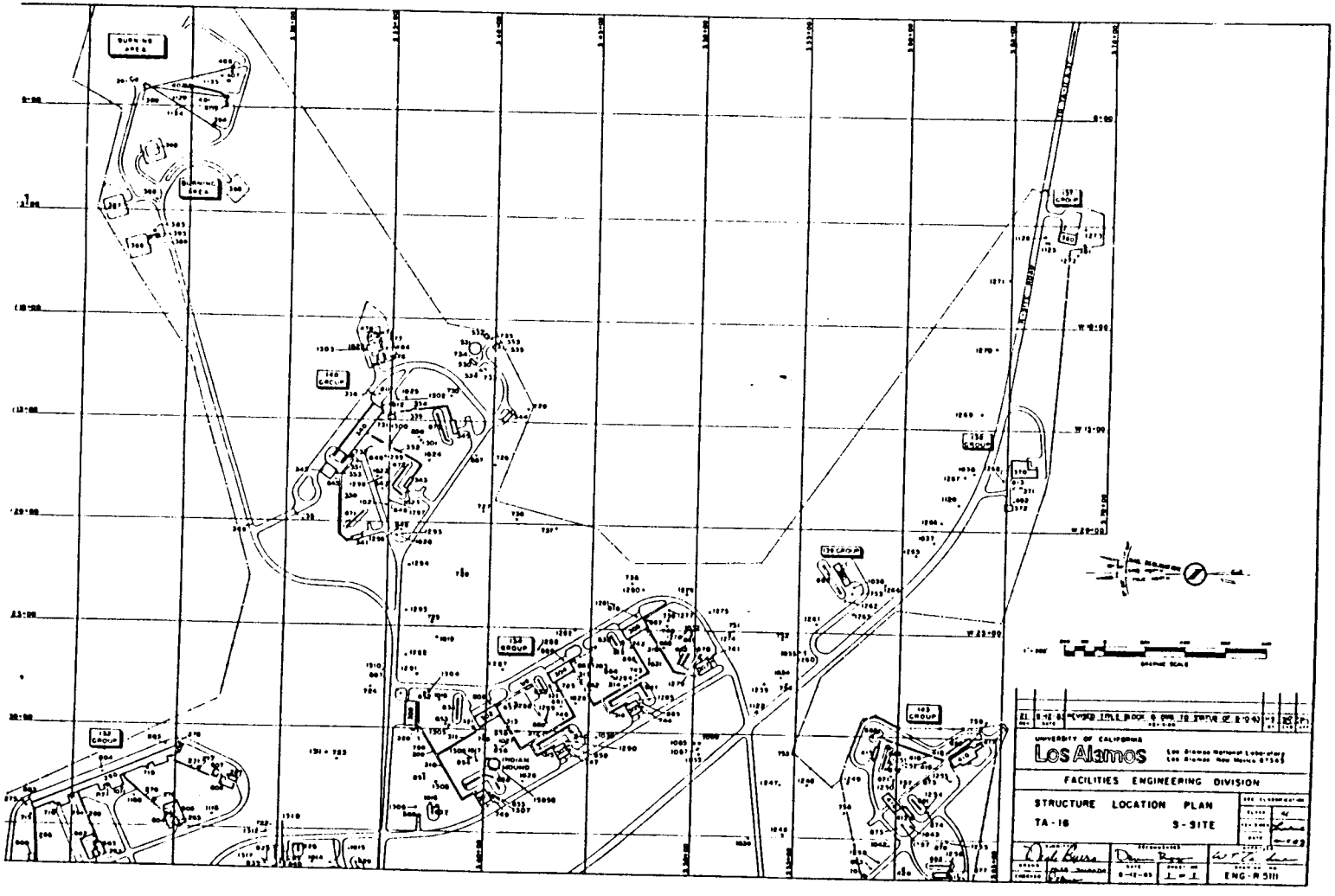

Fig. 4. Map of TA-16 showing burning areas.

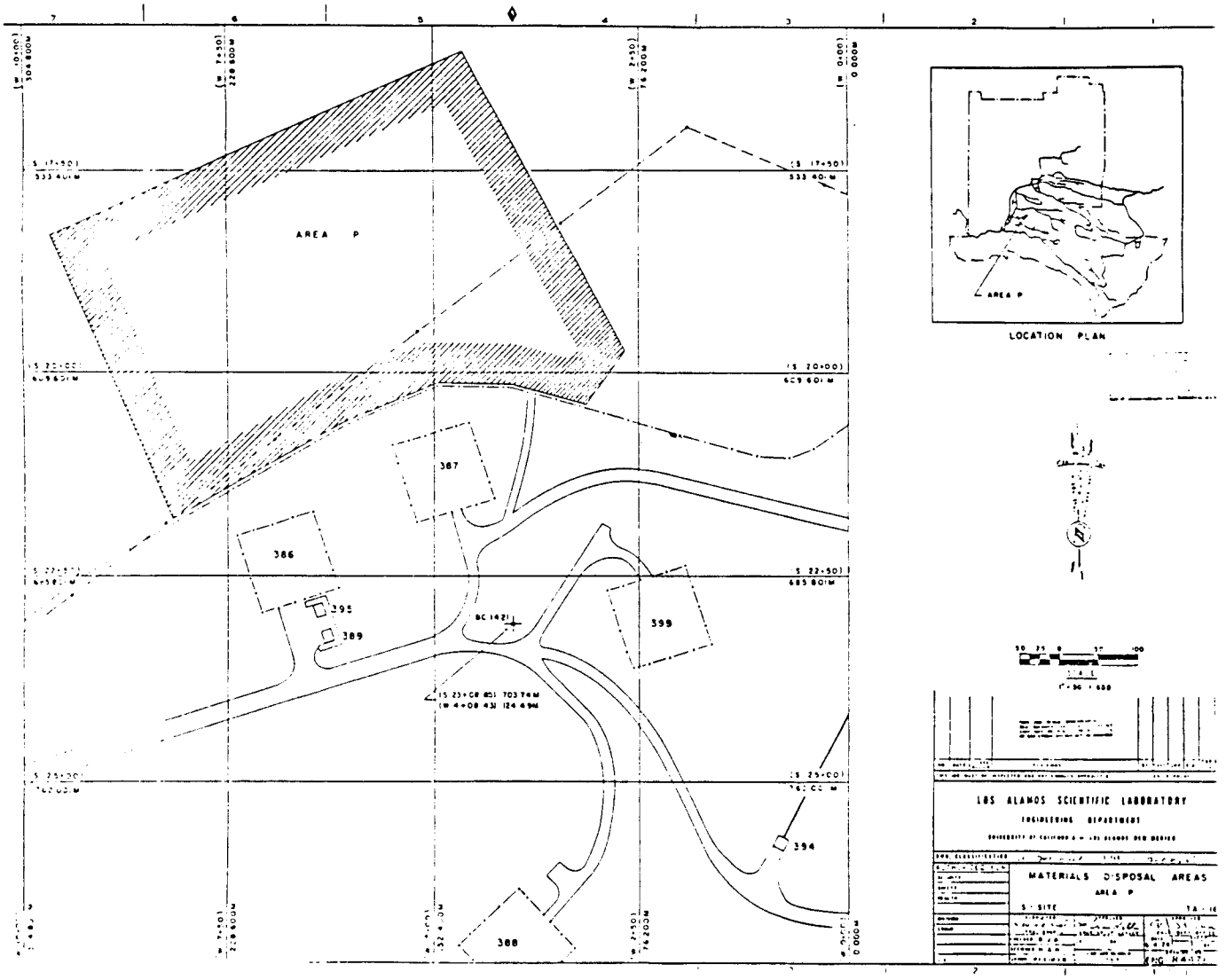

Fig. 5. Map of Waste Disposal Area P.

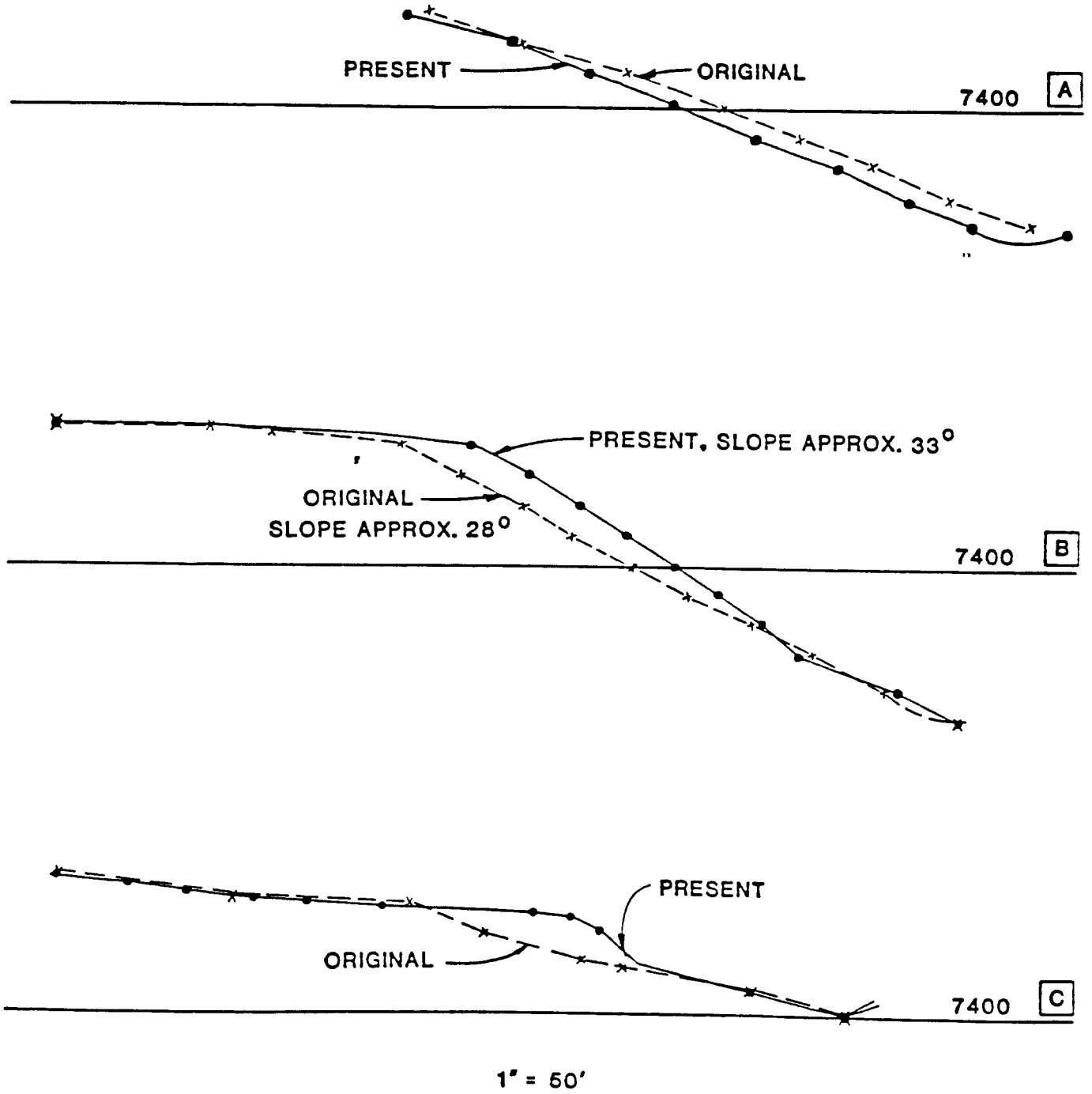

Fig. 6. Map of three cross sections of Waste Disposal Area P showing locations of original and present land surfaces relative to an elevation of 7400 feet. Cross sections A, B, and C are roughly north-south transects located immediately west of the landfill, through the middle of the west portion of the landfill, and through the middle of the east portion of the landfill, respectively (Delta II Engineering, Ltd. 1985).

The covered portion has no appreciable vegetation, and surface drainage cuts through this portion of the landfill.

Waste Disposal Area P is a regulated landfill because it has been used for disposal of residues that exceed the extraction procedure toxicity limit for barium. Prior to November 1985, high explosive (HE) contaminated wastes and equipment were burned on sand-covered pads at S Site (TA-16), and the sand was then removed after the burn and placed in the landfill. All HE is currently burned on lined trays then the sand and ash residue is collected, placed in metal drums, and sent to the Laboratory's Waste Management Group for treatment and disposal as nonhazardous waste. The source of barium in the residue is barium nitrate used in the formulation of some HE. The concentration in the pad sand varies with the barium nitrate concentration in the HE and the HE concentration in the waste.

There is very little documentation of the types or quantity of wastes buried at Waste Disposal Area P (Delta H Engineering, Ltd. 1985). The site was initially used in the early 1950s to dispose of burned equipment that had been HE-contaminated and rubble from building demolition. Known wastes include concrete rubble, structural steel, burn-pad sand, burned equipment, and empty solvent cans.

The procedure for handling HE-contaminated equipment was to disassemble it and to clean the surfaces as well as possible. The equipment was then taken to the burn pad and flashed, along with other combustible material needed to support the fire. After the thermal treatment, the equipment was inspected and determined to be free of HE. Because of the hazard associated with HE, the burned equipment was buried at Waste Disposal Area P, rather than salvaged or shipped to an off-site landfill, to protect the public in case any HE residue had not burned and was not found during the final inspection. Equipment buried at Area P includes several large items, including two trucks and large pieces of concrete rubble from building demolition.

Empty solvent containers have been placed in Waste Disposal Area P. A majority of these containers are quart metal cans and glass bottles. Larger containers, as large as 55-gal. drums, were also in the landfill. During a site inspection, an empty acetone and an empty methanol can were found in the landfill. Both acetone and methanol are regulated as ignitable hazardous wastes, but both containers found were empty as defined by the regulations.

IV. EVALUATION OF CLIMATIC INPUT PARAMETERS TO BE USED IN THE HYDROLOGIC MODELS

The main climatic data required by the CREAMS water balance model are daily rainfall, mean monthly temperature, and mean monthly solar radiation. As discussed earlier, precipitation is the input to the water balance equation and is used in the computation of all the other terms. Mean monthly temperature and mean monthly solar radiation are fitted with Fourier series and then interpolated to daily values for use in the evapotranspiration calculations.

A major problem with performing hydrologic modeling at the Area P landfill is that long-term climatic data are not available specifically at Area P. Precipitation in the area usually increases with elevation and proximity to the Jemez Mountains. Thus, for the entire county, the precipitation records available at the S Site weather station (elevation of 2338 m) are the weather data collected closest to the landfill, but these records are only available from 1977 (with the 1978 data missing). The next closest weather data has been collected at the Occupational Health Laboratory (OHL) at Technical Area 59 (TA-59), which is located at an elevation of 2248 m, but is farther away from the Jemez Mountains. However, the OHL data base is excellent because its weather records go back to 1911. The only other weather station with a record of any substantial length is located in White Rock, but it is located the farthest distance away from Waste Disposal Area P and has an elevation of 1944 m.

A triple-mass plot of the precipitation data available from 1977 through 1987 was constructed to determine differences between the precipitation received at the S Site, OHL, and White Rock stations (Fig. 7). This plot clearly shows that the temporal precipitation pattern at S Site is similar to that at OHL, but both of these stations receive a different precipitation pattern than that observed in White Rock. The average annual precipitation received at the S Site station was 20.50 in., only 1.23 in. more than that observed at OHL for this time period. The White Rock station, in contrast, exhibited an annual average precipitation of only 12.80 in.

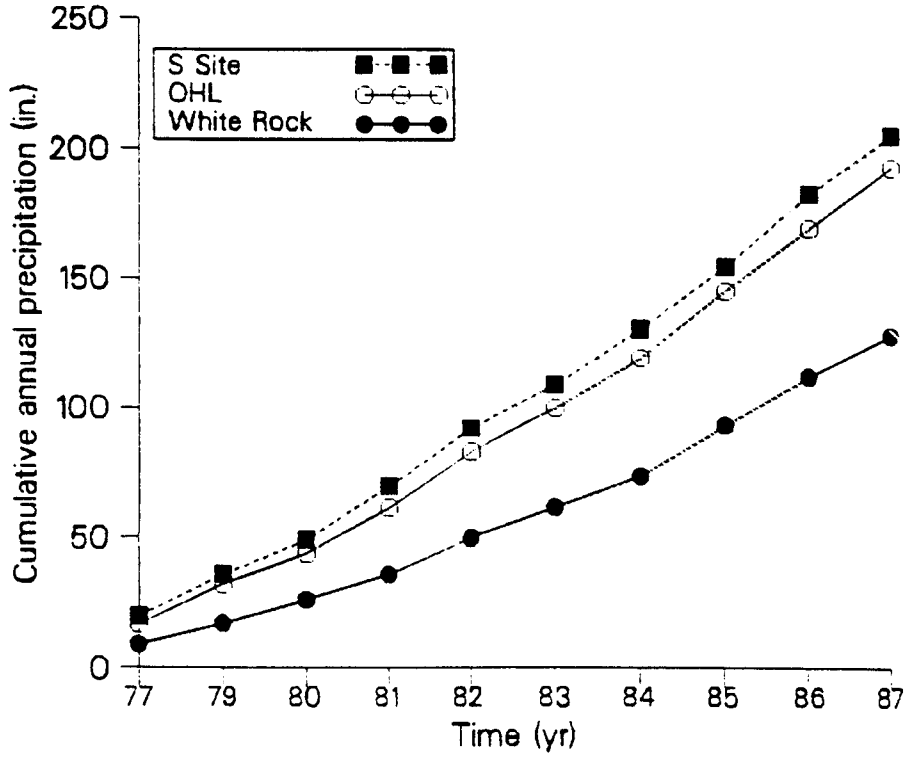

Fig. 7. Triple mass precipitation plot for three meteorological stations.

However, past modeling experience has demonstrated that seasonal inputs of precipitation can have a big effect on water balance components, such as seepage. For example, two locations could potentially have the same annual precipitation, but the location having the heaviest winter precipitation would probably have a larger amount of seepage. Therefore, we also analyzed the precipitation data for seasonal differences (Fig. 8). The results of this analysis show that there are no significant differences in the seasonal distribution of precipitation between OHL and S Site, but that the White Rock station seems to receive substantially less precipitation from July through September than do the other two stations.

Because performance requirements for site closure are specified for time periods like 100 yr (Table I), we utilized a graphical and statistical analysis of the annual precipitation data collected at OHL (Nyhan *et al.* 1989) performed for use with another hydrologic modeling study (Nyhan and Barnes 1988). The statistically calculated values for the 10-yr, 100-yr, and 200-yr events (25.0, 32.9, and 35.0 in., respectively) matched the corresponding graphically derived values for annual precipitation (25.9, 32.9, and 35.0 in., respectively). We also calculated the 95% one-sided tolerance intervals for these estimates (Table II) to provide estimates of the variation about these mean values. The 95% tolerance intervals for the 10-yr, 100-yr, and 200-yr annual events were 27.0, 36.8 and 41.3 in., respectively. The interpretation of this statistical analysis for the 100-yr event, for example, is that 95% of all the 100-yr precipitation events will be less than 36.8 in., with the average 100-yr event being 32.9 in.

Monthly air temperature data were also used as an input parameter in CREAMS. Although temperature data were not available from S Site (Fig. 9), we were able to make a comparison between the OHL and the White Rock stations. The average annual temperatures for OHL (1951-1980 data) and White Rock (1965-1987 data) were 48.2 F and 49.2 F, respectively. The major seasonal difference between these two locations seems to be that White Rock has relatively warmer summers. Thus, because there was such a small difference between White Rock and OHL, we decided it was safe to use the OHL data to represent the Area P landfill in the hydrologic modeling.

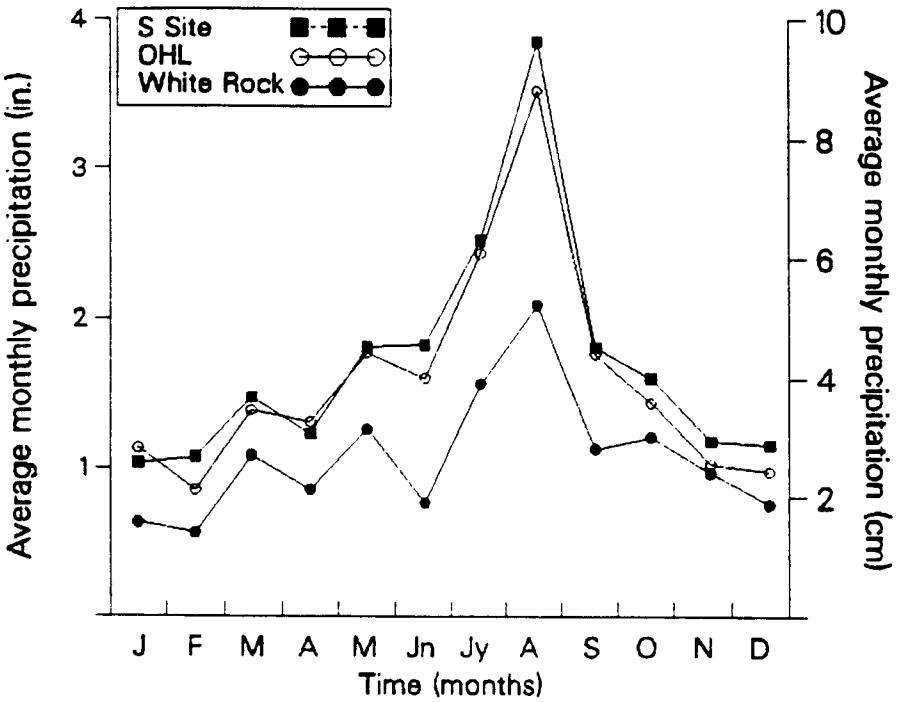

Fig. 8. Monthly precipitation for three meteorological stations (1977–1987).

TABLE II. Precipitation Estimates for Los Alamos (OHL data: 7373 ft elevation)

Time Period	Annual Precipitation Estimate (in.)	95% Tolerance Interval
10 year	25.0	27.0
100 year	32.9	36.8
200 year	35.0	41.3
500 year[a]	39.9	– –

[a]Derived from tree ring index data.

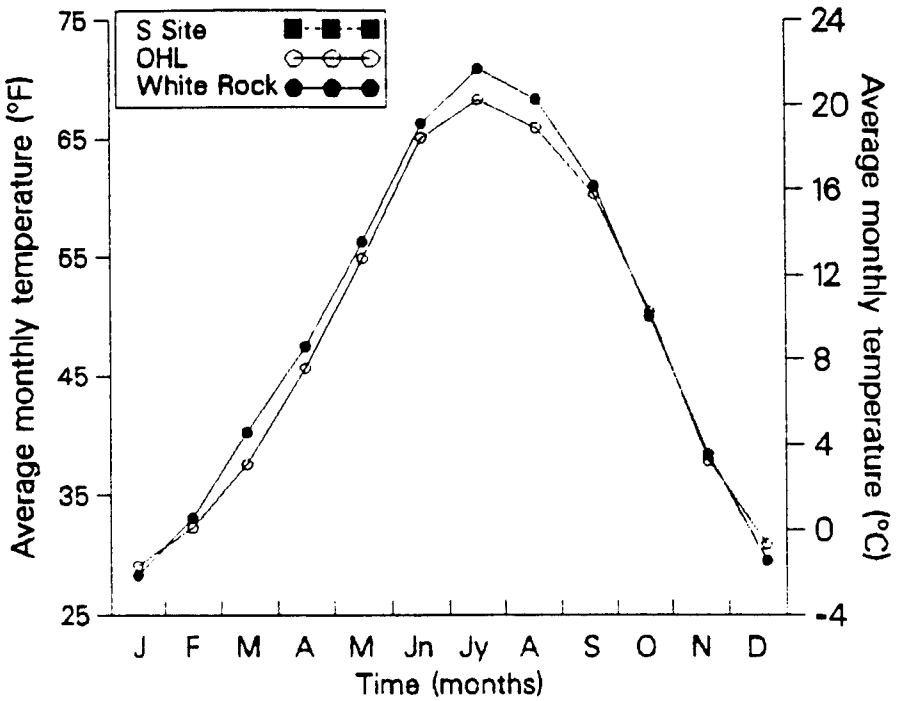

Fig. 9. Monthly air temperature for three meteorological stations.

V. EVALUATION OF THE VOLUMETRIC WATER CONTENT DATA COLLECTED AT WASTE DISPOSAL AREA P

The volumetric water content of several sampling areas around the Area P landfill was evaluated before the hydrologic modeling was performed, for several reasons. First, this data base represented the only source of hydrologic information available for modeling purposes, even though no information was available within the landfill boundaries. Initially, it was hoped that something might be gained by examining the overall site dynamics of the water balance equation, such as changes in soil water content with time, even though no field information was available for evapotranspiration, seepage, and runoff changes with time. The other reason for evaluating the data was that each access tube emplaced adjacent to the landfill had an invaluable geologic log associated with it. With this knowledge of the geology of the site, gross estimates of site hydrologic properties could be made from experience (Abeele 1984, Abeele *et al.* 1981, Abrahams 1963).

The most informative data were collected at sampling locations P-12, P-13, and P-16 within TA-16 (Fig. 10). Sampling location P-12 was located over 1000 ft southeast of the landfill, whereas sampling locations P-13 and P-16 were situated less than 30 ft immediately to the south of the landfill (Fig. 10). Thus, the P-12 location acted like a "background," with the other two sampling locations sharing a portion of the temporary, crushed-tuff cover that had been emplaced over the entire landfill.

The volumetric water content data collected in 1987 and 1988 by the Environmental Surveillance Group (HSE-8) personnel are presented in Figs. 11–13. The data for location P-12 is a representative background 100-ft profile, with winter volumetric water contents ranging from about 25%-33% in the soil layers above the tuff, 4%-7% in the Unit 3d tuff, and 5%-7% in the underlying Unit 3c tuff (Fig. 11). Slightly elevated levels of tuff water content were observed near the contact zone between tuff units, as should be expected in these lower conductivity layers.

Both sampling locations adjacent to the landfill exhibited elevated levels of volumetric water content (Figs. 12 and 13) relative to the location P-12 data. The samples collected from location P-13, for example,

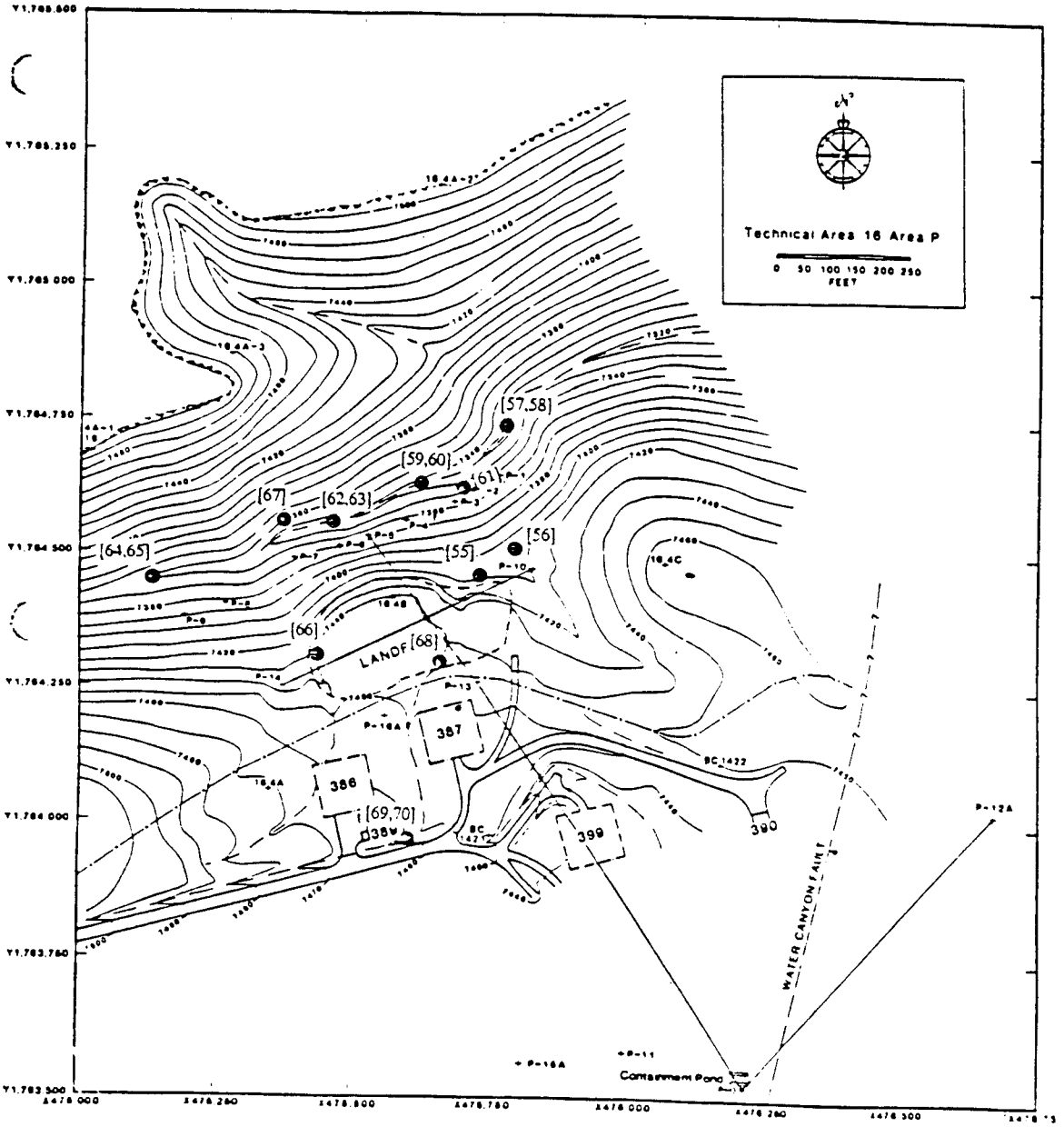

Fig. 10. Map of Waste Disposal Area P showing locations of neutron probe access tubes.

exhibited volumetric water contents greater than 40% in the top 7 ft of coarse-textured tuff backfill, 21%-24% in the underlying Unit 3d tuff, and 20%-26% in the lowest Unit 3c tuff.

The elevated volumetric water content in the undisturbed tuff units beneath the landfill can be appreciated even further by comparing the water content profiles in the three locations in March 1988 (Fig. 14). A calculation of the inventory of water in each of these three profiles to a depth of 90 ft was determined to further demonstrate this point. Whereas the entire profile at location P-12 contained a total soil water inventory of only 100.9 in., locations P-16 and P-13 adjacent to the landfill exhibited similiar inventories of 275.3 and 318.7 in. of water, respectively.

This data base, combined with a knowledge of the hydrologic properties of the temporary tuff backfill cover at the landfill, allowed us to derive the following scenario as to what could be happening at the landfill. First, the crushed-tuff cover was emplaced across the top of the site with minimum compaction, probably resulting from the difficulty in successfully compacting a layer of crushed tuff over a loosely packed assortment of metallic rubble. Thus, there is a crushed-tuff backfill layer (7 ft thick) at the surface

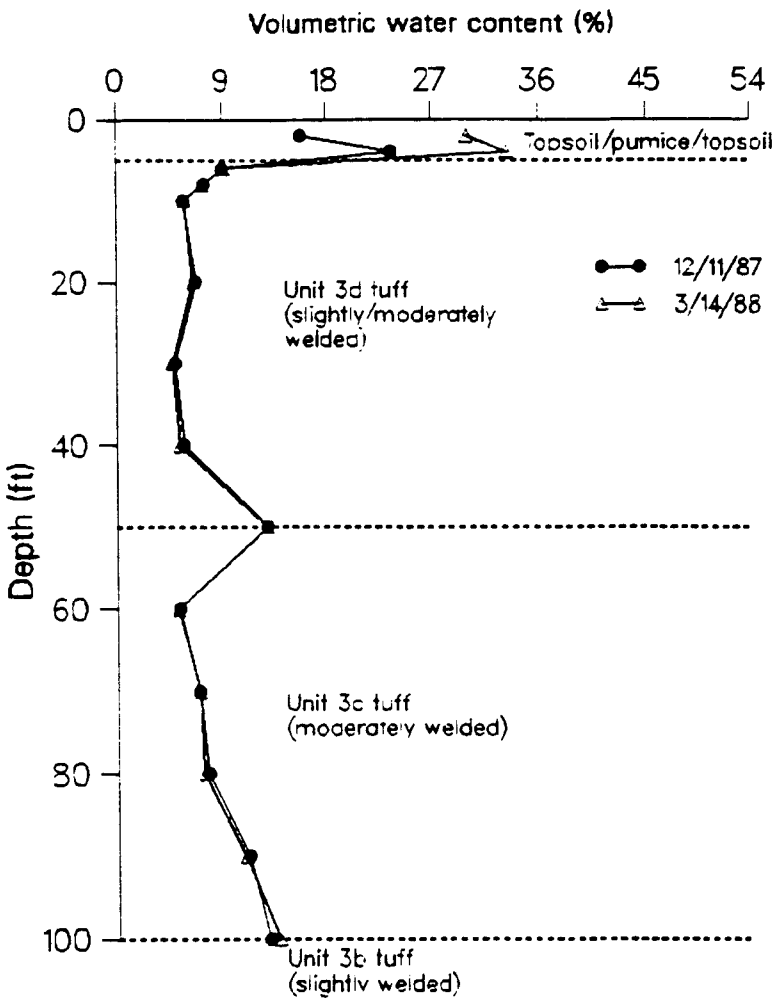

Fig. 11. Volumetric water content data for location P-12.

of the landfill with a very high porosity and saturated conductivity, two factors that would contribute to very low runoff rates and very high infiltration rates. However, the data (Figs. 12 and 13) demonstrated that volumetric water contents in excess of 40% were observed in the tuff backfill, which suggests that the undisturbed Unit 3d tuff layer beneath the backfill (or a layer of fine-textured soils materials) is acting as a barrier to vertical soil water movement in the profile. This makes good sense because the saturated hydraulic conductivity of this tuff unit (or the layer of fine-textured soils materials) is surely orders of magnitude lower than that of the backfill.

However, the above explanation may account for some of the soil water inventory differences observed earlier (Fig. 14), but not a difference as large as about 200 in. of water as discussed previously. The only way to account for a difference this large is to have a water input to the landfill (locations P-13 and P-16) beyond the infiltration of precipitation occurring at all three sampling locations. A field inspection of the landfill immediately provided us with the major probable culprit: the unlined drainage ditch that traverses the southern landfill boundary. This ditch collects runoff from a large area above the landfill, and this runoff undoubtedly infiltrates into the coarse-textured backfill along the southern border of the landfill. This would act the same as making a five- to ten-fold increase in the precipitation input to the landfill area. Of course, other "culprits," such as horizontal subsurface flow of soil water into the site from upland regions, could also be found to play a role once more information is known about this site.

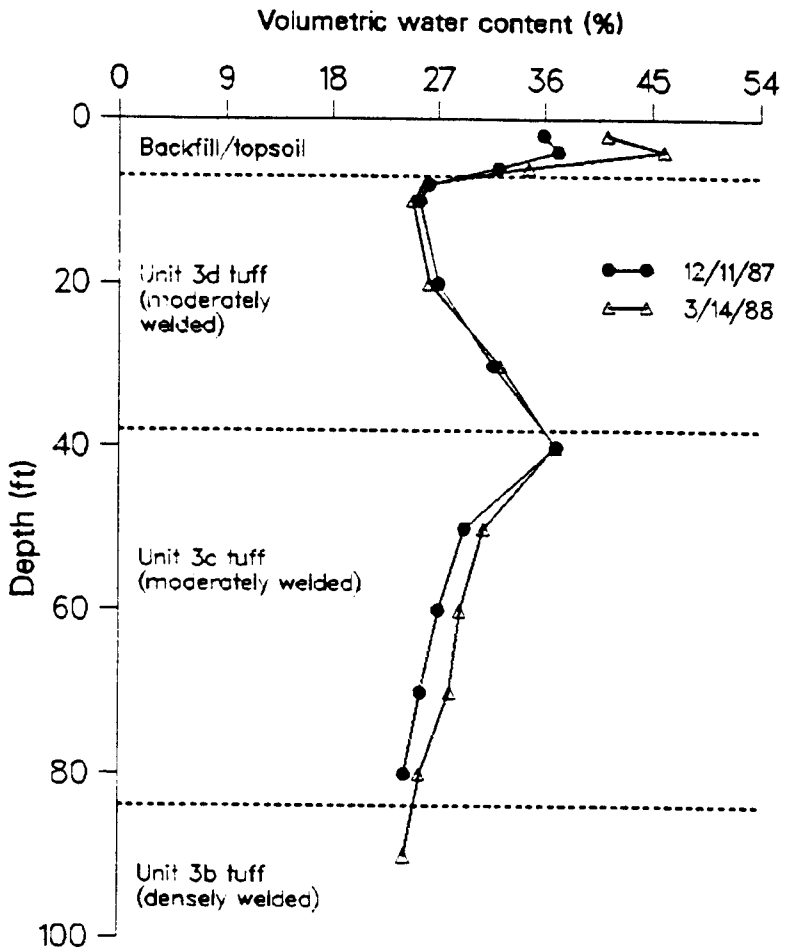

Fig. 12. Volumetric water content data for location P-13.

VI. HYDROLOGIC MODELING AT THE AREA P LANDFILL

The CREAMS modeling activities for the Area P landfill had two general objectives. The first objective was to estimate soil and plant modeling parameters to model the Area P landfill as it currently exists without implementation of a closure cover. The southeast and southwest portions of the landfill currently have no vegetation and sparse vegetation, respectively, so both of these scenarios had to be modeled. The second objective was to use a field-calibrated CREAMS model to help evaluate cover features, such as cover thickness, to help improve a final approved closure plan for this landfill.

A. Area P Landfill Scenario Without a Closure Cover

The CREAMS modeling scenarios in this subsection involved modeling the 7-ft-deep backfill at the landfill for the vegetated and nonvegetated portions of the site. Model parameter estimates were initially chosen using past experience (Nyhan 1989, Nyhan and Barnes 1989, Nyhan and Lane 1982) and other instructions on how to use CREAMS (Lane 1984). The daily precipitation input file used was the 1977-1987 data collected at S Site by Group HSE-8 personnel.

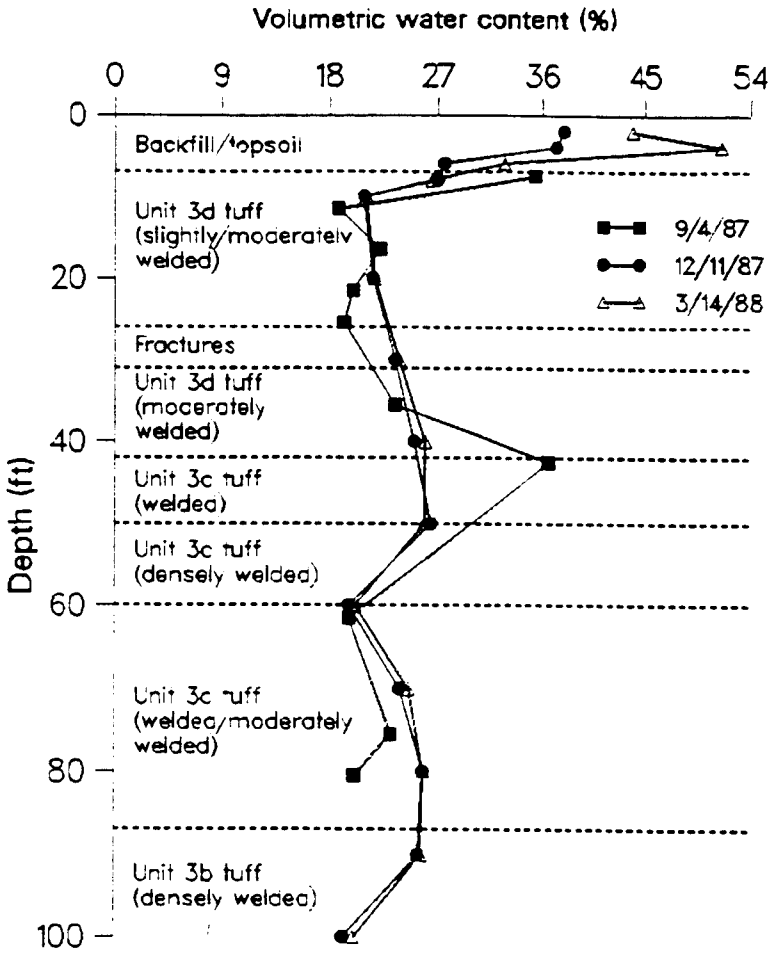

Fig. 13. Volumetric water content data for location P-16.

Because the only real site data for this time period consisted of volumetric water content data collected in December 1987, clearly, this was an attempt to extrapolate and estimate hydrologic variables to the maximum! However, after several CREAMS simulations, parameter optimization techniques lead to the estimation of volumetric water content with time while varying the saturated hydraulic conductivity (RC) in the model. The CREAMS RC parameter represents the slowest estimated hydraulic conductivity of either (1) any layer in the crushed tuff profile considered in the simulation at the Area P landfill, or (2) a layer immediately beneath the crushed tuff profile, such as a layer of either undisturbed tuff or fine-textured soil particles. The results are presented in Fig. 15 for the bare backfill scenario and in Fig. 16 for a cover with poor range-grass cover.

Two important conclusions resulted from these initial CREAMS simulations. First, as we discussed at the end of the last section, RC values as large a 0.070 in./hr and greater (which would be characteristic values for crushed tuff backfill alone) resulted in CREAMS-estimated volumetric water contents that were much lower (Figs. 15 and 16) than those observed in the field (Figs. 12 and 13). Thus, the rate-limiting saturated hydraulic conductivity that finally used in CREAMS simulations of the tuff backfill had to match the ra in RC factors known for the less-conductive underlying tuff (or a fine-textured soil layer immediately above the tuff), *i.e.*, 0.003 to 0.070 in./hr! Even within this range of conductivity values, field-observed

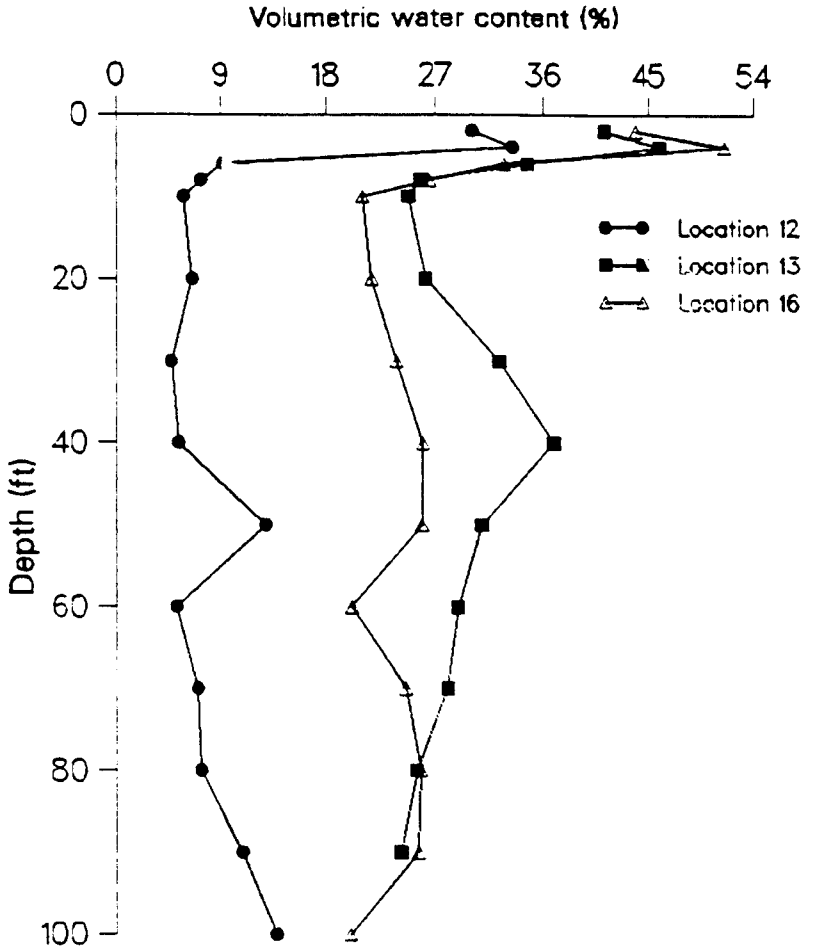

Fig. 14. Volumetric water content data for three sampling locations in March 1988.

water contents were not simulated in 10 yr until RC values closer to 0.003 in./hr were used (Figs. 15 and 16).

The second major conclusion reached was a verification that even a poor range-grass cover seemed to enhance simulated evapotranspiration, thus reducing volumetric water content (Fig. 16) predicted by CREAMS over that observed in the bare-backfill scenario (Fig. 15). Although CREAMS-predicted volumetric water content does gradually increase with time in the backfill, this occurs dramatically slower with time with a small amount of vegetation present.

These CREAMS simulations are summarized in Fig. 17 in terms of the volumetric water content predicted by the model in December 1987 and the average annual seepage as a function of the saturated hydraulic conductivity. Again, the point is made that as the saturated conductivity for the cover profile decreases, the volumetric water content increases and the average annual seepage through the fill cover decreases.

From the simulation results shown in Fig. 17, we decided to set the final RC factor at 0.003 in./hr and simulate seepage production over the 10 yr of precipitation observed at S Site (Figs. 18 and 19). CREAMS predicts annual seepage ranging from 0 in. to almost 7 in. from the 7-ft profile either with or without vegetation. Notice that there seems to be a lag period in maximum seepage production of about a year after a year with high-precipitation.

The simulation results presented in Figs. 17 to 19 are examples of what could be learned when a field-calibrated hydrologic model is developed for the Area P Landfill in the future. Current experience

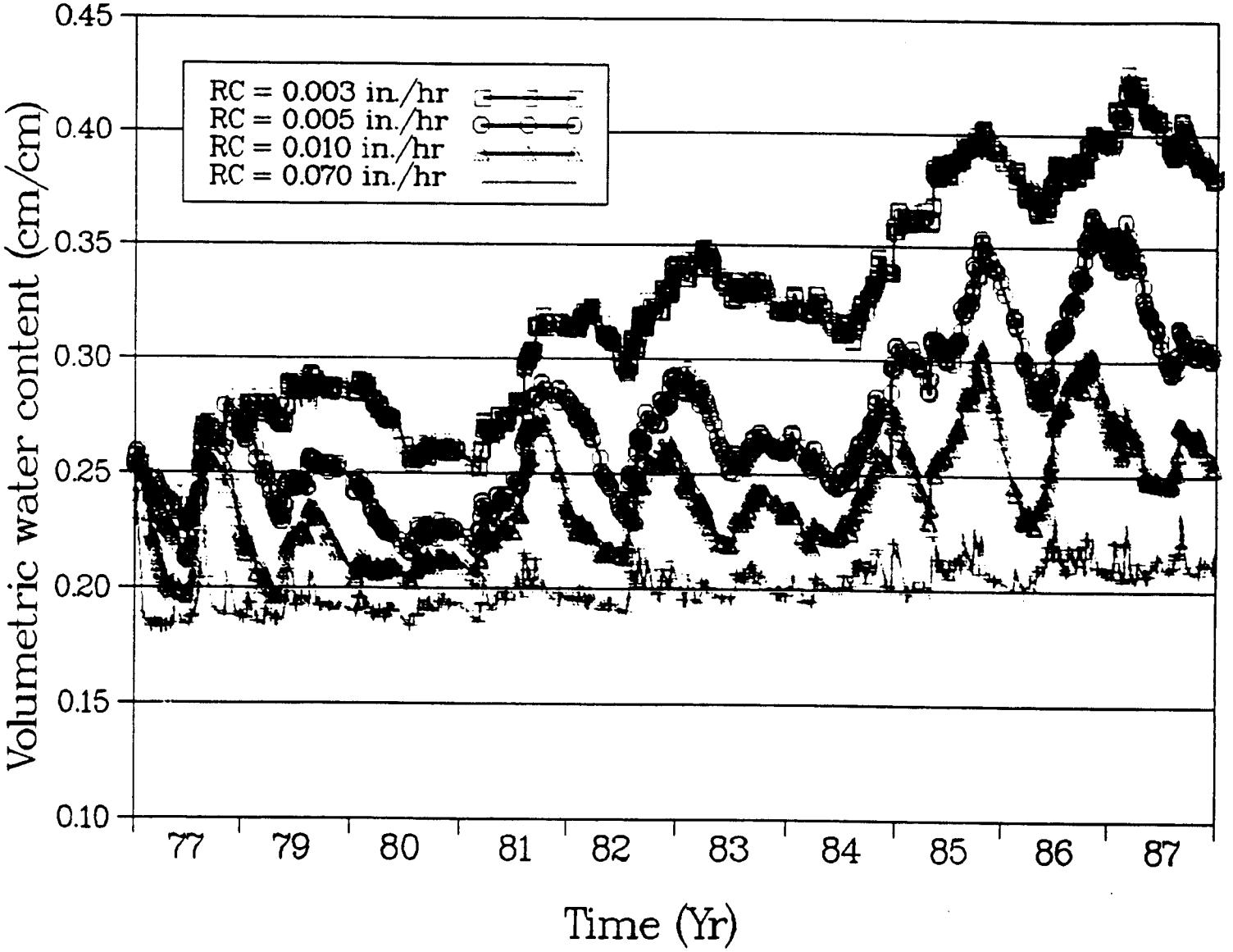

Fig. 15. CREAMS—predicted soil water content at Waste Disposal Area P (bare backfill cover scenario).

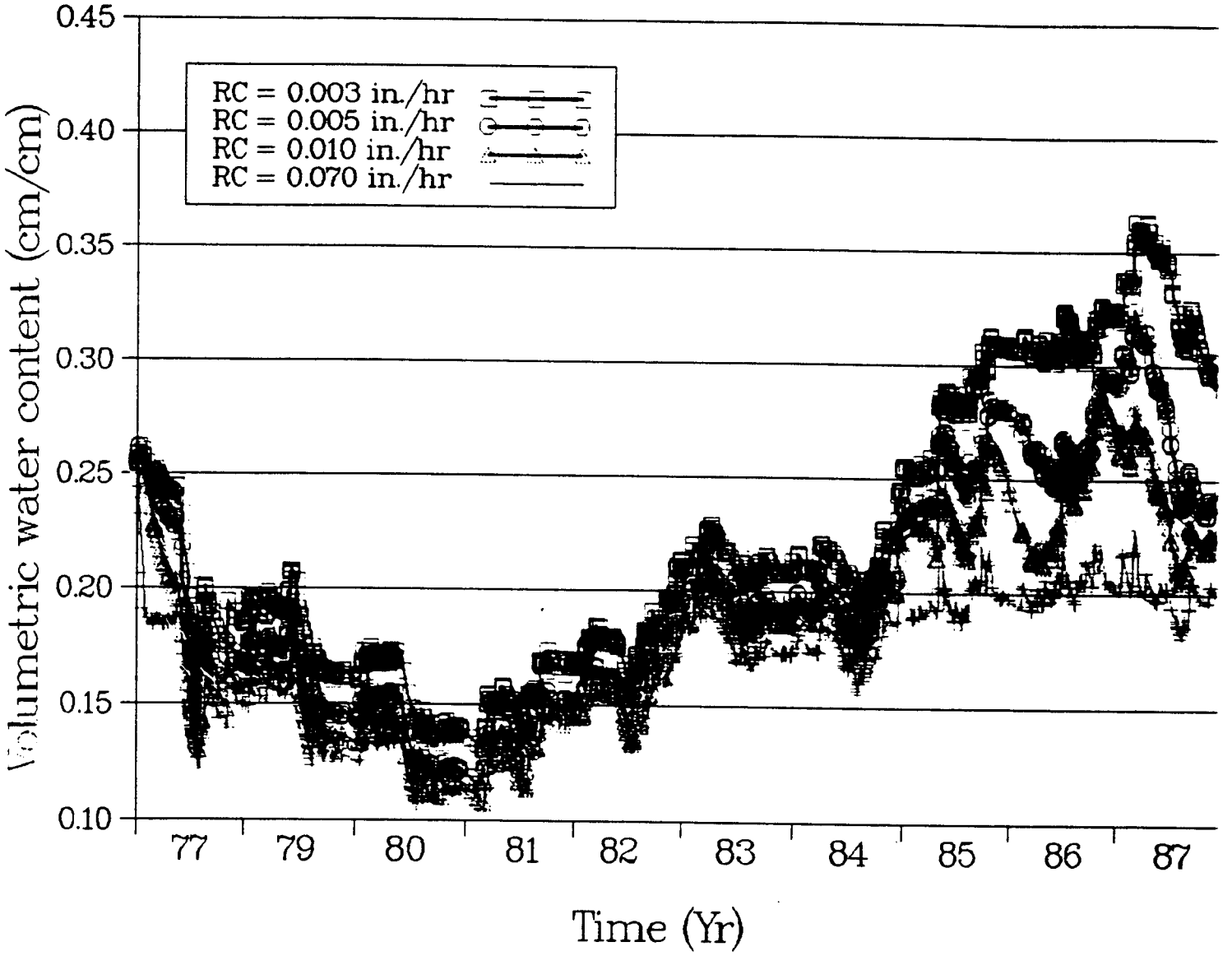

Fig. 16. CREAMS—predicted soil water content at Waste Disposal Area P (poor range grass cover scenario).

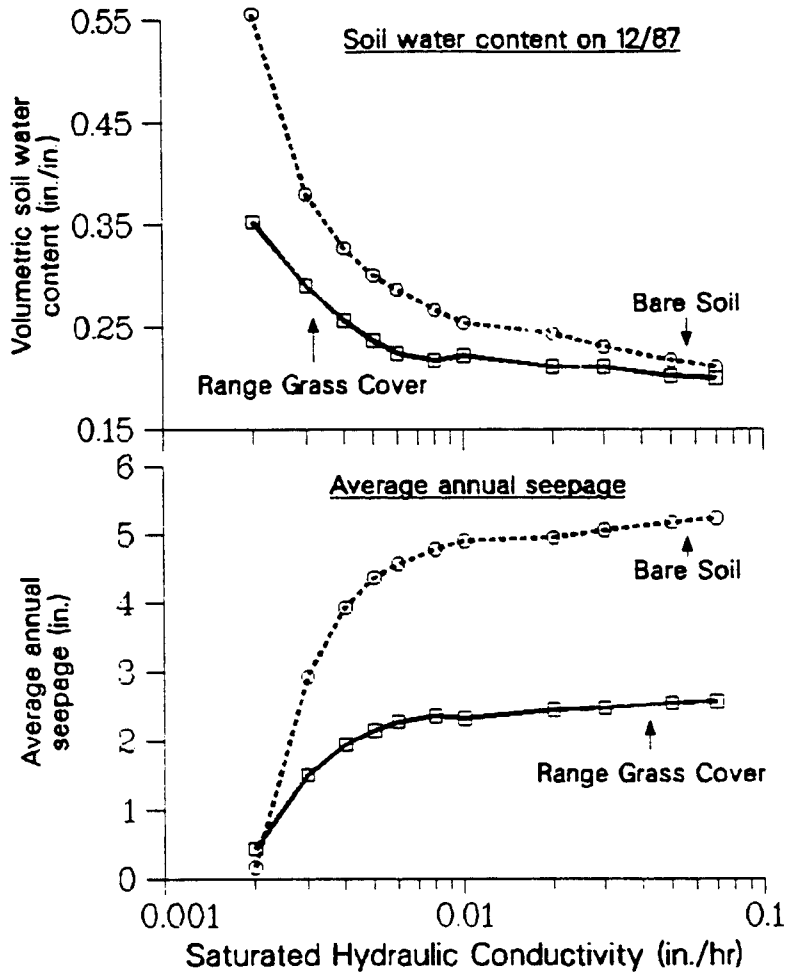

Fig. 17. CREAMS 10-yr simulation at Waste Disposal Area P.

with the CREAMS model at the Laboratory only involves modeling of land areas similar to the upper, flat portions of the Area P Landfill. The model also does not have the ability to describe two-dimensional unsaturated flow of soil water through the landfill, as could currently occur as a result of either runon or subsurface downhill transport at the interface between the tuff backfill and the undisturbed tuff at this site.

B. Area P Landfill Scenarios With a Closure Cover

This entire exercise was based on two field-calibrated models developed in previous research sponsored by the DOE National Low Level Waste Management Program. The integrated test plot (ITP) cover demonstration involved a comparison of water balance on a conventional Los Alamos landfill cover design (15 cm of topsoil emplaced on top of 76 cm of crushed tuff backfill) with that of an improved design containing a capillary barrier (Nyhan *et al.* 1989). The CREAMS model was calibrated for the conventional design (Nyhan and Barnes 1989), and was just calibrated for the improved design (Nyhan 1989).

As was pointed out earlier in this report, SLB design characteristics such as landfill cover thickness do not have to be arbitrarily chosen. Now that a field-calibrated hydrologic model existed that described

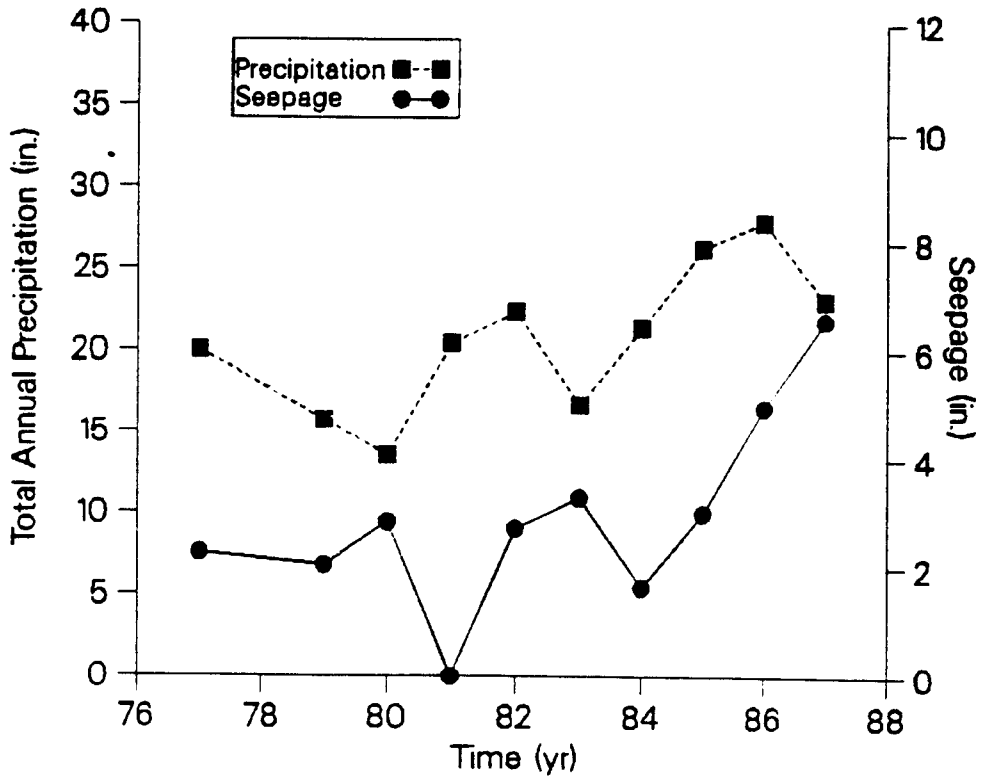

Fig. 18. Precipitation vs seepage predicted by CREAMS at Waste Disposal Area P (bare backfill cover scenario).

water balance relationships for the improved SLB design configuration at Los Alamos, CREAMS was used as a tool to improve the design of SLB.

Before the modeling activities for the design of the closure cover were initiated, a comparison was made between a CREAMS simulation (with a 1977-1987 daily precipitation data) of S Site and OHL. One of the 7-ft-thick scenarios was arbitrarily used (Fig. 16) with RC = 0.004 in./hr. The average annual amounts of precipitation varied from 19.2 in. at OHL to 20.7 in. at S Site during this time period. The simulation results demonstrated a negligible increase in soil water content and only a 5% increase in annual evapotranspiration using the S Site data base rather than the OHL data. There were 1.5 in. more annual precipitation received at S Site than at OHL, which resulted in only 0.6 in. of increased seepage production. Thus, it was felt that it was acceptable to use the longer OHL precipitation data base for the hydrologic modeling at the Area P Landfill because the simulation results using the two precipitation bases were so similar.

Using daily OHL precipitation data from 1968 to 1987, a series of CREAMS simulations were performed by varying the thickness of the landfill cover and determining the predicted amount of seepage occurring for both the average year and the wettest year for each thickness. The parameters used in this effort were the same as those used for the improved plots in the ITP experiment, with the exception that the 1985 plant leaf area index distributions were used for the entire simulation period. One CREAMS simulation was performed for each of nine landfill cover thicknesses (0.31, 0.46, 0.61, 0.91, 1.30, 1.52, 1.83, 2.13, and 2.52 m).

One of the first major discoveries made in the use of CREAMS for SLB landfill cover designs at Los Alamos was the influence of vegetative cover on decreasing seepage through the SLB landfill cover (Nyhan and Lane 1982). Because these early efforts were performed without the field-calibrated CREAMS model, it was decided to repeat this exercise with our field-calibrated model. The results of these CREAMS simulations are presented in Fig. 20, where the performance of a landfill cover with a bare soil surface

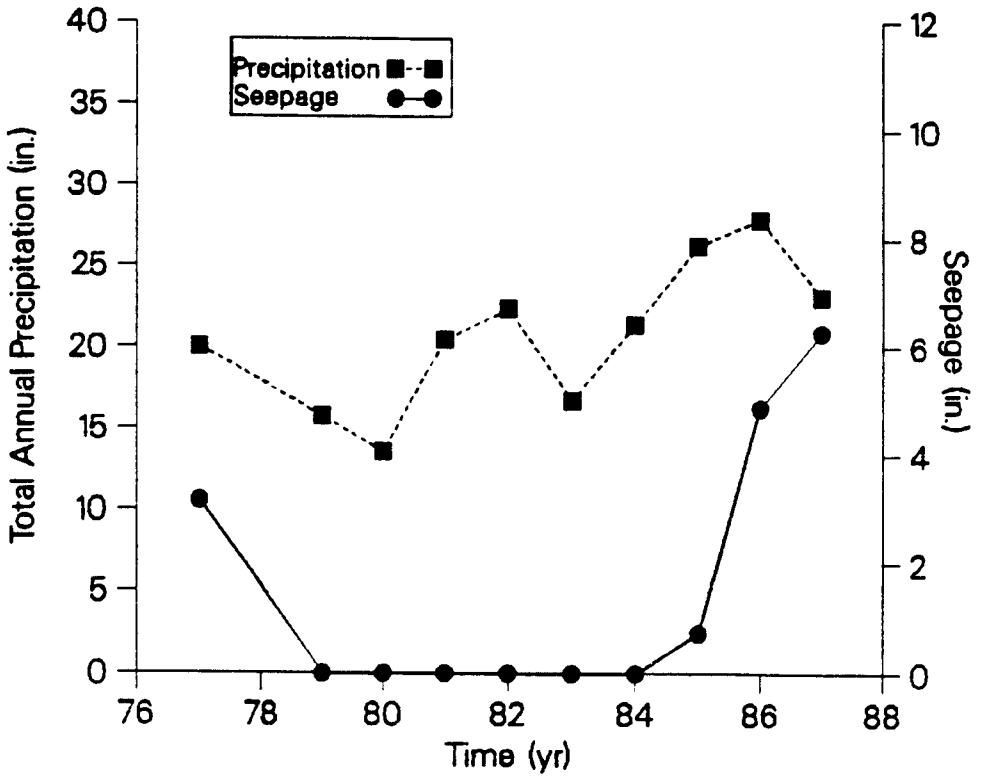

Fig. 19. Precipitation vs seepage predicted by CREAMS at Waste Disposal Area P (poor range grass cover scenario).

with a 70% cover of gravel is compared with one similar to that found on the ITP improved plot design (one with a 70% cover of gravel and a good cover of range grass).

The results of this comparison (Fig. 20) show that the bare soil/gravel cover consistantly produces about 10 cm of annual seepage in the average year and about 23 cm of annual seepage in the worst case (wettest year), regardless of the thickness of the landfill cover. In contrast, the good range grass/gravel cover produces average annual seepage that ranges from 5.6 to 0.27 cm as the landfill cover thickness increases from 0.31 to 2.5 m. In the wettest year, the good range grass/gravel cover produced from 14 to 5.4 cm of annual seepage as the landfill cover thickness increased from 0.31 to 2.5 m. The major factor causing this observed difference between these two cover designs revolves around the effort to use vegetation to enhance evapotranspiration, and thus decrease annual seepage, during the plant growing season. Thus, as the landfill cover with the good range-grass cover becomes thicker, the effective plant rooting depth increases, allowing increased plant interception of infiltrating precipitation.

If the results from the good range grass/gravel cover CREAMS simulation were used to design a landfill cover for long-term repository closure, we can see (Table II) that about 7.4 cm of annual seepage is predicted to occur in the wettest year (1987) with the thickness of one proposed landfill cover closure configuration (3 ft thickness: see Fig. 3). However, regardless of whether the CREAMS seepage predictions for the good range grass/gravel cover (Fig. 20) are for the 0.30 cm cover thickness (15 cm) or the 2.5-m-thick landfill cover (5.4 cm), the amounts of annual seepage predicted for the wettest years between 1968 and 1987 are usually about tenfold larger than the annual seepage occurring on the average year. The reason for this, of course, is that the wettest years (*i.e.*, 1968 and 1987) are years when snowmelt dominates the seepage production temporal pattern and times when plant transpiration does not occur to help reduce seepage production. This is a very important observation because neither the winter of 1968 nor 1987 was even a 10-yr event, in which 15 cm of precipitation would be received by the landfill cover let alone a 100-yr winter, in which even more precipitation would have occurred (Table II). Because our CREAMS simulations generally underestimated seepage occurring in the field, the implications for the

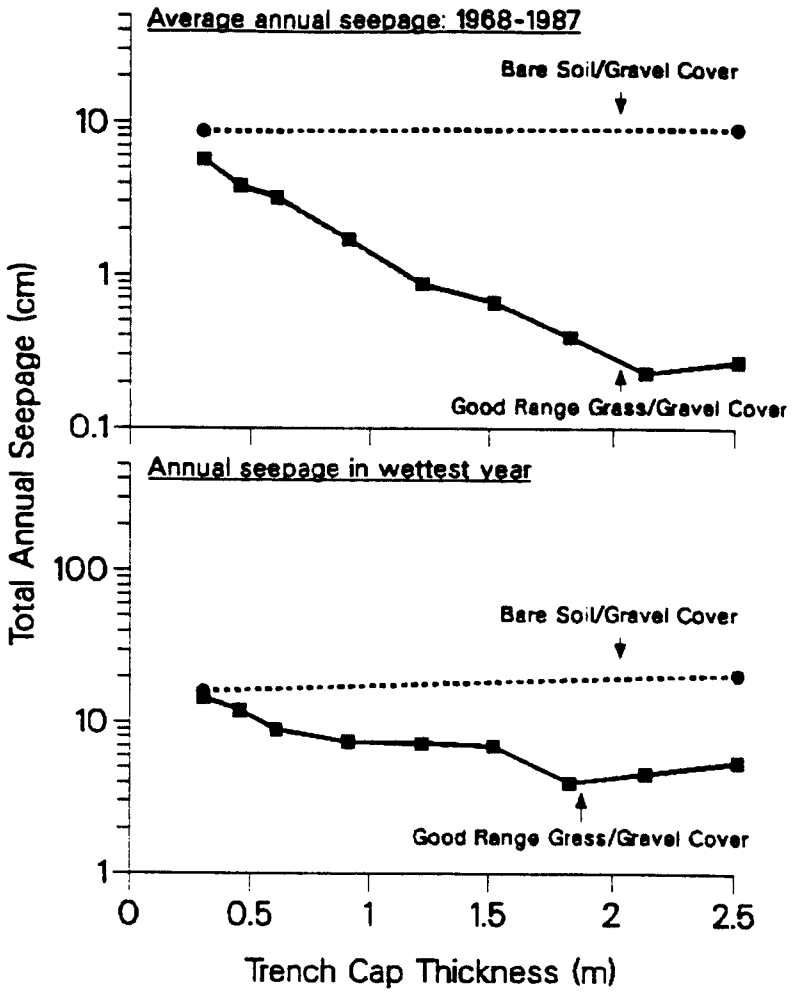

Fig. 20. CREAMS 20-yr simulation at Waste Disposal Area P.

waste management site operator are that large amounts of percolation could occur in 10-yr and 100-yr winters, especially when antecedent fall soil moisture levels are high.

VII. RECOMMENDATIONS FOR FUTURE STUDIES AND SPECIFIC WASTE MANAGEMENT PRACTICES AT WASTE DISPOSAL AREA P

An ongoing field study at Waste Disposal Area B is currently studying runoff/infiltration characteristics of landfill covers consisting of shrubs, grasses, and shrub and grass covers with partial gravel cover. One area for highly recommended future modeling activities would be to investigate the influence of reducing the bare soil evaporation parameter (C) in CREAMS simulations of disposal site hydrologic dynamics and design. The ITP modeling activities performed in previous studies indicated that C values should be decreased dramatically from those suggested (Lane 1984) when a gravel cover was involved. Further field validation of this effect would greatly enhance the accuracy of the CREAMS predictions of seasonal seepage in SLB designs, especially if a partial gravel cover is used in the Area P landfill designs to reduce erosion of the closure cover. The near-surface field studies performed at Waste Disposal Area B will also greatly enhance our ability to predict soil loss rates for different cover treatments using the erosion component of CREAMS.

Another recommendation can be made as a result of the overall modeling efforts in this study. Since appreciable annual seepage is predicted to occur in the wettest years, capillary barriers should be used in the long-term closure designs of all SLB facilities. More specifically, this would mean that the Delta H Engineering, Ltd., closure plan approach to essentially leave the western portion of the Area P landfill as is could be improved; it could also be improved because a portion of the water infiltrating the western portion of the landfill would infiltrate horizontally into the eastern portion of the landfill, with its proposed concrete cover. Since the improved plot design in the ITP experiment contained capillary barriers that dramatically reduce annual seepage, this data base should be further expanded by collection of field data at Waste Disposal Area P in the future. The field data and the modeling expertise are unique to Los Alamos and do not exist anywhere else in the US.

Several recommendations can be made in terms of what types of moisture, or capillary, barriers could be emplaced as part of the landfill cover at Waste Disposal Area P. First, as was mentioned earlier, synthetic liners have limited expected lifetimes (Fig. 2). This automatically eliminates closure covers made of concrete and polyethylene. This would leave either a rock barrier type of moisture barrier or a clay admixture barrier as the alternative. Of these two, the potential health hazards at Waste Disposal Area P from uptake of contaminants by plants growing on the cover do not warrant the expense of the gravel cobble biointrusion-moisture barrier. Thus, the recommendation would be to construct a landfill cover using a moisture barrier consisting of a mixture of crushed tuff and 4% bentonite in the final approved cover design (Abeele 1984a and 1984b, Abeele 1986a and 1986b, Abeele *et al.* 1986).

A possible alternative to the use of capillary barriers alone might be to dramatically reduce winter seepage using conifers in conjunction with capillary barriers. Using an evergreen cover on the trench cap, in addition to a good cover of range grass, could greatly enhance evapotranspiration in the winter and early spring, thus reducing seepage in the wettest years (worst case) described in this study. This would probably make a good waste management decision, but would necessitate further studies of capillary/biointrusion barriers to prohibit conifer roots from penetrating waste materials beneath the trench cap.

Finally, additional future field research and concurrent hydrologic modeling should be performed in three other areas involved in the water balance equation. First, transpiration studies of various grass, shrub, and tree species need to be performed in the field on a scale larger than the 3- by 10-m plots used in the ITP experiment. Ultimately, the precision of a model like CREAMS to predict evapotranspiration will depend on our ability to accurately describe both seasonal transpiration and evaporation processes involved. The second area that needs further research involves further field investigations into seepage production in SLB configurations. Without seepage field data, both evapotranspiration and runoff parameter estimates need to directly measured, which may not be possible with the technology currently at hand. Finally, a reliable technique needs to be developed and evaluated for determining the saturated hydraulic conductivity for the field soils that agrees with the model estimates of RC in a generic sense. A good field estimate of RC representing a large field area would take a lot of guesswork out of CREAMS parameter estimation, resulting in greatly enhanced accuracy in model predictions.

Several additional waste management suggestions should be made specific to ultimately deriving a final approved closure plan for the Area P landfill:

1. Based on our hydrologic modeling of the site, the first thing to be done immediately (before site closure) is to relocate and to line the runoff diversion ditch located on the south side of the landfill. The runoff diversion ditch should also be relocated so that it takes the runoff coming from the total area uphill and to the south of the landfill and sends it northeastward down the road into the canyon (around the landfill).
2. Collect neutron moisture gauge data inside of the Area P landfill, and collect soil samples for contaminant assays when the holes are drilled for the access tubes.
3. Perform a flood frequency analysis in the canyon (to the north of the site) to determine if the current, or future, landfill cover will undergo water erosion.
4. Before the final closure cover is emplaced on the landfill, be sure to compact the final subsurface layer under the cover (using approved safety procedures) to avoid subsidence problems. The extremely high volumetric water content in the current crushed tuff backfill cover will greatly enhance subsidence of these layers in the future, resulting of course, in subsidence of soil layers placed on top of the current cover.

5. Set up the final approved closure cover so that its performance can be both successfully monitored with time with a minimal manpower requirement and successfully modeled with time. This will allow HSE Division and the Laboratory to be in a better position to design covers for future waste disposal areas to undergo site closure.

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APPENDIX D

VADOSE ZONE MONITORING OBSERVATIONS AT THE TA-16 AREA P LANDFILL

by

Stepher G. McLin

with the

Solid Waste and Remedial Action Section

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Los Alamos National Laboratory

8/21/89

FYI
Any comments or suggestions?
Steve McL

Los Alamos National Laboratory

Los Alamos, New Mexico

August 18, 1989

THIS PRELIMINARY REPORT IS SUBJECT TO FINAL REVIEW

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VADOSE ZONE MONITORING OBSERVATIONS

AT THE TECHNICAL AREA 16 AREA P LANDFILL

by

Stephen G. McLin

ABSTRACT

A vadose monitoring system consisting of eight separate wells clustered together into four well nests was installed into and below the landfill at Technical Area 16 (TA-16) Area P during the fall of 1988. Each well nest consists of either a single or duel completion pressure-vacuum lysimeter borehole, and an adjacent neutron moisture access well. The four lysimeter boreholes contain a total of seven independent lysimeters located at varying depths in and below the landfill, while the neutron access wells penetrate into the underlying native Bandelier tuff down to a maximum depth of 30 feet.

Soil and tuff core samples collected during these installations indicate that barium in excess of 18,000 mg/l is present in the eastern half of the landfill, while the western portion has barium below detection limits. This barium occurs as barium oxide in white crystalline stringers of wastes located several feet below the surface. These wastes originated from barium nitrate contaminated sands associated with HE waste processing and disposal operations dating from the 1950s. At least some of this barium has been mobilized by infiltrating precipitation, and has penetrated to a depth of approximately 19 feet, or at least six feet below the landfill bottom. Four of the seven lysimeters have yielded small volumes of water at routine sampling intervals over a one year period; all of these lysimeters are adjacent to landfill materials. Barium concentrations in these water samples ranged from 1.1 to 37.8 mg/l, and averaged 9.23 mg/l. The three remaining lysimeters that did not yield water are all located below the landfill-tuff contact.

Monthly neutron moisture access well measurements from March to September 1989 have shown a consistently stable moisture distribution in four landfill access wells, and five perimeter access wells. The volumetric moisture contents over depth from individual landfill access wells is consistently higher than for the perimeter wells. Background volumetric moisture contents typically exceed 15% in the top one foot, but quickly drop below 5% at 4 feet, and remain relatively constant down to 170 feet. However the eastern landfill wells show moisture contents between 15 to 25% above the landfill-tuff contact, and between 15 to 20% in the tuff. Western landfill wells show similar moisture contents compared to those in the east, but higher moistures extend to greater depths. Western portions of the landfill have waste and fill deposits that are thicker than in the east, and contain more clayey materials.

I. INTRODUCTION

An industrial landfill, located in Technical Area 16 Area P (TA-16 Area P) at the Los Alamos National Laboratory (LANL), was actively used from the early 1950s until about 1985. At that time several landfill soil samples revealed the presence of barium in excess of Extraction Procedure (EP) toxicity limits defined in 40 CFR 261.24, and the landfill was subject to regulation under the Resource Conservation and Recovery Act (RCRA) of 1976, as amended. The vadose zone monitoring activities described herein were conducted in support of the main aquifer ground-water monitoring waiver demonstration (McLin and Purtymun, 1988) and the interim status closure and post-closure care plans (Delta H Engineering, 1985; HSE-8, 1988) that were submitted to the New Mexico Environmental Improvement Division (NMEID).

There is very little documentation of the types or quantities of wastes placed into the Area P landfill. The site was used in the early 1950s to dispose of burned equipment that had been contaminated with high explosives (HE), and building demolition rubble. The procedure for handling HE-contaminated equipment and wastes has been relatively constant over the years; the notable exception is that sand-covered burn pads have recently been replaced by fire-brick lined metal trays that are elevated above the ground surface. Initially any equipment or waste debris that is potentially HE-contaminated is partially disassembled and all surfaces are cleaned. Prior to 1987 this equipment ~~was~~ then taken to ~~one of three~~ sand-covered burn pads and flashed, along with other combustible material needed to support the fire. ~~Currently fire-brick lined metal trays are used for this flashing operation~~. After the thermal treatment, waste equipment and debris are inspected for any unburned HE residue. Before 1985 all flashed HE-free wastes, including the burn pad sands, were removed from the flash pads and placed in the landfill; since 1985 ~~these~~ ash wastes have be drummed after thermal treatment and transported to TA-54 for subsequent disposal. The source of elevated barium in the waste residue is barium nitrate that was used in the formulation of some HE materials. Barium concentrations in the sand wastes vary with barium nitrate concentrations in the HE, and with HE concentrations in the wastes. At elevated temperatures associated with the thermal treatment process, nitrates would be reduced to volatile oxides of nitrogen, and would tend to be absent in the ash.

The Area P landfill (Figs. 1 and 2) is located in a topographic saddle on a short, east-trending narrow mesa. This saddle is near the southern rim of Canon de Valle immediately north of the TA-16 thermal treatment pad number 387. The elliptically shaped landfill is about 170 wide in the north-south direction, and 400 feet long in the east-west direction; it contains an estimated 13,000 cubic yards of waste construction debris, crushed tuff and sandy clay fill material, and barium contaminated sands. Landfilling activities progressed from west to east. The western portion was closed by leveling and covering wastes with crushed tuff and sandy clay soils. These leveling operations resulted in some landfill debris

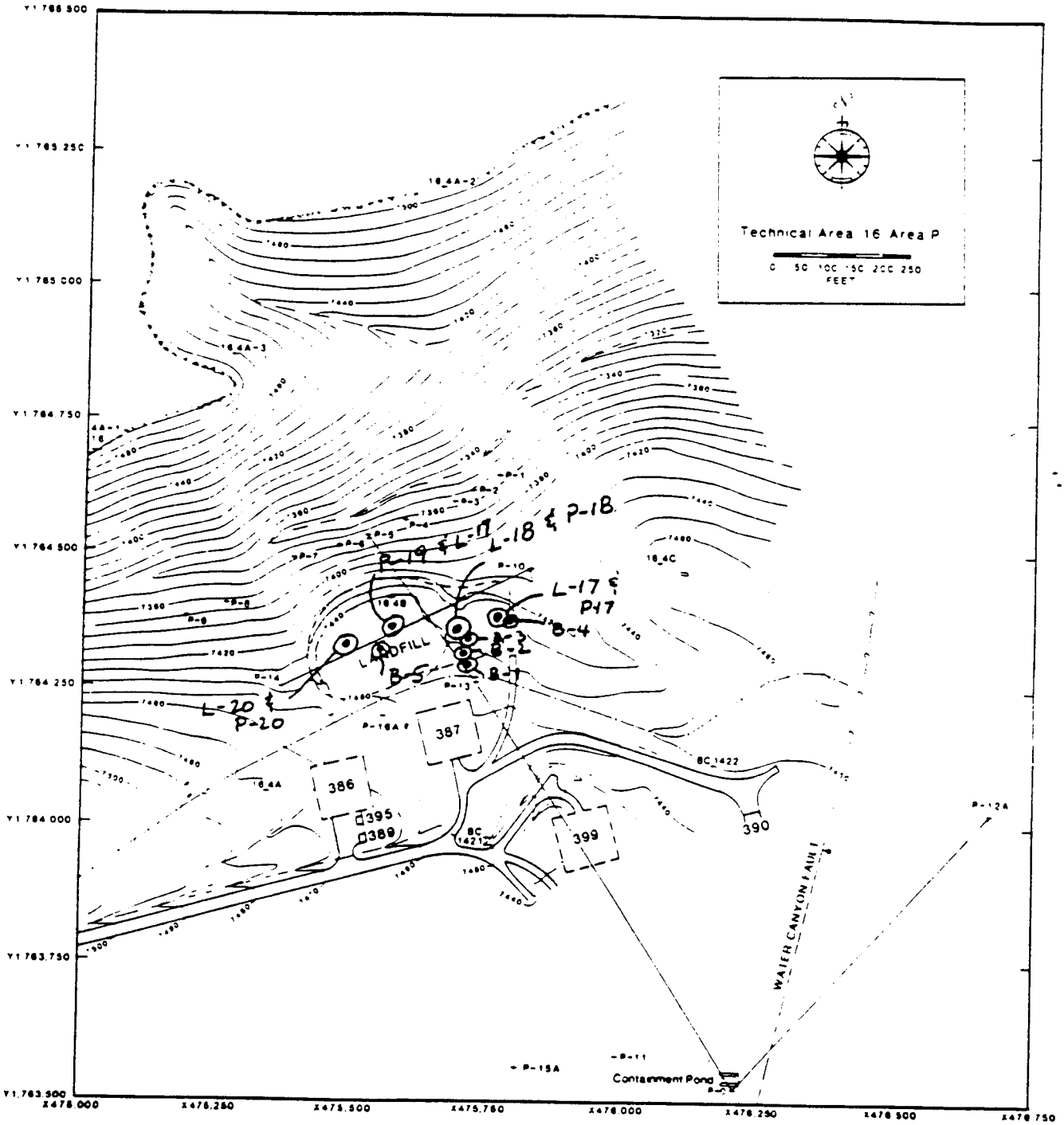

Figure 1. Site map of TA-16 Area P. Boreholes are marked with crosses, numbered P-0 through P-20, and L-17 through L-20. Additional crosses are survey marks (after Brown, et al., 1988).

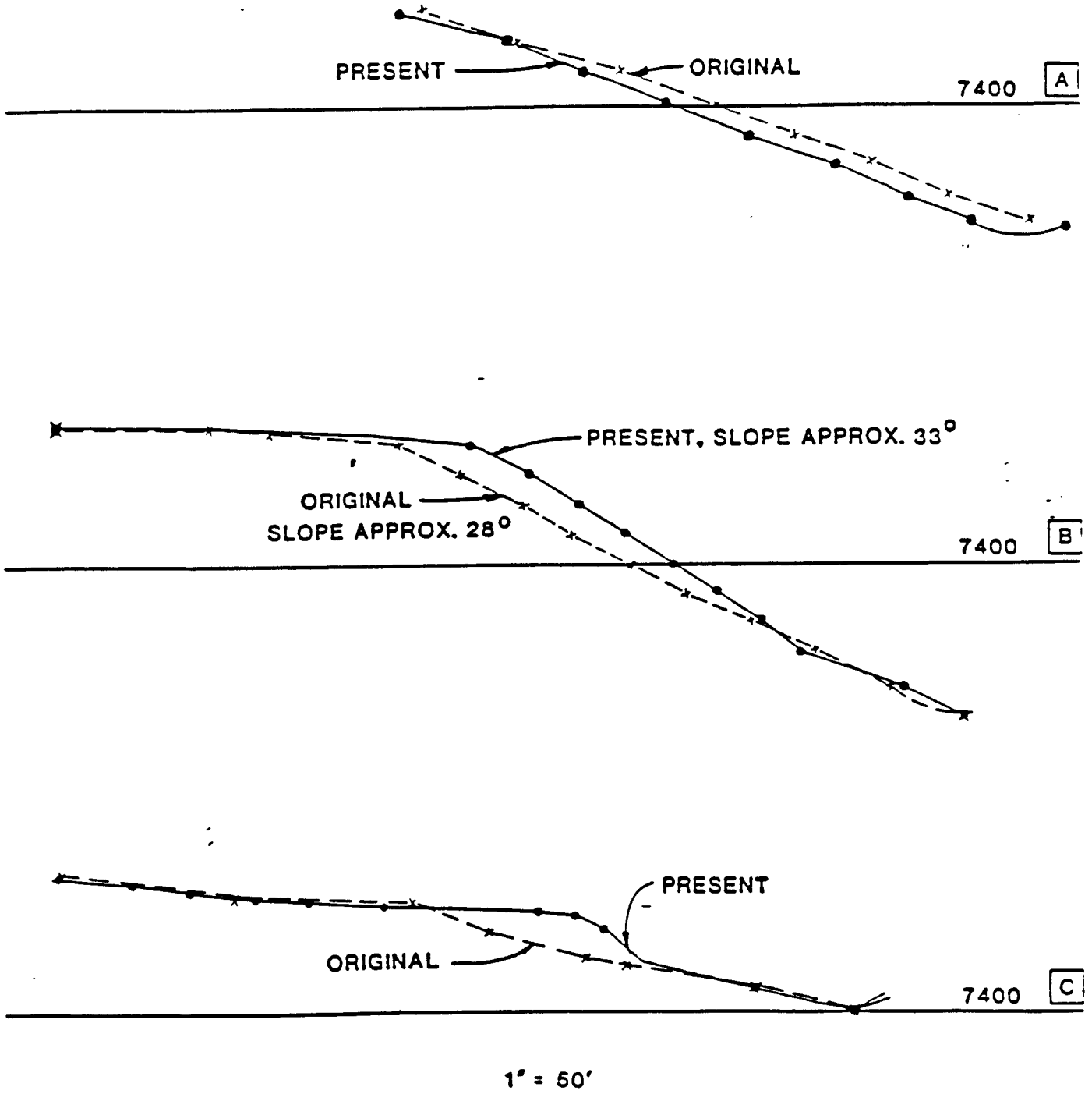

Figure 2. Map of three cross sections of waste disposal Area P showing locations of original and present land surfaces relative to elevation of 7400 feet. Cross sections A, B, and C are roughly north-south transects located immediately west of the landfill, through the middle of the landfill, and through the middle of the east portion of the landfill, respectively (after Nyhan, 1989).

overflowing the canyon rim along the northwest quadrant. Earlier investigations, including a site geological characterization (Brown, et al. 1988) and a water balance study (Nyhan, 1989), have reported that waste deposition reaches only 30 to 40 feet back from the canyon rim, and extends down the slope to the canyon floor. However, results from this study indicate that waste deposition extends at least 100 feet back from the existing canyon rim; furthermore, barium wastes may or may not be present in the entire landfill area. Elevations across the landfill vary from about 7,350 feet above mean sea level in the canyon bottom, to about 7,450 feet at the landfill top.

The western portion of the landfill has been naturally revegetated with grasses, wild rose, wormwood, oak brush, and juniper. There are occasional protrusions of concrete rubble, steel pipe, and metal that aids in binding the mass together. In the recently active eastern portion, fill has progressed from south to north with cover soil being added as the fill advanced. Wastes on the northern face of the landfill are exposed, and no appreciable natural revegetation has occurred in the eastern portion.

II. GEOLOGY AT AREA P

The regional and site geology of the Area P landfill has been previously reported in detail (Brown, et al., 1988). However a brief geological summary is presented here to assist the reader in understanding site drilling logs presented in this report.

There are about 1,230 feet of unsaturated Bandelier Tuff and Puye fanglomerates with interbedded volcanics underlying the mesa at TA-16 (Purtymun, 1984; Purtymun and Stoker, 1987; and McLin and Purtymun, 1988). The thickness of the tuff is at its maximum along the western edge of Pajarito Plateau, roughly delineated by New Mexico Highway 4 west of LANL and the TA-16 entrance gate. This tuff gradually thins to about 600 feet in thickness near the Rio Grande located approximately 10 miles to the east. The thickness of the unsaturated tuff and sediments below the TA-16 area is indicated below in Table 1.

The 950 feet of unsaturated tuff beneath the mesa at TA-16 consists of quartz and sanadine crystals and crystal fragments, and small rock fragments of latite, rhyolite, and pumice in a glassy gray ash matrix. The degree of welding in the tuff increases westward across the plateau toward the source area at Valles Caldera. This increase in welding reduces the porosity and capillary size of the pores. It is also likely that the hydraulic transmitting characteristics of the unsaturated tuff are also reduced with increased degrees of tuff welding (Abeele, 1984; and Stephens, 1988).

In order to establish the shallow subsurface geology at Area P, 17 boreholes (numbered P-0 through P-16) were drilled in the fall of 1987. In addition, 13 auxiliary boreholes were drilled in the fall

Table 1. Geologic Section at TA-16.

Geologic Section	Thickness (ft)	Depth (ft)
BANDELIER TUFF		
Tshierege Member		
Unit 3	190	190
Unit 2	150	340
Unit 1	360	700
Otowi Member	210	910
Guaje Member	40	950
PUYE CONGLOMERATE		
Fanglomerate with interbedded volcanics	500	1,450
TESUQUE FORMATION		
Siltstones and sandstones, occasional conglomerates interbedded with volcanics, earlier volcanics, and sediments	2,000	3,450
PRECAMBRIAN		
Basement rocks	unknown	+3,450

of 1988 (numbered P-17 through P-20, L-17 through L-20, and B-1 through B-5). All of these drill logs are contained in Appendix A of this report and in HSE-8 (1988); all borehole locations are shown in Fig. 1. A rotary drilling technique utilizing air and either 4 or 6 inch continuous flight auger were employed. Continuous drill cuttings were recovered with the 4-inch solid-stem auger, while the 6-inch hollow-stem auger allowed continuous core recovery when a split-spoon sampler was employed. Lithologic logging was done for each borehole; however, logs from continuously cored holes are more accurate. Each log description was based on the following characteristics: (1) color; (2) degree of welding; (3) shape and abundance of pumice lapilli; and (4) distribution of lithic fragments. Four distinct types of welding were recognized during drilling operations, and included:

1. Nonwelded: High porosity, low cohesion of glassy fragments, and crumbly texture. In core samples, this can be recognized by disaggregation and little or no flattening of pumice lapilli.

2. Moderately Welded: Less porosity, moderate cohesion, brittle texture, and slight deformation of glassy fragments. In core samples, this texture crumbles easily in the hand and contains some noticeably flattened pumice lapilli.

3. Welded: Low porosity, good cohesion, brittle texture, and noticeable deformation of glassy fragments. This texture

normally requires a hammer to break, and the majority of pumice fragments are noticeably flattened.

4. Densely Welded: Texture noticeably impedes or halts drilling, with little or no drill-bit penetration and poor core recovery.

Two major lithologic units of the Bandelier Tuff were identified at Area P during drilling operations (Fig. 3 and Table 1). The uppermost Unit 3 consists of four individual ash flows that appear to have cooled contemporaneously, forming a single compound unit. These ash flows were designated by Brown, et al. (1988) as Subunits 3a, 3b, 3c, and 3d (bottom to top). Unit 3 rests conformably above Unit 2, the lowermost unit encountered. In general, the Bandelier Tuff dips 2 to 5 degrees toward the east; however, at the landfill no dip was apparent and the units are essentially horizontal and of uniform thickness.

Subunit 3a consists of a welded dark yellowish brown tuff, with rare pumice lapilli that are slightly flattened. This subunit also contains abundant pebble-sized red porphyritic quartz latite and gray rhyolite lithic fragments. The ratio of quartz to rhyolite increases towards the base of the subunit. The contact between Subunit 3a and the underlying Unit 2 tends to be densely welded in the vicinity of the landfill, but is nonwelded farther east near P-12.

Subunit 3b consists of a welded pale yellowish brown tuff, with common gray and red pumice lapilli that are noticeably flattened. This subunit also contains rare pebble-sized rhyolite lithic fragments. This subunit weathers to a dark brown, and may also contain abundant clayey pumice lapilli.

Subunit 3c consists of a moderately welded brownish gray to yellowish brown tuff, with common gray pumice lapilli that are noticeably flattened, and rare pebble-sized rhyolite lithic fragments. Clay-filled vertical fractures are common throughout this subunit. The contact between 3c and 3d tends to be densely welded.

Subunit 3d outcrops along the higher rim of the topographic saddle at the landfill, and consists of a moderately welded yellowish brown tuff, with rare pebble-sized rhyolite lithic fragments ans common gray pumice lapilli. Subunit 3d is overlain by scattered deposits of El Cajete Pumice.

Locally, Unit 2 consists of a welded to densely welded tuff, light gray to pinkish gray in color, with common pumice lapilli and pebble-sized rhyolite fragments. Because of this dense welding, the drill bit was only able to penetrate the upper 5 to 10 feet of this unit.

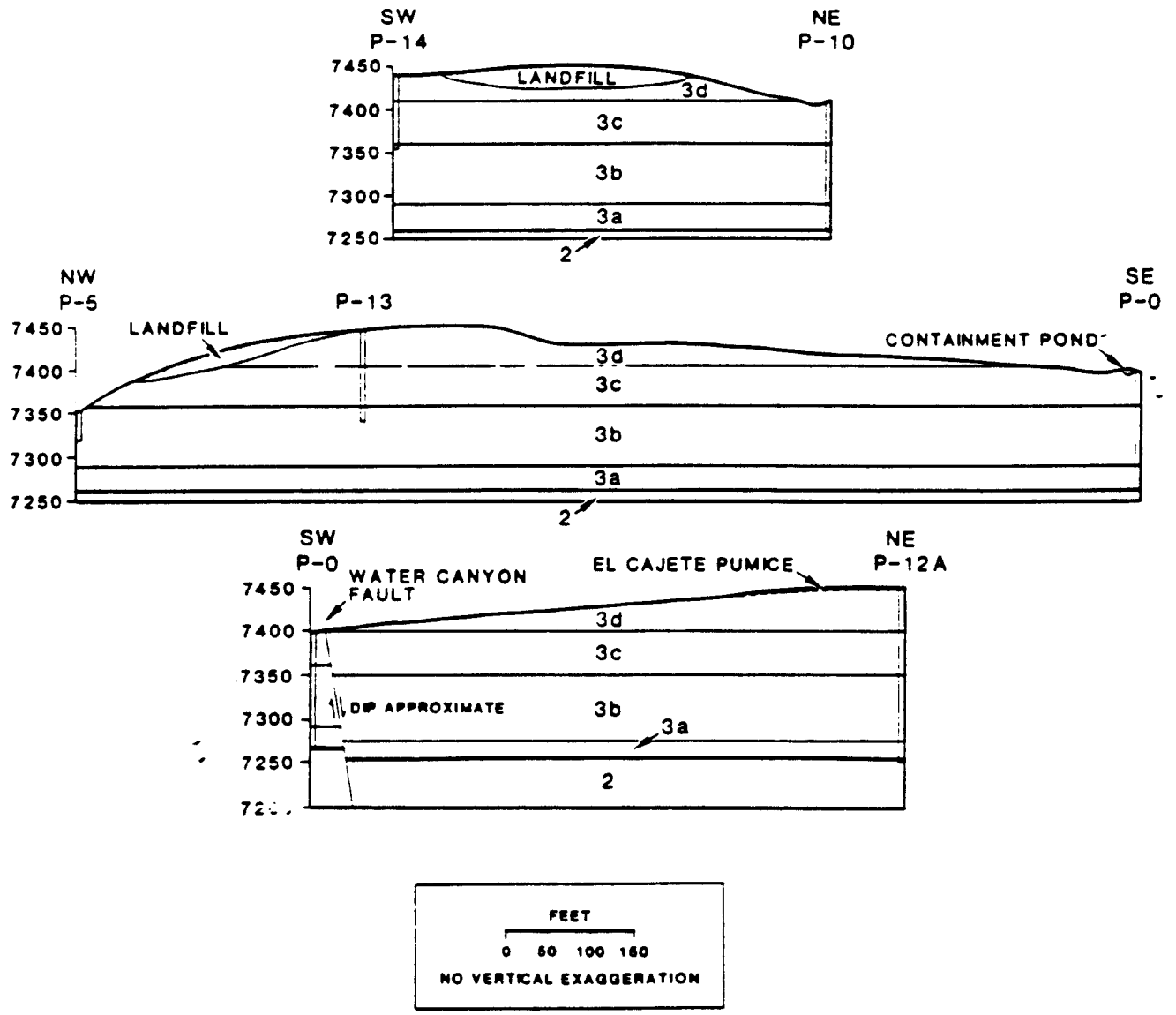

Figure 3. Geologic cross sections through Area P. Section lines are shown in Figure 1 (after Brown, et al., 1988).

Additional hydrogeological information from the Area P landfill is contained in the Delta H Engineering (1985) closure plan, the HSE-8 closure plan modifications (HSE-8, 1988), McLin and Purtymun (1988), and Stephens (1988).

III. SHALLOW VADOSE ZONE MONITORING SYSTEM

The geological profile extending from the ground surface downward to the upper surface of the principal water-bearing formation has been defined as the vadose zone (Everett, et al., 1984). These authors present an extensive discussion on field methods for monitoring pollution movement in the vadose zone at active or abandoned sites. According to this source, ceramic-type suction samplers are the best available technology for in-situ sampling of unsaturated media. In fact, it is not physically possible for saturated monitoring systems to extract water from the vadose zone because water held here is below atmospheric pressure. Hence a coupled network of pressure-vacuum lysimeters and neutron moisture access wells was installed at the Area P landfill to supplement the existing ground-water monitoring system and neutron moisture access wells. This vadose zone monitoring system is described below.

Of the 17 boreholes drilled in the fall of 1987 (HSE-8, 1988), eight were completed as saturated monitoring wells (i.e, boreholes P-1, and P-3 through P-9 in Appendix A), 5 were completed as neutron moisture access wells (i.e., boreholes P-0, P-12 through P-14, and P-16), and 4 were sealed closed (i.e., boreholes P-2, P-10, P-11, and P-15) after logging. In the fall of 1988, 13 additional boreholes were installed to complete a vadose monitoring system. Each of these boreholes penetrated through the landfill and into the underlying native Bandelier tuff. These boreholes were completed as a coupled network of seven pressure-vacuum lysimeters utilizing multiple completions in four boreholes (i.e., boreholes L-17 through L-20), four neutron moisture access wells (i.e., boreholes P-17 through P-20), and five exploration boreholes (i.e., B-1 through B-5) that were plugged and abandoned after logging. Completion summaries are provided for each of these in Appendix A.

The pressure-vacuum lysimeter and neutron moisture access boreholes were completed as two-well nests, with approximately six to eight feet of horizontal separation between nest boreholes to avoid interference effects. Hence lysimeter L-17 is within eight feet of neutron moisture access well P-17, and so on for the other three nests (i.e., numbered 18 to 20). The 4.0 inch diameter neutron moisture access boreholes were cased with 12 foot lengths of 2.50 inch O.D. seamless aluminum tubing having a 0.049 inch wall thickness. Two 12 foot sections of tubing were welded together into a single 24 foot section, and these 24 foot sections were joined together using a two-inch stainless steel coupling with internal neoprene liner; the bottom section of tubing contained an end-cap plug. The remaining 0.75 inch borehole annulus was filled with a fine to medium grained silica sand to provide uniform density and

compaction. A concrete surface seal and protective top-cap were installed to prevent any borehole infiltration.

Each lysimeter borehole was cored with 6-inch hollow-stem auger and split-spoon sampler. Multiple pressure-vacuum lysimeter depth locations were identified from core samples in the field; individual completion details are listed with the drilling logs in Appendix A. All lysimeters were manufactured by Soilmoisture Equipment Corporation, model number 1940. A lysimeter schematic is shown in Fig. 4. For wells P-17, P-18, and P-20, one lysimeter was placed at a depth slightly above the landfill-tuff contact, and a deeper lysimeter was placed below this contact. For well P-19, only a single lysimeter was installed above the landfill-tuff contact. The borehole annulus surrounding each lysimeter was filled with a fine to medium pure silica sand. A one to two foot concrete seal was installed between each lysimeter to prevent borehole infiltration, and a concrete surface seal and locking steel cap was also installed.

During borehole coring and drilling operations, landfill soil and undisturbed tuff samples were collected for barium, nitrate, and residual explosives analyses. Barium was analyzed using the EP toxicity test procedure specified in 40 CFR 261 Appendix II, and represents barium solubility in a mixture agitated for 24 hours at 20 to 40 degrees Celsius. This mixture has a constant pH of 5.0, and consists of soil, deionized water, and 0.5 N acetic acid. Since precipitation in Los Alamos County typically has a pH of about 5.5 to 6.5, this procedure provides a crude indication of barium leaching potential in the landfill. All of these chemical data are summarized in Appendix B.

IV. MOISTURE AND WATER QUALITY DATA

At periodic intervals, each lysimeter was evacuated to approximately 50 centibars (cb) vacuum pressure (equivalent to 15 inches of mercury or 7.4 psig). This vacuum pressure was maintained for approximately one week before a water sample was collected. Four of the seven lysimeters have yielded water using this procedure, although at sporadic intervals coinciding with heavy precipitation or snow melt periods. All of the lysimeters located in the undisturbed tuff have consistently failed to yield any water, while the landfill lysimeters have yielded small volumes (i.e., less than 25 ml) on occasion. When sufficient water volumes could be collected, they were analyzed for barium and nitrate. Results of these chemical analyses are shown in Appendix C.

During the fall of 1988, a stream sampling survey was conducted along Canon de Valle upstream of Area P to New Mexico Highway 4. Stream water and sediment samples were collected at periodic distances for barium and nitrate analyses; results are summarized in Appendix D. These data suggest that the NPDES outfall at TA-16 Building 260 is a primary source of observed barium contamination in

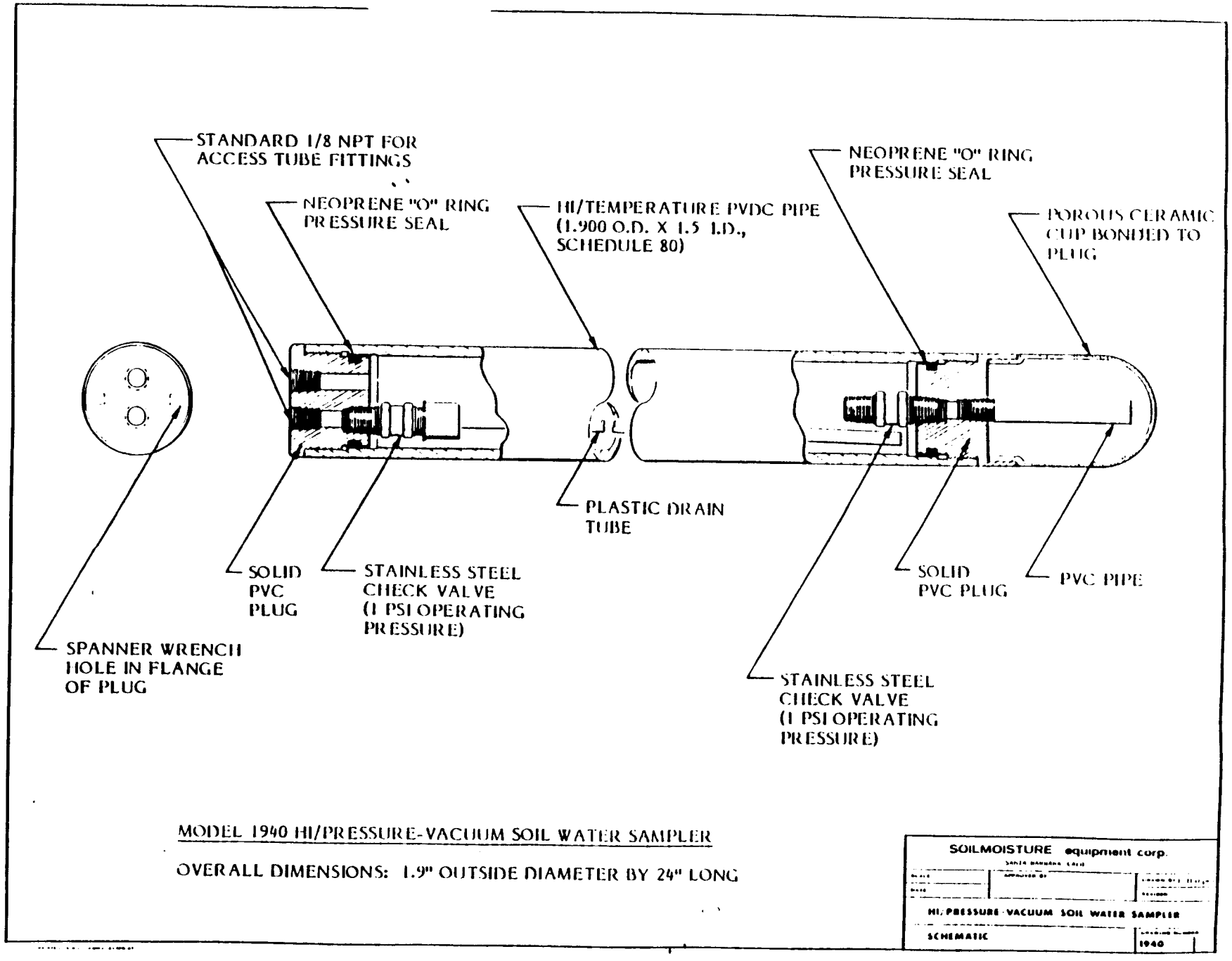

Figure 4. Schmetic of pressure vacuum lysimeter.

both surface waters and sediments in Canon de Valle at the landfill boundary.

Since March 1988, all of the neutron moisture access wells were tested monthly for moisture contents using a model 503-DR hydroprobe manufactured by Campbell Pacific Nuclear Corporation. This moisture gauge contains a Cesium-137 and Americium-241 sealed high energy neutron source, and a slow thermal neutron detector. Its design is based on the principal that any hydrogen present in the vadose zone opposite the cased wellbore will attenuate the fast moving neutrons from the probe source and be detected. This probe is capable of producing raw data in the form of neutron counts, or a variety of calibrated moisture content readings corresponding to these counts. The probe was factory calibrated to pure silica sand at a density of 2.65 grams per cubic centimeter (gm/cc) over the moisture range from dry to fully saturated. It was also calibrated to crushed Bandelier tuff by HSE-8 personnel at a density of 1.45 gm/cc over the same moisture range following the procedure of Nyhan, et al. (1983). Neutron moisture data were recorded in neutron counts, and later converted to volumetric moisture contents for this report using the factory calibration curve. Since all of the calibration curves were nearly identical (see Appendix E), the factory curve was used for these data conversions. In addition, it should be noted that the landfill materials have a density midway between that for Bandelier tuff and silica sand.

Monthly volumetric moisture contents recorded in individual neutron moisture access wells did not vary significantly during the period from March to September 1989. The six month average volumetric moisture content versus depth for each well is shown in Figs. 5-13 in Appendix F; each figure also shows the maximum and minimum moisture values recorded at each depth over the six-month period. The tabulated volumetric moisture data is also shown in Appendix F for future reference.

For well P-12 in Fig. 13, one should interpret the maximum-minimum moistures as an approximate instrument error band, and not as actual moisture fluctuations. However, in the remaining wells shown in Figs. 5-12, temporal moisture fluctuation are apparent even though these have not been segregated from small instrument fluctuation. These observations suggest that the landfill-tuff contact is exposed to a small but dynamic system of moisture infiltration, and that the dynamic equilibrium between moisture contents, unsaturated hydraulic conductivities, and infiltration rates increases toward the surface and decreases with depth. This equilibrium is obviously controlled at the surface by evapotranspiration and precipitation. Still, individual moisture profiles depicted in Figs. 5-13 are approximately at steady state conditions, and transient moisture fluctuations at depth can not be adequately measured at the monthly time interval utilized here. Hence these observations also suggest that average moisture profiles for individual neutron wells have not significantly changed below about 5 to 10 feet (i.e., in the lower portions of the landfill and in the undisturbed tuff below the landfill) during the past six months at this site.

V. CONCLUSION AND RECOMMENDATIONS

After a detailed review of the information presented in the Appendices section of this report, the following conclusions have been reached.

1. Barium concentrations as high as 18,000 mg/l were detected in landfill core samples using the EP toxicity method. All of these elevated barium concentration levels were from samples collected in the eastern half of the landfill. Samples from the western portion of the landfill exhibited barium concentration levels below the detection limit at 5 mg/l. A clear delineation of barium concentration levels in the eastern and western portions of the landfill has not been made. These same core samples also indicate that nitrate concentrations in the landfill are at or below 2.6 mg/l.

2. There is evidence that at least some barium contamination has occurred below the landfill near boreholes B-4 and L-17. Elevated barium levels were recorded in core samples from the undisturbed tuff in these boreholes to a depth of 19 feet, and represent at least 6 feet of barium penetration into the tuff.

3. Barium concentration levels in sediment and water samples collected in Canon de Valle immediately upstream and downstream of the landfill indicate that extensive soil erosion from the landfill does not appear to be a significant problem. A stream sampling survey indicates that the majority of barium present in Canon de Valle has probably originated from the NPDES outfall at Building 260, located approximately 1,700 feet upstream of Area P. Data from this survey are summarized in Appendix D.

4. Four of seven pressure-vacuum lysimeters installed within and below the landfill have yielded at least some water. Three of these water yielding lysimeters are within the eastern portion of the landfill, and the forth is in the western portion. Recovered water volumes range from 1 to 25 milliliters (ml) after one week of 50 centibar (cb) vacuum pressure, indicating that at least some precipitation infiltration has penetrated into the landfill. Lysimeter locations that have yielded water correspond to volumetric moisture readings above 20%, while lysimeter locations not yielding water have volumetric moistures below 20%. Several imaginary horizontal planes throughout the landfill consistently have moisture contents above 20%, but do not have any lysimeters installed nearby. Barium concentrations in recovered lysimeter waters are generally less than about 3 mg/l, suggesting that extensive barium mobilization has not occurred. However, one of the first lysimeter water samples showed barium as high as 37.8 mg/l. This elevated barium level was probably created in response to lysimeter water additions during well completion; these municipal water supply additions are required for proper installation. All of the lysimeters that have yielded water

samples are located within the landfill, while those that have not yielded any water are completed into the underlying tuff.

5. All of the soil and core samples listed in Table B-1 (Appendix B) were field screened for residual explosives contamination. Twelve of these samples that showed a slightly positive indication were submitted to the M-1 Analytical Laboratory for detailed analyses using a high pressure liquid chromatography procedure (Baytos, 1989); results of these tests are summarized in Tables B-3 and B-4 (Appendix B). The residual explosives content from replicate samples for all cases was below the 1.68% level. These results suggest that landfill materials do not contain a dangerously high level of residual explosives contamination. However, landfill waste deposition activities were never fully documented. Hence there remains an unknown element of risk at this site with regard to landfill excavation.

6. Unsaturated core samples recovered from the shallow tuff immediately south of the landfill were tested for saturated and unsaturated hydraulic transmitting characteristics in 1987 (Stephens, 1987). These data indicate that the shallow tuff has a saturated hydraulic conductivity approaching that of the main aquifer located some 1,230 feet below ground surface. However, because this tuff is unsaturated, its relative (i.e., unsaturated) hydraulic conductivity is three to six orders of magnitude below its saturated value. Hence the downward movement of water in the vadose zone is greatly restricted. In addition, there are several densely welded tuff units at depths under the landfill that have lower unsaturated hydraulic conductivity versus moisture content relationships than these shallow cores. However, if this shallow tuff material ever becomes fully saturated, it will readily convey water vertically downward to deeper flow restricting units at a rapid rate. It should also be recognized that the Area P landfill has no engineered under-liner; however, a thin natural clay layer may be present immediately above the unsaturated tuff and below the landfill.

7. Neutron moisture access wells that penetrate the landfill (i.e., P-17 through P-20) consistently have shown a higher volumetric moisture inventory over depth than those neutron wells completed elsewhere. In addition, these landfill wells have consistently shown a higher moisture inventory in landfill materials than in the underlying native tuff. Well P-12, the background neutron moisture access well, has shown the lowest moisture inventory of all wells over its entire depth. Well P-0 is immediately south of the TA-16 surface impoundment, and its moisture inventory over depth may have been influenced by impoundment precipitation seepage because the hypolon liner and all wastes were removed in 1988. Wells P-13, P-14, and P-16 are located to the immediate south and west of the Area P landfill. These landfill perimeter wells have respective moisture inventories that are higher than at P-12, but are

consistently lower than landfill well moisture inventories. This observation tends to support the conclusion that landfill moisture inventories are the result of direct precipitation infiltration through the existing landfill cover, and that landfill infiltration rates are higher than those for surrounding undisturbed areas. Nyhan (1988), however, suspects that the unlined diversion ditch located south of the landfill is primarily responsible for the elevated moisture inventory in the landfill. His water balance study was conducted prior to the installation of wells P-17 through P-20, so he has not benefited from these recent data.

8. While no detailed evaluation of maximum landfill infiltration rates has been made, one can reasonably argue that they are probably on the order of 25 milliliters per week per square foot of surface area (i.e., equivalent to 0.0384 cm/sec). This upper limit infiltration rate estimate is equal to the maximum water volume that was ever collected from an individual landfill lysimeter. It is 243 times larger than the maximum saturated hydraulic conductivity value (Stephens, 1988, Table 4) measured in a Bandelier tuff core sample recovered in well P-16 at 7.5 feet below the surface (i.e. sample no. 7-8 in Stephens); furthermore, it is about 243,000 times larger than the unsaturated hydraulic conductivity of this same core sample when the moisture content is at 20% (Stephens, 1988, unnumbered figure entitled, "Relative Hydraulic Conductivity vs. Moisture Content, Sample No. 7-8"). One can also argue that landfill infiltration rates are considerably lower in the western portions of the landfill as compared to the eastern portions becasuse eastern landfill lysimeters have consistently yielded more water than western landfill lysimeters. Finally, one can conclude that infiltration rates vary throughout the year, and are probably highest during the spring snow-melt season.

9. A similar procedure to estimate infiltration rates in the underlying tuff can not be made because these lysimeters never yielded any water. However, if one uses the relative hydraulic conductivity vs. moisture content data of Stephens (1988), the neutron moisture data presented herein, and assumes a unit unsaturated hydraulic gradient for these tuff units, then an infiltration rate can be estimated. One concludes from this procedure that the tuff underlying the landfill is completely restricting all deep infiltration below the landfill.

The following recommendations are made with regard to the Area P landfill.

1. Additional lysimeters should only be installed after an adjacent neutron moisture access well has been completed and moisture readings have been recorded. Preliminary results in this study indicate that lysimeters can extract water from a target horizon only when the moisture content in an adjacent

neutron moisture access well exceeds about 20%. Hence neutron moisture access wells can be used as indicators to target optimal depth locations for subsequent lysimeter placement.

2. Unsaturated laboratory column leaching studies at infiltration rates typical of those in the landfill would be helpful in characterizing any future barium mobility from the landfill. This recommendation implies that an average infiltration rate into the landfill should be computed to support these soil column studies. These soil column leaching studies would support or refute the contention that no deep aquifer monitoring below the 1,230 foot interval is necessary. A sufficient volume of these waste barium sands is currently held in drum storage for off-site disposal, and could be used to perform such studies.

3. Two and three dimensional vadose zone flow modeling studies should be used as a supplement the above recommendations, and would assist in the evaluation of alternative landfill cover designs that might eventually proposed.

4. Additional vadose zone monitoring wells should be installed through the landfill and into the shallow tuff to supplement the existing monitoring network by giving more spatial coverage over the 1.5 acre site. During these drilling operations, additional soil samples should be collected so that the areal and vertical extent of barium contamination is completely defined. Furthermore, vadose zone monitoring wells should also be installed on the floor of Canon de Valle immediately north of the landfill. Locations should be similar to the saturated monitoring system that is presently in place, unless the vadose zone modeling efforts indicate more optimal locations are desirable.

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VII. APPENDICES

Appendix A. Borehole Logs from TA-16 Area P Landfill

See Figure 1 for borehole locations

DRILLING LOG

BOREHOLE	: B-1	**ELEVATION**	: Not Surveyed
GEOLOGIST	: Purtymun & McLin	**TOTAL DEPTH**	: 5 feet
DATE DRILLED	: August 26, 1988	**DIAMETER**	: 6.875 in
LOCATION	: Eastern Landfill	**CASING MATERIAL**	: Cuttings Fill

DEPTH	**DESCRIPTION**
0- 2	Dark brown clay soil, moist
2- 5	Dark brown sandy clay soil - looks like cover-fill material

WELL COMPLETION SUMMARY

Borehole B-1 was used as an exploration hole; it was then filled with bentonite and drill cuttings before being abandoned. No samples were collected.

DRILLING LOG

BOREHOLE	: B-2	**ELEVATION**	: Not Surveyed
GEOLOGIST	: Purtymun & McLin	**TOTAL DEPTH**	: 4 feet
DATE DRILLED	: August 26, 1988	**DIAMETER**	: 6.875 in
LOCATION	: Eastern Landfill	**CASING MATERIAL**	: Cuttings Fill

DEPTH	**DESCRIPTION**
0- 2	Dark brown clay soil, moist
2- 4	Dark brown sandy clay soil - looks like cover-fill material

WELL COMPLETION SUMMARY

Borehole B-2 was used as an exploration hole; it was then filled with bentonite and drill cuttings before being abandoned. No samples were collected.

DRILLING LOG

BOREHOLE : B-3
GEOLOGIST : Purtymun & McLin
DATE DRILLED: August 26, 1988
LOCATION : Eastern Landfill

ELEVATION : Not Surveyed
TOTAL DEPTH : 14 feet
DIAMETER : 6.875 in
CASING MATERIAL: Cuttings Fill

DEPTH	DESCRIPTION
0- 1	Dark brown sandy clay cover, moist
1- 4	Mixture of brown clay and sand waste - white BaO crystals 95% Core recovery; moderate moisture
4- 8	Dark brown sticky clay with some gray sand - waste material Fragments of tuff and charcoal throughout 80% Core recovery; moderate moisture
8-13	Dark brown to black sticky clay with tuff & BaO fragments 85% Core recovery; optimal moisture; solid tuff in bit
13-14	Tuff; Unit 3d; low moisture

WELL COMPLETION SUMMARY

Borehole B-3 was used as an exploration hole ; it was then filled with bentonite and drill cuttings before being abandoned. No samples were collected.

DRILLING LOG

BOREHOLE	: B-4	**ELEVATION**	: Not Surveyed
GEOLOGIST	: McLin & Purtymun	**TOTAL DEPTH**	: 19 feet
DATE DRILLED	: August 30, 1988	**DIAMETER**	: 6.875 in
LOCATION	: Eastern Landfill	**CASING MATERIAL**	: Cuttings Fill

DEPTH	DESCRIPTION
0- 3	Brown clay with black burn debris inclusions 50% Core recovery, little moisture Tests positive for explosive compounds using field test kit
4- 9	Brown clay and sand with black burn debris inclusions 10% Core recovery, very little moisture
9-14	Brown clay and sand mixture with burn debris inclusions 5% Core recovery, very dry
14-19	Tuff, Unit 3d, non-welded, very low moisture 85% Core recovery; coarse to medium grain size tuff
	WX-12 field representative confirms presence of explosives and drilling operation terminated until M-1 Analytical Lab verified. On 9-1-88 M-1 Lab reported < 1% TNT, HMX, and RDX was present in sample.

WELL COMPLETION SUMMARY

Borehole B-4 was used as an exploration hole and for sample recovery; it was then filled with bentonite and drill cuttings before being abandoned.

DRILLING LOG

BOREHOLE : B-5
GEOLOGIST : Purtymun & McLin
DATE DRILLED: September 15, 1988
LOCATION : Western Landfill

ELEVATION : Not Surveyed
TOTAL DEPTH : 12 feet
DIAMETER : 6.875 in
CASING MATERIAL: Cuttings Fill

DEPTH	DESCRIPTION
0- 1	Topsoil of crushed tuff, sand, and clay mixture
1- 4	Brown crushed tuff cover-fill material 50% Core recovery; dry
4- 8	Brown crushed tuff cover-fill material; moderately dry 60% Core recovery; saturated clay lense 6-7 ft
8-12	Brown dense clay; moderately dry 90% Core recovery; waste not apparent

WELL COMPLETION SUMMARY

Borehole B-5 was used as an exploration hole and for sample recovery; it was then filled with bentonite and drill cuttings before being abandoned.

DRILLING LOG

BOREHOLE	: L-17	**ELEVATION**	: Not Surveyed
GEOLOGIST	: McLin & Purtymun	**TOTAL DEPTH**	: 19 feet
DATE DRILLED	: September 6, 1988	**DIAMETER**	: 6.875 in
LOCATION	: Eastern Landfill	**CASING MATERIAL**	: Lysimeters

DEPTH	**DESCRIPTION**
0- 1	Light brown sandy clay soil
1- 2	Dark brown clay with black sandy waste
2- 4	Black sandy waste with white BaO crystalline stringers 60% Core recovery 0-4 ft; all moderately dry
4-11	Light brown clayey sand; wood chips at 9 ft Less than 10% core recovery
11-19	Tuff; Unit 3d, non-welded, lt. brown color 50% recovery 9-14 ft; 100% recovery 14-19 ft.

LYSIMETER COMPLETION SUMMARY - DUEL COMPLETION

```
LOCKING STEEL CAP IN CEMENT ->KC|  |<---- TOPSOIL COVER
                               C|  |<---- TOP OF LANDFILL AT 1 FT
                               T|  |
                               T|  |
                               T|  |
                               S|  |
SHALLOW LYSIMETER AT 7 FT --->SL|  |
ONE FT CEMENT SEAL 7-8 FT ---->C|  |
                               T|  |
                               T|  |<----- BASE OF LANDFILL AT 11 FT
                               T|  |<----- TUFF CONTACT AT 11 FT
                               T|  |
                               S|  |
                               S|  |
                               S|  |
                               S|  |
DEEP LYSIMETER AT 17 FT ----->SL|  |
                               S|  |
                               T|  |<----- TOTAL DEPTH AT 19 FT
```

DIAGRAM NOT TO SCALE

STEEL LOCKING CAP.....K
CEMENT SLURRY SEAL.....C
BACKFILLED TUFF CUTTINGS....T
MEDIUM GRAIN SILICA SAND....S
PRESSURE-VACUUM LYSIMETER...L
CAVED IN.....X

DRILLING LOG

BOREHOLE : P-17
GEOLOGIST : McLin & Purtymun
DATE DRILLED: September 21, 1988
LOCATION : Eastern Landfill

ELEVATION : Not Surveyed
TOTAL DEPTH : 30 feet
DIAMETER : 4.00 in
CASING MATERIAL: Aluminum

DEPTH	DESCRIPTION
0-19	Off-set from L-17 6 ft; see drilling log for L-17 & B-4
19-30	Tuff; Unit 3d; low moisture; not cored Light brown tuff with rhyolite fragments Appears to be non-welded to moderately welded

NEUTRON ACCESS WELL COMPLETION SUMMARY

```
ONE FT CEMENT SEAL AND CAP -->CA|  |<---- TOPSOIL COVER
ANNULUS FILLED WITH SAND ---->SA|  |<---- TOP OF LANDFILL AT 1 FT
                              SA|  |
                              SA|  |
                              SA|  |
                              SA|  |<---- BASE OF LANDFILL AT 11 FT
                              SA|  |<---- TUFF CONTACT AT 11 FT
                              SA|  |
                              SA|  |
                              SA|  |
                              SA|  |
                              SA|  |
                              SA|  |
                              SA|  |
                              SA|P |<---- TOTAL DEPTH AT 30 FT
```

DIAGRAM NOT TO SCALE

```
----------------------------
CEMENT SLURRY SEAL..........C
BACKFILLED TUFF CUTTINGS....T
MEDIUM GRAIN SILICA SAND....S
ALUMINUM CASING, 2 in ID....A
END-CAP PLUG................P
CAVED IN....................X
----------------------------
```

DRILLING LOG

BOREHOLE	: L-18	**ELEVATION**	: Not Surveyed
GEOLOGIST	: McLin & Purtymun	**TOTAL DEPTH**	: 19 feet
DATE DRILLED	: September 8, 1988	**DIAMETER**	: 6.875 in
LOCATION	: Eastern Landfill	**CASING MATERIAL**	: Lysimeters

DEPTH	**DESCRIPTION**
0- 1	Light brown sandy soil cover
1- 4	Light to bark brown clay with sand stringers; some moisture Some white BaO crystals; 95% Core recovery
4-13	Dark brown sticky black clay with some gray sand at 4 ft Fragments of charcoal and tuff 5-8 ft; BaO crystals 8-12 ft 80% Core recovery; optimal moisture; hard tuff in bit 13 ft
13-19	Tuff; Unit 3d; non-welded, low moisture Light grey to light brown color; 100% Core recovery

LYSIMETER COMPLETION SUMMARY - DUEL COMPLETION

```
LOCKING STEEL CAP IN CEMENT ->KC|  |<---- TOPSOIL COVER
                              C|  |<---- TOP OF LANDFILL AT 1 FT
                              T|  |
                              T|  |
                              T|  |
                              S|  |
SHALLOW LYSIMETER AT 7 FT --->SL|  |
                              T|  |
                              T|  |
                              T|  |
                              C|  |
THREE FT CEMENT SEAL 10-13 FT->C|  |<----- BASE OF LANDFILL AT 13 FT
                              T|  |<----- TUFF CONTACT AT 13 FT
                              T|  |
                              T|  |
                              S|  |
                              S|  |
DEEP LYSIMETER AT 18 FT ----->SL|  |
                              T|X|<----- TOTAL DEPTH AT 19 FT
```

DIAGRAM NOT TO SCALE

```
-----------------------------
STEEL LOCKING CAP............K
CEMENT SLURRY SEAL...........C
BACKFILLED TUFF CUTTINGS....T
MEDIUM GRAIN SILICA SAND....S
PRESSURE-VACUUM LYSIMETER...L
CAVED IN....................X
-----------------------------
```

DRILLING LOG

BOREHOLE	: P-18	**ELEVATION**	: Not Surveyed
GEOLOGIST	: McLin & Purtymun	**TOTAL DEPTH**	: 30 feet
DATE DRILLED	: September 21, 1988	**DIAMETER**	: 4.00 in
LOCATION	: Eastern Landfill	**CASING MATERIAL**	: Aluminum

DEPTH	**DESCRIPTION**
0-19	Off-set from L-18 6 ft; see drilling log for L-18 & B-3
19-30	Tuff; Unit 3d; low moisture; not cored Light brown tuff with rhyolite and sanadine fragments Appears to be non-welded to moderately welded

NEUTRON ACCESS WELL COMPLETION SUMMARY

```
ONE FT CEMENT SEAL AND CAP -->CA|  |<---- TOPSOIL COVER
ANNULUS FILLED WITH SAND ---->SA|  |<---- TOP OF LANDFILL AT 1 FT
                              SA|  |
                              SA|  |
                              SA|  |
                              SA|  |
                              SA|  |<----- BASE OF LANDFILL AT 13 FT
                              SA|  |<----- TUFF CONTACT AT 13 FT
                              SA|  |
                              SA|  |
                              SA|  |
                              SA|  |
                              SA|  |
                              SA|  |
                              SA|P |<----- TOTAL DEPTH AT 30 FT
```

DIAGRAM NOT TO SCALE

CEMENT SLURRY SEAL.....C
BACKFILLED TUFF CUTTINGS....T
MEDIUM GRAIN SILICA SAND....S
ALUMINUM CASING, 2 in ID....A
END-CAP PLUG.....P
CAVED IN.....X

DRILLING LOG

BOREHOLE	: L-19	**ELEVATION**	: Not Surveyed
GEOLOGIST	: McLin & Purtymun	**TOTAL DEPTH**	: 14 feet
DATE DRILLED	: September 14, 1988	**DIAMETER**	: 6.875 in
LOCATION	: Western Landfill	**CASING MATERIAL**	: Lysimeters

DEPTH	**DESCRIPTION**
0- 1	Sandy soil cover; dry
1- 4	Crushed tuff fill 60% Core recovery; moderately dry
4- 9	Crushed tuff fill; no wastes apparent 70% Core recovery; moderately dry
9-14	Crushed tuff fill; no wastes apparent 75% Core recovery; moderately dry

LYSIMETER COMPLETION SUMMARY - SINGLE COMPLETION

```
LOCKING STEEL CAP IN CEMENT ->KC|  |<---- TOPSOIL COVER
                              C|  |<---- TOP OF LANDFILL WASTE
                              T|  |                NOT APPARENT
                              T|  |
                              T|  |
                              T|  |
                              T|  |
                              T|  |
                              T|  |
                              T|  |
                              S|  |
SINGLE LYSIMETER AT 12 FT --->SL|  |<----- BASE OF LANDFILL NOT
                              T|X|                     DETECTED
                              T|X|<----- TOTAL DEPTH AT 14 FT
```

DIAGRAM NOT TO SCALE

STEEL LOCKING CAP.....K
CEMENT SLURRY SEAL.....C
BACKFILLED TUFF CUTTINGS....T
MEDIUM GRAIN SILICA SAND....S
PRESSURE-VACUUM LYSIMETER...L
CAVED IN.....X

DRILLING LOG

BOREHOLE	: P-19	**ELEVATION**	: Not Surveyed
GEOLOGIST	: McLin & Purtymun	**TOTAL DEPTH**	: 30 feet
DATE DRILLED	: September 20, 1988	**DIAMETER**	: 4.00 in
LOCATION	: Western Landfill	**CASING MATERIAL**	: Aluminum

DEPTH	**DESCRIPTION**
0-14	Off-set from L-19 6 ft; see drilling log for L-19
19-30	Tuff; Unit 3d; low moisture; not cored Light brown tuff with rhyolite and sanadine fragments Appears to be non-welded to moderately welded

NEUTRON ACCESS WELL COMPLETION SUMMARY

```
ONE FT CEMENT SEAL AND CAP -->CA| |<---- TOPSOIL COVER
ANNULUS FILLED WITH SAND ---->SA| |<---- TOP OF LANDFILL WASTES
                              SA| |                NOT APPARENT
                              SA| |
                              SA| |
                              SA| |
                              SA| |
                              SA| |<----- APPROXIMATE TUFF CONTACT
                              SA| |          AT 15 FT
                              SA| |
                              SA| |
                              SA| |
                              SA| |
                              SA| |
                              SA|P|<----- TOTAL DEPTH AT 30 FT
```

DIAGRAM NOT TO SCALE

```
----------------------------
CEMENT SLURRY SEAL..........C
BACKFILLED TUFF CUTTINGS....T
MEDIUM GRAIN SILICA SAND....S
ALUMINUM CASING, 2 in ID....A
END-CAP PLUG................P
CAVED IN....................X
----------------------------
```

DRILLING LOG

BOREHOLE	: L-20	**ELEVATION**	: Not Surveyed
GEOLOGIST	: McLin & Purtymun	**TOTAL DEPTH**	: 29 feet
DATE DRILLED	: September 15, 1988	**DIAMETER**	: 6.875 in
LOCATION	: Western Landfill	**CASING MATERIAL**	: Lysimeter

DEPTH	**DESCRIPTION**
0- 4	Sandy crushed tuff and soil mixture; concrete at 3 ft 50% Core Recovery; dry; does not look like waste sands
4-13	Sandy light brown crushed tuff and soil mixture 50% Core Recovery; dry
13-15	Dark brown sandy clay soil; wastes not apparent 50% Core Recovery; dry
15-21	Tuff fill and brown clay with charcoal fragments & waste 70% Core Recovery; some moisture
21-22	Brown native clay soil; moderately moist 75% Core Recovery
22-29	Tuff; Unit 3d; non-welded, low moisture 100% Core Recovery

LYSIMETER COMPLETION SUMMARY - DUEL COMPLETION

```
LOCKING STEEL CAP IN CEMENT ->KC|  |<---- TOP SOIL COVER
                               T|  |<---- TOP OF LANDFILL AT 1 FT
                               S|  |
SHALLOW LYSIMETER AT 8 FT --->SL|  |
                               S|  |
                               T|  |
                               T|  |
                               T|  |
                               T|  |<----- LANDFILL BASE AT 21 FT
                               T|  |<----- NATIVE 1 FT CLAY LAYER
                               T|  |<----- TUFF CONTACT AT 22 FT
ONE FT CEMENT PLUG 22-23 FT -->C|  |
                               T|  |
                               S|  |
DEEP LYSIMETER AT 29 FT ----->SL|  |<----- TOTAL DEPTH AT 29 FT
```

DIAGRAM NOT TO SCALE

```
-----------------------------
STEEL LOCKING CAP...........K
CEMENT SLURRY SEAL..........C
BACKFILLED TUFF CUTTINGS....T
MEDIUM GRAIN SILICA SAND....S
PRESSURE-VACUUM LYSIMETER...L
CAVED IN....................X
-----------------------------
```

DRILLING LOG

BOREHOLE	: P-20	**ELEVATION**	: Not Surveyed
GEOLOGIST	: McLin & Purtymun	**TOTAL DEPTH**	: 30 feet
DATE DRILLED	: September 20, 1988	**DIAMETER**	: 4.00 in
LOCATION	: Western Landfill	**CASING MATERIAL**	: Aluminum

DEPTH	**DESCRIPTION**
0-29	Off-set from L-20 6 ft; see drilling log for L-20 & B-5
29-30	Tuff; Unit 3d; low moisture; not cored Light brown tuff with rhyolite and sanadine fragments Appears to be non-welded to moderately welded

NEUTRON ACCESS WELL COMPLETION SUMMARY

```
ONE FT CEMENT SEAL AND CAP -->CA|  |<---- TOPSOIL COVER
ANNULUS FILLED WITH SAND ---->SA|  |<---- TOP OF LANDFILL AT 1 FT
                               SA|  |
                               SA|  |
                               SA|  |
                               SA|  |
                               SA|  |
                               SA|  |
                               SA|  |
                               SA|  |<----- BASE OF LANDFILL AT 21 FT
                               SA|  |<----- NATIVE 1 FT CLAY LAYER
                               SA|  |<----- TUFF CONTACT AT 22 FT
                               SA|  |
                               SA|  |
ALUMINUM CASING TO 26 FT ---->SA|P|
                                T|X|
                                T|X|
                                T|X|<----- TOTAL DEPTH AT 30 FT
```

DIAGRAM NOT TO SCALE

CEMENT SLURRY SEAL.....C
BACKFILLED TUFF CUTTINGS....T
MEDIUM GRAIN SILICA SAND....S
ALUMINUM CASING, 2 in ID....A
END-CAP PLUG.....P
CAVED IN.....X

DRILLING LOG

BOREHOLE	: P-0	**ELEVATION**	: 7399
GEOLOGIST	: Brown & Purtymun	**TOTAL DEPTH**	: 135 feet
DATE DRILLED	: July 21, 1987	**DIAMETER**	: 6.875 in
LOCATION	: S of TA-16 Pond	**CASING MATERIAL**	: Aluminum
COORDINATES	: X=476215, Y=1763523	**MAP SYSTEM**	: NM State

See Appendix D (in HSE-8, 1988) for detailed log.

NEUTRON ACCESS WELL COMPLETION SUMMARY

```
ONE FT CEMENT SEAL AND CAP -->CA| |<---- TOPSOIL COVER
ANNULUS FILLED WITH TUFF ---->TA| |<---- UNIT 3c CONTACT AT 3 FT
                               TA| |
                               TA| |
                               TA| |
                               TA| |
                               TA| |
                               TA| |<---- UNIT 3b CONTACT AT 40 FT
                               TA| |
                               TA| |
                               TA| |
                               TA| |
                               TA| |
                               TA| |
                               TA| |
                               TA| |
                               TA| |
                               TA| |
                               TA| |
                               TA| |
                               TA| |
                               TA| |<---- UNIT 3a CONTACT AT 110 FT
                               TA| |
CASING PLUG AT 120 FT ------->TA|P|
                                T|X|
                                T|X|
TOTAL DEPTH AT 135 FT -------> T|X|<---- UNIT 2 CONTACT AT 135 FT
```

DIAGRAM NOT TO SCALE

```
-----------------------------
CEMENT SLURRY SEAL..........C
BACKFILLED TUFF CUTTINGS....T
MEDIUM GRAIN SILICA SAND....S
ALUMINUM CASING, 2 in ID....A
WELDED END CAP PLUG.........P
CAVED IN....................X
-----------------------------
```

DRILLING LOG

BOREHOLE	: P-1	**ELEVATION**	: 7344
GEOLOGIST	: Brown & Purtymun	**TOTAL DEPTH**	: 35 feet
DATE DRILLED	: July 29, 1987	**DIAMETER**	: 6.875 in
LOCATION	: Canon de Valle	**CASING MATERIAL**	: 2 in PVC
COORDINATES	: X=475756, Y=1764645	**MAP SYSTEM**	: NM State

See Appendix D (in HSE-8, 1988) for detailed log.

GROUND-WATER MONITORING WELL COMPLETION SUMMARY

```
LOCKING STEEL CAP IN CEMENT->KCV|  |<---- TOPSOIL COVER
                             CV|  |<---- UNIT 3b CONTACT AT 4 FT
                             CV|  |
                             CV|  |
                             CV|  |
                             CV|  |
BOTTOM OF CEMENT AT 13 FT --->CV|  |
                             BV|  |
BOTTOM OF BENTONITE AT 15 FT->BV|  |
                             SF|=|
                             SF|=|
                             SF|=|
                             SF|=|
20 FT FACTORY SLOTTED SCREEN->SF|=|
   0.010 in SLOTTED PVC      SF|=|
                             SF|=|
                             SF|=|
                             SF|=|
                             SF|=|
TOTAL DEPTH AT 35 FT -------->SF|P|
```

DIAGRAM NOT TO SCALE

```
----------------------------
STEEL LOCKING CAP...........K
CEMENT SLURRY SEAL..........C
BENTONITE PELLETS...........B
BACKFILLED TUFF CUTTINGS....T
MEDIUM GRAIN SILICA SAND....S
PVC CASING 2 in ID..........V
FACTORY SLOTTED 0.010 in....F
PVC END CAP.................P
CAVED IN....................X
----------------------------
```

DRILLING LOG

BOREHOLE	: P-2	**ELEVATION**	: 7341
GEOLOGIST	: Brown & Purtymun	**TOTAL DEPTH**	: 10 feet
DATE DRILLED	: July 23, 1987	**DIAMETER**	: 6.875 in
LOCATION	: Canon de Valle	**CASING MATERIAL**	: Abandoned
COORDINATES	: X=475708, Y=1764617	**MAP SYSTEM**	: NM State

See Appendix D (in HSE-8, 1988) for detailed log.

EXPLORATION BOREHOLE LOG SUMMARY

```
                                  T|  |<---- SANDY LOAM TOP SOIL
                                  T|  |
                                  T|  |<---- UNIT 3b CONTACT AT 3 FT
                                  T|  |
                                  T|  |
                                  T|  |
                                  T|  |
                                  T|  |
                                  T|  |
TOTAL DEPTH AT 10 FT ---------->T|  |
```

DIAGRAM NOT TO SCALE

BENTONITE PELLET SEAL.....B
BACKFILLED TUFF CUTTINGS....T
CAVED IN.....X

DRILLING LOG

BOREHOLE	: P-3	**ELEVATION**	: 7342
GEOLOGIST	: Brown & Purtymun	**TOTAL DEPTH**	: 9 feet
DATE DRILLED	: July 23, 1987	**DIAMETER**	: 6.875 in
LOCATION	: Canon de Valle	**CASING MATERIAL**	: 2 in Teflon
COORDINATES	: X=475676, Y=1764596	**MAP SYSTEM**	: NM State

See Appendix D (in HSE-8, 1988) for detailed log.

GROUND-WATER MONITORING WELL COMPLETION SUMMARY

```
LOCKING STEEL CAP IN CEMENT->KCE| |<---- TOPSOIL COVER
CEMENT 0-1 & PELLETS 1-2 FT ->BE| |
                             SF| |<---- UNIT 3b CONTACT AT 3 FT
5 FT THREADED TEFLON SCREEN ->SF| |
   0.01 in FACTORY SLOTTED    SF| |
                              SF| |
TEFLON END CAP AT 7 FT ------>SF|P|
                                |X|
TOTAL DEPTH AT 9 FT --------->  |X|
```

DIAGRAM NOT TO SCALE

```
-----------------------------
STEEL LOCKING CAP...........K
CEMENT SLURRY SEAL..........C
BENTONITE PELLETS...........B
BACKFILLED TUFF CUTTINGS....T
MEDIUM GRAIN SILICA SAND....S
THREADED TEFLON CASING......E
FACTORY SLOTTED 0.010 in....F
TEFLON END CAP PLUG.........P
CAVED IN....................X
-----------------------------
```

DRILLING LOG

BOREHOLE	: P-4	**ELEVATION**	: 7348
GEOLOGIST	: Brown & Purtymun	**TOTAL DEPTH**	: 10 feet
DATE DRILLED	: July 28, 1987	**DIAMETER**	: 6.875 in
LOCATION	: Canon de Valle	**CASING MATERIAL**	: 2 in Teflon
COORDINATES	: X=475588, Y=1764562	**MAP SYSTEM**	: NM State

See Appendix D (in HSE-8, 1988) for detailed log.

GROUND-WATER MONITORING WELL COMPLETION SUMMARY

```
LOCKING STEEL CAP IN CEMENT->KCE|  |<---- TOPSOIL COVER
CEMENT 0-1 & PELLETS 1-3 FT ->BE|  |
                              BE|  |
                              SF|  |<---- UNIT 3b CONTACT AT 4 FT
5 FT THREADED TEFLON SCREEN ->SF|  |
   0.01 in FACTORY SLOTTED    SF|  |
                              SF|  |
TEFLON END CAP AT 8 FT ------>SF|P|
                                |X|
TOTAL DEPTH AT 10 FT -------->  |X|
```

DIAGRAM NOT TO SCALE

```
-----------------------------
STEEL LOCKING CAP............K
CEMENT SLURRY SEAL...........C
BENTONITE PELLETS............B
BACKFILLED TUFF CUTTINGS....T
MEDIUM GRAIN SILICA SAND....S
THREADED TEFLON CASING......E
FACTORY SLOTTED 0.010 in....F
TEFLON END CAP PLUG.........P
CAVED IN....................X
-----------------------------
```

DRILLING LOG

BOREHOLE	: P-5	**ELEVATION**	: 7353
GEOLOGIST	: Brown & Purtymun	**TOTAL DEPTH**	: 35 feet
DATE DRILLED	: July 29, 1987	**DIAMETER**	: 6.875 in
LOCATION	: Canon de Valle	**CASING MATERIAL**	: 2 in PVC
COORDINATES	: X=475520, Y=1764532	**MAP SYSTEM**	: NM State

See Appendix D (in HSE-8, 1988) for detailed log.

GROUND-WATER MONITORING WELL COMPLETION SUMMARY

```
LOCKING STEEL CAP IN CEMENT->KCV|  |<---- TOPSOIL COVER
                             CV|  |<---- UNIT 3b CONTACT AT 3 FT
                             CV|  |
                             CV|  |
                             CV|  |
                             CV|  |
BOTTOM OF CEMENT AT 13 FT --->CV|  |
                             BV|  |
BOTTOM OF BENTONITE AT 15 FT->BV|  |
                             SF|=|
                             SF|=|
                             SF|=|
                             SF|=|
20 FT FACTORY SLOTTED SCREEN->SF|=|
   0.010 in SLOTTED PVC      SF|=|
                             SF|=|
                             SF|=|
                             SF|=|
                             SF|=|
TOTAL DEPTH AT 35 FT -------->SF|P|
```

DIAGRAM NOT TO SCALE

```
----------------------------
STEEL LOCKING CAP...........K
CEMENT SLURRY SEAL..........C
BENTONITE PELLETS...........B
BACKFILLED TUFF CUTTINGS....T
MEDIUM GRAIN SILICA SAND....S
PVC CASING 2 in ID..........V
FACTORY SLOTTED 0.010 in....F
PVC END CAP.................P
CAVED IN....................X
----------------------------
```

DRILLING LOG

BOREHOLE	: P-6	**ELEVATION**	: 7352
GEOLOGIST	: Brown & Purtymun	**TOTAL DEPTH**	: 10 feet
DATE DRILLED	: July 28, 1987	**DIAMETER**	: 6.875 in
LOCATION	: Canon de Valle	**CASING MATERIAL**	: 2 in Teflon
COORDINATES	: X=475467, Y=1764514	**MAP SYSTEM**	: NM State

See Appendix D (in HSE-8, 1988) for detailed log.

GROUND-WATER MONITORING WELL COMPLETION SUMMARY

```
LOCKING STEEL CAP IN CEMENT->KCE|  |<---- TOPSOIL COVER
CEMENT 0-1 & PELLETS 1-2 FT ->BE|  |
                              SF|  |
5 FT THREADED TEFLON SCREEN ->SF|  |<---- UNIT 3b CONTACT AT 4 FT
   0.01 in FACTORY SLOTTED    SF|  |
                              SF|  |
TEFLON END CAP AT 7 FT ------>SF|P|
                                |X|
                                |X|
TOTAL DEPTH AT 10 FT -------->  |X|
```

DIAGRAM NOT TO SCALE

```
-----------------------------
STEEL LOCKING CAP...........K
CEMENT SLURRY SEAL..........C
BENTONITE PELLETS...........B
BACKFILLED TUFF CUTTINGS....T
MEDIUM GRAIN SILICA SAND....S
THREADED TEFLON CASING......E
FACTORY SLOTTED 0.010 in....F
TEFLON END CAP PLUG.........P
CAVED IN....................X
-----------------------------
```

DRILLING LOG

BOREHOLE	: P-7	**ELEVATION**	: 7356
GEOLOGIST	: Brown & Purtymun	**TOTAL DEPTH**	: 35 feet
DATE DRILLED	: July 29, 1987	**DIAMETER**	: 6.875 in
LOCATION	: Canon de Valle	**CASING MATERIAL**	: 2 in PVC
COORDINATES	: X=475381, Y=1764491	**MAP SYSTEM**	: NM State

See Appendix D (in HSE-8, 1988) for detailed log.

GROUND-WATER MONITORING WELL COMPLETION SUMMARY

```
LOCKING STEEL CAP IN CEMENT->KCV|  |<---- TOPSOIL COVER
                             CV|  |<---- UNIT 3b CONTACT AT 2 FT
                             CV|  |
                             CV|  |
                             CV|  |
                             CV|  |
BOTTOM OF CEMENT AT 13 FT --->CV|  |
                             BV|  |
BOTTOM OF BENTONITE AT 15 FT->BV|  |
                             SF|=|
                             SF|=|
                             SF|=|
                             SF|=|
20 FT FACTORY SLOTTED SCREEN->SF|=|
   0.010 in SLOTTED PVC      SF|=|
                             SF|=|
                             SF|=|
                             SF|=|
                             SF|=|
TOTAL DEPTH AT 35 FT -------->SF|P|
```

DIAGRAM NOT TO SCALE

STEEL LOCKING CAP	K
CEMENT SLURRY SEAL	C
BENTONITE PELLETS	B
BACKFILLED TUFF CUTTINGS	T
MEDIUM GRAIN SILICA SAND	S
PVC CASING 2 in ID	V
FACTORY SLOTTED 0.010 in	F
PVC END CAP	P
CAVED IN	X

DRILLING LOG

BOREHOLE	: P-8	**ELEVATION**	: 7370
GEOLOGIST	: Brown & Purtymun	**TOTAL DEPTH**	: 10 feet
DATE DRILLED	: July 28, 1987	**DIAMETER**	: 6.875 in
LOCATION	: Canon de Valle	**CASING MATERIAL**	: 2 in Teflon
COORDINATES	: X=475257, Y=1764405	**MAP SYSTEM**	: NM State

See Appendix D (in HSE-8, 1988) for detailed log.

GROUND-WATER MONITORING WELL COMPLETION SUMMARY

```
LOCKING STEEL CAP IN CEMENT->KCE|  |<---- TOPSOIL COVER
CEMENT 0-1 & PELLETS 1-2 FT ->BE|  |
                              SF|  |<---- UNIT 3b CONTACT AT 3 FT
5 FT THREADED TEFLON SCREEN ->SF|  |
   0.01 in FACTORY SLOTTED    SF|  |
                              SF|  |
TEFLON END CAP AT 7 FT ------>SF|P|
                                |X|
                                |X|
TOTAL DEPTH AT 10 FT -------->  |X|
```

DIAGRAM NOT TO SCALE

```
-----------------------------
STEEL LOCKING CAP...........K
CEMENT SLURRY SEAL..........C
BENTONITE PELLETS...........B
BACKFILLED TUFF CUTTINGS....T
MEDIUM GRAIN SILICA SAND....S
THREADED TEFLON CASING......E
FACTORY SLOTTED 0.010 in....F
TEFLON END CAP PLUG.........P
CAVED IN....................X
-----------------------------
```

DRILLING LOG

BOREHOLE	: P-9	**ELEVATION**	: 7376
GEOLOGIST	: Brown & Purtymun	**TOTAL DEPTH**	: 35 feet
DATE DRILLED	: July 29, 1987	**DIAMETER**	: 6.875 in
LOCATION	: Canon de Valle	**CASING MATERIAL**	: 2 in PVC
COORDINATES	: X=475183, Y=1764381	**MAP SYSTEM**	: NM State

See Appendix D (in HSE-8, 1988) for detailed log.

GROUND-WATER MONITORING WELL COMPLETION SUMMARY

```
LOCKING STEEL CAP IN CEMENT->KCV|  |<---- TOPSOIL COVER
                             CV|  |<---- UNIT 3c CONTACT AT 3 FT
                             CV|  |
                             CV|  |
                             CV|  |
                             CV|  |
BOTTOM OF CEMENT AT 13 FT --->CV|  |
                             BV|  |
BOTTOM OF BENTONITE AT 15 FT->BV|  |<---- UNIT 3b CONTACT AT 15 FT
                             SF|=|
                             SF|=|
                             SF|=|
                             SF|=|
20 FT FACTORY SLOTTED SCREEN->SF|=|
   0.010 in SLOTTED PVC      SF|=|
                             SF|=|
                             SF|=|
                             SF|=|
                             SF|=|
TOTAL DEPTH AT 35 FT -------->SF|P|
```

DIAGRAM NOT TO SCALE

```
-----------------------------
STEEL LOCKING CAP............K
CEMENT SLURRY SEAL...........C
BENTONITE PELLETS............B
BACKFILLED TUFF CUTTINGS....T
MEDIUM GRAIN SILICA SAND....S
PVC CASING 2 in ID...........V
FACTORY SLOTTED 0.010 in....F
PVC END CAP.................P
CAVED IN....................X
-----------------------------
```

DRILLING LOG

BOREHOLE	: P-10	**ELEVATION**	: 7411
GEOLOGIST	: Brown & Purtymun	**TOTAL DEPTH**	: 150 feet
DATE DRILLED	: July 30, 1987	**DIAMETER**	: 6.875 in
LOCATION	: E of Landfill	**CASING MATERIAL**	: Abandoned
COORDINATES	: X=475814, Y=1764473	**MAP SYSTEM**	: NM State

See Appendix D (in HSE-8, 1988) for detailed log.

EXPLORATION BOREHOLE LOG SUMMARY

```
                                T| |<---- SANDY LOAM TOP SOIL
                                T| |<---- UNIT 3c CONTACT AT 3 FT
                                T| |
                                T| |
                                T| |
                                T| |
                                T| |
                                T| |
                                T| |
                                T| |<---- UNIT 3b CONTACT AT 50 FT
                                T| |
                                T| |
                                T| |
                                T| |
                                T| |
                                T| |
                                T| |
                                T| |
                                T| |
                                T| |
                                T| |
                                T| |
                                T| |
                                T| |<---- UNIT 3a CONTACT AT 120 FT
                                T| |
                                T| |
                                T| |
                                T| |
                                T| |
TOTAL DEPTH AT 150 FT -------->T| |<---- UNIT 2 CONTACT AT 150 FT
```

DIAGRAM NOT TO SCALE

BENTONITE PELLET SEAL.....B
BACKFILLED TUFF CUTTINGS....T
CAVED IN.....X

DRILLING LOG

BOREHOLE	: P-11	**ELEVATION**	: 7409
GEOLOGIST	: Brown & Purtymun	**TOTAL DEPTH**	: 70 feet
DATE DRILLED	: August 27, 1987	**DIAMETER**	: 6.875 in
LOCATION	: W of TA-16 Pond	**CASING MATERIAL**	: Abandoned
COORDINATES	: X=475991, Y=1763584	**MAP SYSTEM**	: NM State

See Appendix D (in HSE-8, 1988) for detailed log.

EXPLORATION BOREHOLE LOG SUMMARY

```
                                T|  |<---- SANDY LOAM TOP SOIL
                                T|  |<---- UNIT 3c CONTACT AT 2 FT
                                T|  |
                                T|  |
                                T|  |
                                T|  |
                                T|  |
                                T|  |
                                T|  |
                                T|  |
                                T|  |<---- UNIT 3b CONTACT AT 50 FT
                                T|  |
                                T|  |
                                T|  |
TOTAL DEPTH AT 70 FT --------->T|  |
```

DIAGRAM NOT TO SCALE

BENTONITE PELLET SEAL.....B
BACKFILLED TUFF CUTTINGS....T
CAVED IN.....X

DRILLING LOG

BOREHOLE	: P-12	**ELEVATION**	: 7448
GEOLOGIST	: Brown & Purtymun	**TOTAL DEPTH**	: 200 feet
DATE DRILLED	: August 21, 1987	**DIAMETER**	: 6.875 in
LOCATION	: NW of TA-16 Pond	**CASING MATERIAL**	: Aluminum
COORDINATES	: X=476664, Y=1764036	**MAP SYSTEM**	: NM State

See Appendix D (in HSE-8, 1988) for detailed log.

NEUTRON ACCESS WELL COMPLETION SUMMARY

```
ONE FT CEMENT SEAL AND CAP -->CA| |<---- TOPSOIL COVER
ANNULUS FILLED WITH TUFF ---->TA| |<---- UNIT 3d CONTACT AT 3 FT
                               TA| |
                               TA| |
                               TA| |
                               TA| |
                               TA| |<---- UNIT 3c CONTACT AT 50 FT
                               TA| |
                               TA| |
                               TA| |
                               TA| |
                               TA| |
                               TA| |
                               TA| |
                               TA| |
                               TA| |<---- UNIT 3b CONTACT AT 102 FT
                               TA| |
                               TA| |
                               TA| |
                               TA| |
                               TA| |
                               TA| |
                               TA| |
                               TA| |
                               TA| |
CASING PLUG AT 171 FT ------->TA|P|
                                T|X|<---- UNIT 3a CONTACT AT 173 FT
                                T|X|
                                T|X|
                                T|X|<---- UNIT 2 CONTACT AT 195 FT
TOTAL DEPTH AT 200 FT -------> T|X|
```

DIAGRAM NOT TO SCALE

CEMENT SLURRY SEAL.....C
BACKFILLED TUFF CUTTINGS....T
MEDIUM GRAIN SILICA SAND....S
ALUMINUM CASING, 2 in ID....A
WELDED END CAP PLUG.....P
CAVED IN.....X

DRILLING LOG

BOREHOLE	: P-13	**ELEVATION**	: 7445
GEOLOGIST	: Brown & Purtymun	**TOTAL DEPTH**	: 103 feet
DATE DRILLED	: October 3, 1987	**DIAMETER**	: 6.875 in
LOCATION	: S of Landfill	**CASING MATERIAL**	: Aluminum
COORDINATES	: X=475720, Y=1764264	**MAP SYSTEM**	: NM State

See Appendix D (in HSE-8, 1988) for detailed log.

NEUTRON ACCESS WELL COMPLETION SUMMARY

```
ONE FT CEMENT SEAL AND CAP -->CA|  |<---- TOPSOIL COVER
ANNULUS FILLED WITH TUFF ---->TA|  |<---- UNIT 3d CONTACT AT 0 FT
                               TA|  |
                               TA|  |
                               TA|  |
                               TA|  |
                               TA|  |
                               TA|  |<---- UNIT 3c CONTACT AT 38 FT
                               TA|  |
                               TA|  |
                               TA|  |
                               TA|  |
                               TA|  |
                               TA|  |
                               TA|  |
                               TA|  |
                               TA|  |<---- UNIT 3b CONTACT AT 84 FT
                               TA|  |
CASING PLUG AT 92 FT -------->TA|P|
                                T|X|
                                T|X|
TOTAL DEPTH AT 103 FT -------> T|X|
```

DIAGRAM NOT TO SCALE

CEMENT SLURRY SEAL.....C
BACKFILLED TUFF CUTTINGS....T
MEDIUM GRAIN SILICA SAND....S
ALUMINUM CASING, 2 in ID....A
WELDED END CAP PLUG.....P
CAVED IN.....X

DRILLING LOG

BOREHOLE	: P-14	**ELEVATION**	: 7437
GEOLOGIST	: Brown & Purtymun	**TOTAL DEPTH**	: 85 feet
DATE DRILLED	: August 28, 1987	**DIAMETER**	: 6.875 in
LOCATION	: W of Landfill	**CASING MATERIAL**	: Aluminum
COORDINATES	: X=475365, Y=1764251	**MAP SYSTEM**	: NM State

See Appendix D (in HSE-8, 1988) for detailed log.

NEUTRON ACCESS WELL COMPLETION SUMMARY

```
ONE FT CEMENT SEAL AND CAP -->CA| |<---- TOPSOIL COVER
ANNULUS FILLED WITH TUFF ---->TA| |<---- UNIT 3d CONTACT AT 4 FT
                              TA| |
                              TA| |
                              TA| |
                              TA| |
                              TA| |<---- UNIT 3c CONTACT AT 30 FT
                              TA| |
                              TA| |
                              TA| |
                              TA| |
                              TA| |
                              TA| |
                              TA| |
                              TA| |
                              TA| |<---- UNIT 3b CONTACT AT 75 FT
CASING PLUG AT 79 FT -------->TA|P|
                               T|X|
TOTAL DEPTH AT 85 FT --------> T|X|
```

DIAGRAM NOT TO SCALE

CEMENT SLURRY SEAL.....C
BACKFILLED TUFF CUTTINGS....T
MEDIUM GRAIN SILICA SAND....S
ALUMINUM CASING, 2 in ID....A
WELDED END CAP PLUG.....P
CAVED IN.....X

DRILLING LOG

BOREHOLE	: P-15	**ELEVATION**	: 7413
GEOLOGIST	: Brown & Purtymun	**TOTAL DEPTH**	: 70 feet
DATE DRILLED	: August 27, 1987	**DIAMETER**	: 6.875 in
LOCATION	: W of TA-16 Pond	**CASING MATERIAL**	: Abandoned
COORDINATES	: X=475803, Y=1763520	**MAP SYSTEM**	: NM State

See Appendix D (in HSE-8, 1988) for detailed log.

EXPLORATION BOREHOLE LOG SUMMARY

```
                                T|  |<---- SANDY LOAM TOP SOIL
                                T|  |<---- UNIT 3c CONTACT AT 4 FT
                                T|  |
                                T|  |
                                T|  |
                                T|  |
                                T|  |
                                T|  |
                                T|  |
                                T|  |
                                T|  |
                                T|  |<---- UNIT 3b CONTACT AT 55 FT
                                T|  |
                                T|  |
TOTAL DEPTH AT 70 FT ---------->T|  |
```

DIAGRAM NOT TO SCALE

BENTONITE PELLET SEAL.....B
BACKFILLED TUFF CUTTINGS....T
CAVED IN.....X

DRILLING LOG

BOREHOLE	: P-16	**ELEVATION**	: 7452
GEOLOGIST	: Brown & Purtymun	**TOTAL DEPTH**	: 105 feet
DATE DRILLED	: September 4, 1987	**DIAMETER**	: 6.875 in
LOCATION	: S of Landfill	**CASING MATERIAL**	: Aluminum
COORDINATES	: X=475550, Y=1764200	**MAP SYSTEM**	: NM State

See Appendix D (in HSE-8, 1988) for detailed log.

NEUTRON ACCESS WELL COMPLETION SUMMARY

```
ONE FT CEMENT SEAL AND CAP -->CA|  |<---- TOPSOIL COVER
ANNULUS FILLED WITH TUFF ---->TA|  |
                               TA|  |<---- UNIT 3d CONTACT AT 7 FT
                               TA|  |
                               TA|  |
                               TA|  |
                               TA|  |
                               TA|  |
                               TA|  |<---- UNIT 3c CONTACT AT 42 FT
                               TA|  |
                               TA|  |
                               TA|  |
                               TA|  |
                               TA|  |
                               TA|  |
                               TA|  |
                               TA|  |
                               TA|  |<---- UNIT 3b CONTACT AT 87 FT
CASING PLUG AT 88 FT -------->TA|P|
                                T|X|
                                T|X|
TOTAL DEPTH AT 105 FT -------> T|X|
```

DIAGRAM NOT TO SCALE

CEMENT SLURRY SEAL.....C
BACKFILLED TUFF CUTTINGS....T
MEDIUM GRAIN SILICA SAND....S
ALUMINUM CASING, 2 in ID....A
WELDED END CAP PLUG.....P
CAVED IN.....X

VII. APPENDICES

Appendix B. Chemical Data from Soil Core Samples

TABLE B-1. EP Toxic Barium Concentrations in mg/l.

DEPTH (ft)	BOREHOLE NUMBER ===> B-4	B-5	L-17	L-18	L-19	L-20
1	686.5		2486.4	18114.4	< 5.0	
2		< 5.0	13206.9		< 5.0	< 5.0
3	4169.7			12.3		
4			16803.3	11.0		
5					< 5.0	
6		< 5.0		7.5		
7	11300.0					
8				< 5.0		< 5.0
9			3014.8	< 5.0		
10			2048.5		< 5.0	< 5.0
11	1839.5			< 5.0		
12		< 5.0	6.5			
13				< 5.0		< 5.0
14		< 5.0	17.8	< 5.0		
15			9.0			< 5.0
16	229.3		8.8	< 5.0		
17	23.4					
18	20.7			< 5.0		< 5.0
19	14.8					
20						< 5.0
21						
22						
23						< 5.0
24						
25						< 5.0
26						< 5.0
27						
28						< 5.0
29						< 5.0
30						

Appendix B. Chemical Data from Soil Core Samples

TABLE B-2. Nitrate Concentrations in mg/l.

DEPTH (ft)	BOREHOLE NUMBER ===> B-4	B-5	L-17	L-18	L-19	L-20
1	0.3		0.7	0.5	0.7	
2		< 0.2	6.0		< 0.3	< 0.2
3	0.5			0.3		
4			2.6	0.8		
5					< 0.2	
6		< 0.2		0.8		
7	1.2					
8				< 0.2		< 0.2
9			< 0.7	< 0.2		
10			2.2		< 0.3	< 0.2
11	2.6			< 0.2		
12		0.4	1.0			
13				< 0.2		< 0.2
14		0.4	0.4	< 0.2		
15			0.3			< 0.2
16	< 0.2		0.9	1.8		
17	< 0.2					
18	0.3			< 0.2		0.2
19	0.25					
20						< 0.2
21						
22						
23						< 0.2
24						
25						< 0.3
26						< 0.2
27						
28						< 0.2
29						< 0.2
30						

Appendix B. Chemical Data from Soil Core Samples

TABLE B-3. Average residual high explosives content, expressed as soluble acetonitrile (wt %).

DEPTH (ft)	BOREHOLE NUMBER ===> B-2	B-4	B-5	L-17	L-18	L-19	L-20
1				0.27			
2	0.12			0.98			
3		1.46			0.07		
4				0.78	0.06		
5							
6					0.09		0.12
7		0.20					
8							
9				0.77			
10				0.56			
11							
12							
13							
14							
15							
16							
17							
18							
19							
20							
21							
22							
23							
24							
25							
26							
27							
28							
29							
30							

Appendix B. Chemical Data from Soil Core Samples

TABLE B-4. Residual high explosives content.

BOREHOLE NUMBER	DEPTH (ft)	ACETONITRILE (soluble wt %)	HMX (ppm)	RDX (ppm)	TNT (ppm)	DNT (ppm)
B-2	2	0.11	0	0	0	0
B-2	2	0.12	0	0	0	0
B-4	3	1.68	730	343	7869	0
B-4	3	1.24	1010	292	7115	0
B-4	7	0.21	585	13	26	0
B-4	7	0.18	370	4	12	0
L-17	1	0.27	1201	32	0	0
L-17	1	0.27	1301	139	1	0
L-17	2	0.95	2551	2206	0	0
L-17	2	1.00	2582	2138	0	0
L-17	4	0.77	821	4133	594	0
L-17	4	0.78	1099	4132	557	0
L-17	9	0.70	164	1195	211	0
L-17	9	0.83	146	983	406	0
L-17	10	0.58	220	2639	1497	0
L-17	10	0.53	270	2655	1275	0
L-18	3	0.06	14	3	17	0
L-18	3	0.08	0	0	54	0
L-18	4	0.08	22	2	4	0
L-18	4	0.04	22	1	0	0
L-18	6	0.10	0	2	0	0
L-18	6	0.07	5	0	7	0
L-20	6	0.18	21	50	27	0
L-20	6	0.05	0	0	0	0

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Appendix C. Pressure-Vacuum Lysimeter Water Samples[1]

Sample Number	Sample Date	Volume Recovered	Barium Concentration	Nitrate Concentration
L-18S	11-23-88	10 ml	37.8 mg/l	3.4 mg/l
L-18D[3]	11-23-88	< 1 ml	NA[2]	NA[2]
L-18S[3]	11-29-88	10 ml	18.5 mg/l	1.2 mg/l
L-17S	3-17-89	2 ml	1.1 mg/l	5.5 mg/l
L-18S	3-17-89	10 ml	1.1 mg/l	0.735 mg/l
L-19	3-17-89	25 ml	3.0 mg/l	0.44 mg/l
L-17S	3-28-89	< 1 ml	NA[2]	NA[2]
L-18S	3-28-89	2 ml	1.1 mg/l	2.37 mg/l
L-19	3-28-89	10 ml	2.0 mg/l	0.21 mg/l
L-17S	6-02-89	< 1 ml	NA[2]	NA[2]
L-18S	6-02-89	< 1 ml	NA[2]	NA[2]
L-19	6-02-89	< 1 ml	NA[2]	NA[2]
L-17S	8-11-89	trace	NA[2]	NA[2]
L-18S	8-11-89	< 1 ml	NA[2]	NA[2]
L-19	8-11-89	trace	NA[2]	NA[2]

[1] = All other lysimeters failed to yield water on the sample dates indicated above. Samples were collected after one week of 50 cb vacuum pressure was applied.

[2] = Not Analyzed; insufficient water volume

[3] = S represents the shallow lysimeter in a duel completion borehole, while D means the deep lysimeter in the same borehole.

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Appendix D. Canon de Valle Stream Survey Samples

TABLE D-1. Barium and Nitrate Concentrations in Water Samples. See location map for station numbers.

STATION	STATION DESCRIPTION	BARIUM (mg/l)[1]	NITRATE (mg/l)[2]
1	Channel at Hiway-4.....	dry	dry
2	Channel below old pond...	35.8	< 0.2
3	Channel above Bldg-260...	9.9	0.8
4	Bldg-260 NPDES outfall...	4.4	0.8
5	Tributary above outfall..	dry	dry
6	Tributary below outfall..	6.4	7.7
7	Tributary below outfall..	38.1	< 0.2
8	Tributary below outfall..	39.9	2.5
9	Channel below outfall....	10.0	0.8
10	Channel below outfall....	12.4	0.7
11	Channel below outfall....	9.1	0.8
12	Channel below outfall....	8.7	0.6
13	Channel above landfill...	9.5	0.6
14	Channel below landfill...	9.5	NA[3]

TABLE D-2. Barium and Nitrate Concentrations in Sediment Samples. See location map for station numbers.

STATION	STATION DESCRIPTION	BARIUM (mg/l)[1]	NITRATE (mg/l)[2]
1	Channel at Hiway-4.....	< 5.0	< 0.2
2	Channel below old pond...	< 5.0	< 0.3
3	Channel above Bldg-260...	5.6	< 0.2
4	Bldg-260 NPDES outfall...	< 5.0	< 0.2
5	Tributary above outfall..	< 5.0	< 0.2
6	Tributary below outfall..	6.4	< 0.2
7	Tributary below outfall..	33.5	< 0.2
8	Tributary below outfall..	51.2	0.3
9	Channel below outfall....	< 5.0	< 0.2
10	Channel below outfall....	< 5.0	< 0.2
11	Channel below outfall....	< 5.0	< 0.2
12	Channel below outfall....	< 5.0	< 0.2
13	Channel above landfill...	< 5.0	0.4
14	Channel below landfill...	< 5.0	NA[3]

[1] = EP toxicity test procedure.

[2] = Total inorganic nitrates.

[3] = Not Analyzed.

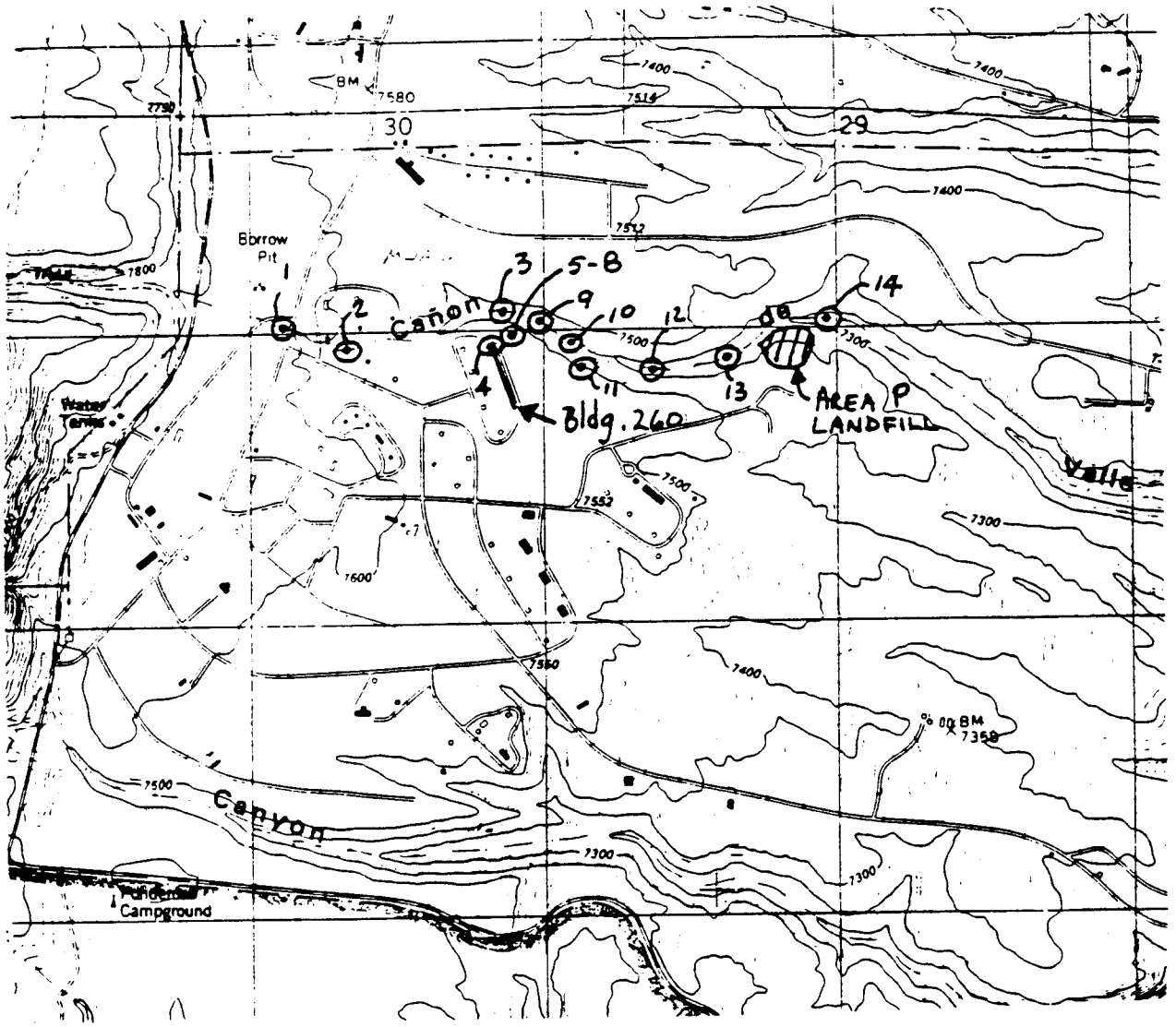

Figure D-1. Location map for Canon de Valle stream samples.

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Appendix E. Calibration Curves for the Neutron Moisture Probe

Calibration curves for the CPN Model 503-DR Hydroprobe, serial number H36076933, are shown in the attached figure.

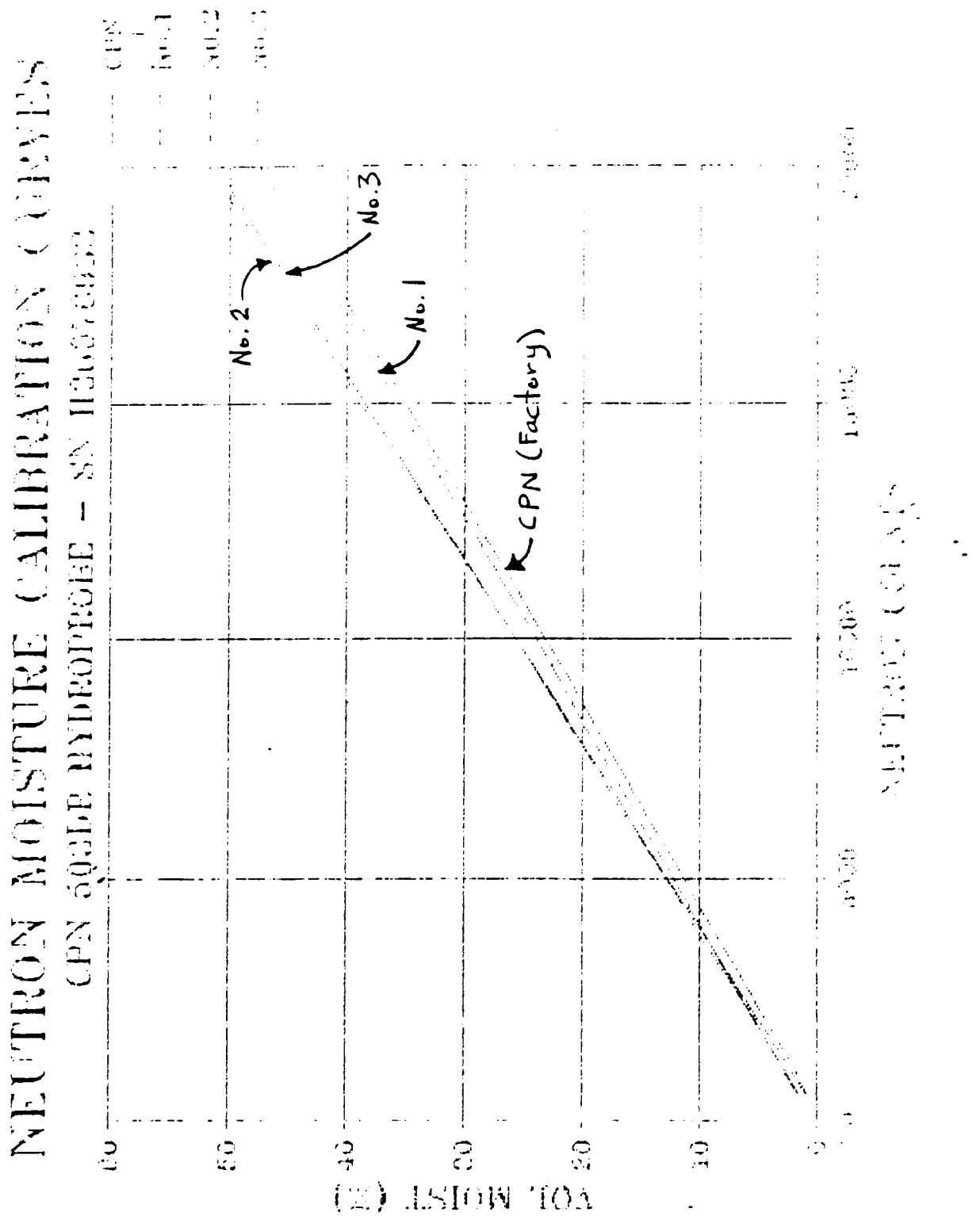

Figure E-1. Calibration curves for the neutron moisture probe.

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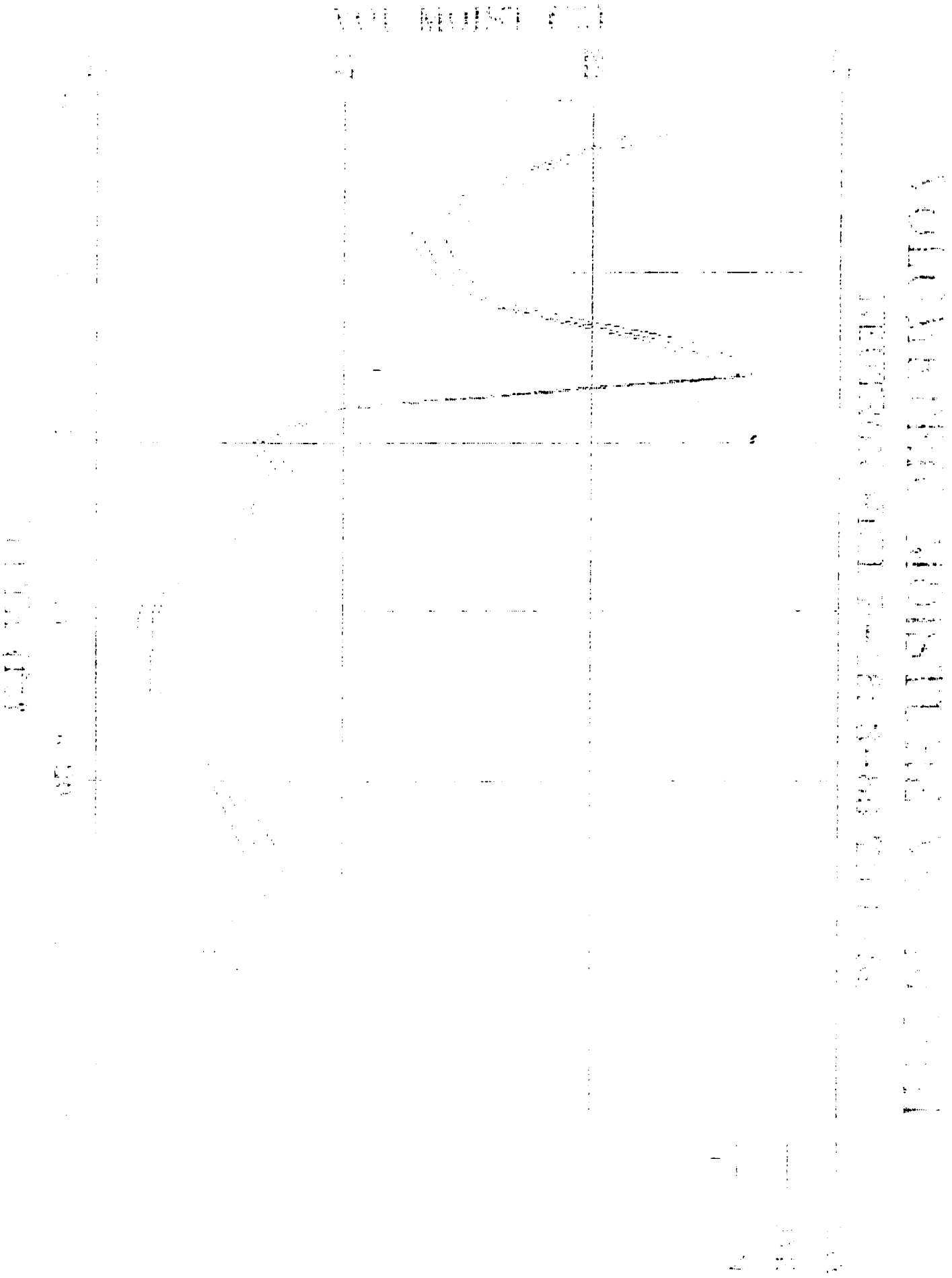
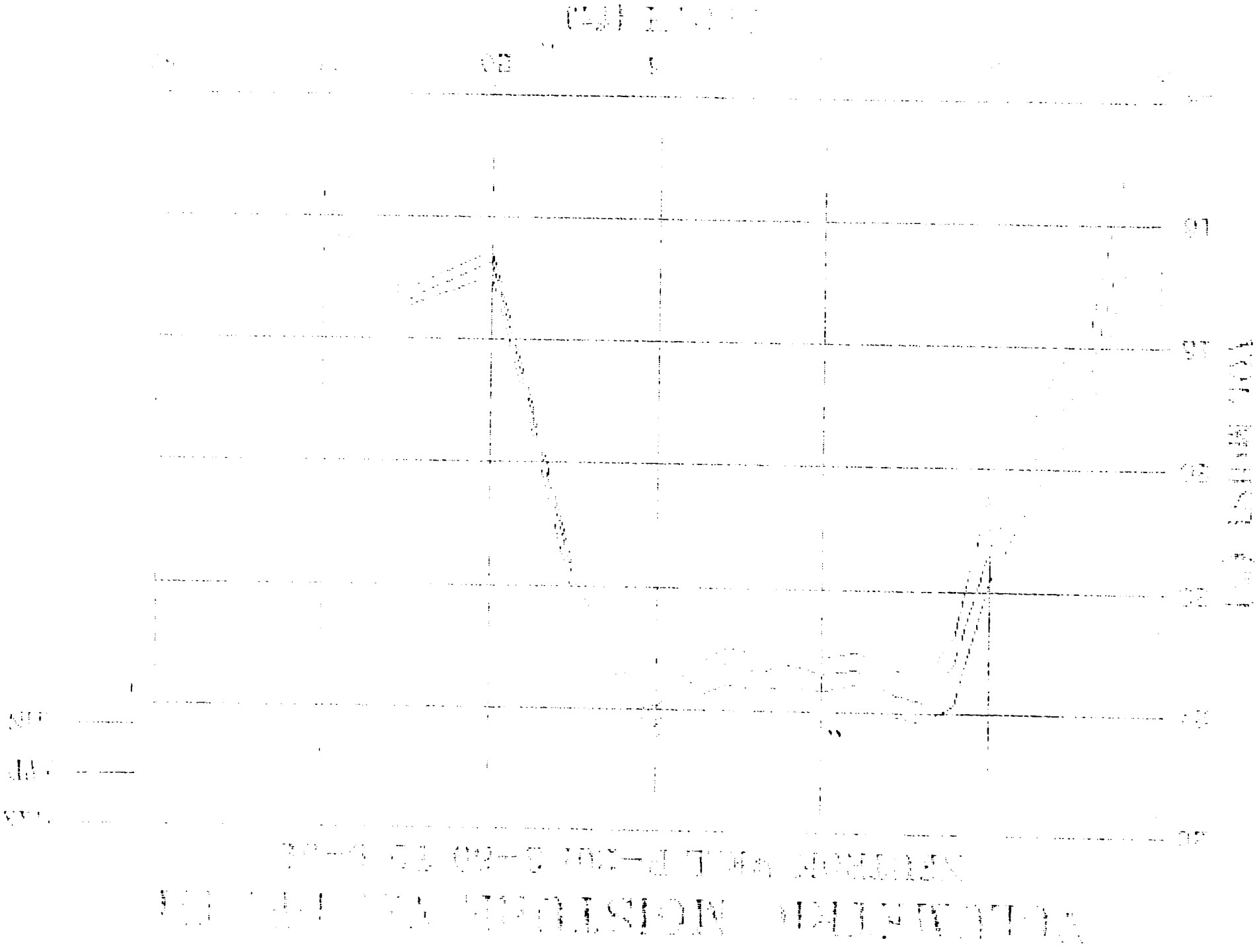
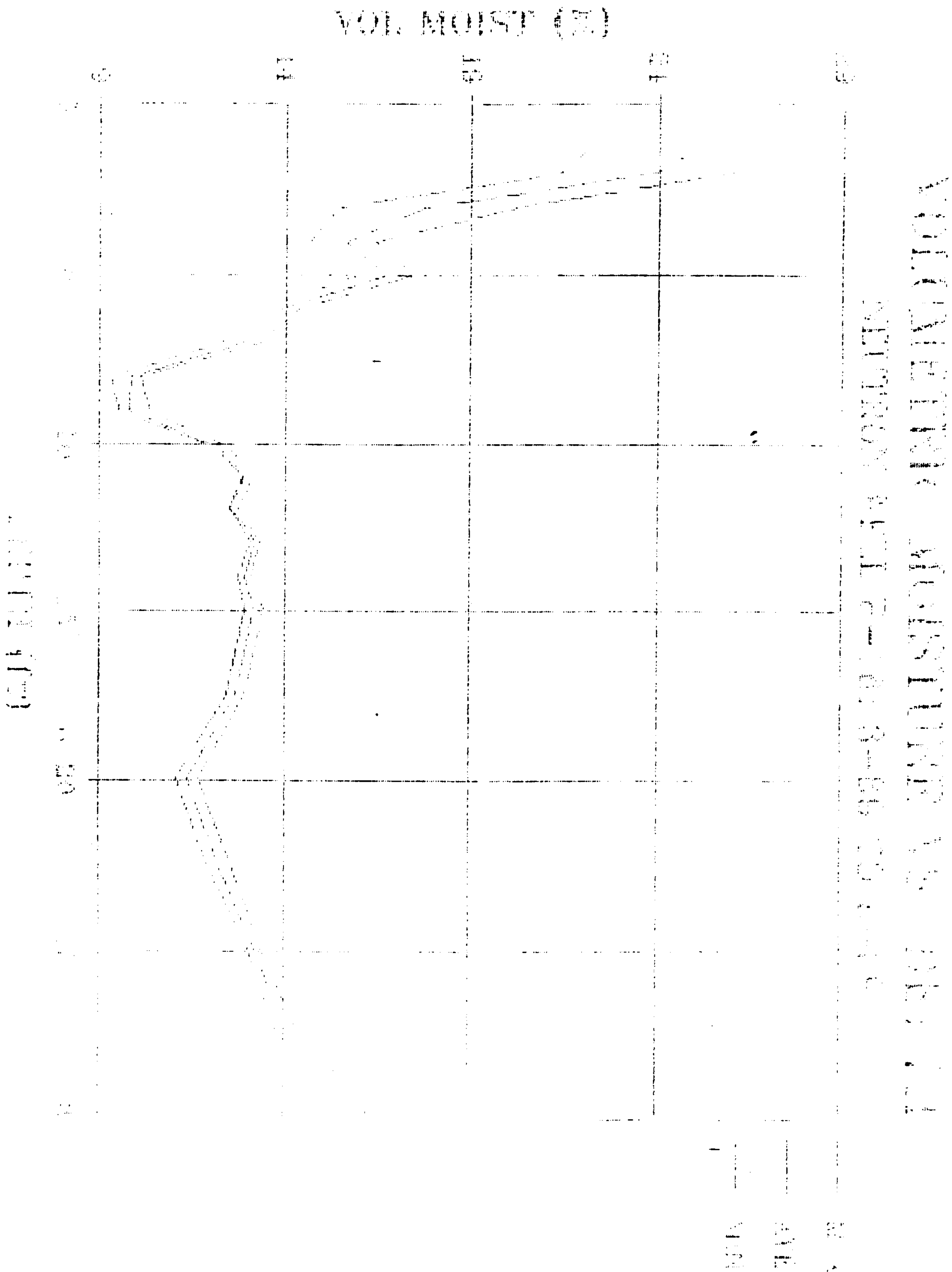
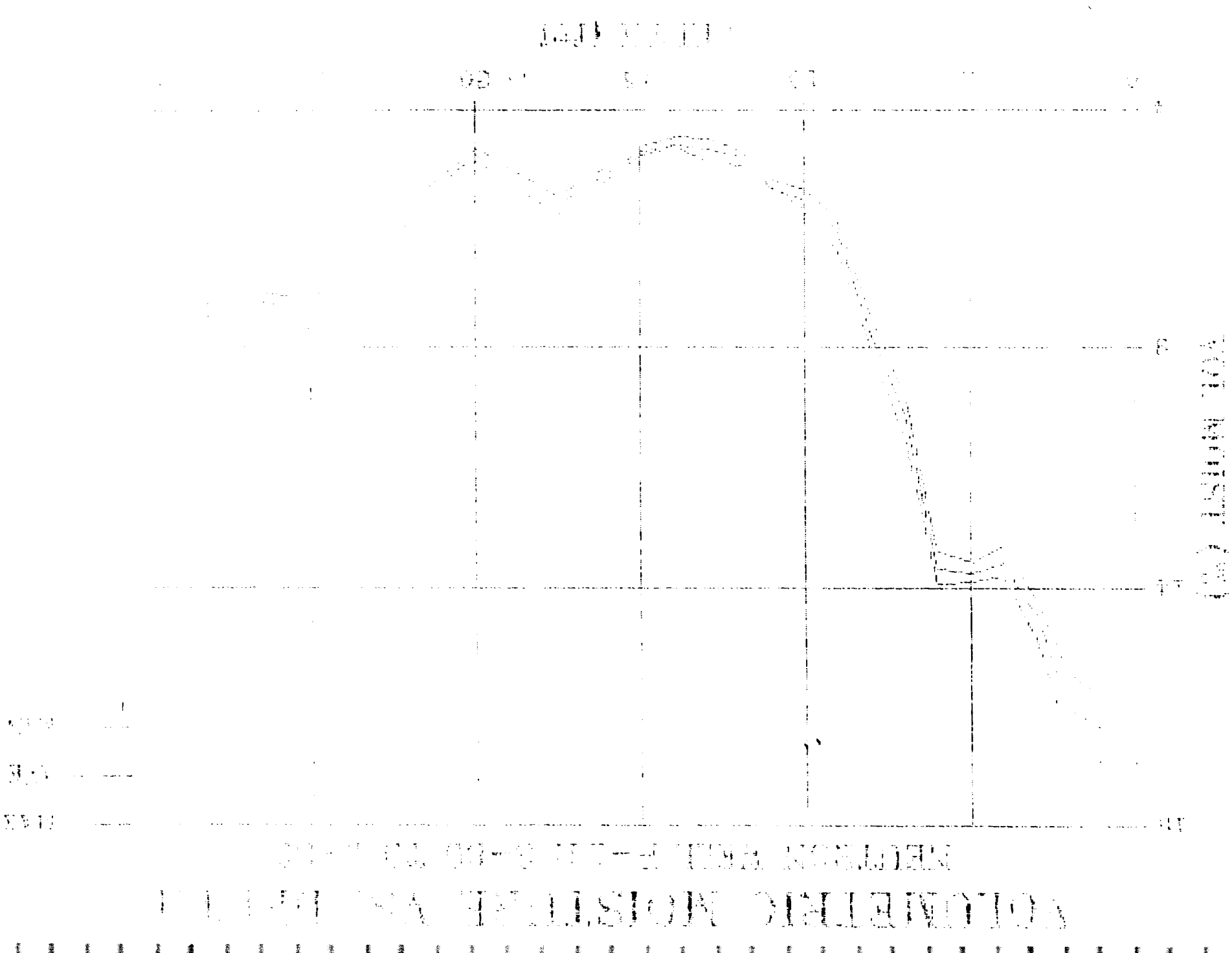
Appendix F. Neutron Moisture Readings

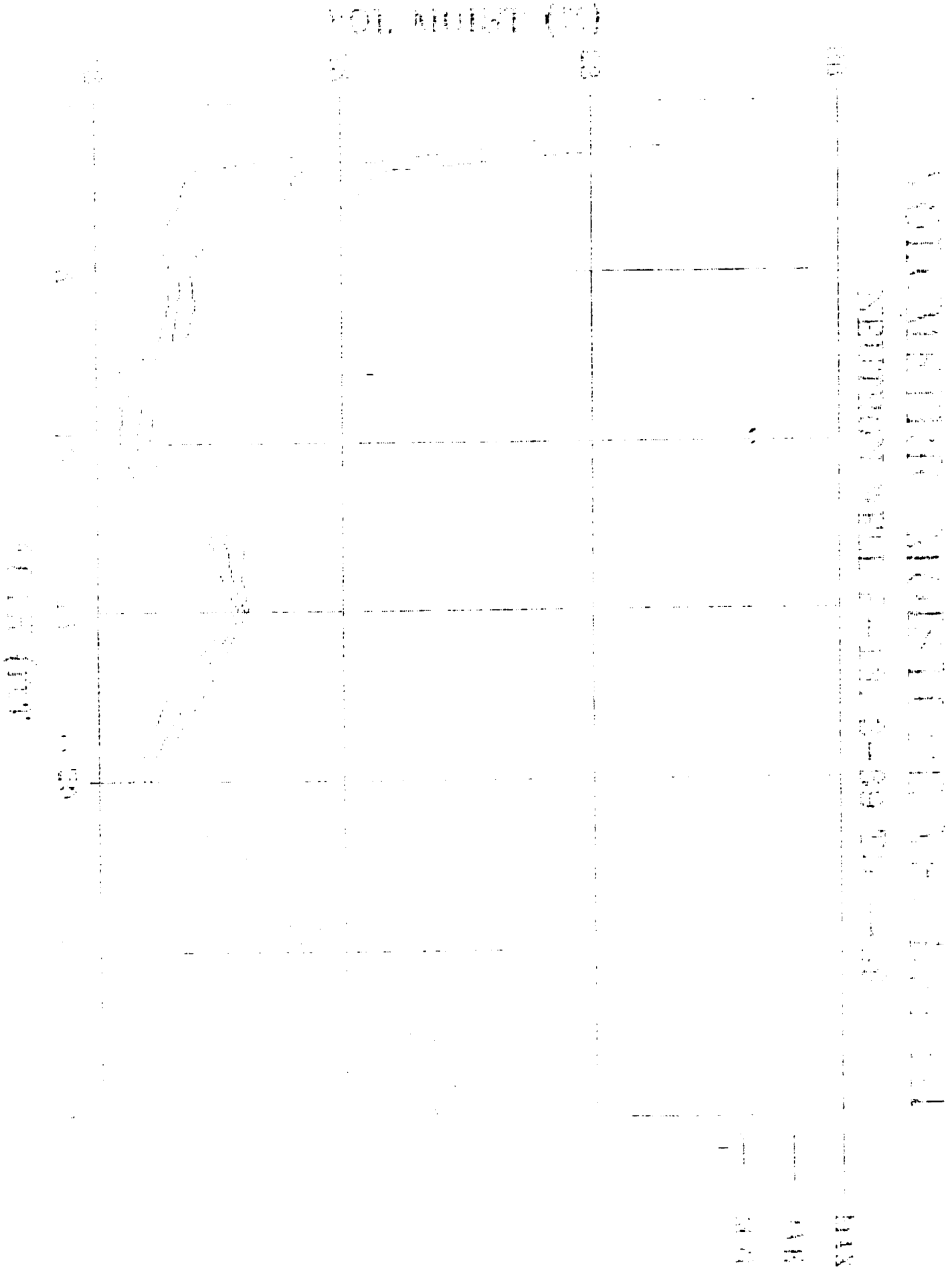
Plots of volumetric moisture content versus depth below ground surface are attached. These data are from neutron access wells numbered P-0, P-12, P-13, P-14, P-16, P-17, P-18, P-19 , and P-20. Tabulated data were recorded on a monthly basis from March through September 1989, and are also attached for reference purposes.



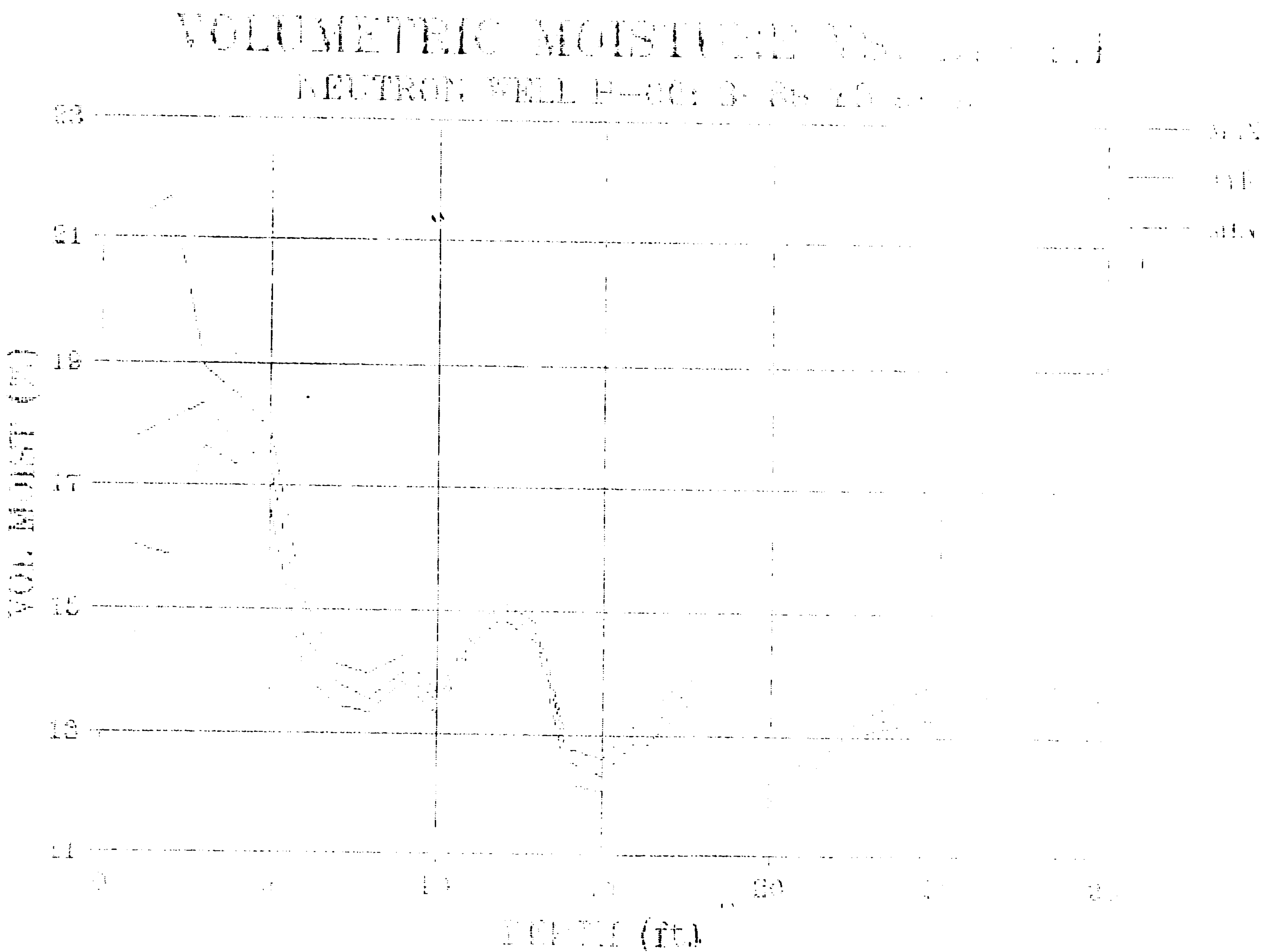



VOL. MOIST (%)





VOLUMETRIC MOISTURE VS. DEPTH
NEUTRON WELL F-12
VOL. MOIST (%)
5
10
MAX
AVE
MIN


VOL. MOIST (%)
23
21
19
17
15
13
11
0
10
20
(ft.)

APPENDIX E

Focused Feasibility Study for Area P Landfill

28 September 1992
Revision 1

Prepared for
Operable Unit 1082
Los Alamos National Laboratory
Environmental Restoration Program
Los Alamos, NM

Valerie A. Rhodes
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SECTION 1 INTRODUCTION

1.1 Purpose and Scope

Environmental Resources Management, Inc. (ERM) was tasked under Environmental Restoration Program Work Release 92-0008 dated 10 August 1992 to conduct a focused feasibility study of Remedial Options for the Area P Landfill Site located at Technical Area 16 (TA-16).

The purpose of this focused feasibility study is to develop and review technologically possible options for remediation. An evaluation will be performed for each alternative utilizing the baseline criteria of: implementability; long term effectiveness and permanence; protectiveness of the environment and public health; and cost. This evaluation will then be used to perform a relative ranking of alternatives to aid in decision-making about the site. Alternatives that are not feasible based on the criteria utilized may be identified and other alternatives that are most feasible will be highlighted. While this type of a focused study is not sufficient to select a final remedial alternative, it can provide a sound basis for the design of site characterization studies and for predesign studies of site closure as well as to identify specific data to be collected during sampling. In the instance of the Area P Landfill, a closure plan has already been developed for closure in place by capping and leachate collection. A possible alternative scenario is remediation/closure under the RCRA corrective action process following inclusion of the site in the RCRA Facility Investigation for Operable Unit 1082 (of which TA-16 is a part). The focus of this study will be to aid in the determination of whether to proceed with efforts to obtain State regulatory approval of the previously developed closure plan, or to include the site in the planned RCRA Facility Investigation prior to final determination of the appropriate remedial/closure option that should be implemented.

Los Alamos National Laboratory (LANL) operated Area P as an industrial landfill from the 1950s to 1984. Disposed materials primarily consist of residues and noncombustible debris resulting from burning high explosive-contaminated equipment, building materials, and trash. The landfilling procedure was to dump this waste material over the edge of the slope that forms the beginning of the canyon wall. The landfill covers an area of approximately two (2) acres and contains an estimated 16,000 cubic yards of material. Disposal records do not exist to document the types, amounts, and locations of wastes buried at the Area P site. Several waste residue samples taken in 1984 exceeded the hazardous waste Extraction Procedure (EP) toxicity limit for barium and, subsequently, the landfill became

regulated under the New Mexico Hazardous Waste Management Regulations. LANL opted not to continue operation of the Area P Landfill and waste disposal was discontinued at the site in 1985. Following the loss of interim status provisions, LANL submitted a closure and post-closure plan to the New Mexico Environmental Improvement Division in 1988, and the state regulatory review process is pending.

1.2 Report Organization

This feasibility study report includes a list of the technologically possible remedial options for the Area P Landfill Site and a comparative evaluation of those options using the following criteria:

- Implementability
- Long-term effectiveness and permanence
- Protectiveness of the environment and public health
- Cost

The use of these criteria will help narrow the field of possible options in later, more formal evaluations under the Corrective Measures Studies of the RCRA Corrective Action provisions of LANL's hazardous waste facilities permit.

In order to develop remedial alternatives, detailed reviews of existing data (archival information, reports, maps, etc.), EPA and State regulatory constraints, and remedial precedents were conducted. In addition, the site was inspected to view current site conditions and to make simple field measurements to verify existing site area and volume estimates.

The first section of the report, Section 1, discusses site history, the scope of previous investigations, and the physical site inspection that was conducted by ERM. Section 2 provides an interpretation of contaminants of concern identified by the previous investigations and the available data. An analysis of the known extent of the contamination and the possible routes of exposure is also provided in Section 2.

Section 3 discusses regulatory issues which govern the closure/remediation of the site. This section also provides the results of a literature search for precedents from closure/remediation of similar sites.

Section 4 identifies and evaluates remedial alternatives that are judged technically possible. The alternatives are compared based on the criteria

mentioned above to narrow the probable alternatives that may ultimately be chosen for the site.

Lastly, Section 5 provides recommendations concerning the suggested actions that should be followed in order to develop sufficient data upon which final closure/remediation decisions can be made.

1.3 Site History and Description

Material Disposal Area P (MDA P) is an industrial landfill located in TA-16 that was active from the 1950s to approximately 1985. In 1984, the landfill became subject to RCRA regulation when several landfill soil/waste residue samples were analyzed for EP toxicity and threshold limits for barium were exceeded. There are no records documenting the types, quantities, or locations of wastes placed into the MDA P Landfill. Since the early 1950s, the site was used to dispose of building demolition rubble and equipment and waste materials that had been contaminated with high explosives. Prior to November 1985, high explosive (HE) contaminated wastes and equipment were burned on sand-covered pads at S Site (TA-16). After the burn, the sand and burned wastes were removed and placed in the landfill. The sources of barium in the residue are oxidized and environmentally degraded byproducts of barium nitrate that were used in the formulation of some high explosives. Known wastes placed in the landfill include concrete rubble, structural steel, burn pad sand, burned equipment, and empty solvent cans. Lead shielding, beryllium metal fragments, and other metals may be present in the landfill. It is not known if radiologically contaminated materials, such as depleted uranium, incorrectly found their way into the landfill.

The Area P Landfill (Figure 1) is located in a topographic saddle of a short, eastern-trending, narrow mesa. The saddle is near the southern rim of Canon de Valle, immediately north of the TA-16 thermal treatment pad number 387. A 1983 photograph of the site is enclosed following Figure 1. Figures 2 and 3 show the areas influenced by the landfill as determined by a comparison between a pre-landfill survey and a more recent survey (Delta H Engineering, Ltd., 1985). The surface runoff over the face of the landfill shown in Figure 2 is currently collected by a drainage trench located immediately north of and parallel to the fence. This collected surface water runoff is directed around the eastern edge of the landfill into the canyon. The area impacted by the landfill is approximately two acres and contains an estimated 16,000 cubic yards of waste construction debris, crushed tuff, sandy clay fill material, and barium contaminated sands and wastes. Within this two acre site are two distinct waste lobes created as landfilling progressed from the west to the east. The west area of the landfill was closed by leveling and covering the wastes with crushed tuff and sandy clay

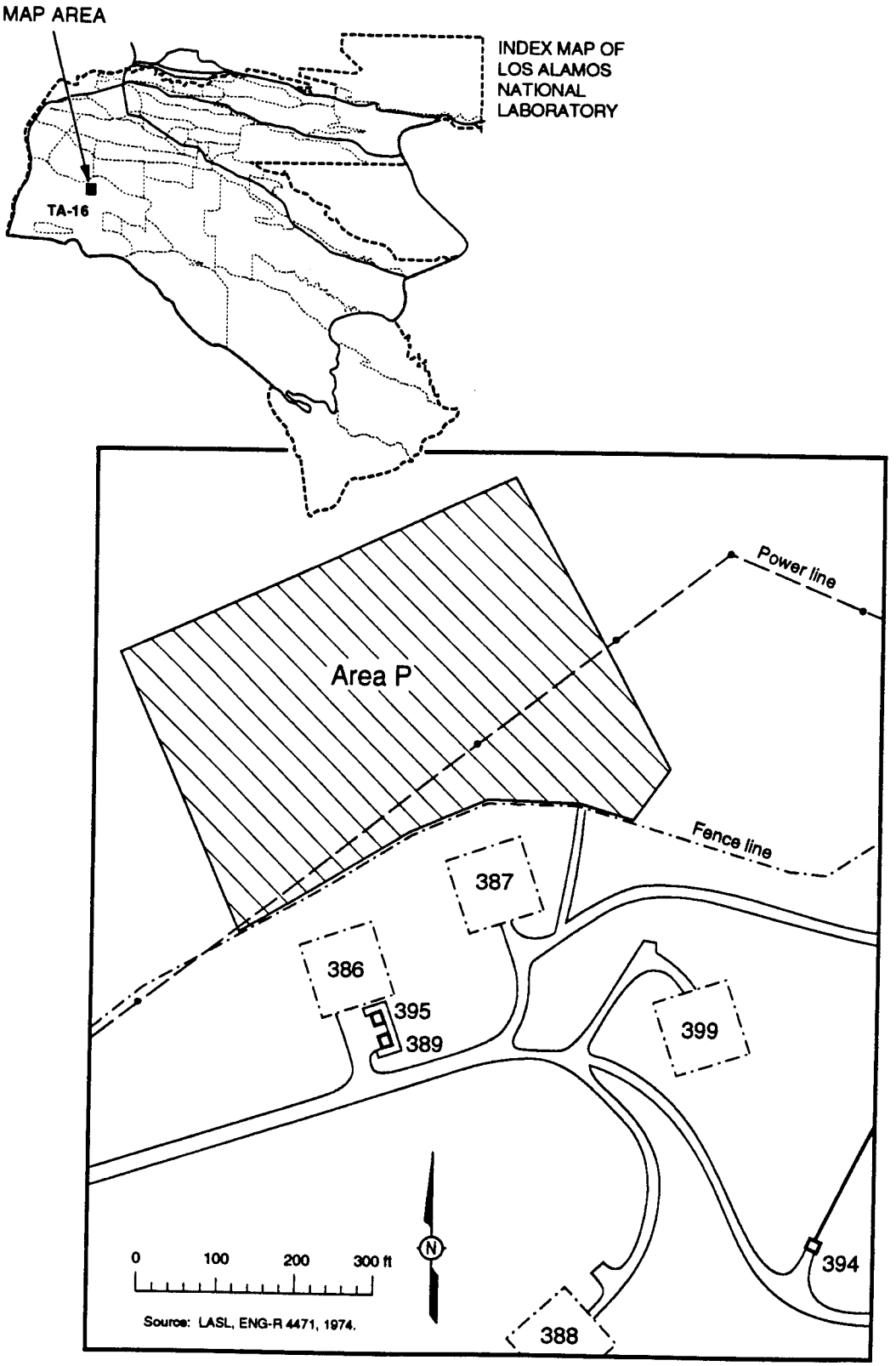

Figure 1. Area P site location map.

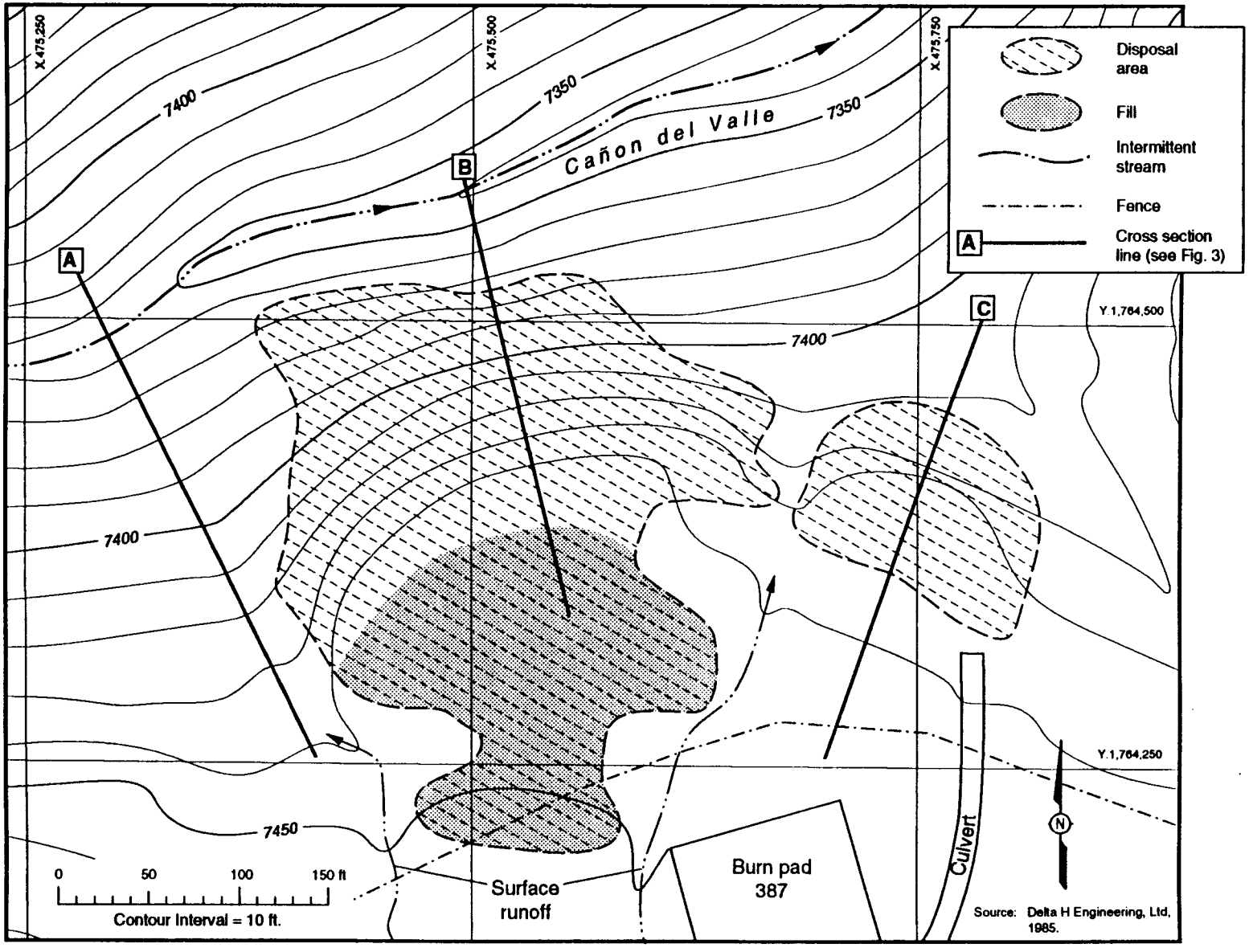

Figure 2. Area P landfill.

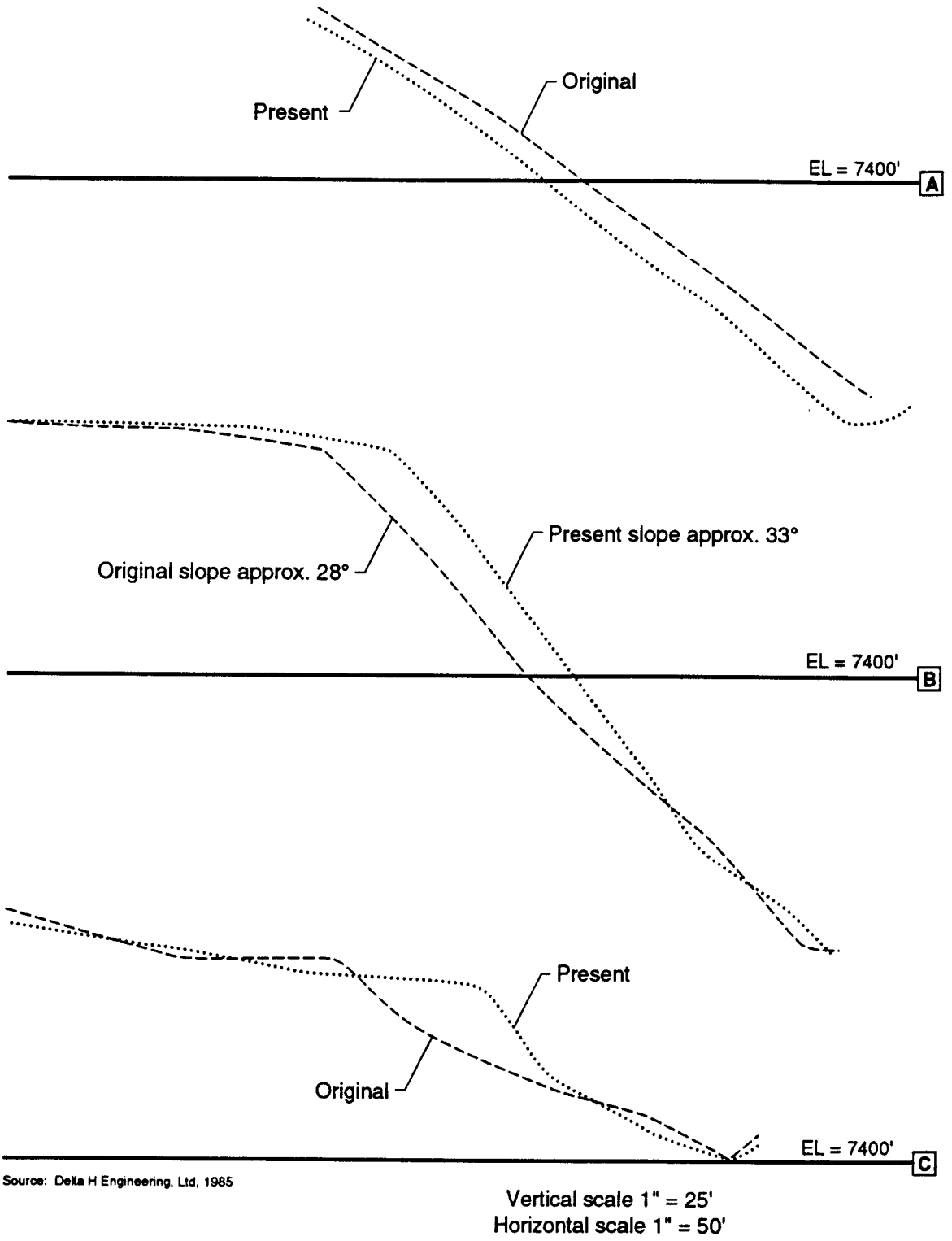

Figure 3. Area P cross sections A, B, and C.

soils. The leveling process overflowed the rim in the northwest quadrant of the west area, as documented by the original undisturbed elevation changes shown in cross section A. Cross sections B and C (respectively in the western and eastern areas of the landfill) show large quantities of wastes (12 to 14 feet deep at the rim) located on the steep canyon slope. While the cross sections suggest that waste deposition begins only 30-40 feet south from the rim, the visual inspection (and Figure 2) indicate that this deposition distance may be three or four times higher. It should be noted that the cross sections shown resulted in a 1985 volume estimate of 13,000 cubic yards. The 16,000 cubic yard estimate was computed by ERM based on field measurements (see Section 1.4).

The western area of the site is believed to be covered with approximately one foot or more of cover material. The eastern area was covered with earth as waste deposition proceeded. The depth of the eastern cover material is unknown and is probably less than the cover placed over the western area. Past proposals have suggested different closure schemes to the western and eastern areas because of this difference in cover material and depth. No evidence could be found in historical documents, however, to differentiate waste materials placed in the western versus eastern areas.

1.4 Site Visit

ERM conducted a site visit on 18 August to view current site conditions and to make field measurements to confirm landfill volume estimates. Current site status is consistent with previous reports and documents. The site appears essentially the same today with the exception of surface drainage control.

As previously described in past documents, the landfill has two distinct portions; the west area that was partially closed by leveling and covering with soil and the smaller east area that was the most recently active portion of the site. Sandy clay soil covers the west side of the landfill and supports fair stands of grasses and brush. Although leveled and covered, demolition rubble and piping remain visible on parts of the western portion north slope. The east landfill area progressed from south to north, with some cover material being applied as the landfill advanced. The covered portion of the east area supports very little vegetation and the wastes on the north slope remain virtually totally exposed. The steep landfill slopes appear to be only partially stable, as indicated by the amount of debris that has fallen to the canyon floor. Surface drainage skirts the southeastern boundary of the eastern landfill area. A well-drilling access road that leads around the west perimeter of the western landfill area is heavily eroded by surface runoff.

A wide variety of waste types have been placed in MDA P based on visual observation. The types of wastes observed include large items such as sumps, filter baskets, foundation concrete blocks, structural steel supports, and metal piping. Many types of empty containers are present ranging from small metal solvent cans, glassware, and bottles to large 55-gallon drums.

In order to confirm reported landfill volume, taped field measurements were made across the top of the two disposal areas. The original slope angle and height were approximated at 32° and 80 feet, respectively. Using the disposal depth documented by the previous cross sections and simple straight line geometry, the landfill disposal volume was calculated to be approximately 16,000 cubic yards. This quantity is consistent with previous reported estimates of 13,000 cubic yards.

1.5 Previous Investigations

Previous investigations and studies at MDA P have focused respectively on: establishing a database of information; submitting landfill closure and post-closure plans; and identifying landfill closure alternatives. These three types of investigations/studies will be discussed in the following three subsections.

1.5.1 Data Collection

Data collection has proceeded in two phases that include: characterization, monitoring the subsurface, and sampling and analyzing site media. Phase 1 was conducted from mid-1987 to early-1988 and involved groundwater monitoring well installation along the north face of the landfill, analyses of core samples from these well borings for metal contamination and hydraulic properties, and stream surface and sediment sampling. Phase 2, conducted in late-1988, consisted of installation of vadose zone monitoring wells through the landfill wastes, core analyses from these well borings for barium, nitrate, and explosives contamination, and a survey of stream surface water and sediments.

The Phase 1 investigation began with a drilling program to characterize the subsurface and to sample the groundwater beneath the site. Seventeen boreholes were drilled and logged in the vicinity of the landfill site. Four holes were completed as RCRA groundwater monitoring wells (P-3, P-4, P-6, and P-8) and are located at the northern limit of the waste disposal area. These wells have been screened partially in the alluvium and partially in the underlying tuff to detect liquids travelling along the alluvium-tuff horizon. Four additional holes were completed as wells (P-1, P-5, P-7, and P-9) to detect groundwater in the alluvium between the canyon stream and the

landfill. Five boreholes were completed as neutron moisture access wells (P-0, P-12A, P-13, P-14, and P-16A) and four boreholes (P-2, P-10, P-11, and P-15) were sealed and closed after logging. Monitoring did not detect free-flowing groundwater in any of the 17 holes. Core samples recovered from borehole P-16A were analyzed for metal concentrations, volumetric moisture content, and average gravimetric moisture content. Additional laboratory analyses were conducted on unidentified core samples for saturated hydraulic conductivity, unsaturated hydraulic conductivity, initial moisture content, bulk density, and porosity. The Phase 1 investigation concluded with a reconnaissance water quality and sediment sampling survey. Five surface water samples (57, 59, 63, 64, and 70) and 11 stream sediments and soil samples (55, 56, 58, 60, 61, 62, and 65-69) were collected and analyzed for metal concentrations.

Thirteen boreholes were installed to complete a vadose monitoring well system as part of the Phase 2 investigations. Each borehole penetrates through the landfill and into the underlying tuff material. These boreholes were completed as a coupled network of seven pressure-vacuum lysimeters in four boreholes (L-17 through L-20), four neutron moisture access wells (P-17 through P-20), and five exploration boreholes (B-1 through B-5) that were plugged and abandoned after logging. The pressure-vacuum lysimeter and neutron moisture access boreholes were completed as two-well nests; each well nest consists of a lysimeter well and a neutron moisture access well; approximately 8 feet separates the wells from each other (horizontally). Landfill soil and underlying tuff samples were recovered and analyzed for barium, nitrate, and residual explosives concentrations. Pore water samples collected by lysimeters were tested for barium and nitrate concentration. Similar to Phase 1, Phase 2 investigations concluded with a stream sampling survey. Stream surface water and sediment samples were collected at 14 stations along Canon de Valle and analyzed for barium and nitrate concentrations.

No radiological surveys have been performed on materials or wastes at the site.

The Phase 1 and 2 investigations have yielded the following findings:

- Several landfill residue core samples have exceeded the RCRA regulated EP toxicity limit for barium. Other metals in leachate extracts from these samples are below detectable limits. Nitrate concentrations in the same leachate extracts are at or below 2.6 mg/l. This can be compared to a drinking water maximum contaminant level (MCL) of 10 mg/l for nitrate.

- Stream water and sediment samples taken on the stream and in drainage channels from the landfill surface indicate that the landfill is not the

source of elevated barium concentrations levels in the stream water and sediment. These contaminants apparently originate from upstream wastewater discharges. Lead was the only other metal identified above detection limits, appearing in only one sediment sample taken from a surface runoff drainage channel on the surface of the landfill.

- Landfill materials contain low levels of residual explosives (less than 1.5 wt.% acetonitrile solubles).

- Barium concentrations in recovered lysimeter pore water samples are significant, ranging from 1.1 mg/l to 37.8 mg/l. The barium MCL is 2 mg/l.

1.5.2 Landfill Closure Plans

The Area P Landfill Closure and Post-Closure Plan was originally prepared by Delta H Engineering, Ltd. in 1985. The plan was later modified by LANL and submitted to the New Mexico Environmental Improvement Division in 1988. The plan modifications were submitted with the intent that the Area P landfill fully comply both with interim status (40 CFR Part 265) for closure and permitting (40 CFR Part 265) for post closure care. The plan documents closure and post-closure activities based on current knowledge of the site, including landfill extent, possible hazardous constituents, geology, and hydrology. The west and the east area of the landfill site were proposed to be closed separately. Because the west area of the landfill is already leveled and covered, the closure plan includes only the installation of an adequate monitoring system. Monitoring consists of using neutron probe test holes and two trenches to detect and collect leachate, if generated. The east area closure plan requires surficial stabilization and a cap. The face of the east area would be stabilized by constructing a concrete blanket and installing a RCRA cap. Monitoring through the post-closure period for both east and west portions includes:

- leachate sampling and analysis
- neutron probe measurement of tuff below landfill
- erosion rate monitoring
- ground water monitoring of perched water in canyon
- surface water monitoring

1.5.3 Landfill Closure Alternatives

Closure alternatives for the Area P landfill have been outlined in a 1990 report by IT Corporation. The report provides a general discussion of the options available for closure. Also included are the geotechnical and regulatory issues and the health and safety and cost considerations regarding each option in general terms. The four conceptual closure options included in this report are total removal, partial removal, in situ treatment, and no removal-no treatment. The total removal option requires excavation of the entire landfill and contaminated tuff, treatment on- or off-site, and disposal on- or off-site. Partial removal involves excavation, treatment and disposal of only the hazardous portions of the landfill. The in situ treatment alternative uses either in situ leaching or in situ stabilization. There are three methods pertaining to the no removal-no treatment alternative: total encapsulation, partial encapsulation, and no action. Total and partial encapsulation would involve stabilizing the slopes and covering either the entire area or only a portion of the landfill. No action leaves the landfill in its current state. All three of the no removal-no treatment alternatives would require post-closure monitoring.

SECTION 2 CHARACTERIZATION OF SITE CONTAMINATION

2.1 Contaminants of Concern

As explained in Section 1.5, contaminants that have been monitored during the various past investigations at the site have included: nitrate; metals including arsenic, barium, cadmium, chromium, lead, mercury, selenium, and silver; high explosives including, total acetonitrile solubles, HMX, RDX, TNT, and DNT. No analyses on environmental or waste samples from the site or site area have been performed for solvents, beryllium, or radiological contaminants.

Based on the analysis of available data, it is apparent that barium is the primary contaminant of concern at the site. It is the constituent of the waste materials that originally caused the site to be regulated as a RCRA facility and it is soluble in water as well. Additionally, barium is also a constituent for which there is an established maximum contaminant level (MCL) under the safe drinking water act of 2 mg/l. This level of barium therefore could be used as a threshold level in groundwater and surface waters to determine if significant contaminant migration is indeed taking place. The MCL would also likely be applied as a clean-up goal for any

landfill closure/remedial activities as a level that must be maintained in groundwater and surface waters around the site.

A second contaminant of concern, that has only been analyzed to a limited extent at the site, is nitrate. Although nitrate is not a constituent that would cause a waste to be regulated under RCRA, it is a contaminant for which an MCL exists of 10 mg/l. Additionally, as was previously mentioned, existing sampling of surface water and sediment from drainage channels across the face of the landfill and in the stream on the canyon floor did not detect any metal contamination with the exception of one positive result for lead. Although this is a strong indication that lead is not migrating at the site, historical records indicate that it is highly possible that quantities of lead materials could be disposed in the landfill. Lead could also be naturally occurring. For this reason, lead should continue to be an ongoing constituent of concern.

Previously, analyses for high explosives (both total acetonitrile and specific HE compounds) have revealed no safety hazards in samples taken from the landfill. Sampling for these materials has not been conducted in surface water or sediment around the landfill site, however. Because there are environmental concerns in addition to those safety concerns for the migration of HE constituents from the landfill, HE should continue to be a contaminant of concern.

Lastly, no analyses for beryllium or for radiological materials that may be present in the landfill has ever been conducted. It has believed unlikely that radiological materials or beryllium are present in significant quantity in the landfill. However, parameters of concern for future characterization of the potential landfill contaminant migration should include basic radiological screening (gamma, alpha, and beta) and analyses for beryllium to confirm that none of these materials are present.

In summary, contaminants of concern include the following:

- barium
- nitrate
- lead
- HE including HMX, RDX, TNT, DNT
- screen for gamma, alpha, beta radiation
- beryllium

2.2 Extent of Contamination

Although the distribution of contaminants within the landfill is not well characterized, there is a substantial amount of data to show that at least some of the contaminants of concern previously mentioned have not significantly migrated outside the landfill area. This data would include analyses for barium and for other metals. Vertical migration of barium into the tuff underlying the landfill has been documented to a depth of approximately six (6) feet beneath the landfill in at least one (1) boring that penetrated directly through the landfill. Additionally, pore water samples taken from pressure vacuum lysimeters located within the waste materials showed results of up to 37.8 mg/l barium to be present. No lysimeter samples of pore water were able to be obtained from the tuff materials located under the landfill. All of the lysimeters located at wells surrounding the landfill have also failed to yield any water samples.

In summary, the existing data shows that the only contaminant of concern that has migrated beyond the landfill limits of waste materials is barium, which has been documented to have been carried into the tuff under the landfill to a depth of 6 feet; it is not known if barium has migrated further than this distance vertically. There is no significant evidence of migration of any other contaminants of concern via surface water runoff, sediment erosion, seeps or any perched areas of alluvial ground water.

2.3 Routes of Exposure

Based on the review of the previous investigation data, it is apparent that two potential routes of exposure exist for the migration of contaminants of concern. The first potential route of exposure is physical transport of waste materials via stormwater erosion, seeps from the landfill caused by precipitation intrusion into the surface of the landfill, or surface-derived water from the hillside underneath the landfill. The second potential route of exposure is through soluble contaminant migration via infiltrated precipitation or seeps as above mentioned.

The first route of migration is made possible due to the incomplete cover of the surface of the landfill and the north face of both the eastern and western areas of the landfill where waste materials are present at the surface. This route of migration has been mitigated by the previously described covering of portions of the landfill and also by the rerouting of surface drainage around the landfill. The second route of exposure via the vertical infiltration of precipitation into the landfill is much more difficult to

quantify. Previous attempts have been made to model this migration route in a report by Nyhan dated March 1989. There is little information, however, concerning the existence or possible extent of any migration of water into the landfill through the bottom surface of the landfill via cracks or seeps in the former canyon hillside. The only possible migration route for any dissolved contamination that would originate from the landfill would be through surface water transport via the stream that flows through the canyon. McLin (1989) has reported that the downward movement of water in the vadose zone is greatly restricted due to the very low rated hydraulic conductivity of the shallow tuff materials beneath the landfill and the existence of several densely welded tuff units at deeper depths that have even lower unsaturated hydraulic conductivity values. The main aquifer is located approximately 1,230 feet below ground surface. As reported in the Delta Engineering closure report (as modified by the Laboratory in January 1988), the moderately welded and welded tuff underlying the landfill has saturated hydraulic conductivity for moderately welded tuff ranging from 0.1 to 1.7 ft/day, and for welded tuff ranging from 0.009 to 0.26 ft/day. The possibility of a joint penetrating several layers of tuff and forming a conduit to ground water is highly unlikely. Generally these joints are filled, particularly at the surface, with clay weathered from the tuff, effectively sealing the joint.

In summary, the two routes of contaminant migration are:

- physical erosion via contact of surface water runoff or precipitation infiltration with the waste materials

- dissolved migration of contaminants through lateral seepage or infiltration of surface water into the landfill and movement of contaminants to the surface water stream in the canyon.

SECTION 3 REGULATORY ISSUES

3.1 RCRA Closure Requirements

At closure, owners/operators of hazardous waste management facilites are allowed to choose between removing/decontaminating all hazardous wastes and waste residues ("clean closures") which terminates responsibility for the unit, or closing the unit with hazardous wastes or waste residues remaining in place and instituting post-closure care.

The interim status requirements for clean closure are now nearly identical to the Part 264 Permit Requirements. Owner/operators can remove or decontaminate hazardous wastes and waste residues to avoid the post-closure care requirements. This means that an owner/operator must remove

all wastes or waste residues that pose a "substantial present or potential threat to human health or the environment." EPA intends to review site-specific demonstrations submitted by the owner/operator to determine if the removal or decontamination is sufficient. The closure demonstrations to be submitted must document that the contaminants left in the soil and/or groundwater will not have an impact on ground water, surface water, or the atmosphere, in excess of EPA-recommended limits, and direct contact through dermal exposure, inhalation, or ingestion will not result in a threat to human health or the environment. If an owner/operator can demonstrate that a unit is clean-closed in accordance with regulations, a post-closure permit is not required. However, if EPA determines that the facility did not close in accordance with the clean-closure requirements, the facility is subject to the post-closure care and permitting requirements.

If an owner/operator either chooses not to conduct a clean closure, or fails to do so, the owner/operator must provide post-closure care. At closure of the landfill, the owner/operator must place a final cover over the landfill to control the infiltration of moisture that could increase leaching and to prevent erosion or escape of contaminated soil. After the final cover is installed, the owner/operator must conduct certain monitoring and maintenance activities during the post-closure care period, which continues for 30 years. The post-closure plan must outline procedures to maintain the integrity and effectiveness of the final cover, maintain and monitor the groundwater monitoring system, prevent run-on and run-off from eroding or damaging the final cover, and protect and maintain surveyed benchmarks showing the location of the landfill. An approved ground and surface water and vadose zone monitoring program would be included in the post-closure plan in order to first establish background levels and then to detect contaminant migration. Typical sampling frequency is quarterly for the first year and then annually for the following years.

3.2 Land Disposal/Restrictions

The Hazardous and Solid Waste Amendments established Land Disposal Restrictions (LDRs) to minimize or eliminate reliance on land disposal, particularly landfills and surface impoundments. These restrictions prohibit continued land dispoal of hazardous wastes beyond specified dates unless it has been demonstrated to EPA "to a reasonable degree of certainty that there will be no migration of hazardous consitituents for the disposal unit for as long as the waste remains hazardous; or unless the waste meets promulgated treatment standards. The statute requires treatment standards based on concentration levels or available treatment technologies that substantially diminish the toxicity of the waste or substantially reduce the likelihood of migration of hazardous constituents from the disposal unit so

that short-term and long-term threats to human health and the environment are minimized.

Previous investigations indicate that the major hazardous constituent present in the Area P Landfill is barium. However, the possibility exists that other regulated constituents have been disposed. While barium is not acutely toxic, its potential quantities and mobility present significant risk. EPA lists barium as hazardous for land disposal and has established its treatment standard at an EP toxicity concentration of 100 mg/l.

3.3 Remedial Action/Corrective Action Evaluation Criteria

RCRA corrective action regulations have several evaluation criteria that are used to determine which remedial options are the appropriate actions to be taken at a site. In the case of the focused feasibility study, however, it is more appropriate to perform a preselection review of possible alternatives using a limited number of criteria. For this study four criteria have been selected which are:

- protectiveness of the environment and public health,
- implementability,
- long-term effectiveness and permanence, and
- cost

These criteria are judged to be the most important for making a preliminary decision as to what remedial alternatives may be feasible at the Area P Landfill Site. Several factors must be considered in the evaluation of these criteria. Protectiveness of the environment and public health should include a determination as to whether the proposed remedy can achieve Applicable or Relevant and Appropriate Requirements (ARARs). In the case of the Area P Landfill this would mean that a remedy would have to ensure that no degradation of ground water or surface waters existed via the two previously-mentioned pathways of exposure. The standard that would be used to make this judgement would be the MCL level, as was previously mentioned. Factors to consider concerning the implementability of a particular remedial alternative would include issues such as technology development status and commercial availability of a particular technology, permitting and regulatory complexity, state/community/laboratory acceptance, and site/transportation logistics. The factors that would affect ranking of a particular alternative for long-term effectiveness and permanance would include the likelihood that a particular remedy would need to be supplemented or replaced. For example, should a landfill cap be

installed at this time but later be shown to not be able to achieve satisfactory protectiveness of the environment and public health, subsequent clean closure may need to be accomplished by removing all waste materials.

3.4 Similar Remedial Precedents

In order to determine whether the USEPA has established a remedial precedent regarding barium-contaminated landfills, an EPA record of decision (ROD) search was conducted using the ROD-SCAN service. Five barium-contaminated landfill sites that have proceded with EPA-approved remedial actions were identified; however, barium was not the primary contaminant of concern for any of the sites. The selected remedial actions for these sites are site-specific. Two sites required excavation, off-site stabilization/treatment, and disposal in RCRA cells. Two other sites required only RCRA landfill caps, site regrading and revegetating, and post-closure ground water monitoring. Remedal actions at the final site included onsite fixation and construction of a slurry wall ground water barrier and impermeable cap containment system. To date, there is no EPA remedial action precedent pertaining to barium-contaminated landfills.

SECTION 4 EVALUATION OF REMEDIAL ALTERNATIVES

4.1 Identification of Remedial Technologies

Technologies that may be applicable to the Area P Landfill Site may be grouped into three catagories: removal, containment, and treatment technologies. Each of these groups of remediation technologies will be discussed in the following paragraphs.

All technologies associated with removal would include some form of treatment prior to either on-site or off-site disposal. The treatments required would involve segregation of RCRA hazardous from non-RCRA hazardous materials and the flashing or other treatment of non-RCRA hazardous materials (non-porous rubble, metal, and other solid objects) to ensure that no HE hazard exists prior to recycling this material. Recyclable non-RCRA hazardous rubble material would likely have to be taken to the Los Alamos County Landfill or to a recycler for reuse.

RCRA hazardous waste materials that receive Land Disposal Restriction treatment to comply with regulations would require ultimate disposal in a RCRA-permitted hazardous waste landfill. This disposal could be either on-site in a Laboratory-permitted landfill or off-site in a permitted facility that would accept the wastes, such as the secure land burial facility operated by USPCI near Salt Lake City, Utah. Requirements in various EPA regions

concerning the replacement of LDR-treated RCRA hazardous wastes in the same location from which they were excavated have varied considerably. At one time, EPA guidance required that this was only permissible if the waste materials were never physically excavated but could be treated in place by such techniques as in-situ stabilization of the sludge materials in a lagoon, for example, without pumping the sludge out of the lagoon. This guidance was recently relaxed to allow the excavation of waste materials and replacement following treatment in the same location on a case by case basis. Given the margin of suitability of the Area P Landfill Site for even construction demolition debris, the acceptability of this on-site landfilling of RCRA treated wastes would prohibit this from being a feasible technology.

Containment technologies that have been judged to be feasible for the Area P Landfill site include:

- site capping
- immobilization by in-situ stabilization utilizing polymer or grout injection

Capping of the landfill, while technically difficult because of the slope and unstable location of waste materials, is feasible with substantial movement of the wastes and probable use of a containment wall at the foot of the waste slope. The feasibility of in-situ grout or polymer injection to immobilize waste materials, either with or without an associated chemical fixation step is somewhat questionable. The presence of large amounts of concrete rubble, very small to very large pieces of metal wastes of all types (including even a demolished truck), and other non-homogenous waste materials would make the introduction of grout or polymer through small borings extremely difficult. This technology has been retained, however, as potentially feasible.

Treatment techologies that are possible for the waste materials at Landfill P include:

- stabilization with cement or pozolonic materials and chemical fixation for barium
- ex-situ soil washing for barium
- in-situ soil flushing for barium
- in-situ bio-remediation
- downgradient surface water/alluvial water interception and treatment

Technologies that have been rejected as being unfeasible for the Area P Landfill Site include:

- vitrification - for reasons of the extensive presence of metal materials
- incineration - due to the presence of metals such as barium and lead which will not be rendered non-hazardous by incineration
- thermal desorption - which is not appropriate for materials of low volatility

4.2 Development of Remedial Alternatives

Technologies discussed in the previous section can be grouped into three areas of potential remedial alternatives. These include excavation treatments (either partial or complete), in-situ treatments, and capping and monitoring, possibly with the inclusion of surface water/alluvial ground water interception and treatment. Utilizing these groupings, ten remedial alternatives have been developed for the site. These options are listed below:

Alternative A. Excavation, segregation, partial fixation/recycle, and off-site disposal

Alternative B. Excavation, segregation, partial soil washing/recycle and off-site disposal

Alternative C. Excavation, fixation, and off-site disposal

Alternative D. Partial removal, fixation, and off-site disposal, cap and monitor remainder

Alternative E. Partial insitu stabilization (polymer/grout injection/chemical fixation), cap and monitor

Alternative F. Insitu soil flushing (leaching)

Alternative G. Insitu bioremediation

Alternative H. Downgradient surface water/alluvial ground water interception and treatment-discharge, cap and monitor

Alternative I. Cap and monitor

Alternative J. No action

Section 4.3 Comparison of Alternatives

Table 1 lists the ten remedial alternatives that have been developed for the Area P Landfill and provides rating factors for the four criteria for evaluation. The rating factors show a 0, +, or -, by each criteria to assist in the evaluation of the group of alternatives as a whole. Based on this evaluation as illustrated by Table 1, five of the ten alternatives have been judged to be not feasible. The following paragraph will provide a discussion of each non-feasible option and the reasons why there were rejected.

Alternative D involves partial removal and fixation and off-site disposal of waste materials containing barium, and capping and monitoring of the remaining portion of the Area P Landfill. This alternative was judged to not be implementable because of the uncertainty of the location of the barium-containing waste materials. Based on the previous investigations, it is apparent that barium wastes may be distributed throughout any portion of the landfill and also may have migrated into other landfill materials and underlying tuff. Therefore, the entire excavation of the waste materials would be necessary in order to find all barium-containing wastes. Additionally, segregation of barium-containing materials from non-barium materials would be extremely difficult (beyond the level of segregation of rubble and metal from soil and loose materials). Therefore, the partial removal Alternative D is rejected.

Similarly Alternative E involves partial in-situ stabilization and is rejected due to the inability to locate which waste materials should be stabilized in-situ. An additional factor disqualifying this alternative is the great difficulty in implementing either partial or complete in-situ stabilization due to the large amount of rubble and large metallic objects present in the landfill.

In-situ soil flushing, Alternative F, is judged to be unacceptable due to the possibility of enhanced risk to the environment and public health that might be caused. This alternative would require introduction of either aqueous- or solvent-based solutions into the waste material to dissolve and flush constituents of concern. This technique involves collection of introduced water or solvent from either wells through ground water withdrawal, or shallow ground water diversion devices such as infiltration galleries or collection drains. Given the complex geology of the area, there is a definite possibility that some of the introduced liquids could not be recovered. Therefore, the danger of increased mobility of waste constituents by this alternative causes this scheme to be rejected.

In-situ bioremediation, Alternative G, is also rejected due to the need to introduce liquid materials to the waste. It would be necessary to introduce

Table 1
Comparison of Remedial Alternative Criteria

Alternative	Protectiveness of the Environment and Public Health	Implementability	Long-term Effectiveness and Permanence	Cost	Relative Ranking
A	+	+	+	0	1
B	+	–	–	0	3
C	+	+	+	–	2
D	–	–	0	0	
E	–	–	–	0	
F	–	–	0	0	
G	–	–	0	0	
H	–	0	0	+	4
I	0	+	+	+	1
J	–	na	na	+	

Note: (1) Alternatives D,E,F,G and J are rejected
(2) Alternatives A and I are both equally ranked
na = not applicable

nutrient materials as well as oxygen to the wastes in place to encourage bioremediation. There is no current means of physical introduction of nutrients or oxygen other than by liquids. Therefore, this alternative is rejected as unimplementable due to the danger of encouraging the migration of constituents.

Alternative J, no action, is rejected due to the minimum requirement of RCRA site closure by capping and long-term monitoring.

Of the remaining Alternatives, (A, B, C, H, and I), Alternative I involves capping and monitoring which has previously been proposed as the RCRA closure alternative. Alternative H involves the same capping and monitoring with the addition of alluvial ground water and surface water interception downgradient of the landfill and subsequent treatment of this collected water prior to discharge to the stream. The other three alternatives involve excavation of all of the waste materials and various schemes for segregation and appropriate treatment and either on-laboratory disposal or off-site disposal of the segregated portions of the waste. Most importantly, prior to the selection of any of the above five feasible alternatives, a more thorough site characterization and determination of the resultant risk to public health and the environment should be completed to determine the relative protectiveness of the alternatives.

An order of magnitude cost estimate for each of the five feasible alternatives listed above is provided in Tables 2 through 6. Alternative C, Excavation, Fixation (of all wastes), and Off-site Disposal is the most costly feasible remedial option. The cost of this alternative is estimated at $21.8 million (present worth). Alternative I, Cap and Monitor, is the least costly feasible remedial action at a cost of $7.5 million (present worth), including a substantial 30-year monitoring plan. All cost estimates include 50% contingency allowance and 30% administrative cost for engineering, technical, and legal costs. The contingency costs are included to allow for uncertainties of waste quantities and variability of unit prices for individual treatment elements.

SECTION 5 SUMMARY AND RECOMMENDATIONS

The previously submitted RCRA closure plan recommended that the site be capped and monitored pursuant to RCRA requirements and that no other action would be necessary to ensure no migration of the waste materials. Based on the review contained in this report of the previous investigations of the site, it is believed that there is currently insufficient data to show that all of the constituents of concern that may be present in the landfill are not migrating via the two routes of exposure identified. These routes are (1) by physical transport of sediment/waste materials, and (2) by dissolved

Table 2
Alternative A
Excavate, Segregate, Partial Fixation/Recycle,
and Off-Site Disposal Alternative
TA-16 Area P Landfill

Item	Quantity	Unit Cost	Cost
Excavate and Segregate	16,000 cy*	$100/cy	$1,600,000
Fixate**	12,960 tons	$120/ton	$1,600,000
Transportation**	12,960 tons	$81/ton	$1,100,000
Tax**	12,960 tons	$35/ton	$500,000
Disposal**	12,960 tons	$120/ton	$1,600,000
Transportation and Disposal***	12,960 tons	$15/ton	$200,000
	Total Direct Cost		**$6,600,000**
	Contingency Allowance @ 50%		**$3,300,000**
	Subtotal		**$9,900,000**
	Engineering , Technical, and Legal Costs @ 30%		**$3,000,000**
	Estimated Total Cost		**$12,900,000**

*16,000 cy = 25,920 tons @ density of 120 lb/cf (3,240 lb/cy)
**Half of waste is fixated, transported, and disposed at USPCI in Salt Lake City
***Half of waste transported and disposed at local Class C landfill

Table 3
Alternative B
Excavate, Segregate, Partial Soil Washing/Recycle
and Off-Site Disposal Alternative
TA-16 Area P Landfill

Item	Quantity	Unit Cost	Cost
Excavate and Segregate	16,000 cy	$100/cy	$1,600,000
Soil Washing*	12,960 tons	$240/ton	$3,200,000
Transportation*	12,960 tons	$81/tons	$1,100,000
Tax*	12,960 tons	$35/ton	$500,000
Disposal*	12,960 tons	$120/ton	$1,600,000
Transportation and Disposal**	12,960 tons	$15/ton	$200,000
	Total Direct Cost		**$8,200,000**
	Contingency Allowance @ 50%		**$4,100,000**
	Subtotal		**$12,300,000**
	Engineering , Technical, and Legal Costs @ 30%		**$3,700,000**
	Estimated Total Cost		**$16,000,000**

*Half of waste is washed, then transported and disposed at USPCI in Salt Lake City
**Half of waste transported and disposed at local Class C landfill

Table 4
Alternative C
Excavate, Fixate, and
Off-Site Disposal Alternative
TA-16 Area P Landfill

Item	Quantity	Unit Cost	Cost
Excavate and Segregate	16,000 cy	$100/cy	$1,600,000
Fixate*	25,920 tons	$120/ton	$3,200,000
Transportation*	25,920 tons	$81/ton	$2,100,000
Tax*	25,920 tons	$35/ton	$1,000,000
Disposal*	25,920 tons	$120/ton	$3,200,000
	Total Direct Cost		**$11,100,000**
	Contingency Allowance @ 50%		**$5,600,000**
	Subtotal		**$16,700,000**
	Engineering , Technical, and Legal Costs @ 30%		**$5,100,000**
	Estimated Total Cost		**$21,800,000**

*Fixated, transported, and disposed at USPCI in Salt Lake City

Table 5
Alternative H
Down Gradient Surface Water/Alluvial Ground Water Interception and Treatment-Discharge, Cap and Monitor Alternative
TA-16 Area P Landfill

Item	Quantity	Unit Cost	Cost
Cap and Monitor		TDC from Alternative I	$3,800,000
Construct Interception System (assuming 10 gpm)	1	$500,000	$500,000
Construct Treatment System	1	$400,000	$400,000
Ground Water Treatment Operation and Maintenance			
Labor	1,460 hr/yr	$30/hr	($44,000/yr)
Utilities/Chemicals		$20,000/yr	($20,000/yr)
Sludge Disposal	4 tons/yr	$500/ton	($2,000/yr)
		O & M Annual Total:	($66,000/yr)
		30-Year O & M Total*:	$1,100,000
	Total Direct Cost		**$5,800,000**
	Contingency Allowance @ 50%		**$2,900,000**
	Subtotal		**$8,700,000**
	Engineering , Technical, and Legal Costs @ 30%		**$2,700,000**
	Estimated Total Cost (present worth)		**$11,400,000**

* Annual costs multiplied by Present Worth Factor (15.372, 30 yr, 5%)

Table 6
Alternative I
Cap and Monitor
Alternative
TA-16 Area P Landfill

Item	Quantity	Unit Cost	Cost
Stabilize Landfill and Slope		$250,000	$250,000
Install RCRA Cap	88,000 sq ft*	$5.00/sq ft	$440,000
Monitor Ground Water, Surface Water, and Vadose Zone ; Sampling and Reporting	100 samples/yr	$1,000/sample $100,000/yr	($100,000/yr) ($100,000/yr)
		Monitoring Annual Total: 30-Year Monitoring Total**:	($200,000/yr) $3,100,000

Total Direct Cost	**$3,800,000**
Contingency Allowance @ 50%	**$1,900,000**
Subtotal	**$5,700,000**
Engineering , Technical, and Legal Costs @ 30%	**$1,800,000**
Estimated Total Cost (present worth)	**$7,500,000**

*Two-acre site is approximately 88,000 sq ft (1 acre = 43,560 ft)
** Annual costs multiplied by Present Worth Factor (15.372, 30 yr, 5%)

contaminant transport via water. The data that has been taken is focused largely on barium and little or no data has been collected to show whether or not migration of lead and HE materials is occurring. Also, the potential migration of beryllium or radiological materials, if they are present in the waste, has not been disproven because these constituents have not been analyzed in samples of site materials.

The McLin report of August 1989 supports these conclusions. This report additionally goes on to make recommendations, most of which are believed to still be applicable. These recommendations include the collection of additional data to enable a decision concerning closure/remedial alternatives to be made with more certainty of permanence. The recommendations from the McLin report include:

- the installation of additional lysimeters based on moisture measurements taken from existing neutron moisture access wells.

- soil column leaching studies on sample waste materials, including waste barium sands.

- two-and three-dimensional vadose zone flow modeling studies to assist in the evaluation of alternative landfill cover designs.

- the installation of additional vadose zone monitoring wells through the landfill and into the shallow tuff to supplement the existing monitoring well network. Also additional vadose zone monitoring wells should be installed in the floor of Canon de Valle immediately north of the landfill.

Many of these above recommendations are still applicable. The installation of additional wells through the landfill waste materials may not be required; however, a better understanding of whether liquid-born contaminants are entering the tuff materials outside of the area of the landfill should be gained.

In summary, a better understanding of whether any of the contaminants of concern are migrating in surface water/alluvial groundwater must be made in order to make a correct decision on site closure. It is likely that the contaminants of concern are not migrating through either route of exposure in sufficient quantities to cause unacceptable risk to the environment or human health. If this can be determined to be the case, capping and monitoring the site may be an acceptable closure. The purpose of the capping would be to further limit infiltration and to remove the pathway of physical erosion of waste materials. It is possible, however, after additional sampling and analysis, that some migration of waste constituents may be occurring. If this is the case, modeling will be able to determine what type

of cap, if any, can limit this migration sufficiently so that no significant environmental degradation will occur. Until additional data collection and monitoring are accomplished, the efficacy and permanence of the cap as an ultimate remediation for the site cannot be accurately determined. Therefore, it is prudent to include the Area P Landfill in the RFI process for Operable Unit 1082. Thus, in a two to three year period, sufficient site characterization data will be obtained to make a more accurate decision on the choice between site closure by capping and monitoring or one of the three removal options.

References

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APPENDIX F

Appendix J: SCREENING ASSESSMENT METHODOLOGY

DRAFT

1.0 Introduction

Screening assessment is performed at LANL to identify the presence of contaminants of concern at a particular PRS. Contaminants of concern are constituents whose concentration levels in one or more environmental medium are above a level of concern defined by media-specific screening action levels (SALs). The screening assessment begins with the identification of potential constituents and environmental media of concern based on knowledge of the history and processes that occurred at a PRS. Existing or new environmental data collected during the RFI are then compared to SALs for the identified constituents.

The principal test carried out during the screening assessment is the comparison of sampling data with SALs. If SALs are not exceeded, then the PRS may be recommended for no further action (NFA). If SALs are exceeded, then further evaluation, either statistical or sampling, is required at the PRS. However, some additional screening evaluation may be required if two or more constituents are present to determine the potential for combined effects. Where SALs are less than background concentrations, comparison of constituent concentrations to background distributions are performed as an additional step in screening assessment (see Appendix H).

This appendix presents the methodology used to derive radiological and nonradiological SALs at the Laboratory. The laboratory's approach to handling multiple constituents is also presented.

2.0 Screening Action Levels for Nonradiological Constituents

Proposed Corrective Action for Solid Waste Management Units (Subpart S) to the Resource Conservation and Recovery Act (RCRA) (EPA 1990, 0432) presents a methodology for calculating action levels to determine the need for further evaluation of contamination in various environmental media (i.e., groundwater, surface water, air, and soil). The action levels are calculated using chemical-specific toxicity values and default exposure parameters. In order to comply with the Hazardous and Solid Waste Amendments (HSWA) Module for Los Alamos National Laboratory (the Laboratory), screening action levels (SALs) have been developed that follow the Subpart S methodology for exposure parameter defaults, but that incorporate more recent toxicity values available from the Environmental Protection Agency's (EPA's) Integrated Risk Information System (IRIS) data base (EPA 1992, 0830) and Health Effects Assessment Summary Tables (HEAST) (EPA 1992, 0833).

A plan for evaluating data is needed before any data are collected in order to ensure that the data will be adequate for comparison with SALs and for

possible subsequent human health risk assessment. For example, detection limits need to be lower than SALs to permit adequate comparisons. Details of appropriate data evaluation steps, both before and after data are obtained, are currently under development and will be provided in other sections and appendixes of this IWP.

In Sections 2.1 and 2.2, the assumptions and equations for calculating nonradiological constituent SALs for soil, groundwater, surface water, and air are presented. Section 2.3 discusses the evaluation of multiple constituents present in a single environmental medium. Section 2.4 discusses an interim methodology which is used to derive SALs when subchronic or chronic toxicological data is lacking in IRIS or HEAST EPA databases. Section 2.5 addresses the derivation of SALs for other media or substances that may be present in various operable units at the Laboratory. Section 3.0 presents the SALs for radiological constituents.

2.1 Assumptions

The SAL values presented in Table J-1 are based on the methodology presented under proposed Subpart S (EPA 1990, 0432) and on toxicity values (i.e., reference doses and carcinogenic slope factors) from the IRIS data base (EPA 1992, 0830) or the HEAST (EPA 1992, 0833). The constituents included in Table J-1 are those of the EPA's Target Analyte List (EPA 1991, 0778) and Target Compound List (EPA 1991, 0779). Uranium has also been added to the list because it may have significant chemical toxicity in addition to effects associated with its radiological activity. Other constituents may need to be added as the results of site characterization become available. Table J-1 will be updated on an annual basis to reflect any modified toxicity values.

The SALs are based on the following assumptions and equations contained in proposed Subpart S:

1. In deriving soil SALs that consider systemic (i.e., noncarcinogenic) effects, a child's daily intake is modeled in oreder to take the most conservative approach. A soil ingestion rate of 200 mg/day by a 16-kg child is assumed. Intake is assumed to occur 365 days/yr.

   For carcinogenic constituents in soil, the long-term exposure of an adult is modeled. A soil ingestion rate of 100 mg/day by a 70-kg adult is assumed. Intake is assumed to occur 365 days/yr over a 70-yr exposure duration.

2. A modification to the Subpart S methodology has been introduced to account for exposure to organic compounds volatilizing from potentially contaminated soil. The modification is applied to account for potential inhalation exposure, as presented in more recent EPA

guidance for the calculation of preliminary remediation goals (PRG) (EPA 1991, 0302). Because SALs for volatile substances calculated using this modified approach are lower (i.e., more conservative) than those calculated using the unmodified Subpart S method, this approach has been selected for use in the Laboratory's Environmental Restoration Program. For the purpose of calculating SALs, volatile constituents are defined as those with molecular weight less than 200 and Henry's Law Constant greater than 1×10^{-5} atm/m^3-mole (EPA 1991, 0302).

The equation for calculating SALs for volatile constituents has been expanded to account for potential inhalation exposure (equation below). The soil-to-air volatilization factor was calculated based on an equation given by EPA (1991, 0302) and chemical-specific parameters (Strenge and Peterson 1989, 0777; EPA 1988, 0747). The default particulate emission factor was used in SAL calculations for volatile constituents to maintain consistency with the equation given in the PRG guidance document (EPA 1991, 0302), although this factor is so low that it does not impact the calculated SALs. The SAL calculation for volatile constituents with systemic effects models exposure of a 16-kg child with a soil ingestion rate of 200 duration, with a soil ingestion rate of 100 mg/day and an inhalation rate of 20 m^3/day.

3. In deriving SALs for constituents in water, the ingestion rate is assumed to be 2 L/day of water by a 70-kg adult. Exposure is assumed to occur 365 days/yr over a 70-yr exposure duration. These SALs apply both to groundwater and to surface water constituents.

4. In deriving SALs for constituents in air, the inhalation rate is assumed to be 20 m^3/day by a 70-kg adult. Exposure is assumed to occur 365 days/yr over a 70-yr exposure duration.

5. Proposed Subpart S specifies the use of maximum contaminant levels (MCLs) promulgated under the Safe Drinking Water Act as action levels for groundwater constituents. Subpart S also indicates that state water quality standards established pursuant to the Clean Water Act, Section 303c will be used as action levels for surface water constituents when these standards have been established for the surface water body in question. When numeric water quality standards have not been established by the state, Subpart S specifies that MCLs will be used as action levels, if the surface water has been designated as a drinking water source by the state.

Federal MCLs and State groundwater standards are presented in Table J-2. In keeping with Subpart S instructions, when the MCL value or State groundwater standard are not available, the value calculated using the specified exposure assumptions for water (Number 3 above) will be used as

the SAL for chemicals. Although not specifically stated, it is consistent with Subpart S to use the same SAL criteria for both groundwater and surface water constituents. For surface water constituents, these criteria may be more stringent than required because the state has not designated the surface waters to be evaluated as drinking water sources.

A summary table of soil, water and air screening action levels used at LANL is shown in Table J-3.

2.2 Equations

2.2.1 General Equations for Calculating SALs

2.2.1.1 Systemic Toxicants

(2.1)

where:

SAL	=	SAL: mg/kg for soil SALs, μg/L for water SALs, μg/m^3 for air SALs
THI	=	target hazard index: 1
RfD	=	chronic reference dose (mg/kg/day): oral RfD used for soil and water SALs, inhalation RfD used for air SALs
B W	=	body weight: 16 kg for child (for soil SALs), 70 kg for adult (for water and air SALs)
CF	=	conversion factor: 10^6 mg/kg for soil SALs, 10^3 μg/mg for water and air SALs
I	=	intake rate: 200 mg/day for soil SALs, 2 L/day for water SALs, 20 m^3/day for air SALs
A	=	absorption factor: 1.

2.2.1.2 Carcinogenic Constituents

(2.2)

where:

R	=	target risk: 10^{-6} for Class A and B carcinogens, 10^{-5} for class C carcinogens
B W	=	body weight: 70 kg
LT	=	assumed lifetime: 70 yr
CF	=	conversion factor: 10^6 mg/kg for soil SALs, 10^3 μg/mg for water and air SALs
SF	=	slope factor (mg/kg/day)$^{-1}$: oral SF used for soil and water SALs; inhalation SF used for air SAL
I	=	intake rate: 100 mg/day for soil SALs, 2 L/day for water SALs, 20 m^3/day for air SALs

A = absorption factor: 1
ED = exposure duration: 70 yr.

2.2.2 Equations for Calculating Soil SALs for Volatile Constituents

2.2.2.1 Systemic Toxicants

SAL = (2.3)

where:

THI = target hazard Index: 1
BW = body weight: 16 kg
RfD_o = chronic oral reference dose: mg/kg/day
ING = soil ingestion rate: 200 mg/day
RfD_i = chronic inhalation reference dose: mg/kg/day
INH = inhalation rate: 20 m^3/day
VF = soil-to-air volatilization factor (chemical-specific): m^3/kg, calculated using equation given by EPA (1991 0302) and chemical-specific parameters (Strenge and Peterson 1989, 0777; EPA 1988, 0747).
PEF = particulate emission factor: 4.63×10^9 m^3/kg (EPA 1991, 0302).

2.2.2.2 Carcinogenic Constituents

SAL = (2.4)

where:

R = target risk: 10^{-6} for Class A and B carcinogens, 10^{-5} for Class C carcinogens
BW = body weight: 70 kg
LT = assumed lifetime: 70 yr
ED = exposure duration: 70 yr
SF_o = oral slope factor $(mg/kg/day)^{-1}$
ING = soil ingestion rate: 100 mg/day
SF_i = inhalation slope factor $(mg/kg/day)^{-1}$
INH = inhalation rate: 20 m^3/day
VF and PEF as defined above.

2.4 Derivation of SALs When Lacking Toxicological Data

When SALs are needed for specific noncarcinogenic contaminant evaluation and comparison but the compound of interest does not have adequate

chronic toxicological information, an interim conservative estimated value will be derived using an extrapolation from acute toxicological data. As explained in the previous sections of this appendix, SALs are derived using the EPA's Health Effect Assessment Summary Tables (HEAST) or Integrated Risk Information System (IRIS) databases that carry toxicological information substantiating the EPA's development of a toxicological reference dose (RfD) for noncarcinogens or a cancer slope factor for carcinogens.

If toxicological information is either inadequate or nonexistent for the development of a RfD for noncarcinogens in the EPA's databases, a method using more widely available acute oral toxicity data to estimate chronic oral RfDs have been suggested in peer reviewed literature (Layton, et al. 1987; Venman and Flaga 1985). Layton, et al. suggest multiplying oral acute LD50 values (dose lethal to 50% of the tested animals expressed in mg toxicant/kg animal weight) by a factor in the range of $5x10^{-6}$ to $1x10^{-5}$ day^{-1} to convert to an estimated chronic oral RfD value. The lower range of the conversion factors suggested by Layton et al. will be used with an assumption that a 16 kg child will incidentially ingestion soil at a rate of 200 mg/kg-day. This estimation has been shown to give an oral RfD value below the EPA RfD value 95% of the time.

Derivation of SALs lacking toxicity data will be done only for compounds that are estimated to be a human risk via the ingestion pathway and is not likely to have a significant inhalation pathway risk effect. SALs derived in this manner will serve as interim values until approved by the EPA.

2.5 Derivation of SALs for Other Media or Substances

Values analogous to SALs may be needed for evaluating substances that involve unique exposure considerations (e.g., structural surfaces and debris, shrapnel, high explosives, asbestos). The methods that will be used to evaluate these substances are discussed in the following paragraphs.

2.5.1 Structural Surfaces and Debris

Proposed Subpart S does not provide guidance on the derivation of SALs for potentially contaminated structural surfaces or debris (e.g., concrete, wood). These values may be needed for evaluating unused buildings. Plausible exposure routes for structural materials (i.e., demolition debris) that are currently buried or at the land surface are through human contact with the surrounding media (e.g., soil, water, air) because easily removable constituents would already have been released as the result of weathering processes. Therefore, nonradiological contamination from exposed and buried structural debris can be evaluated by comparing SALs with constituent

levels in surrounding media. Appropriate SALs are being developed for sediments and liquids present in buried pipes and tanks.

The structural surfaces of unused buildings may contain removable nonradiological constituents because these surfaces have not been subjected to weathering processes. SALs for these structural surfaces may be derived using wipe test data and appropriate assumptions on dust resuspension rates, inhalation and ingestion rates, and exposure period. These SALs for structural surfaces will be derived on an as-needed basis when characterization data become available.

2.5.2 High Explosives and Asbestos

Special consideration is needed for shrapnel and unexploded high explosives that are present in some operable units. The primary health hazard associated with these materials is damage by explosion. Toxicity from chemicals that might be released from these materials will be evaluated for individual constituents using appropriate SALs for soil, water, air, and structural surfaces. SALs for some high explosives and constituents of high explosives known to have been used at LANL, and for which toxicity data exists, are presented in Table J-3. (Toxicity data for high explosives are listed under semi-volatile organics of Table J-1). SALs for high explosives were developed using Subpart S methodology. The work plans for individual operable units will address characterization of sites with respect to shrapnel and high explosives, as needed.

Another special substance that will need criteria for screening decisions is asbestos. The SAL approach developed for evaluating most other constituents will not be appropriate for asbestos; criteria consistent with federal and state guidance is being sought for evaluation of asbestos-contaminated soils.

3.0 Screening Action Levels for Radioactive Constituents

As described above, screening action levels for many RCRA-regulated non-radioactive constituents have been recommended in, and derived using, the Subpart S regulations. However, radioactive compounds are not regulated under RCRA and Subpart S regulations do not address radioactive constituents. To ensure that radioactive compounds and non-radioactive compounds are addressed similarly and to simplify the integration of the RCRA, DOE, and CERCLA requirements for radioactive compounds, screening action levels similar to those recommended in proposed Subpart S have been developed for radioactive compounds.

3.1 Rationale for Deriving SALs for Radioactive Constituents in Soils

In developing screening action levels for radioactive constituents, it is necessary to consider all relevant and applicable standards for the protection of human health. For radionuclides in the environment, regulatory guidance assumes that the protection standards that govern human health generally protect other biotic species (NCRP 1991; IAEA 1992). The limits of radiation exposure to humans is governed by listing an upper bound of a radiation dose established in the radiation protection standards which corresponds to an acceptable health risk. The upper bounded radiation dose limit cannot be exceeded but may be reduced by using health physics principles and DOE guidance of "As Low As Reasonably Achievable Principle" (ALARA).

Because current radiation protection standards (EPA 1991a,b) are based on radiation dose limits rather than corresponding cancer slope factors or risk levels as are other Subpart S non-radioactive compounds, the development of radioactive compounds' screening action levels is dependent upon radiation dose levels considered as "acceptable" standards to individuals in the general public. The national and international radiation communities and DOE (NCRP 1988; ICRP 1990; DOE 1990) have set a limit of 100 millirems/year (mrem/yr) as a maximum acceptable dose to individuals in the general public to radiation exposure from all contaminant pathways, radionuclides, and exposure sources. Radiation dose to the public is further limited to 25 mrem/yr from individual facilities or sources (e.g. DOE 1988; EPA 1977). The general public radiation dose limits apply to cumulative exposure from multiple radioactive constituents through multiple pathways, whereas non-radioactive compounds SALs in Subpart S have been derived for a single contaminant via a single exposure pathway.

A screening action level for radionuclides in soils at Los Alamos National Laboratory has been proposed at an annual dose limit of 10 mrem/yr (above natural background levels) from a single radioactive constituent via all pathways for radionuclides that do not have media specific concentration limits specified in other regulatory statutes (e.g. MCLs).

The conservative proposed dose level limit of 10 mrem/yr was chosen as a screening level due to the following rationale (presented in full in Chapter 4, Section 4.2.2.2):

- Fraction of 100 mrem/yr and 25 mrem/yr regulatory standards;
- Specified in DOE Order 5400.5 (DOE 1990) as a reporting level;
- Compatible with the detection limits for current field instruments; and
- Discernible from background radiation (see Table J-4) in the U.S.

The proposed 10 mrem/yr limit, however, may not be implemented entirely as the Subpart S action levels for non-radiological constituents are implemented. Characterization of radioactive constituents would require the consideration of DOE health physics ALARA practices before reaching a NFA decision even if the contamination levels were below specific radionuclide screening action levels.

3.2 SALs for Radioactive Constituents in Soil

Preliminary screening action levels have been derived for several radionuclides that may be encountered in contaminated soils at LANL (Table J-5). The following methodology and assumptions were used in deriving the screening action levels:

- The RESRAD computer code (Gilbert, et al. 1989), version 4.6, was used in the computational derivation of the values. This code is the DOE choice of methodology required by DOE Order 5400.5 to be used in the derivation of radionuclide soil cleanup criteria at DOE sites;

- A residential scenario was used in the derivation of each radionuclide SAL and included the following pathways: a) external exposure from gamma emitters in soil; b) inhalation of contaminated dust and radon gas; c) ingestion of contaminated soil and plants grown on the site; and d) consumption of municipal water which is not contaminated due to the great depth of the main aquifer in Los Alamos. Other site specific scenarios such as industrial or recreational users may be used but screening action levels will not be calculated for these less conservative exposure scenarios;

- The input data used in the RESRAD calculations typify the range of soil concentrations encountered on the Los Alamos National Laboratory mesa top environment (Dorries 1992; 1993). The contaminated soil is assumed to extend down to 3m from the surface and cover an area of 500 m^2. When site specific data were not available, default values were used in the model (Gilbert, et al. 1989). These default values were derived from both national and LANL soil-type averages by Gilbert, et al.

Screening action levels are to be used only for screening assessments and are not to be used in baseline risk assessments or as cleanup criteria in a corrective measures study or corrective remediation implementation. If results of the screening assessment show that the specific levels are exceeded, more site specific data and analysis may be indicated and/or required.

3.3 SALs for Radioactive Constituents in Water

Screening action levels for radionuclides in water are based on 40 CFR 141 regulations that govern maximum contaminant levels in community drinking water supplies (CFR 1991). For alpha emitting radionuclides 40 CFR 141.15 states that:

a) The combined maximum contaminant level for Ra^{226} and Ra^{228} is 5 pCi/L; and,
b) The maximum contaminant level for gross alpha activity (including Ra^{226} but excluding radon and uranium) is 15 pCi/L.

For beta and gamma emitting radionuclides, 40 CFR 141.16 states that:

a) Average annual concentrations of beta particle and gamma radioactivity from man-made radionuclides in drinking water shall not produce an annual dose equivalent to the total body or any internal organ greater than 4 mrem/yr (above background); and,
b) Except for H^3 and Sr^{90}, the concentration of man-made radionuclides causing 4 mrem total body or organ dose equivalents shall be calculated on the basis of a 2 liter per day water intake using the 168 hour data listed in "Maximum Permissible Body Burdens and Maximum Permissible Concentrations of Radionuclides in Air or Water for Occupational Exposure", NBS Handbook 69 (limits in Table A of 40 CFR 141.16 are 20,000 pCi/L for H^3 and 8 pCi/L for Sr^{90}). If two or more radionuclides are present, the sum of their annual dose equivalent to the total body or to any organ shall not exceed 4 mrem/yr (above background).

The referenced NBS Handbook 69 contains dose conversion factors based on the whole body/critical organ dose methodology in ICRP 2 (ICRP 1959). This ICRP 2 methodology is no longer current; it has been replaced by ICRP 26 and 30 (ICRP 1977; 1979) and, more recently, by ICRP 60 (ICRP 1990). The current guidance and methodologies are based on the concept of effective dose equivalents, which uses organ weighting factors to assess the equivalent dose to the whole body. The ICRP methodology has been incorporated in EPA's Federal Guidance Report No. 11 (EPA 1988) which tabulates dose conversion factors for intakes of radionuclides. The Federal Guidance Report No. 11 is currently used to derived the SALs for radionuclides in water at LANL.

The effective dose equivalent factors contained in this document are

consistent with the dose conversion factors published by DOE (DOE 1988) and EPA (EPA 1988). The following calculations are used to derive concentration limits of radionuclides for water that may be present at LANL. Limits for other radionuclides may be derived using the methodology discussed below.

For beta and gamma emitting radionuclides, the yearly dose limit of 4 mrem/yr is converted to a SAL by dividing the annual dose limit by the water intake rate and effective dose equivalent factor, as shown below:

$$\mathrm{SAL} = \frac{DL \times 10^6}{IR \times DCF_{b-g}} \tag{2.5}$$

where:

SAL	=	Screening Action Level for beta-gamma emitters in pCi/L;
DL	=	Annual dose limit of 4 mrem/yr;
10^6	=	Conversion factor, pCi/μCi;
IR	=	Water intake rate of 2 L/day or 730 L/yr;
$DCF_{\beta-\gamma}$	=	Ingestion effective dose equivalent factor for beta-gamma emitters, mrem/μCi (DCFs for ingestion are listed in Table 2.2 of Federal Guidance Report 11 in units of Sv/Bq. To convert to mrem/μCi, these values were multiplied by 3.7×10^9).

Alpha-emitting radionuclides have a 15 pCi/L limit which include the contributions from Ra^{226} and its daughter compounds but excludes uranium and radon isotopes. However, for Ra^{226} and Ra^{228} (Ra^{226} + Ra^{228}), 5 pCi/L is the limit. Uranium is specifically exempted from consideration in 40 CFR 141.15(b), but limits for uranium isotopes can be derived based on the 4 mrem/yr method used for beta-gamma emitters.

Derived water SALs for radionuclide constituents are presented in Table J-5.

4.0 Addressing Multiple Constituents

Proposed Subpart S does not address the evaluation of several constituents with concentrations close to, but below, SALs in a single environmental medium. To address, this concern, and in keeping with the philosophy that screening assessment corresponds to comparison of observed concentrations to an action level concentration, a simple method based on normalized concentrations is presented in this Section. Although the basic methods are the same for the three groups of constituents considered (systemic toxicants, carcinogens, and radionuclides), these groups must be considered separately to account for their differing risk effects.

The underlying idea is based on a concept of concentration data normalized by SALs.

SALs for all constituents are normalized to one, such that concentration data can be treated as proportions of the respective SALs. For PCOCs that record concentrations close to, but below, SALs, this proportion will be close to one. If the sum of proportions for the different PCOCs within a single sample, is greater than one, then the effect of the multiple constituents is considered adverse and further action may be taken. Otherwise, No Further Action will be proposed.

This method is fully consistent with the comparison of observed concentrations to the SAL for a single constituent. If the single constituent has a maximum concentration greater than its SAL, then the equivalent normalized maximum concentration will be greater than one.

For any particular group of constituents the following decision rule can be applied:

> If the maximum observed cumulative normalized observed concentration from a single sample is less than one, then propose No Further Action. Otherwise, propose further action.

The following formula is used to determine the appropriate normalized sum to apply in the decision rule, where "M" represents the maximum sum of the normalized concentrations:

$$M = \max_{samples} \left\{ \sum_{\text{PCOCs}} {C_i}/{SAL_i} \right\} \tag{2.5}$$

The maximum is taken over all samples, such that the normalized sum of concentrations represents concentration data from within a single sample. The decision rule is restated in terms of a comparison of the maximum normalized sum of concentrations ("M") to one.

The choice of PCOCs to include in the calculation also needs to be addressed. If all PCOCs are included, then exceedance is very likely. However, it may not be reasonable to include PCOCs for which observed concentrations are very low compared to their respective SALs.

One basis for determining the list of PCOCs to include in an analysis that uses Equation (2.5) is to compare observed concentrations to the respective background distributions. If a difference is observed, then that PCOC should be included. This basis is not as conservative as it may, at first, appear, since differences between observed concentration distributions and background distributions are only likely if there are some observed concentrations that are considerably greater than the normal range of background. A further advantage of tying the list of PCOCs to include in the calculation to background comparisons is that it provides a rationale basis for inclusion.

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TABLE J-1

SCREENING ACTION LEVELS FOR CHEMICAL ANALYTES IN SOIL, WATER, AND AIR FOR ENVIRONMENTAL CHARACTERIZATION OF LOS ALAMOS NATIONAL LABORATORY[a]

Chemicals[b]	Chronic Oral RfD mg/kg-day	Oral Slope Factor $(mg/kg\text{-}d)^{-1}$ and Group[c]	Chronic Inhalation RfD mg/kg-d	Inhalation Slope Factor $(mg/kg\text{-}d)^{-1}$ and Group[c]	VF[k] m^3/kg	Soil Screening Action Level Systemic Toxicant mg/kg	Soil Screening Action Level Carcinogen mg/kg	Water Screening Action Level Systemic Toxicant µg/l	Water Screening Action Level Carcinogen µg/l P	Air Screening Action Level Systemic Toxicant $\mu g/m^3$	Air Screening Action Level Carcinogen $\mu g/m^3$	CRQL[d] mg/kg and µg/l
Inorganics												
Aluminum[e], 7429-90-5												40, 200
Antimony, 7440-36-0	0.0004					32		14				12, 60[g]
Arsenic, 7440-38-2	0.0003	1.75, A		15, A		24	0.40	11	0.02		0.00023	2, 10[g]
Barium, 7440-39-3	0.07		0.00014[f]			5,600		2,400		0.49		40, 200
Beryllium, 7440-41-7	0.005	4.3, B2		8.4, B2		400	0.16	170	0.0081		0.00042	1, 5[g]
Cadmium, 7440-43-9	0.001[m]			6.3, B1		80		35			0.00056	1, 5
Calcium[e], 7440-70-2												1000, 5000
Chromium III, 16065-83-1	1.0					80,000		35,000				2, 10
Chromium VI, 7440-47-3	0.005			42, A		400		170			0.000083	2, 10
Cobalt[e], 7440-48-4												10, 50
Copper, 7440-50-8	0.037[f]					3,000		1,300				5, 25
Cyanide, 57-12-5	0.02	ND, D		ND, D	8.2e+03	1,600		700				2, 10
Iron[e], 1543-83-10												20, 100
Lead[e], 7439-92-1		ND, B2		ND, B2								0.6, 3
Magnesium[e], 7786-30-3												1000, 5000

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Manganese, 7439-96-5	0.1	ND, D	0.00011	ND, D		8,000		3,500		0.39		3, 15
Mercury, 7439-97-6	0.0003[f]	ND, D	8.6e-5[f]	ND, D		24		11		0.30		0.04, 0.2
Nickel, 7440-02-0	0.02			0.84, A		1,600		700			0.0042	8, 40
Nitrate	1.6[q]					130,000						
Nitrite, 14797-65-0	0.1					8,000						
Potassium[e], 7447-40-7												1000, 5000
Selenium, 7782-49-2	0.005	ND, D		ND, D		400		170				1, 5
Silver, 7440-22-4	0.005					400		170				2, 10
Sodium[e], 7647-14-5												1000, 5000
Thallium, 7440-28-0	0.00008 n					6.4		2.8				2, 10[g]
Uranium[b], 7440-61-1	0.003					240		100				
Vanadium, 7440-62-2	0.007[f]					560		240				10, 50
Zinc, 7440-66-6	0.3	ND, D		ND, D		24,000		10,000				4, 20

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Volatile Organic Compounds												
Acetone, 67-64-1	0.1				1.4e+04	8,000		3,500				0.01, 10
Benzene, 71-43-2		0.029, A		0.029, A	5.7e+03		0.67[h]		1.2		0.12	0.01, 10[g]
Benzoic acid, 65-85-0	4					320,000		140,000				
Bromodichloromethane, 75-27-4	0.02	0.062, B2		ND, B2	8.0e+02	1,600	11	700	0.56			0.01, 10[g]
Bromoform, 75-25-2	0.02	0.0079, B2		0.0039, B2		1,600	89	700	4.4		0.90	0.01, 10[g]
Bromomethane, 74-83-9	0.0014	ND, D	0.0014	ND, D	3.9e+02	0.43[h]		49		4.9		0.01, 10
2-Butanone (Methyl ethyl ketone), 78-93-3	0.6	ND, D	0.29	ND, D	1.9e+04	4,000[h]		1,700		1,000		0.01, 10
Carbon disulfide, 75-15-0	0.1		0.0029[f]		3.2e+03	7.4[h]		3,500		10		0.01, 10
Carbon tetrachloride, 56-23-5	0.0007	0.13, B2		0.053, B2	3.3e+03	56	0.21[h]	25	0.27		0.066	0.01, 10[g]
Chlorobenzene, 108-90-7	0.02	ND, D	0.0057[f]	ND, D	1.5e+04	67[h]		700		20		0.01, 10
Chloroethane, 75-00-3			2.9		1.4e+03	3,300[h]				10,000		0.01, 10
Chloroform, 67-66-3	0.01	0.0061, B2		0.081, B2	4.8e+03	800	0.21[h]	350	5.7		0.043	0.01, 10[g]

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Chloromethane, 74-87-3		0.013, C[f]		0.0063, C[f]	1.2e+03		6.4[h]		27		5.6	0.01, 10
Dibromochloromethane, 124-48-1	0.02	0.084, C		ND, C		1,600	83	700	4.2			0.01, 10[g]
1,1-Dichloroethane, 75-34-3	0.1[f]	ND, C	0.14[f]	ND, C	3.8e+03	410[h]		3,500		500		0.01, 10
1,1-Dichloroethene, 75-35-4	0.009	0.6, C		0.12, C	2.1e+03	720	0.59[h]	310	0.58		0.29	0.01, 10[g]
1,2-Dichloroethane, 107-06-2		0.091, B2		0.091, B2	5.5e+03		0.20[h]		0.38		0.038	0.01, 10[g]
1,2-Dichloroethene (total), 540-59-0	0.01[f,i]				4.6e+03	800		350				0.01, 10
1,2-Dichloropropane, 78-87-5		0.068, B2[f]	0.0011	ND, B2[f]	7.1+03	6.5[h]	10		0.51	4.0		0.01, 10[g]
cis-1,3-Dichloropropene, 10061-01-5	0.0003	0.18, B2[f]	0.0057	0.13, B2[f]	6.8+03	14[h]	0.17[h]	11	0.19	20	0.027	0.01, 10[g]
trans-1,3-Dichloropropene, 10061-02-6	0.0003	0.18, B2[f]	0.0057	0.13, B2[f]	6.8+3	14[h]	0.17[h]	11	0.19	20	0.027	0.01, 10[g]
Ethyl benzene, 100-41-4	0.1	ND, D	0.29	ND, D	2.2e+04	3,100[h]		3,500		1000		0.01, 10
n-Hexane, 110-54-3	0.06[f]					4,800		2,100				
2-Hexanone[e], 591-78-6					5.5e+04							0.01, 10
Methanol, 67-56-1	0.5					40,000		18,000				
4-Methyl-2-pentanone (MIK), 108-10-1	0.05[f]		0.023[f]		3.2e+04	510[h]		1,700		80		0.01, 10

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Methylene Chloride, 75-09-2	0.06	0.0075, B2	0.86[f]	0.0016, B2	2.9e+03	1,400[h]	5.6[h]	2,100	4.7	3000	2.2	0.01, 10[g]
Styrene, 100-42-5	0.2				1.8e+04	16,000		7,000				0.01, 10[g]
1,1,2,2-Tetrachloroethane, 79-34-5		0.2, C		0.2, C	2.9e+04		3.9[h]		1.8		0.18	0.01, 10[g]
Tetrachloroethene, 127-18-4	0.01	0.052, B-C[o]		0.002, B-C[o]	6.0e+03	800	5.9[h]	350	0.67		1.8	0.01, 10[g]
Toluene, 108-88-3	0.2	ND, D	0.40	ND, D	1.1e+04	890[h]		7,000		380		0.01, 10
1,1,1-Trichloroethane, 71-55-6	0.09[f]	ND, D	0.29[f]	ND, D	5.1e+03	1,000[h]		3,100		1,000		0.01, 10
1,1,2-Trichloroethane, 79-00-5	0.004	0.057, C		0.056, C	1.1e+04	320	6.3[h]	140	6.1		0.63	0.01, 10[g]
Trichloroethene, 79-01-6		0.011, B-C[o]		0.006, B-C[o]	5.8e+03		3.2[h]		3.2		0.58	0.01, 10[g]
Vinyl Chloride, 75-01-4		1.9, A[f]		0.294, A[f]	1.1e+03		0.013[h]		0.018		0.012	0.01, 10[g]
Xylenes (Total), 1330-20-7	2				9.6e+03	160,000		70,000				0.01, 10

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Semi-Volatile Organic Compounds												
Acenaphthene, 83-32-9	0.06				3.4e+05	4,800		2,100				0.33, 10
Acenaphthylene[e], 208-96-8					6.1e+04							0.33, 10
Anthracene, 120-12-7	0.3	ND, D		ND, D	1.8e+05	24,000		10,000				0.33, 10
Benzo[a]anthracene[e], 56-55-3		ND, B2		NA, B2								0.33, 10
Benzo[b]fluoranthene[e] 205-99-2		ND, B2		ND, B2								0.33, 10
Benzo[k]fluoranthene[e], 207-08-9		ND, B2		ND, B2								0.33, 10
Benzo[ghi]perylene[e], 191-24-2		ND, D		ND, D								0.33, 10
Benzo[a]pyrene, 50-32-8		7.3, B2		6.1, B2[f]			0.10		0.0048		0.00057	0.33, 10[g]
alpha-BHC, 319-84-6		6.3, B2					0.1		0.0056			
beta-BHC, 319-85-7		1.8, C					4		0.19			
Bis(2chloroethoxy)methane[e], 111-91-1		ND, D		ND, D								0.33, 10
Bis-(2-chloroethyl)ether, 111-44-4		1.1, B2		1.1, B2	4.9e+04		0.13[h]		0.032		0.0032	0.33, 10[g]

Chemicals[b]	Chronic Oral RfD mg/kg-day	Oral Slope Factor (mg/kg-d)$^{-1}$ and Group[c]	Chronic Inhalation RfD mg/kg-d	Inhalation Slope Factor (mg/kg-d)$^{-1}$ and Group[c]	VF[k] m^3/kg	Soil Screening Action Level Systemic Toxicant mg/kg	Soil Screening Action Level Carcinogen mg/kg	Water Screening Action Level Systemic Toxicant µg/l	Water Screening Action Level Carcinogen µg/ P	Air Screening Action Level Systemic Toxicant µg/m^3	Air Screening Action Level Carcinogen µg/m^3	CRQL[d] mg/kg and µg/l
Bis(2-ethylhexyl)phthalate, 117-81-7	0.02	0.014, B2		ND, B2		1,600	50	700	2.5			0.33, 109
4-Bromophenyl-phenylether, 101-55-3												0.33, 10
Butyl benzyl phthalate, 85-68-7	0.2	ND, C		ND, C		16,000		7,000				0.33, 10
Carbazole, 86-74-8		0.02, B2[f]		ND, B2[f]			35		1.8			0.33, 10
Chlordane, 57-74-9	0.00006	1.3, B2				4.8	0.54					
4-Chloroaniline, 106-47-8	0.004					320		140				0.33, 10
4-Chloro-3-methylphenol (p-chloro-m-cresol), 59-50-7	2[f, j]					160,000		70,000				0.33, 10
2-Chloronaphthalene, 91-58-7	0.08				1.4e+05	6,400		2,800				0.33, 10
2-Chlorophenol, 95-57-8	0.005					400		170				0.33, 10
4-Chlorophenyl phenyl ether[e], 7005-72-3												0.33, 10
Chrysene[e], 218-01-9		ND, B2		ND, B2								0.33, 10
DDD, 72-54-8		0.24, B2					2.9		0.15			
DDT, 50-29-3	0.0005	0.34, B2				40	2.1	18	0.1			
Dibenz[a,h]anthracene[e], 53-70-3		ND, B2		ND, B2								0.33, 10
Dibenzofuran[e], 132-64-9												0.33, 10
Di-n-butylphthalate, 84-74-2	0.1	ND, D		ND, D		8,000		3,500				0.33, 10
1,2-Dichlorobenzene, 95-50-1	0.09		0.057[f]		4.5e+04	1,600[h]		3,100		200		0.33, 10
1,3-Dichlorobenzene[e], 541-73-1					3.3e+04							0.33, 10
1,4-Dichlorobenzene, 106-46-7		0.024, C[f]	0.2[f]	ND, C	3.6e+04	5,800[h]	290		15	700		0.33, 10

TABLE J-1

SCREENING ACTION LEVELS FOR CHEMICAL ANALYTES IN SOIL, WATER, AND AIR FOR ENVIRONMENTAL CHARACTERIZATION OF LOS ALAMOS NATIONAL LABORATORY[a]

Chemicals[b]	Chronic Oral RfD mg/kg-day	Oral Slope Factor $(mg/kg\text{-}d)^{-1}$ and Group[c]	Chronic Inhalation RfD mg/kg-d	Inhalation Slope Factor $(mg/kg\text{-}d)^{-1}$ and Group[c]	VF[k] m^3/kg	Soil Screening Action Level Systemic Toxicant mg/kg	Soil Screening Action Level Carcinogen mg/kg	Water Screening Action Level Systemic Toxicant µg/l	Water Screening Action Level Carcinogen µg/l P	Air Screening Action Level Systemic Toxicant $\mu g/m^3$	Air Screening Action Level Carcinogen $\mu g/m^3$	CRQL[d] mg/kg and µg/l
3,3-Dichlorobenzidine, 91-94-1		0.45, B2		ND, B2			1.6		0.078			0.33, 10[g]
2,4-Dichlorophenol, 120-83-2	0.003					240		100				0.33, 10
Diethylphthalate, 84-66-2	0.8	ND, D		ND, D		64,000		28,000				0.33, 10
Dimethylformamide, 68-12-2	0.1[f]					8,000		3,500				
2,4-Dimethylphenol, 105-67-9	0.02			ND, D	1.1e+05	1,600		700				0.33, 10
Dimethyl phthalate, 131-11-3	1[f]	ND, D		ND, D		80,000		35,000				0.33, 10
4,6-Dinitro-2-methylphenol[e] (4,6-dinitro-o-cresol), 534-52-1												0.8, 25
2,4-Dinitrophenol, 51-28-5	0.002					160		70				0.8, 25
2,4-Dinitrotoluene, 121-14-2		0.68, B2		ND, B2			1.0		0.051			0.33, 10[g]
2,6-Dinitrotoluene, 606-20-2		0.68, B2		ND, B2			1.0		0.051			0.33, 10[g]
Di-n-octyl phthalate, 117-84-0	0.02[f]					1,600		700				0.33, 10
Endosulfan, 115-29-7	0.00005 [t,f]					4		1.8				
Ethyl acetate,141-78-6	0.9					72,000		32,000				
Ethylene glycol, 107-21-1	2		2			160,000		70,000				
Fluoranthene, 206-44-0	0.04	ND, D		ND, D		3,200		1,400				0.33, 10
Fluorene, 86-73-7	0.04				5.1e+05	3,200		1,400				0.33, 10

TABLE J-1

SCREENING ACTION LEVELS FOR CHEMICAL ANALYTES IN SOIL, WATER, AND AIR FOR ENVIRONMENTAL CHARACTERIZATION OF LOS ALAMOS NATIONAL LABORATORY[a]

Chemicals[b]	Chronic Oral RfD mg/kg-day	Oral Slope Factor (mg/kg-d)$^{-1}$ and Group[c]	Chronic Inhalation RfD mg/kg-d	Inhalation Slope Factor (mg/kg-d)$^{-1}$ and Group[c]	VF[k] m^3/kg	Soil Screening Action Level Systemic Toxicant mg/kg	Soil Screening Action Level Carcinogen mg/kg	Water Screening Action Level Systemic Toxicant µg/l	Water Screening Action Level Carcinogen µg/ P	Air Screening Action Level Systemic Toxicant µg/m^3	Air Screening Action Level Carcinogen µg/m^3	CRQL[d] mg/kg and µg/l
Hexachlorobenzene, 118-74-1	0.0008	1.6, B2		1.6, B2		64	0.44	28	0.022		0.0022	0.33, 10[g]
Hexachlorobutadiene, 87-68-3	0.002[u]	0.078, C		0.077, C		160	90	70	4.5		0.45	0.33, 10[g]
Hexachlorocyclopentadiene, 77-47-4	0.007		0.00002[f]			560		240		0.07		0.33, 10
Hexachloroethane, 67-72-1	0.001	0.014, C		0.014, C		80	500	35	25		2.5	0.33, 10
Indeno[1,2,3-cd]pyrene[e], 193-39-5		ND, B2		ND, B2								0.33, 10
Isophorone, 78-59-1	0.2	0.00095		ND, C		16,000	7,400	7,000	370			0.33, 10
2-Methylnaphthalene[e], 91-57-6					1.9e+05							0.33, 10
2-Methylphenol (o-cresol), 95-48-7	0.05	ND, C		ND, C		4,000		1,700				0.33, 10
4-Methylphenol (p-cresol), 106-44-5	0.05[f]	ND, C		ND, C		4,000		1,700				0.33, 10
Naphthalene, 91-20-3	0.04[f]				6.8e+04	3,200		1,400				0.33, 10
2-Nitroaniline, (o-nitroaniline) 88-74-4	6.0e-05[f]		5.7e-05[f]			4.8		2.1		0.20		
3-Nitroaniline(m-nitroaniline)[e], 99-09-2												0.8, 25
4-Nitroaniline(p-nitroaniline)[e], 100-01-6												0.8, 25
Nitrobenzene, 98-95-3	0.0005	ND, D	0.00057[f]	ND, D	1.3e+04	5.3[h]		18		2.0		0.33, 10

TABLE J-1

SCREENING ACTION LEVELS FOR CHEMICAL ANALYTES IN SOIL, WATER, AND AIR FOR ENVIRONMENTAL CHARACTERIZATION OF LOS ALAMOS NATIONAL LABORATORY[a]

Chemicals[b]	Chronic Oral RfD mg/kg-day	Oral Slope Factor $(mg/kg\text{-}d)^{-1}$ and Group[c]	Chronic Inhalation RfD mg/kg-d	Inhalation Slope Factor $(mg/kg\text{-}d)^{-1}$ and Group[c]	VF[k] m^3/kg	Soil Screening Action Level Systemic Toxicant mg/kg	Soil Screening Action Level Carcinogen mg/kg	Water Screening Action Level Systemic Toxicant µg/l	Water Screening Action Level Carcinogen µg/ P	Air Screening Action Level Systemic Toxicant $\mu g/m^3$	Air Screening Action Level Carcinogen $\mu g/m^3$	CRQL[d] mg/kg and µg/l
2-Nitrophenol[e], 88-75-5												0.33, 10
4-Nitrophenol[e], 100-02-7					1.9e+04							0.8, 25
N-Nitrosodiphenylamine, 86-30-6		0.0049, B2		ND, B2			140		7.1			0.33. 10[g]
N-Nitroso-di-N-dipropylamine, 621-64-7		7, B2		ND, B2			0.10		0.0050			0.33, 10[g]
2,2-Oxybis(1-chloropropane) (bis[2-chloroisopropyl]ether), 108-60-1	0.04	0.07[f], C		0.035, C[f]		3,200	100	1,400	0.50		1.0	0.33, 10
PCB (aroclors), 1336-36-3		7.7, B2					0.09					
Pentachlorophenol, 87-86-5	0.03	0.12, B2		ND, B2		2,400	5.8	1,000	0.29			0.8, 25[g]
Phenanthrene[e], 85-01-8		ND, D		ND, D	4.4e+05							0.33, 10
Phenol, 108-95-2	0.6					48,000		21,000				0.33, 10
Pyrene, 129-00-0	0.03	ND, D		ND, D		2,400		1,000				0.33, 10
1,2,4-Trichlorobenzene, 120-82-1	0.01	ND, D	0.0026[f]	ND, D	9.5e+04	160[h]		350		9.0		0.33, 10
2,4,5-Trichlorophenol, 95-95-4	0.10					8,000		3,500				0.8, 25
2,4,6-Trichlorophenol, 88-06-2		0.011, B2		0.011, B2			64		3.2		0.32	0.33, 10[g]

SCREENING ACTION LEVELS FOR CHEMICAL ANALYTES IN SOIL, WATER, AND AIR FOR ENVIRONMENTAL CHARACTERIZATION OF LOS ALAMOS NATIONAL LABORATORY[a]

Chemicals[b]	Chronic Oral RfD mg/kg-day	Oral Slope Factor $(mg/kg\text{-}d)^{-1}$ and Group[c]	Chronic Inhalation RfD mg/kg-d	Inhalation Slope Factor $(mg/kg\text{-}d)^{-1}$ and Group[c]	VF[k] m^3/kg	Soil Screening Action Level Systemic Toxicant mg/kg	Soil Screening Action Level Carcinogen mg/kg	Water Screening Action Level Systemic Toxicant µg/l	Water Screening Action Level Carcinogen µg/ P	Air Screening Action Level Systemic Toxicant $\mu g/m^3$	Air Screening Action Level Carcinogen $\mu g/m^3$	CRQL[d] mg/kg and µg/l
<u>High Explosives</u>												
2-amino-2,6-DNT (aminodinitrotoluene)[r]												
4-amino-2,6-DNT (amino-dinitrotoluene)[r], 19406-51-0												
Ammonium nitrate[r], 6484-52-2												
Barium nitrate (soluble barium)	0.07	ND, D		ND, D		5,600						
CEF (tri(b-chloroethyl)-phosphate)[r], 115-96-8												
1,3-DNB (dinitrobenzene), 99-65-0	0.0001	ND, D		ND, D		8		3.5				
2,4-DNT (dinitrotoluene), 121-14-2	0.002	0.68, B2[f]		ND, B2		160	1					
2,6-DNT (dinitrotoluene), 606-20-2	0.001[q]	0.68, B2[f]		ND, B2		80	1					
DPA (diphenylyamine), 122-39-4	0.025					2,000		880				
HMX (cyclotetramethyl-enetetranitramine), 2691-41-0	0.05			ND, D		4,000						
Nitrocellulose (non-toxic)[q/r], 9004-70-0												
Nitromethane[q/r], 75-52-5												

Chemicals[b]	Chronic Oral RfD mg/kg-day	Oral Slope Factor $(mg/kg\text{-}d)^{-1}$ and Group[c]	Chronic Inhalation RfD mg/kg-d	Inhalation Slope Factor $(mg/kg\text{-}d)^{-1}$ and Group[c]	VF[k] m^3/kg	Soil Screening Action Level Systemic Toxicant mg/kg	Soil Screening Action Level Carcinogen mg/kg	Water Screening Action Level Systemic Toxicant µg/l	Water Screening Action Level Carcinogen µg/ P	Air Screening Action Level Systemic Toxicant $\mu g/m^3$	Air Screening Action Level Carcinogen $\mu g/m^3$	CRQL[d] mg/kg and µg/l
NP (bis(2,2-dinitropropyl) acetal/formal)[r], 5917-61-3												
PETN (pentaerythritolletra-nitrate), 78-11-5	0.02[s]					1,600		700				
RDX (trimethylenetri-nitramine), 121-82-4	0.003	0.11, C		ND, C		240	64					
TATB (triaminotrinitro-benzene)[r], 3058-38-6												
Tetryl (N-methyl-N,2,4,6-tetranitrobenzeneamine), 479-45-8	0.01					800		350				
1,3,5-TNB (trinitrobenzene), 99-35-4	0.00005					4		1.8				
2,4,6-TNT (trinitrotoluene), 118-96-7	0.0005	0.03, C		ND, C		40	230					

a. Screening action levels based on methodologies given by EPA (1990, 0432; EPA 1991, 0778). Reference dose (RfD) and slope factor data obtained from EPA (July 1993, 0830), unless otherwise noted. Screening action levels are rounded to two significant figures. Water screening action levels are used for both groundwater and surface water. ND = not determined.

c. Carcinogens grouped as follows: Group A—human carcinogen; Group—B probable human carcinogen; Group C—possible human carcinogen; Group D—not classifiable as to human carcinogenicity.

d. Contract-Required Quantitation Limits (CRQLs) for soil and water, respectively. For inorganics, CRQL for soil is obtained by multiplying water CRQL by 0.2. For organics, the soil CRQL given is for low soil samples (wet weight). CRQLs not available for air.

e. Toxicity data (e.g., RfDs and/or slope factors) were not available; therefore, screening action levels were not calculated.

f. Toxicity data obtained from EPA (1992, 0833).

g. The screening action level is less than the CRQL; therefore, special analytical services may be required.

h. Soil screening action level incorporates inhalation pathway [only for substances with both an inhalation RfD or slope factor and a volatilization factor (VF) listed]. See below for equation.

i. Oral RfD for cis-1,2-dichloroethene used.

j. Subchronic RfD; chronic RfD for 4-chloro-3-methylphenol not available.

k. Soil-to-air volatilization factor; calculated based on equation given by EPA (1991, 0778) and chemical-specific parameters given in Strenge and Peterson (1989, 0777) and EPA (1988, 0747). VF is given only for substances with molecular weight less than 200 and Henry's Law constant greater than 10^{-5}atm/m^3-mole.
m. Oral RfD for cadmium in food/solids.
n. Oral RfD for thallium (I) sulfate.
o. Values obtained from the Superfund Health Risk Technical Support Center, Cincinnati, Ohio, October 1992.
p. Water SALs not calculated for compounds with MCLS (See Table J-2)
q. Drinking Water Regulations and Health Advisory Tables (May 1993.)
r. Toxicity data (e.g., RfDs and/or slope factors) were not available; therefore, screening action levels were not calculated.
s. Acceptable Dose Rate for oral route of exposure, Layton et al, UCRL-21109 (December 1987).
t. Oral RfD has been withdrawn on 12/1/92 until further review (EPA 1993, 0830).
u. Oral RfD has been withdrawn on 5/1/92 until further review (EPA 1993, 0830).

General equations for calculation of screening action levels

Systemic Toxicants

SAL = (THI x RfD x BW x CF)/(I x A), where

SAL = soil screening action level (mg/kg for soil SALs; µg/L for water SALs; µg/m^3 for air SALs).
THI = target hazard index; 1.
RfD = chronic reference dose (mg/kg/day); oral RfD used for soil and water SALs; inhalation RfD used for air SAL.
BW = body weight; 16 kg for child (used for soil SAL); 70 kg for adult (used for water and air SALs).
CF = conversion factor; 10^6 mg/kg for soil SAL; 1000 ug/mg for water and air SALs.
I = intake assumption; 200 mg/day for soil SAL (child); 2 L/day for water SAL; 20 m^3/day for air SAL.
A = absorption factor; 1.

Carcinogenic Constituents

SAL = (R x BW x LT x CF)/(SF x I x A x ED), where

R = target risk; 10^{-6} for Class A and B carcinogens; 10^{-5} for Class C carcinogens.
BW = body weight; 70 kg.
LT = assumed lifetime; 70 yr.
CF = conversion factor; 10^6 mg/kg for soil SAL; 1000 µg/mg for water and air SALs.
SF = slope factor $(mg/kg/day)^{-1}$; oral SF used for soil and water SALs; inhalation SF used for air SALs.
I = intake assumption; 100 mg/day for soil SAL; 2 L/day for water SAL; 20 m^3/day for air SAL.
A = absorption factor; 1.
ED = exposure duration; 70 yr.

Equations for calculation of soil screening action levels for volatile contaminants

Systemic Toxicants

$$SAL = (THI \times BW)/((1/RfD_o \times 10^{-6}\ kg/mg \times ING) + (1/RfD_i \times INH \times (1/VF + 1/PEF)),$$

where

THI = target hazard index; 1.
BW = body weight; 16 kg.
RfD_o = chronic oral reference dose (mg/kg/day).
RfD_i = chronic inhalation reference dose (mg/kg/day).
ING = ingestion intake assumption; 200 mg/day.
VF = soil-to-air volatilization factor (m^3/kg; chemical-specific).
INH = inhalation intake assumption; 20 m^3/day.
PEF = particulate emission factor (4.63×10^9 m^3/kg;) (EPA 1992, 0833).

Carcinogens

$$SAL = (R \times BW \times LT)/ED \times [(SF_o \times 10^{-6}\ kg/mg \times ING) + (SF_i \times INH \times (1/VF + 1/PEF))],$$

where

R = target risk; 10^{-6} for Class A and B carcinogens; 10^{-5} for Class C carcinogens.
BW = body weight; 70 kg.
LT = assumed lifetime; 70 yr.
ED = exposure duration; 70 yr.
SF_o = oral slope factor $(mg/kg/day)^{-1}$.
ING = ingestion intake assumption; 100 mg/day.
SF_i =inhalation slope factor $(mg/kg/day)^{-1}$.
INH = inhalation intake assumption; 20 m^3/day.
VF and PEF as defined above.

TABLE J-2

SAFE DRINKING WATER ACT MAXIMUM CONTAMINANT LEVELS AND NEW MEXICO WATER QUALITY CONTROL COMMISSION GROUNDWATER STANDARDS

Substance	SDWA MCL (µg/L)	State of New Mexico Standard (µg/L)
INORGANICS		
Arsenic	50	100
Barium	2,000	1,000
Cadmium	5	10
Chromium III	100	50
Chromium IV	100	50
Cyanide		200
Lead	50	50
Mercury	2	2
Nitrate	10,000	
Nitrite	1,000	
Selenium	50	50
Silver	50	50
Uranium		5,000
ORGANICS		
Benzene	5	10
Benzo[a]pyrene		0.70
Carbon Tetrachloride	5	10
Chlorobenzene	100	
Chloroform		100
1,2-Dichlorobenzene	600	
1,4-Dichlorobenzene	75	
1,1-Dichloroethane		25
1,2-Dichloroethane	5	10
1,1-Dichloroethene	7	5
cis-1,2-Dichloroethene	70	
trans-1,2-Dichloroethene	100	
1,2-Dichloropropane	5	
Ethyl Benzene	700	750
Methylene Chloride		100
Naphthalene		30
Styrene	100	
Tetrachloroethene	5	20
1,1,2,2-Tetrachloroethane		10
Toluene	1,000	750
Trichloroethene	5	100
1,1,1-Trichloroethane	200	60
Vinyl Chloride	2	1
Xylene	10,000	620

Table J-3 Summary of Screening Action Levels for Chemical Analytes in Soil, Water, and Air - For Environmental Characterization of Los Alamos National Laboratory[a]

Chemicals	Soil Screening Action Level mg/kg	Water Screening Action Level µg/l	Air Screening Action Level µg/m^3	CRQL[c] mg/kg and µg/l
Inorganics				
Aluminum[d], 7429-90-5				40, 200
Antimony, 7440-36-0	32	14		12, 60[e]
Arsenic, 7440-38-2	0.40	50	0.00023	2, 10[e]
Barium, 7440-39-3	5,600	1,000	0.49	40, 200
Beryllium, 7440-41-7	0.16	0.0081	0.00042	1, 5[e]
Cadmium, 7440-43-9	80	5	0.00056	1, 5
Calcium[d], 7440-70-2				1000, 5000
Chromium III, 16065-83-1	80,000	50		2, 10
Chromium VI, 7440-47-3	400	50	0.000083	2, 10
Cobalt[d], 7440-48-4				10, 50
Copper, 7440-50-8	3,000	1,300		5, 25
Cyanide, 57-12-5	1,600	200		2, 10
Iron[d], 1543-83-10				20, 100
Lead[f], 7439-92-1	500	50		0.6, 3
Magnesium[d], 7786-30-3				1000, 5000
Manganese, 7439-96-5	8,000	3,500	0.39	3, 15
Mercury, 7439-97-6	24	2	0.30	0.04, 0.2
Nickel, 7440-02-0	1,600	700	0.0042	8, 40
Nitrate	130,000	10,000		
Nitrite, 14797-65-0	8,000	1,000		
Potassium[d], 7447-40-7				1000, 5000
Selenium, 7782-49-2	400	50		1, 5
Silver, 7440-22-4	400	50		2, 10
Sodium[d], 7647-14-5				1000, 5000
Thallium, 7440-28-0	6.4	2.8		2, 10[e]
Uranium, 7440-61-1	240	100		
Vanadium, 7440-62-2	560	240		10, 50
Zinc, 7440-66-6	24,000	10,000		4, 20

Table J-3 Summary of Screening Action Levels for Chemical Analytes in Soil, Water, and Air - For Environmental Characterization of Los Alamos National Laboratory[a]

Chemicals	Soil Screening Action Level mg/kg	Water Screening Action Level µg/l	Air Screening Action Level µg/m^3	CRQL[c] mg/kg and µg/l
High Explosives				
2-amino-2,6-DNT (aminodinitrotoluene)[d]				
4-amino-2,6-DNT (aminodinitrotoluene)[d], 19406-51-0				
Ammonium nitrate[d], 6484-52-2				
Barium nitrate (soluble barium)	5,600	2,000[h]		
CEF (tri(b-chloroethyl)-phosphate)[d], 115-96-8				
1,3-DNB (dinitrobenzene), 99-65-0	8	3.5		
2,4-DNT (dinitrotoluene), 121-14-2	1	0.17[h]		
2,6-DNT (dinitrotoluene), 606-20-2	1	0.0068[h]		
DPA (diphenylyamine), 122-39-4	2,000	880		
HMX (cyclotetramethylenetetranitramine), 2691-41-0	4,000	400[h]		
Nitrocellulose (non-toxic)[d/h], 9004-70-0				
Nitromethane, 75-52-5				
NP (bis(2,2-dinitropropyl) acetal/formal)[d], 5917-61-3				
PETN (pentaerythritolletranitrate), 78-11-5	1,600	700		
RDX (trimethylenetrinitramine), 121-82-4	64	2[h]		
TATB (triaminotrinitrobenzene)[d], 3058-38-6				
Tetryl (N-methyl-N,2,4,6-tetranitrobenzene-amine), 479-45-8	800	350		
1,3,5-TNB (trinitrobenzene), 99-35-4	4	1.8		
2,4,6-TNT (trinitrotoluene), 118-96-7	40	2[h]		

Table J-3 Summary of Screening Action Levels for Chemical Analytes in Soil, Water, and Air - For Environmental Characterization of Los Alamos National Laboratory[a]

Chemicals	Soil Screening Action Level mg/kg	Water Screening Action Level µg/l	Air Screening Action Level µg/m^3	CRQL[c] mg/kg and µg/l
Organics				
Volatile Organic Compounds				
Acetone, 67-64-1	8,000	3,500		0.01, 10
Benzene, 71-43-2	0.67	5	0.12	0.01, 10[e]
Benzoic Acid, 65-85-0	320,000	140,000		
Bromodichloromethane, 75-27-4	11	0.56		0.01, 10[e]
Bromoform, 75-25-2	89	4.4	0.90	0.01, 10[e]
Bromomethane, 74-83-9	0.43	49	4.9	0.01, 10
2-Butanone (Methyl ethyl ketone), 78-93-3	4,000	1,700	1,000	0.01, 10
Carbon disulfide, 75-15-0	7.4	3,500	10	0.01, 10
Carbon tetrachloride, 56-23-5	0.21	5	0.066	0.01, 10[e]
Chlorobenzene, 108-90-7	67	100	20	0.01, 10
Chloroethane, 75-00-3	3,300		10,000	0.01, 10
Chloroform, 67-66-3	0.21	100	0.043	0.01, 10[e]
Chloromethane, 74-87-3	6.4	27	5.6	0.01, 10
Dibromochloromethane, 124-48-1	83	4.2		0.01, 10[e]
1,1-Dichloroethane, 75-34-3	410	25	500	0.01, 10
1,1-Dichloroethene, 75-35-4	0.59	5	0.29	0.01, 10[e]
1,2-Dichloroethane, 107-06-2	0.20	70	0.038	0.01, 10[e]
1,2-Dichloroethene (total), 540-59-0	800	70		0.01, 10
1,2-Dichloropropane, 78-87-5	6.5	0.51	4.0	0.01, 10[e]
cis-1,3-Dichloropropene, 10061-01-5	0.17	0.19	0.027	0.01, 10[e]
trans-1,3-Dichloropropene, 10061-02-6	0.17	0.19	0.027	0.01, 10[e]
Ethyl benzene, 100-41-4	3,100	700	1000	0.01, 10
n-Hexane, 110-54-3	4,800	2,100		
2-Hexanone[d], 591-78-6				0.01, 10
Methanol, 67-56-1	40,000	18,000		
4-Methyl-2-pentanone (MIK), 108-10-1	510	1,700	80	0.01, 10

Table J-3 Summary of Screening Action Levels for Chemical Analytes in Soil, Water, and Air - For Environmental Characterization of Los Alamos National Laboratory[a]

Chemicals	Soil Screening Action Level mg/kg	Water Screening Action Level µg/l	Air Screening Action Level µg/m^3	CRQL[c] mg/kg and µg/l
Methylene Chloride, 75-09-2	5.6	100	2.2	0.01, 10[e]
Styrene, 100-42-5	16,000	100		0.01, 10[e]
1,1,2,2-Tetrachloroethane, 79-34-5	3.9	1.8	0.18	0.01, 10[e]
Tetrachloroethene, 127-18-4	5.9	5	1.8	0.01, 10[e]
Toluene, 108-88-3	890	750	380	0.01, 10
1,1,1-Trichloroethane, 71-55-6	1,000	60	1,000	0.01, 10
1,1,2-Trichloroethane, 79-00-5	6.3	6.1	0.63	0.01, 10[e]
Trichloroethene, 79-01-6	3.2	5	0.58	0.01, 10[e]
Vinyl Chloride, 75-01-4	0.013	0.018	0.012	0.01, 10[e]
Xylenes (Total), 1330-20-7	160,000	620		0.01, 10
Semi-Volatile Organic Compounds				
Acenaphthene, 83-32-9	4,800	2,100		0.33, 10
Acenaphthylene[d], 208-96-8				0.33, 10
Anthracene, 120-12-7	24,000	10,000		0.33, 10
Benzo[a]anthracene[d], 56-55-3				0.33, 10
Benzo[b]fluoranthene[d],205-99-2				0.33, 10
Benzo[k]fluoranthene[d],207-08-9				0.33, 10
Benzo[ghi]perylene[d], 191-24-2				0.33, 10
Benzo[a]pyrene, 50-32-8	0.10	0.0048	0.00057	0.33, 10[e]
alpha-BHC, 319-84-6	0.1	0.0056		
beta-BHC, 319-85-7	4	0.19		
Bis(2chloroethoxy)methane[d], 111-91-1				0.33, 10
Bis-(2-chloroethyl)ether, 111-44-4	0.13	0.032	0.0032	0.33, 10[e]
Bis(2-ethylhexyl)phthalate, 117-81-7	50	2.5		0.33, 10[e]
4-Bromophenyl-phenylether[d], 101-55-3				0.33, 10
Butyl benzyl phthalate, 85-68-7	16,000	7,000		0.33, 10

Table J-3. Summary of Screening Action Levels for Chemical Analytes in Soil, Water, and Air - For Environmental Characterization of Los Alamos National Laboratory[a]

Chemicals	Soil Screening Action Level mg/kg	Water Screening Action Level µg/l	Air Screening Action Level µg/m^3	CRQL[c] mg/kg and µg/l
Carbazole, 86-74-8	35	1.8		0.33, 10
Chlordane, 57-74-9	0.54	0.027		
4-Chloroaniline, 106-47-8	320	140		0.33, 10
4-Chloro-3-methylphenol[g] (p-chloro-m-cresol), 59-50-7	16,000	7,000		0.33, 10
2-Chloronaphthalene, 91-58-7	6,400	2,800		0.33, 10
2-Chlorophenol, 95-57-8	400	170		0.33, 10
4-Chlorophenyl phenyl ether[d], 7005-72-3				0.33, 10
Chrysene[d], 218-01-9				0.33, 10
DDD, 72-54-8	2.9	0.15		
DDT, 50-29-3	2.1	0.1		
Dibenz[a,h]anthracene[d], 53-70-3				0.33, 10
Dibenzofuran[d], 132-64-9				0.33, 10
Di-n-butylphthalate, 84-74-2	8,000	3,500		0.33, 10
1,2-Dichlorobenzene, 95-50-1	1,600	600	200	0.33, 10
1,3-Dichlorobenzene[d], 541-73-1				0.33, 10
1,4-Dichlorobenzene, 106-46-7	290	75	700	0.33, 10
3,3-Dichlorobenzidine, 91-94-1	1.6	0.078		0.33, 10[e]
2,4-Dichlorophenol, 120-83-2	240	100		0.33, 10
Diethylphthalate, 84-66-2	64,000	28,000		0.33, 10
Dimethylformamide, 68-12-2	8,000	3,500		
2,4-Dimethylphenol, 105-67-9	1,600	700		0.33, 10
Dimethyl phthalate, 131-11-3	80,000	35,000		0.33, 10
4,6-Dinitro-2-methylphenol[d] (4,6-dinitro-o-cresol), 534-52-1				0.8, 25
2,4-Dinitrophenol, 51-28-5	160	70		0.8, 25
2,4-Dinitrotoluene, 121-14-2	1.0	0.051		0.33, 10[e]
2,6-Dinitrotoluene, 606-20-2	1.0	0.051		0.33, 10[e]
Di-n-octyl phthalate, 117-84-0	1,600	700		0.33, 10
Endosulfan, 115-29-7	4	1.8		
Ethyl acetate, 141-78-6	72,000	32,000		
Ethylene glycol, 107-21-1	160,000	70,000		

Table J-3 Summary of Screening Action Levels for Chemical Analytes in Soil, Water, and Air - For Environmental Characterization of Los Alamos National Laboratory[a]

Chemicals	Soil Screening Action Level mg/kg	Water Screening Action Level µg/l	Air Screening Action Level µg/m3	CRQL[c] mg/kg and µg/l
Fluoranthene, 206-44-0	3,200	1,400		0.33, 10
Fluorene, 86-73-7	3,200	1,400		0.33, 10
Hexachlorobenzene, 118-74-1	0.44	0.022	0.0022	0.33, 10[e]
Hexachlorobutadiene, 87-68-3	90	4.5	0.45	0.33, 10[e]
Hexachlorocyclopentadiene, 77-47-4	560	240	0.07	0.33, 10
Hexachloroethane, 67-72-1	80	25	2.5	0.33, 10
Indeno[1,2,3-cd]pyrene[d], 193-39-5				0.33, 10
Isophorone, 78-59-1	7,400	370		0.33, 10
2-Methylnaphthalene[d], 91-57-6				0.33, 10
2-Methylphenol (o-cresol), 95-48-7	4,000	1,700		0.33, 10
4-Methylphenol (p-cresol), 106-44-5	4,000	1,700		0.33, 10
Naphthalene, 91-20-3	3,200	30		0.33, 10
2-Nitroaniline, (o-nitroaniline) 88-74-4	4.8	2.1	0.20	0.8, 25[e]
3-Nitroaniline(m-nitroaniline)[d], 99-09-2				0.8, 25
4-Nitroaniline(p-nitroaniline)[d], 100-01-6				0.8, 25
Nitrobenzene, 98-95-3	5.3	18	2.0	0.33, 10
2-Nitrophenol[d], 88-75-5				0.33, 10
4-Nitrophenol[d], 100-02-7				0.8, 25
N-Nitrosodiphenylamine, 86-30-6	140	7.1		0.33. 10[e]
N-Nitroso-di-N-dipropylamine, 621-64-7	0.10	0.0050		0.33, 10[e]
2,2-Oxybis(1-chloropropane) (bis[2-chloroisopropyl]ether), 108-60-1	100	0.50	1.0	0.33, 10
PCB (Aroclors), 1336-36-3	0.09	0.50		
Pentachlorophenol, 87-86-5	5.8	0.29		0.8, 25[e]
Phenanthrene[d], 85-01-8				0.33, 10
Phenol, 108-95-2	48,000	21,000		0.33, 10
Pyrene, 129-00-0	2,400	1,000		0.33, 10
1,2,4-Trichlorobenzene, 120-82-1	160	350	9.0	0.33, 10
2,4,5-Trichlorophenol, 95-95-4	8,000	3,500		0.8, 25
2,4,6-Trichlorophenol, 88-06-2	64	3.2	0.32	0.33, 10[e]

[a] Screening action levels based on methodologies given in EPA 1990 (0432) and EPA 1991c (0302). See Table J-1 for derivations; levels presented are lowest levels from Tables J-1 and J-2 for each substance and media. Screening action levels are rounded to two significant figures. Water screening action levels are used for both groundwater and surface water.

[c] Contract-Required Quantitation Limits (CRQLs) for soil and water, respectively. For inorganics, CRQL for soil is obtained by multiplying water CRQL by 0.2. For organics, the soil CRQL given is for low soil samples (wet weight). CRQLs not available for air.

[d] Toxicity data (e.g., RfDs and/or slope factors) were not available; therefore, screening action levels were not calculated.

[e] The screening action level is less than the CRQL; therefore, Special Analytical Services may be required.

[f] Soil screening action level based on EPA OSWER Directive 9355.4-02, "Interim Guidance on Establishing Lead Cleanup Levels at Superfund Sites", Office of Solid Waste and Emergency Response 1989

[g] Based on subchronic RfD divided by 10; chronic RfD not available.

[h] Drinking Water Regulations and Health Advisory Tables (May 1993).

TABLE J-4 Published U.S. Average Effective Dose Equivalent Rates and Estimates for the Los Alamos Area from Natural Background Radiation.

RADIATION SOURCE	U.S.AVERAGE (mrem/yr)	LOS ALAMOS (mrem/yr)
Cosmic Rays	27	58
Cosmogenic Radiation	1	1
External Terrestrial	28	39
Radionuclides in Body	40	40
Inhaled Radionuclides	200	200
Rounded Total	300	338

NOTES:

1. The U.S. average data is from Table 9.7, page 148, NCRP Report 94.

2. With the exception of the Cosmogenic source, the Los Alamos data are from the report "Environmental Surveillance at Los Alamos during 1990." The cosmic and external terrestrial components were based on measurements; the balance of the values in the report were taken from NCRP 94.

Table J-5 Summary of Screening Action Levels for Radionuclides in Soil and Water[a]

Radionuclides	Soil Screening Action Level (pCi/g dry soil)[b]	Water Screening Action Level pCi/l	Air Screening Action Level µg/m^3	CRQL[c] mg/kg and µg/l
Americium-241	22.0	15[g]		
Carbon-14	4.7×10^5	2,700[h]		
Cesium-134	1.90	77[h]		
Cesium-137	4.0	110[h]		
Cobalt-57	40.0	4,800[h]		
Cobalt-60	0.90	210[h]		
Iodine-129	41.0	20[h]		
Manganese-54	3.40	2,000[h]		
Plutonium-238	27.0	15[g]		
Plutonium-239	24.0	15[g]		
Radium-226[d,e]	.73	20[i]		
Rubidium-106	15.0	210[j]		
Sodium-22	1.30	490[h]		
Strontium-90	8.90	8[j]		
Thorium-230	10.0			
Thorium-232[d]	0.88	15[g]		
Tritium[f]	1.5×10^7	2×10^4[j]		
Uranium-233	86.0	20[h]		
Uranium-234	86.0	20[h]		
Uranium-235	18.0	20[h]		
Uranium-238	59.0	20[h]		
Depleted Uranium	58.6			
Natural Uranium	66.3			

a Screening action levels based on methodologies given in EPA 1990 (0432) and EPA 1991c (0302). See Table J-1 for derivations; levels presented are lowest levels from Tables J-1 and J-2 for each substance and media. Screening action levels are rounded to two significant figures. Water screening action levels are used for both groundwater and surface water.

b Based on 10 mrem/yr (above background) dose limit. Input data are representative of mesa top environment at LANL.

c Contract-Required Quantitation Limits (CRQLs) for soil and water, respectively. For inorganics, CRQL for soil is obtained by multiplying water CRQL by 0.2. For organics, the soil CRQL given is for low soil samples (wet weight). CRQLs not available for air.

d Generic limits for Radium^{226} and Thorium^{232} are set in DOE 5400.5 (DOE 1990) at 5 pCi/g averaged over the first 15 cm of soil and 15 pCi/g averaged over each additional 15 cm interval. The more conservative derived screening action levels are to be used for screening purposes only.

e Includes Radium^{228} concentration.

f When Tritium (H^3) is measured in µCi/mL of soil moisture, the Tritium SAL in µCi/mL is a function of soil moisture: 15(1-M)/M, where M is the moisture fraction of the sample (g water/g total sample).

g As part of gross alpha activity, per 40 CFR 141.15(b).

h Calculated based on 4 mrem/yr dose limit

i Drinking Water Regulations and Health Advisory Tables (May 1993).

j From Table A in 40 CFR 141.16.

DRAFT

4.0 TECHNICAL APPROACH

This chapter presents the Los Alamos National Laboratory ER Program's technical approach to the corrective action process. This work is conducted under the Resource Conservation and Recovery Act (RCRA) as amended by the Hazardous and Solid Waste Amendments (HSWA). Because it is the Laboratory's policy to comply with CERCLA as well as RCRA requirements, this approach includes elements of the CERCLA process as well as RCRA. In particular, it is applicable to all Potential Release Sites (PRSs), including those that are not subject to the provisions of the HSWA module.

The Los Alamos technical approach is modeled on DOE's streamlined approach for environmental restoration (SAFER), which combines elements of the observational approach (see Appendix G) and EPA's data quality objectives (DQO) process for designing data collection to support environmental decisions, described in this chapter and in Appendix H. Section 4.1 describes the decision framework for the investigation and remediation of Potential Release Sites within the Los Alamos ER Program. This framework provides for phased site investigations and for the early identification of important problems to facilitate prioritization and timely implementation of corrective actions. The DQO process is used to design field investigations for site characterization, remedy selection, verification of cleanup, and site monitoring that are closely tied to the corresponding decisions.

The decision points in the general framework correspond to decisions described in RCRA Corrective Action guidance. The Los Alamos ER Program has developed detailed decision criteria to supplement this regulatory guidance. In particular, the Los Alamos ER Program has determined that a risk-based approach to site prioritization and remediation is generally appropriate, given the great variety of potential release sites that have been identified and the complexity of the natural environment on the Pajarito Plateau. However, other criteria are also important, as ER decisions entail significant monetary, social, and legal consequences that must be incorporated into a technical framework. These decision criteria are described briefly in Sections 4.2 and 4.3. Appendix I describes decision strategies for the ER Program. Site screening criteria are derived in Appendix J, and Appendix K provides more detailed information about human health risk-based decision criteria. Appendix L discusses ecological risk assessment and natural resource damage assessment.

Sections 4.4 and 4.5 of this chapter provide brief surveys of technological options for site characterization and corrective action that may be considered during the investigative and remedial stages of the program, respectively.

Defined below are several terms used frequently in this chapter that carry meanings specific to the ER Program decision processes and to risk assessment. Additional definitions may be found in the glossary at the end of this document.

Baseline risk assessment A risk assessment conducted using an appropriate, site-specific exposure scenario but assuming no mitigating or corrective measures beyond those already in place.

Background levels The distribution of concentrations of naturally occurring or widely distributed constituents in environmental media.

Contaminant, Contaminant of concern Any constituent present in environmental media or on structural debris at a concentration that may present a risk to human health or the environment.

Constituent Any compound or element present in environmental media, including both naturally occurring and anthropogenic elements.

Clean-up levels Media-specific target concentration levels for contaminants which must be met by a selected corrective action. Cleanup levels are established at the conclusion of the CMS using selection-of-remedy criteria such as protection of human health and the environment; compliance with regulatory requirements; reduction of toxicity, mobility or volume through treatment; long- and short-term effectiveness; implementability; cost; and public acceptance.

CMS risk assessment A risk assessment conducted using an appropriate, site-specific exposure scenario to estimate the expected reduction in risk resulting from a proposed corrective measure.

Deferred investigation Postponement of complete evaluation of a PRS, which may be proposed where investigation would have negative impacts on current Laboratory operations if it is determined than the site presents no current risk to human health or the environment.

Environmental medium Any medium capable of absorbing or transporting constituents released from a SWMU, including tuffs, soils and sediments derived from these tuffs, surface water, ground water, air, structural surfaces, and debris.

Exposure unit (EU) The bounded area or volume within which a person or other environmental receptor is exposed, under an assumed exposure scenario for risk assessment, to contaminants that have been released to the environment. An exposure unit may be smaller or larger than the potential release site; its size and the associated exposure frequencies and durations are determined by the exposure scenario.

No further action (NFA) One of the possible endpoints of the corrective action process: a decision that no further investigation or remediation is warranted for a PRS. No further action may be proposed if it is determined that no release that entails potentially significant risks to human health or the environment has occurred.

Regulatory standard, regulatory concentration criteria Media-specific contaminant concentration levels of potential concern that are mandated in specific pieces of federal or state legislation (e.g., the Safe Drinking Water Act, New Mexico Water Quality Control Commission Regulations).

Risk assessment An assessment of the potential human health or environmental risk associated with contamination of environmental media. Risk assessment includes hazard identification, exposure assessment, and dose response analysis. For human health risk assessments, two endpoints are generally estimated: (1) excess lifetime cancer risk, and (2) systemic toxicological impacts.

Screening action levels (SAL) Media-specific concentration levels for constituents derived using conservative assumptions. The derivation of SALs for non radioactive constituents is based on low risk under a very restrictive exposure scenario. SALs for radioactive constituents are based on dose.

Screening assessment Evaluation of information about a PRS to determine whether hazardous or radioactive constituents are present above the levels of concern defined by media-specific screening action levels or regulatory standards.

Voluntary corrective action (VCA) Selection and implementation of an obvious and effective corrective action during or following the RFI.

4.1 RFI and Corrective Action Strategies

4.1.1 Decisions During the RCRA Process

The RCRA process outlined in Chapter 1 is designed to generate and implement appropriate decisions concerning corrective actions for potential release sites (PRSs) identified by the RCRA Facility Assessment (RFA) for the Los Alamos National Laboratory (the Laboratory). Following site identification, further decisions during the RCRA process demarcate the three stages of the RCRA process illustrated in Figure 1-1. Among the decisions that are required by the conclusion of the RCRA facility investigation (RFI) stage are

- determining whether constaminants have been released to the environment,
- determining whether corrective action is required for the site, and
- determining whether a formal CMS is required to select and design an appropriate corrective action.

Some of the options available at the end of the RFI move the corrective action process to an endpoint outside of the flow shown in Figure 1-1. These include

- proposing no further action,
- deferring action, and often deferring investigation as well, until an active site becomes inactive, or
- voluntary corrective action.

No further action (NFA) may be proposed for administrative reasons (the PRS was incorrectly listed, corrective action is being or will be undertaken outside the ER Program, etc.), or following a determination that no environmental release has occurred or that there are no human health or environmental risks associated with the site. If the PRS is listed in the HSWA module of the Laboratory's RCRA Permit, the Laboratory will apply for delisting following the procedures described in the HSWA module. Comparable DOE and public review procedures will be followed for other PRSs for which no further action is proposed.

Deferred investigation is the postponement of site evaluation at a PRS that is either itself an active operational site or else is so closely associated with an active site that immediate investigation would negatively affect current Laboratory operations. A proposal for deferred investigation must be accompanied by a determination that the PRS poses no unacceptable current risk to human health or the environment. Deferred investigation proposals in the RFI work plan are subject to EPA approval.

Voluntary Corrective Action (VCA) is an expedited remediation option described in proposed Subpart S to RCRA (EPA 1990, 0432). The ER Program's implementation of this option is illustrated in Figure 4-1. A decision to proceed with a VCA may be made at any time during the RFI when an obvious and effective remedy is available and meets treatment and disposal restrictions and other limiting criteria. Site-specific cleanup standards for a VCA may be developed using risk-based criteria.

Implementation of a VCA requires a change control with DOE approval, and VCAs on sites that contain mixed or land disposal restricted (LDR) wastes may not proceed without an plan for

storage and/or disposal of these wastes that has been approved by DOE and the appropriate regulatory agencies. In particular, VCAs that will produce mixed waste will be postponed until the Mixed Waste Storage/Disposal Facility is available unless the site is not on DOE property or poses an immediate health hazard. Voluntary corrective actions will be described in technical quarterly reports to EPA, and the public will be informed of VCAs in quarterly public meetings, but there will be no formal solicitation of approval until final approval of the cleanup is requested.

If a CMS is performed to evaluate remedial alternatives as shown in Figure 1-1, it includes additional decisions:

- determining cleanup standards for contaminated environmental media, and
- selecting a corrective measure to meet these standards.

The corrective measure is implemented during the third stage of the corrective action process, CMI. The principal decisions during this stage are

- identifying significant deviations from anticipated site conditions that require modification of the corrective measure, if they exist, and
- verifying the attainment of cleanup standards.

4.1.2 The Streamlined Approach to Environmental Restoration

The Department of Energy's (DOE's) Streamlined Approach for Environmental Restoration (SAFER) provides a starting point for a technical approach to investigations to support the decisions outlined above. The streamlined approach combines elements of the observational approach developed for geotechnical engineering (see Appendix G) and EPA's data quality objectives (DQO) process for designing data collection activities to support environmental decision-making. The streamlined approach implements many of the suggestions for improving the Comprehensive Environmental Response and Liability Act (CERCLA) RI/FS process that evolved from an EPA review of early Superfund projects (EPA 1987, 0821).

In particular, the streamlined approach implements a program of phased site characterization that continues beyond the RFI into the corrective action stages of the process. Such a phased approach is recommended in the proposed Corrective Action rule for RCRA (EPA 1990, 0432). This avoids the delays that would result from attempting an excessively detailed characterization of the site during the RFI. It expedites corrective action by early consideration of possible remedial alternatives and by progressing to the later steps of the RCRA process as soon as possible. Although understanding of the site (the "probable conditions" in observational approach terminology) may change somewhat as more site detail is revealed by CMI activities, "reasonable deviations" from the probable conditions can be accommodated by contingency planning during the CMS and site monitoring during the CMI. Thus the goal of RFI site characterization is first, to determine whether the problem warrants corrective action, and second, to develop an understanding of the probable site conditions in sufficient detail to design a corrective measure that includes contingency alternatives. More detailed characterization, designed to evaluate whether one of these modifications should be invoked, is carried out during the CMI. The DQO process is used to design each of these phases of data collection, from the initial screening assessment through CMI monitoring and verification sampling.

Figure 4-2 shows the overall decision flow for site investigations within the streamlined approach. The first step, begun during the RFA, consists of evaluating the existing information about a PRS:

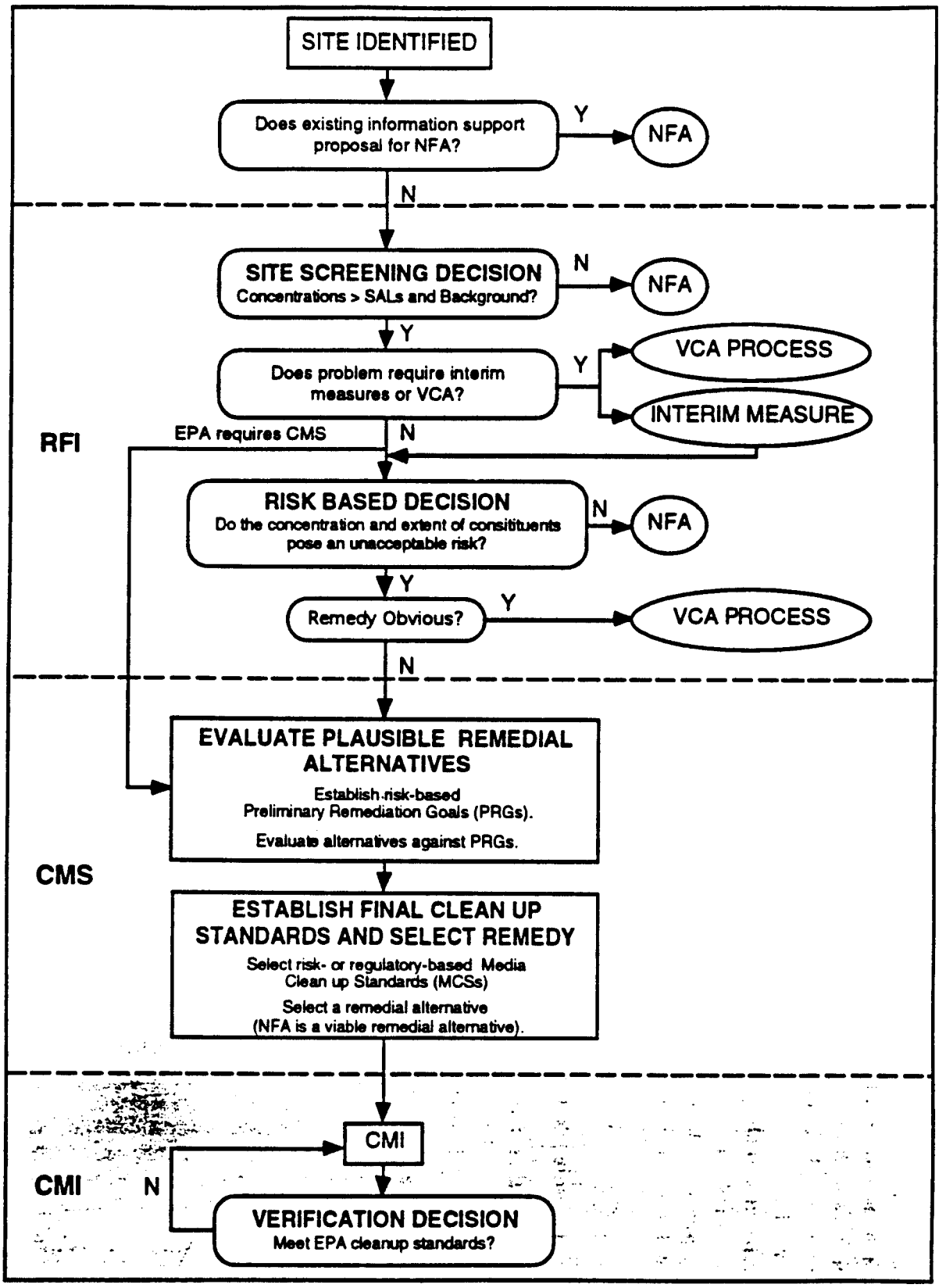

Figure 4-2. Decision Framework for ER Program Technical Approach

- reviewing the operations that created the site;

- constructing a preliminary conceptual exposure model to summarize current knowledge about potential contamination of environmental media at the site, migration pathways through the environment, and biological receptors;

- outlining potential response actions.

Depending on the nature of the site and quality of this information, it may be possible to propose no further action without field investigations at this point. In rare instances where there is a good historical data base for the site existing information may be sufficiently complete to proceed immediately with voluntary corrective action or with a formal CMS. Also a decision to defer investigation until closure of an associated active site may be appropriate.

In general, however, the site will require RFI site characterization. Figure 4-2 shows two RFI activities that may require collecting new data, the screening assessment and baseline risk assessment for a risk-based decision. For the majority of PRSs at the Laboratory, the first investigation phase will support a screening assessment (Section 4.1.4). If the contaminants of concern have been identified by previous work or can be determined from the archival information, it may be possible to design the first phase of the RFI work to support a risk-based decision. In some cases a field investigation can be designed to support both decisions, although such a design may be less than optimal for either purpose. Rarely, the first phase of the RFI investigation may be designed to establish probable conditions and reasonable deviations as part of the VCA process or in preparation for evaluating remedial alternatives during CMS.

A key element of the Los Alamos technical approach is the design of focussed data collection efforts. The primary tool for assuring that the sampling and analysis plan will produce data of the required types, quantity and quality is the Data Quality Objectives (DQO) process (EPA 1992, XXXX). An explicit problem statement together with a list of specific decision alternatives is central to the process. For screening assessment, this might take the form:

- Are hazardous constituents present above screening action levels in the soils at this site? If so, a baseline risk assessment will be performed to evaluate the associated risks (which may require the collection of additional data); if not, no further action will be proposed.

To support a risk-based decision, we might ask:

- Do the level and extent of contamination at this site pose a health risk greater than 10^{-5} to future recreational users of the area? If so, VCA will be evaluated as an option to CMS/CMI (which again may require additional data); if not, no further action will be proposed.

Formulating an appropriate problem statement requires evaluating the current state of knowledge about the site. This evaluation is the first step of the seven-step DQO process outlined by the EPA (1991, 0746) and discussed in Appendix H. At the beginning of the RCRA process, archival information is used to construct a preliminary conceptual model for the problem. For later investigations, this step updates the conceptual model using data from previous investigations. Step 2 of the DQO process generates the specific problem statement and decision alternatives. Subsequent steps specify what types of measurements are needed, where and when measurements should be made and how the data will be used to support the decision. Design criteria that must be met in order to reduce decision uncertainty to a manageable level are developed in Step 6. The final step of the process is the preparation of a sampling and analysis plan that balances cost and uncertainty constraints to generate the required information.

While not all of the PRSs in the ER Program require that DQOs be developed following an extended formal process, the products of this process—the data quality objectives—are essential to ensuring that field investigations produce the necessary information. The RFI work plan Chapter 5 outline (Table 3-2) includes each of these products. Review of archival information and construction of a conceptual model (Step 1 of the DQO process) comprises the first of the four subsections devoted to a given PRS or aggregate. The second subsection reviews the potential response actions for the site and the current RFI decision in order to define the current problem and decision alternatives (Step 2 of the DQO process). The third subsection specifies data needs and data quality objectives for field work to collect environmental data in support of thisdecision (DQO Steps 3-6). The fourth and final subsection presents a sampling and analysis plan that meets these specifications (DQO Step 7).

Statistical aspects of the DQO process are further discussed in Appendix H.

4.1.3 Sampling Decisions in a Phased Investigation

The remediation decisions outlined in Section 4.1.1 must be supplemented throughout the RCRA process by a second important category of decisions, sampling decisions. A phased approach helps to ensure that sampling decisions remain closely tied to ultimate goal of selecting an appropriate corrective action, and that they incorporate what is already known about the site. Because there are some fixed costs associated with each deployment to the field, as well as variable costs that are proportional to the number of samples and the effort required to collect them, a phased RFI may have some drawbacks. However, in situations where a large number of sites must be screened and many may prove to be of little or no concern, the benefits of a phased approach far outweigh the costs.

The first phase of RFI field work, that is, the phase for which detailed sampling and analysis plans are written into the RFI work plan, collects information for the first decision in the flow of Figure 4-2 that can not be made on the basis of existing information alone. For many Laboratory's PRSs, this decision turns out to be determining the presence or absence of contaminants of concern at the site. Often an RFI investigation to answer this question is designed to detect contaminants if present above screening action levels (SALs) in environmental media at the site. Sampling plans are generally small and often incorporate professional judgment in their design. Because the goal is to detect contamination if it is present, sampling may be biased towards areas or media that are most likely to be contaminated, rather than being representative of the entire site. Screening assessments are discussed in more detail in Section 4.2, and statistical design aspects are discussed in Section 4 of Appendix H.

Investigation to support risk assessment is the type of sampling that is most often described and illustrated in regulatory guidance. The most site-specific aspect of risk assessment is exposure assessment to estimate the actual intake of contaminants that could occur under reasonable, site-specific exposure scenarios. If the exposure scenario involves receptors located at the site, exposure assessment requires estimates of the mean contaminant levels over exposure units whose size depends on current and future patterns of land use and other exposure assumptions. For receptors off the site, mean contaminant levels in exposure units removed from the source in space and time must be estimated, and it may be necessary to characterize potential environmental transport pathways or potential receptors as well as the level and extent of contamination at the site. Conservative estimates of these means such as upper confidence bounds are recommended. Risk assessment is discussed in Section 4.3, and statistical design of sampling plans to support risk assessment is considered in Section 5 of Appendix H.

An investigation designed to support a baseline risk assessment may not provide the amount or type of detail about the site that is necessary to design a corrective measure. If corrective action is

necessary, additional site characterization may be required to establish the most probable site conditions, together with the deviations from those conditions that may reasonably be anticipated. The goal of such additional sampling is often improved understanding of the spatial distribution of the contaminants or better characterization of hazardous constituents for treatment or disposal purposes. These diverse goals lead to diverse sampling designs.

Two possible RFI sampling decisions are actually decisions not to sample. Proposing no further action may be an appropriate decision based on archival information. In the RFI work plan outline shown in Table 3-2, PRSs for which no further action is being proposed on the basis of archival information are discussed in Chapter 6 of the work plans.

Deferred investigation may be proposed for a PRS where corrective action, if necessary, will be postponed until an associated active site is closed. If no investigation will occur during the RFI, these PRSs are discussed in Chapter 6 of the RFI work plan. Deferred investigation may also be proposed for a site where voluntary corrective action is planned. In this case sampling is integrated with the voluntary corrective action, for example, sampling to document the nature of the wastes for disposal or to verify that cleanup standards have been attained. The voluntary corrective action with its the sampling and analysis plan are described in Chapter 5 of the work plan.

For some sites where complete characterization is being postponed until VCA or decommissioning, an RFI screening assessment may still be appropriate. Screening assessment or perimeter monitoring may be required at a site where full investigation will be deferred. A limited RFI investigation may be designed to forestall unpleasant surprises such as the discovery of a large organic vapor plume under an old septic tank during VCA. These activities are described in Chapter 5 of the work plans.

Site characterization to detect deviations from probable conditions is handled by appropriate monitoring of the site during the CMI. Site monitoring may include in-situ measurement, sampling, or both. If sampling is performed, fast turnaround for analyses are important (i.e., indicator measurements that can be performed in a field laboratory are preferred whenever possible), and pilot studies to select appropriate measurement techniques may be useful. Long-term site perimeter monitoring may be installed to verify the continuing effectiveness of the corrective measure. The goal of monitoring, and hence its design, depends on the context within which it is used, but timely data analysis and predefined responses to potential anomalous observations are two important components of any monitoring plan.

Sampling to verify the attainment of cleanup standards is the final step in many corrective actions. In some respects, it is far more straightforward than sampling for site characterization. If clean-up has been successful, residual contamination should be fairly homogeneous as well as low level, and simple random sampling or grid sampling is usually entirely appropriate. Guidance for this type of sampling is found in EPA documents (e.g., EPA 1989, 0794).

4.1.4 Screening Assessment

For sites where there has been little or no previous investigation, the first RFI decision will generally be a screening decision. The goal of screening assessment is to identify contaminants of concern, that is, constituents whose concentration levels in one or more environmental media are above a level of concern, usually defined by media-specific screening action levels. Although some screening action levels are based on risk calculations, following the guidelines laid out in Appendices D and E of the proposed RCRA Corrective Action rule (EPA 1990, 0432), the screening decision is not a true risk-based decision. Screening action level calculations (described in Section 4.2.2 and Appendix J) use very conservative exposure assumptions that in

many cases are not appropriate for the sites under consideration. Moreover, the screening decision may be affirmative if only one sample contains constituent concentrations above the SAL. By contrast, a risk-based decision considers the distribution of contamination relative to the activities engaged in by a receptor under a realistic exposure scenario, which generally requires several observations.

The logic of a screening assessment is shown in Figure 4-3. The starting point is the identification of constituents and environmental media of potential concern, based on knowledge of the process or processes that occurred at the PRS. Elimination of other constituents from further consideration should be justified by reference to these processes. Screening for the identified constituents is then carried out using either existing data or new data collected during the RFI. It is essential to identify decision criteria (levels of concern), because the data, whether old or new, should be collected using procedures whose detection limits are below these levels.

Many screening assessments perform comparisons with SALs using individual observations; that is, a contaminant of concern may be identified on the basis of a single observation above the SAL (equivalently, if the sample maximum exceeds the SAL). The proposed RCRA Corrective Action rule also allows the use of "statistical analysis", implying that some statistic other than the sample maximum could be compared with the action level. If screening action levels are not exceeded for any constituent, then again the site may be a candidate for no further action, but in some cases additional site evaluation may be required. In particular, if two or more constituents are detected at elevated levels, even if below SALs, further evaluation is needed to determined their combined effects, as described in Appendix J.

Comparison of observed constituent concentrations with SALs is complicated for a handful of constituents because they are present in environmental media independently of Laboratory activities. These constituents are said to have positive or nonzero "background concentrations". At Los Alamos, constituents with positive natural background concentrations include many metals in the tuffs of the Pajarito Plateau and the soils and sediments derived from those tuffs. Anthropogenic background constituents include low levels of radionuclides from world-wide fallout. The background concentrations of radionuclides are well documented in existing literature. The ER Program's Framework Studies is currently collecting data to estimate background distributions for other constituents.

Where background concentrations and variability are far lower than SALs (which is the case for the majority of these background constituents) they may be ignored. However, observations of some constituents must be compared with the background distribution, as shown in Figure 4-3, and background comparisons may also be useful when summarizing results or communicating risks. In general, background comparisons need to be made in more than one way. The observations may fail to resemble the background distribution because they are uniformly large although possibly not excessivly large, or because there are one or two observations that are outside the normal range although the sample mean is not significantly different from the mean of the background distribution. Statistical tests for these conditions are described in Section 4 of Appendix H.

Constituents whose concentrations exceed both background levels and screening action levels, or that are included because they are significant in combination with other constituents present, require further evaluation and possibly remediation. Further evaluation may include comparing the observed levels with regulatory standards such as TSCA guidelines for PCBs or ALARA guidelines for radionuclides as well as baseline risk assessment, and may require additional field investigation.

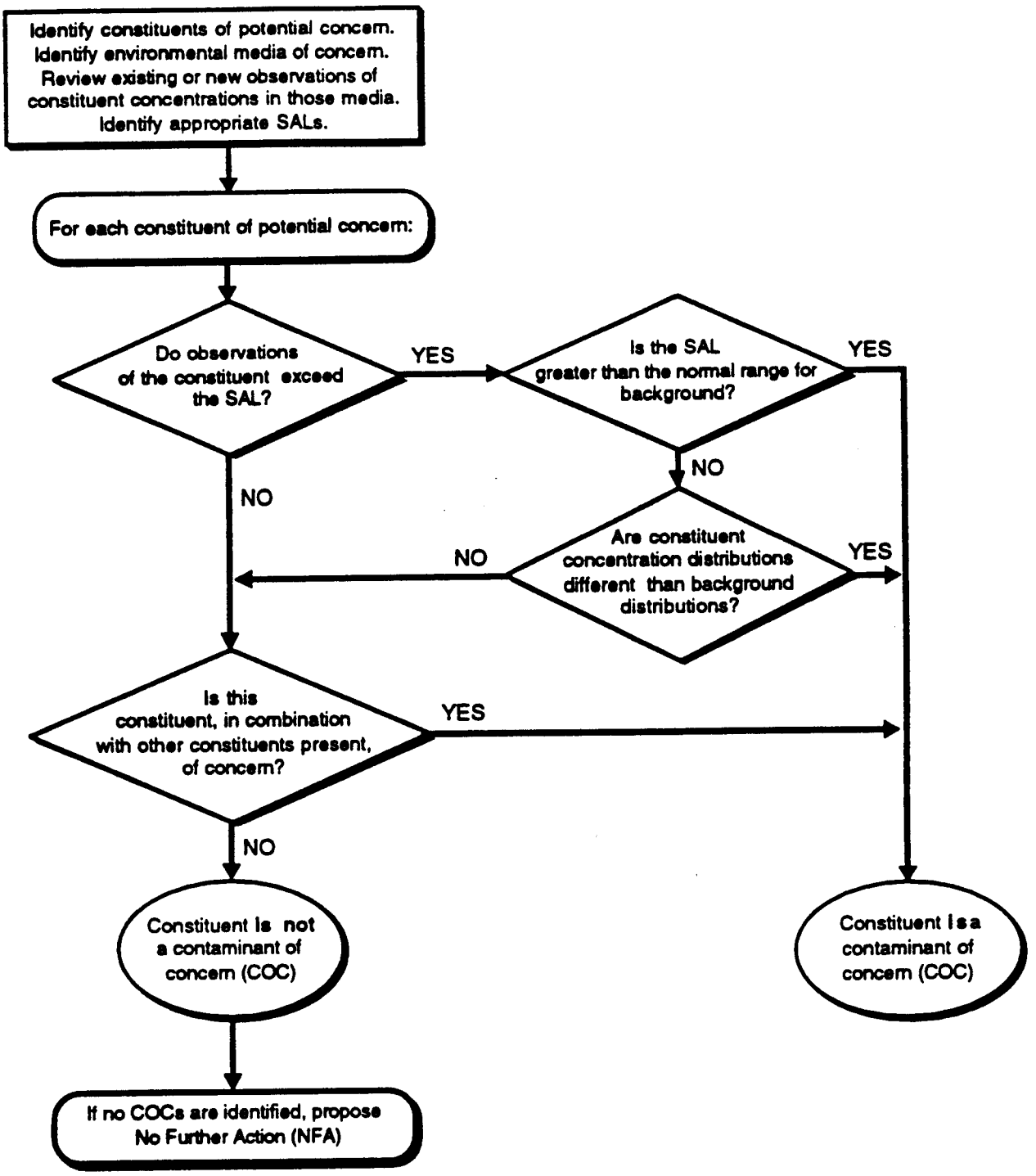

Figure 4-3. Decision Logic for Screening Assessments.

4.1.5 Risk-based Decisions

The presence of contaminant concentrations above SALs may not in itself warrant corrective action for any of a number of reasons. Screening action levels are purposely set very low, at levels to which sensitive receptors could be exposed on a daily basis without appreciable risk of adverse effects during their lifetimes. The extent and overall level of contamination may be such as to preclude negative impacts under a realistic exposure scenario for the actual site, or the available remediation alternatives may be far more destructive of the ecosystem than any historical release. Thus as outlined in the proposed RCRA Corrective Action rule (EPA 1990, 0432), further evaluation of the site may lead to the conclusion that a CMS is not necessary.

Further decisions about the site must take into consideration the actual risks associated with the identified contaminants. Among these risk-based decisions are determining whether corrective action is needed, establishing target cleanup levels for corrective actions, and defining levels of concern for site monitoring as part of a conditional remedy.

Risk-based decisions take into consideration not only contamination levels at the site but also the mechanisms by which biological organisms (human or other) might be exposed to this contamination, under exposure scenarios that are consistent with current and plausible future land use patterns. The risk associated with contamination depends on the actual dose to these receptors, which in turn is proportional to the intake of contaminants by the receptor integrated over both the spatial domain and temporal duration of exposure. Therefore a risk-based decision is most appropriately based on an estimate of the distribution of contamination throughout an exposure unit (EU) whose definition depends on the exposure scenario for which risk is being calculated. An EU may not be coterminous with the PRS; it may be smaller, or possibly larger. When it is smaller, then a risk-based decision for the PRS is actually a set of decisions, one for each EU contained within the PRS. Some current and future land use scenarios that can be used to derive appropriate exposure units, as well as exposure durations and frequencies, for Los Alamos PRSs are described in Appendix K.

Decision criteria for a risk-based decision can be formulated in two ways which are equivalent for simple cases. The more generally applicable formulation is based on the total risk associated with all of the contaminants of concern within an exposure unit and all of the potential exposure pathways for those contaminants. Risk calculations are described in Section 4.3 and Appendix K. This total risk is compared with a target risk level.

An alternative formulation, applicable to individual COCs with one or two significant exposure pathways, uses the risk model to translate the target risk level into a media-specific target concentration level. Calculations of this type are used in defining preliminary remediation goals and target cleanup levels that are protective of human health, as discussed in Section 4.2 and in the proposed RCRA Corrective Action rule. These target concentration levels are compared with estimates of the average concentration within the exposure unit, which is analogous to comparing the risk calculated from the integrated exposure of the receptor in that unit to the target risk level.

4.1.6 Data Quality Assurance

Data quality assurance is an integral part of the decision-oriented approach to field investigations described in the preceding sections. Specifically, as sampling strategies are logically derived from decision criteria and design specifications using the DQO process, many additional assumptions must be made. For example, in determining appropriate sample sizes for estimating the mean concentration of a contaminant within an exposure unit, assumptions are made about the expected types and sizes of errors arising from sampling and analytical measurement. When professional judgment or field surveys are used to bias sampling for screening assessments, it is

assumed that this will increase, or at least not decrease, the probability of detecting contamination if it is present above levels of concern. Many other assumptions, some more critical than others, will be made in the course of developing a sampling strategy to support an environmental decision. One of the main benefits of the DQO process is that it exposes these assumptions both for regulatory and public review. It also calls attention to important areas to be addressed by the data quality assurance program.

The purpose of data quality assurance is to ensure that the data are fit for their intended use in support of an environmental decision. A complete data quality assurance program has several aspects. It begins with a complete set of data quality objectives derived from the decision criteria and design specifications. It is implemented following a site-specific quality assurance project plan (QAPjP) that includes several components:

- in-line quality control (QC) measurements such as calibration checks and replicate analyses;
- formal and informal process audits, ranging from inspections by independent evaluators to daily "tailgate" briefings of the field crews;
- the collection of quality assessment (QA) samples that will be used to evaluate critical assumptions identified during the DQO process.

The final aspect of data quality assurance is data validation and assessment. Validation includes verification of completeness and review of documentation supporting the analytical results, as well as an analytical data assessment process that includes a review of calibration data, analyses of blanks, duplicates, and matrix spike samples, and other supporting information for at least a fraction of the reduced data. The final step, data quality assessment, evaluates the results in the context of the assumptions and the decision-based requirements.

Guidance for preparing quality assurance project plans (QAPjPs) for the ER Program is under revision, following recent revisions of EPA guidance. Existing RFI Work Plans include QAPjPs that are based on the draft Generic Quality Assurance Project Plan for RCRA Facility Investigations **(LANL 1991, XXXX Betsy, I want to cite the generic QAPjP but it is somewhere in limbo at the moment; what can I use for a reference? KC)**. Procedures for data verification and validation are being developed by the Sample Coordination Facility, which will perform these aspects of analytical data assessment. Data quality assessment procedures are described in Appendix H.

4.2 Evaluation Factors and Criteria

Section 4.2.1 describes the key factors to be considered in making sampling and remedial decisions. Among the concerns underlying these factors, risks to human health and the environment are of primary interest. Risk assessment (Section 4.3) will be used both during the RFI and during the later stages of the process. For the initial phase of the RFI, however, it is important to have simpler criteria that can be used to screen and prioritize the PRSs at the Laboratory. These criteria take the form of media-specific SALs (Section 4.2.2) against which environmental data can be compared directly. During site cleanup, it is also necessary to have media-specific criteria for evaluating progress (Section 4.2.3).

4.2.1 Evaluation Factors for the Laboratory's ER Program

In the Laboratory's ER Program, criteria used to evaluate decisions are based on common sets of

evaluation factors. The five major categories of concern for the Laboratory's ER Program are the same categories used by the Laboratory for many other decisions:

- impacts on human health and safety,
- environmental risks,
- impacts on the social and economic well-being of both the local community and the general public,
- management concerns related to compliance and operations, and
- monetary costs.

The HSWA Module of the Laboratory's RCRA permit (EPA 1990, 0306) and the DOE Office of Environmental Restoration and Waste Management explicitly state that the primary concern of the ER Program will be impacts on human and environmental health and safety, that is, the first two categories listed above. These priorities are reflected by the technical approach adopted throughout the ER Program.

For the ER Program, human health and safety include impacts on both site workers and members of the general public. Public and worker health effects are commonly estimated by risk assessment relative to two end points: excess lifetime cancer risk and noncarcinogenic toxicological impacts. Safety impacts are most often estimated for site workers; however, for some sites, such as those where undetonated explosives or ordnance may remain, public safety may also be a major concern. Safety impacts can also be quantified using probabilistic measures of risk. Health and safety concerns include not only the impacts associated with an actual or potential operational release but also those occurring as a result of remediation efforts.

Environmental risks will be evaluated through ecological risk assessments. Ecological risk quantifies the effect of releases of hazardous substances and by the physical disturbance cause by sampling and remediation on endpoints that represent individuals, populations, and ecosystems. Possible endpoints include threatened and endangered species (e.g., Jemez salamander, goshawk), economically important species (e.g., deer, elk), and significant ecological processes (e.g., detritivory, presence of a keystone species). The ER Program is developing a strategy to conduct ecological risk assessment that is coordinated with existing environmental laws, regulations, and guidelines; see Appendix L. The federal regulatory framework for evaluating environmental risks includes the National Environmental Policy Act, the Endangered Species Act, and the National Contingency Plan (for Natural Resource Damage Assessments).

Social and economic concerns include impacts on commercial and potentially developable natural resources, as mentioned above; impacts on the local community, such as the need to absorb large numbers of new, possibly temporary, workers; and public alarm over actual or potential releases of toxic materials to the atmosphere or major aquifers.

Direct impacts on the Laboratory include both operational impacts (such as loss of productivity caused by disruption of normal research and development activities) and penalties for noncompliance with legislative or regulatory directives.

The final category of concerns, costs, includes not only the direct monetary costs of performing RCRA investigations and corrective actions but also other impacts of these activities on ER Program operations, including the program's ability to coordinate resources such as mobile laboratories, analytical laboratories, and personnel.

Methods for decision making to satisfy multiple objectives, especially in the presence of uncertainty both about actual conditions and about the effectiveness of proposed actions, range from the intuitive approaches used in everyday life to formal decision analysis as described in Appendix I. Given the legal and other ramifications of RCRA process decisions, methods near the formal end of this spectrum may be preferred to less formal approaches. However, the primary RCRA requirement is that the decision process be technically sound and well documented. The technical approach of the ER Program at the Laboratory provides for a range of methods so that the formality of the decision-making process can reflect the complexity of the problem.

4.2.2 Screening Action Levels

SALs are media-specific concentration levels for constituents that can be compared with measurements of concentration levels made during RFI investigations in order to make preliminary or even final decisions about the site. SALs are used

- to prioritize RFI/CMS activities, focusing resources appropriately for timely and cost-effective investigations and corrective actions;
- to identify contaminants of concern should a more thorough risk assessment be required; and
- to indicate PRSs at which constituent concentrations are very unlikely to be of concern from the perspective of human health and the environment and that are therefore appropriate to propose for NFA. In addition, an evaluation of the NFA proposal will incorporate consideration of ALARA guidelines, appropriate regulatory standards, ecological impacts, and the potential for effects from multiple contaminants.

Appendix J provides tables of SALs for some potential chemical and radiological constituents of PRSs at the Laboratory. SALs to be used as above should be conservative. The calculated values are conservative partially because they are based on an assumed land use that involves intensive exposure to contaminants (i.e., residential). Therefore, detection of constituents in concentrations greater than SALs does not necessarily indicate the need for corrective action, only for more site-specific evaluation and possibly further site characterization. A site-specific baseline risk assessment using more realistic current and future land use assumptions, as discussed in Section 4.3, may indicate that NFA is appropriate. For a few contaminants cleanup standards that exceed the SALs calculated in Appendix J are established by law.

There are a small number of constituents for which detection limits less than SALs are not technically achievable. The available analytical method with the lowest detection limit will be selected for these constituents, and this detection limit will be used as a SAL.

4.2.2.1 Nonradiological Constituents

The ER Program will derive SALs for nonradiological constituents following the methodology published in proposed Subpart S to RCRA (EPA 1990, 0432). The list of action levels provided in the supporting materials for proposed Subpart S includes a limited number of organic and inorganic constituents but does not address all potential constituents of concern at the Laboratory. Screening action levels for additional nonradiological hazardous constituents are shown in Table J-3 of Appendix J.

The following principles, as given in proposed Subpart S, are used to develop SALs for the RFI:

- SALs must be determined in a manner consistent with the principles and procedures set forth in EPA guidelines for assessing the health risks of environmental pollutants.

- Toxicology studies must be scientifically valid and must be conducted in accordance with the good-laboratory-practice standards set forth in 40 CFR 272 (EPA 1989, 0433). Because the verification of these requirements is labor-intensive, SALs will be based, when possible, on toxicity values available from the most recent version of EPA's Integrated Risk Information System (IRIS) data base (EPA 1992, 0830) or on EPA's health effects assessment summary tables (HEAST) document (EPA 1991, 0658). These values have undergone extensive scientific scrutiny. When IRIS or HEAST does not provide toxicity values for a constituent, other toxicological data may be used. In particular, derivation of toxicity values may be necessary for certain chemical mixtures (e.g., high explosives) that are likely to be present in some media at the Laboratory.

- For Class A and B (known and probable, respectively) nonradiological carcinogens, SALs must be consistent with a 10^{-6} upper-bound excess cancer risk. For Class C (possible) carcinogens, SALs must be consistent with a 10^{-5} upper-bound excess cancer risk.

- Concentrations of systemic toxicants should be set so that a human population could be exposed on a daily basis without appreciable risk of adverse health effects over a lifetime. This method of evaluation uses "reference doses" as toxicity values; these values are concentrations below which adverse effects have not been observed and which incorporate uncertainty factors.

- Applicable federal and state regulatory standards exist for maximum contaminant levels in drinking water, they will be used as SALs.

At Los Alamos, SALs are needed primarily for soil materials. Analogous SALs will be used for other environmental media (e.g., groundwater, surface water, and air), as necessary. Because the EPA has not recommended special criteria for sediments or for saturated soils that are not part of an aquifer, the Laboratory will use the same SALs for these media as for soils. Additional evaluation methods may be needed for substances that involve unique exposure considerations (e.g., structural debris, shrapnel, high explosives, asbestos); these evaluation methods are discussed in Appendix J.

SALs for soil, groundwater, surface water, and air will be based on the default exposure assumptions recommended in Subpart S (EPA 1990, 0432). In general, the receptor is assumed to be a long-term (i.e., 70-yr) resident at the PRS and is assumed to be present 365 days/yr, drink 2 L of water per day, and inhale 20 m^3 of air per day. Following Subpart S guidance, soil ingestion scenarios assume that the receptor is a child who ingests 200 mg/day of soil (for systemic toxicants) or an adult who ingests 100 mg/day of soil (for carcinogenic constituents).

SALs for soils are applicable to surface soils (e.g., the upper 2 ft of earth) and also to near-surface soils (e.g., the upper 12 ft of earth) for locations where excavation for housing or commercial/industrial development could bring subsurface soils to the surface. These soil depths are specified in EPA's interim final RFI guidance (EPA 1989, 0088). For mesa top areas, where the soil that overlies the tuff or basalt is sometimes only a few inches deep, constituent levels are evaluated for soils down to the depth at which consolidated materials are located.

When volatile constituents are present in soils or tuff, exposure via inhalation is also possible. Evaluation of this exposure route for soil constituents with significant volatilization potential is accomplished using an EPA methodology (EPA 1991, 0302) and appropriate residential exposure assumptions (Appendix J).

If constituents are detected above background levels in unsaturated deep soils, for which the direct exposure scenarios underlying the definition of SALs for surface soils are inappropriate, the RFI assesses whether these constituents might migrate to an aquifer in concentrations exceeding the SALs for groundwater. Determination that such a potential exists could trigger a CMS.

SALs for water will apply to groundwater, alluvial aquifers, and perennial surface waters. As defined in 40 CFR 260.10, an aquifer is a geologic formation, group of formations, or part of a formation capable of yielding a significant amount of groundwater to wells or springs. SALs for water will be calculated as shown in Appendix J. If regulatory standards (e.g., maximum contaminant levels specified in the Safe Drinking Water Act, 40 CFR 141.11;141.61) exist that are lower than calculated values, these lower values will be used as SALs. With the exception of one or two OUs, data on hazardous constituent levels in groundwater will not be collected for initial characterization of individual PRSs. If subsurface data for any PRS indicate that contamination caused by Laboratory operations may have migrated to the depth of the main aquifer (i.e., several hundred to 1,000 ft), groundwater data from that PRS will be obtained and compared with SALs. Additionally, if alluvial aquifers capable of yielding sufficient water to maintain a well are identified, constituent concentrations in the aquifer will be compared with SALs.

The regulations that implement the Clean Water Act (40 CFR 122.2) define surface waters, or "waters of the United States," as lakes, rivers, streams (including intermittent and ephemeral streams) and other surface water bodies (and their tributaries) that could be used for recreational purposes, fishing, or industrial purposes. Perennial surface water features at or near the Laboratory include Ashley Pond in TA-1 and the upper reaches of streams in the canyons. The lower reaches of most canyon streams in the Los Alamos area become intermittent or ephemeral surface water features as they near the Rio Grande. SALs derived for groundwater will be applied to Ashley Pond and canyon stream water, as discussed above and in Appendix J; this approach is consistent with proposed Subpart S guidance.

The derivation of SALs for air is described in Appendix J. Currently, there are no known operative emission sources (e.g., stacks) at the PRSs to be evaluated under the ER Program. However, if needed, SALs for air will be applied at the point of closest public access to the PRS under investigation. Exposure to volatile contaminants in soils will be evaluated using soil screening criteria (as discussed above and in Appendix J).

4.2.2.2 Radiological Constituents

Radiological materials (except mixed wastes) are not regulated by RCRA and are not subject to the provisions of the HSWA Module; therefore, the action levels in proposed Subpart S do not address radioactive constituents. However, to allow consideration of all relevant and applicable standards for the protection of human health and the environment, consistent with DOE orders stipulating that corrective actions meet the requirements of CERCLA, the ER Program will address radiological as well as nonradiological constituents. Thus screening criteria are needed for radiological constituents. Together with the SALs for nonradiological constituent levels, the SALs for the radiological constituents will permit prioritizing sites needing characterization and subsequent remedial actions.

Considerations that influence the development of SALs for radiological constituents include the following:

- Most current radiation protection standards (e.g., 40 CFR 190; 40 CFR 141.16; DOE Orders 5400.5 and 5480.14;10 CFR 61; and 10 CFR 20) are based on dose limits rather than on concentration limits in environmental media. Many of these radiation dose limits apply to cumulative exposures from all radioactive constituents present and may apply to a specific exposure pathway or multiple pathways.

- Radiation dose to humans from background radiation [approximately 327 mrem/yr (LANL 1992, 0740)] is much higher than limits established in radiation protection standards for the public.

- The generally accepted radiation dose limit for the individual in the general public who receives the maximum exposure is 100 mrem/yr over background (DOE 1990, 0080; ICRP 1991, 0777; NCRP 1988, 0778; and 10 CFR 20). Radiation dose to the public is further limited to 25 mrem/yr from individual facilities or sources [e.g., 40 CFR 190-192; DOE Order 5820.2A (DOE 1988, 0074); and 10 CFR 61]. These are cumulative limits for all radioactive constituents and pathways, and lower limits must be used when considering individual pathways or radionuclides. Thus, it seems appropriate to set the dose limit for individual radionuclides at a fraction of the 100-mrem/yr and 25-mrem/yr limits in order to derive appropriate SALs for a single constituent at a PRS.

- In addition to dose-based criteria, DOE Order 5400.5 contains a requirement to adhere to the ALARA principle to maintain all radiation exposures to levels as low as reasonably achievable (DOE 1990, 0080).

- SALs must also be high enough to allow discrimination between areas of manmade contamination and uncontaminated areas. Limitations of current instruments for discriminating between background and above-background levels of ionizing radiation must be considered.

In view of the above considerations, an annual dose limit of 10 mrem/yr (incremental above background and cumulative over all exposure routes) is proposed here as the basis for deriving SALs for the radioactive constituents in soils. The rationale for this proposed dose limit is as follows:

- The proposed dose limit of 10 mrem/yr is a fraction of the current regulatory standards of 100 mrem/yr and 25 mrem/yr above background.

- The dose limit of 10 mrem/yr is specified in DOE Order 5400.5 as a reporting level for doses to the general public resulting from activities conducted under DOE programs.

- The recommended dose limit is compatible with the direct detection limit (about 1 mR/hr) for current instruments designed to detect gamma radiation in the field.

- A lower dose value may not be discernible from the background radiation.

Screening levels for radionuclides based on the proposed dose limit can be derived using the RESRAD code (Gilbert et al. 1989, 0754), which has been developed by DOE for use in developing guidelines for residual radioactive material. Use of RESRAD methodology for developing guidelines is specified under DOE Order 5400.5. As for nonradiological constituents,

SALs for radionuclides will be derived based on the assumption of residential land use in order to derive the most conservative (i.e., lowest) SALs. Environmental parameter values (e.g., soil properties, rainfall) required by the code are set appropriately for the Pajarito Plateau.

RESRAD can be used to model exposure to multiple radionuclides from multiple environmental media and pathways, including soil, air, surface water, groundwater, and food products. Potential exposure routes include direct external exposure, inhalation (particulates and radon), and ingestion (soil, water, and food products). In order to derive media-specific SALs, RESRAD is used for single radionuclides and individual environmental media. Existing regulatory standards for certain radionuclides [such as 4 mrem/yr for manmade beta-gamma emitters in drinking water (40 CFR 141.16)] will be used as SALs when they exist.

Screening action levels for soil and water are presented in Table J-5 of Appendix J.

If all radiological constituents in a PRS are determined to be below SALs, the DOE nonetheless requires that a further evaluation be conducted to determine that levels are as low as reasonably achievable (DOE 1990, 0080). If social, technical, economic, and public policy considerations indicate that lower levels are achievable, remediation may be required.

4.2.3 Cleanup Criteria

SALs are not cleanup criteria; they are generally used only to identify contaminants of concern and to guide further sampling efforts. Because they are conservative, their use as media cleanup levels might be unnecessarily restrictive and often impracticable as well. Development of appropriate media cleanup standards is one of the tasks of the CMS for each site (Section 3.5.2). There are also some legislative cleanup standards, such as those provided for polychlorinated biphenyls (PCBs) to implement the Toxic Substances Control Act (40 CFR 761), that may be applied, especially for VCAs. Proposed media cleanup standards are included in the RCRA permit modification that initiates the CMI (Section 3.5.2).

Methodologies for establishing preliminary target cleanup levels have been recommended by EPA in CERCLA risk assessment guidance documents (EPA 1991, 0302). For nonradiological constituents, target cleanup levels are generally established within the protective risk range of 10^{-4} to 10^{-6}, as specified under proposed Subpart S guidance for CMS evaluations (EPA 1990, 0432). Among the radionuclides, standards have been established only for radium and thorium (40 CFR 192); therefore, they will need to be derived for other radiological contaminants of concern.

In addition to the protection of human health and the environment, a number of other factors need to be considered in selecting a remedy, together with the final media cleanup standards. Factors mentioned in the National Contingency Plan (40 CFR 300, EPA 1990, 0559) include reduction of toxicity, mobility, and volume of wastes; short-term effectiveness; compliance with regulatory requirements; long-term effectiveness; implementability; public acceptance; and cost. The proposed RCRA Corrective Action rule (EPA 1990, 0432) reserves to the EPA the right to set cleanup standards different from the preliminary target levels, because those standards may be affected by remedy factors that can not be fully evaluated until the CMS is completed.

4.3 Approach to Programmatic Human-Health-Based Risk Assessment

4.3.1 Background

To meet the requirements of RCRA and CERCLA, the RFIs at the Laboratory address the potential risks to human health associated with contaminants at, or released from, PRSs. The nature, level, and extent of contamination at PRSs are determined through the site characterization process. The ER Program has adopted a phased approach to site characterization and evaluation of potential health risk (Section 4.1 and Figure 4-1). In this approach, baseline risk assessment may be needed following the identification of some contaminants of concern or following determination that corrective action may be needed based on ALARA guidelines, ecological risks, or other considerations.

EPA has not published detailed risk assessment guidance for sites regulated under RCRA. The ER Program's approach to risk assessment generally follows the methods EPA has recommended for CERCLA sites (EPA 1989, 0305; EPA 1991, 0302; EPA 1991, 0831). However, some modifications to that approach will be made in the Laboratory's ER Program. In particular, a comparison of contaminant levels at a PRS with SALs will be substituted for the CERCLA procedure for identifying contaminants of concern (EPA 1990, 0432).

The major elements of baseline risk assessments to be conducted for the Laboratory's ER Program are

- identification of contaminants of concern by means of the screening process described in Section 4.2.2;
- exposure assessment, the identification of appropriate land use scenarios, and environmental migration pathways and receptors, and estimation of contaminant migration and intake parameters in order to translate concentrations of contaminants in environmental media into chemical intake and radiological dose levels for human receptors;
- toxicity assessment, the identification of significant toxic effects and routes of toxicity of contaminants of concern, and quantification of these effects; and
- risk characterization, the estimation of noncarcinogenic toxic impacts, and excess cancer risks as a function of intake or dose.

These four steps can be applied to characterize the cumulative risk associated with multiple PRSs in an operable unit (OU) or across the Laboratory, as well as the impact of a single PRS.

For PRSs containing constituents in excess of SALs, baseline risk assessments may be performed using the data collected for the screening assessment if these are adequate. In other cases additional data may be required. Baseline risk assessment may serve either to support an RFI decision that no further action is required, or to provide a point of comparison relative to which the benefits of a proposed corrective action can be evaluated. CMS risk assessments address both long-term risks remaining after implementation of a proposed remedial alternative and short-term risks to workers and the public of implementing the proposed alternatives.

A risk assessment methodology is being developed to (1) establish the scope of baseline risk assessments, (2) establish the scope of the CMS risk assessments, and (3) establish a consistent approach to risk assessment for all OUs. This methodology is described in Appendix K, which

specifies the contents of the OU-specific baseline risk assessments to be prepared during the RFI. Risk assessment to evaluate corrective alternatives is under development.

In the following sections, the components of baseline risk assessments outlined above and of risk assessment for the CMS process are described in greater detail.

4.3.2 Identification of Contaminants of Concern

PRS constituents measured at levels above SALs and background levels will be considered contaminants of concern that need to be considered in risk assessments for a given PRS. In addition, as noted in Section 4.1.4, some constituents may be identified as contaminants of concern even when below their SALs in cases where more than one hazardous constituent is present. Exposure assessment and risk assessment, as described below and in Appendix K, will be conducted for these contaminants only.

4.3.3 Conceptual Models for Exposure Assessment

Conceptual exposure models are used to describe the source or sources of contamination, the movement of contaminants through the environment, and the exposure of human receptors. These models will be used to help identify appropriate media and locations for sampling. The data will be used to estimate model parameters so that radiological doses and chemical intake by receptors can be estimated with site-specific information.

Contaminant sources can be categorized as primary (e.g., the PRS itself) or secondary. Examples of primary sources at the Laboratory are septic tanks, drainlines, buried structures and wastes, lagoons, debris on canyon walls, and landfills. Secondary sources are environmental media that have been contaminated as a result of a historical release from a primary source, such as channel sediments contaminated by releases from outfalls and soil and tuff beneath a leaking tank.

Potential mechanisms by which contamination may be released from a source to the environment include leakage, infiltration, leaching, re-entrainment of contaminated particulate matter by wind or surface run-off, particulate settling, erosion, human and animal intrusion, and evapotranspiration. Possible environmental migration pathways include air, surface water, the vadose zone, groundwater, plants and animals, and direct contact with soil or structural surfaces. Laboratory studies support the current assessment that extensive liquid-phase migration in the vadose zone is highly unlikely in the Bandelier Tuff because the tuff is extremely dry and infiltration of natural precipitation cannot provide the quantities of water necessary to sustain movement of contaminants downward (Purtymun and Stoker 1988, 0205). However, vapor phase migration is possible in the vadose zone.

Potential contact media are those with which a receptor may come into contact: soil, groundwater, surface water, air, and the surfaces of structures or debris. Groundwater in the regional aquifer is not currently considered a potential contact medium because of the great depth to the water table and limited transport in the vadose zone. However, it is possible that in the future alluvial aquifers could serve as a source of domestic water. Exposure may occur as a result of inhaling, ingesting, or coming in direct contact with these contaminated media.

Exposure to external radiation is a special type of exposure because transport of contaminants through environmental media is not necessary for the receptor to receive a dose. However, dose decreases exponentially with increasing distance from the source.

Assumptions about current and future land uses are important in identifying the receptors to be

used in baseline risk assessments. Current PRS land uses include residential, recreational, and commercial/industrial use as part of continued Laboratory operations. A few PRSs located in the town of Los Alamos are classified as residential. A few other PRSs that are neither located on Laboratory property nor used residentially are categorized as recreational land use. In general, land use of the OUs located on Laboratory property is considered commercial/industrial, although recreational use of a few unfenced sites may occur. However, many of the technical areas are fenced and most are under some form of institutional control (i.e., access is restricted).

It is assumed that future use of all PRSs not currently located on Laboratory property may be residential. For most PRSs located on Laboratory property, continued commercial/industrial use and eventual release of these lands for recreational use (e.g., camping) is assumed. The use of such assumptions for risk assessment is supported by proposed Subpart S, which states that

> "contaminated soil would be remediated to levels consistent with plausible future patterns of use... . At industrial sites or sites dedicated to long-term hazardous waste management, cleanup to less stringent levels (than residential cleanup levels) might be appropriate, although institutional controls could be necessary to ensure that the use pattern did not change" (EPA 1990, 0432).

If Laboratory property is released for recreational use in the future, risk assessment based on these assumptions will remain appropriate. However, limited areas that might be used residentially (e.g., for ranger housing) should be re-evaluated at the time of transfer, using assumptions for a residential exposure scenario.

The Laboratory plans long-term hazardous waste management for some of the material disposal areas (MDAs) and possibly for a small number of additional PRSs. For baseline risk assessments, it is assumed that these sites will be under institutional control for 100 years or more. At MDAs in which buried transuranic waste contains concentrations greater than 100 nCi/g, a longer period of institutional control may be assumed. Risk assessment for appropriate exposure scenarios (e.g., exposure of trespassers) will be conducted for these areas.

Current occupational exposures to Laboratory workers are evaluated by the operating groups of various facilities or by the Health Physics Operations (HS-1), Safety and Risk Assessment (HS-3), and Industrial Hygiene (HS-5) groups in compliance with Occupational Health and Safety Act requirements and with DOE Order 5480.11 (DOE 1988, 0076). Risk assessment for future commercial/industrial use scenarios will evaluate non-Laboratory workers as the primary receptor at these PRSs. Standard default exposure parameters for commercial/industrial receptors will be used for these assessments.

4.3.4 Toxicity Assessment

Two types of toxicity will be considered: systemic toxicity and carcinogenic effects. Methods for estimating the carcinogenic effects of nonradiological contaminants differ from those to be used for radiological contaminants.

Systemic toxicity and carcinogenic risk for nonradiological contaminants of concern will be evaluated using toxicity values (if available) obtained from the most recent versions of EPA's IRIS data base and HEAST document. Other toxicity values may be derived based on data from the literature if values are not available from IRIS or HEAST. The hazard index (Appendix J) provides a measure of systemic toxicity. Excess cancer risks will be estimated for potential carcinogens.

Exposure to radiological contaminants of concern will be evaluated initially by estimating annual doses for the appropriate potential receptors using the RESRAD code. These dose estimates will

be converted to carcinogenic risk estimates using data from EPA (1989, 0781) and the National Research Council (BEIR 1988, 0030).

Other potential toxicological effects of radiation exposure include genetic and reproductive effects. However, the risk that these effects will occur is generally much lower than the risk of cancer induction. Therefore, the EPA considers that carcinogenic risk assessment is sufficient evaluation of toxic effects for radionuclides (EPA 1989, 0305).

4.3.5 Risk Characterization

The exposure model and the toxicological model are used together to estimate the risk of systemic toxicity and carcinogenic effects associated with one or several PRSs impacting the same receptor. Risk estimates for nonradiological contaminants of concern will be compared with the acceptable risk range designated by EPA for exposure to the general public (target risk range). This risk range is 10^{-4} to 10^{-6} excess upper-bound lifetime cancer risk to an individual (EPA 1990, 0432) for carcinogens. For systemic toxicity, exposure levels will be evaluated by comparison with an acceptable hazard index equal to one. For radiological contaminants of concern, estimated doses, will be compared with the target dose limit of 10 mrem/yr.

Cumulative impacts across PRSs in an OU will be evaluated in OU-specific baseline risk assessments. The need for a separate risk assessment addressing cumulative health effects from multiple OUs is evaluated in Appendix K.

4.3.6 Risk Assessment for Corrective Actions

The CMS risk evaluations will generally follow the methodology used for baseline risk assessment. The risks for each alternative will be evaluated to determine how well the alternatives meet requirements for overall protection of human health and the environment. CMS assessments will generally focus on the long-term effectiveness of the corrective measure alternatives by evaluating the anticipated residual risks remaining after remediation. Short-term risks associated with the alternatives will also be evaluated, including risks to workers implementing the proposed alternatives.

Following CMI or VCA, a final risk assessment may be performed to provide another measure (in addition to or instead of direct comparison with media cleanup standards) of the effectiveness of the implemented remedy. These evaluations will also follow the methodology used for baseline risk assessment but will incorporate data collected during the corrective action or by a longer-term monitoring program.

4.4 Field Analytical Measurements

Many field survey instruments have been developed for health and safety (H&S) monitoring, and some of these may provide useful information for field investigations as well. In addition, many new instruments intended for field data collection are becoming available commercially or in prototype. Another field option for the Los Alamos ER Program is the use of mobile field laboratories capable of providing rapid turnaround for many types of analyses using modified laboratory procedures.

Neither field survey measurements nor field laboratory analyses can replace fixed (offsite) analytical laboratories, but they can make decision-making more efficient by improving timeliness,

resource use, and data quality. During investigations for screening assessments, for example, field laboratory measurements may be used to bias sampling towards areas where COCs have higher concentrations. At a well-characterized site it may be possible to calibrate a field survey instrument with sufficient precision to guide remedial work.

The selection of appropriate field methods, like the selection among alternative laboratory procedures, must always be specific to the site decision that is being made. This section includes a very brief survey of the most commonly used options. For detailed performance information and for suggestions for tailoring their use to the problem at hand, the analytical technical team should be consulted.

4.4.1 Field Screening

Field screening instruments are usually hand-held or easily transportable devices that provide a direct data readout for a specific analyte or for class of analytes (e.g., volatile organics or gamma emitters). While quantitative readings are usually obtained for the analyte or class of analytes, these quantitative estimates often have high measurement uncertainty. Typically, these measurements are not used directly to make RFI or CMI decisions, but are helpful in selecting biased samples for submission to field and off-site laboratories on which decisions in these phases are made. Several of these instruments find their primary use in meeting site worker health and safety (H&S) requirements. Their use helps ensure that appropriate worker protective equipment is used even before laboratory data is available.

4.4.1.1 Organic Vapor Surveys

A photo ionization detector (PID) is a general survey instrument capable of detecting in real time the concentrations of many complex organic compounds and a few inorganic compounds volatilized into air. It is a non specific detector for volatile "straight chain" hydrocarbons and volatile aromatic components. Compounds are detected when a UV light source of sufficient energy excites volatile organic compounds and ionizes them. (Air samples must be confined with the probe to give a representative reading, otherwise air currents will tend to dilute VOC concentrations.) The instrument reports concentration in ppm based upon some standard (typically benzene) on three scales: 0-20 ppm, 0-200 ppm or 0-2000 ppm, with a nominal minimum detection level of 1 ppm.

A flame ionization detector (FID) may also be used as a general screening instrument to detect the presence of many organics. Its response to an unidentified sample is relative to the response to a gas, typically benzene, to which the instrument has been calibrated, with a nominal minimum detection level of 1 ppm. The detector's use is limited by problems with the flame being extinguished under breezy to windy field conditions.

The organic vapor analyzer (OVA) is based on gas chromatography, which separates organic volatile compounds based on their retention time in a column. This instrument is typically not used for H&S since it is relatively slow. (The retention time of benzene is five minutes.) It is useful at sites where the analytes have been identified and approximate boundaries of contamination need to be established, as during cleanup when a quick determination can be used to move remedial activities on to other areas. These analyte concentration estimates are not used to confirm the adequacy of the remediation. The nominal MDL is 1 ppm.

4.4.1.2 Inorganic Surveys

In laser-induced breakdown spectroscopy (LIBS), a laser spark is used as an excitation source for the analysis of inorganic compounds via atomic emission spectroscopy (AES). The laser pulse is focused on or in the material to be analyzed, vaporizing the material and forming a plasma of high temperature and high electron density. Analyte species of interest are identified in this plasma of electrons and excited atoms by their emission spectra. The minimum detection limit for chromium compounds is 2 ppm, with a relative standard deviation of 20% and 80% recovery. Performance depends on the species, and may vary by an order of magnitude in either direction from these values.

X-ray fluorescence (XRF) is used to measure metal concentrations in samples of dried soil or crushed debris placed in a sample chamber, or in situ on soil or other surfaces. XRF can detect most RCRA metals, excluding Be. A key point of the XRF technology is that only the surface of the solid will be excited by the sources, which means that repeated measurements of a poorly homogenized sample may provide variable results, while in situ measurements represent only the exposed surface. The impact of this aspect of XRF on bias and precision for PCOCs in soils of interest to LANL must be taken into account when planning the environmental data collection survey.

Including set-up time, one sample can be analyzed approximately every 10 minutes by XRF. Up to practical limits, counting time can be increased to decrease detection limits. (The rule-of-thumb for instruments based on a counting technology is that a doubling of counting time decreases the detection limit by 29.3%.) Counting time must be selected with a knowledge of the list of PCOCs and their appropriate SALs. Minimum detection limits vary by element; manufacturer specifications should be consulted. Some units have data storage capacity for several tens of samples, after which data can be downloaded to a PC. Calibration and field application procedures are recommended by the instrument manufacturer.

4.4.1.3 High Explosives Surveys

A field spot-test kit has been developed to identify the presence of explosives as contaminants on equipment and materials. Three reagents in a carrying case with a portable ultraviolet (UV) lamp can be used to detect most of the common explosives used at Los Alamos, except picric acid, NC and TATB. After a suspect area or material is wiped with a clean filter paper, a drop of each of the three reagents placed on different parts of the sample will change color when explosives and/or other nitrogen compounds are present. A UV light (short wavelength, 254 nm) enhances color for RDX/HMX explosives. For checking soil contaminated with TNT, it was possible to detect a content as low as 0.01% (100 ppm) as determined by laboratory experiments. Other reported minimum detection limits are 100 ppm for tetryl and greater than 5% for HMX, RDX, PETN, and NQ.

4.4.1.4 Radiation Surveys

Three hand-held instruments are used primarily for health and safety screening.

- The ESP beta/gamma probe (Eberline) detects beta and gamma radiation. The detector surface is placed on or just above the surface to be sampled for a standard counting time of one minute. This instrument reports total counts and has an optional speaker to alert the operator to areas of very high radionuclide concentrations. Typical background readings are 200-300 cpm, and the H&S action level is 800 cpm, which corresponds to an

exposure of approximately 0.2 mRad/h.

- The micro-R meter detects highly energetic beta and gamma radiation. The detector is enclosed. Measurements are reported in mRem/h, where a background value is approximately 30 mRem/h.

- An alpha meter detects alpha particles. Its external probe is easily damaged; there is a special light sensor in the probe to indicate a problem. If the soil is even slightly damp, an alpha meter will not detect alpha particles. A typical background reading is 3 cpm.

The FIDLER is used for low energy gamma and x-ray surveys, and a more recent version of the FIDLER that is capable of providing spectral data is called the Violinist. These instruments are designed to detect low-energy photons, such as the 60 keV gamma emission from ^{241}Am or the x-rays that accompany the decay of heavy radionuclides such as thorium, plutonium and other transuranic radionuclides, and some fission produces such as ^{137}Cs. The FIDLER detector is optimized to detect plutonium emissions. Surveys are conducted by placing the instrument close to the ground surface (a stand provides a fixed geometry) and observing the rate meter or scalar. A typical counting time for Pu, Am and Cs is 200 seconds. Other radionuclides such as ^{40}K may require longer counting times. Scintillation detectors like FIDLER are sensitive only to surface contamination, and instrument readings can be biased by overburden (snow, soil, moisture, etc.) covering the source. They can be calibrated to read out activity per unit area.

4.4.1.5 Immunoassays

Immunoassays are newly emerging procedures for direct measurement and range quantitation of contaminants such as petroleum products (benzene, toluene, ethyl benzene, and xylene—BTEX), polyaromatic hydrocarbons (PAHs), TCE and several pesticides. The tests use enzymes developed to respond to the presence of a specific contaminant. Their specificity allows for a very low rate of false positive and false negative measurement findings. For example, the false positive and negative measurement findings for BTEX are less than 5%, with water sensitivity of 250 ppb and soil sensitivity of 3.5 ppm. For Total PAHs the detection limit is 0.7 ppm in soil from a 16 PAH component standard.

4.4.2 Mobile Field Laboratories

Two types of mobile laboratories have been developed for use at Los Alamos. The mobile laboratory platforms are based in trailers equipped with the required environmental controls and power to support established or emerging analytical technologies. Analytical instrumentation and methods now available in these platforms generally parallel established fixed laboratory methods.

The mobile chemical laboratory is equipped with gas chromatography, gas chromatography/mass spectrometry, an infrared analyzer for total petroleum hydrocarbon analysis, and an X-ray fluorescence analyzer. Analytical procedures for volatile organics, semi-volatile organics, and PCBs parallel existing U.S. EPA SW-846 methodology (**US EPA, 1990 xxxx**). Analytical procedures performed within the mobile chemical analytical laboratory are designed to minimize sample preparation time, solvent/reagent use, and analytical data turnaround time. Differences between mobile chemical laboratory procedures and fixed based laboratory procedures generally reflect the need to reduce extraction solvent volume and sample volume. This change can result in elevated reporting limits for the mobile chemical laboratory analyses compared to fixed base laboratory analyses. Mobile chemical laboratory analyses generally target specific analytes (organic or inorganic compound). Capability for identification of compound structure can be

developed in some instances.

The mobile radiochemical laboratory is equipped to perform gross alpha/beta, gross gamma, gamma spectroscopy, percent moisture determinations and tritium analyses. Currently, available methods in the mobile radiochemical laboratory are based on established technologies for radiochemical analysis, although counting times for detection of radiological decay have been shortened to ensure rapid data turnaround. This shorter counting time will result in a lowering of sensitivity for analytes (radionuclides). Greater sensitivity for radionuclides can be achieved only by increasing the duration of counting time with a corresponding reduction in sample throughput.

Modifications to fixed laboratory methods reflect the need to expedite field analysis so that quicker data turnaround is provided, consistent with the data needs for decision making. Mobile laboratory analytical procedures are available for most major Laboratory PCOC's, and methods exist or are being developed to target other compounds. Generally, analytical procedures for both mobile laboratories can be tailored to meet site specific needs if those needs can be specifically articulated and sufficient lead time is provided. Analytical method performance data either exist (see LANL, 1993 xxxx) or will be generated to evaluate the adequacy of data quality for decision-making.

Several levels (or tiers) of analytical quality control are written into the mobile laboratory methods to provide for different data quality needs. The level of quality control required depends both on the stability of the measurement process used and on the requirements of the decision it is supporting. Providing analytical data of the highest quality when this is not necessary for the decision will adversely impact the cost and schedule constraints.

The mobile laboratories may be brought to the site to provide real-time support, or left at a fixed base providing two- or three-day turnaround. Some analytical methods are not practical for field operations and some site operations may not require real-time analytical support. On site mobile laboratory support may be indicated when data are used to:

- direct subsequent sampling activities,
- determine the extent of vertical contamination leading to the decision to halt a drilling operation,
- determine if excavated material is hazardous requiring special handling,
- determine transportation requirements for samples to be shipped off-site,
- assess risk for site workers,
- monitor for deviations from anticipated conditions during CMI, or
- direct cleanup activities.

4.5 Response Actions

4.5.1 RCRA Process Endpoints

The RCRA process may terminate at a number of points:

- after review and evaluation of archival information, without additional field

investigations;

- after a screening assessment and review of the need for corrective action based on the results of the first phase of RFI;
- after baseline risk assessment; or
- after the design and implementation of corrective actions.

There are a number of options at each of these end points, including: no further action, deferral of further investigation and/or corrective action until the site is decommissioned, voluntary corrective action, conditional remediation, and final remediation. Interim actions may also be required.

4.5.1.1 No Further Action

A decision as to whether corrective action is required for a site is the principal decision made during the RFI. It may be made at any of the three RFI termination points listed above: following the evaluation of archival information, after the initial investigation of the site, or after a baseline risk assessment. A decision to propose NFA during the RFI implies that neither additional investigation nor corrective action is necessary.

A strategy for selecting and defending a proposal for NFA on the basis of archival information only is outlined in Appendix I. Such a proposal requires a review of archival information not only to ascertain that there are no health and safety risks associated with the site but also to evaluate many of the other factors discussed in Section 4.2.1, particularly environmental risks, compliance with regulatory requirements, public concerns, and impacts on Laboratory operations. For some sites, it may be possible to complete a screening assessment (Section 4.1.4) using historical data.

For many PRSs at Los Alamos, existing nonquantitative information strongly suggests that no environmental release has occurred. Sampling to provide quantitative data for a screening assessment should provide enough information to complete a proposal for NFA in these cases.

The third point at which NFA might be proposed is following baseline risk assessment when this assessment shows that, although contamination is present and potential exposure pathways exist, the associated risks are nevertheless below levels of concern. Once again, before proposing NFA under these conditions, the other evaluation factors discussed in Section 4.2.1 must be reviewed.

4.5.1.2 Deferred Action

Deferred action, like NFA, may be proposed at any of the RFI termination points. It may be appropriate for currently active sites or for other, inactive PRSs that are located in currently active sites. The proposal may be accompanied by plans for a limited site investigation, such as a screening investigation or perimeter monitoring. Otherwise, strategies for selecting and defending this alternative are quite similar to those described in Section 4.5.1. In evaluating health and environmental risks, it is primarily the current risks that are of concern, because only postponement—not cancellation of investigation and/or corrective action—is proposed.

4.5.1.3 Conditional Remedies

Conditional remedies, generally combining a prompt corrective measure to reduce risk, together

with an ongoing schedule for site monitoring, may be proposed for sites where total cleanup is impractical or delaying implementation of the final remedy is in the interest of the environment (Section 3.5.1.2.2). In particular, site stabilization using appropriate containment technologies (Section 4.5.4.1) will be implemented as a conditional remedy at some of the large MDAs. Site monitoring is a second technological component of any conditional remedy. Continued institutional control to control public access, to track Laboratory activities in the area, and to prevent further degradation of the environment is a required administrative component.

4.5.1.4 Corrective Measures

When remedial action is necessary, an appropriate corrective measure is generally selected following a CMS. If an obvious and effective alternative exists, it may be proposed as a VCA without a formal CMS, either immediately after the evaluation of archival information or else after a limited screening investigation. VCAs tend to use removal with off-site treatment and disposal options, rather than in-situ treatment or containment, and therefore must meet restrictions on treatment and disposal of hazardous wastes and other restrictions that apply to alternatives of this type. If there are significant questions about the ability of the proposed option to meet these criteria, then CMS and CMI are more appropriate than VCA.

4.5.2 Corrective Actions

The development and implementation of a comprehensive response action or corrective measure is a time consuming process. Between the time of the identification of a contaminant release at a PRS and the completion of a definitive corrective measure, several phases of screening, field investigation, and corrective measure study may have occurred. Remedial objectives and potential response actions should be considered as early in the corrective action process as possible. In this way information needed to evaluate the alternatives and to initial their design can be collected during the RFI.

Technical considerations in evaluating remedial technologies include site characteristics, waste characteristics, and technology limitations.

Site Characteristics. Site data collected during the RFI will be reviewed to identify conditions that may limit or promote the use of certain remedial technologies such as climatic setting , geology, hydrology, and the physical nature of contamination. Technologies whose use is clearly precluded by site characteristics will be eliminated from further consideration. For example, the presence of very low permeability soils may preclude the use of in-situ stabilization methods due to the difficulty of mixing treatment reagents with contaminant constituents.

Waste Characteristics. Technologies that are clearly limited by waste characteristics such as concentration, reactivity, solubility, toxicity and treatability will be eliminated form further consideration. Waste characteristics particularly affect the feasibility of in-situ methods, direct treatment methods, and land disposal (on- or off-site).

Technology Limitations. The level of technology development, performance record, and inherent construction, operation, and maintenance problems will be identified for each technology identified during the corrective action process. For example, certain grouting and in-situ methods have not been developed to a point where they can be implemented in the complex geological conditions at the Laboratory without extensive research. Remedial technologies at the laboratory will be assessed for suitability based on performance, reliability, implementability, safety, time considerations, and costs.

Once technologies have been screened and have been found to technically applicable to the contamination problems at a PRS, they then may be combined to form overall corrective measure alternatives. These alternatives represent a workable number of options to be evaluated during the CMS. Each alternative may consist of an individual technology or a combination of technologies. Corrective measure alternatives will then be subject to detailed evaluation to provide the level of analysis required to support the selection of the most cost-effective corrective measure that meets the remedial objectives. Each corrective measure alternative will be analyzed in terms of technical considerations, public health concerns, environmental concerns, institutional concerns, and costs. The CMS process terminates in the selection of the lowest cost alternative which effectively mitigates and minimizes damages and provides adequate protection of public health, welfare, and the environment. Selection and implementation of corrective measures will be addressed in future EPA regulations, and in separate guidance to be developed by EPA.

The following brief descriptions of available remedial technologies are adapted from an EPA manual (EPA 1990, 0791). The discussion is not intended to be exhaustive but covers those technologies most likely to be useful for the Laboratory's ER Program. New and innovative technologies are continually being developed, as are methods to adapt established technologies to the specialized needs and conditions of the Laboratory.

4.5.2.1 Containment Technologies

Capping is the process of covering contaminated materials to prevent direct contact with receptors, to control the infiltration of surface water and precipitation, and to control the release of soil vapors. Various cap designs and capping materials are available, including

- soil caps consisting of a compacted layer of local soil and a layer of topsoil;
- hard caps made of asphaltic concrete or Portland cement concrete; and
- multilayered caps designed to meet RCRA standards, typically consisting of an upper vegetative (topsoil) layer, a drainage layer, and a low-permeability layer.

The Laboratory is conducting pilot studies to determine combinations of capping features that are most appropriate for the climatological conditions of the Pajarito Plateau (Appendix D).

Surface water control measures, including grading and terracing; ditches and channels; and structures such as berms, dikes, and flood walls, are used to control surface drainage on, around, and through an area. Surface run-off occurs over most of the Pajarito Plateau during severe storm events and rapid snow melt, and thus some form of surface water control may be required at Laboratory sites with contaminated soils.

4.5.2.2 Removal Technologies

Although excavation of earth materials and dredging in sediments are standard construction practices, their application to the removal of hazardous wastes entails some special technical considerations:

- The work can be extremely hazardous, and extensive safety procedures and monitoring may be required to ensure the protection of the workers and the public and to prevent collateral damage to the environment.
- Special equipment, adapted to minimize disturbance of the deposit and

secondary migration, may be required.

- Areas containing drums, buried tanks, or similar obstructions may require significant amounts of hand and small-machine work.

- Selective removal of wastes to ensure the segregation of incompatible wastes and of wastes requiring different disposal and treatment methods may be required.

- Removed sediments must be dewatered, and the removed water must be treated for possible contamination.

Pumpable liquids and sludges can be removed from pits, ponds, lagoons, sumps, trenches, and tanks to prevent the contamination of adjacent soils and aquifers. The waste must be categorized by phase (e.g., organic, aqueous, and heavy sludge phases) to determine the appropriate removal method(s).

Standard gas collection and migration control systems for landfills are very effective in controlling emissions from municipal and similar landfills, whose gases are typically about half methane and half carbon dioxide, with small amounts of other gases. These systems consist of a combination of monitoring wells, negatively pressured perimeter control, and interior collection and recovery systems. These technologies may be useful at a limited number of Laboratory sites.

4.5.2.3 Treatment Technologies

Incineration, onsite or offsite, is a well-proven method of treating waste streams containing organics, which routinely obtains destruction and removal efficiencies in excess of 99.99% for most organics and PCBs. Incineration is also used to reduce wastes to the minimum feasible volume and to reduce liquid wastes and sludges to residual solids. Wastes and air are introduced into a rotary kiln and are ignited either by an ignition source or by heating the combustibles to autoignition temperature. The gases that evolve from combustion must be further treated in an afterburner or secondary combustion chamber, then fed through a pollution control train to remove particulates and acid gases before being released to the atmosphere. Solid residues from the kiln and pollution control train must be collected and disposed separately. Potential barriers to applying this technology at the Laboratory are community resistance to the construction of an onsite incinerator and the distances to offsite incinerators that meet RCRA requirements.

In-situ biodegradation is a rapidly emerging technology that has been used very successfully to clean up aquifers contaminated with gasoline and other fuel hydrocarbons and is potentially applicable to any biodegradable organic compound. The Laboratory is conducting studies of in-situ biodegradation of high explosives (Unkefer 1992, 0822). The methods most commonly involve stimulating the activity of native microorganisms by introducing oxygen and inorganic nutrients. Microbial actions that may be involved include degrading organic contaminants to carbon dioxide and water (or at least to more soluble by-products), emulsifying adsorbed contaminants, and producing natural, complex organic compounds. These activities result in a net removal of contaminants adsorbed to subsurface soil particles and reduction in the toxicity of remaining organic matter. Because there are many site-specific factors that control the effectiveness and cost of in-situ biodegradation, bench- and pilot-scale studies are necessary. This is particularly true for the arid soils of the Pajarito Plateau.

In-situ solidification/stabilization refers to processes that can be implemented in place to improve the physical characteristics of waste by rendering wastes non hazardous and nonleachable.

Stabilization/solidification reagents are incorporated in the wastes either by pneumatic injection (for nonviscous liquids, fluids, and sludges) or by backhoe mixing (for viscous fluids, solids, and contaminated soil). These technologies are well established for treating inorganic wastes, less so for organic wastes.

Solidification techniques that depend on a reaction between lime and fine siliceous materials in the presence of water are most effective for wastes that have relatively high moisture content (e.g., sludges) and high levels of toxic metals, and that possibly include some miscellaneous materials such as asbestos, sulfides, and solid plastics but typically not more than 10% to 20% of organic constituents. Solidification processes limit solubility, detoxify the waste contaminants, and produce a monolithic block with some structural integrity; however, the product is still a hazardous waste unless it is delisted.

Soil slurry bioreactor systems can be used to remediate excavated sludges and soils containing organic contaminants. These hybrid systems use aerobic microbial action to degrade or detoxify the contaminants in a slurry reactor (a suspension of soil in water). Both pretreating the wastes, using such pretreatment methods as separating coarser materials and particle scrubbing, and posttreating the slurry and off-gases are generally necessary. Emerging variations of the technology include inoculating the system with special strains of bacteria and adding organic cometabolites to enhance biodegradation of compounds that are difficult to degrade.

Soil vapor extraction is used when volatile organic compounds (VOCs) are the primary contaminants. At Los Alamos, a vapor extraction system is being developed for Area L, where the environmental medium is not soil but tuff. Soil vapor extraction is conventionally performed using a network of wells with perforated well screens packed with gravel, which are connected to a vacuum extraction unit through a surface collection manifold. The vacuum not only draws vapors from the unsaturated zone but also, by decreasing the pressure in soil voids, causes the release of additional VOCs. Extracted gas is either vented to the atmosphere, connected to a vapor-phase carbon adsorption system, or flared, depending on the nature and extent of VOC contamination.

4.5.2.4 Disposal Technologies

Some remedial alternatives will require the disposal of hazardous waste in a RCRA-approved landfill. In addition to RCRA permitting standards, such landfills must meet local, state, and other federal standards, which may result in a decrease in offsite disposal capacity in the future. Onsite RCRA-approved landfills are typically constructed in an uncontaminated area to minimize effects on cleanup operations, on the environment, and on costs and must meet current RCRA standards for design, operations, and closure. Usual components include a primary leachate collection system, a primary liner, a secondary leachate collection (leak detection) system, a composite bottom liner, and a multilayered RCRA cap, together with run-on and run-off controls and environmental monitoring. The Laboratory is proposing to build a Mixed-Waste Storage and Disposal Facility to handle materials with both hazardous and radioactive constituents.

Aqueous solutions (either raw or pretreated waste water), which generally contain low to moderate concentrations of pollutants, may undergo conventional treatment in a municipal waste water treatment plant. This option applies primarily to short-term discharges and to low-flow, longer-term situations, however, and may be a sensitive political issue. Another alternative when suitable land is available is water infiltration, a process in which treated effluent is applied to the soil surface using infiltration trenches, infiltration basins, or spray irrigation.

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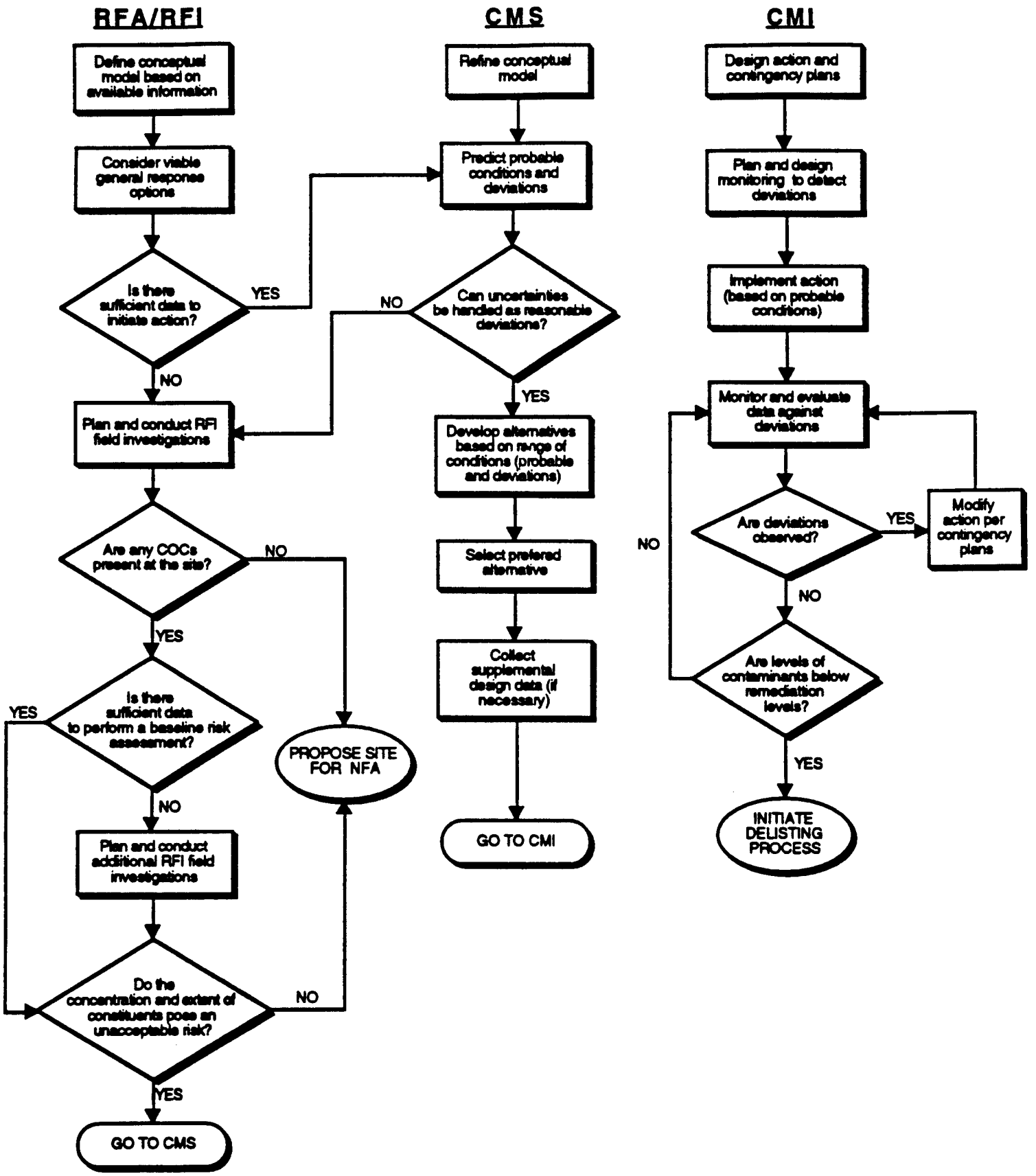
RFA/RFI
Define conceptual model based on available information
Consider viable general response options
Is there sufficient data to initiate action?
YES
NO
Plan and conduct RFI field investigations
Are any COCs present at the site?
NO
YES
Is there sufficient data to perform a baseline risk assessment?
YES
NO
PROPOSE SITE FOR NFA
Plan and conduct additional RFI field investigations
Do the concentration and extent of constituents pose an unacceptable risk?
NO
YES
GO TO CMS
CMS
Refine conceptual model
Predict probable conditions and deviations
Can uncertainties be handled as reasonable deviations?
NO
YES
Develop alternatives based on range of conditions (probable and deviations)
Select prefered alternative
Collect supplemental design data (if necessary)
GO TO CMI
CMI
Design action and contingency plans
Plan and design monitoring to detect deviations
Implement action (based on probable conditions)
Monitor and evaluate data against deviations
Are deviations observed?
YES
Modify action per contingency plans
NO
Are levels of contaminants below remediation levels?
NO
YES
INITIATE DELISTING PROCESS

Figure G.-1.

APPENDIX G

Los Alamos National Laboratory **Environmental Restoration Program** Standard Operating Procedure	No: LANL-ER-SOP-01.02 Rev: 0

Sample Containers and Preservation

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Effective Date: 3.16.92

Sample Containers and Preservation

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Sample Containers and Preservation

1.0 PURPOSE

This procedure describes specific requirements for sample containers, preservation techniques and holding times as specified by field regulations and guidance documents.

2.0 SCOPE

2.1 Applicability

This procedure is applicable to all Environmental Restoration (ER) activities involving the collection and preservation of samples that will be shipped to the Los Alamos National Laboratory Sample Coordination Facility (SCF) for subsequent chemical or physical testing.

2.2 Training

The Field Team Leader (FTL) is responsible for the implementation of this procedure and the FTL and field team members must document that they have read and understand this procedure and the other procedures in Section 1.0, General Instructions.

3.0 DEFINITIONS/ACRONYMS

A. ASTM: American Society for Testing and Materials

B. CLP: Contract Laboratory Program

C. DOT: U.S. Department of Transportation

D. EPA: U.S. Environmental Protection Agency

E. Holding time: The elapsed time between sample collection and initiation of laboratory analysis. The holding time is from date of sampling to date of analysis, not the date the designated laboratory receives the sample.

F. IATA: International Air Transport Association

G. RCRA: Resource Conservation and Recovery Act

H. RFI: RCRA Facilities Investigation

I. SCF: Sample Coordination Facility

J. SW-846: EPA approved test methods for Solid Waste identified in EPA-SW-846.

K. TCLP: Toxicity Characteristic Leaching Procedure (Method 1311), which is a codified (40CFR Parts 261, 264, 265, 268, 271, and 302) procedure.

4.0 BACKGROUND AND/OR CAUTIONS

The use of specific types of sample container and preservation techniques is mandatory for hazardous site investigations because the integrity of any sample is diminished over time. Physical factors (light, pressure, temperature, etc.), chemical factors (changes in pH, volatilization, etc.), and biological factors may alter the original quality of the sample. Because the various target parameters are uniquely altered at varying rates, distinct sample containers, preservation techniques, and holding times have been established to maintain sample integrity for a reasonable and acceptable period of time.

The volume of sample collected should be sufficient to perform all the required analyses, plus an additional amount to provide for any quality control needs, split samples, or repeat examinations. The volumes, preservatives, and holding times listed in Attachments A through F are the EPA requirements. Since the SCF operated by EM-9 will be either performing the analyses or making arrangements for the analyses, sampling schedules and sample needs must be coordinated with the SCF prior to sampling.

All proposed ER Program sampling plans are reviewed at the SCF for adherence to sampling protocols mandated by all applicable EPA regulations and analytical methods. The Sampling and Analysis Plan (SAP) will address the proper analytical protocol. SW-846 provides test procedures and guidance which are recommended for use in conducting the evaluations and measurements needed to comply with the RCRA (Public Law 94-850). These methods are approved by EPA to satisfy the data requirements of 40 CFR 120-270. The topics of concern include the sampling schedule, proper sample sizes and containers, correct preservation techniques, chain-of-custody requirements, and transportation of samples to the SCF. Appendix O of the Los Alamos National Laboratory Installation Work Plan details the duties of the SCF.

5.0 EQUIPMENT

Equipment needed to implement this procedure is listed on the Equipment and Supplies Check List for Sample Containers and Preservation (Attachment G).

6.0 PROCEDURE

A. Contact the SCF for guidance and assistance in obtaining the proper sample containers and preservatives.

B. Refer to an Operable Unit (OU)-specific SAP for site-specific procedures for sample containers and preservation. In addition, follow the protocols established in EPA's SW-846, Test Methods for Evaluation of Solid Waste.

C. Record all pertinent comments and any deviations on the Daily Activity Log per LANL-ER-SOP-01.04.

D. Contact the SCF for guidance and acquisition of the proper sample containers.

1. Identify the containers required for analysis by matrix as shown in Attachments A through F (for example, amber glass, narrow-mouth bottles for polychlorinated biphenyl [PCB] analysis of water samples).

   a. Based on information in the SAP, choose a sample container that is nonreactive with the sample and the particular analytical parameter to be tested.

   b. Use glass or fluorocarbon resin containers with samples analyzed for organic compounds to prevent the introduction of extraneous organic compounds, such as those that might be leached from plastic containers.

   c. The rigid plastic screw caps for the bottles must be Teflon lined to prevent contamination of the sample.

2. Calculate and order the number of each type of container required by including duplicates and blanks with the number of investigative samples specified in the OU-specific SAP.

3. Acquire a sufficient number of containers to ship the proper sample volume. For example, Department of Transportation (DOT) and International Air Transport Authority (IATA) regulations limit the size of a sample container to 16 oz if the contents may include hazardous materials. In this case, two 500-ml or four 250-ml containers would be required to ship a 1-liter fluid sample.

4. Adhere to DOT regulations for on-site transfer of samples to the SCF over public-access roads. Refer to SOP-01.03, Handling, Packaging, and Shipping of Samples, for additional information.

6.1 Containing Procedures

A. If soil, sludge or wastes are submitted to the laboratory in containers other than those in which they were collected, the container should be glass, wide mouth bottles with a Teflon cap liner. For specific methods, see Attachment D.

B. If soil samples are submitted to the laboratory in the sample equipment in which they were collected, the container must have the end covered with Teflon or aluminum foil, have a plastic cap placed over the end, and have the cap taped in place. This procedure reduces the chance for loss of moisture or volatile organic compounds (VOCs).

C. The type and size of container used for water samples and aqueous waste samples varies based on the type of analysis to be performed. Refer to Attachments A and B for specific information on water sample containers and Attachment C for information on aqueous waste sample containers.

D. Sample containers received from SCF will be precleaned to EPA specifications before they are sent to the site. A certificate of cleanliness will be retained by the SCF, with a copy provided with the containers.

6.2 Sample Preservation

A. Regardless of the sample type or container, unless site-specific guidelines state otherwise, samples collected for chemical analysis should be preserved by placing them in an insulated container (cooler) and maintained on ice (ice in bags or chemical "blue" ice) at 4° Centigrade (C).

B. Avoid freezing the sample by wrapping it in bubble pack to isolate from the "blue" ice.

C. Containers for water samples and aqueous waste may arrive at the OU site from the SCF with the proper type and amount of preservatives in them. If so, do not prerinse or overfill.

D. If on-site preservation of aqueous samples is necessary, the proper reagents should be provided to field team members in an easily usable form that can be added at the time of sampling. Reagents that are designated as hazardous by the DOT Hazardous Materials Table, Title 49 Code of Federal Regulations (CFR) 172.101, are shipped pursuant to the appropriate DOT regulations.

E. If using an acid or base preservative, check the pH adjustment with pH paper.

F. Preservation required for the specific analyses requested for aqueous samples may be determined by using Attachments A through C, or by consulting the referenced documents.

G. Solid sediment and solid waste for chemical analysis will always be preserved on ice to 4°C. See Attachments D through F.

H. A sufficient amount of ice should be brought to the field to ensure proper sample cooling immediately following collection. A temperature of 4°C must be maintained until the samples arrive at the SCF.

I. The temperature shall be checked and recorded at the laboratory to determine if preservation has been accomplished.

6.3 Holding Time

A. Analyze samples as soon as possible after collection.

B. Some parameters are required to be analyzed in the field (refer to Attachment A).

C. Allowable holding times are listed and are the maximum times that samples are considered valid, based on available guidance (see Attachments A through F).

D. The OU-specific maximum holding times will be listed in the RFI Workplan.

E. Holding times for SW-846 methods start when the sample is collected. Both the sampler and the laboratory use this time/date.

F. Holding times for the Contract Laboratory Program (CLP) methods for the samples is the day of collection. The laboratory date is date received at the designated laboratory. Delayed shipping will result in missed holding time for the data. Transfer the samples to the SCF as soon as possible.

7.0 REFERENCES

The following procedures are directly associated with this procedure and should be reviewed before field operations commence:

LANL-ER-SOPs in Section 1.0, General Instructions
LANL-ER-SOP-02.07, General Equipment Decontamination
LANL-ER-SOP-06.03, Sampling for Volatile Organics

Title 40 CFR Part 261

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8.0 RECORDS

A. Completed Chain-of-Custody/Request for Analysis Form

B. Completed Daily Activity Log

9.0 ATTACHMENTS

A. Recommendation for Sampling and Preservation of Water Samples According to Measurement (Low- to Medium-Contaminant Concentration Samples)

B. Sampling and Preservation Procedures for RCRA Groundwater Detection Monitoring

C. Containers for Aqueous Waste Samples

D. Preservation Plan for Soil/Sediment Samples

E. Sample Containers for Waste

F. Preservation Plan for Soil/Sediment Waste Samples

G. Equipment and Supplies Check List for Sample Containers and Preservation

RECOMMENDATION FOR SAMPLING AND PRESERVATION OF WATER SAMPLES ACCORDING TO MEASUREMENT[a] (LOW TO MEDIUM CONTAMINANT CONCENTRATION SAMPLES)

Measurement	Volume Requirement millimeter (ml)	Container[b,c]	Preservative[d,e]	Holding Time[f,g]
		Physical Properties		
Color	50	P,G	Ice[h]	48 hrs
Specific Conductance	100	P,G	Ice	24 hrs
Hardness	100	P,G	HNO_3 to pH<2	6 mos
Odor	200	G only	Ice	24 hrs
pH	25	P,G	N/A	Determine on site
Residue				
Filterable	100	P,G	Ice	7 days
Nonfilterable	100	P,G	Ice	7 days
Total	100	P,G	Ice	7 days
Volatile	100	P,G	Ice	7 days
Settleable Matter	1000	P,G	Ice	48 hrs
Temperature	1000	P,G	N/A	Determine on site
Turbidity	100	P,G	Ice	48 hrs
		Metals (except Mercury and Chromium^{+6})		
Dissolved	200	P,G	Filter on site HNO_3 to pH<2	6 mos 6 mos[i]
Suspended	200	P,G	Filter on site	6 mos
Total	100	P,G	HNO_3 to pH<2	6 mos
Chromium^{+6}	200	P,G	Ice	24 hrs
Mercury				
Dissolved	100	P,G	Filter HNO_3 to pH<2	28 days
Total	100	P,G	HNO_3 to pH<2	28 days

RECOMMENDATION FOR SAMPLING AND PRESERVATION OF WATER SAMPLES ACCORDING TO MEASUREMENT[a] (LOW TO MEDIUM CONTAMINANT CONCENTRATION SAMPLES) (Continued)

Measurement	Volume Requirement (ml)	Container[b,c]	Preservative[d,e]	Holding Time[f,g]
		Inorganics, Nonmetallics		
Acidity	100	P,G	Ice	14 days
Alkalinity	100	P,G	Ice	14 days
Bromide	100	P,G	None Required	28 days
Chloride	100	P,G	None Required	28 days
Chlorine	200	P,G	N/A	Determine on site
Cyanides	500	P,G	Cool 4°C Ice NaOH to pH>12 0.6 g ascorbic acid	14 days
Fluoride	300	P,G	Ice	28 days
Iodide	100	P,G	Ice	24 hrs
Nitrogen				
Ammonia	400	P,G	Ice H_2SO_4 to pH<2	28 days
Nitrogen, Total Kjeldahl	500	P,G	Ice H_2SO_4 to pH<2	28 days
Nitrate Plus Nitrite	100	P,G	Ice H_2SO_4 to pH<2	28 days
Nitrate[j]	100	P,G	Ice	48 hrs
Nitrite	50	P,G	Ice	48 hrs
Dissolved Oxygen				
Probe	300	G bottle and top	N/A	Determine on site
Winkler	300	G bottle and top and store in dark	Fix on site	8 hrs
Phosphorus				
Orthophosphate, Dissolved	50	P,G	Filter on site, Ice	48 hrs
Hydrolyzable	50	P,G	Ice H_2SO_4 to pH<2	28 days

RECOMMENDATION FOR SAMPLING AND PRESERVATION OF WATER SAMPLES ACCORDING TO MEASUREMENT[a] (LOW TO MEDIUM CONTAMINANT CONCENTRATION SAMPLES) (Continued)

Measurement	Volume Requirement (ml)	Container[b,c]	Preservative[d,e]	Holding Time[f,g]
Total, Dissolved	50	P,G	Filter on site, Ice H_2SO_4 to pH<2	24 hrs
Silica	50	P only	Ice	28 days
Sulfate	50	P,G	Ice	28 days
Sulfide	50	P,G	Ice 2 ml zinc acetate(2N) NaOH to pH >9	24 hrs
Sulfite	100	P,G	N/A	Determine on site
		Organics		
BOD	1,000	P,G	Ice	48 hrs
COD	50	P,G	Ice H_2SO_4 to pH<2	28 days
Oil and Grease	1,000	P,G	Ice H_2SO_4 to pH<2	28 days
Organic Carbon	25	P,G	Ice H_2SO_4 or HCl to pH<2	28 days
Phenolics	500	G only	Ice H_2SO_4 to pH<2	28 days
Cyanides	1,000	P,G	Ice 40% NaOH to pH>12 0.6 g ascorbic acid	14 days
Coliform, Fecal, and Total	250	P,G	Ice Sterile	6 hrs
Oil and Grease	1,000	G	Ice H_2SO_4 to pH<2	28 days
Organic Carbon	25	P,G	Ice H_2SO_4 to pH<2	28 days
Phenols	1,000	G, Teflon™-lined cap	Ice	7 days until extraction; 40 days after extraction
Total Organic Halogen and Purgeable Aromatics	40	G, vial with Teflon™-lined septum	Ice 0.008% $Na_2S_2O_3$[j]	14 days

RECOMMENDATION FOR SAMPLING AND PRESERVATION OF WATER SAMPLES ACCORDING TO MEASUREMENT[a] (LOW TO MEDIUM CONTAMINANT CONCENTRATION SAMPLES) (Continued)

Measurement	Volume Requirement (ml)	Container[b,c]	Preservative[d,e]	Holding Time[f,g]
Purgeable Aromatics	40	G, vial with Teflon™-lined septum	Ice 0.008% $Na_2S_2O_3$[k]	14 days
Acrolein and Acrylonitrile	1,000	G, Teflon™-lined septum	Ice 0.008% $Na_2S_2O_3$[k]	14 days
Phenols	1,000	G, Teflon™-lined cap	Ice	7 days until extraction; 40 days after extraction
Benzidines	1,000	G, Teflon™-lined cap	Ice 0.008% $Na_2S_2O_3$[k]	7 days until extraction; 40 days after extraction
Phthalate Esters	1,000	G, Teflon™-lined cap	Ice 0.008% $Na_2S_2O_3$[k]	7 days until extraction; 40 days after extraction
Nitrosamines	1,000	G, Teflon™-lined cap	Ice store in dark 0.008% $Na_2S_2O_3$[k]	7 days until extraction; 40 days after extraction
Nitroaromatics and Isophorone	1,000	G, Teflon™-lined cap	Ice	7 days until extraction; 40 days after extraction
Polynuclear Aromatic Hydrocarbons	1,000	G, Teflon™-lined cap	Ice	7 days until extraction; 40 days after extraction
Haloethers	1,000	G, Teflon™-lined cap	Ice	7 days until extraction; 40 days after extraction
Chlorinated Hydrocarbons	1,000	G, Teflon™-lined cap	Ice	7 days until extraction; 40 days after extraction

RECOMMENDATION FOR SAMPLING AND PRESERVATION OF WATER SAMPLES ACCORDING TO MEASUREMENT[a] (LOW TO MEDIUM CONTAMINANT CONCENTRATION SAMPLES) (Continued)

Measurement	Volume Requirement (ml)	Container[b,c]	Preservative[d,e]	Holding Time[f,g]
Tetrachlorodibenzo-p-dioxin	1,000	G, Teflon™-lined cap	Ice	7 days until extraction; 40 days after extraction
		Pesticides and PCBs		
Pesticides and PCBs	1,000	G, Teflon™-lined cap	Ice	7 days until extraction; 40 days after extraction
		Radiological Tests		
Alpha, Beta and Radium	1,000	P,G	HNO_3 to pH<2	No limit
Tritium	25	G	None	No limit
Isotopic Uranium	500	P	HNO_3 to pH<2	No limit
^{90}Sr	1,000	P	HNO_3 to pH<2	No limit
^{238}Pu	500	P,G	HNO^3 to pH<2	No limit
^{239}Pu	500	P,G	HNO^3 to pH<2	No limit
^{137}Cs	500	P,G	HNO^3 to pH<2	No limit
^{241}Am	500	P,G	HNO^3 to pH<2	No limit

[a]More specific instructions for preservation and sampling are found with each applicable SAP. A general discussion about sampling water and industrial wastewater is found in EPA Region IV (1991); EPA (1986); and EPA (1985).

[b]Container Types:

P = Plastic (polyethylene)
G = Glass
T = Fluorocarbon resins (PTFE, Teflon™, FEP or PFA)
PP = Polypropylene

[c]Shipping containers (cooling chest with ice or ice pack) should be certified as to the 4°C temperature at the time of sample placement into these containers. Preservation of samples requires that the temperature of collected samples be cooled to 4°C upon collection of sample and during shipment. Field personnel will check the temperature in the container at the time of shipping and ice the samples to maintain a cool temperature during shipment. Maximum-minimum thermometers can be placed into the shipping chest to record temperature history. Chain-of-custody forms will include the temperature in the container at the time of shipment and at delivery to the laboratory in addition to in-transit (maximum) temperature, if available.

[d]Sample preservation should be performed immediately upon sample collection. For composite samples, each aliquot should be preserved at the time of collection. When use of an automated sampler makes it impossible to preserve each aliquot, samples may be preserved by cooling to 4°C until compositing and splitting are completed.

[e]When any sample is to be shipped by common carrier or sent through the United States mail, it must comply with the DOT Materials Regulations (49 CFR Part 172). The SCF is responsible for ensuring compliance. For preservation requirements, the Office of Hazardous Materials Materials Transportation Bureau, Department of Transportation has determined that the Hazardous Materials Regulations do not apply to the following material: Hydrochloric acid (HCl) in water solutions at concentrations of 0.22% by weight or less, with pH less than 2.0 but greater than or equal to 1.0.

[f]Samples should be analyzed as soon as possible after collection. The times listed are the maximum periods that samples may be held and still be considered valid. Samples may be held for longer periods only if the permittee, or analytical laboratory, has data on file to show that the specific types of samples under study are stable for a longer time and has received a variance from the EPA Regional Administrator.

[g]Maximum holding time is 24 hours when sulfide is present. Optional testing of all samples with lead acetate paper before the pH adjustment will determine if sulfide is present. If sulfide is present, it can be removed by adding of cadmium nitrate powder until a negative spot test is obtained. The sample is filtered and the pH is adjusted to 12 with NaOH.

[h]Shipping containers (cooling chest with ice or ice pack) should be verified as to the 4°C temperature at the time of sample placement into these containers. Preservation of samples requires that the temperature of collected samples be cooled to 4°C upon collection of sample and during shipment. Field personnel will check the temperature in the container at the time of shipping and ice the samples to maintain a cool temperature during shipment. Chain-of-custody forms will include the temperature in the container at the time of shipment and at delivery to Laboratory.

[i]Samples should be filtered on site immediately, before adding preservative for dissolved metals.

[j]For samples from nonchlorinated drinking water supplies, concentrated H_2SO_4 should be added to lower sample pH to less than 2. The sample should be analyzed within 14 days.

[k]Should only be used in the presence of residual chlorine.

[l]Use ml volume requirements for water and gram requirements for media other than liquids.

[m]No preservation for media other than water.

SAMPLING AND PRESERVATION PROCEDURES FOR RCRA GROUNDWATER DETECTION MONITORING[a]

Parameter	Minimum Volume Required for Analysis (ml)	Recommended Container[b,c]	Preservative[d,e]	Maximum Holding Time[f,g]
		Indicators of Groundwater Contamination[h]		
pH	25	T,P,G	Field determined	None
Specific Conductance	100	T,P,G	Field determined	None
Total Organic Carbon	4 x 15	G, amber, T-lined cap[f]	Ice	28 days HCl to pH<2
Total Organic Halogen	4 x 15	G, amber, T-lined septa or caps	Ice, add 1.1M sodium sulfite	7 days
		Groundwater Quality Characteristics		
Chloride	50	T, P, G	Ice	28 days
Iron Manganese Sodium	200	T, P	Field acidified to pH <2 with HNO_3	6 months
Phenols	500	G	Ice/H_2SO_4 to pH <2	28 days
Sulfate	50	T, P, G	Ice	28 days
		Drinking Water Characteristics		
Arsenic Barium Cadmium Chromium	500 500	T, P	Total Metals Field acidified to pH <2 with HNO_3	6 months 6 months
			Dissolved Metals	
Lead Mercury Selenium Silver	500	T,P T,P T,P Dark Bottle	Field filtration Acidify to pH <2 with HNO_3	6 months

SAMPLING AND PRESERVATION PROCEDURES FOR RCRA GROUNDWATER DETECTION MONITORING[a] (Continued)

Parameter	Minimum Volume Required for Analysis (ml, unless noted otherwise)	Recommended Container[b,c]	Preservative[d,e]	Maximum Holding Time[f,g]
Fluoride	300	T, P	Ice	28 days
Nitrate/Nitrite[i]	1,000	T, P, G	Ice/H_2SO_4 to pH <2	14 days
Endrin Lindane Methoxychlor Toxaphene 2,4 Dichlorophenol 2,4,5 Trichlorophenol Silvex	2,000	T, G	Ice	7 days
Radium Gross Alpha Gross Beta	1 gallon	P, G pH <2 with HNO_3	Field acidified to	6 months
Coliform bacteria	200	PP, G (sterilized)	Ice	6 hours
		Other Groundwater Characteristics of Interest[h]		
Cyanide	250	P, G pH >12. 0.6 g ascorbic acid[j]	Ice, NaOH to	14 days
Oil and Grease	1,000	G only pH <2	Ice H_2SO_4 to	28 days
Semivolatile, Nonvolatile Organics	60	T, G	Ice	14 days
Volatiles	60	G, T-lined	Ice	14 days

[a]References:

EPA (U.S. Environmental Protection Agency) 1986. "Test Methods for Evaluating Solid Waste - Physical/Chemical Methods," Report EPA-SW-846 (3rd edition). Washington, D.C.

EPA (U.S. Environmental Protection Agency) 1983. "Methods for Chemical Analysis of Water and Wastes," Report EPA-600/4-79-020. Washington, D.C.

"Standard Methods for the Examination of Water and Wastewater," 16th edition (1985).

[b]Container Types:

P = Plastic (polyethylene)
G = Glass
T = Fluorocarbon resins (PTFE, Teflon™, FEP or PFA)
PP = Polypropylene

[c]Shipping containers (cooling chest with ice or ice pack) should be certified as to the 4°C temperature at the time of sample placement into these containers. Preservation of samples requires that the temperature of collected samples be cooled to 4°C upon collection of sample and during shipment. Field personnel will check the temperature in the container at the time of shipping and ice the samples to maintain a cool temperature during shipment. Maximum-minimum thermometers can be placed into the shipping chest to record temperature history. Chain-of-custody forms will include the temperature in the container at the time of shipment and at delivery to the laboratory in addition to in-transit (maximum) temperature, if available.

[d]Sample preservation should be performed immediately upon sample collection. For composite samples, each aliquot should be preserved at the time of collection. When use of an automated sampler makes it impossible to preserve each aliquot, samples may be preserved by cooling to 4°C until compositing and splitting are completed.

[e]When any sample is to be shipped by common carrier or sent through the United States mail, it must comply with the DOT Materials Regulations (49 CFR Part 172). The SCF is responsible for ensuring compliance. For preservation requirements, the Office of Hazardous Materials, Materials Transportation Bureau, Department of Transportation has determined that the Hazardous Materials Regulations do not apply to the following material: Hydrochloric acid (HCl) in water solutions at concentrations of 0.22% by weight or less, with pH less than 2.0 but greater than or equal to 1.0.

[f]Maximum holding time is 24 hours when sulfide is present. Optionally, all samples may be tested with lead acetate paper before the pH adjustment to determine if sulfide is present. If sulfide is present, it can be removed by adding of cadmium nitrate powder until a negative spot test is obtained. The sample is filtered and then the pH is adjusted to 12 with NaOH.

[g]Based on the requirements for detection monitoring (40 CFR 265.93), the owner/operator must collect a sufficient volume of ground water to allow for the analysis of four separate replicates.

[h]Do not allow any headspace in the container.

[i]For samples from nonchlorinated drinking water supplies, concentrated H_2SO_4 should be added to lower sample pH to less than 2. The sample should be analyzed within 14 days.

[j]Use ascorbic acid only in the presence of oxidizing agents.

CONTAINERS FOR AQUEOUS WASTE SAMPLES[a]

Analyte	Sample Container	Sample Volume	Preservative[b,c]	Holding Time(days)
Hazardous Substance List (HSL) Volatile	G vials (2)	40 ml	Ice	14
HSL Base/Neutral/ Acid[d]	Amber G	1 l	Ice	7/40[e]
HSL Pesticide/PCB	Amber G	1 l	Ice	7/40[e]
HSL Inorganic[f]	P,G	1 l	pH<2,w/HNO_3	180
Non-HSL Metals[g]	P,G	1 l	pH<2,w/HNO_3	180
Cyanide	P,G	0.5 l	pH>11,w/NaOH	14
pH[h]	P,G	N/A	None	N/A
Specific Conductivity[h]	P,G	N/A	None	N/A
Temperature[h]	P,G	N/A	None	N/A
Dissolved Oxygen[h]	G	N/A	None	N/A
Total Dissolved Solids (TDS)	P,G	0.1 l	Ice	7
Total Suspended Solids (TSS)	P,G	0.1 l	Ice	7
Total Phosphate	P,G	1 l	Ice, pH<2, w/H_2SO_4	28
Chloride, Sulfate	P,G	1 l	Ice	28
Carbonate/ Bicarbonate[i]	P,G	1 l	Ice	14
Nitrate	P,G	1 l	Ice	2
Hexavalent Chromium	P,G	1 l	Ice	24

[a]Reference:

1. EPA (U.S. Environmental Protection Agency) 1986. "Test Methods for Evaluating Solid Waste," Report EPA SW-846 (3rd edition). Washington, D.C.

[b]All samples, with the exception of those for total metals, will be filtered within four hours of sample collection and preservatives will be added to the filtrate as specified.

[c]All samples will be kept at 4°C after arrival at the Laboratory.

[d]The HSL base/neutral/acid fractions analytical parameters are the HSL semivolatiles.

[e]Extract within 7 days; analysis within 40 days of extraction.

[f]Includes cesium, molybdenum, and strontium, which are non-HSL metals, but are analyzed using the same methods.

[g]Includes Target Analyte List (TAL) Metals

[h]Field measurements.

[i]These are reported as carbonate and biocarbonate alkalinity.

PRESERVATION PLAN FOR SOIL/SEDIMENT SAMPLES

Analyte	Sample Volume (mL)	Sample Container[f]	Method	Preservative	Holding Time (days)
Volatile Organics	5	40-ml vial (2) with Teflon™-lined silicon rubber septum	Ref. 2	Ice	14
Base/Neutral/Acid Extractable Organics	10-30	Amber G, 1 l	Ref. 3	Ice	7/40[a]
Organochlorine Pesticide/PCB	10-30	Amber G, 1 l	Ref. 4	Ice	7/40[a]
HSL Inorganic[b]	200	P, G, 1 l	Ref. 5	Ice	180
Non-HSL Metals[c]	200	P, G, 1 l	SW-846	Ice	180
Reactivity	---	Amber G	Ref. 6	Ice	N/A
Chloride	20	G, 1 l	EPA 300.0[d]	Ice	N/A
Sulfate	20	G, 1 l	EPA 300.0[d]	Ice	N/A
Nitrate	20	G, 1 l	EPA 300.0[d]	Ice	N/A
Cyanide	200	G, 1 l	Ref. 1	Ice	14
Hexavalent Chromium	100	G, 1 l	S.M. 312b[e]	Ice	1

[a]Extract within 7 days; analysis within 40 days of extraction.

[b]Includes cesium, molybdenum, and strontium, which are non-HSL metals, but are analyzed using the same methods.

[c]Includes Target Analyte List (TAL) metals

[d]Soil/sediments will be leached with laboratory reagent water (20 grams (g) soil to 50 ml water) and water extract will be analyzed using the procedure in "Methods for Chemical Analysis of Water and Wastes," 1983; EPA 600/4-79-020.

[e]Soil/sediment will be leached with laboratory reagent water (5 g soil and 100 ml of water) by shaking for 2 hours, and the water extract will be filtered and subsequently analyzed. This is in accordance with method 312B in Standard Methods for the Examination of Water and Wastewater, 16th Edition, 1985.

[f]Container types:
P = Plastic (polyethylene)
G = Glass

Method References

Ref. 1. Method 9010 - "Test Methods for Evaluating Solid Wastes," EPA report EPA-SW-846, Office of Solid Waste and Emergency Response, Washington, D.C. 20460, Revised September 1986.

Ref. 2. Method 8240 - "Test Methods for Evaluating Solid Wastes," EPA report EPA-SW-846, Office of Solid Waste and Emergency Response, Washington, D.C. 20460, Revised September 1986.

Ref. 3. Method 8270 - "Test Methods for Evaluating Solid Wastes," EPA report EPA-SW-846, Office of Solid Waste and Emergency Response, Washington, D.C. 20460, Revised September 1986.

Ref. 4. Method 8080 - "Test Methods for Evaluating Solid Wastes," EPA report EPA-SW-846, Office of Solid Waste and Emergency Response, Washington, D.C. 20460, Revised September 1986.

Ref. 5. Method 6010 or 7000 Series Methods - "Test Methods for Evaluating Solid Wastes," EPA report EPA-SW-846, Office of Solid Waste and Emergency Response, Washington, D.C. 20460, Revised September 1986.

Ref. 6. Method 9010 or 9030 Series Methods - "Test Methods for Evaluating Solid Wastes," EPA report EPA-SW-846, Office of Solid Waste and Emergency Response, Washington, D.C. 20460, Revised September 1986.

SAMPLE CONTAINERS FOR WASTE[a]

Waste Type	Recommended Container	Closure	Analysis
Photosensitive wastes: 1,000 or 2,000 ml	Amber HDPE[b] or amber glass caps with Teflon™ liners for glass bottles	Teflon™ caps for HDPE bottles; Bakelite	Waste characterization per 40 CFR Part 261
Pesticides: hydrocarbon chlorinated; hydro-carbons; petroleum distillates	Wide-mouth, borosilicate glass bottles 1,000 or 2,000 ml	Bakelite caps with Teflon™ liner	Waste characterization per 40 CFR Part 261
Oil wastes	HDPE bottles, wide mouth, 1,000 or 2,000 ml	Teflon™ caps	Waste characterization per 40 CFR Part 261
Strong alkali or hydrofluoric acid	HDPE bottles, 1,000 ml	Teflon™ caps, wide mouth	Waste characterization per 40 CFR Part 261
Aqueous waste--characterization of organics	Borosilicate glass bottles 1,000 or 2,000 ml	Caps with Teflon™ liner	Waste characterization per 40 CFR Part 261
Solids (sludge, soils, and granular)	8-oz wide-mouth glass bottle	Bakelite caps with Teflon™ liners	Waste characterization per 40 CFR Part 261

[a]References

1. Title 40 CFR Part 261.

2. EPA (U.S Environmental Protection Agency) 1986. "Test Methods for Evaluating Solid Waste," Report EPA SW-846 (3rd edition). Washington, D.C.

b High Density Polyethylene (HDPE).

PRESERVATION PLAN FOR SOIL/SEDIMENT WASTE SAMPLES

Analyte	Sample Container	Sample Volume	Preservation	Holding Time (days)
HSL Volatile	40 ml vials (2)	5 g	Ice	14
TCLP Volatile	40 ml vials (2)	5 g	Ice	14
HSL Base/Neutral/ Acid[a]	Amber G	10-30 g	Ice	7/40[b]
TCLP Semivolatiles	Amber G	10-30g	Ice	7/40[b]
HSL Pesticide/PCB	Amber G	10-30 g	Ice	7/40[b]
TCLP Pesticides/ Herbicides	Amber G	10-30g	Ice	7/40[b]
HSL Inorganic[c]	P,G	200 g	Ice	180
Non-HSL Metals[d]	P,G	200 g	Ice	180
TCLP Metals	P,G	200g	Ice	180
Reactivity	Amber G	100 g	Ice	N/A
EP Toxicity	Amber G	100 g	Ice	N/A
Chloride	G[e]	20 g	Ice	N/A
Sulfate	G[e]	20 g	Ice	N/A
Nitrate	G[e]	20 g	Ice	N/A
Cyanide	G	200 g	Ice	14
Hexavalent Chromium	P,G[f]	1,000 g	Ice	24

[a]The HSL base/neutral/acid fractions analytical parameters are the HSL semivolatiles.

[b]Extract within 7 days; analysis within 40 days of extraction.

[c]Includes cesium, molybdenum, and strontium, which are non-HSL metals, but are analyzed using the same methods.

[d]Includes Target Analyte List (TAL) Metals

[e]Soil/sediments will be leached with laboratory reagent water (20 g soil to 50 ml water) and water extract will be analyzed using referenced procedure. Procedure references: "Methods for Chemical Analysis of Water and Wastes," 1983; EPA 600/4-79-020.

[f]Soil/sediment will be leached with laboratory reagent water (5 g soil and 100 ml of water) by shaking for 2 hours. The water extract is filtered and subsequently analyzed. This is in accordance with method 312B in "Standard Methods for Examination of Water and Wastewater," 15th Edition, 1985

EQUIPMENT AND SUPPLIES CHECK LIST FOR SAMPLE CONTAINERS AND PRESERVATION

Forms

_____ Sample Collection Logs

_____ Daily Activity Log

_____ Chain-of-Custody/Request for Analysis Form

Sample Containers, as appropriate

_____ Narrow-mouth amber glass bottles with Teflon™-lined caps (0.5, 1, and 2 liters)

_____ Amber glass vials with Teflon™ septa (40 ml)

_____ 250-ml sterile bottle

_____ Wide-mouth polyethylene bottles (0.5, 1, and 2 liters)

_____ New or cleaned polyethylene narrow-mouth bottles (1 l,.10 l, 500 ml. 125 ml, and 60 ml)

Sampling Materials

_____ Ballpoint pen (indelible dark ink)

_____ Felt-tip marker pen (indelible dark ink)

_____ 1-14 pH indicator paper

_____ Ascorbic acid crystals

_____ Disposable surgical gloves (latex, PVC, other suitable plastic, or rubber)

_____ NaOH pellets

_____ Disposable wipes

_____ Crystalline $Na_2S_2O_3$

_____ Methanol and deionized water in Teflon™ wash bottles

EQUIPMENT AND SUPPLIES CHECKLIST FOR SAMPLE CONTAINERS AND PRESERVATION (Continued)

_____ Concentrated HNO_3, H_2SO_4, and HCl

_____ Temperature probe

_____ Clipboards

_____ Deionized water

_____ Duct tape

_____ Wooden tongue depressors

_____ Aluminum foil

_____ Teflon™ tape

_____ Paper towels

Shipping Materials (acquire from Sample Coordinator Facility)

_____ Cardboard boxes

_____ Ice

_____ Blue Ice or equivalent

_____ Insulated coolers

_____ Heavy-duty poly bags and ties

_____ Strapping tape

_____ Plastic trashcan liners

_____ Canvas bags

_____ Parafilm

_____ Padding for packaging of samples

_____ Ziplock® bags

_____ Bubble pack

_____ Unique sample sticker sheets

_____ Chain-of-Custody/Request for Analysis forms

EQUIPMENT AND SUPPLIES CHECKLIST FOR SAMPLE CONTAINERS AND PRESERVATION (Continued)

_____ Sample labels

_____ Custody seals or custody tape

_____ Other equipment specified in EPA Methods, as needed

Los Alamos National Laboratory **Environmental Restoration Program** Standard Operating Procedure	No: LANL-ER-SOP-1.04	Rev: 0

Sample Control and Field Documentation

	(Print Name)	(Signature)	(Date)
Prepared by	Sandra E. Wagner	Sandra E. Wagner	2-12-92
Quality Review by	Larry Maassen	Larry Maassen	12 FEB 92
Technical Review by	Micheline Devaurs	Micheline Devaurs	2/12/92
Technical Review by	John J. Miglio	John J. Miglio	2/18/92
PM Approval	Robert W Vocke	Robert W Vocke	3-4-92
QPPL Approval	Karen L. Wrathen	Karen L Wrathen	3/4/92

Effective Date: 3-16-92

Sample Control and Field Documentation

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Sample Control and Field Documentation

1.0 PURPOSE

This procedure describes the steps necessary to document the collection of data that will be legally defensible and technically correct.

2.0 SCOPE

2.1 Applicability

This procedure is applicable to all Environmental Restoration (ER) program activities involving sample handling.

2.2 Training

The Field Team Leader (FTL) and site workers responsible for collecting data and preparing documentation should be familiar with the objectives of sample control and documentation, and must document that they have read and understand this procedure and the remaining procedures in Section 1.0, General Instructions.

3.0 DEFINITIONS

Sample custody: A sample is in one's custody when the criteria listed below have been satisfied:

- the sample is in one's physical possession, or
- the sample is in one's view at all times, or
- the sample is transferred from one's physical possession to a safe and lockable container to prevent tampering, and one possesses the only key to the container.

4.0 BACKGROUND AND/OR CAUTIONS

All work performed for the ER Program must be documented. Sample control and documentation is necessary to ensure the reliability and defensibility of data and to verify the quality and quantity of work performed in the field. Field documentation is an important part of the project's permanent record, and should be concise and factual. Data collection must be thorough and accurately documented. Failure to have complete documentation may result in loss of field work and may have serious legal ramifications.

5.0 EQUIPMENT

N/A

6.0 PROCEDURE

General Instructions:

A. Obtain forms and supplies associated with this SOP from the Sample Coordination Facility (SCF).

B. Complete all forms with dark (black or blue preferred) indelible ink.

C. Complete the forms at the time the field activity takes place. The originator of each form must sign and date the form.

D. Specific forms for media-specific sample collection have been developed for recording specific data. These forms will be included in the specific Standard Operating Procedures and will be completed when applicable.

E. Documents will not be altered, destroyed, or discarded, even if they are illegible or contain inaccuracies that require replacement documents. If an incorrect entry is made on a document, make corrections by drawing a single line through the error, entering the correct information, and initialing and dating the change.

6.1 Sample Identification

Forms and labels have been prepared so that identification and chain-of-custody records can be maintained and sample disposition can be controlled. These items are obtained from the SCF. The labels and forms associated with this procedure are listed below. Examples are provided as Attachments A through F.

- unique sample number stickers
- sample label stickers
- sample collection logs
- master sample collection log
- chain-of-custody/request for analysis forms
- custody seals

6.1.1 Unique Sample Stickers

1. The ER Program sample identification system uses a set of preprinted stickers (Attachment A). The FTL obtains a sufficient number of sheets of stickers in numeric order to collect the number of samples required by the Operable Unit Specific Sampling and Analysis plan. Each sheet contains a set of ten stickers that name a unique seven-character alphanumeric identifier and bar code.

2. Only one unique numbered sticker is used per sample even if the sample has more than one sample container. Apply the same sample number to each container of the same sample.

3. Immediately following the sampling activity, one sticker is affixed to each of the following:

   - sample container lid (except 40 ml vials without protective caps over the Teflon™ septum);
   - sample label;
   - sample collection log;
   - master sample collection log; and
   - chain-of-custody/request for analysis form.

4. Discard any remaining stickers.

6.1.2 Sample Labels

1. Sample labels (Attachment B) provide information regarding the samples. Preprinted sample labels will be provided by the SCF.

2. Each label should be completed with the following information:

   - Operable Unit;
   - Technical Area;
   - unique sample sticker;
   - date and time of collection;
   - site location;
   - location of collection;
   - type of analysis requested;
   - preservative (if any); and
   - signature of collector.

3. Affix sample labels to the sample containers immediately following the sampling activity.

4. When necessary, the label will be protected from water and solvents with clear tape placed over the label.

6.1.3 Sample Collection Logs

1. The FTL is responsible for the completion of this log and will record all information pertinent to the collection of sample media on this log.

2. A sample collection log (Attachment C) will be completed for each sample collected.

3. The logs will be paginated for each sheet prepared on a single day (i.e., if a total of 24 pages is completed, number 1 of 24, 2 of 24, etc.).

4. Information will be supplied for all spaces provided on the Sample Collection Log. If the space is not applicable to a specific project, write N/A. Record additional information in the comments section.

5. Daily entries on these logs will include:

   - Date and Time: The date and time when the measurement was made in the following formats: DD-MMM-YY (e.g., 01-JAN-91), and the 24-hour clock time (e.g., 0837 for 8:37 a.m. and 1912 for 7:12 p.m.);

   - Sheet Number: Number all the sheets that are used consecutively (e.g., 1 of 2, 2 of 2, etc.);

   - Technical Area (TA): Two-digit number indicating the TA in which the sampling activities are being executed;

   - Operable Unit (OU): Four-digit number indicating the OU where the sampling activities are being executed;

   - Site Work Plan: The title and number of the site work plan that pertains to the sampling event;

   - Signature: Name and title of preparer;

   - Sample Identification: Affix one sample sticker.

   - Control Number: A preprinted number from the Chain-of-Custody/Request for Analysis form.

   - Sample Location: Use boring or monitor well number, grid location (transect), sample station identification, or coordinate with respect to physical features with measured distances. Include a sketch in the comments section if necessary.

   - Sample Type: Example descriptions include soil; ground water; surface water; filter air, charcoal tubes, ambient air, personnel air; sludge; drum contents; oil; vegetation; wipe; or sediment. Also include sample collection method (e.g., SUMMA® canister, bailer, Shelby tube, stainless steel scoops, animal traps, etc.).

   - Containers Used: Number, volume, and type of containers used (e.g., two, 1-liter glass containers).

- Amount Collected: Approximate volume in container.
- Composite Type: If composite samples are taken, identify the type of composite sample (e.g., 24-hour composite, spatial composite).
- Depth of Sample: Description of sample intervals (e.g., depth of sample in feet, distance on transect in feet).
- Weather: Appropriate temperature, sun and moisture conditions.
- Any additional field observations/comments, which may include but are not limited to the following:

  sample preservation (e.g., ice, cooled to 4°C, HNO_3);

  calibration procedures for field equipment; or

  results of photoionization detection (PID) and flame ionozation detection (FID) in parts per million (ppm).

NOTE: LANL ER Program purchases pre-cleaned containers.

6.1.4 Master Collection Log

1. The Master Collection Log (Attachment D) is used to track samples from the site to the SCF and to the final laboratory destination. As some sites require numerous samples, this log is a helpful organizational tool.

2. The following information will be included on this log:

   - Date: The date (Day-Month-Year) of entry.
   - Sheet Number: Number all the sheets that are used consecutively (e.g., 1 of 2, 2 of 2, etc.).
   - Technical Area: Two-digit number indicating the TA in which the sampling activities are being executed.
   - Operable Unit: Four-digit number indicating the OU where the sampling activities are being executed.
   - Site Work Plan: The title and number of the site work plan that pertains to the sampling event.
   - Signature: Name and title of preparer.

- Sample Identification: Place a unique sample sticker in the box Affix Sample Sticker for each sample included in the Master Collection Log.

- Date/Time Collected: The date and time when the sample was collected, made in the following formats: DD-MMM-YY (e.g., 01-JAN-91), and the 24-hour clock time (e.g., 0837 for 8:37 a.m. and 1912 for 7:12 p.m.).

- Sample Type: Example descriptions include soil; ground water; surface water; filter air, charcoal tubes, ambient tubes, ambient air, personnel air; sludge; drum contents; oil; vegetation; wipe; or sediment. Also include sample collection method (e.g., SUMMA® canister, bailer, Shelby tube, stainless steel scoops, animal traps, etc.).

- Sample Location: Use boring or monitor well number, grid location (transect), sample station identification, or coordinate with respect to physical features with measured distances. Include a sketch in the comments section if necessary.

- Date Samples Shipped: Include the date that the samples are shipped to the SCF, leave room to supply the date that SCF ships the samples to the final laboratory destination.

- QC Samples: Number and type of Quality Control Samples.

- Control Number: Preprinted number from the Chain-of-Custody/Request for Analysis form coinciding with the first sample collected for that sampling event that will be recorded on the Sample Collection Log for the first sample taken.

- Date Samples Received: The date (day-month-year) that the analytical laboratory receives the samples provided by the laboratory.

6.1.5 Chain-of-Custody/Request for Analysis Forms

1. Chain-of-Custody/Request for Analysis (Attachment E) forms are used to document the integrity of all samples, maintain a record of sample collection, transfer between personnel, shipment, and receipt by the laboratory.

2. Complete a Chain-of-Custody/Request for Analysis form for each sample set at each sampling location. Obtain this three-part form from the SCF.

3. The top (original) copy of the Chain-of-Custody/Request for Analysis form will accompany the sample to the laboratory. The second copy will be given to the Operable Unit Project Leader (OUPL or OUPL designee). The third copy will be sent to the ER Records Processing Facility.

4. Information will be supplied for all blank spaces on the Chain-of-Custody/Request for Analysis form. If the space is not applicable, write N/A.

5. The Chain-of-Custody/Request for Analysis form will contain the following information:

   - Date: The date the Chain-of-Custody/Request for Analysis is filled out.

   - Control Number: A preprinted unique number on each Chain-of-Custody/Request for Analysis form. (Note: Remember to write this number on the Sample Collection Log that coincides with the first sticker, affixed to the Chain-of-Custody/Request for Analysis form).

   - Site Work Plan: The title and number of the site work plan that pertains to the sampling event.

   - Technical Area: A two-digit number indicating the TA in which the sampling activity is being executed.

   - Operable Unit: A four digit number indicating the OU in which sampling activities are being executed.

   - Send Lab report to: The name and address of the SCF Coordinator to whom the laboratory results should be sent.

   - OU Contact: Provide the name of the OUPL or FTL to be contacted regarding the samples.

   - Contact Phone No: Give the telephone number of the OUPL or FTL indicated as the OU contact.

   - Date Samples Shipped: Include the date that the samples are shipped to the SCF, leave room for EM-9 (SCF) to supply the date that SCF ships the samples to the final laboratory destination.

   - Lab Destination: The laboratory destination will always be EM-9. When EM-9 receives the samples, it will determine where the samples will be sent and provide the name of the designated laboratory.

- Laboratory Contact: Contact the SCF on the date the samples will be collected. Furnish the name of the person contacted at the SCF regarding the samples. The SCF will fill in the name of the laboratory employee it contacted regarding the samples prior to shipment.

- Date Lab Report Required: Give an approximate date that the lab results will be needed.

- Field Unique Sample Number/Identification: Sample Number/Identification for each sample in shipment.

- Date and Time Collected (for each sample in shipment).

- Indicate if it is a grab sample or composite sample.

- Sample Container: Type of sample container used and volume (e.g., 1 liter glass bottle).

- Matrix: Sample description (e.g., environmental matrix, liquid, soil, core, sludge).

- Preservative: Type of preservative used.

- Analysis: Analysis requested for each sample.

- Remarks: Any additional remarks that supply relevant information pertaining to the samples (i.e.,. condition on receipt, etc.).

- Relinquished by: When the possession of the samples is transferred to the SCF, the individual relinquishing the samples signs his/her name and affiliation and records the date and time on the Chain-of-Custody/Request for Analysis document in the "Relinquished By" box.

- Received by: The individual receiving the samples repeats the procedure in the "Received By" box. The shipping company is not a part of the chain-of-custody procedures. However, the shipping company's waybill number documents method of transportation. CAUTION: If you do not sign the form in the relinquish block, custody will be broken and you will have to resample.

- Possible Hazard Identification: Indicate if sample(s) is hazardous material and/or suspected to contain high levels of hazardous substances. Check spaces provided for Radiological, Highly Toxic, Flammable, Skin Irritant, Non-hazard, and Other.

- Sample Disposal: Indicate what actions will be taken for final disposal of the samples. Check spaces provided for Return to Client, Disposal by Lab, and Archive. If archived, indicate the number of months.

- Indicate the Turnaround Required, Normal or Rush.

- Comments: Any additional comments are included here.

- Sampling Team: The names of those field team members involved with the sampling and the name of the FTL. Only these persons are to be involved in the chain-of-custody procedures.

5. The FTL is responsible for shipping the samples to the SCF and for the completion of the Chain-of-Custody/Request for Analysis form. The FTL will inspect the form for completeness and accuracy.

6.1.6 Custody Seals

1. Custody seals (Attachment F) will be used to ship the samples to the SCF.

2. Custody tape will be placed over the lid of every sample container. For 40 milliliter vials, the custody tape will be wrapped around the bottle and lid horizontally and not over the exposed septia.

3. The custody tape for every sample will be signed and dated by the FTL.

4. After the samples have been properly packaged and the shipping container has been wrapped with binding tape, custody tape will be placed over the opening/closing edge of the shipping container. The FTL will sign and date the custody seal.

6.2 Field Investigation Summaries

Daily Activity Log (Attachment G) forms have been developed for detailed summaries of information pertaining to the field investigation and for recording additional field data (Attachment A). The forms can be obtained from the SCF.

6.2.1 Daily Activity Logs

1. The FTL is responsible for preparing daily field reports that briefly summarize each day's progress.

2. Paginate each sheet of the Daily Activity Log for each day (e.g., 1 of 4, 2 of 4, etc).

3. Entries on the Daily Activity Logs will include:

   - Date: The date and time when the sample was collected, in the following formats: DD-MMM-YY (e.g., 01-JAN-91), and the 24-hour clock time (e.g., 0837 for 8:37 a.m. and 1912 for 7:12 p.m.)

   - Sheet Number: Number all the sheets that are used consecutively (e.g., 1 of 2, 2 of 2, etc.);

   - Technical Area: Two-digit number indicating the TA in which the sampling activities are being executed;

   - Operable Unit: Four-digit number indicating the OU where the sampling activities are being executed;

   - Site Work Plan: The title and number of the site work plan that pertains to the sampling event;

   - Signature: Name and title of preparer.

   - Comments: The comments section will include, but is not limited to, the following:

     - deviations from approved plans or procedures;

     - a description of general field conditions encountered;

     - special problems;

     - sketches and calculations as they pertain to the job;

     - performance of subcontractors, such as their equipment's suitability and adequacy;

     - names and affiliations of all ER Program personnel on site;

     - supplies and equipment used;

     - when photographs are taken in the field, the time, date, location, roll identification number, picture number on the roll, general compass direction, a description of the subject matter, and the photographer's name;

     - decontamination practices, such as time decontamination is performed and results of equipment inspection after decontamination;

- a description of waste generated as a result of the field investigation; and
- any additional field observations pertinent to the investigation.

6.3 Records Management

A. The OUPL should provide the FTL with a list of expected records from each task.

B. The FTL should collect all completed signed forms from site workers at the end of each day.

C. The FTL should check the records against the list received from the OUPL, noting any additions and/or deletions with brief explanations, sign and date the list and give the list and the records to the OUPL.

D. The OUPL should sign and date the list under the FTL's signature to confirm the acceptance of the list.

E. The OUPL should make copies for his/her use at this time. The original completed field forms will be maintained at the ER Records Processing Facility (See LANL-ER-SOP-01.01).

7.0 REFERENCES

LANL-ER-SOPs in Section 1.0, General Instructions

8.0 RECORDS

Sample Collection Log
Master Collection Log
Chain of Custody/Request for Analysis Form
Daily Activity Log

9.0 ATTACHMENTS

Attachment A - Unique Sample Stickers
Attachment B - Sample Labels
Attachment C - Sample Collection Log
Attachment D - Master Collection Log
Attachment E - Chain-of-Custody/Request for Analysis form
Attachment F - Custody Seal
Attachment G - Daily Activity Log

UNIQUE SAMPLE NUMBER STICKERS

XXX0000

EXAMPLE ONLY

SAMPLE LABELS

LOS ALAMOS NATIONAL LABORATORY	
OU _____ TA _____	AFFIX SAMPLE STICKER HERE
LOCATION:	DATE:
ANALYSIS:	TIME: PRESERVATIVE:
SIGNATURE:	

EXAMPLE
CONTACT THE
ER PROGRAM OFFICE
(665-4557) TO OBTAIN
ORIGINAL FOR YOUR USE

Los Alamos National Laboratory Environmental Restoration
SAMPLE COLLECTION LOG

Date: _____ Time (24 hour clock) _____ Sheet _____ of _____

Technical Area _____ Operable Unit _____

Site Work Plan _____

Signature _____

AFFIX SAMPLE STICKER HERE

Control No. _____ Sample Type _____

Sample Location _____

Composite _____ Yes _____ No

Composite Type _____

Depth of Sample _____

Weather _____

Containers Used	Amount Collected

COMMENTS _____

EXAMPLE
CONTACT THE ER PROGRAM OFFICE (665-4557) TO OBTAIN ORIGINAL FOR YOUR USE

LEGEND

1. A sample collection log is to be completed for samples in each sampling interval and reaffix stickers to form when the sample label is prepared.
2. Date: Use DD-MMM-YY; e.g., 01-JAN-91.
3. Time: Use 24-hour clock; i.e.., 1835 for 6:35 PM.
4. All entries on the log are to be completed. If not applicable, mark N/A.
5. Page: Each sample team should number sheet ___ of ___ for the day's activities for all sheets prepared on a single day, i.e., if there is a total of 24 pages, number 1 of 24, 2 of 24, etc.
6. Control No.: obtain from chain of custody/request for analysis form.
7. Sample Location: Use boring or monitor well number, grid location (transect), sample station I.D., or coordinate to physical features with distances. Include sketch in comment section, if necessary.
8. Sample Type: Use the following - soil; water (surface or ground); air (filter, tubes, ambient, personnel); sludge, drum contents; oil; vegetation; wipe; sample.
9. Composite Type: i.e., 24-hour, list sample numbers in composite, spatial composite.
10. Depth of Sample: Give units, write out units such as feet.
11. Weather: Approximate temperature, sun, and moisture conditions.
12. Containers Used: List each container type as number, volume, material type (e.g., 2 - 1L glass, 4 - 40 ml glass vial, 1 - 400 ml plastic, 1 - 3 inch steel tube, 1 - 8 ox. glass jar).
13. Amount Collected: Volume of container.

Los Alamos National Laboratory Environmental Restoration
MASTER COLLECTION LOG

Date: _____ Sheet ____ of ____

Technical Area _____ Operable Unit _____

Site Work Plan _____

Signature _____

AFFIX SAMPLE STICKER HERE

Date/Time Collected _____ Sample Type _____
Sample Location _____ Data Samples Shipped _____
QC Samples _____ Control Number _____
Dates Samples Received _____

AFFIX SAMPLE STICKER HERE

Date/Time Collected _____ Sample Type _____
Sample Location _____ Data Samples Shipped _____
QC Samples _____ Control Number _____
Dates Samples Received _____

AFFIX SAMPLE STICKER HERE

Date/Time Collected _____ Sample Type _____
Sample Location _____ Data Samples Shipped _____
QC Samples _____ Control Number _____
Dates Samples Received _____

AFFIX SAMPLE STICKER HERE

Date/Time Collected _____ Sample Type _____
Sample Location _____ Data Samples Shipped _____
QC Samples _____ Control Number _____
Dates Samples Received _____

AFFIX SAMPLE STICKER HERE

Date/Time Collected _____ Sample Type _____
Sample Location _____ Data Samples Shipped _____
QC Samples _____ Control Number _____
Dates Samples Received _____

AFFIX SAMPLE STICKER HERE

Date/Time Collected _____ Sample Type _____
Sample Location _____ Data Samples Shipped _____
QC Samples _____ Control Number _____
Dates Samples Received _____

EXAMPLE
CONTACT THE ER PROGRAM OFFICE (665-4557) TO OBTAIN ORIGINAL FOR YOUR USE

Los Alamos National Laboratory Environmental Restoration
CHAIN OF CUSTODY/REQUEST FOR ANALYSIS

Date: _____ Control No. **(Pre-printed Number)**

Technical Area _____ Send Lab Report to: _____

Operable Unit _____ Address _____

Site Work Plan _____

OU Contact _____ Date Samples Shipped _____ Laboratory Contact _____

Contact Phone No. _____ Lab Destination EMSL _____ Date Lab Report Required _____

Field Unique Sample #/ID	Date & Time Collected	GRAB	COMP	Sample Container Volume/mat'l	Matrix (Liquid, Soil, Core, Sludge, Etc.)	Preservative	ANALYSIS REQUESTED TEST	METHOD	REMARKS (Condition of receipt, etc.)
AFFIX SAMPLE STICKER HERE									
AFFIX SAMPLE STICKER HERE									
AFFIX SAMPLE STICKER HERE									

Relinquished by: *(Signature)*: Affiliation:	Date: Time:	Relinquished by: *(Signature)*: Affiliation:	Date: Time:	Relinquished by: *(Signature)*: Affiliation:	Date: Time:
Received by: *(Signature)*: Affiliation:	Date: Time:	Received by: *(Signature)*: Affiliation:	Date: Time:	Received by: *(Signature)*: Affiliation:	Date: Time:

POSSIBLE HAZARD IDENTIFICATION:
(Please indicate if sample(s) are hazardous materials and/or suspected to contain high levels of hazardous substances.)

Radiological _____ Highly Toxic _____ Flammable _____

Skin Irritant _____ Non-hazard _____ Other _____

SAMPLE DISPOSAL:

Return to client _____ Disposal by Lab _____ Archive _____ (Indicate number of months): _____

TURNAROUND TIME REQUIRED: Normal _____ Rush _____

COMMENTS: _____

SAMPLING TEAM: _____

WHITE - To accompany samples YELLOW - OUPL designee PINK - To Record Processing Facility

SAMPLE

CONTACT THE PROGRAM OFFICE (6557) TO OBTAIN FOR YOUR USE

Los Alamos National Laboratory Environmental Restoration
CUSTODY SEAL

(Example Only)

Los Alamos
Los Alamos National Laboratory
Los Alamos, NM 87545

LAB SAMPLE

DO NOT TAMPER

Date _____

Initials _____

E X A M P L E

CONTACT THE
ER PROGRAM OFFICE
(665-4557) TO OBTAIN
ORIGINAL FOR YOUR USE

This Label Is Void

Los Alamos National Laboratory Environmental Restoration
DAILY ACTIVITY LOG

Date: _____ Sheet ____ of _____

Technical Area _____ Operable Unit _____

Site Work Plan _____

Signature _____

Comments:

EXAMPLE

CONTACT THE
ER PROGRAM OFFICE
(665-4557) TO OBTAIN
ORIGINAL FOR YOUR USE

Los Alamos National Laboratory **Environmental Restoration Program** Standard Operating Procedure	No: LANL-ER-SOP-01.05 Rev: 0

Field Quality Control Samples

	(Print Name)	(Signature)	(Date)
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Effective Date: 3-16-92

Field Quality Control Samples

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Field Quality Control Samples

1.0 PURPOSE

This procedure provides instructions for the collection of field quality control (QC) samples to ensure the reliability and validity of field and laboratory data.

2.0 SCOPE

2.1 Applicability

This procedure is applicable to all Environmental Restoration (ER) Program activities involving the collection of field QC samples.

2.2 Training

The Field Team Leader (FTL) is responsible for monitoring the proper implementation of this procedure and must ensure that field team members collecting QC samples are trained on each sampling procedure to be used. Additionally, the FTL and field team members must document that they have read and understood this procedure and the other procedures in Section 1.0, General Instructions.

3.0 DEFINITIONS

A. Aliquot: A sample aliquot is a portion of a sample that is representative of the entire sample.

B. Background Sample: A sample collected from an area or site similar to the one being studied, but located in an area known or thought to be free from pollutants of concern.

C. Equipment (Rinsate) Blank: Usually organic-free water that is as free of analyte as possible and is transported to the site, opened in the field, and poured over or through the sample collection device, collected in a sample container, and returned to the laboratory.

D. Field Blank: Usually organic-free water solution that is transferred from one container to another at the sampling site and preserved with the appropriate reagents.

E. Field Duplicate (Replicate) Samples: Two separate, independent samples taken from the same source that are collected in such a manner that they are co-located samples, equally representative of the sample matrix at a given location and time.

F. Quality Control Samples: Samples used in a planned check of the operation of a measurement system to obtain a measure of the quality of the data generated.

G. Reagent Blank: Usually an organic-free aqueous solution that is as free of analyte as possible and contains all the reagents in the same volume as used in the processing of the samples. A reagent blank must be carried through the complete sample preparation procedure and contains the same preservation reagent concentrations in the final solution as in the sample solution used for analysis.

H. Trip Blank: Usually an organic-free aqueous solution that is as free of analyte as possible and is transported to the sampling site and returned to the Sample Coordination Facility (SCF) without being opened. A trip blank is usually prepared by the SCF prior to the sampling event.

4.0 BACKGROUND AND/OR CAUTIONS

The majority of ER field efforts require the collection of samples for various quality control purposes. These include the isolation of site effects (control samples), definition of background (background sample), evaluation of field/laboratory methodology (duplicate samples), and assessment of the integrity of the sampling equipment (equipment rinsate blanks).

Sampling procedures outlined in the Sampling and Analysis Plans (SAPs) will be applied to QC samples in the same way they are applied to samples taken in the field. QC sample containers must be labeled and transported, and the samples analyzed in a manner identical to all other samples taken at a site.

5.0 EQUIPMENT

Equipment required for this procedure is only that specified by the Operable Unit (OU) Sampling and Analysis Plans.

6.0 PROCEDURE

The requirements for field QC samples will be evaluated as part of the OU-specific Sampling and Analysis Plan. QC sample requirements for radiological samples differ from those for nonradiological samples. Summaries of these requirements for radiological and nonradiological sampling are provided in Attachments A and B, respectively. The requirements are also provided in the Generic Quality Assurance Project Plan for Resource and Conservation Recovery Act (RCRA) Facility Investigation (LANL, 1991). In addition to the QC samples listed in these summaries, projects may require other types of samples be collected to obtain information concerning the sampling site (e.g., background and control samples). Determine the need for these samples during the preparation activities.

Obtain organic-free water in sealed containers appropriate for transport to the field and in sufficient quantity to prepare the required equipment (rinsate) blanks, field blanks, and reagent blanks. Organic-free water can be acquired at the Sample Coordination Facility (SCF).

Collect each type of QC sample required in the manner defined below.

See Attachment A for frequency of QC samples.

6.1 Background Sample

Based on knowledge of the site and surrounding areas, identify areas and/or bodies of water that are similar to those being studied, but that are known or thought to be free of the contaminates of concern. Collect samples in the contaminate-free locations using the same sampling procedures used for samples from the site being studied.

6.2 Equipment (Rinsate) Blank

After field cleaning the sampling equipment, rinse with organic-free water and collect the rinsate for analysis. Assure that all equipment surfaces that come in contact with the sampling materials are rinsed (e.g., the inside of a bailer).

6.3 Field Blank

In the immediate vicinity of the sample collection activity, pour a quantity of organic-free water into designated sample containers. Follow the sample preservation procedure using the same preservatives and volumes as used with the other collected samples.

6.4 Field Duplicate (Replicate)

At the frequency specified for the type of sample(s) being collected, collect two separate samples from the same source and at the same location and time. Place the samples in separate containers, follow the sample preservation procedure, mark each as a unique sample, and submit both samples for the same analyses.

6.5 Reagent Blank

Pour a quantity of organic-free water that is free of the analyte(s) of interest into designated sample containers. Add to this container all preservation reagents, in the same concentration and volume, as those added to a sample.

6.6 Trip Blank

Request that trip blanks be prepared by the SCF providing the sample containers for the sampling activities and that they be shipped with those containers. The number to be requested depends upon the number and type of samples to be collected. (See Attachments A and B for guidance.) Maintain the trip blanks with the sample containers throughout the sampling event and return them to the laboratory with the collected samples. Do NOT open the trip blanks.

7.0 REFERENCES

The following procedures are directly associated with this procedure and should be reviewed before field operations:

LANL-ER-SOPs in Section 1.0, General Instructions

LANL (Los Alamos National Laboratory), May 1991. "Generic Quality Assurance Project Plan for RCRA Facility Investigations for the Los Alamos National Laboratory Environmental Restoration Program, Los Alamos, New Mexico (current version).

LANL (Los Alamos National Laboratory), November 1991. "Installation Work Plan for Environmental Restoration," Los Alamos, New Mexico (current version).

Sisk, S.W., 1981, "NEIC Manual for Ground Water Subsurface Investigations at Hazardous Waste Sites," EPA Office of Enforcement, National Enforcement Investigations Center, Denver, Colorado. (Sisk, 1981, _____)

8.0 RECORDS

Records to be generated during sampling are listed in the applicable sampling procedures.

9.0 ATTACHMENTS

A. Quality Control Sample Summary for Radiological Samples

B. Quality Control Sample Summary for Nonradiological Samples

Quality Control Sample Summary for Radiological Samples[a]

QC Sample Type	Matrix of Samples	Frequency	Purpose
Field Duplicate	Soil Water	1 per 20 samples 1 per 20 samples (or less)	To evaluate the reproducibility of the sampling technique.
Rinsate Blank	Water used to rinse equipment	1 per 20 samples[b] decontamination	To evaluate procedures.

[a]Generic Quality Assurance Project Plan for RCRA Facility Investigations for the LANL ER Program, May 1991, Sections 5 and 10 (subject to annual update).

[b]Or 1 per shipment if less than 20 samples are collected in a day.

Quality Control Sample Summary for Nonradiological Samples[a]

QC Sample Type	Matrix of Samples	Frequency	Purpose
Field Blank	Soil Water	1 per 20 samples* 1 per 20 samples*	To determine reagent and field contamination from other than sampling matrix.
Reagent Blank	Water	1 per 20 samples*	To determine any contamination from preparation and processing of samples.
Field Duplicate (Replicate)	Soil Water	1 per 20 samples 1 per 10 samples	To evaluate the reproducibility of the sampling technique.
Rinsate Blank	Soil Water	1 per 20 samples* 1 per 10 samples**	To evaluate decontamination procedures.
Trip Blank	Water	1 per shipping container for VOA[b] analyses only.	To determine contamination during storage and transport.

[a]Generic Quality Assurance Project Plan for RCRA Facility Investigations for the LANL ER Program, May 1991, Section 5 (subject to annual update).

[b]VOA - Volatile Organic Compounds

* or 1 per shipment if less than 20 samples are collected in a day.
** or 1 per shipment if less than 10 samples are collected in a day.

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Fracture Characterization

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Effective Date: 3-16-92

FRACTURE CHARACTERIZATION

1.0 PURPOSE

This procedure details the methodology to be applied for characterization of all natural rock fractures in the Bandelier Tuff. Through application of this standardized approach, field studies of the Bandelier Tuff can give statistically significant measurements of (1) linear density of rock fracture, (2) fracture width, (3) fracture strike and dip, and (4) nature of fracture filling materials.

The fracture characterization plots and data table that result from this study constitute sufficient documentation of rock fracture to locate possible fault zones, tectonic and compaction deformation amounts, density of fractures contributing to fracture permeability, and overall competency of the Bandelier Tuff. The primary intent of this standardized approach is to make fracture characterizations from various field studies compatible such that fault zones from one field area to another can be correlated.

2.0 SCOPE

This procedure is applicable for all fracture characterization studies of the Bandelier Tuff where fractures are consistently exposed, either along road and blade cuts, cliff exposures, mesa tops, or excavation sites.

2.1 Applicability

This procedure is applicable to all researchers working on the Environmental Restoration Program that are responsible for characterizing rock fractures occurring within boundaries covered by the Environmental Restoration Program.

2.2 Training

Completion of a college-level course in field geology and a laboratory/lecture course in structural geology is required to use this procedure. In addition to fulfilling the requirements of this procedure, familiarity with the computer data-base RS/1 or similar system is necessary. Researchers must document that they have read and understood this procedure and the seven procedures in Section 1.0, General Instructions.

3.0 DEFINITIONS

The term "fracture" refers to any natural, linear to curvilinear break in the Bandelier Tuff without regard to the origins of the break. Displacement or opening of the break may exist but is not necessary. Terms having similar connotation for this work are "joint" or "crack." A fracture along which significant displacement has occurred is a "fault." The level of significance required for this designation depends upon locality and geological structure.

4.0 BACKGROUND AND/OR CAUTIONS

Fracture analysis in volcanic tuff follows techniques described in the structural geology text by Dennis (1972). An example document that describes a fracture characterization study on the Bandelier Tuff, using this procedure is by Vaniman and Wohletz (1990).

The main caution that must be taken in this procedure to avoid error is measurement of fractures along traverses where fracture exposure is uniform. The recognition and documentation of a fracture is dependent solely upon the researcher's ability to measure its strike, dip, and opening. In many cases these measurements require projection of the fracture plane by visual alignment. The statistical methods of fracture interpretation are intended to minimize uncertainty in these measurements. Judgement is a critical aspect of field geology and is covered in the text by Compton (1962) and the procedure covering field work SOP-03.09, Geologic Mapping of Bedrock Units.

5.0 EQUIPMENT

Fracture documentation and measurement requires a Polaroid camera to make prints for documenting fracture location, a tape measure, a brunton compass, a geological pick to clear debris from fracture surfaces, a hand lens to identify fracture-filling materials, and a flexible cardboard or plastic sheet that can be inserted into fractures to aid in projecting their strike and dip.

6.0 PROCEDURE

Three phases are required by this methodology: (1) photographic documentation of area or traverse along which fractures will be characterized, with construction of a photomosaic map base; (2) measurement of fractures and their plotting on the previously constructed fracture map; and (3) entering fracture data into a computer data base and their analysis by designated procedures.

6.1 Photo Documentation

Once a traverse or area has been identified for fracture characterization, noting the above caution that fractures should have uniform exposure, a photo mosaic map of the traverse is constructed using a Polaroid camera. In order to maintain a uniform scale and resolution for this photo mosaic base the distance from the camera lens to the exposure should be held within ± 10%. Generally this distance is on the order of 40 to 60 feet such that the edges of the photo will have a lateral scale within ± 10% of that of the photo's center. Successive photos should be overlapped sufficiently to maintain this scale requirement. Also the scale should provide enough visual resolution that major fractures are easily identified on the photo. Typically this scale requirement is that each photo will cover from 10 to 30 horizontal feet of fracture exposure.

After construction of the photomosaic, tracing paper is overlaid to make a map of outcrop features including key topographic points such as cliff tops and bottoms, prominent fractures, and geographic objects such as buildings, trees, and large sign posts. This map should be attached to the base of the photomosaic such that a one-to-one correspondence can be made between mapped and photographed features.

6.2 Fracture Measurement

Using the fracture map constructed from photomosaics, the fracture traverse is measured using a tape measure; a horizontal scale is then placed upon the map that shows the distance between mapped features. This scale will have some horizontal variability because of the map projection method and photographic error. The scale reliability should be ± 10%. Starting from one end of the fracture traverse, each fracture is sketched upon the map and designated by a number. Fracture strike and dip are measured to an accuracy of ± 1 degree with the brunton compass along with a measurement of fracture opening width (measured perpendicular to fracture surfaces). These data are recorded in a field notebook with the fracture number along with a description of any unique features of the fracture, such as nature of fracture filling materials if present, oxidation or mineralization on fracture surfaces, and cross-cutting relationships with other rock features (pumice or lithic clasts, textural features that might be used to estimate movement along the fracture).

6.3 Fracture Data Base and Analysis

The fracture data recorded in the field notebook are entered into a data base, which allows application of several statistical procedures. The RS/1 data base system is suggested for this work but other systems can be adapted. The data base consists of a table with column for each fracture listing the fracture's number designation, its horizontal location shown on the fracture map, its dip and strike, and its width. From these data several other columns are statistically calculated, including: (1) a linear fracture density calculated as a moving average by counting the number of fractures contained in a given distance interval (10 and 100 feet) centered on each fracture; (2) a cumulative fracture width over a specified interval (10 and 100 feet) centered on each fracture; and (3) relative dip of fracture from vertical where negative values indicate southerly inclinations. Because fractures in the Bandelier Tuff are generally part of conjugate sets of northwest and northeast trending systems, additional columns for the table are separately calculated for each of the three above columns for each conjugate set. The RS/1 procedures for the above calculations are archived as source and compiled codes on essxrf VAX under RS/1 directory [wohletz]@ken@ta55. The procedures are: (1) DENS -- calculates linear fracture densities for several different distance intervals; (2) DIP -- transforms dips measurements to degrees from vertical; and (3) WID -- computes cumulative fracture widths for several distance intervals.

Fracture data are then graphed on several different plots. (1) Fracture density (10 and 100 foot intervals) vs horizontal distance along the traverse; (2) Histograms or rose diagram of fracture strike; (3) Fracture strike vs horizontal distance where positive strikes represent

strike in degrees east of north and negative strikes are west of north. These data are smoothed using the RS/1 data smoothing option to show the trend of northeast and northwest fracture sets as well as the overall trend of all fracture strikes; (4) Fracture dips vs horizontal distance where vertical plots at zero, dips toward the northeast or northwest are positive inflections from vertical, and southerly dips are negative inflections from vertical. Again smoothing of data show average trends for fracture sets; (5) Fracture widths vs horizontal distance with smoothed trends for fracture sets; (6) Cumulative fracture widths (per 100 foot interval) vs horizontal distance with smoothed trends for fracture sets; and (7) Fracture widths greater than 10 cm versus horizontal distance.

7.0 REFERENCES

Compton, R.R. (1962) Manual of Field Geology. John Wiley & Sons, New York, 378 pp.

Dennis, J.G. (1972) Structural Geology. The Ronald Press Co., New York, 532 pp.

Vaniman, D. and Wohletz, K. (1990) Results of geological mapping/fracture studies: TA-55 Area. Los Alamos National Laboratory, Seismic Hazards Program Memo, EES1-SH90-17, 48 pp.

LANL-ER-SOPs in Section 1.0, General Instructions
LANL-ER-SOP-03.09, Geologic Mapping of Bedrock Units

8.0 RECORDS

Fracture characterization is recorded on field forms or Daily Activity Logs in SOP-01.04, on a fracture map, and in the RS/1 computer data base. Fracture maps are clearly located by specified topographic points of reference and notes are keyed to numbered fractures on the map as are tabulated fracture data.

9.0 ATTACHMENTS

None.

Los Alamos National Laboratory **Environmental Restoration Program** Standard Operating Procedure	No: LANL-ER-SOP-03.09 Rev: 0

Geologic Mapping of Bedrock Units

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Effective Date: 3-16-92

GEOLOGIC MAPPING OF BEDROCK UNITS

1.0 PURPOSE

This procedure establishes requirements for the collection, plotting, recording, and interpretation of geologic data to produce a geologic map and associated cross-sections of bedrock (non-soil) units. Because many bedrock exposures in the Los Alamos region occur along tall, vertical cliffs, this procedure also establishes requirements for producing geologic maps on photo mosaics of canyon walls and for recording geologic data on measured stratigraphic sections. Finally, this procedure establishes requirements for collection of rock samples.

2.0 SCOPE

2.1 Applicability

Field geology consists of the methods used to examine and interpret structures and materials at the outcrop and field studies are the primary means of obtaining first-hand geologic knowledge. This procedure applies to all Los Alamos National Laboratory personnel and their subcontractors who will perform geologic mapping of bedrock units for regional or site-specific projects of the Environmental Restoration Program (ERP) being conducted on behalf of Los Alamos National Laboratory.

2.2 Training

Successful completion of college-level courses in stratigraphy, structural geology, field techniques, and geologic mapping or demonstrated experience in geologic mapping through publication are required to use this procedure for ERP projects. Researchers or technicians using this procedure must document that they have read and understood it, as well as the procedures in Section 1.0, General Instructions.

3.0 DEFINITIONS

A. Field geology: The investigation of rocks, rock units, and rock structures in their natural environment and in their natural relations to one another.

B. Bedrock: The solid rock that occurs everywhere beneath a mantle of soil.

4.0 BACKGROUND AND/OR CAUTIONS

This procedure is designed for the Environmental Restoration Program but is based on principles and methods of field geology that are discussed in textbooks on the subject (Lahee, 1941; Compton, 1962). This procedure is an adaptation of U.S. Geol. Survey Technical Procedure GP-01, R1 ("Geologic Mapping") dated 11 August 1988. Because most of Los Alamos National Laboratory and waste sites therein are located on the

most of Los Alamos National Laboratory and waste sites therein are located on the Bandelier Tuff, no researcher or technician can perform competent geologic mapping of bedrock units in this area without referring to works on pyroclastic rocks and ash-flow tuffs (ignimbrites) (e.g., Smith, 1960; Ross and Smith, 1961; Smith and Bailey, 1966; Fisher and Schmincke, 1984). Additionally, the geology and stratigraphic nomenclature of the Los Alamos region have been previously defined and usage refined (Griggs, 1964; Bailey et al., 1969; Smith et al., 1970; Gardner, et al., 1986) thus, all geologic mapping projects for the ERP must adhere to accepted terminology, nomenclature, and usage.

The object of geologic mapping includes identification of geologic features (rock units, faults, geomorphology), definition of their distribution, contact relations, and internal variations, and determination of the age and history of the features. This information provides an understanding of the tectonic and geologic processes that could affect sites and investigations of the ERP at Los Alamos National Laboratory. The information is also required to generate models of tectonism, mass wasting, and geohydrology in the Los Alamos region.

5.0 EQUIPMENT

Equipment required to adequately satisfy this procedure may include, but is not necessarily limited to the following:

- Topographic base maps
- Brunton compass (or equivalent)
- Landscape photographs
- Aerial photographs
- Pocket stereoscope
- Rock hammer
- Hand lens
- Field forms, or ER Field Notebooks
- Altimeter
- Binoculars
- Camera
- Sample bags
- Marking pens, pencils, small drafting implements.
- Daily Activity Log
- Chain-of-Custody/Request for Analysis forms
- Sample Collection Logs
- Variance Logs
- Custody Seals
- Unique Sample Stickers
- Sample Labels

6.0 PROCEDURE

6.1 Objective

The object of this procedure is to produce geologic maps, cross sections, and stratigraphic sections of landforms, surficial deposits (excluding soils), and all bedrock features including rocks, faults, fractures, and folds that may occur within any site or regional area of interest or investigation to the ERP. Because of the unique terrain of this region, geologic maps will be constructed on photo mosaics of cliff walls as well as on standard topographic base maps.

6.2 Methods

Geologic maps are to be constructed through annotation of observations and interpretations pertaining to the geology of the area to be mapped (field area) at their appropriate locations on a previously prepared topographic base map or on photo mosaics.

Observations pertain to geologic features or relations that were observed at a specific place within the field area. Both the nature of the observation and the specific place at which the observation was made are to be recorded at the location on the map or photo representing the actual location. For convenience, the details of the observation may be recorded in ER Field Notebooks or Field Activity Daily Log (see SOP-01.04). If so, the specific place, referred to as a field station, shall be numbered, the number recorded at the location on the map or photo representing the actual location, and the same number with the corresponding observation entered on the Daily Log or the ER Field Notebook. Interpretations shall be similarly recorded.

Interpretations are to be distinguished from observations through use of distinctive symbols on the map, and through clear written distinction in the Daily Log or ER Field Notebook.

Observations and interpretations may be made through visitation and examination (field mapping) of the actual geologic feature. Field mapping may be supplemented or aided through examination and interpretation of aerial photographs of the actual geologic features. In field mapping, observations, interpretations, and/or field stations are to be plotted on a version of the base map (field sheet) or photo carried to the field area, and subsequently replotted on a version of the base map or photo retained at the base camp, field office, or home office. If aerial photographs are employed, observations, interpretations, and field stations may be plotted directly on the aerial photographs and subsequently transferred to a field sheet, to a base map, or to a photo mosaic.

The geologic map shall be drawn on a version of the base map and photo mosaic, and provided with an accompanying explanation. The geologic map and

explanation shall present a synthesis of the geologic information contained in the Daily Log or ER Field Notebook notes, field sheets, other base maps, photos, and such auxiliary information from aerial photographs, sample collections, previously published maps, and other relevant sources of data as may be available. In addition, the geologic map shall present an interpretation of the likely distribution, character and age relationships of the particular geologic features of interest (e.g., rock stratigraphic units, geologic structures, surficial deposits, geomorphic features) consistent with available observational data. Finally, the geologic map, explanation, and supporting documentation and illustrative material (e.g., text and cross-sections), if used, shall distinguish through appropriate symbols or other means that which was observed from that which was interpreted.

6.2.1 Map Scale

This procedure is applicable to geologic mapping of bedrock features at all scales. Specific scales of base maps and photo mosaics are chosen at the discretion of the Principal Investigator (PI) of each site or regional investigation.

6.2.2 Base Maps

Base maps include those prepared by FIMAD or the engineering groups of Los Alamos National Laboratory (a variety of scales <1:24,000) or advance and edition copies of U.S. Geological Survey topographic quadrangle maps at 1:24,000 to 1:100,000 scales. Base maps may be made of paper or transparent plastic such as mylar. Base maps may be cut into pieces or folded for convenient transportability. Plastic overlays may be used to record field station numbers or other data. Photos used for photo mosaics of cliff walls may be of any convenient scale to adequately portray necessary geologic features. Two versions of base maps and photos used for mosaics may be employed. These are field copies for actual field work and compilation copies used in the office for integration of all field data.

6.2.3 Rock Samples of Stratigraphic Units

Hand samples should be collected from the outcrop or from artificial exposures (man-made cuts and pits) and retained in sufficient number to represent the dominant lithologies and significant variants of all mapped rock stratigraphic units. Samples of rock stratigraphic units should normally be obtained by breaking the prospective sample from the outcrop, using a hammer or hammer and chisel. If the sample is taken from material previously separated from the outcrop (e.g., float or talus) that fact should be recorded in the Daily Log or ER Field Notebooks. Samples may be bagged in plastic, cloth, or paper bags if necessary to prevent loss, damage or contamination of the sample during handling, transit, and storage.

Samples of friable materials (soils, uncemented aggregates) should be collected directly from the bed, stratum, or deposit they are to represent, using implements appropriate to the purpose (e.g., shovels, trowels), taking care to prevent contamination of the sample through accidental inclusion of foreign material, and bagged in plastic, cloth, or paper bags.

Processing of these samples is limited to preparation of thin-sections, polished sections, grain mounts, and measurement of physical properties (e.g., specific gravity) or other nondestructive procedures. However, portions of a sample may be removed for destructive tests (e.g., chemical analysis) provided sufficient material remains, in the judgement of the PI, to fulfill the primary purpose of the sample, as described above.
Specialized sampling for other purposes (e.g., dating), which may be necessary or desirable, is outside the scope of this procedure.

6.2.4 Photographs

Aerial photographs (vertical or oblique, color or black and white) may be used as described above to observe, interpret, and plot geologic features and field stations. If annotated, the photographs become part of the formal data base. If not annotated, the photographs are regarded as part of the informal data base, requiring no special documentation or custodial care.

Photographs of specific geologic features may be taken using hand-held cameras as part of field data collection. The field location, frame number, azimuth (approximate), and object of the photograph are to be recorded in the Daily Log or ER Field Notebooks. As soon as practicable thereafter, a print or duplicate transparency of the photograph should be correlated with the information in the Daily Log or ER Field Notebooks, the print or transparency labeled in such a way that this information can be recovered, and filed as part of the formal data base. Other prints, positives, and negatives of the same photograph may be retained by the PI as part of an informal data base, to be used for other purposes, and requiring no special documentation or custodial care.

6.2.5 Attitude of Planar and Linear Features

The attitude of planar and linear features may be measured using hand-held devices (e.g., Brunton compasses) at the discretion of the PI. The measurement may be entered directly on field sheets, aerial photographs, or on Daily Logs or ER Field Notebooks. Magnetic declination will be compensated for by adjustment of the compass to the local declination, or through adjustment of the measurement.

6.2.6 Field Notebooks

Field notebooks may be used if preferred over Daily Log Sheets. The ER Field Notebooks will have perforated sheets that may be removed and attached to field forms, photographs, or other pertinent record information in a record package. The sheets in the ER Field Notebooks must have printed sequential numbers, and the header information on each set of sheets must be complete. In addition the notebooks sheets must contain, as appropriate:

- Title of mapping activity;
- Description of the objective of the mapping activity;
- Identification and scale of field sheets and base map(s) used in the mapping; and
- Equipment used.

Other information may be included, such as, weather and field conditions, sample information, data collected, or diviations, if this information is not included elsewhere.

At the conclusion of the mapping, the final results and a summary of the outcome of the mapping shall be provided. This summary shall include a discussion of whether the mapping objectives, as outlined in the initial entries, were achieved. The summary shall also include a reference to a completed and published report or map; or the summary will be provided in the field notebook. The field notes shall be reviewed and signed by a Technical reviewer.

6.3 Assumptions Affecting the Procedure

A basic assumption is that the individuals applying this procedure are competent, well-trained geologic mappers.

6.4 Data Information

Data collected using this procedure is presented as a geologic map, with accompanying explanation and optional cross-sections, and character of rock- and/or soil-stratigraphic units, geomorphic features, faults, folds, and fractures, their age relationships, and their geologic history.

6.4.1 Quantitative/Qualitative Criteria

An acceptable general purpose geologic map should meet the following criteria:

1. The map should be on a base that meets National Map Accuracy Standards. A topographic base is essential except on small scale maps or in areas of such low relief that the absence of contours does not hinder geologic interpretation. Bedrock geology portrayed on photo mosaics of cliff faces should show obvious reference features or structures.

2. The completed map should be clearly readable and usable at publication scale. All symbols on the map should be fully explained in the marginal material, if not in common usage. The sources of geologic data should be indicated for all parts of the map. Contacts inferred from geophysical, photogeologic, or remote sensing data should be identified and explained.

3. All geologically significant units mappable at the scale selected should be shown, and geologic features should be depicted uniformly throughout the area of the map.

4. Mines, prospects, quarries, wells, trenches, test pits, and drill holes should be shown to the extent possible at the map scale.

5. Geologic interpretations should be internally consistent and plausible. Relations of normal contacts of geologic units to topography should be consistent with rock attitudes, stratigraphy, and structure shown on the map and in cross sections.

6. Structure should be adequately portrayed. Attitudes of significant structural features should be indicated wherever practical. Structure sections should be included if needed for clarity, and these should be consistent with relations depicted on the map.

7. Surficial units should be distinguished and, where possible, subdivided on the basis of age, origin, morphology and/or lithology. If the map meets all criteria but this, it should be termed as bedrock geologic map. If it meets this criterion, but does not portray the bedrock units, it should be termed a surficial geologic map. In some cases several maps may be required to provide adequate general purpose coverage of an area.

8. Faults that display mappable offset of stratigraphic or lithologic units or which display evidence of recent movement, or are of some other special significance, should be mapped and classified as to type (normal, reverse, thrust, strike-slip, etc.); and dip and direction of relative movement should be shown wherever possible.

9. The explanation should be concise and reasonably definitive, and should express the distinctive characteristics and principal variations in the map units. Map units (including surficial units) should be described in terms of lithologic character, physical properties, thickness (where possible), economic significance, geologic and/or absolute age and contact relations. Definition of map units and stratigraphic nomenclature should be consistent with current USGS standards.

6.5 Calibration Requirements

Calibration is not required as a part of this technical procedure.

6.6 Sample Identification

As part of the data records and documentation, all samples will be identified as follows: All samples will be labeled with a unique identifier, using indelible ink whenever possible. Samples with surfaces too rough to mark, or too porous to mark, will be placed in bags and the bags will be marked with the unique sample identifier. Sample identifiers will be recorded on field sheets, base maps, or photos as deemed appropriate by the PI. PIs shall assure that the original sample identifier is traceable to all documentation associated with the samples, and is maintained when the samples are handled by different organizations. All sampling efforts must be coordinated with the Sample Coordination Facility.

6.7 Control and Storage

Samples collected during this work shall be identified and controlled in accordance with the procedure for Sample Control and Field Documentation. (LANL-ER-SOP-01.04).

6.8 Special Treatment

Samples shall be prepared for examination or analyses according to the purpose for which they were collected. Samples are to be routinely prepared for petrographic or geochemical analyses.

7.0 REFERENCES

Lahee, F. H. 1941. Field Geology: McGraw-Hill, New York.

Compton, R. R. 1962. Manual of Field Geology: Wiley & Sons, New York.

Fisher, R. V. and H. U. Schmincke. 1984. Pyroclastic Rocks: Springer-Verlag, New York.

Ross, C. S. and R. L. Smith. 1961. Ash-flow Tuffs: Their Origin, Geologic Relations, and Identification: U.S. Geol. Survey, Prof. Paper 366, 81 p.

Smith, R. L. 1960. Zones and Zonal Variations in Welded Ash Flows: U.S. Geol. Survey, Prof. Paper 354-F, p. 149-159.

Smith, R. L. and R. A. Bailey. 1966. The Bandelier Tuff: A Study of Ash-flow Eruption Cycles from Zoned Magma Chambers: Bul. Volcano. v. 29, p. 83-104.

Griggs, R. L. 1964. Geology and Groundwater Resources of the Los Alamos Area, New Mexico: U. S. Geol. Survey, Water Supply Paper 1753.

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Smith, R. L., R. A. Bailey, and C. S. Ross. 1970. Geologic Map of the Jemez Mountains, New Mexico: U.S. Geol. Survey, Miscell. Geol. Invest. Map I-57.

Gardner, J. N., F. Goff, S. Garcia, and R. C. Hagan. 1986. Stratigraphic Relations and Lithologic Variations in the Jemez Volcanic Field, New Mexico: Jour. Geophys. Res., v. 91, p. 1763-1778.

LANL-ER-SOP-Section 1.0, General Instructions.

8.0 RECORDS

All information collected and recorded under this procedure and that is to be used in support of the Los Alamos ERP must become a part of the official record. Information needed to process each item as a record includes: title or description, subject, originator, date of the document, and whether it is an original, a revision or an addendum.

Specific items from this procedure that will constitute a record are ER Field Notebooks, in their entirely or sheets thereof, field sheets, base maps, annotated aerial photographs, samples, photographs of specific features using hand-held cameras, and logbooks.

8.1 Field

All organized documentation will be prepared as appropriate by the PI or a contributing investigator to record data from this procedure and shall include any information considered pertinent. Each page of documentation will be numbered consecutively and chronologically. Information superseded as a result of any revisions will be lined out, initialed, and dated. All documents will be signed or initialed and dated by the investigator on a daily basis when entries are made.

8.2 Review

All data collected and the applicability of methods used in this procedure will be reviewed and cosigned by a peer or supervisor of the investigator who is knowledgeable in the objectives of this procedure. This indicates that the data are acknowledged by both the investigator and the reviewer to be acceptable and meaningful data that meet appropriate quantitative and qualitative acceptance criteria. Unacceptable data shall be identified in a manner appropriate to the form of the data.

9.0 ATTACHMENTS

N/A

Los Alamos National Laboratory **Environmental Restoration Program** Standard Operating Procedure	No: LANL-ER-SOP-06.03 Rev: 0

Sampling for Volatile Organics

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Effective Date: 3-16-92

SAMPLING FOR VOLATILE ORGANICS

1.0 PURPOSE

This procedure describes the collection of groundwater samples from wells for analysis of volatile organic compounds (VOCs), and the selection of equipment and materials to be used in this process.

2.0 SCOPE

2.1 Applicability

This procedure applies to all personnel responsible for obtaining VOC samples for the Environmental Restoration program.

2.2 Training

The field team leader and the field team member shall be familiar with the objectives of VOC sampling and must document that they have read and understand this procedure and the procedures in Section 1.0, General Instructions.

3.0 DEFINITIONS

N/A

4.0 BACKGROUND AND/OR CAUTIONS

Sample retrieval systems potentially suitable for the valid collection of volatile organic samples are reciprocating piston-type submersible pumps; gear-driven submersible pumps; syringe samplers; and bailers (Barcelona 1984; Bennett 1988; Nielsen 1985; EPA 1986; EPA Region IV 1991). Field conditions and other considerations will limit the choice of system. The focus of concern must be to provide a valid sample for analysis, one that has been subjected to the least amount of turbulence and subsequent aeration possible. Sampling mechanisms capable of obtaining samples for VOC analyses are described below:

A. Reciprocating piston-type submersible pumps. These systems are portable, self-contained, and capable of delivery flow rates of 30 gallons per hour at lifts up to 500 feet. The pump fits into 2-inch wells, which is the most common monitor well diameter. The flow rate of the pump is varied by increasing or decreasing the driving pressure supplied to the pump from a compressed air container. The gas driving the pump does not contact the sample being purged.

B. Gear-driven submersible pumps. These pumps are not as complicated or as expensive as the bladder pumps. They provide comparable samples and are often easier to handle and

cleaner than other pumps. More care, however, must be exercised when sampling with them because the flow rate is not controllable and there is a greater potential for splashing and aeration of the sample.

C. Syringe samplers. Only a limited number of commercial, syringe-type samplers are available (two vendors are IEA and TIMCO). These devices are limited in sample volume and are specific to sampling for volatiles. Essentially, they operate with an evacuated chamber that is lowered down the well and allowed to fill from the pressure of the water. The entire mechanism is then brought to the surface with the sample. The sample can then be transferred to a sample vial, or the entire unit may be sent as the sample container, if preservation with chemical additives is not desired.

D. Bailers. The Teflon™ closed top, bottom charging type is the most appropriate bailer to collect water samples for volatile analysis. The bottom emptying device with a tap is also desirable. Several vendors provide acceptable designs. Generally, bailers can collect a representative sample, provided that the sampling personnel use extra care in the collection process.

Construction materials for pumps, bailers, and tubing are limited to stainless steel, Teflon™, and glass. The tendency of organics to leach into and out of many materials makes the selection of materials critical for these trace analyses. Plastics such as Tygon, for example, will be avoided. There are numerous ways of introducing foreign contaminants into a sample; these must be avoided by following strict sampling procedures and using only trained personnel.

Treatment of the sample with sodium thiosulfate preservative is required only when there is residual chlorine in the water. Residual chlorine could cause free radical chlorination and change the identity of the original contaminants.

If floating organics are of concern (as determined by field measurement for floating organics), a representative sample cannot be obtained with confidence.

The sensitivity of the analysis and the fragility of the samples require that all volatile samples are collected in duplicate.

Holding time for the analysis of volatiles is 7 days; vials for volatile organic analysis (VOA) may be kept for up to 14 days when preserved with acid. The samples will be shipped to the EM-9 Sample Coordination Facility (SCF) daily or following each completed sampling effort. The bottles must be shipped on their sides to aid in maintaining the airtight seal during shipment. Sample shippers (coolers) will be sealed with custody seals. They must also be adequately packed and cooled to ensure that they arrive intact. Refer to SOP-01.03, Handling, Packaging, and Shipping of Samples for further instructions.

5.0 EQUIPMENT

Equipment required to implement this procedure is listed in Attachment A.

6.0 PROCEDURE

A. Assemble the equipment and supplies listed in Attachment A. Ensure the proper operation of all sampling equipment. If any equipment requires calibration, be sure to record this information on the Daily Activity Log (SOP-01.04, Sample Control and Field Documentation).

B. Coordinate the sampling effort with the SCF. The SCF will give guidance regarding sample containers, preservation, and shipment to the SCF.

C. Locate monitor wells to be sampled and establish an appropriate decontamination area. Select the staging area and areas for managing purged water and expendable sampling materials. Provide barricades to public access or intrusion by non-essential personnel.

D. Decontaminate all sampling equipment before taking the first sample and between sampling intervals, in accordance with SOP-02.07, General Equipment Decontamination.

E. Purge wells before sampling, as specified in SOP-06.01, Purging of Wells for Representative Sampling of Ground Water. Ensure that the wells were not pumped dry and that flow was at rates too low to cause turbulence in the formation.

F. Perform other sampling tasks as specified in SOP-06.02, Field Analytical Measurements on Ground Water Samples before collecting volatile samples.

G. Determine if there is residual chlorine in the water to be sampled. If there is residual chlorine, treat the sample vials with a crystal of sodium thiosulfate before sample collection (SOP-01.02, Sample Containers and Preservation).

H. Determine contamination levels of wells. Monitor wells should be sampled from least to most contaminated to reduce the possibility for cross-contamination.

I. Collect VOC samples using the most appropriate sampling mechanism.

J. If a pump is used for sampling, follow the instructions for the specific pump. If a syringe is used, follow these steps:

   1. If necessary, evacuate the syringe and lower the sampling device to just below the well screen.

   2. Remove the constriction from the device and allow the syringe to fill with sample, applying slight suction.

   3. Bring unit to the surface. If necessary, transfer the sample to vials.

K. If a bailer is used, follow these guidelines:

1. Spread new plastic sheet on the ground around the wellhead, inside a secure, delineated zone, to establish a clean working area.

2. Decontaminate all sampling equipment per SOP-02.07.

3. Cool the bailer and sample containers before use to approximate the groundwater temperature. Avoid exposing them to direct sunlight.

4. Lower the Teflon™ closed top, bottom charging bailer into the water column slowly, noting the depth. Stop when the bailer reaches the well's screened interval.

5. Slowly recover the bailer; either retrieve the bailer, using a reel to collect the cable, or collect the cable in a cleaned stainless steel bucket.

6. Use the bailer's bottom discharge tube (Teflon™) to fill the 40-ml vials by <u>slow drainage</u>.

7. Repeat step 5 as necessary to acquire sufficient sample quantities.

8. The vials (40-ml) should be competely filled to prevent volatilization, and extreme caution should be exercised when filling a vial to avoid any turbulence which could also produce volatilization. The sample should be carefully poured down the side of the vial to minimize turbulence. As a rule, it is best to gently pour the last few drops into the vial so that surface tension holds the water in a "convex meniscus." The cap is then applied and some overflow is lost, but air space in the bottle is eliminated. After capping, turn the bottle over and tap it to check for bubbles. If any bubbles are present, repeat the procedure once. If a second try is required, use a new sample container. When collecting water samples for purgeable organic compounds, duplicate samples should always be collected from each location.

   Water samples to be analyzed for purgeable organic compounds should be stored in 40-ml septum vials with screw cap and Teflon™-silicone disk in the cap to prevent contamination of the sample by the cap. The disks should be placed in the caps (Teflon™ side to be in contact with the sample) by the sample container vendor before the beginning of the sampling program.

9. After each use, the sampling equipment must be decontaminated in accordance with SOP-02.07.

10. A sampling blank should be acquired periodically to test the decontamination procedure's efficiency.

11. A trip blank of distilled deionized water should be carried throughout the sampling, preservation, and shipping process.

6.1 Documentation

For each sample collected, initiate a Sample Collection Log, Chain-of-Custody/Request for Analysis form, and affix a Sample Label to the sample container. SOP-01.04, Sample Control and Documentation, contains copies of the forms and labels and instructions for completing them.

6.2 Postoperation Activities

A. If decontamination of sampling equipment is necessary, decontaminate as instructed in SOP-02.07, General Equipment Decontamination.

B. Make sure all wells are properly labeled and the location ID is readily visible on the protective casing. Make sure all samples are properly labeled.

C. Prepare samples and transport them to the SCF according to SOP-01.02, SOP-01.03, and SOP-01.04.

D. The field team leader will contact the SCF (EM-9) to ensure that samples arrived safely and instructions for sample analyses are clearly understood. Record this information on the Daily Activity Log.

7.0 REFERENCES

The following procedures are directly associated with this procedure and should be reviewed before packaging, labelling, and shipping samples:

LANL-ER-SOPs in Section 1.0, General Instructions.
LANL-ER-SOP-02.07, General Equipment Decontamination.
LANL-ER-SOP-06.01, Purging of Wells for Representative Sampling of Ground Water.
LANL-ER-SOP-06.02, Field Analytical Measurements on Ground Water Samples.

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Barcelona, M. J., J. A. Helfrich, and E. E. Garske. 1985. "Sampling Tubing Effects on Groundwater Samples." Analy. Chem. 57: 460-63.

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DOE. 1985. "Field Technical Representative Manual." 2nd ed. U.S. Department of Energy, Uranium Mill Tailings Remedial Action Project Office, Albuquerque Operations Office document, June 1985. Albuquerque, NM.

EPA. 1981. "Manual of Groundwater Quality Sampling Procedures." U.S. Environmental Protection Agency report EPA-600/2-81-160. Washington, D.C.

EPA. 1982. "Handbook for Sampling and Sample Preservation of Water and Wastewater," U.S. Environmental Protection Agency report EPA-600/4-82-029. Washington, D.C.

EPA. 1985. "Practical Guide for Groundwater Sampling.: U.S. Environmental Protection Agency report EPA/600/2-85/104, September 1985. Washington, D.C.

EPA. 1986. "RCRA Ground Water Monitoring Technical Enforcement Guidance Document." OSWER, Washington, D.C.

EPA Region IV, 1991. "Environmental Compliance Branch Standard Operating Procedures and Quality Assurance Manual Environmental Services Division." Athens, GA.

Nielsen, David M., and Gillian L. Yeates. 1985. "A Comparison of Sampling Mechanisms Available for Small-Diameter Groundwater Monitoring Wells." Groundwater Monitoring Review, Spring 1985: 83-99.

8.0 RECORDS

The following records are generated as a result of this procedure:

A. Completed Daily Activity Log including any deviation or other pertinent information

B. Completed Chain-of-Custody/Request for Analysis Form

C. Completed Sample Collection Log including any deviation or other pertinent information.

9.0 ATTACHMENTS

A. Equipment and Supplies Checklist for Sampling Volatile Organics.

EQUIPMENT AND SUPPLIES CHECKLIST FOR SAMPLING VOLATILE ORGANICS

_____ Teflon™ stainless steel bladder pump
_____ Teflon™ stainless steel gear-driven submersible pump
_____ Syringe sampler; stainless steel, Teflon™, or glass
_____ Teflon™ bailer (closed top, bottom charging)
_____ Teflon™ or other chemically inert tubing
_____ Fittings for pump
_____ 40-ml amber glass vials; Teflon™-lined septa
_____ Hach® field kit for chlorine (optional)
_____ $Na_2S_2O_4$ crystals
_____ Foam sleeves, coolers, and Blue Ice (or equivalent)
_____ Stainless steel cable, reel, and tripod (if needed)
_____ Air compressor or bottled nitrogen
_____ Plastic sheet
_____ Daily Activity Logs
_____ Chain-of-Custody/Request for Analysis Forms
_____ Sample Collection Logs
_____ Variance Logs
_____ Custody Seals
_____ Unique Sample Stickers
_____ Sample Labels
_____ Any additional supplies listed in associated procedures, as needed

Los Alamos National Laboratory **Environmental Restoration Program** Standard Operating Procedure	No: LANL-ER-SOP-06.10 Rev: 0

Hand Auger and Thin-Wall Tube Sampler

	(Print Name)	(Signature)	(Date)
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QPPL Approval:	Karen L Warthen	Karen L Warthen	3/3/92
PM Approval:	Robert W Vocke	Robert W Vocke	3-4-92

Effective Date: 3-16-92

HAND AUGER AND THIN-WALL TUBE SAMPLER

1.0 PURPOSE

This procedure defines a method of collecting subsurface solid samples with a hand auger and thin-wall tube sampler for use in the Environmental Restoration (ER) program.

2.0 SCOPE

2.1 Applicability

These procedures are applicable to personnel using this equipment for sampling for the ER program.

2.2 Training

The field team leader is responsible for monitoring the proper implementation of this procedure. The field team members should be familiar with the equipment and must document they have read and understand this procedure and the procedures in Section 1.0, General Instructions.

3.0 DEFINITIONS

A. Thin-Wall Tube Sampler: A tool used to collect undisturbed soil samples. The sample is loaded into a stainless steel tube by the tube sampler as it is being collected. The tube is the sample container and cannot be reused. They are generally used in conjunction with a bucket auger. They cannot be used in extremely hard soil.

B. Bucket Auger: A hand auger that can be used for digging or sample collection. Most bucket augers consist of the auger bucket, various length shafts, and a "T" grip handle. All the parts are threaded and screwed together.

4.0 BACKGROUND AND/OR CAUTIONS

Undisturbed soil samples cannot be collected with a bucket auger. Thin-wall tube samplers cannot be used to dig. A subsurface undisturbed soil sample is collected by digging to six inches above the required sample depth with a bucket auger, then collecting the sample with the tube sampler. A composite or disturbed sample can be collected with the bucket auger.

To save time, a manual or powered post hole digger may be used to dig all but the last foot down to the sample depth. The post hole digger must be decontaminated per SOP-02.07. Gasoline must be handled extremely carefully during sampling events involving volatile organic compounds or fuels that are analytes.

Proper back care must be exercised when pulling a stuck auger out of a hole and turning an auger for long periods of time. Work gloves may be needed to prevent blisters.

5.0 EQUIPMENT

Refer to Attachment A for equipment list.

6.0 PROCEDURE

A. Coordinate the sampling effort with the Sample Coordination Facility (SCF). The SCF will give guidance regarding sample containers, preservation, and shipment to the SCF.

B. Gather and decontaminate needed supplies and equipment (SOP 02.07, General Equipment Decontamination).

C. To dig with the bucket auger:

1. Assemble the auger with a 2-, 3-, or 4-foot-long shaft. Put 1/2-inch Teflon™ tape on all threads to facilitate disassembly.

2. Press down and turn on the auger, dig down 6 to 12 inches then lift the auger out of the hole and remove the soil from the auger bucket. Experience will show how far one can dig with each auger bucket load and still get the auger out of the hole easily. Repeat until the required depth is reached adding additional shaft sections.

D. To collect a sample with the bucket auger:

1. Dig to 6 inches above the required depth. With a clean auger, dig out enough soil for the sample. Discard any soil you suspect fell down the hole and is not from the required sample depth. Put the sample material in the pan. Continue until the required sample volume is reached, then homogenize the sample and put it into the sample containers (SOP-01.02, Samples, Containers, and Preservation).

2. When collecting a composite sample, keep the pan of soil out of the sun and covered with aluminum foil; collect all the aliquots as quickly as possible; do not decontaminate the auger between aliquots.

3. Whenever a sample is collected for chemical analyses, a custody record must be initiated on the Chain-of-Custody/Request for Analysis form and a Sample Label affixed to the sample container (SOP-01.04, Sample Control and Field Documentation).

4. Whenever a sample is collected, complete a description of the sample using the Borehole Log (Soil) Form. An example of this form and instructions for completing this form are supplied in SOP-06.12, Soil and Rock Borehole Logging and Sampling Methods.

E. To collect undisturbed samples:

1. Dig to the required depth. Assemble the tube holder with the appropriate tube inside and attach the tube holder to the auger shaft. Use Teflon™ tape on the threads. Shove or pound the tube holder into the ground until it is full. When pounding, use a plastic hammer and use caution so as not to damage the equipment. If the sample is to be from the surface, remove any rocks, sticks or leaves, then drive the sampler into the ground.

2. Disassemble the tube holder being careful not to let any soil fall out of the tube. Cover the ends of the sample tube with 2-inch-wide Teflon™ tape then put plastic caps over the tape. Lable the bottom end of the tube with "open this end."

F. Label sample containers and complete documentation (SOP-01.04).

G. Decontaminate equipment (SOP-02.07). Pack samples and ship them to the SCF (SOP-01.03). Return all supplies and equipment to their proper storage location.

H. General Instructions

1. Refill the hole and restore the sampling area according to instructions provided in the site-specific work plan.

2. Make sure all sampling locations are properly staked and the location ID is readily visible on the location stake.

I. Postsampling activities

1. Ensure that all equipment is accounted for, decontaminated and ready for shipment.

2. Prepare the samples for transport to the SCF per SOP-01.03.

7.0 REFERENCES

The following procedures are directly associated with this procedure and should be reviewed before field operations:

LANL-ER-SOPs in Section 1.0, General Instructions.
LANL-ER-SOP-02.07, General Equipment Decontamination.
LANL-ER-SOP-06.12, Soil and Rock Borehole Logging and Sampling Methods.

ASTM, 1990. "The 1990 Annual Book of ASTM Standards, Volume 04.08 Soil and rock; Dimension Stone; Geosynthetics, "American Society for Testing and Materials.

DeVera, E. R., B. P. Simmons, R. D. Stephens, and D. L. Storm. 1980. "Samplers and Sampling Procedures for Hazardous Waste Streams." U.S. Environmental Protection Agency report EPA 600/2-80-018, January 1980. U.S. Government Printing Office, Washington, D.C.

8.0 RECORDS

A. Completed Chain-of-Custody/Request for Analysis Form

B. Completed Borehole Log (Soil) Form

C. Record all other pertinent information on the Daily Activity Log.

9.0 ATTACHMENTS

A. Equipment and Supplies Checklist for Sampling Soil with Hand Augers

B. Equipment and Supplies Checklist for Soil Sampling with Thin-Wall Tube Samplers

C. Three Types of Augers

EQUIPMENT AND SUPPLIES CHECKLIST FOR SAMPLING SOIL WITH HAND AUGERS

_____ T handle and rod attachments

_____ Auger

_____ Bucket type

_____ Continuous flight

_____ Posthole

_____ Sample container(s)

_____ Decontamination equipment

_____ Spraver

_____ Distilled water

_____ Scrub brush

_____ Methanol

_____ Disposable laboratory gloves/work gloves

_____ Combustible gas indicator

_____ Portable photoionization detector (PID) or flame ionization detector (FID)

_____ Blue ice or equivalent

_____ Plastic sheet

_____ Any additional supplies listed in associated procedures or health and safety plan, as needed.

_____ Daily Activity Logs

_____ Borehole Log (Soil) Forms

_____ Chain-of-Custody/Request for Analysis Forms

EQUIPMENT AND SUPPLIES CHECKLIST FOR SAMPLING SOIL WITH HAND AUGERS (CONTINUED)

_____ Sample Collection Logs

_____ Variance Logs

_____ Custody Seals

_____ Unique Sample Stickers

_____ Sample Labels

EQUIPMENT AND SUPPLIES CHECKLIST FOR SOIL SAMPLING WITH THIN-WALL TUBE SAMPLERS.

_____ Paraffin wax

_____ Duct tape

_____ Stove and pan (to heat wax)

_____ Drill rods

_____ T handle

_____ Auger

_____ Disposable laboratory gloves

_____ Combustible gas indicator

_____ Thin-wall tube sampler

_____ Personal protective equipment as specified in site specific Health & Safety Plan

_____ Daily Activity Logs

_____ Borehole Log (Soil) Forms

_____ Chain-of-Custody/Request for Analysis Forms

_____ Sample Collection Logs

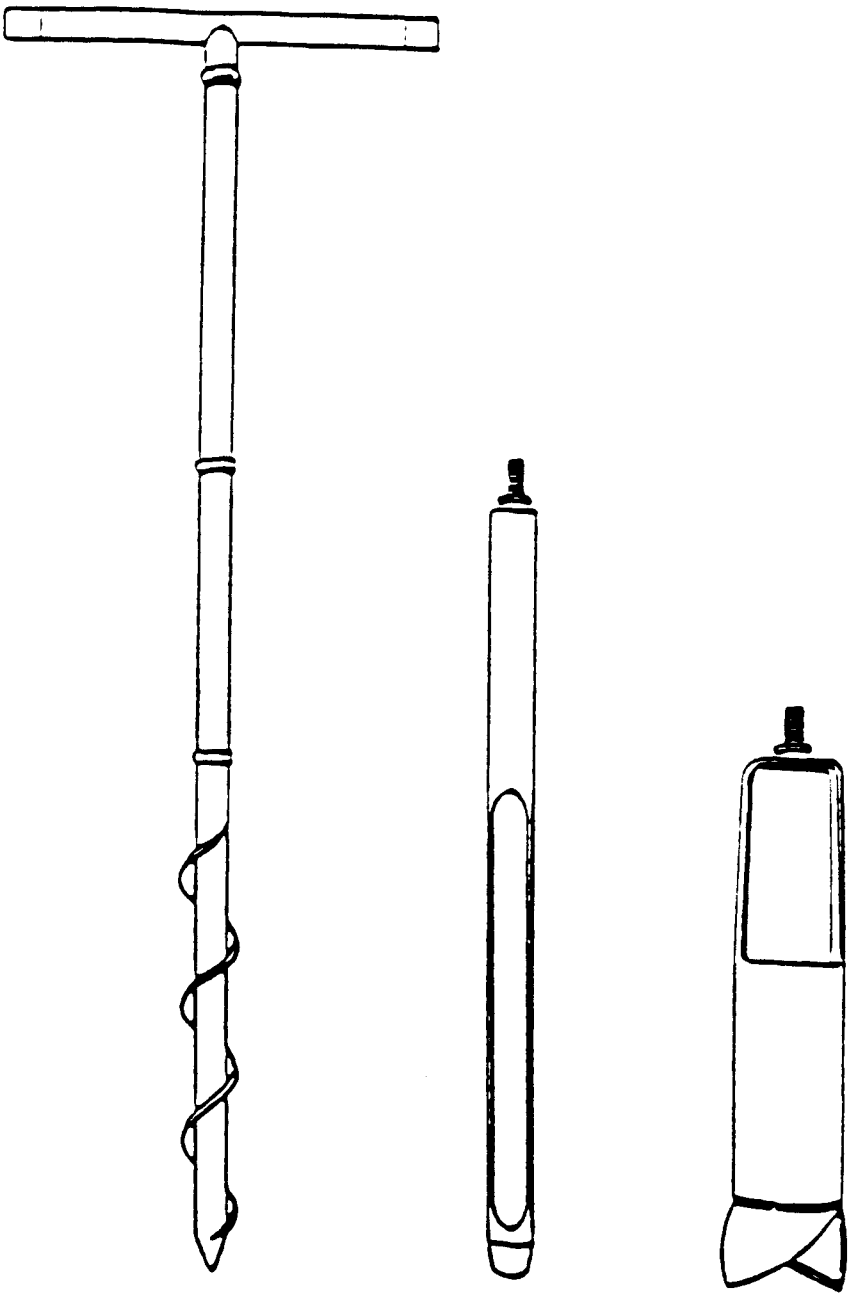
_____ Variance Logs

_____ Custody Seals

_____ Unique Sample Stickers

_____ Sample Labels

THREE TYPES OF AUGERS



Los Alamos National Laboratory **Environmental Restoration Program** Standard Operating Procedure	No: LANL-ER-SOP-06.09 Rev: 0

Spade and Scoop Method for Collection of Soil Samples

	(Print Name)	(Signature)	(Date)
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QPPL Approval:	Karen L Warthen	Karen L Warthen	3/3/92
PM Approval:	Robert W Vocke	Robert W Vocke	3-4-92

Effective Date: 3-16-92

SPADE AND SCOOP METHOD FOR COLLECTION OF SOIL SAMPLES

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SPADE AND SCOOP METHOD FOR COLLECTION OF SOIL SAMPLES

1.0 PURPOSE

This procedure describes the spade and scoop method.

2.0 SCOPE

2.1 Applicability

This procedure is applicable for collection of shallow soil samples with a spade and scoop for the Environmental Restoration Program.

2.2 Training

Field team members must document that they have read and understand this procedure, and the procedures in Section 1.0, General Instructions.

3.0 DEFINITIONS

N/A

4.0 BACKGROUND AND/OR CAUTIONS

The "spade and scoop method" is simply digging a hole and collecting a grab sample from the bottom. A spade is recommended because it digs a flatter bottomed-hole than a shovel.

The spade and scoop method will work in any soil type, including cobbles (which will stop a hand auger). If a spade will not work in a given area, an alternate tool must be used. This could be a concrete saw for concrete, a pick-axe for asphalt, a maddox for roots and rocks, or a back hoe or post hole digger for deep holes or hard soil.

Holes deeper than 2 or 3 feet require much labor; a hand auger or back hoe may be more effective.

Proper back care must be exercised when digging. Work gloves may be needed to prevent blisters. Sturdy work boots are needed for pushing the spade into the ground. Goggles are needed when using a maddox, pick-axe, or concrete saw. Personnel are not to enter excavations deeper than 4 feet unless the hole is shored or terraced.

5.0 EQUIPMENT

Equipment required to implement this procedure is listed in Attachment A.

6.0 PROCEDURE

A. Coordinate the sampling effort with the Sample Coordination Facility (SCF). The SCF will give guidance regarding sample containers, preservation, and shipment to the SCF.

B. Gather and decontaminate the needed supplies and equipment (SOP-02.07, General Equipment Decontamination).

C. Using the most effective tool available, dig to the required depth. Using the scoop, dig down or to the side to undisturbed soil and collect the sample.

D. Label sample containers and complete documentation, (SOP-01.02, Sample Containers and Preservation, and SOP-01.04, Sample Control and Field Documentation).

E. Whenever a sample is collected for chemical analyses, a custody record must be initiated on the Chain-of-Custody/Request For Analysis form and a Sample Label affixed to the sample container. SOP-01.04, Sample Control and Field Documentation, contains copies of the form and label and instructions for completing them.

F. Whenever a sample is collected, complete a description of the sample using the Borehole Log (Soil) form. An example of this form and instructions for completing the form are supplied in SOP-06.12, Soil and Rock Borehole Logging and Sampling Methods. Send all properly prepared samples to the SCF.

G. Decontaminate all equipment per SOP-02.07. Pack samples and ship them to the laboratory (SOP-01.03, Handling, Packaging, and Shipping of Samples). Return all supplies and equipment to their proper storage location.

H. Make sure all sampling locations are properly staked and the location ID is readily visible on the location stake.

7.0 REFERENCES

The following procedures are directly associated with this procedure and should be reviewed before field operations:

LANL-ER-SOPs in Section 1.0, General Instructions.
LANL-ER-SOP-02.07, General Equipment Decontamination.
LANL-ER-SOP-06.12, Soil and Rock Borehole Logging and Sampling Methods.

8.0 RECORDS

Records generated as a result of this procedure are the completed following:

Completed Borehole Log (Soil) Form
Completed Chain-of-Custody/Request for Analysis Form
Completed Daily Activity Log, including any deviations or other pertinent information

9.0 ATTACHMENTS

Attachment A - Equipment and Supplies Checklist for the Spade and Scoop Method

EQUIPMENT AND SUPPLIES CHECK LIST FOR THE SPADE AND SCOOP METHOD

_____ Stainless steel or disposable polystyrene (i.e., or other inert material) scoop or lab spoon (scoopulas)

_____ Stainless steel shovel or fat-pointed mason trowel

_____ Stainless steel spade

_____ Tape measure (tenths)

_____ Sturdy work boots

_____ Work gloves

_____ Alternate tool and eye protection (if needed)

_____ Stakes, as appropriate, for identifying sample location

_____ Sledge hammer for driving in stakes

_____ Safety glasses

_____ Teflon™ sheets or stainless steel sampling bowls

_____ Plastic sheet

_____ Alconox

_____ Brushes (long handle, scrub, and wire)

_____ Galvanized tub

_____ Trash bags

_____ Buckets (galvanized, stainless steel, and plastic)

_____ Garden pressure sprayer

_____ Cleaning wipes

_____ Chem wipes

_____ Storage containers for waste decontaminated solutions

_____ Blue ice or equivalent

_____ Disposable laboratory gloves

EQUIPMENT AND SUPPLIES CHECK LIST FOR THE SPADE AND SCOOP METHOD (continued)

_____ Camera and film

_____ Sample containers and preservatives

_____ Borehole Log (Soil) Form

_____ Daily Activity Logs

_____ Chain-of-Custody/Request for Analysis Forms

_____ Sample Collection Logs

_____ Custody Seals

_____ Unique Sample Stickers

_____ Sample Labels

_____ Any additional supplies listed in associated procedures, as needed

Los Alamos National Laboratory

Environmental Restoration Program

Standard Operating Procedure

): LANL-ER-SOP-06.13 Rev: 0

Surface Water Sampling

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PM Approval:	Robert W Vocki	Robert W Vocki	3-4-92

Effective Date: 3-16-92

SURFACE WATER SAMPLING

1.0 PURPOSE

This procedure describes methods of sampling surface water bodies and documenting all aspects of surface water sample collection.

2.0 SCOPE

2.1 Applicability

This procedure is applicable for collection of surface water samples for the Environmental Restoration program.

2.2 Training

The field team leader and field team members should be familiar with the objectives of surface water sampling at the specific site, and must document that they have read and understand this procedure and the procedures in Section 1.0, General Instructions.

3.0 DEFINITIONS

A. Surface water samples: Water collected from streams, ponds, lagoons, seeps, springs, rivers, lakes, or other water flowing or impounded at the ground surface comprise surface water samples.

B. Grab samples: A specific location at a given time is represented by a discrete aliquot. The sample is collected all at once and at only one particular point in the sample medium.

4.0 BACKGROUND AND/OR CAUTIONS

The preferred method for collecting surface water samples uses a peristaltic pump. The pump system allows the union of the filtration assembly with the pump and the sample container. In this method, surface samples are filtered if needed, and collected directly with minimal elapsed time. With a peristaltic pump, only inert materials contact the sample. The acceptable tubing is medical grade silicon, which is replaced after every sample.

An alternate method for this sampling is to collect surface water as grab samples. This method involves dipping a breaker, dipper, or other transfer device into the surface water to retrieve samples. The water sample can also be collected directly by dipping the collection bottle into the water and filling, removing, and capping it. This method has several drawbacks, including problems associated with sampling shallow waters like seeps, springs, or shallow streams. The likelihood of extensive air contact during the filtering of a sample and the time lapse before

preservatives are added to samples are also problems. The only advantage of the grab-sample method is the low cost.

Grab samples can also be collected with a transfer device constructed of Teflon™ or stainless steel. The transfer device is used to transfer liquid and liquid wastes from surface waters to a sample bottle. This method prevents unnecessary contamination that would result if the outer surface of the sample bottle were directly immersed in the liquid. In general, field personnel must avoid using metal transfer devices for trace-metal analysis or plastic devices for sampling trace organics.

The transfer device should not be used in sampling situations where aeration must be avoided or significant material could be lost through adhesion to the transfer container.

5.0 EQUIPMENT

Equipment to implement this procedure is listed on the Equipment and Supplies Checklist (Attachment A).

6.0 PROCEDURE

A. Coordinate the sampling effort with the Sample Coordination Facility (SCF). The SCF will give guidance regarding sample containers, preservation, and shipment to the SCF.

B. Refer to the site work plan to locate the sampling sites along the surface water body and the appropriate decontamination area.

C. Decontaminate all sampling equipment before taking the first sample and between sampling intervals in accordance with SOP-02.07, General Equipment Decontamination.

D. Sample flowing water in an upstream direction, if necessary.

E. If sampling with a peristaltic pump, follow the steps below:

   1. Refer to general discussion of pumps in SOP-06.01, Purging of Wells for Representative Sampling of Groundwater.

   2. Follow steps A through H, in SOP-06.01.

   3. If the depth to the midpoint of the screened interval exceeds 25 feet or it is anticipated that the depth to water will consistently exceed 25 feet during pumping because of low yield, consider an alternate system.

   4. Follow step I in SOP-06.01.

5. Lower intake into the well a short distance below the water level and begin water removal. Lower suction intake to maintain submergence and allow for successive purging of the water column.

6. Follow steps K through O in SOP-06.01.

7. To collect a sample, use the procedure outlined below.

8. Install new peristaltic pump tubing according to the manufacturer's instructions.

9. Place intake end of the tubing into the water to be sampled and turn on pump. Keep the tubing away from the bottom to minimize the amount of sediment collected. Fill the bottles agitating the water as little as possible. To collect filtered samples, connect the appropriate filter to the outlet end of the pump tube. Before collectiing filtered samples, run a few hundred millilitres of water through the filter.

10. Label sample containers and complete documentation (SOP-01.02, Sample Containers and Preservation, and SOP-01.04, Sample Control and Field Documentation).

F. If sampling with a transfer device, follow the procedure outlined below.

1. Review the Sampling and Analysis Plan for the appropriate number and size of sample containers and preservatives.

2. Use the transfer device to fill the sample containers slowly. Make sure the sample stream flows gently down the sidewall. For sampling some distance offshore, an extension device might be required. If so, firmly attach the transfer device to the dipper and tighten all bolts.

3. Record the appropriate information on the Chain-of-Custody/Request for Analysis Form (SOP-01.04).

4. Perform field chemistry on raw water, in accordance with SOP-06.02.

5. Record the final, stable readings of pH, specific conductance, and temperature on the Water Quality Sampling Record (Attachment B, of SOP-06.02).

6. If raw water is collected directly into the collection bottle, add preservatives after the sample is collected. Rinse the bottle thoroughly and shake it if a preservative (for example, HNO_3, HCl, or H_2SO_4) has been added.

7. Store the sample immediately according to SOP-01.02.

6.1 Documentation

A. For each sample collected, record all field measurements and chemistry determinations on the Water Quality Sampling Record. Also, initiate a custody record on the Chain-of-Custody/Request For Analysis form, and affix a Sample Label to the sample container.

6.2 Post Operation Activities

A. Ensure that all equipment is accounted for and decontaminated in accordance with SOP-02.07.

B. Send all samples to the SCF.

C. Place a permanent reference (sampling point) marker (for example, a wooden or metal stake with flagging that includes the location and site code) as close to the sampling location as possible.

7.0 REFERENCES

The following procedures are directly associated with this procedure and should be reviewed before surface water sampling:

LANL-ER-SOPs in Section 1.0, General Instructions.
LANL-ER-SOP-02.07, General Equipment Decontamination.
LANL-ER-SOP-06.01, Purging of Wells for Representative Sampling of Groundwater.
LANL-ER-SOP-06.02, Field Analytical Measurements on Groundwater Samples.

Berg, E. L. 1982. "Handbook for Sampling and Sample Preservation of Water and Wastewaters," U.S. Environmental Protection Agency report EPA/600/4-82/029. U.S. Government Printing Office, Washington, D.C.

EPA. 1979. "Methods of Chemical Analysis of Water and Wastes," U.S. Environmental Protection Agency report EPA-600/4-79-020. U.S. Government Printing Office, Washington, D.C.

Korte, N., and P. Kearl. 1984. "Procedures for the Collection and Preservation of Ground-water and Surface Water Samples and for the Installation of Monitoring Wells," Bendix Field Engineering Corporation Report, Grand Junction, CO.

8.0 RECORDS

The following forms, completed, are the records generated during the use of this procedure:

A. Water Quality Sampling Record

B. Chain-of-Custody/Request for Analysis Form

C. Daily Activity Log, if appropriate

9.0 ATTACHMENTS

A. Equipment and Supplies Checklist for Surface Water Sampling

B. Water Chemistry Checklist

EQUIPMENT AND SUPPLIES CHECKLIST FOR SURFACE WATER SAMPLING

_____ Peristaltic pump

_____ Filtration unit

_____ Teflon™ bore and fittings

_____ Clean filters and prefilters

_____ Transfer device for grab samples

_____ 2- or 5-gallon carboy container

_____ Wooden stakes

_____ Survey flagging

_____ Plastic or Teflon™ bucket

_____ Stopwatch

_____ Sample containers and preservatives

_____ Blue Ice or equivalent

_____ Any additional supplies listed in associated procedures, as needed

_____ pH and conductivity meter

_____ Disposable gloves if handling acidified sample containers

_____ Safety glasses/splash guard

_____ Water Quality Sampling Records

_____ Daily Activity Logs

_____ Chain-of-Custody/Request for Analysis Forms

_____ Sample Collection Logs

_____ Variance Logs

EQUIPMENT AND SUPPLIES CHECKLIST FOR SURFACE WATER SAMPLING (Continued)

_____ Custody Seals

_____ Unique Sample Stickers

_____ Sample Labels

_____ Any additional supplies listed in associated procedures, as needed

WATER CHEMISTRY CHECKLIST

Complete all blanks before going to the field

_____ Reagents: Alkalinity kit
- _____ Check reagent volumes
- _____ Check glass for breakage

_____ pH meter(s) (circle one)
- _____ Electrode full of fluid
- _____ Electrode glass intact
- _____ Immerse electrode in tap water
- _____ Calibrate electrode, rinse, fill, and replace cap
- _____ Temperature probe in tap water
- _____ Temperature probe in hot water

_____ EC meter
- _____ Battery: OK ____ Dead ____
- _____ Tap water: OK ____ Faulty ____
- _____ Against calibration solution
- _____ Solution temp
- _____ Conductivity of solution

_____ Hand-held thermometer
- _____ Temperature in ice water
- _____ Temperature agrees with lab thermometer

_____ KCl solutions

_____ Filters and tubing

_____ Flow-through bath

Los Alamos National Laboratory **Environmental Restoration Program** Standard Operating Procedure	No: LANL-ER-SOP-06.14 Rev: 0

Sediment Material Collection

	(Print Name)	(Signature)	(Date)
Preparer:	Sandra E. Wagner	Sandra E. Wagner	10-16-91
Quality Review by:	Alan Stokes	[illegible]	12/10/91
Technical Review by:	Richard Romero	R Romero	10/23/91
QPPL Approval:	Karen L Wirthen	Karen L Wirthen	3/3/92
PM Approval:	Robert W Vocke	Robert W Vocke	3-4-92

Effective Date: 3-16-92

SEDIMENT MATERIAL COLLECTION

1.0 PURPOSE

This procedure describes four basic methods of sediment sample collection.

2.0 SCOPE

2.1 Applicability

This procedure is applicable to all personnel who are involved in sediment material collection for the Environmental Restoration program.

2.2 Training

All field team members involved with the sediment material collection must document that they have read and understand this procedure, as well as the procedures in Section 1.0, General Instructions.

3.0 DEFINITIONS

A. Sediments: Particles derived from rocks or biological materials that have been transported by a fluid. Sediments include solid matter (sludges) suspended in or settled from water.

B. Composite samples: Nondiscrete samples composed of more than one specific aliquot collected at various locations or at different times. Analyzing this type of sample produces an average value for the locations or time period covered by sampling.

4.0 BACKGROUND AND/OR CAUTIONS

Sediments may be watery with no cohesion and low viscosity or they may be compacted semi-solids where water is a small part of the mass. The sediment to be sampled may be many feet down at the bottom of a lake or river or it may be exposed in a dry stream bed. Because of such differences, a variety of sampling methods and equipment may be required.

Scoops and trowels provide simple, quick, and easy means of collecting a sample of a sludge or sediment. Hand corers (Attachment A) are applicable to the same situations and materials; and they have the further advantage of collecting an undisturbed sample that can profile any stratification in the sample caused by changes in the deposition. Some hand corers can be fitted with extension handles that will allow the collection of samples underlying a shallow layer of liquid. Most hand corers can also be adapted to hold liners made of brass or polycarbonate plastic. Care should be taken to choose a material that will not compromise the intended analytical procedures.

A gravity corer (Attachment B) is a metal tube with a replaceable tapered nosepiece on the bottom and a ball or other type of check valve on the top. The check valve allows water to pass through the corer on descent but prevents washout during recovery. The tapered nosepiece facilitates cutting and reduces core disturbance during penetration. Most corers are constructed of brass or steel, and many can accept plastic liners and additional weights.

Corers are capable of collecting samples of most sludges and sediments. The corers collect essentially undisturbed samples that represent the profile of strata that may develop in sediments and sludges during variations in the deposition process. Depending on the density of the substrate and the weight of the cores, penetration to depths of 75 cm (30 inches) can be attained. Care should be exercised when using gravity corers in vessels or lagoons that have liners, because penetration depths could exceed depth of substrate and result in damage to the liner material.

The Ponar grab (Attachment C) is a clamshell-type scoop activated by a counter-lever system. The shell is opened, latched in place, and slowly lowered to the bottom. When tension is released on the lowering cable, the latch releases and the lifting action of the cable on the lever system closes the clamshell.

Sediments from large surface water bodies such as streams and lakes may be taken with Ponar grab samplers from a boat. Ponar grab samplers are more applicable to a wide range of sediments and sludges because they penetrate deeper and seal better than spring activated types (e.g., Eckman dredges). Refer to equipment operations manual for use of the sampler.

Ponars are capable of sampling most types of sludges and sediments from silts to granular materials. One version has a 232-square-centimeter sample area that is light enough to be operated without a winch or crane. Penetration depths will usually not exceed several centimeters. Grab samplers are not capable of collecting undisturbed samples. As a result, material in the first centimeter of sludge cannot be separated from that at lower depths. The sampling action of these devices causes agitation currents that may temporarily resuspend some settled solids. This disturbance can be minimized by slowly lowering the sampler the last half-meter and by allowing a very slow contact with the bottom. It is advisable, however, to collect sludge or sediment samples only after all overlying water samples have been obtained.

5.0 EQUIPMEMT

Equipment required to implement this procedure is listed in Attachment D, Equipment and Supplies Checklist.

6.0 PROCEDURE

6.1 Sludge or sediment sampling using scoops or trowels

A. Insert a decontaminated scoop or trowel into material and remove sample. In the case of sludges exposed to air, it may be desirable to remove the first 1 to 2 cm of material

prior to collecting sample. Record any pertinent information, e.g., location, sample size, on the Daily Activity Log (SOP-01.01.01, Records).

B. If compositing a series of grab samples, use a decontaminated glass or stainless steel mixing bowl or Teflon™ tray for mixing.

C. Transfer sample into an appropriate sample container.

6.2 Sludge or sediment sampling using a hand corer

A. Push corer into material with smooth continuous motion, twist, then withdraw in a single smooth motion. Record any pertinent information in the Daily Activity Log.

B. Remove sample and place in an appropriate container.

6.3 Sediment and sludge sampling using a gravity corer:

A. Attach a precleaned corer to the required length of sample line. Solid braided 5 mm (3/16 inch) nylon line is sufficient; 20 mm (3/4 inch) nylon, however, is easier to grasp during hand hoisting.

B. Measure and mark distance to top of sludge on sampler line to determine depth of sludge or sediment coring.

C. Allow corer to free fall through liquid to bottom.

D. Determine depth of sludge penetration. Depending on the hardness and depth of the sediment and the weight and diameter of the corer, the corer may penetrate too far or not far enough. The amount of weight on the corer may need to be changed. Trial and error is required to find the correct weight for any given situation.

E. Retrieve corer with a smooth, continuous lifting motion. Do not bump corer because this may result in some sample loss.

F. Remove sample and place in an appropriate container. Record any pertinent information in the Daily Activity Log.

6.4 Sediment and sludge sampling using a Ponar grab sampler

A. Attach a decontaminated Ponar to the necessary length of sample line.

B. Measure and mark the distance to top of sludge on the sample line. Record depth to top of sludge and depth of sludge penetration in the Daily Activity Log.

C. Open sampler jaws until latched. From this point on, support the sampler by its lift line, or the sampler will be tripped and the jaws will close.

D. Begin lowering the sampler until the proximity mark is reached.

E. Use a slow rate of descent through last meter until contact is felt.

F. Allow sample line to slack several centimeters. In strong currents, more slack may be necessary to release mechanism.

G. Slowly raise sampler clear of surface.

H. Remove sample and place in an appropriate container.

6.5 Postoperation Activities

A. Label samples and complete sample documentation (SOP-01.04, Sample Control and Documentation).

B. Prepare the samples for shipping (SOP-01.03, Handling, Packaging, and Shipping of Samples).

C. Ensure that all equipment is accounted for, decontaminated (SOP-02.07, General Equipment Decontamination), and ready for shipment.

7.0 REFERENCES

The following procedures are directly associated with this procedure and should be reviewed before sediment sample collections:

LANL-ER SOPs in Section 1.0, General Instructions.
LANL-ER SOP-02.07, General Equipment Decontamination.

DeVera, E. R., B. P. Simmons, R. D. Stephens, and D. L. Storm. "Samplers and Sampling Procedures for Hazardous Waste Streams." EPA 600/2-80-018. January 1980.

Environmental Monitoring System Laboratory (EMSL), ORD, U.S. Environmental Protection Agency. *Characterization of Hazardous Waste Sites--A Method Manual, Volume II--Available Sampling Methods.* 1983. Las Vegas, NV.

Lind, Orent. *Handbook of Common Methods of Limnology.* C.V. Mosby Co., 1974. St. Louis, MO.

OWDC, U.S. Geological Survey, U.S. Department of the Interior. *National Handbook of Recommended Methods for Water-Data Acquisition.* Prepared cooperatively by agencies of the U.S. Government, Reston, VA. 1977.

Smith, R., and G.V. James. *The Sampling of Bulk Materials.* London: The Royal Society of Chemistry. 1981.

8.0 RECORDS

A. Completed Daily Activity Log which will include all pertinent information, e.g., location, sample size, and comments

B. Completed Chain-of-Custody/Request for Analysis Form

9.0 ATTACHMENTS

A. Diagram of Hand Corer

B. Diagram of Gravity Corer

C. Diagram of Ponar Grab Sampler

D. Equipment and Supplies Checklist

DIAGRAM OF HAND CORER

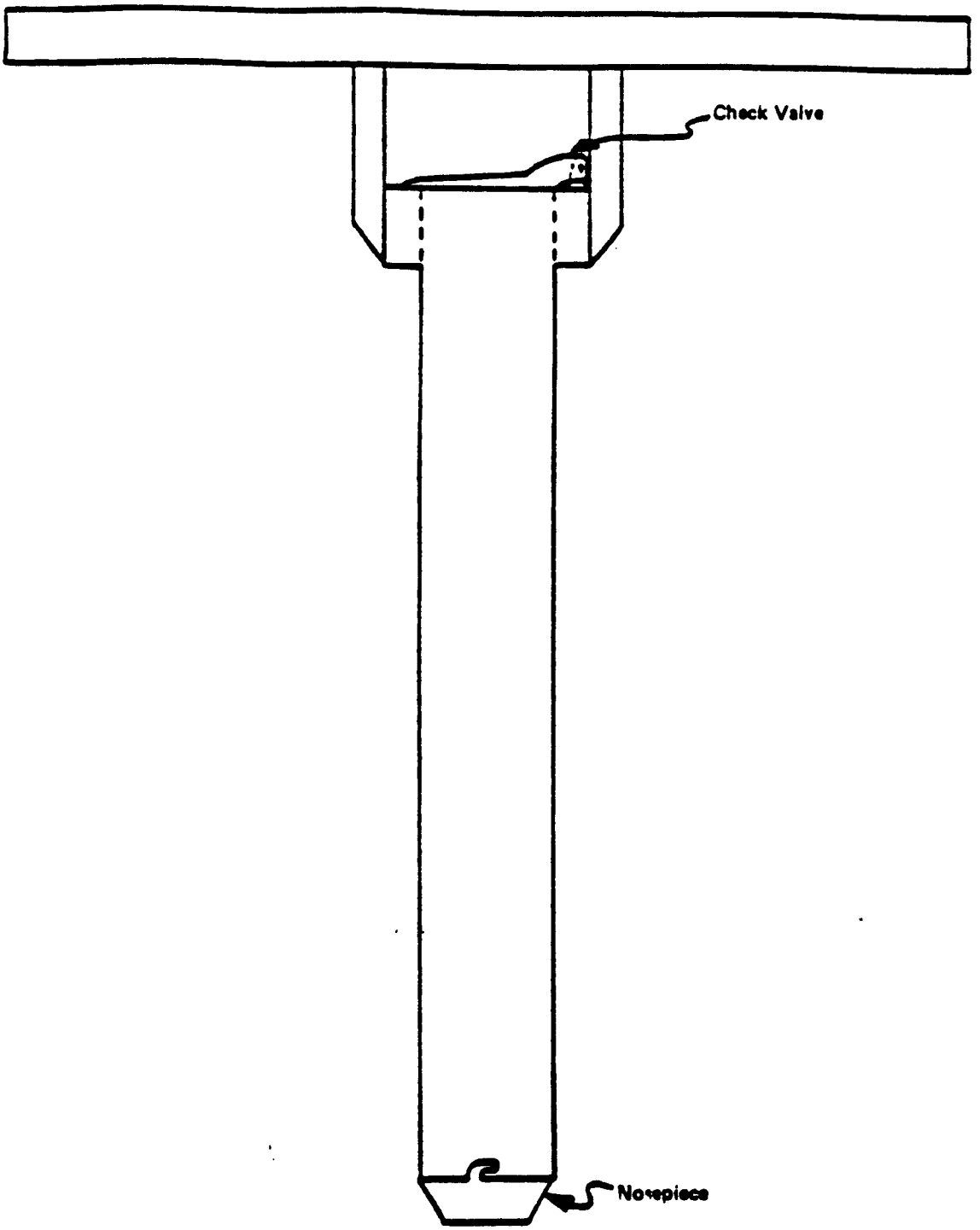


DIAGRAM OF GRAVITY CORER

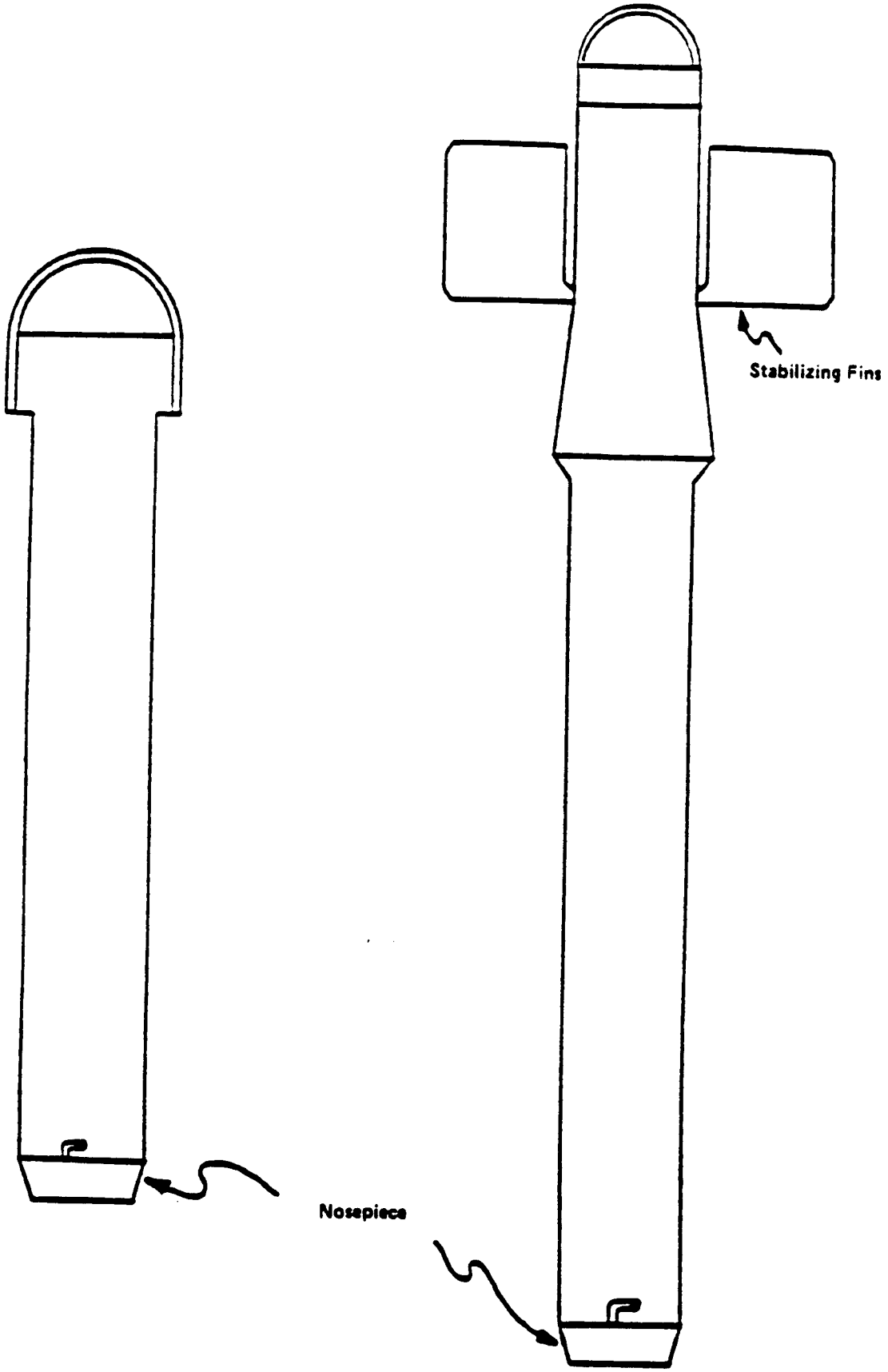
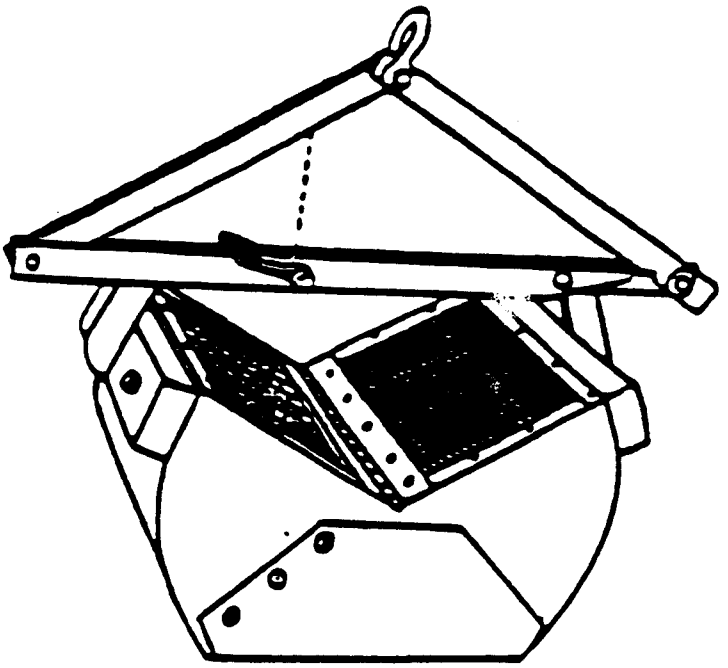


DIAGRAM OF PONAR GRAB SAMPLER



EQUIPMENT AND SUPPLIES CHECKLIST

_____ Hand Corer or

_____ Gravity Corer or

_____ Ponar Grab Sampler or

_____ Trowel or

_____ Scoop

_____ Operations manuals

_____ Bowl

_____ Tray

_____ Sample containers

_____ Rope (Review well depths prior to purchase)

_____ Protective gloves

_____ Life jacket

_____ Tape measure

APPENDIX H

LA-10574-MS

Technology Development for the Design of Waste Repositories at Arid Sites: Field Studies of Biointrusion and Capillary Barriers

Los Alamos National Laboratory
Los Alamos, New Mexico 87545

Los Alamos National Laboratory is operated by the University of California for the United States Department of Energy under contract W-7405-ENG-36.

This work was supported by the US Department of Energy, National Low-Level Waste Management Program.

Edited by Julia Olsen
Prepared by Mary Moore, HSE Division, and Sylvia Gonzales, Group HSE-12

Cover photo: Four biointrusion-barrier plots under construction in 1981 at the waste disposal site, Area G, in Los Alamos, New Mexico.

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LA-10574-MS

UC-70B
Issued: March 1986

Technology Development for the Design of Waste Repositories at Arid Sites: Field Studies of Biointrusion and Capillary Barriers

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Tom Hakonson
Edward A. Lopez

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Los Alamos National Laboratory
Los Alamos, New Mexico 87545

TECHNOLOGY DEVELOPMENT FOR THE DESIGN OF WASTE REPOSITORIES AT ARID SITES: FIELD STUDIES OF BIOINTRUSION AND CAPILLARY BARRIERS

by

John W. Nyhan, Willy Abeele, Tom Hakonson, and
Edward A. Lopez

ABSTRACT

The field research program involving the development of technology for arid shallow land burial (SLB) sites is described. Results of field testing of biointrusion barriers installed at an active low-level radioactive waste disposal site (Area G) at Los Alamos are presented. A second experiment was designed to test the ability of a capillary barrier to effectively convey water infiltrating a SLB trench around and away from underlying buried wastes. The performance of the capillary barrier was tested in the field for a barrier of known thickness (2 m), slope (10%), and slope length (2 m), and for one combination of porous materials [a crushed tuff-clay (2% w/w) mixture overlying Ottawa sand] subjected to a known water addition rate. The waste management implications of both studies are also discussed.

I. INTRODUCTION

The purpose of the Shallow Land Burial (SLB) Technology Development task of the National Low-Level Waste Management Program is to provide research for technology development to determine and quantify essential components of SLB integrated systems for optimal designs to control contaminant mobilization and migration at arid sites.

Reliable and comprehensive experimental data are just becoming available to allow analyses for design of SLB facilities at arid sites or to predict the future performance of proposed SLB designs. Additional analyses and information are needed to allow preparation of manuals to design SLB

facilities at arid sites. Particularly important issues are the ability to predict long-term performance (modeling ability) and the reliability of those predictions. Moreover, data must be obtained on system interactions when integrated system designs are based on optimal components. Applications of component models (e.g., hydrologic transport models for surface and near-surface processes and unsaturated flow and transport models for subsurface processes) need to be evaluated for validity of predictions in integrated systems environments (Nyhan and Lane 1982, Nyhan et al. 1984). These data and evaluations are necessary to demonstrate the ability to model, monitor, and predict future performance of SLB facilities. Gaps in knowledge still exist on component processes even as our component experiments have produced new information and optimal designs. These gaps include questions of scale, interactions, and field performance. Additional information is required to predict plant succession and to specify the influence of burrowing animals on the water balance (Hakonson et al. 1982a, Hakonson et al. 1982b). Additional information is needed to more accurately determine the potential for radionuclide movement within, near, and off-site and to design systems that include barriers to control this migration (Lane and Nyhan 1985). Additional data and model testing are required to predict long-term SLB performance using validated mathematical models.

The experiments performed under this task will provide experimental information from controlled experiments at or nearly at field scale and from integrated experiments. This information will specifically address most of the gaps in knowledge identified above and, moreover, provide additional information on interactive surface, near-surface, and subsurface processes operating at an arid site SLB facility. In addition, the experimental data are being used to validate mathematical models and thus assist in development

of an arid site predictive capability for SLB processes. Finally, the data and our interpretations will become part of a model validation data base available to the national program.

An important aspect of developing a validated and credible predictive capability is extensive testing and evaluation. These tests and evaluations are being done as part of field experiments presented in this report. The data collection and analysis activities presented in this report involve field experiments on biointrusion-barrier testing at an active low-level radioactive waste disposal area at Los Alamos, and on capillary-barrier testing for subsurface water management at waste burial sites.

II. AREA G STUDY

A. General Description and Waste Use History of Area G

The U. S. Geological Survey cooperated with the Atomic Energy Commission in the selection of Area G and recommended that disposal pits be no closer than 15 m to the canyons, be no more than 15 m deep, and that open joints in the pits be sealed with fine-grained material. The area was selected because it is relatively isolated and probably is large enough for disposal of solid wastes for 10 or more years. Area G is currently being used for the disposal of radioactive wastes and is located on Mesita del Buey approximately 3.2 km southeast of the intersection of the access road and Pajarito Road (S 1/2 sec. 31 T. 19 N., R. 7 E). Mesita del Buey is approximately 4.8 km south of the Los Alamos townsite. It is a narrow, southeast-trending mesa that is part of the Pajarito Plateau. Bounded by vertical cliffs with steep slopes at their base, the mesa is as narrow as 91.4 m, as wide as 402 m, and is approximately 3.2 km long. Mesita del Buey is about 30.5 m above the Pajarito Canyon floor at its western margin and less than 24.4 m above the canyon floor at its

eastern end. The surface slopes gently to the southeast from an altitude of 2103 m to 2012 m. Soil cover along the axis is 0.3 to 0.6 m thick and thins toward Pajarito Canyon on the south and Canada del Buey on the north.

The zone of saturation (water table) lies at unknown depth beneath Area G (Rogers 1977). It is at a depth greater than 100.6 m. The depth to water at local well PM-2 [elevation 2046.7 m] was 250.9 m. Water is perched seasonally in the alluvium in Pajarito Canyon.

Until 1971, no attempt to segregate waste by pit was made. Pits received nonroutine and routine radioactively contaminated waste. All pits were initially used for nonroutine waste followed by a mixture of routine and nonroutine waste. Nonroutine contaminated waste included debris from the demolition of TA-1 and Bayo Site, classified materials, and pieces of heavy equipment such as dump trucks. Routine contaminated waste consisted of cardboard boxes (33 cm X 33 cm X 61 cm), 5-mil plastic bags (33 cm X 61 cm and 256 cm X 61 cm) of material generated in the chemistry laboratories, and 0.20-m^3 barrels of sludge from the waste treatment plants at Building 35 DP-West, TA-45 and TA-50.

A December 1970 radionuclide inventory states (Rogers 1977) the following:

> The following report is based on all available H-1 records for radioactive waste buried at Los Alamos. From many entries in the H-1 records, the amount and type of radioactive materials are listed as Classified (SECRET/RD). Because of entries such as these, and also other similar ones, this report is an audit of H-1 records and not an investigation of complete facts. Group H-1 records from 1945 through 1960 have almost no information concerning what radioactive material or how much in gram quantities. These records were of the monitoring results of radioactive material or contaminated materials. These records also included volume of waste, location of waste, date of the burial, signatures of persons involved, and from which group the material originated. Area G has 50 007 lbs [22682.8 kg] of D-38, 9034 g of U-235, 1084 g of Pu-239, 0.204 g of Pu-238, 0 g of U-233 and less than 10 g of tritium.

The next radionuclide inventory was published May 1974 (Rogers 1977) and states:

> The records describing the material placed in these pits generally do not contain information on the curie content of the material, but the isotopic composition is generally indicated. Uranium- and plutonium-contaminated wastes are placed in separate pits. Americium-241 is known to be present in the pits, occurring in association with plutonium in drums of sludge generated by liquid treatment facilities. A reliable estimate can be made of the curie content of the various isotopes using material accountability data. Other radioisotopes, such as tritium, are known to be present in the disposal pits in unknown quantities. Records on the type and activity of wastes placed in disposal shafts are generally quite good.

Currently, low-level radioactive solid waste materials continue to be disposed of at Area G in SLB pits. Engineering Drawing ENG-C 18463 (Materials Waste Pits Standard Specifications, Mesita del Buey, TA-0), dated February 26, 1957, shows a pit in plan view, in longitudinal cross section, and in cross section at right angles to the axis of the pit. Pits were to be 182.9 m (maximum where possible) long and 30.5 m wide. One ramp of the pit was to have a 6:1 slope, and the other ramp was to have a 4:1 slope. The up ramp, a 6:1 slope, covers an approximate horizontal distance of 45.7 m; the down ramp, a 4:1 slope, covers an approximate horizontal distance of 30.5 m. A 7.6-m depth is shown for the pit with a note stating "actual depth will be determined by conditions encountered in the field." The walls of the pit were to be cut "as nearly vertical" as excavating equipment will permit (Rogers 1977).

B. Biointrusion Barrier Study at Area G

1. Experimental Plan and Techniques. The Laboratory's low-level waste operations group, in the process of closing out a trench at Area G in late 1981, provided the opportunity to install an intermediate-scale biointrusion experiment on the site. In order to address some of the issues

raised by the small-scale lysimeter study (Hakonson 1986), an experiment was designed to monitor the performance of several trench cap designs with respect to plant root intrusion and percolation of water into the trench backfill.

The use of rock materials in intrusion-barrier designs leads to questions about the effects of such materials on water balance. Obviously, replacing a layer of crushed tuff within the trench cap with an equal depth of rock greatly reduces the soil moisture storage capacity of the cap. Consequently, the amount of water that eventually percolates through the cover and into the trench backfill may be increased, given that no special consideration is given to the lost moisture-storage capacity. One method of replacing lost storage capacity would be to increase topsoil depth over the rocks. However, in order to produce observable treatment effects over the short life of the Area G study, topsoil depths over the barriers were purposefully applied at less than optimum depth.

Four plots, 6 m X 12 m each, were constructed (Fig. 1) on trench 25 at Area G and consisted of 1 m of four different barrier configurations covered with only 15 cm of Hackroy series topsoil (Fig. 1). Although the 15-cm topsoil depth provided relatively little soil-moisture storage capacity (about 6 cm of water at saturation), it did increase the probability of root intrusion and of percolation occurring into and through the various intrusion-barrier materials for purposes of determining the characteristics and magnitude of these failure modes. Thus, any precipitation event that resulted in greater than 6 cm of infiltration into the topsoil had a high probability of water percolating into the biobarrier and, in the case of the rock barrier systems with little water storage capacity, into the underlying backfill.

One plot, which served as a control, approximated the current practice of applying a trench cap of 1 m of crushed tuff covered with 15 cm of topsoil.

The other three plots consisted of various combinations of cobble and gravel covered with 15 cm of topsoil (Fig. 1). A 4-5% surface slope provided for some surface runoff.

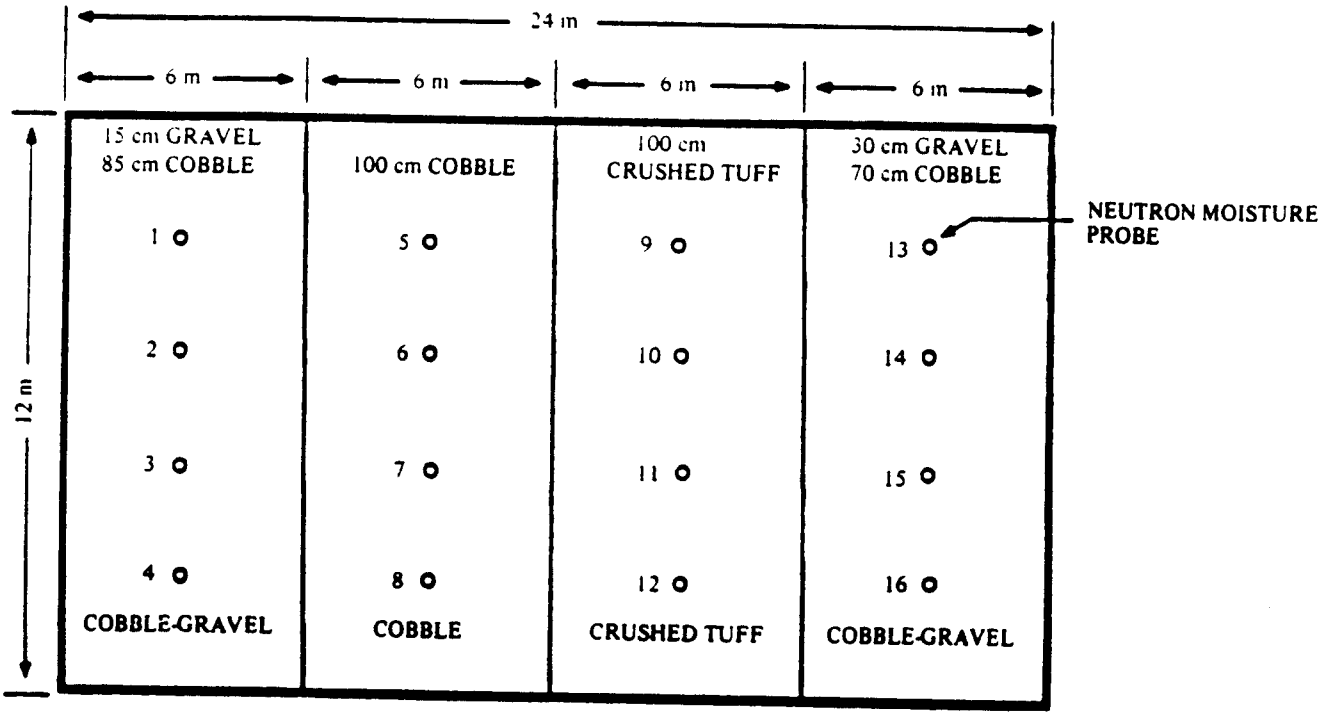

Fig. 1. Intermediate-scale biointrusion-barrier experiment at Area G.

Galvanized roofing material was used to delineate plot boundaries (Fig. 2) in order to facilitate plot construction and to prevent soil water interflow between plots. Neutron moisture gauge access tubes were installed to a depth of 30 cm into the backfill underlying the cap designs to allow for the monitoring of soil moisture in the backfill. Cesium chloride was applied at a rate of 30 g/m^2 to the backfill surface to serve as a plant-available simulated waste for evaluating root intrusion. The plots were then filled

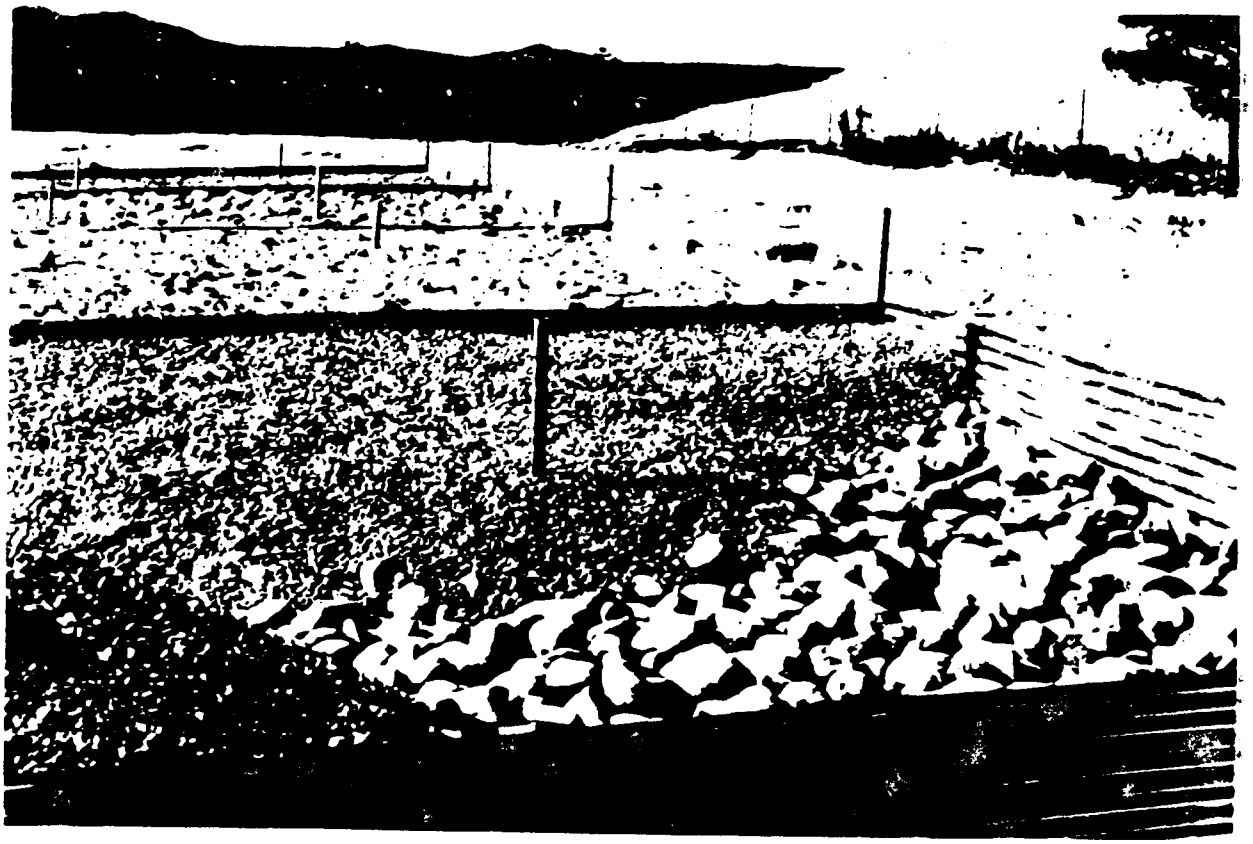

Fig. 2. Four biointrusion-barrier plots under construction on trench 25 at Area G in 1981. Galvanized metal plot borders, neutron access tubes, and portions of the barrier materials are shown as they were before the final 15 cm of topsoil was added.

with the appropriate barrier material (Fig. 2) and topsoil before seeding with a seed mixture of nine native grass species (Hakonson 1986).

Soil moisture in the backfill underlying the caps was measured with a Campbell Pacific model 503DR neutron moisture gauge to provide an indirect measure of percolation. In the control plot, changes in soil water content

were monitored at depths of 92, 107, 122 and 137 cm, and the water content at the 137-cm depth was monitored with respect to time in the biobarrier plots. Vegetation samples (five/plot/sampling period) were collected periodically throughout the study and analyzed for cesium using neutron activation analysis. The only water added to the plots was natural precipitation.

2. Results and Discussion of Area G Study. In general, cesium concentrations in all samples averaged less than background levels of 1 ppm or less through November 8, 1983 (Hakonson 1986), although concentrations in individual samples from the plot with 100 cm of crushed tuff measured as high as 83 ppm, or about 100 times background. Only two of the intrusion-barrier designs (one using 100 cm of cobble and one using 30 cm of gravel over 70 cm of cobble) proved to be essentially 100% effective in preventing root penetration into the cesium layer during this 18-month study period. A relatively high percentage (15-20%) of the samples from the soil-crushed tuff and soil-gravel/cobble (15 cm gravel-85 cm cobble) plots exhibited higher than background levels of cesium. Samples collected from August 29, 1983, through November 8, 1983 (toward the end of the second growing season), on the control treatment (soil-crushed tuff) were definitely showing that plant roots had grown into the cesium layer: 47% of the 15 samples collected during this period had above-background cesium concentrations. The rock barriers were very effective in preventing roots from penetrating the cesium layer during this time interval: only 1 sample out of 45 showed elevated cesium concentrations.

Data are available on the cesium content of the grass species that dominated the cover through 1985. The results through July 3, 1984, do indicate that the biobarriers were continuing to perform satisfactorily. Over

80% of the plant samples collected on the control plot from December 12, 1983, through July 3, 1984, demonstrated above-background cesium concentrations as high as 206 ppm, indicating that the plant roots were well established in the cesium layer after the third growing season. Plant samples collected on August 12, 1985, showed similar results: below-background levels of cesium were found in all samples collected above the rock barriers, whereas 40% of the control plot samples had elevated cesium concentrations at the end of the fourth growing season.

Time series measurements of soil moisture taken about 30 cm into the backfill (137-cm depth) underlying the four cap designs are presented in Fig. 3 for the time period starting in 1982 through the first half of 1984 (see Appendix A for more detail). Each value presented here represents the average water content of all four access tubes in each plot (Fig. 1) for each depth and sampling date.

Important features of the data in Fig. 3 are that percolation of water through all four cap designs occurred several times over the 31-month observation period and that backfill soil moisture generally increased with time following a step-function pattern. Several sharp increases in backfill moisture coincided with precipitation events and, in particular, snowmelt during mid to late winter. Backfill moisture during the summer growing season was relatively constant or decreased slightly despite the occurrence of several large summer rainstorms, which, on the average, deposit about 75% of the annual precipitation at Los Alamos. That suggests that even though very little moisture storage capacity was available in the 15 cm of topsoil, the capacity, when coupled with the large losses of soil water to evapotranspiration, was sufficient to prevent percolation into the backfill. However, during winter, when plant transpiration was essentially zero and evaporation

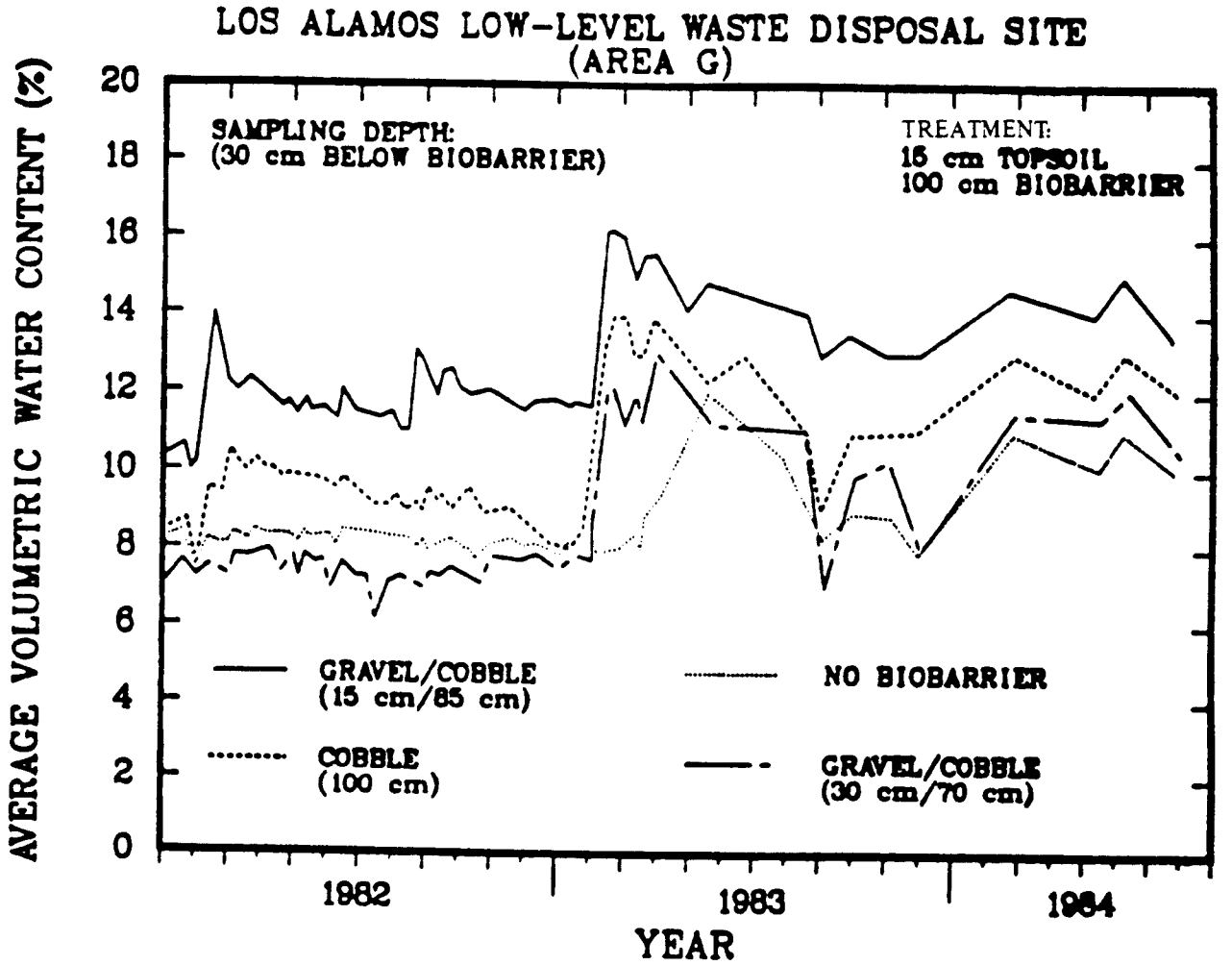

Fig. 3. Volumetric water content of backfill under the biointrusion-barrier study plots at Area G.

from the soil surface was greatly reduced, percolation did occur and was followed by a commensurate rise in backfill moisture.

More recent soil water data are presented in Fig. 4 for the time period from February 21, 1984, through August 13, 1985. In the plot with the crushed-tuff treatment, the water content of all four depths remained essentially constant in 1984 until November 6 (Fig. 4), indicating very little

percolation [snowmelt (January through March) and rain (July through August)] of precipitation into the profile. However, the next 6-month period was more than 240% wetter than normal for Los Alamos. The water content dramatically increased at all sampling depths in the crushed tuff from about 5-10% on October 17, 1984 (Fig. 4), to about 18-20% on May 14, 1985.

The three biobarrier treatments involving gravel and cobble demonstrated higher water-content values (about 30 cm beneath the biobarrier) with time than similar values for the crushed-tuff treatment (Fig. 4). This observation reflects the loss of water storage capacity in the 1-m-thick layer of gravel and/or cobble that would otherwise be present in the corresponding 1-m-thick layer of crushed tuff in this experiment. This point is further demonstrated by comparing the vertical distributions of water measured in these plots at the end of this very wet season in late April, 1985 (Figs. 5-8). The volumetric water content in the gravel-cobble biobarriers remains at 4-5% (Figs. 5-7), whereas the water content in the tuff, at a similar sampling depth, ranges from 8-14% (Fig. 8).

This loss of water-holding capacity in the rock barrier designs can obviously result in significantly greater percolation of precipitation and, concurrently, more rapid changes in soil water content (Fig. 4). This effect is most apparent under the very wet conditions occurring at the end of snowmelt and the late winter rainstorms in 1985 and under the cobble biobarrier. Thus, the water content 30 cm under the cobble biobarrier went from 19% on May 14 (Fig. 4) to 26% on May 22 and then to 17% on May 30. This trend also indicates that many of the pockets of topsoil between the individual rocks at the top of the cobble biobarrier became saturated after May 14, resulting in a surge of water percolating into the underlying tuff layer (Fig. 4).

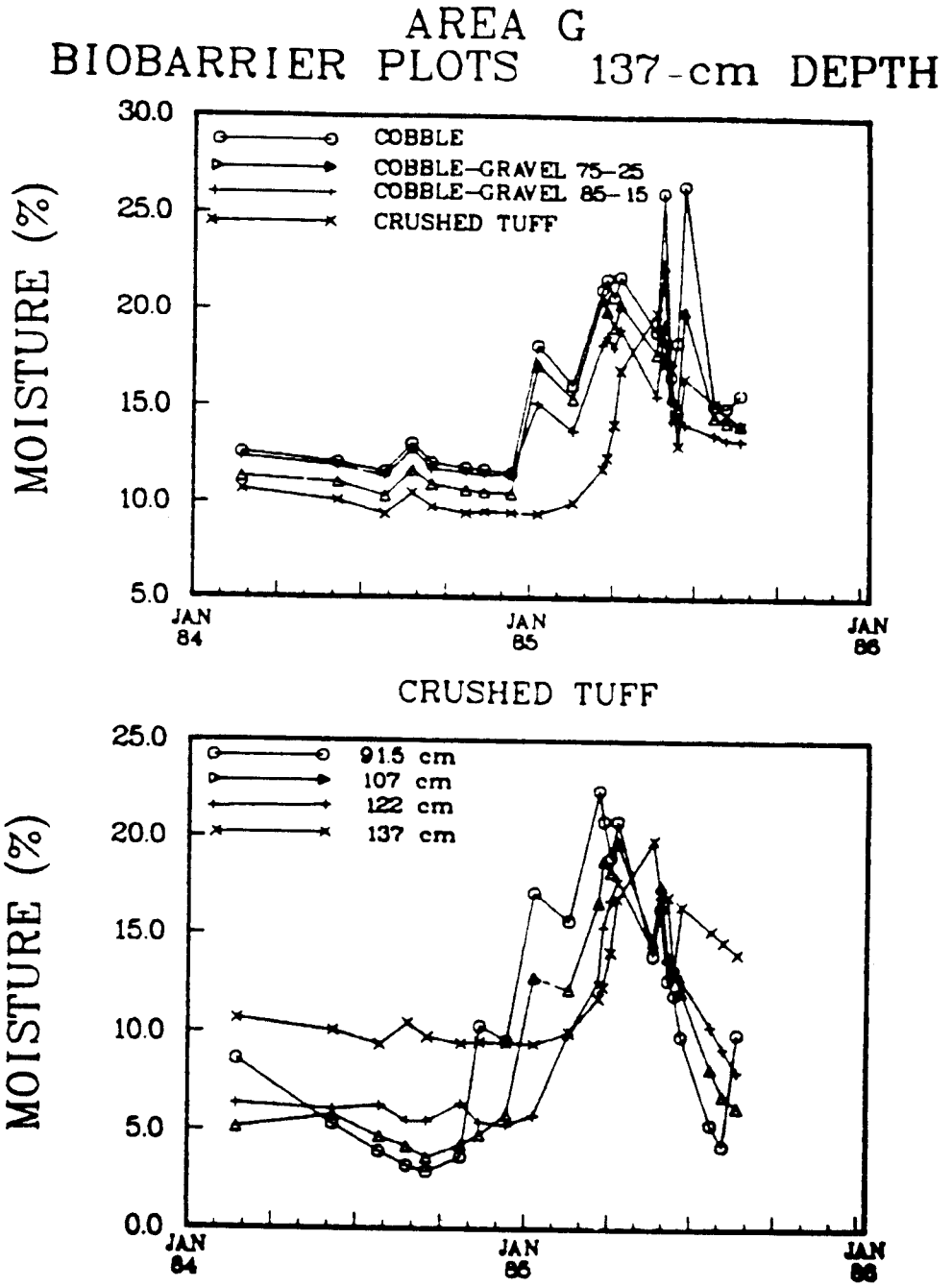

Fig. 4. Distribution of water in the tuff at Area G versus time in 1984 and 1985.

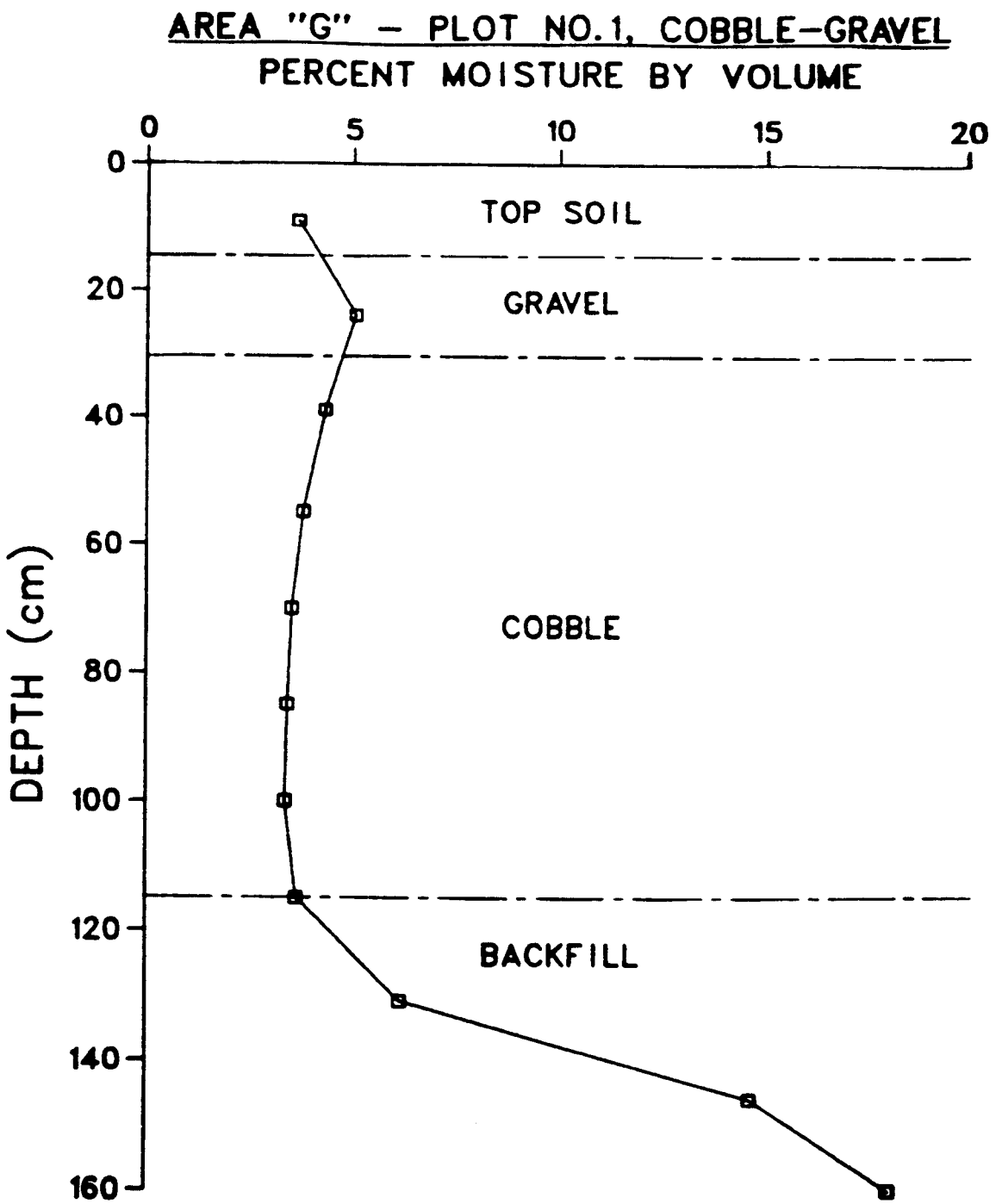

Fig. 5. Distribution of volumetric water content as a function of sampling depth at Area G at the end of April 1985 (15 cm gravel/85 cm cobble).

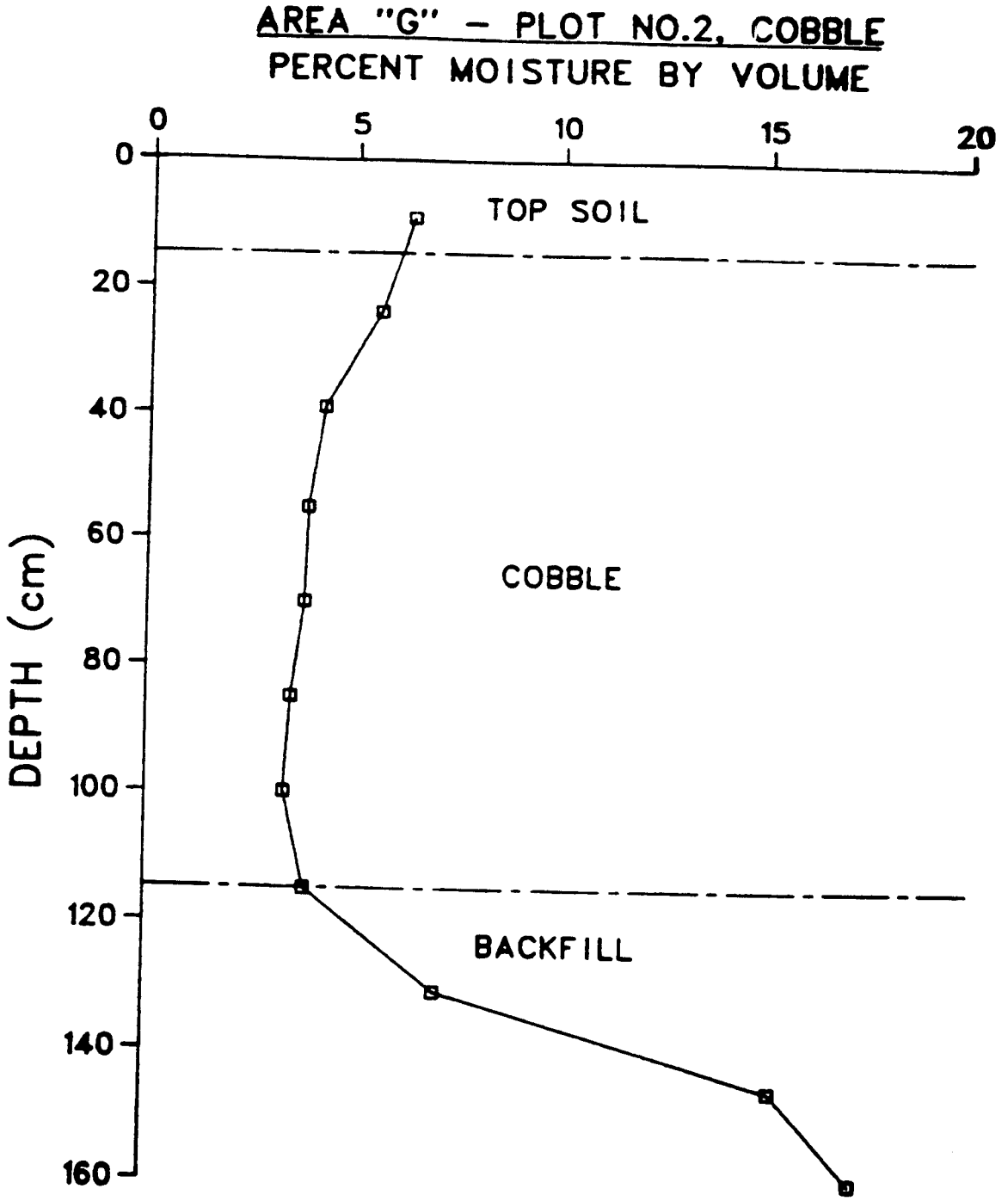

Fig. 6. Distribution of volumetric water content as a function of sampling depth at Area G at the end of April 1985 (100 cm gravel).

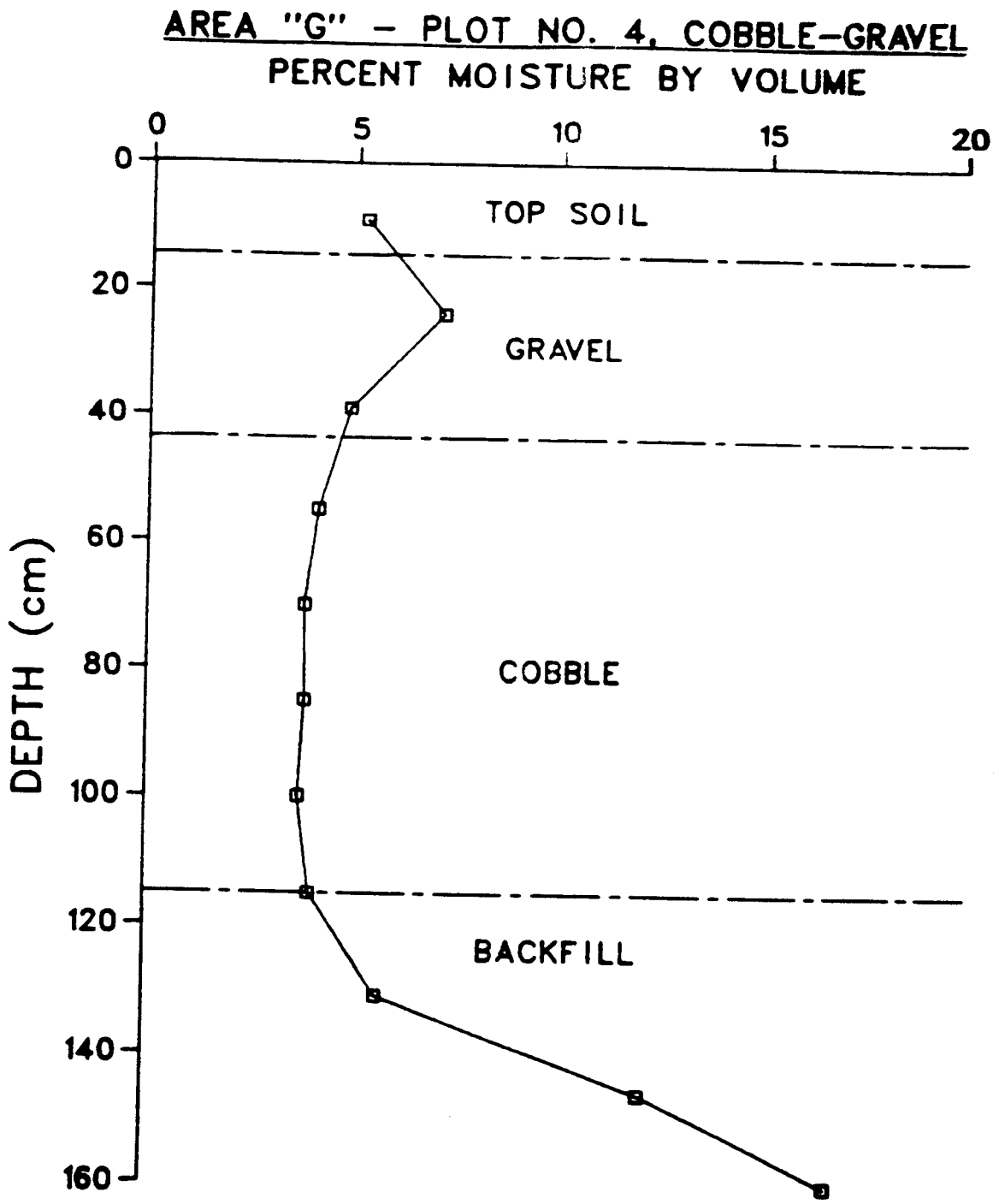

Fig. 7. Distribution of volumetric water content as a function of sampling depth at Area G at the end of April 1985 (30 cm gravel/70 cm cobble).

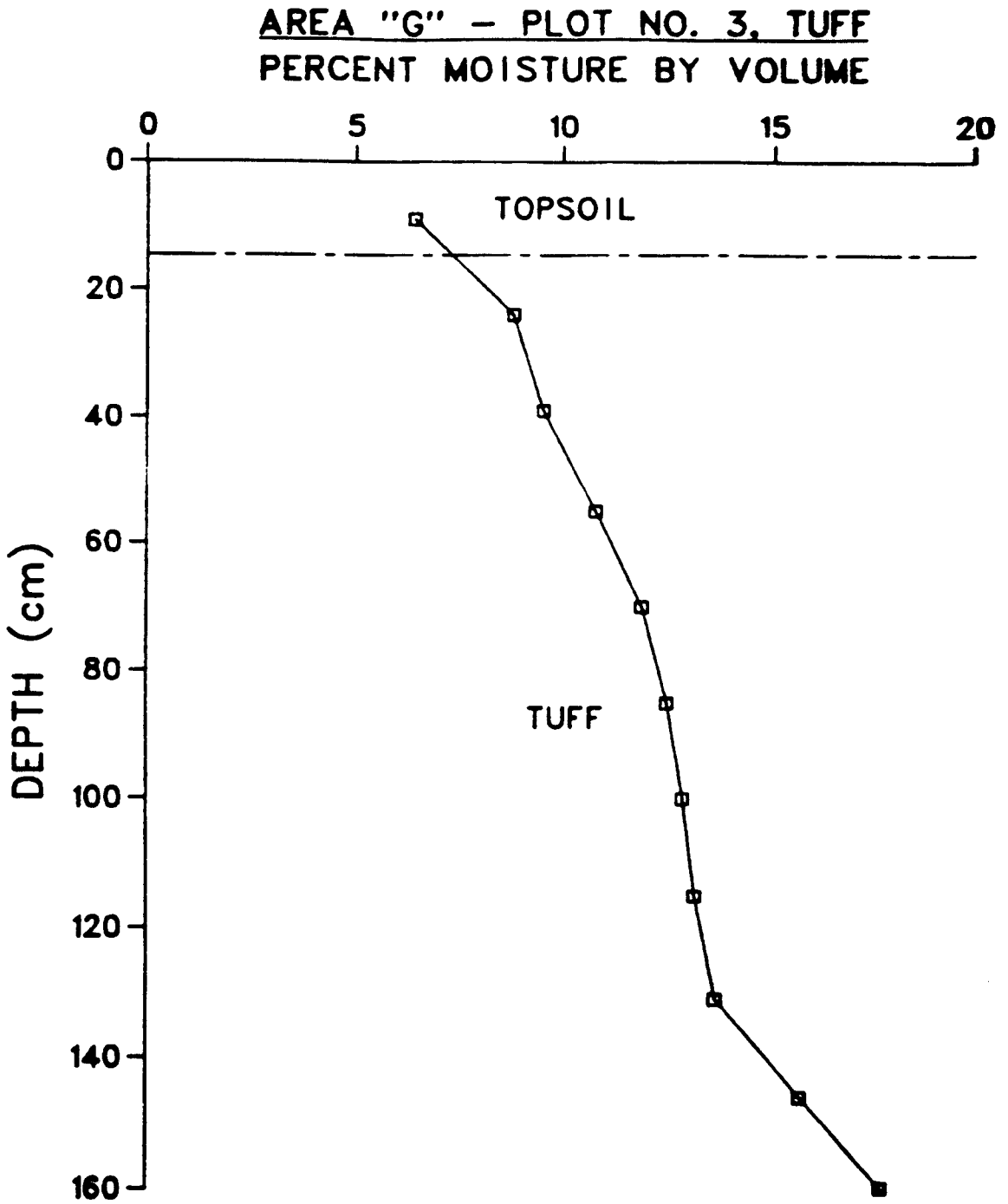

Fig. 8. Distribution of volumetric water content as a function of sampling depth at Area G at the end of April 1985 (100 cm tuff control plot).

In summary, the moisture content of backfill beneath the rock barrier designs responded rapidly to water percolating out of the topsoil because of the low storage capacity and high hydraulic conductivity of the rock material. In contrast, changes in the water content of backfill beneath the crushed-tuff cap design were relatively insensitive to precipitation inputs because of the added storage capacity and lower hydraulic conductivity of the crushed-tuff barrier material. Although seasonal patterns in the moisture content of the backfill under all cap designs were evident, the overall pattern suggests one of increasing moisture with time. In general, backfill moisture in all plots had increased by 2-4% by mid-1984 over that measured at the beginning of the study. The soil water content in the backfill beneath the biobarriers almost doubled in value after the snowmelt and late spring rainstorms in 1985 (Fig. 4) and then decreased as the water gradually moved into the below-lying layers of backfill in trench 25.

Further monitoring of backfill moisture beneath the 137-cm depth and hydrologic modeling studies would be necessary to understand the full impact of the water infiltrating this SLB trench. However, it does appear that when a wet winter/spring season occurs at Los Alamos, some water does infiltrate the trench cap, and under these conditions, the rock biobarriers do seem to perform successfully in preventing roots from penetrating the waste materials buried beneath them.

III. CAPILLARY BARRIER STUDY

A. Introduction

The purpose of our experiments with capillary barriers is to field-test systems that can be used to control the movement of water on top of and around SLB trenches. These systems will insure the execution of the performance

objectives for low-level radioactive waste disposal sites set up by the Nuclear Regulatory Commission (NRC) and by the DOE.

Small-scale modeling has demonstrated it is possible, by using capillary barriers, to maintain dry structures in porous media. Barriers are created by differences in particle size and are effective because suction predominates over gravity forces. The percolating liquid will penetrate the coarser material only after the overlying finer materials are near saturation. Consequently, the structure, which is enclosed in the coarser material, remains dry. As long as the pressure at the coarse/fine interface remains negative, water infiltrating the finer layer will not cross the interface but will flow laterally within the finer layer; percolation occurs where the saturated water front reaches the edge of the coarse layer. The limiting granulometric differences beyond which this phenomenon ceases to exist have been determined. This barrier concept has sometimes been referred to as the "wick effect." It was found that under saturated conditions a gravel lens caused lateral flow in a finer-textured overlying material. The lateral distance over which the water can be transported is limited and will be influenced by the slope of the interface.

At equal matric potentials, a fine-grained medium will contain more water than a coarse-grained medium. During drainage, an initially saturated soil will drain its largest pores first, whereas in wetting a dry soil, the smallest pores will fill first as the matric potential is allowed to increase (getting less negative); the water content increases as progressively larger pores are filled. This will be accompanied by an increase in hydraulic conductivity and lateral diversion of water already promoted by the presence of a sloping surface. The coarser medium, on the other hand, with its predominantly large pores will remain relatively dry with a low hydraulic

conductivity until the matric potential reaches zero and near zero at the interface (Figs. 9 and 10). The systems will fail when or before the matric potential at the interface ceases to be negative. Point readings at the interface are provided through tensiometers. Proximity of the failure point to zero will be the function of abruptness and magnitude of particle size difference at the interface.

Our wick-system designs indicate that an effective wick system is one where the suction at the wick interface is about 4 kPa tension or less before failure (Abeele and DePoorter 1984). To obtain such a low suction between our backfill and sand, the addition of a small amount of bentonite to the backfill materials at our land disposal site is necessary (Fig. 11), resulting in a major change in saturated hydraulic conductivity with only small amounts of clay added (Abeele 1984a).

The geotechnical aspects of Fig. 11 are important to waste management site designs because permeability is the dominant parameter in the design and implementation of waste disposal facilities. Clay is prominent among the materials usually considered to line or cap disposal pits. Foremost among the problems connected with the use of clays is cracking during periods of desiccation, although both the Environmental Protection Agency (EPA) and the NRC seem to feel that clays, as barriers to water leachate migration and inflow of water, are the principal materials to be considered as liners and caps in waste disposal facilities. Clays and soils, in general, also offer by far the longet service life of any liner material.

Use of clay mixes instead of pure clays may be warranted but not solely on the basis of economics; mechanical benefits may even become overriding in mandating the use of mixes. In Los Alamos, New Mexico, the use of local tuff with low amounts of bentonite appeared to be very promising in greatly

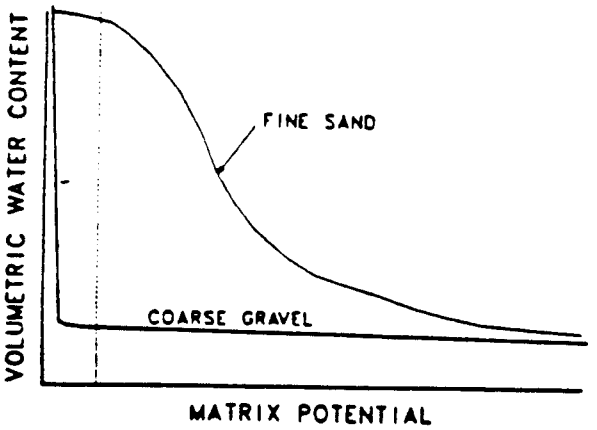

Fig. 9. Hypothetical wetting curve for a fine sand and a coarse gravel.

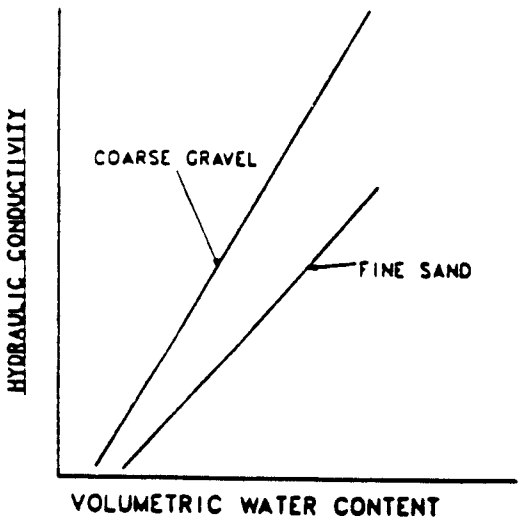

Fig. 10. Hypothetical $K(\theta)$ curves for a fine sand and a coarse gravel.

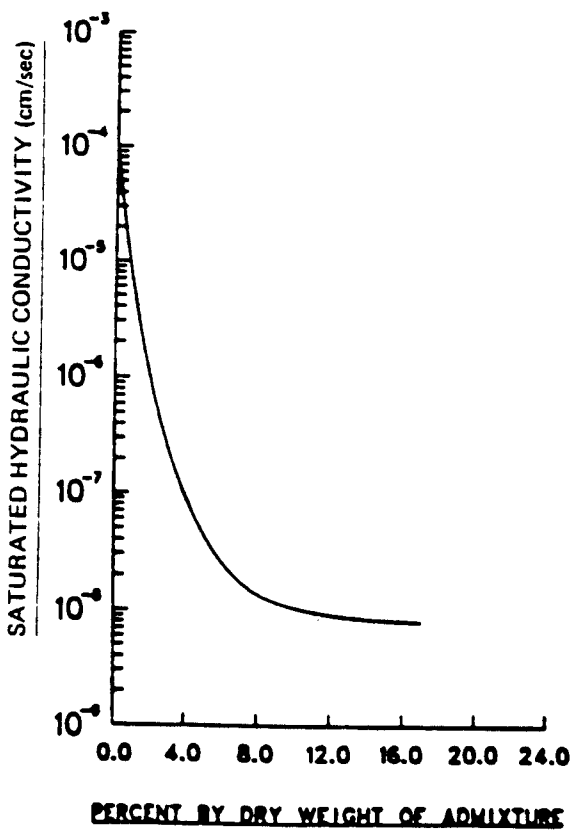

Fig. 11. Effects of adding bentonite to Los Alamos tuff.

decreasing hydraulic conductivity without showing any of the mechanical impairments of clays (Abeele 1984a). Saturated sodium bentonite absorbs water up to 5 times its own mass to form a gel up to 15 times its own dry volume. Besides being less expensive, a liner or cap, consisting of a mix of the local medium and bentonite clay, would probably not crack when desiccated. Cracking from desiccation can be further minimized by proper compaction. A low hydraulic conductivity, combined with acceptable mechanical characteristics, should be obtainable at some ideal mix of two materials, each possessing one or the other property.

B. Experimental Design and Techniques

Our field experiment was designed to test the performance of a wick system emplaced in a 6.1-m-deep caisson with a diameter of 3.05 m for a wick system of known thickness (2 m), slope (10%), and slope length (2 m), and for one combination of porous materials [a bentonite-tuff mix having a 0.02 bentonite ratio by mass overlying Ottawa sand] subjected to a known addition rate of water (Fig. 12). Using the soil water and tension data collected over time at several positions within the wick layer, we will then be able to field-validate a hydrologic model describing the two-dimensional, unsaturated flow of water through a multilayered system. This data set will then be available to field-validate several hydrologic models, which can subsequently be used for the design of future capillary barriers.

The caissons used in this field experiment are located in experiment clusters (DePoorter 1981) at the Los Alamos Experimental Engineered Test Facility (EETF); the development of this site was sponsored by the DOE National Low-Level Waste Management Program. Each experiment cluster consists of six corrugated metal culverts, 3 m in diameter and 6 m deep, placed around a central instrument and access caisson of the same size. In five of the six

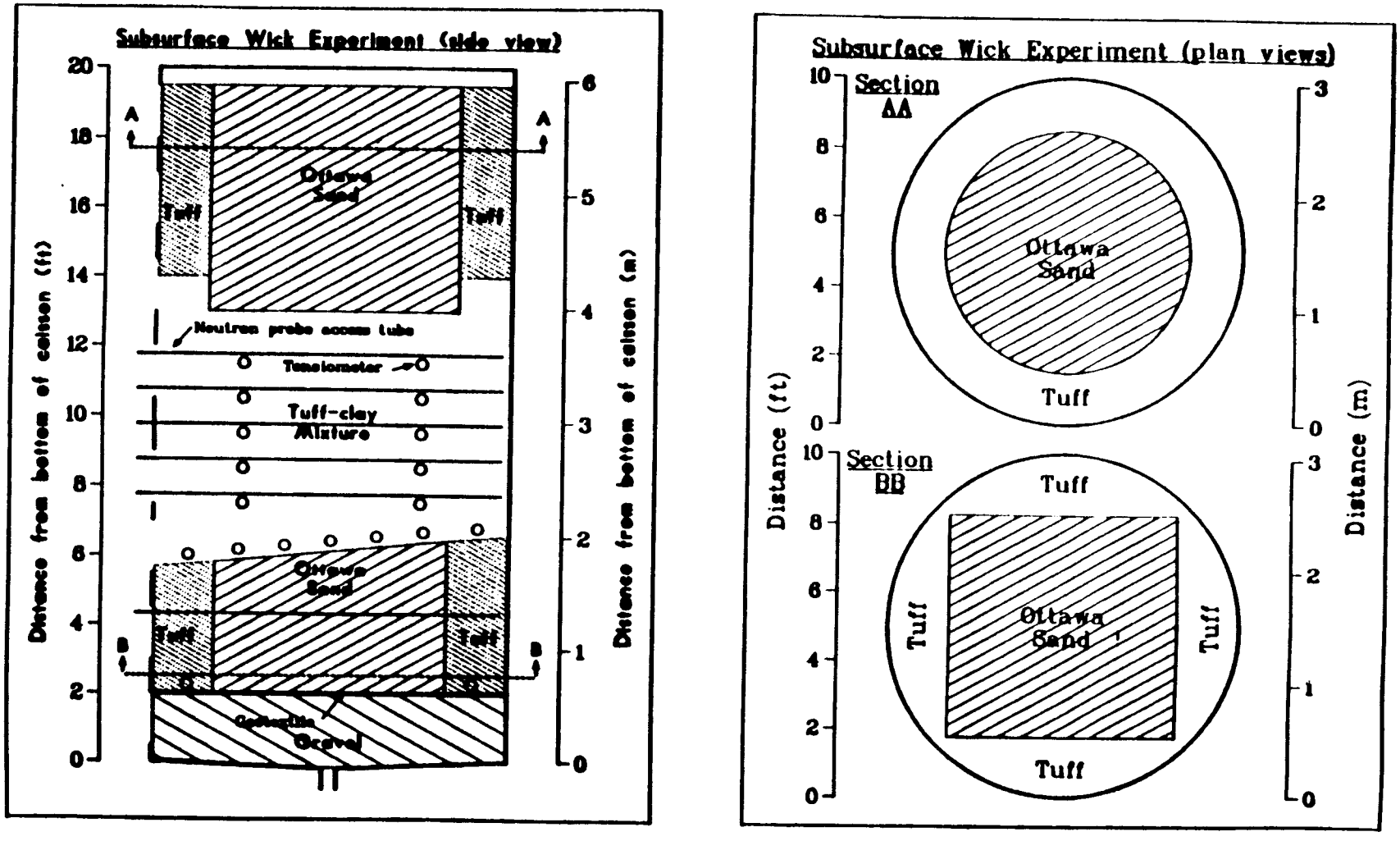

Fig. 12. Capillary-barrier experiment in Caisson E.

interstitial positions, there are pipes 46 cm in diameter and 6 m long. Access ports are situated at 75-cm-depth intervals between the central caisson and each of the 11 surrounding caissons (the access ports are shown in detail in Fig. 13).

The Ottawa sand was replaced in the caisson in April 1984 using two metal frames to insure precise geometries of the sand in the experiment. The first metal frame was emplaced (Fig. 14) to aid in emplacing all but the very top of the sand layer. After this was accomplished and the sand was compacted along with the surrounding tuff (see Fig. 12), the first frame was removed and a second frame, containing a 10% slope along the top of the frame, was emplaced. The tuff and sand were added and compacted as before and the second metal frame was then removed.

The 2% clay/crushed-tuff mixes were made in a cement truck using dried crushed tuff previously screened at the batch plant. The dry tuff (1-2% water content on a weight basis) was added to the cement truck (the weight of the tuff was determined by weighing the truck before and after the addition of tuff), and an amount of dry sodium-saturated bentonite clay was then added to make the 2% w/w mixture. After mixing the dry mix for about an hour, water was added to bring the volumetric water content to about 12-13%, and this final mixture was mixed for another hour and then added to the caisson. Lifts about 10 to 20 cm thick were added to Caisson E; these were compacted and their density was determined as previously described (Abeele 1984b).

Soil moisture determinations were performed using a Campbell Pacific model 503 neutron moisture gauge. Readings were collected every 30 cm across the entire width of the caisson on each sampling date. Soil water tension was determined with a Soil Moisture Equipment Corporation model 2100F soil moisture probe (with a 3-m-long, flexible plastic tube) modified to determine

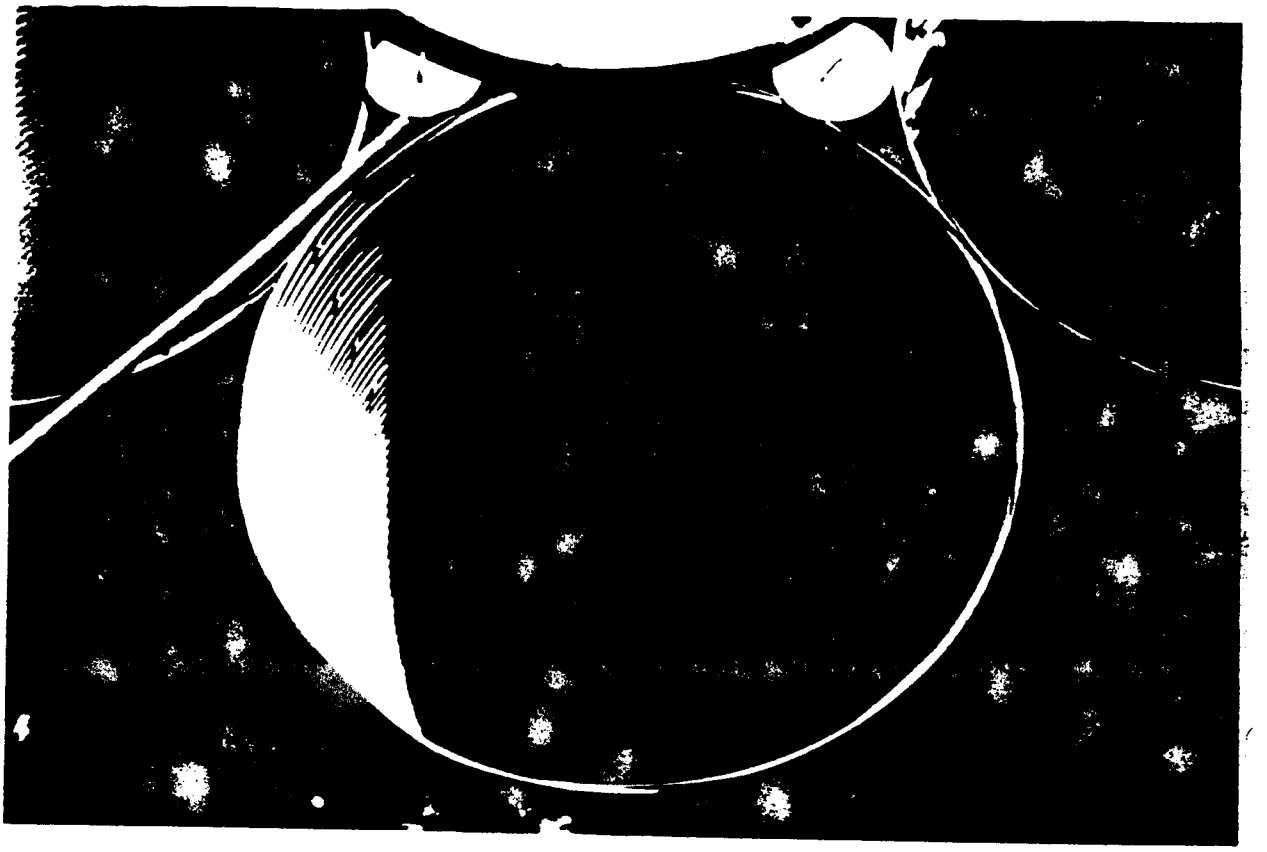

Fig. 13. Access port details in a caisson at the EETF in Los Alamos.

tension using a Soil Measurement Systems tensimeter previously described (Marthaler et al. 1983).

C. Results and Discussion

Over a year's worth of neutron moisture gauge data are presented in Figs. 15 through 19 and summarized in Fig. 20. To be fully understood, this data base needs to be interpreted in conjunction with the water-tension data collected at these same sampling depths (Fig. 21) and at depths located 2 cm above the interface between the Ottawa sand and the 2% bentonite-tuff mixture (Fig. 22).

These soil water content and tension data show that with the increase of moisture with depths greater than 0.8 m beneath the mix surface layer, highly

Fig. 14. Emplacing a metal frame in Caisson E to be used to position the Ottawa sand layer (frame was removed after the sand was added and compacted).

unsaturated conditions still prevail. The interesting thing, however, is that for the first time on April 5 (almost a year from the start of the experiment), a discharge of approximately 40 mg of water per second was measured. The fact that the intermediate (thick) layer between the upper surface and the wick interface is unsaturated (negative tension values in Fig. 21) and that, nontheless, a breakthrough or failure of the wick occurred, are sure indications that the wick is behaving the way it is supposed to--somewhere along the interface the wick provided for saturation (positive tension values in Fig. 22) to occur (through unsaturated flow addition of water) with subsequent failure of the system as a result. After saturation reaches deeper levels, drainage of the system under controlled conditions can occur to permit the application of the instantaneous profile method for unsaturated conductivity computations.

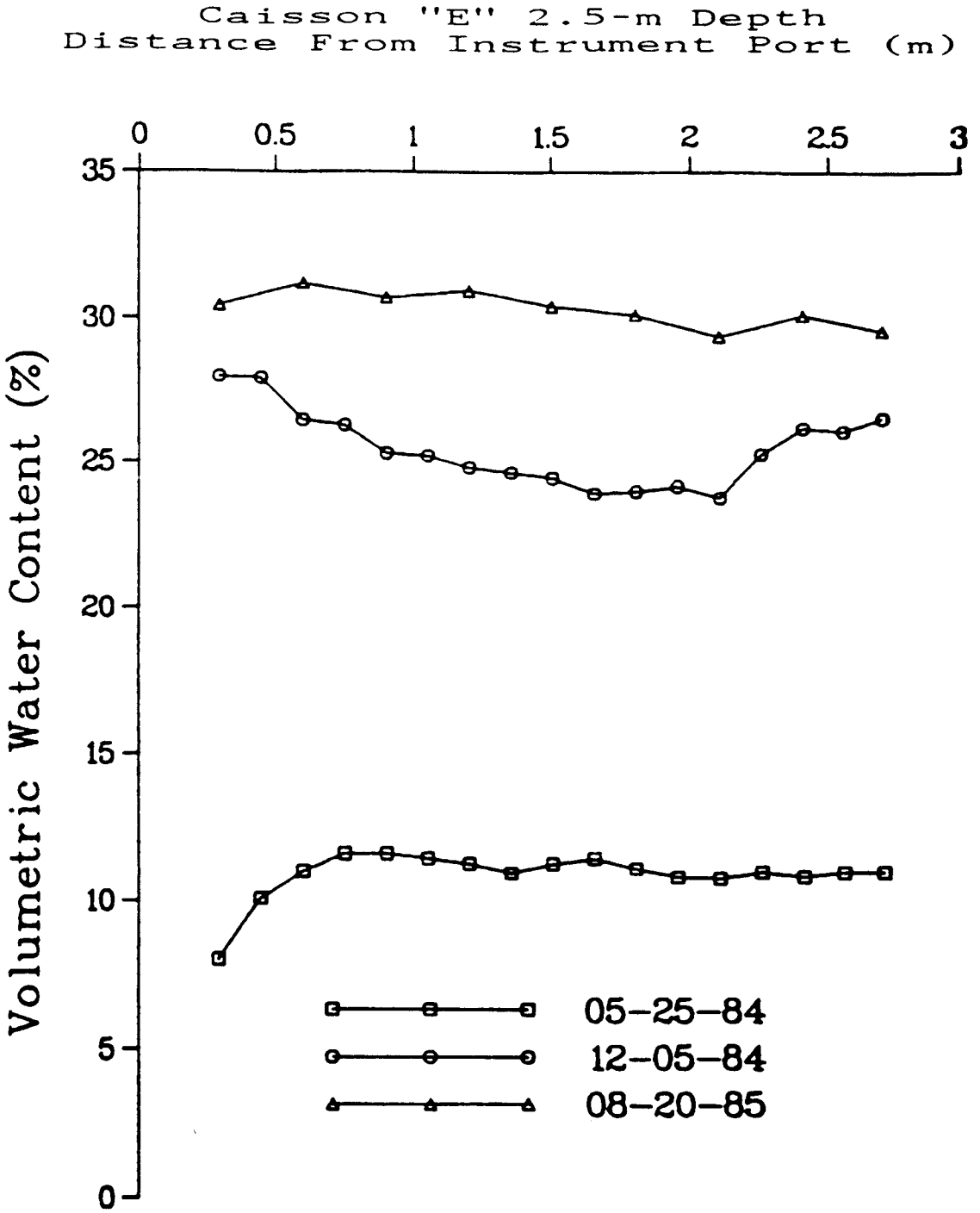

Fig. 15. Soil/water data collected at three sampling dates in Caisson E at the 2.5-cm depth.

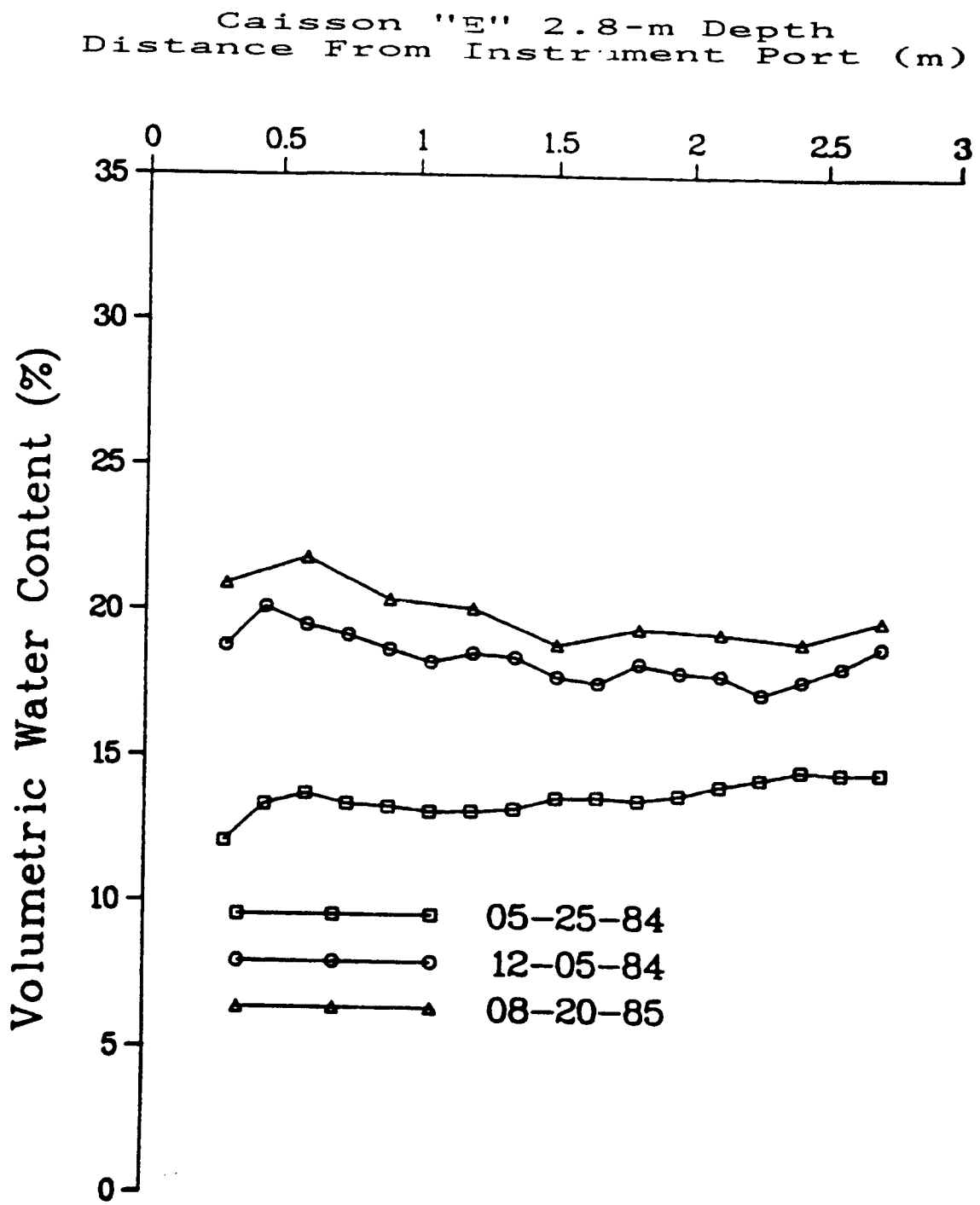

Fig. 16. Soil/water data collected at three sampling dates in Caisson E at the 2.8-m depth.

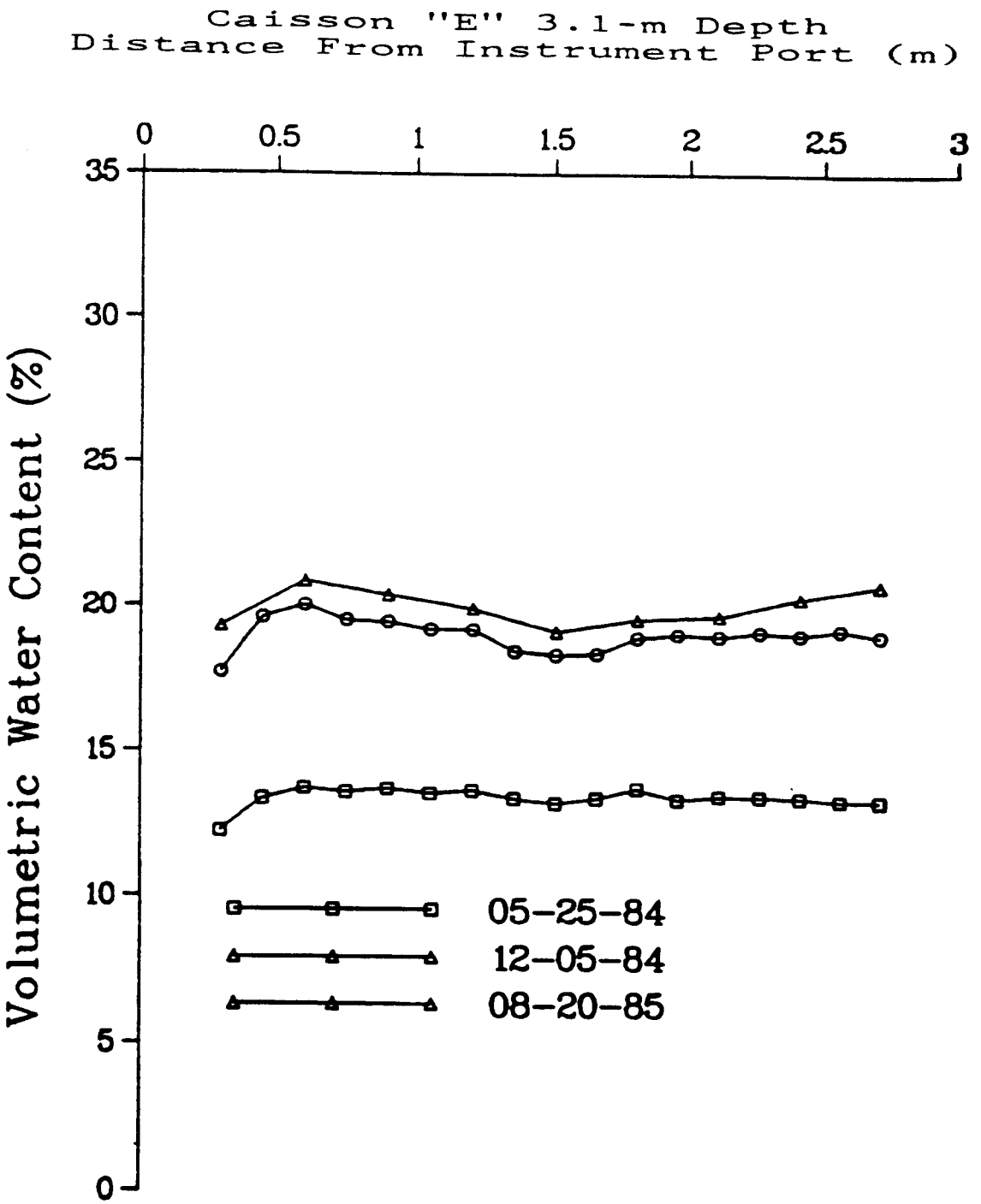

Fig. 17. Soil/water data collected at three sampling dates in Caisson E at the 3.1-m depth.

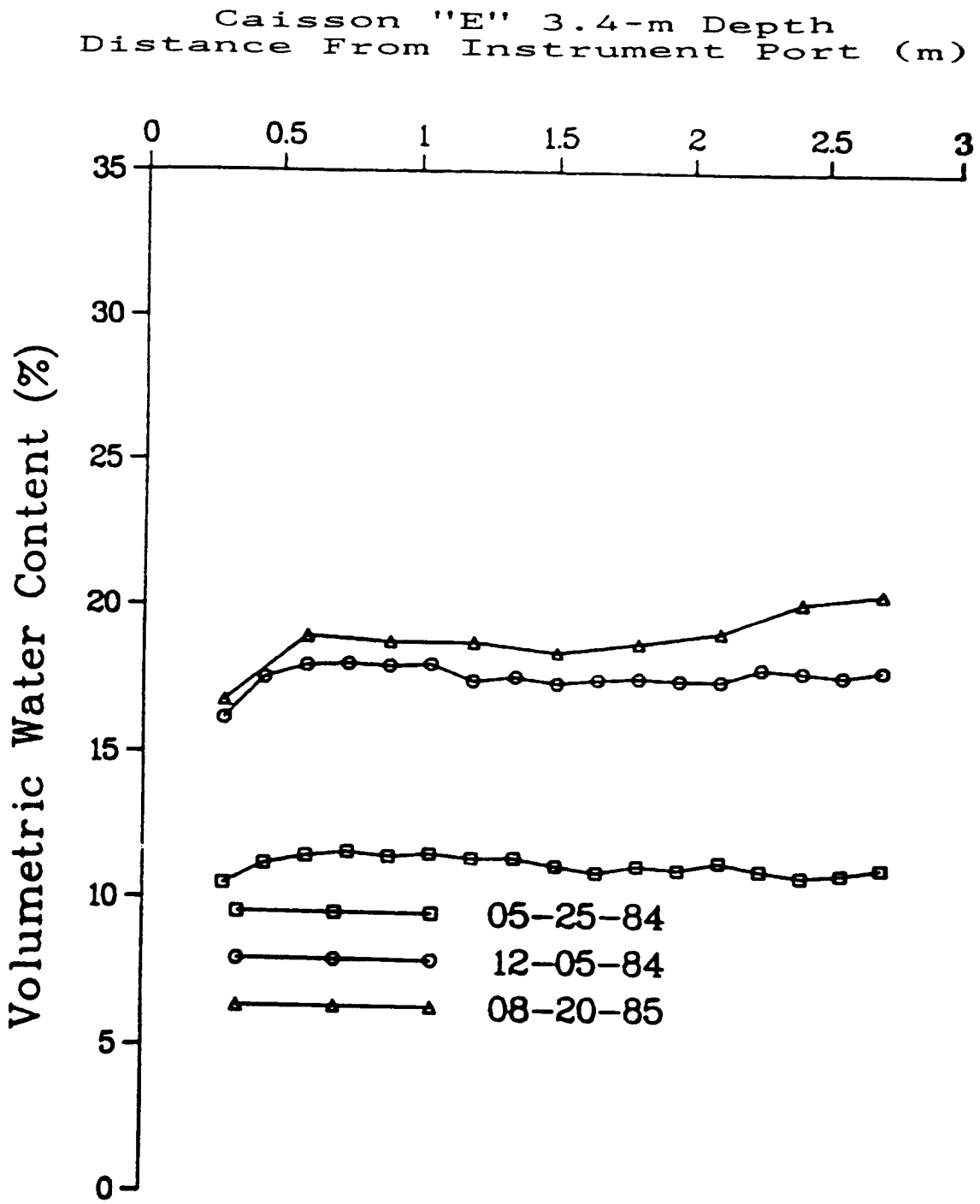

Fig. 18. Soil/water data collected at three sampling dates in Caisson E at the 3.4-m depth.

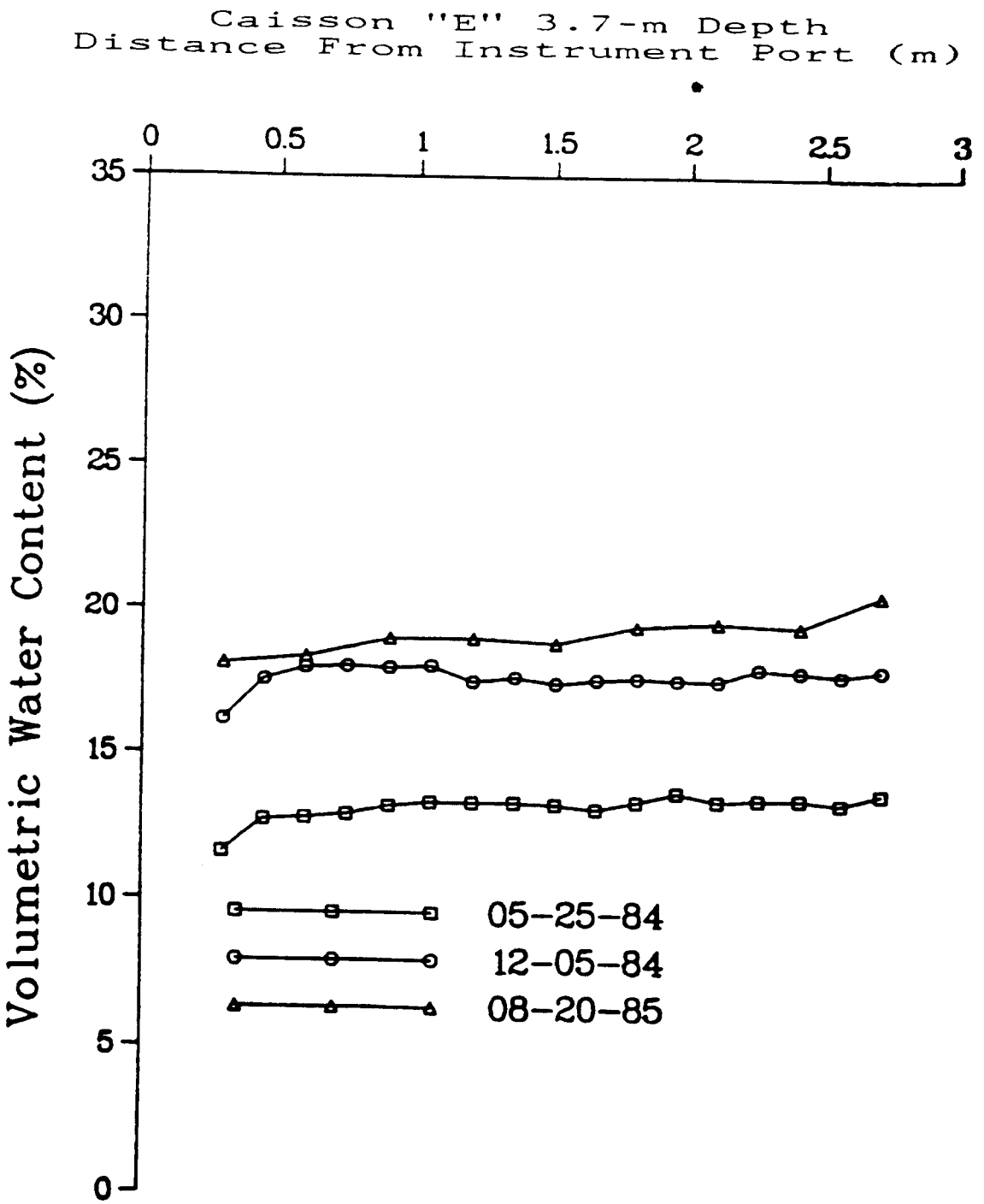

Fig. 19. Soil/water data collected at three sampling dates in Caisson E at the 3.7-m depth.

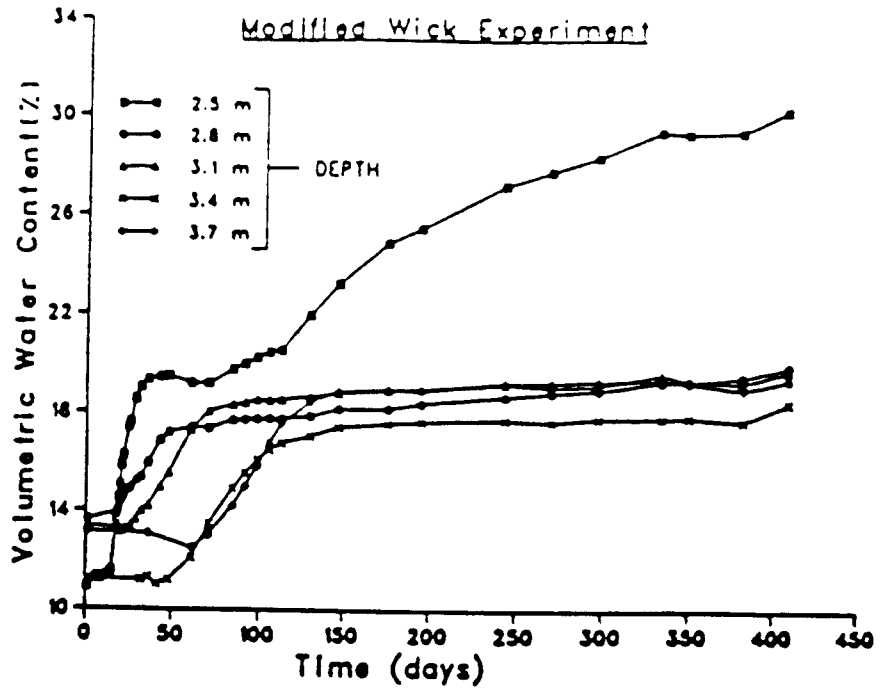

Fig. 20. Distribution of volumetric water content for five sampling depths in the clay-tuff mixture versus time in the envelope wick experiment.

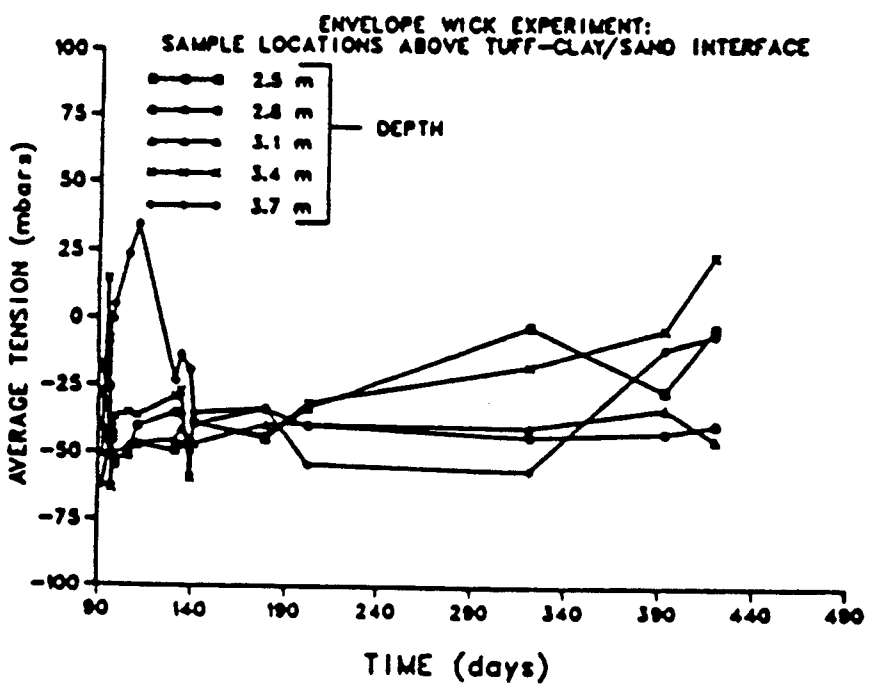

Fig. 21. Soil/water tension data collected above the tuff-clay/sand interface in the envelope wick experiment.

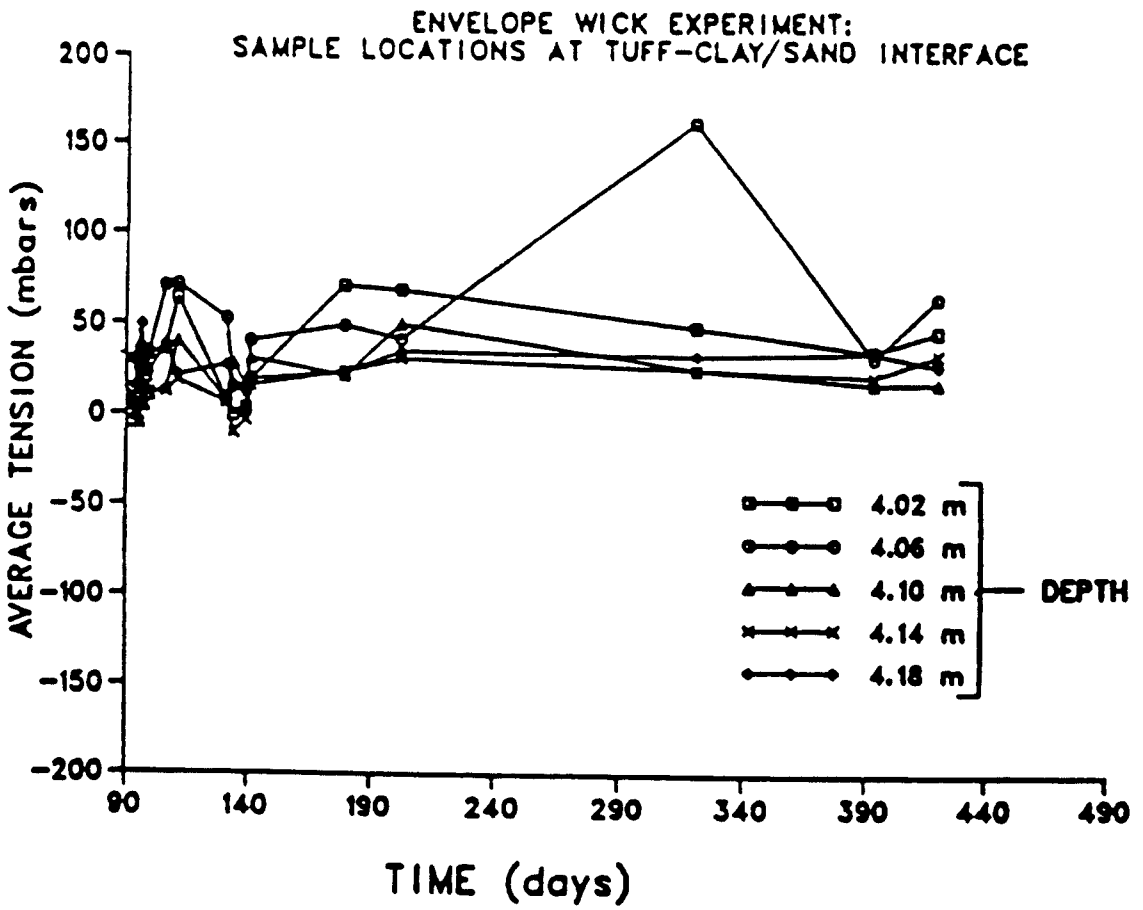

Fig. 22. Soil/water tension data collected at the tuff-clay/sand interface in the envelope wick experiment.

If we go by the assumption that the discharge from this caisson is regulated by the layer with the lowest hydraulic conductivity, then, since discharge began, the moisture content of the drier layer hovered around 18.4% moisture by volume and the discharge rate was $4.4 \times 10^{-8} m^3 s^{-1}$. This corresponds to a flux of $6.08 \times 10^{-9} ms^{-1}$ or a hydraulic conductivity estimated at $3.87 \times 10^{-9} ms^{-1}$ for a matric potential gradient tentatively measured to be 1.57. At a moisture content of 18.4% by volume, the hydraulic conductivity of pure crushed tuff turned out to be $K = 9.3 \times 10^{-3} \theta_v^{8.21} = 8.64 \times 10^{-9} ms^{-1}$. This shows that at a moisture content by volume of 18.4%, the hydraulic conductivities of ure crushed tuff and of crushed tuff mixed with 2% bentonite differ by no more than a factor of ten; however, the hydraulic conductivity at saturation is about 1000 times greater in pure crushed tuff than in the mix. These data seem to indicate that for the mix there is very little change of permeability as a function of moisture content. It also needs to be pointed out how a big difference in moisture content between the sampling levels results in minor differences in moisture tension (Figs. 21 and 22).

During FY1986, additional data collection activities will continue in this field experiment after saturated flow conditions are met. After this, as the bentonite-tuff mixture dries, our plans are to collect additional tension and soil water-content data for subsequent model verification and validation activities.

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APPENDIX A

DESCRIPTION OF VOLUMETRIC WATER CONTENT DATA BASE FOR AREA G

Sixteen acess tubes were emplaced in the four plots at Area G for the determination of soil water content as a function of time and depth (see Fig. 1 in text). The metal plot borders encompassing the entire study area are actually 23.8 m long (approximately east-west direction). Proceeding from the east to the west, the plot numbers and treatments are as follows:

(1) Plot 1 (30 cm gravel/70 cm cobble),

(2) Plot 2 (crushed tuff),

(3) Plot 3 (cobble), and

(4) Plot 4 (15 cm gravel/85 cm cobble).

Proceeding from north to south within each of these four plots, access tubes 501, 502, 503, and 504 are located in plot 4; access tubes 505, 506, 507, and 508 are located in plot 3; access tubes 509, 510, 511, and 512 are located in plot 2, and access tubes 513, 514, 515, and 516 are located in plot 1.

Access tubes 501 and 513 are located 2.3 m and 2.1 m, respectively, from the northern plot boundary. Acess tubes 504 and 516 are located 2.3 m and 2.1 m, respectively, from the southern plot boundary. The north-south distances between tubes 501 and 502, 502 and 503, 503 and 504, 505 and 506, 506 and 507, 507 and 508, 509 and 510, 510 and 511, 511 and 512, 513 and 514, 514 and 515, and 515 and 516 are 2.4 m, 2.3 m, 2.1 m, 2.3 m, 2.4 m, 2.3 m, 2.3 m, 2.4 m, 2.3 m, 2.0 m, 2.5 m, and 2.6 m, respectively. The east-west distances between tubes 501-504 and 505-508, 505-508 and 509-512, and 509-512 and 513-516 are 6.0 m, 5.6 m, and 6.2 m, respectively.

----------Type = Cobble only Tube Number = 505----------

Sampling Date	Depth From Surface (cm)	Volumetric Moisture Content (%)
22FEB84	137.16	14.8
04JUN84	137.16	14.3
24JUL84	137.16	14.0
22AUG84	137.16	15.8
12SEP84	137.16	14.7
18OCT84	137.16	14.1
07NOV84	137.16	14.3
07NOV84	137.16	14.3
06DEC84	137.16	14.1
04JAN85	137.16	20.2
11FEB85	137.16	18.2
15MAR85	137.16	23.4
20MAR85	137.16	24.1
28MAR85	137.16	22.7
04APR85	137.16	24.0
14MAY85	137.16	18.5
22MAY85	137.16	17.3
30MAY85	137.16	17.8
06JUN85	137.16	17.9

----------Type = Cobble only Tube Number = 506----------

Sampling Date	Depth From Surface (cm)	Volumetric Moisture Content (%)
22FEB84	137.16	13.4
04JUN84	137.16	12.8
24JUL84	137.16	12.4
22AUG84	137.16	13.7
12SEP84	137.16	12.9
18OCT84	137.16	12.6
07NOV84	137.16	12.6
07NOV84	137.16	12.6
06DEC84	137.16	12.4
04JAN85	137.16	17.4
11FEB85	137.16	15.9
15MAR85	137.16	20.1
20MAR85	137.16	20.8
28MAR85	137.16	19.6
04APR85	137.16	20.3
14MAY85	137.16	20.4
22MAY85	137.16	25.7
30MAY85	137.16	16.0
06JUN85	137.16	15.9

14JUN85	137.16	29.5
16JUL85	137.16	15.3
29JUL85	137.16	14.9
13AUG85	137.16	16.3

----------Type = Cobble only Tube Number = 507----------

Sampling Date	Depth From Surface (cm)	Volumetric Moisture Content (%)
22FEB84	137.16	11.6
04JUN84	137.16	11.2
24JUL84	137.16	10.4
22AUG84	137.16	11.9
12SEP84	137.16	10.9
18OCT84	137.16	10.8
07NOV84	137.16	10.4
07NOV84	137.16	10.4
06DEC84	137.16	10.2
04JAN85	137.16	18.8
11FEB85	137.16	16.0
15MAR85	137.16	21.3
20MAR85	137.16	21.5
28MAR85	137.16	21.0
04APR85	137.16	22.2
14MAY85	137.16	17.1
22MAY85	137.16	26.3
30MAY85	137.16	16.9
14JUN85	137.16	30.7
16JUL85	137.16	15.6
29JUL85	137.16	15.4
13AUG85	137.16	16.2

----------Type = Cobble only Tube Number = 508----------

Sampling Date	Depth From Surface (cm)	Volumetric Moisture Content (%)
22FEB84	137.16	10.5
04JUN84	137.16	9.9
24JUL84	137.16	9.5
22AUG84	137.16	10.7
12SEP84	137.16	9.7
18OCT84	137.16	9.6
07NOV84	137.16	9.4
07NOV84	137.16	9.4
06DEC84	137.16	9.3
04JAN85	137.16	16.0
11FEB85	137.16	14.2
15MAR85	137.16	19.5

20MAR85	137.16	20.2
28MAR85	137.16	19.4
04APR85	137.16	20.6
14MAY85	137.16	19.3
22MAY85	137.16	35.0
30MAY85	137.16	15.3
06JUN85	137.16	21.1
14JUN85	137.16	19.2
16JUL85	137.16	14.4
29JUL85	137.16	14.5
13AUG85	137.16	14.3

----------Type = Cobble-gravel 75-25 Tube Number = 513----------

Sampling Date	Depth From Surface (cm)	Volumetric Moisture Content (%)
22FEB84	137.16	12.4
04JUN84	137.16	11.9
24JUL84	137.16	11.3
22AUG84	137.16	12.9
12SEP84	137.16	11.7
18OCT84	137.16	11.5
07NOV84	137.16	11.1
07NOV84	137.16	11.1
06DEC84	137.16	11.2
04JAN85	137.16	17.5
11FEB85	137.16	16.4
15MAR85	137.16	21.2
20MAR85	137.16	20.0
28MAR85	137.16	19.3
04APR85	137.16	20.4
14MAY85	137.16	17.0
22MAY85	137.16	16.0
30MAY85	137.16	16.0
06JUN85	137.16	15.4
14JUN85	137.16	30.0
16JUL85	137.16	15.0
29JUL85	137.16	14.6
13AUG85	137.16	14.8

----------Type = Cobble-gravel 75-25 Tube Number = 515----------

Sampling Date	Depth From Surface (cm)	Volumetric Moisture Content (%)
22FEB84	137.16	10.7
04JUN84	137.16	10.7
24JUL84	137.16	9.9
22AUG84	137.16	11.0
12SEP84	137.16	10.5

18OCT84	137.16	10.2
07NOV84	137.16	10.4
07NOV84	137.16	10.4
06DEC84	137.16	10.3
04JAN85	137.16	17.7
11FEB85	137.16	15.0
15MAR85	137.16	21.4
20MAR85	137.16	20.3
28MAR85	137.16	19.6
04APR85	137.16	21.0
14MAY85	137.16	21.1
22MAY85	137.16	22.3
30MAY85	137.16	15.8
06JUN85	137.16	15.5
14JUN85	137.16	15.2
16JUL85	137.16	14.5
29JUL85	137.16	14.4
13AUG85	137.16	14.1

----------Type = Cobble-gravel 75-25 Tube Number = 516----------

Sampling Date	Depth From Surface (cm)	Volumetric Moisture Content (%)
22FEB84	137.16	10.9
04JUN84	137.16	10.5
24JUL84	137.16	9.8
22AUG84	137.16	11.1
12SEP84	137.16	10.5
18OCT84	137.16	10.2
07NOV84	137.16	10.1
07NOV84	137.16	10.1
06DEC84	137.16	10.0
04JAN85	137.16	16.0
11FEB85	137.16	14.9
15MAR85	137.16	19.2
20MAR85	137.16	19.5
28MAR85	137.16	18.3
04APR85	137.16	19.4
14MAY85	137.16	14.9
22MAY85	137.16	28.9
30MAY85	137.16	14.8
06JUN85	137.16	14.0
14JUN85	137.16	14.7
16JUL85	137.16	13.9
29JUL85	137.16	13.5
13AUG85	137.16	13.4

----------Type = Cobble-gravel 85-15 Tube Number = 501----------

Sampling	Depth From	Volumetric

Date	Surface (cm)	Moisture Content (%)
22FEB84	137.16	15.8
04JUN84	137.16	15.3
24JUL84	137.16	14.9
22AUG84	137.16	16.7
12SEP84	137.16	15.1
18OCT84	137.16	14.9
07NOV84	137.16	15.1
07NOV84	137.16	15.1
06DEC84	137.16	15.4
04JAN85	137.16	19.9
11FEB85	137.16	17.2
15MAR85	137.16	23.0
20MAR85	137.16	23.1
28MAR85	137.16	22.5
04APR85	137.16	23.4
14MAY85	137.16	17.2
22MAY85	137.16	19.8
30MAY85	137.16	17.2
06JUN85	137.16	18.3
14JUN85	137.16	17.3
16JUL85	137.16	16.5
29JUL85	137.16	16.3
13AUG85	137.16	16.6

----------Type = Cobble-gravel 85-15 Tube Number = 502----------

Sampling Date	Depth From Surface (cm)	Volumetric Moisture Content (%)
22FEB84	137.16	13.9
04JUN84	137.16	13.3
24JUL84	137.16	12.9
22AUG84	137.16	14.4
12SEP84	137.16	13.6
18OCT84	137.16	12.9
07NOV84	137.16	12.7
07NOV84	137.16	12.7
06DEC84	137.16	12.6
04JAN85	137.16	17.9
11FEB85	137.16	16.4
15MAR85	137.16	22.0
20MAR85	137.16	22.2
28MAR85	137.16	21.5
04APR85	137.16	22.3
14MAY85	137.16	17.1
22MAY85	137.16	16.3
30MAY85	137.16	16.9
06JUN85	137.16	17.0
14JUN85	137.16	16.8

16JUL85	137.16	16.0
29JUL85	137.16	15.7
13AUG85	137.16	15.6

----------Type = Cobble-gravel 85-15 Tube Number = 503----------

Sampling Date	Depth From Surface (cm)	Volumetric Moisture Content (%)
22FEB84	137.16	13.2
04JUN84	137.16	12.9
24JUL84	137.16	12.4
22AUG84	137.16	13.8
12SEP84	137.16	12.6
18OCT84	137.16	12.8
07NOV84	137.16	12.4
07NOV84	137.16	12.4
06DEC84	137.16	12.5
04JAN85	137.16	16.1
11FEB85	137.16	14.9
15MAR85	137.16	19.2
20MAR85	137.16	20.6
20MAR85	137.16	8.4
28MAR85	137.16	20.0
04APR85	137.16	21.6
14MAY85	137.16	21.6
22MAY85	137.16	17.4
30MAY85	137.16	16.3
06JUN85	137.16	16.2
14JUN85	137.16	16.0
16JUL85	137.16	15.4
29JUL85	137.16	15.2
13AUG85	137.16	14.6

----------Type = Cobble-gravel 85-15 Tube Number = 504----------

Sampling Date	Depth From Surface (cm)	Volumetric Moisture Content (%)
22FEB84	137.16	6.5
04JUN84	137.16	5.9
24JUL84	137.16	5.1
22AUG84	137.16	5.9
12SEP84	137.16	5.6
18OCT84	137.16	5.6
07NOV84	137.16	5.6
07NOV84	137.16	5.6
06DEC84	137.16	5.5
04JAN85	137.16	6.7
11FEB85	137.16	6.4

15MAR85	137.16	8.5
28MAR85	137.16	8.1
04APR85	137.16	8.6
14MAY85	137.16	6.3
22MAY85	137.16	23.4
30MAY85	137.16	6.6
06JUN85	137.16	6.5
14JUN85	137.16	6.3
16JUL85	137.16	6.3
29JUL85	137.16	5.9
13AUG85	137.16	6.1

----------Type = Crushed tuff Tube Number = 509----------

Sampling Date	Depth From Surface (cm)	Volumetric Moisture Content (%)
22FEB84	91.44	7.9
22FEB84	106.68	4.6
22FEB84	121.92	7.1
22FEB84	137.16	11.2
04JUN84	91.44	3.8
04JUN84	106.68	5.6
04JUN84	121.92	6.8
04JUN84	137.16	10.6
24JUL84	91.44	2.9
24JUL84	106.68	4.9
24JUL84	121.92	7.6
24JUL84	137.16	9.7
22AUG84	91.44	2.4
22AUG84	106.68	3.2
22AUG84	121.92	6.5
22AUG84	137.16	11.1
12SEP84	91.44	1.9
12SEP84	106.68	3.3
12SEP84	121.92	6.7
12SEP84	137.16	10.5
18OCT84	91.44	2.9
18OCT84	106.68	4.1
18OCT84	121.92	7.5
18OCT84	137.16	10.2
07NOV84	91.44	9.0
07NOV84	91.44	9.0
07NOV84	106.68	3.9
07NOV84	106.68	3.9
07NOV84	121.92	6.4
07NOV84	121.92	6.4
07NOV84	137.16	10.2
07NOV84	137.16	10.2
06DEC84	91.44	8.9
06DEC84	106.68	5.2
06DEC84	121.92	5.8

06DEC84	137.16	9.8
04JAN85	91.44	16.7
04JAN85	106.68	13.3
04JAN85	121.92	6.7
04JAN85	137.16	9.9
11FEB85	91.44	15.6
11FEB85	106.68	12.1
11FEB85	121.92	10.5
11FEB85	137.16	10.5
15MAR85	91.44	21.9
15MAR85	106.68	17.1
15MAR85	121.92	12.8
15MAR85	137.16	12.7
20MAR85	91.44	20.1
20MAR85	106.68	19.3
20MAR85	121.92	15.8
20MAR85	137.16	13.1
28MAR85	91.44	17.9
28MAR85	106.68	18.8
28MAR85	121.92	17.1
28MAR85	137.16	15.2
04APR85	91.44	19.7
04APR85	106.68	20.4
04APR85	121.92	18.2
04APR85	137.16	18.1
14MAY85	91.44	12.8
14MAY85	106.68	15.0
14MAY85	121.92	14.6
14MAY85	137.16	21.4
22MAY85	91.44	13.1
22MAY85	106.68	14.9
22MAY85	121.92	14.5
22MAY85	137.16	17.4
30MAY85	91.44	12.0
30MAY85	106.68	14.4
30MAY85	121.92	13.7
30MAY85	137.16	17.5
06JUN85	91.44	11.2
06JUN85	106.68	13.6
06JUN85	121.92	13.4
06JUN85	137.16	17.1
14JUN85	91.44	9.9
14JUN85	106.68	12.4
14JUN85	121.92	12.8
14JUN85	137.16	17.2
16JUL85	91.44	5.0
16JUL85	106.68	8.3
16JUL85	121.92	10.3
16JUL85	137.16	16.1
29JUL85	91.44	3.9
29JUL85	106.68	7.3
29JUL85	121.92	9.5
29JUL85	137.16	15.1
13AUG85	91.44	11.2

13AUG85	106.68	7.9
13AUG85	121.92	9.0
13AUG85	137.16	14.5

----------Type = Crushed tuff Tube Number = 510----------

Sampling Date	Depth From Surface (cm)	Volumetric Moisture Content (%)
22FEB84	91.44	9.1
22FEB84	106.68	3.4
22FEB84	121.92	4.3
22FEB84	137.16	11.4
04JUN84	91.44	3.1
04JUN84	106.68	3.3
04JUN84	121.92	3.8
04JUN84	137.16	10.5
24JUL84	91.44	2.0
24JUL84	106.68	1.9
24JUL84	121.92	3.6
24JUL84	137.16	9.5
22AUG84	91.44	2.1
22AUG84	106.68	2.0
22AUG84	121.92	2.7
22AUG84	137.16	10.8
12SEP84	91.44	1.8
12SEP84	106.68	1.8
12SEP84	121.92	3.1
12SEP84	137.16	9.7
18OCT84	91.44	3.1
18OCT84	106.68	2.4
18OCT84	121.92	4.4
18OCT84	137.16	9.7
07NOV84	91.44	10.8
07NOV84	91.44	10.8
07NOV84	106.68	3.0
07NOV84	106.68	3.0
07NOV84	121.92	3.4
07NOV84	121.92	3.4
07NOV84	137.16	10.1
07NOV84	137.16	10.1
06DEC84	91.44	9.3
06DEC84	106.68	4.7
06DEC84	121.92	3.1
06DEC84	137.16	10.1
04JAN85	91.44	16.5
04JAN85	106.68	12.6
04JAN85	121.92	3.6
04JAN85	137.16	10.2
11FEB85	91.44	15.0
11FEB85	106.68	11.9
11FEB85	121.92	9.0

11FEB85	137.16	10.3
15MAR85	91.44	22.5
15MAR85	106.68	16.5
15MAR85	121.92	12.0
15MAR85	137.16	12.0
20MAR85	91.44	20.6
20MAR85	106.68	18.5
20MAR85	121.92	14.6
20MAR85	137.16	12.9
28MAR85	91.44	19.1
28MAR85	106.68	18.1
28MAR85	121.92	16.0
28MAR85	137.16	14.6
04APR85	91.44	20.9
04APR85	106.68	19.7
04APR85	121.92	17.1
04APR85	137.16	17.4
14MAY85	91.44	14.3
14MAY85	106.68	14.7
14MAY85	121.92	13.6
14MAY85	137.16	26.4
22MAY85	91.44	18.2
22MAY85	106.68	17.2
22MAY85	121.92	21.5
22MAY85	137.16	17.3
30MAY85	91.44	12.2
30MAY85	106.68	13.7
30MAY85	121.92	13.4
30MAY85	137.16	17.8
06JUN85	91.44	11.3
06JUN85	106.68	12.8
06JUN85	121.92	13.2
06JUN85	137.16	0.4
14JUN85	91.44	7.0
14JUN85	106.68	11.5
14JUN85	121.92	12.3
14JUN85	137.16	16.9
16JUL85	91.44	2.6
16JUL85	106.68	4.7
16JUL85	121.92	9.8
16JUL85	137.16	15.3
29JUL85	91.44	2.5
29JUL85	106.68	3.5
29JUL85	121.92	7.6
29JUL85	137.16	15.1
13AUG85	91.44	11.6
13AUG85	106.68	3.1
13AUG85	121.92	5.4
13AUG85	137.16	14.2

----------Type = Crushed tuff Tube Number = 511----------

Sampling	Depth From	Volumetric

Date	Surface (cm)	Moisture Content (%)
22FEB84	91.44	7.4
22FEB84	106.68	4.2
22FEB84	121.92	6.0
22FEB84	137.16	9.8
04JUN84	91.44	5.2
04JUN84	106.68	5.3
04JUN84	121.92	5.4
04JUN84	137.16	9.1
24JUL84	91.44	3.8
24JUL84	106.68	4.4
24JUL84	121.92	6.0
24JUL84	137.16	8.6
22AUG84	91.44	2.8
22AUG84	106.68	3.9
22AUG84	121.92	5.2
22AUG84	137.16	9.5
12SEP84	91.44	2.4
12SEP84	106.68	3.6
12SEP84	121.92	5.6
12SEP84	137.16	8.9
18OCT84	91.44	3.1
18OCT84	106.68	4.1
18OCT84	121.92	6.6
18OCT84	137.16	8.7
07NOV84	91.44	8.8
07NOV84	91.44	8.8
07NOV84	106.68	4.2
07NOV84	106.68	4.2
07NOV84	121.92	5.6
07NOV84	121.92	5.6
07NOV84	137.16	8.6
07NOV84	137.16	8.6
06DEC84	91.44	8.9
06DEC84	106.68	4.9
06DEC84	121.92	5.2
06DEC84	137.16	8.8
04JAN85	91.44	17.9
04JAN85	106.68	11.4
04JAN85	121.92	5.1
04JAN85	137.16	8.5
11FEB85	91.44	16.4
11FEB85	106.68	12.0
11FEB85	121.92	9.2
11FEB85	137.16	8.7
15MAR85	91.44	22.6
15MAR85	106.68	15.9
15MAR85	121.92	12.2
15MAR85	137.16	10.0
20MAR85	91.44	21.5
20MAR85	106.68	18.4
20MAR85	121.92	14.4

20MAR85	137.16	10.2
28MAR85	91.44	19.6
28MAR85	106.68	18.2
28MAR85	121.92	16.1
28MAR85	137.16	11.0
04APR85	91.44	21.5
04APR85	106.68	19.4
04APR85	121.92	17.4
04APR85	137.16	14.2
14MAY85	91.44	14.5
14MAY85	106.68	14.6
14MAY85	121.92	13.9
14MAY85	137.16	15.3
22MAY85	91.44	19.3
22MAY85	106.68	23.0
22MAY85	121.92	15.8
22MAY85	137.16	15.8
30MAY85	91.44	13.2
30MAY85	106.68	14.0
30MAY85	121.92	13.5
30MAY85	137.16	15.6
06JUN85	91.44	12.9
06JUN85	106.68	13.2
06JUN85	121.92	13.2
06JUN85	137.16	17.0
14JUN85	91.44	10.9
14JUN85	106.68	12.3
14JUN85	121.92	12.8
14JUN85	137.16	15.7
16JUL85	91.44	6.1
16JUL85	106.68	9.6
16JUL85	121.92	10.7
16JUL85	137.16	14.5
29JUL85	91.44	4.7
29JUL85	106.68	8.3
29JUL85	121.92	9.7
29JUL85	137.16	14.1
13AUG85	91.44	7.2
13AUG85	106.68	7.7
13AUG85	121.92	9.0
13AUG85	137.16	13.7

----------Type = Crushed tuff Tube Number = 512----------

Sampling Date	Depth From Surface (cm)	Volumetric Moisture Content (%)
22FEB84	91.44	10.2
22FEB84	106.68	8.5
22FEB84	121.92	8.2
22FEB84	137.16	10.3
04JUN84	91.44	9.2

04JUN84	106.68	9.1
04JUN84	121.92	8.4
04JUN84	137.16	10.2
24JUL84	91.44	7.1
24JUL84	106.68	7.6
24JUL84	121.92	8.0
24JUL84	137.16	9.7
22AUG84	91.44	5.4
22AUG84	106.68	7.7
22AUG84	121.92	7.6
22AUG84	137.16	10.5
12SEP84	91.44	5.5
12SEP84	106.68	5.7
12SEP84	121.92	6.6
12SEP84	137.16	9.9
18OCT84	91.44	5.6
18OCT84	106.68	6.7
18OCT84	121.92	7.3
18OCT84	137.16	9.2
07NOV84	91.44	12.7
07NOV84	91.44	12.7
07NOV84	106.68	8.2
07NOV84	106.68	8.2
07NOV84	121.92	6.5
07NOV84	121.92	6.5
07NOV84	137.16	9.2
07NOV84	137.16	9.2
06DEC84	91.44	11.3
06DEC84	106.68	8.9
06DEC84	121.92	7.2
06DEC84	137.16	9.2
04JAN85	91.44	17.5
04JAN85	106.68	14.0
04JAN85	121.92	7.9
04JAN85	137.16	9.1
11FEB85	91.44	15.5
11FEB85	106.68	12.7
11FEB85	121.92	11.2
11FEB85	137.16	10.6
15MAR85	91.44	22.7
15MAR85	106.68	17.1
15MAR85	121.92	13.5
15MAR85	137.16	12.4
20MAR85	91.44	21.2
20MAR85	106.68	18.9
20MAR85	121.92	16.7
20MAR85	137.16	13.2
28MAR85	91.44	19.2
28MAR85	106.68	17.8
28MAR85	121.92	17.7
28MAR85	137.16	15.5
04APR85	91.44	21.2
04APR85	106.68	19.5
04APR85	121.92	18.7

04APR85	137.16	17.6
14MAY85	91.44	14.1
14MAY85	106.68	14.3
14MAY85	121.92	14.9
14MAY85	137.16	16.2
22MAY85	91.44	14.7
22MAY85	106.68	14.9
22MAY85	121.92	17.9
22MAY85	137.16	17.9
30MAY85	91.44	13.3
30MAY85	106.68	13.5
30MAY85	121.92	14.3
30MAY85	137.16	17.0
06JUN85	91.44	12.4
06JUN85	106.68	12.8
06JUN85	121.92	13.7
06JUN85	137.16	17.5
14JUN85	91.44	11.6
14JUN85	106.68	12.3
14JUN85	121.92	13.1
14JUN85	137.16	16.1
16JUL85	91.44	7.9
16JUL85	106.68	10.2
16JUL85	121.92	10.7
16JUL85	137.16	14.8
29JUL85	91.44	6.0
29JUL85	106.68	8.3
29JUL85	121.92	9.9
29JUL85	137.16	14.1
13AUG85	91.44	9.8
13AUG85	106.68	6.2
13AUG85	121.92	8.8
13AUG85	137.16	13.7

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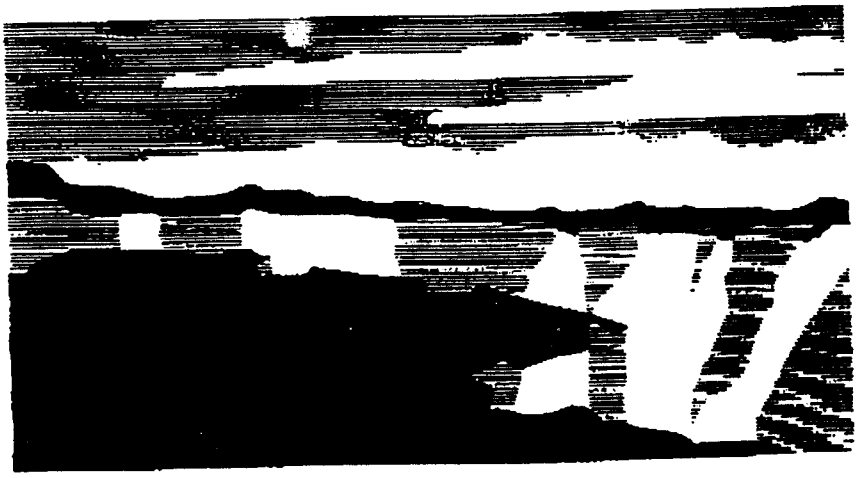
Submitted to: Proceedings of the 1993 International Conference on Nuclear Waste Management and Environmental Remediation, September 5-11, 1993 Prague, Czechoslovakia



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FIELD STUDIES OF ENGINEERED BARRIERS FOR CLOSURE OF LOW LEVEL RADIOACTIVE WASTE LANDFILLS AT LOS ALAMOS, NEW MEXICO, USA

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ABSTRACT

The Los Alamos National Laboratory examined water balance relationships for four different landfill cover designs containing engineered barriers. These field experiments were performed at Los Alamos, New Mexico, USA, in 1.0- by 10.0-m plots with downhill slopes of 5, 10, 15, and 25%. This plot size and these slopes were chosen to complement similar experiments currently being performed at the Universities of Hamburg, Munchen, Darmstadt, and Karlsruhe, Germany, as part of the US Department of Energy's International Technology Exchange and Environmental Restoration programs.

Field measurements of seepage, precipitation, interflow, runoff, and soil water content were collected in each of the 16 plots representing four slopes each with four cover designs: Conventional, EPA, Loam Capillary Barrier and Clay Loam Capillary Barrier. A seepage collection system was installed beneath each cover design to evaluate the influence of slope length on seepage using a series of four metal pans filled with medium gravel that were placed end-to-end in the bottom of each field plot. An automated waterflow datalogging system was used to collect hourly seepage, interflow and runoff data and consisted of 100 100-liter tanks, each of which was equipped with an ultrasonic liquid-level sensor and a motor-operated ball valve used to drain the tank. Soil water content was routinely monitored every six hours at each of 212 locations throughout the 16 plots with time domain reflectrometry (TDR) techniques using an automated and multiplexed measurement system.

Field data is presented to show the effects of slope and slope length on the performance of each landfill cover design for the first 15 months of this field experiment.

INTRODUCTION

Institutional control and maintenance of low-level radioactive-waste repositories are expected to cease 100 years after the closure of a waste site, after which time the repository's engineered barriers and geohydrologic conditions need to act passively to isolate the radionuclides for an additional 300 to 500 years (US NRC, 1982). There are currently neither experimental nor experiential real-time bases for long-term projections regarding the effectiveness of engineered barriers in landfill covers for long-term containment of either radionuclides (Bedinger, 1989) or other waste forms.

Even though the successful performance of the entire landfill is very much a function of interactive water balance processes, traditional remedial engineering solutions have ignored these processes, leading to numerous landfill failures (Jacobs et al., 1980; Hakonson et al., 1982). Field water balance data do not exist to enable the site operator to define and engineer suitable barriers to prevent the migration of waste materials out of the landfill.

Our approach to developing an effective landfill cover technology is based on the results of ten years of individual shallow land burial studies at Los Alamos and Utah (Abeele, 1986a, 1986b; DePoorter, 1981; Hakonson et al. 1982; Nyhan et al. 1984, 1990a, 1990b; Pertusa, 1980). These studies were combined (with the help of the US Department of Energy's International Technology Exchange Program) with current European research (Anonymous, 1988; Berger et al., 1991; Gregersen et al., 1991; Hozl and Wohnlich, 1992; von der Hude, 1991a,1991b; Matter, 1991; Melchior et al., 1990a,1990b, 1991,1992; Melchoir and Miehlich, 1988; Mielich and Melchoir, 1992; Mock et al., 1991; Wohnlich 1990,1991) to design and emplace the Protective Barrier Landfill Cover Demonstration at the Los Alamos National Laboratory in Los Alamos, New Mexico, USA. The purpose of this field demonstration was to monitor and compare water balance relationships on four landfill cover designs in a semiarid temperate mountain climate as functions of slope and slope length. This field data was to be used to calibrate several hydrologic models that will be used to design landfill covers.

MATERIALS AND METHODS

Plot Construction, Design and Rationale

The purpose of the Protective Barrier Landfill Cover Demonstration was to monitor and compare water balance on the conventional landfill cover design, similar to that used in Los Alamos and the waste management industry for waste disposal (Jacobs et al., 1980), with that on three other designs containing engineered barriers. The performance of all four designs was evaluated at dominant downhill slopes of 5, 10, 15 and 25%. These plots were installed during the spring, summer and fall of 1991 in our 8-ha field test facility (DePoorter, 1981) and were instrumented so that a complete accounting of precipitation falling on the plots could be measured. The plots were constructed and instrumented to provide measures of runoff and interflow, as well as seepage and soil water storage as a function of slope length.

The technology for controlling soil water erosion on all cover designs consisted of applying a 70% surface cover of medium gravel (8.0- to 25-mm diam). Dominant downhill slopes up to 25% were used on the plot surfaces to insure a range of slopes up to the maximum slope that would be allowable for the safe operation of large earth-moving equipment at a landfill.

The Protective Barrier Landfill Cover Demonstration was emplaced on an east-facing 10.7- by 37.5-m parcel of land with crushed tuff backfill on the surface (Nyhan et al., 1984). This backfill is used in landfills at Los Alamos as a result of excavating disposal trenches in local Bandelier Tuff, which is then crushed and emplaced around the waste materials. This area was surveyed into four 10.7- m-long areas, each of which received additional crushed tuff to establish the varying downhill slopes. The crushed tuff on each of these pads was then compacted and resurveyed to confirm the desired slopes. A south-facing 4.6-m-wide, 40-m-long ramp that abutted the lower ends of these four east-facing pads was constructed similarly, only with a 2% dominant downhill slope. A set of four 1.0- by 10.0-m plots with common sidewalls was then constructed on the center of each pad, with a distance of 3.05 m between each set of plots. All of the plot walls except the downhill endplates were fabricated using two pieces of plywood (1.27 cm by 1.88 m by 1.22 m) emplaced within a framework consisting of vertically placed iron I beams (2.5 by 5.1 by 0.32 cm) on 1.22 m centers, with channel iron (2.5 by 5.1 by 0.32 cm) top and bottom framing. The endplates were fabricated from 14 gauge sheet metal, and had 7.62-cm and 10.2-cm diam steel half couplings welded into the endplate wall to connect plumbing used for the collection of seepage and interflow, respectively. The interflow collection system consisted of a 1.0-m long, 30.5-cm-deep, 30.5-cm-wide 14 gauge metal trough welded to the inside of the plot's endplate. The runoff collection system was also fabricated using 14 gauge sheet metal and consisted of a 1.0-m long, 15.2-cm-wide trough with a floor that sloped to divert runoff (30.5-cm deep at the low end and only 25.4 cm deep at the high end); this trough was welded to the top of each endplate and had a 15.2-cm-diam steel half coupling welded into the trough wall to connect plumbing used to collect runoff.

A seepage collection system was installed in the bottom of each of the plots and was designed to evaluate seepage as a function of slope length. Sixty-eight 2.02- by 0.76 m pans with a depth of 0.30 m were fabricated from 14 gauge sheet metal. Each pan was designed with a 5.0-cm-tall, 2.02-m-long channel iron foot that was welded to the bottom of the pan; this foot insured a slope on the bottom of the pan for seepage water to flow out of the pan through a standard 1.3-cm-diam standard pipe coupling which was welded into a corner of the pan. Four of these pans were placed end-to-end in the bottom of each plot, and were attached to each other at the top of each pan using a sheet metal clip. An 11.4-cm-wide space was purposely left between each sidewall of the plot and the pan to minimize sidewall effects in this experiment, which might allow water to migrate down the sidewalls of the plot and be incorrectly measured as seepage. Each pan and the rest of the bottom of each plot were then filled with medium gravel (8.0- to 25-mm diam). A sharp interface between this gravel layer and the above-lying soil layers was maintained with a high conductivity (0.024 m/s) geotextile (600X Brand, manufactured by MIRAFI, El Toro, CA) with a range in apparent opening size of 300 to 850 µm between the polypropylene strands of the fabric.

After every plot corner was resurveyed to make sure of the final slopes, 15 cm of backfill was emplaced around the outside of each of the four sets of plots and compacted with a walk-behind dual drum trench roller with a cleated drum width of 0.38 m capable of exerting 3.08 metric tons of applied force (Model MDR-T38S, Mikasa USA, Multiquip, Carson, CA) and a vibratory plate compactor with a 0.50 by 0.56 m plate capable of exerting 1.52 metric tons of applied force (Model MVC-90A, Mikasa USA, Multiquip, Carson, CA). The next step involved emplacing 15 cm of various soils materials inside each of the plots using a Clark Bobcat Model 975 skid-steer trencher (American Trencher Inc., Delhi, IA) and a 15.9-m long Model HSDU-52 conveyor with a hydraulic cleated belt (Clearfield Conveyors Corp., Clearfield, UT). These two consecutive steps were repeated until the last soil layer was added to the plots.

All of the soils materials used in each landfill cover design except the medium gravel were compacted using the equipment described above for each 15-cm lift of soil emplaced in each plot. Laboratory compaction tests were performed on the sands using Standard Test Methods for Maximum Index Density of Soils Using a Vibratory Table (American Society for Testing and Materials, 1979; Test Method D4253-83) and on the other soils using the Modified Proctor Method (American Society for Testing and Materials, 1979; Test Method D1557). After the first lift of each type of soil material was added to a plot and compacted, a set of 13 nuclear gauge readings of soil water content and bulk density was collected over the depth of the lift every 61 cm down the length of the plot. A semivariogram analysis of this data was performed to determine how many Proctor determinations would be necessary to characterize the compaction of each lift of soil added to the plots. For a specified range of soil water content, our typical construction specifications required that our soils materials be compacted to a minimum dry unit weight. These values were 85%, 95% and 90% of the maximum dry unit weight from standard Proctor compaction for the two topsoils, the sands, and the tuff-clay mixture, respectively.

Schedule 40 PVC pipe was used to connect the water collection systems for runoff, interflow and seepage to the automated water flow datalogging system. Each of the four pans of the seepage collection system was plumbed with 2.5-cm diam pipe, which were then emplaced in a 7.62-cm diam pipe outside the plot endplate for added protection against crushing as the pipes were buried with additional backfill. The interflow and runoff collection systems were plumbed with 10.2- and 15.2-cm diam pipe, respectively. All of this pipe was initially laid on the 4.6-m wide ramp at the bottom of the plots to insure the gravity flow of water with a minimal 2% slope.

The plots with the conventional landfill cover design contained 15 cm of a loam topsoil consisting of a 2:1:1 (V:V:V) mixture of an uncharacterized topsoil with a large organic matter content, sand, and aged sawdust (<9.5-mm diam). This topsoil was underlain by 76 cm of crushed tuff backfill described previously (Nyhan et al., 1984 and 1990a). The crushed tuff backfill beneath a depth of about 1 m in a profile like this would normally contain wastes in an actual waste disposal site at Los Alamos.

One set of plots contained the EPA-recommended final cover design (US EPA, 1989). These plots contained 61 cm of the loam topsoil described previously (this corresponds to the EPA "vegetated topsoil layer"), emplaced on top of 30 cm of a medium sand (8.0- to 25-mm diam) made in a sand classifying/blending tank system (Portec Kolberg Division, Yankton, SD). The latter layer corresponds to the EPA "drainage layer" and was overlain with the MIRAFI geotextile layer described above to provide the EPA-recommended filter layer necessary to prevent fine soil particles from migrating into the drainage layer. The bottom layer in the EPA-recommended final cover, called the "low-permeability layer," usually consists of a 20 mil (0.5 mm) minimum thickness flexible membrane liner (FML) on top of a 60-cm-thick layer of soil with an in-place saturated hydraulic conductivity of $<1\times10^{-9}$ m/s. Since the plastic FML would last less than 35 years (Pertusa, 1980), this feature of the EPA design was omitted in our EPA design to evaluate the worst possible case. The results of previous research on mixtures of local crushed tuff and sodium-saturated bentonite (Abeele, 1986a and 1986b) indicated that a 1:10 (W:W) mixture of finely ground Aquagel (Baroid Drilling Fluids, Farmington, NM) and crushed tuff should easily provide us with the low conductivity required for this layer. This mixture was prepared in a cement truck by adding 10 45.4-kg bags of dry Aquagel to 4.54 metric tons of <6.4-mm diam crushed tuff that had been screened and dried using an asphalt batch plant. This dry mixture was mixed for 40 minutes, approximately 200 liters of water was added (for dust control and to optimize compaction), followed by an additional 30 minutes of mixing. A 15-cm-deep lift of mixture was finally added to each plot. After compaction this lift was covered to prevent the mixture from drying, and this lift was sprayed with water before adding the next 15-cm lift of mixture to promote the uniformity of the entire 61-cm layer.

Two designs contained capillary barriers varying only in the type of soil used in the uppermost layer. One of the designs contained 61 cm of the same loam mixture used in the previous designs, whereas the other design contained 61 cm of a local clay loam backfill classified (Nyhan et al., 1978) as a Lithic Aridic Haplustalf (clayey, mixed, mesic family) and used in two previous studies (Nyhan et al., 1984 and 1990a). These soils were emplaced on top of 76 cm of a fine sand (0.05-to 0.425-mm diam) made in the sand classifier/blender described previously. The fine sand was specifically chosen to complement the underlying medium-sized gravel in terms of optimizing both the hydraulic conductivity and water-holding properties of the capillary barrier (Wohnlich, 1991).

Measurement of Seepage, Interflow, Runoff, and Precipitation

Runoff, interflow, and seepage were collected in 100 100-liter tanks housed in two instrument trailers that were heated in the winter to allow year-round hydrologic measurements. Water levels in each tank was measured with a microprocessor-controlled ultrasonic liquid level sensor (model DCU-7, Lundahl Instruments, Logan, UT) mounted in the top end of a 1.5-m-long stilling well (5.1-cm diam PVC pipe) attached to the inside of the tank. The sensor output was connected to one of five multiplexer boards (model CIO-MUX32, CyberResearch, New Haven, CT) located in five junction boxes. This multiplexer board was organized as a pair of 16-to-1 multiplexers. The output of each multiplexer was connected by way of shielded flat cable to a digitizer card (model CIO-AD08, CyberResearch, New Haven, CT) in a computer with a widely used personal computer motherboard (model 386N33, Hauppauge Computer Works, Inc., Commack, NY) and a 200 megabyte hard drive (model ST1239A, Seagate Technology, Scotts Valley, CA). Two digitizer cards served the ten multiplexers in this system, in which the digitizer cards accepted 4 and 6 analog inputs, one from each multiplexer.

The computer was used to capture and store the water level data from each tank and to activate the draining of the tank when it was nearly full by actuating a 5.1-cm-diam electrically-actuated ball valve (115 volt alternating current Electromni model, Asahi/America Inc., Medford, MA) mounted in the bottom of the tank. The digital output card in the computer (model PCL 722, CyberResearch, New Haven, CT) was organized as six channels of 24 bits each, with five channels being connected to five relay driver boards (model DB-3737, PERX, Inc., San Mateo, CA) located in the junction boxes. Thus, the computer read the water levels in the 100 tanks and made the decision to actuate the valves and repeated this loop at a rep rate of approximately 1.5 hertz. The water levels in the tanks were routinely recorded hourly, but much more frequently when the tank was emptying and when it was nearly full. This data was routinely copied into a single large file every 24 hours.

Precipitation was measured using a tipping bucket rain gauge and a long-term event recorder (Weathermeasure Corp., Sacramento, CA).

Measurement of Soil Water Content

Since the goals of this experiment were to provide field data to calibrate several hydrologic models and to collect water balance data, it was necessary to measure soil water content at multiple points in space and time. Thus, soil water content was routinely monitored once every six hours at each of 212

locations throughout the 16 plots using Time Domain Reflectrometry (TDR) techniques with the help of an automated and multiplexed measurement system. Volumetric water content was measured with a pair of stainless steel waveguides (60-cm long, 3-mm diam soil moisture probes; model number 6860, Campbell Scientific, Logan, UT) which are buried parallel and 5 cm apart in the soil. One set of waveguides was emplaced vertically in every soil layer above the bottom end of each of the metal pans in the seepage collection system; these waveguides allowed us to determine soil water inventory in four locations in each field plot. A second set of waveguides was emplaced horizontally in several soil layers to provide us with a more detailed picture of soil water dynamics close to the interfaces of a few soil layers.

Each set of waveguides was connected to 4.6 m of shielded twin-lead antenna cable that was connected to a molded balun connected to a 26-m length of RG-8/U coaxial cable. An instrument trailer housed a 256-to-1 coaxial switch that connected one set of waveguides at a time to a TDR cable tester (model 1502B, Tektronix Inc., Beaverton, OR) through a system of 37 8-to-1 coaxial switches (model 610-007A, Autek Systems Corp., Santa Clara, CA). The computerized TDR system captured and stored the information from each pair of waveguides as a 220-point waveform (which represented an average of 16 waveform determinations). The personal computer (model 386-20, Compaq Computer Co., Austin, TX) stored the waveform data on a hard disk, which was then used to determine the water content of the soil through a calibration curve relating water content to measured dielectric constant (Topp et al., 1980).

RESULTS AND DISCUSSION

Estimates of Precipitation

In New Mexico, average annual precipitation ranges from less than 25 cm over much of the southern desert and the Rio Grande valley to more than 50 cm at higher elevations in the state. Los Alamos has a semiarid, temperate mountain climate with an average total annual precipitation of 46.9 cm for the years 1911 through 1986 (Nyhan et al., 1989). July and August are the rainiest months, with 48% of the annual precipitation falling at this time in Los Alamos as intense thundershowers. These months are also characterized by warm temperatures and high evapotranspiration, with the net result that precipitation occurring in the winter and spring result in seepage production within landfill covers (Nyhan et al., 1990a,1990b).

Precipitation data collected at the Protective Barrier Landfill Cover Demonstration (Fig. 1) show that 37.4 cm of precipitation occurred during 1992, with a total of 53.0 cm occurring between November 1991 through January 1993. The precipitation received during the winter of 1991-1992 amounted to 4.65 cm, making this a dry winter compared with the 1911-1986 average of 6.71 cm for winter (Nyhan et al., 1989). However, this was followed by a wet spring in which 12.4 cm of precipitation occurred compared with the long-term average of 9.37 cm. The precipitation during the dry summer of 1992 amounted to 13.3 cm, only 59% of the long-term summer average precipitation.

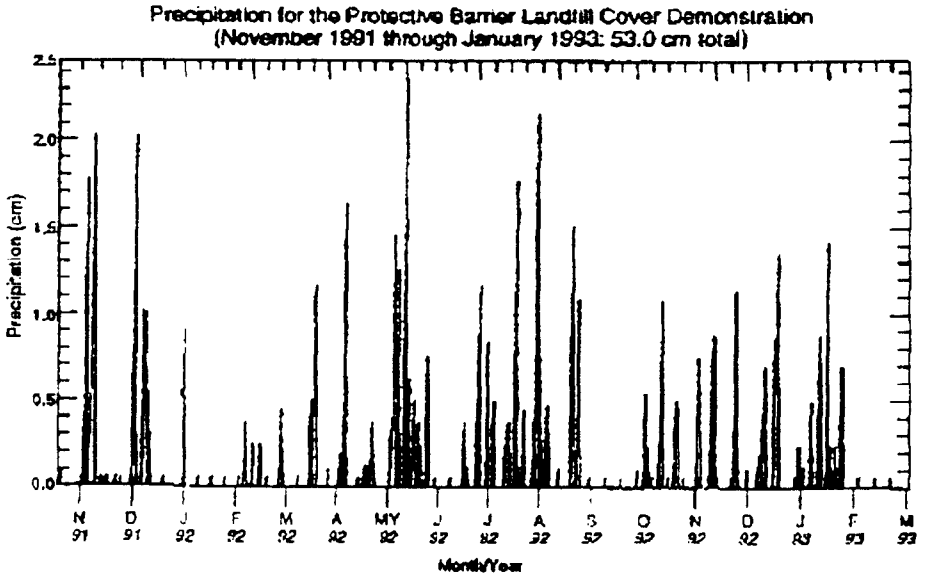

Fig. 1. Precipitation Data Collected at the Protective Barrier Landfill Cover Demonstration In Los Alamos, NM From November 1991 Through January 1993.

Seepage, Interflow, and Runoff Data

Very little field data are available on the flow of water through landfill cover designs, making the data gathered in this field study unique. Each of the 100 different estimates of seepage, interflow, and runoff in our experiment resulted in a hydrograph chart with flow data for approximately 14,000 sampling times (a computer file of about 0.6 megabytes) for the 15 months of this study. This hourly data was reduced to daily flow estimates (Fig. 2), which represent interflow estimates for two of the capillary barrier designs with dominant downhill slopes of 5%. The capillary barrier design with the loam topsoil exhibited maximum daily interflow production rates approaching 0.24 cm, with 3.45 cm of total interflow occurring from February through April of 1992. The design with the clay loam topsoil exhibited maximum daily interflow rates of only 0.034 cm with only 0.71 cm of interflow occurring during this time period. Most of this large difference in interflow can probably be attributed to the fact that the clay loam has a low conductivity (Nyhan et al., 1984), compared to the loam topsoil, which limited the flow of soil water into the fine sand layer in this design.

The estimates of interflow and seepage on all 16 plots for the 15 months of this study are summarized in Table 1. This data shows that all of the capillary and hydraulic barriers are preventing seepage at all slopes and slope lengths tested in the study. Total interflow for the 15 months of the study ranged from 3.4 to 6.1 cm on all of the EPA and capillary barrier designs containing the loam topsoil. In contrast, the conventional design, which did not contain an engineered barrier, produced seepage in almost every case tested and most of this seepage occurred from February through April of 1992, during and following a relatively dry winter (Fig. 1).

For the Conventional design evaluated on the 5% slope, this 15-month total seepage occurred in the seepage collection system located 3.64-5.66 m downslope (0.21 cm), 5.66-7.68 m downslope (0.37 cm), and 7.68-9.70 m downslope (2.86 cm). This design only produced seepage 5.66 to 9.70 m downslope with a 15% slope, and 7.68 to 9.70 m downslope with a 25% slope.

Runoff occurred on these unvegetated plots from December 1991 through February 1992, as a result of snowmelt and during May and August 1992, as a result of thunderstorm activity. The total runoff from all 16 plots is summarized in Table 2 for the 15 months of the study. The largest daily runoff (0.54 cm) occurred on the EPA design with the 25% slope after a 2.16-cm precipitation event on August 24, 1992.

No consistent relationship exists between slope and runoff for either the clay loam topsoil used on the Clay Loam Capillary Barrier design or the loam topsoil used on all the other designs. Less than 15% of this total runoff (Table 2) usually came from snowmelt events during the first winter of the study, but this is not surprising since almost 30% of the total precipitation for the entire 15 months was received in May and August, 1991 (Fig. 1).

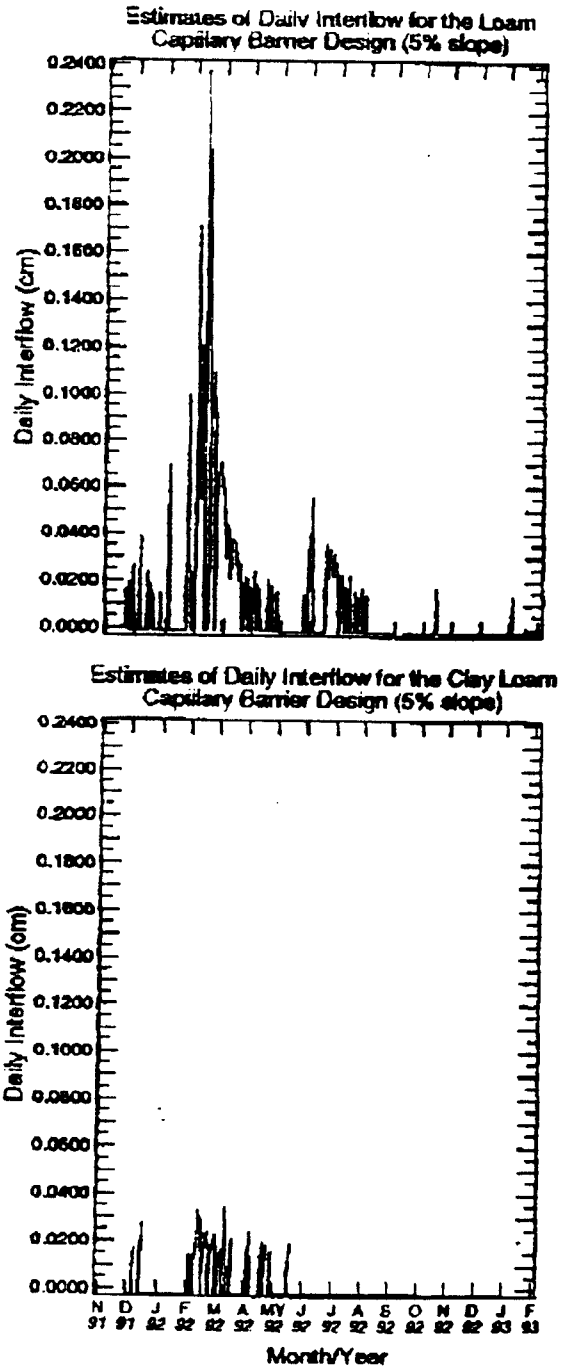

Fig. 2. Estimates of Daily Interflow for the Loam and Clay Loam Capillary Barrier Designs (5% Slope) At the Protective Barrier Landfill Cover Demonstration in Los Alamos, NM.

TABLE 1
Interflow and Seepage Estimates for the Protective Barrier Landfill Cover Demonstration at Los Alamos, NM (November 1991 through January 1993)

Landfill Cover Design	Interflow (Seepage) (cm) for Dominant Downhill Slopes of 5%	10%	15%	25%
Conventional	3.2 (3.4)	8.8 (0)	5.8 (4.0)	4.6 (0.41)
EPA	5.4 (0)	6.1 (0)	4.3 (0)	4.5 (0)
Loam Capillary Barrier	4.8 (0)	5.1 (0)	3.4 (0)	3.9 (0)
Clay Loam Capillary Barrier	0.78 (0)	3.2 (0)	0.12 (0)	0.36 (0)

TABLE 2
Runoff Estimates for the Protective Barrier Landfill Cover Demonstration at Los Alamos, NM. (November 1991 through January 1993)

Landfill Cover Design	Runoff (cm) for Dominant Downhill Slopes of 5%	10%	15%	25%
Conventional	1.3	0.48	0.87	0.10
EPA	0.27	0.50	0.72	0.74
Loam Capillary Barrier	0.31	2.6	0.79	1.6
Clay Loam Capillary Barrier	0.88	2.1	1.7	3.3

Soil Water Data

Each of the 212 locations throughout the 16 plots was monitored for soil water content once every six hours from November 1991 through December 1992, resulting in several 60-megabyte monthly computer files of TDR waveforms. This waveform data was then reduced to soil water content data.

Soil water data is presented for several layers of the Conventional design evaluated at a position 9.7 m downslope in the plots with dominant downhill slopes of 5% (Fig. 3) and 15% (Fig. 4). The water content of the loam topsoil is presented in the top half of each of these two figures, representing the readings of a horizontally-emplaced pair of waveguides within the 15-cm deep topsoil (at an actual depth of 5 to 10 cm).

The topsoil water content data from these two plots can be used to demonstrate the influence of aspect on snowmelt dynamics during the short daylight periods of the winter when the sun is at a low angle on the horizon. For the plot with the 15% slope (Fig. 4), the volumetric water content rises from 14.2% on December 10, 1991 (at 6:20 am), to 27.9% on December 11 (at 2:44 PM), as a result of a snow event that accounted for 2.4 cm of precipitation added to the surface of the site. The volumetric water content steadily decreased to 7.1% on December 15 (at 5:08 am). All of this happened as the snow melted on the surface of this high-aspect plot, unlike what happened on the plot with the 5% slope (Fig. 3). This plot retained snow cover and only demonstrated a small increase in volumetric water content to 19.0% on December 11, 1991 (at 2:44 PM).

The bottom portions of Figures 3 and 4 contain the soil water content data for the crushed tuff layer of the Conventional design at a depth of 15 to 91 cm. The vertically-emplaced waveguides were used to measure the average tuff water content from 20 to 80 cm and the horizontally-emplaced waveguides measure the water content at the bottom of the crushed tuff layer (80 to 86 cm depth). This latter data, collected at the bottom and toward the end of the plot (9.7 m downslope), gives a good representation of the influence of slope and seepage on water dynamics in these two plots. Seepage occurred in January, April, May, and June of 1992 on the plot with the 15% slope, and finally stopped, resulting in an enormous decrease in volumetric water content (Fig. 4). The Conventional design on the 5% slope demonstrated a gradual increase in tuff water content resulting in seepage starting in February 1991 (Fig. 3) instead of January 1991 (Fig. 4). The average tuff water content of the 20-80-cm depth was also significantly larger in the plot with the 5% slope than in the plot with the larger slope (Fig. 4).

Soil water content data is presented in Fig. 5 for the EPA design with the 25% dominant downhill slope. The TDR data presented in the top portion of the curve represents the measurements collected from a pair of 60-cm-long waveguides emplaced vertically in this soil layer. Many of the same snowmelt relationships shown for the topsoil in the Conventional design with the 15% slope (Fig. 4) can also be observed for this plot in December 1991. Soil water in the topsoil decreased as water drained into the medium sand layer (the EPA "drainage layer") at a depth of 61-91 cm. The horizontally-emplaced waveguides in this medium sand layer demonstrated increased soil water content as interflow occurred in December 1991, as well as in the succeeding months of January, and late May through June. During the time that the interflow was occurring, the water content of the top portion (96-102 cm depth) of the hydraulic layer (the clay-tuff mixture) gradually increased from 10% to 20%, followed by a substantial increase to 36% by the end of the summer of 1992, as water from thunderstorms infiltrated the highly conductive loam topsoil (Fig. 5). The water content of both the medium sand layer and the top of the underlying hydraulic layer then decreased with reduced precipitation events in the fall of 1992.

The TDR data presented for the Loam Capillary Barrier designs at slopes of 5% (Fig. 6) and 25% (Fig. 7) is meant to demonstrate the dynamics of three-dimensional water movement through the loam topsoil and underlying fine sand layers. Since no seepage occurred in either of these two designs the soil water content data presented here can be used to understand why the barrier was a success hydrologically and will be used to field validate several hydrologic models. The interflow data presented in Fig. 2 corresponds with the TDR data presented in Fig. 6 for the Loam Capillary Barrier

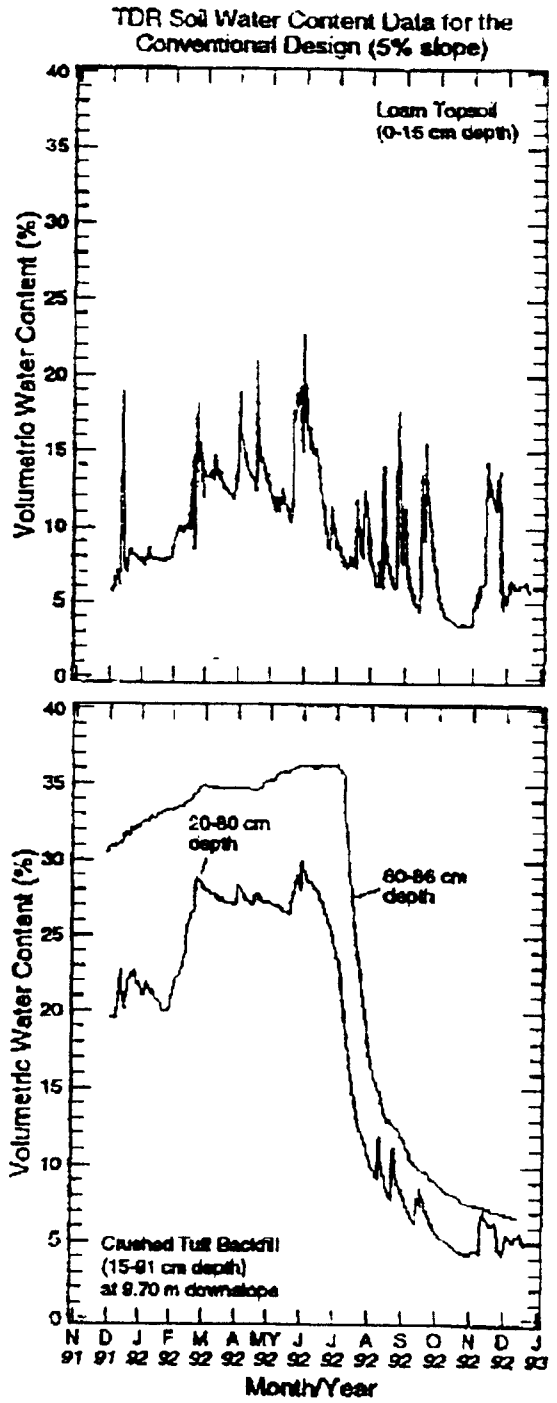

Fig. 3. TDR Soil Water Content Data Collected For the Conventional Landfill Cover Design With the 5% Dominant Downhill Slope At the Protective Barrier Landfill Cover Demonstration in Los Alamos, NM.

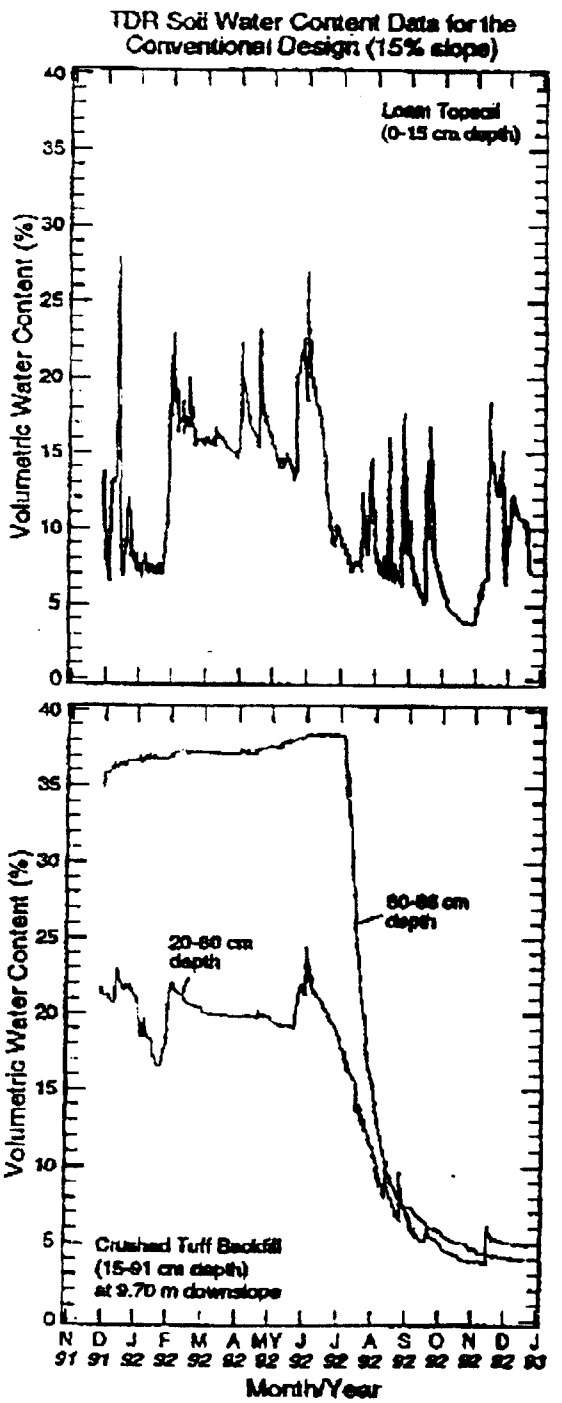

Fig. 4. TDR Soil Water Content Data Collected For the Conventional Landfill Cover Design With the 15% Dominant Downhill Slope At the Protective Barrier Landfill Cover Demonstration in Los Alamos, NM.

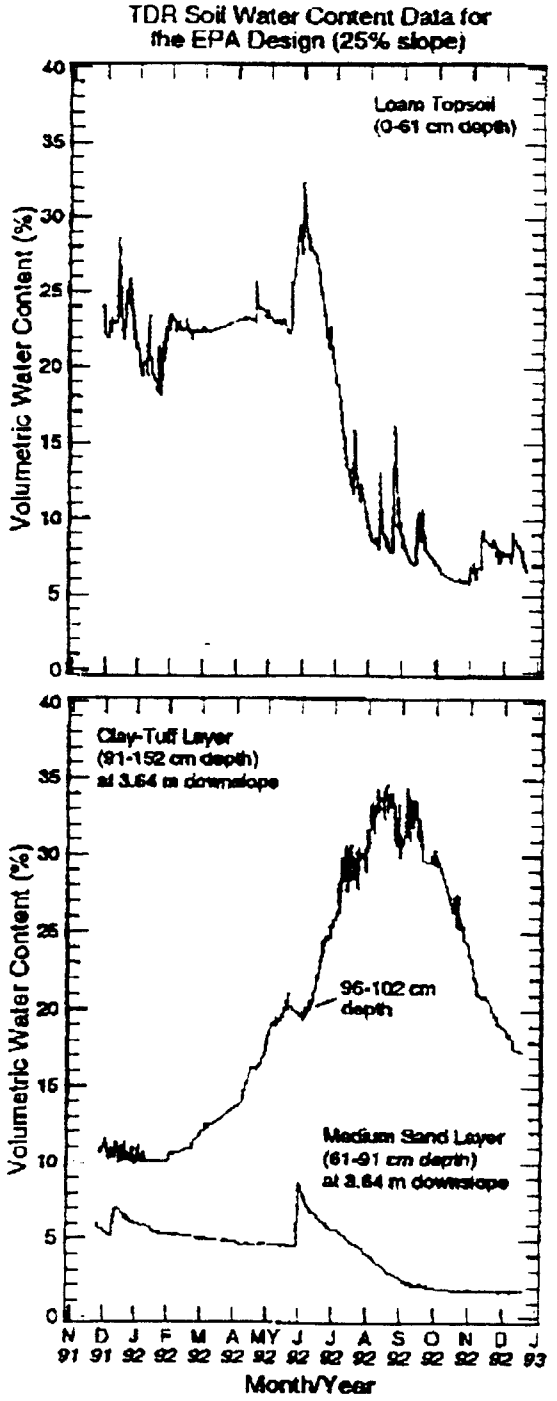

Fig. 5. TDR Soil Water Content Data Collected For the EPA Landfill Cover Design With the 25% Dominant Downhill Slope At the Protective Barrier Landfill Cover Demonstration in Los Alamos, NM.

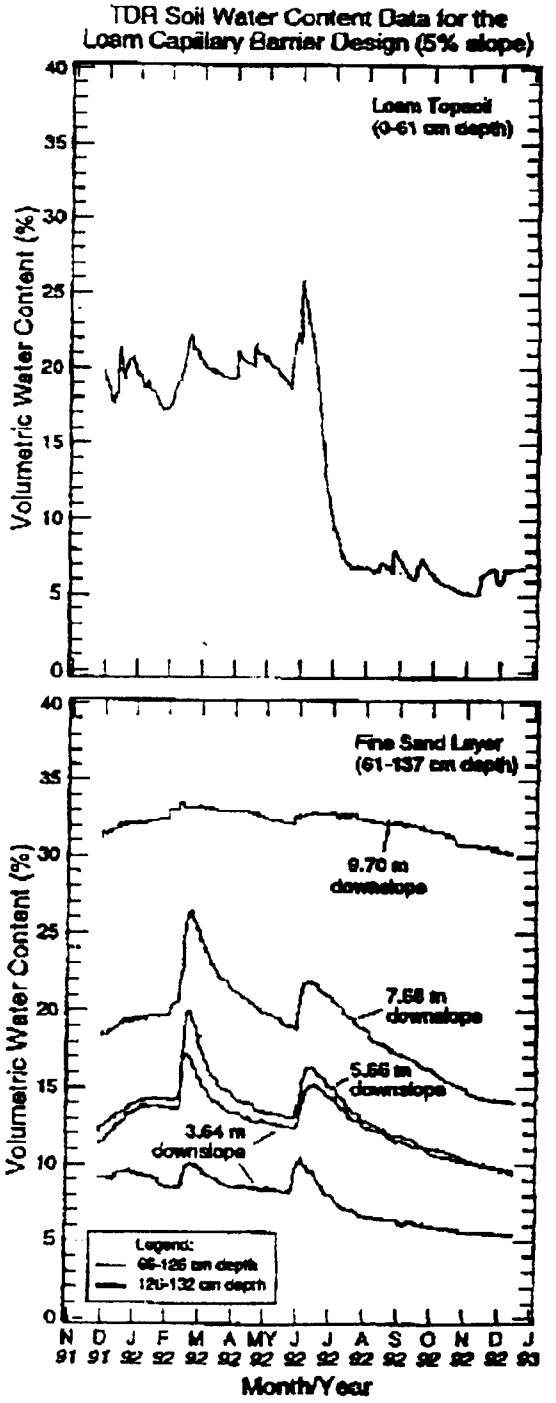

Fig. 6. TDR Soil Water Content Data Collected For the Loam Capillary Barrier Landfill Cover Design With the 5% Dominant Downhill Slope At the Protective Barrier Landfill Cover Demonstration in Los Alamos, NM.

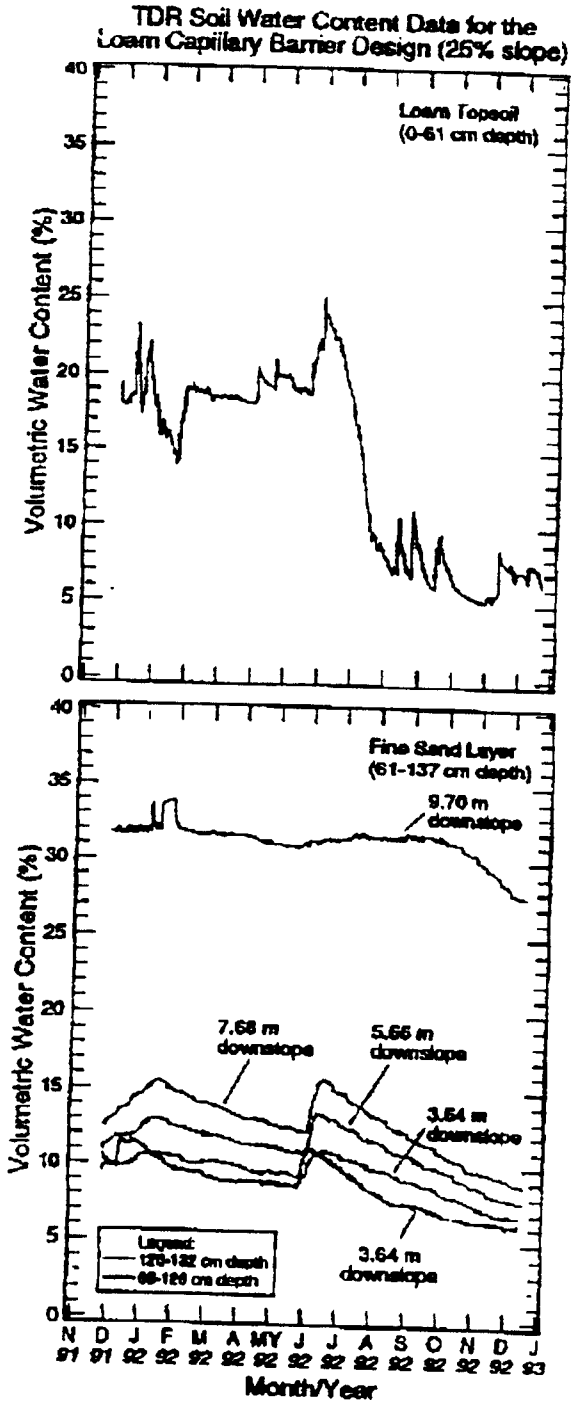

Fig. 7. TDR Soil Water Content Data Collected For the Loam Capillary Barrier Landfill Cover Design With the 25% Dominant Downhill Slope At the Protective Barrier Landfill Cover Demonstration in Los Alamos, NM.

design with the 5% slope. Approximately 3.5 cm of water moved out of the topsoil in this plot from January through March 1992 resulting in a dramatic increase in the water content of the underlying fine sand layer. TDR data (bottom portion of Fig. 6) was collected to evaluate the water status of the entire 66-126 cm layer of fine sand, as well as of the bottom of the fine sand layer (126-132 cm depth) for four downslope positions within the plot. This data shows that the water content at the bottom of the fine sand layer is considerably larger than the average water content of the entire layer. The TDR data also demonstrates that the water content at the bottom of the fine sand layer increased during interflow as a function of slope length, resulting in volumetric water content values observed at the maximum slope length (9.7 m downslope) in excess of 33% (Fig. 6). Thus, even at this location in the capillary barrier, the rate of infiltration of water into the fine sand layer was less than the capillary barrier's ability to conduct water laterally: matrix potential forces were still able to hold the water within the fine sand at the interface between the fine sand and the medium gravel.

The TDR data presented for the Loam Capillary Barrier with the 25% slope (Fig. 7) shows several of the same relationships discussed above for the same design evaluated on a 5% slope. Due to a much larger slope, probably resulting in enhanced lateral flow rates, smaller differences were observed in the water content of the fine sand as a function of slope length than for the data from the 5% plot (Fig. 6). However, the same conclusions can be made for both plots for the data collected at the bottom of the fine sand layer at the *maximum* slope length tested (9.7 m downslope).

The TDR data for the Clay Loam Capillary Barrier design with the dominant downhill slope of 25% is presented in Fig. 8 to demonstrate the effect of a low-conductivity topsoil on capillary barrier dynamics. The daily interflow data presented in Fig. 2 for this design evaluated on a 5% slope is typical for this design compared with similar data from the plots on the other three slopes. The soil water content data for the bottom of the fine sand layer (25% slope) do not demonstrate multiple large pulses of water coming through the clay loam topsoil (Fig. 8), in contrast to what happened on the capillary and hydraulic barrier plots with the highly conductive loam topsoil (Figs. 5-7). Instead, we observed a pattern indicating a very slow drainage rate of water from the clay loam layer into the underlying fine sand layer, whose soil water content dramatically decreased from September through December 1992 (notice the TDR data at the 9.70 m downslope position), following the decrease in soil water content of the soil layer about 1 month previous to this time period (top portion of Fig. 8).

USEFULNESS OF STUDY AND FUTURE RESEARCH

The most practical comparisons among the four landfill cover designs for a semiarid region, in terms of their usefulness to the burial site operator, should be the overall performance comparison of the water balance parameters for the duration of this field study. Ultimately, the site operator wants a design for a specific slope and slope length that minimizes long-term runoff and seepage and maximizes interflow and

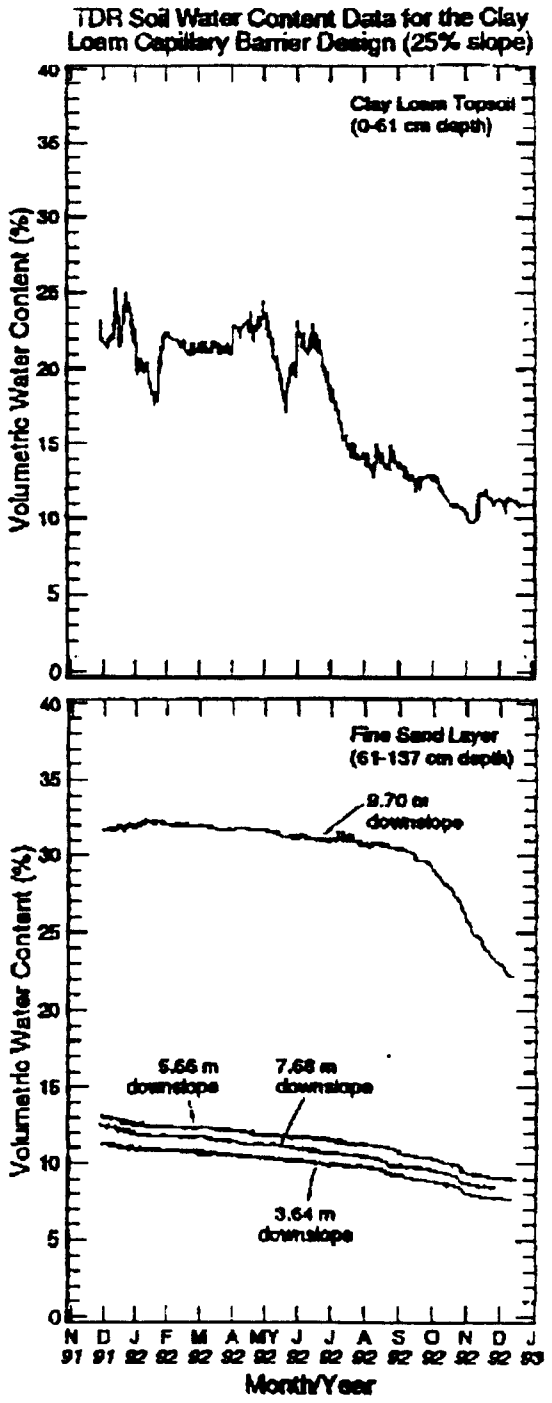

Fig. 8. TDR Soil Water Content Data Collected For the Clay Loam Capillary Barrier Landfill Cover Design With the 25% Dominant Downhill Slope At the Protective Barrier Landfill Cover Demonstration in Los Alamos, NM.

evapotranspiration. These water balance parameters are interdependent and need to be evaluated in the field using techniques and field data similar to those in this study.

Only 15 months of data is presented in this manuscript for this study, yet we are already struggling to keep up with data analysis. Many of the commonly used computer software programs and hardware do not have the capacities to handle such large data sets, so we are in the process of connecting our measurement systems for water flow and TDR to a local area net of computers to solve this problem. This will allow us to perform routine system diagnostic checks on our hydrologic sensors and to calculate water balance estimates on this entire data set. Once this is accomplished, we can evaluate important issues such as the time scale necessary to adequately describe a landfill cover design for waste management purposes. Coupled with this effort will be a major activity to develop field-calibrated hydrologic models that then can be used to evaluate future performance of the designs, such as the effect of a 100-year precipitation event on the design. The cost effectiveness and practicality of various designs can then be evaluated with the help of burial site operators and regulators, who will have major inputs into the selection of a final closure design for low-level radioactive and hazardous waste sites.

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