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Summary of Unconsolidated-Deposits Investigations at the UniFirst Property, Woburn, Massachusetts

September 2, 1994

Prepared For:
UniFirst Corporation

Submitted To:
U.S. Environmental Protection Agency
Region I

Prepared By:

Applied Groundwater Research Ltd.
and
Environmental Project Control, Inc.

SDMS Doc ID 547775

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September 2, 1994

Mary Garren
US EPA – Region I
Waste Management Division
JFK Federal Building (HRR-CAN3)
Boston, MA 02203-2211

RE: RD/RA of the Unconsolidated Deposits, UniFirst Corporation
Wells G&H Site, Woburn, Massachusetts
EPC Reference No.: 01.03/JTL.1030

Dear Mary,

Enclosed are two copies of the report titled *Summary of Unconsolidated Deposits Investigation at the UniFirst Property, Woburn, Massachusetts*. I have noted below those persons to whom I have also sent copies pursuant your instruction. On behalf of UniFirst, I look forward to your comments on this report and continuing to work with the EPA toward closure of this matter.

Please call me should you have any questions regarding the enclosed report.

Sincerely,

Jeffrey T. Lawson, P.G.
President

JTL/car

cc:
Paula Fitzsimmons (EPA)
Dick Willey (EPA)
Gretchen Muench (EPA)
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Deirdre Menoyo (GP&H)
Stan Feenstra (AGR)
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File: 01.03/74.12.00

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Executive Summary

Background

The UniFirst Property is one of the five Source Area Properties which are part of the Wells G & H Superfund Site in Woburn, Massachusetts. As part of the effort to identify and remediate contamination beneath its Property, UniFirst Corporation has conducted numerous investigations of conditions in the unconsolidated deposits and bedrock.

UniFirst has implemented the remedy for the groundwater, i.e., pumping and treatment of groundwater from well UC22. The remedy prescribed presently for the unconsolidated deposits is soil vapor extraction (SVE) as specified in the 1991 Explanation of Significant Differences (ESD). This report presents UniFirst's evaluation of this remedy.

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According to the regulatory decision and settlement documents concerning the remediation of the contaminated unconsolidated deposits, the sole goal for any such remedial efforts is the protection of groundwater. The cleanup level for contaminated unconsolidated deposits of 36.7 µg/kg PCE specified in the 1989 Record of Decision (ROD) was meant to reflect the concentration, that, if present in unconsolidated deposits, would leach to the groundwater and cause exceedance of the MCL for PCE (5 µg/L).

The ROD, the Consent Decree Statement of Work (SOW) and ESD all indicate that the remedy for the contaminated unconsolidated deposits at the UniFirst Property should commence at some appropriate time during operation of the groundwater remedial measures so as to avoid recontamination of the unconsolidated deposits by vapor migration from the groundwater.

At the time these decisions were made, several aspects of the Property conditions were uncertain. The location and mass of PCE in the unconsolidated deposits was not known. The relative contributions of the contamination in the unconsolidated deposits and the DNAPL in the bedrock to the groundwater contamination was not known. Also, it was not known how long significant groundwater contamination in the bedrock might persist.

Results of Recent Investigations

Detailed investigations conducted during 1992 through 1994 have led to the formulation of a comprehensive conceptual model for the nature and extent of PCE contamination in the unconsolidated deposits at the UniFirst Property. This conceptual model provides the basis for conclusions as to whether

remedial measures for the unconsolidated deposits are necessary to control the effects of the contamination present, and also provides the basis for the evaluation of prospective remedial measures.

The most important aspects of the site conditions are:

- There are two areas in which PCE was released to the ground surface: the waste-oil contamination area and the area to the south of the current loading dock.
- The release areas are small in lateral extent with the waste-oil contamination area measuring about 15 feet by 35 feet, and the current loading-dock area measuring about 20 feet by 35 feet.
- Evidence of residual DNAPL has been found only in small discontinuous zones within the release areas.
- The mass of PCE estimated to remain in the release areas is small, less than approximately one hundred pounds, a small fraction of the several thousand pounds or more likely present in the bedrock or other off-Property sources. REDACTED REDACTED REDACTED REDACTED
- The flux of PCE to the groundwater from the release areas is very small, 0.05 pounds/month or less, due to the small size of the release areas and the relatively low permeability of the unconsolidated deposits. The calculated PCE flux to the groundwater from the unconsolidated deposits is about 0.02 per cent to 0.2 per cent of the 25 to 30 pounds/month of PCE removed by the pumping of UC22.
- A zone of diffuse contamination extends from the east end of the Property measuring about 13,000 ft^2 in area. Low to moderate concentrations of PCE in this area result from vapor migration upward from the contaminated groundwater.
- The presence of DNAPL in the shallow bedrock is indicated by the findings in UC8. The magnitude of dissolved PCE concentrations and the persistence of high concentrations in UC22 indicate the presence of DNAPL in the deeper bedrock.
- Groundwater contamination is expected to persist indefinitely, decades or longer, because of the large mass of PCE estimated to exist in the bedrock, the presence of other off-Property sources, and the rate of removal by pumping of UC22. REDACTED

Benefit of Remediation of the Unconsolidated Deposits

It can now be concluded that groundwater contamination will persist for decades or longer because of the large mass of DNAPL in the bedrock and the other off-Property sources. Vapor migration upward from the contaminated groundwater will negate the effectiveness of remedial measures

implemented in the unconsolidated deposits while groundwater contamination persists beneath the Property.

The contribution of PCE from the unconsolidated deposits to the groundwater is negligible in comparison to the contribution from DNAPL present in the bedrock and other off-Property sources.

Because of these conditions, no measurable benefit in terms of groundwater protection could result from remediation of the unconsolidated deposits in the foreseeable future. In the event that restoration of the groundwater is achieved at some time in the distant future, it is possible that no further remediation would be required in the unconsolidated deposits in order to protect groundwater. Because the contribution of PCE to the groundwater from the unconsolidated deposits is estimated to be so small, the presence of a small mass of PCE in the unconsolidated deposits may not have any significant effect on potential drinking water supplies in the underlying groundwater.

Irrespective of whether any potential benefit with regard to groundwater protection could be derived from remediation of the unconsolidated deposits, the small size and shallow depth of the contaminated areas, the relatively low permeability, and the spatial variability in soil properties at the Property would severely limit the performance of most in situ treatment or removal remedies.

Feasibility of SVE

SVE was selected in the 1991 ESD at a time when there was little quantitative information on the distribution of contaminants or the physical properties of the unconsolidated deposits. Based on the understanding gained from the detailed investigations conducted during 1992 through 1994, the feasibility of SVE for remediation of the unconsolidated deposits at the UniFirst Property was assessed according to the remedy screening factors set out in EPA guidance.

Although the PCE at the UniFirst Property would be amenable to removal by SVE if only its physical and chemical properties were considered, almost all the factors related to soil characteristics and site characteristics at the UniFirst property will have a negative effect on the performance of SVE. The most significant of these factors are:

- the shallow depth of contamination in both the release areas and the zone of diffuse contamination;
- the small volume of contaminated unconsolidated deposits associated with the release areas;

- the low air permeability found generally in the unconsolidated deposits, and very low air permeability values found in the release areas; and REDACTED REDACTED REDACTED
- the extreme spatial variability in air permeability and contamination concentrations in the unconsolidated deposits.

SVE can never contribute to the protection of groundwater while contaminated groundwater persists and allows upward migration of vapors. It is unlikely that protection of groundwater could be achieved practicably by SVE, even if remediation of the unconsolidated deposits were to be required following restoration of the underlying contaminated groundwater at some time in the future. Other remedial technologies would likely be more cost effective than SVE for part or all of the contamination that might remain in the unconsolidated deposits at that time in the future.

As a result, it is concluded that further study of SVE by means of field pneumatic testing or pilot testing is not warranted. Neither pneumatic testing nor short duration SVE pilot testing could provide more definitive information on the factors most critical to the effectiveness of SVE, namely, the effect of slow diffusion of contaminants out of lower permeability zones, and the length of time that an SVE system would need to operate to achieve any specified cleanup target.

Alternate Cleanup Target

When the decisions outlined in the 1989 ROD and 1991 ESD were made, there was little information on the nature and extent of contamination in the unconsolidated deposits. At that time, there had been no indication of residual DNAPL in the unconsolidated deposits. Since then, the waste-oil-contamination release area was discovered and the contamination in the current loading-dock area has been delimited. PCE concentrations in samples of the unconsolidated deposits indicate discontinuous zones of residual DNAPL, but these areas are small in size, are at shallow depth, and are generously estimated to contain less than approximately one hundred pounds of PCE. In view of the finding of these release areas, it is appropriate to consider alternate soil cleanup targets intended to protect against exposures via other pathways.

UniFirst proposes to utilize the action level for PCE that the EPA has set out in the proposed RCRA rule titled "Corrective Action for Solid Waste Management Units (SWMUs) at Hazardous Waste Management Facilities," which, UniFirst understands, is currently being utilized in Region I. As the most stringent soil standard where groundwater protection is not at issue, the EPA proposed an "action level" for PCE concentrations in unconsolidated deposits of 10 mg/kg (10,000 µg/kg).

UniFirst proposes that a PCE concentration of 10 mg/kg (10,000 μg/kg) be applied as an alternate cleanup target for the unconsolidated deposits in order to protect against the risk of direct exposure to contamination close to the ground surface. The material that presently exceeds the alternate cleanup target is found only at shallow depth in the release areas. All PCE concentrations exceeding about 10,000 μg/kg are found in the waste-oil contamination area and the vicinity of the current loading dock. The volume of contaminated unconsolidated deposits in these areas is small, about 100 to 200 yd^3.

Cleanup to this alternate target would constitute a permanent remedy that would not be negated by the effect of vapor migration upward from the underlying contaminated groundwater. Evidence from the Property indicates that PCE contamination of the unconsolidated deposits by upward vapor migration from the groundwater should not exceed 10,000 μg/kg.

Cleanup to this alternate target would remove about 90 per cent of the less than approximately one hundred pounds of PCE estimated to be present in the unconsolidated deposits and would increase the likelihood that no further remediation of the unconsolidated deposits would be required to protect groundwater, at some time in the distant future if groundwater remediation were ever to be completed.

Alternate Remedial Measures

Remedial measures to achieve the alternate cleanup target will focus on the small volume of contaminated unconsolidated deposits found at shallow depth in the waste-oil contamination area and the vicinity of the current loading dock. Excavation is probably the most suitable technology for remediation in this situation. However, in situ oxidation by permanganate infiltration also deserves consideration because this in situ treatment technology may not be limited by geological variability to the same degree as technologies such as SVE.

For a cleanup target of 10,000 μg/kg, the implementation and costing of an excavation remedy can be well defined. UniFirst proposes to prepare a plan for implementation and preliminary costs for an excavation remedy.

The use of in situ oxidation of PCE in the unconsolidated deposits by infiltration with a solution of potassium permanganate may have advantages over other in situ removal or treatment technologies such as SVE because it may be less impaired by the effects of geological variability. In addition, in situ oxidation would not require shipment of contaminated soil off site for treatment or disposal.

As a first stage in the evaluation of permanganate infiltration, UniFirst proposes to assess the site conditions at the Property and information available from experimental testing of the technology in order to develop a conceptual remedial design and preliminary costing. The expected effectiveness of the technology and possible cost would then be compared to those of an excavation remedy.

1.0 Introduction

The UniFirst Property at 15 Olympia Avenue (Property) constitutes one of the five Source Area Properties, and is located in the north-central portion of the Wells G&H (Site), Woburn, Massachusetts (Figure 1-1). As part of the effort to delineate and remediate contamination beneath the Property, UniFirst Corporation has conducted numerous investigations of conditions in the unconsolidated deposits and bedrock. This report provides a summary of the pertinent history of the Property, including the investigations and the regulatory negotiations and agreements pertaining to contamination in the unconsolidated deposits. This historical summary provides the necessary context and background for the subsequent discussion that articulates UniFirst's opinions regarding the practicability and utility of attempting to remediate the unconsolidated deposits on the Property. In particular, the report presents UniFirst's position on the prognosis for soil-vapor extraction as a remedial action for the Property. As such, this report comprises the summary document requested by the EPA that is referenced in the July 21, 1994 letter from Deirdre Menoyo (UniFirst's counsel) to Paula Fitzsimmons (EPA).

This report is organized in three parts. In Part I of the document, Section 2.0 summarizes the relevant history of the site and the geological setting beneath the Property. It also recounts the chronology of regulatory events, negotiations, and decision documents pertaining to the unconsolidated deposits beneath the Property. This account includes, as requested by EPA, UniFirst's interpretation of the pertinent references in the relevant decision documents and their technical implications for remediation of the unconsolidated deposits.

Part II of the document reviews the investigative activities conducted on the Property and the development of the conceptual model for contamination beneath the Property. Section 3.0 sets forth a summary of all the data pertaining to the unconsolidated deposits generated by the on-Property investigations as well as a description of the tasks undertaken, and the findings of each of those investigations. Section 3.0 is organized chronologically and explains the relevance of each investigative phase at the Property to the gradual evolution of the current conceptual model. Section 4.0 describes the conceptual model for the nature and extent of contamination in the unconsolidated deposits. This conceptual model provides the essential basis for UniFirst's technical opinions regarding the practicability and utility of implementing remedial measures in the unconsolidated deposits beneath the Property.

Part III of the document contains a discussion of the evaluation of remedial measures in the unconsolidated deposits. Section 5.0 provides a description of the technical basis for UniFirst's conclusion that there is no practicable

application for SVE at the Property. Section 6.0 includes a description of potential alternative remedial goals and technologies. A summary of the main points made in the document and the stated conclusions is given in Section 7.0.

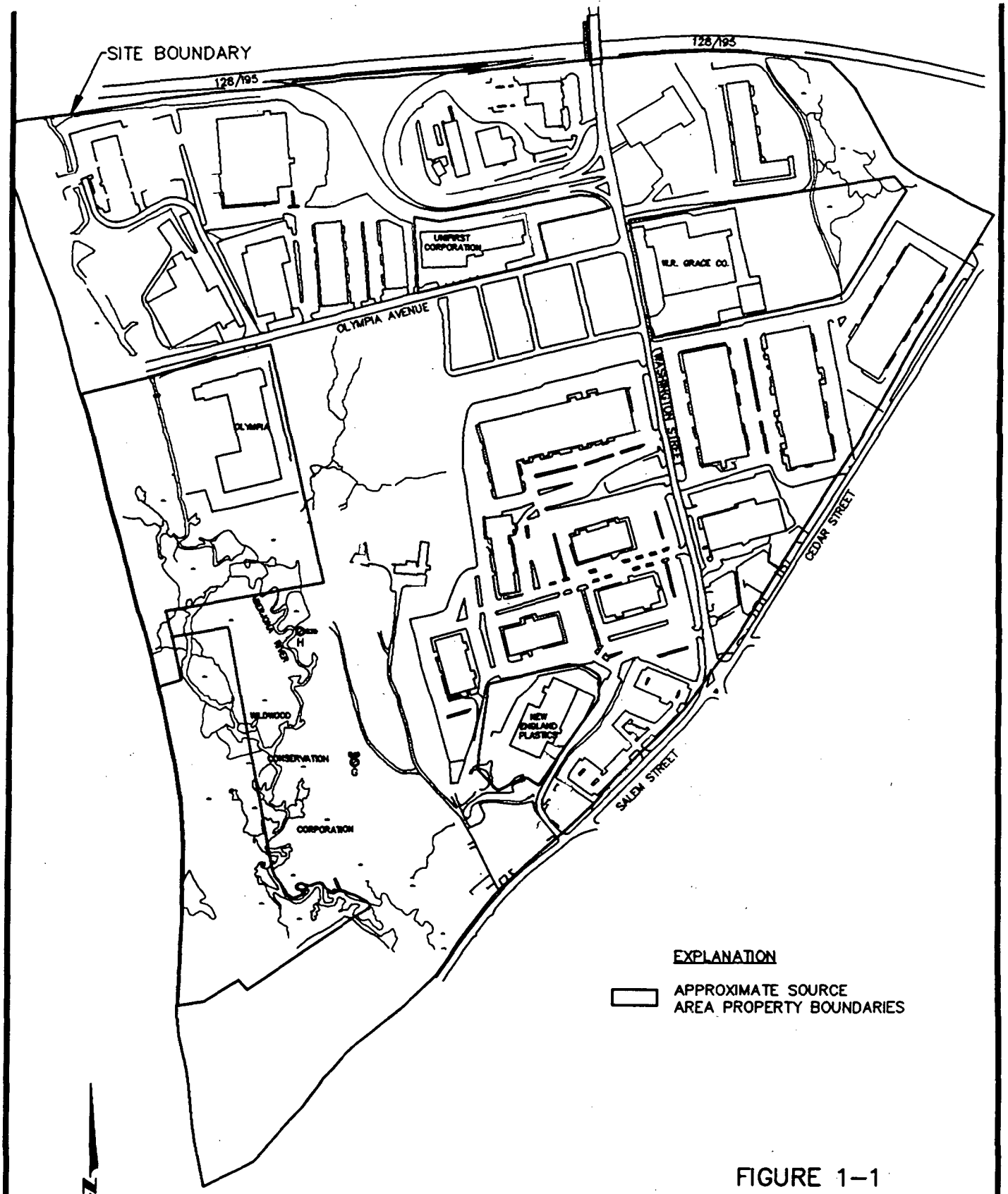

FIGURE 1-1

0 600 1200

SCALE IN FEET

REV. 1-11/12/92 UD-MAP 21 BY: FD		
ENSR CONSULTING & ENGINEERING		
WELLS G & H SITE MAP		
DRAWN BY:	DATE:	PROJECT NO.
FD	11/5/92	3140-023

314005A

2.0 Background

2.1 History of Site Use

Since 1983, UniFirst has researched the history of the use of the Property through interviews of its employees, review of numerous public—state and local—and company records and examination of available aerial photographs of the Property and surrounding areas. UniFirst has reported to the EPA historical information resulting from that research in a series of formal submittals that includes: *Assessment of Ground Water Contamination Potential of Interstate Uniform Service Company's Facility at Woburn, Massachusetts*, ERT, June 6, 1983; *Evaluation and Recommendations for Alternatives Concerning Additional Investigation of Ground-Water Contamination*, ERT, September 24, 1984; UniFirst's responses to the EPA's "104(e) requests" are contained in these letters—Ronald D. Croatti to Gwen Ruta, February 17, 1987, Ronald D. Croatti to Gwen Ruta, February 19, 1987, Jeffrey C. Bates to Gwen Ruta, February 25, 1987, Ronald D. Croatti to Barbara Newman, April 11, 1988; *Draft Remedial Design Investigation Report and Final Design*, Section 6, EPC, October 22, 1991; *Draft Pre-Design Work Plan*, Water Waste & Land, Inc., et al., November 13, 1992; *Analyses for Petroleum-Hydrocarbon Characterization of Unconsolidated Deposits, DNAPL and Bituminous Concrete from the UniFirst Property*, J.P.Maney and S.Feenstra, January 28, 1994.

This section recapitulates, from the extensively researched and reported site-use history of the Property, a chronology of those events which are noteworthy in light of the findings of the now eleven years of field investigations. In addition, this section describes the chronology of building construction. Figure 2-1, which is modified after the figure in ERT's 1983 report, illustrates the Property, discrete construction events and the locations of the structures referenced below.

Prior to the early 1950's, historical aerial photographs reveal that the Property was not actively used. Neighboring land uses, such as greenhouses, orchards and commercial businesses resulted in minor impacts on the Property, including surface disturbances, minor excavation and land clearing. The highway, Route 128 (Interstate 95), first appears to the north of the Property in an aerial photograph from 1954, which shows the original location of Route 128, and the Washington Street ramp and bridge.

In 1961 and 1962, the Massachusetts Department of Public Works (DPW) records show that the DPW widened Route 128 adjacent to the Property. This road construction included: the demolition of the old Washington Street bridge, re-alignment of Washington Street, widening of Route 128, and reconfiguration of the Washington Street exit ramp from Route 128, which abuts the northern boundary of the Property. DPW records and interviews with former DPW employees indicate that construction debris from this construction was disposed of in the ramp embankments of the Route 128 and Washington Street interchange. As described in

Section 3.3.4, evidence of this disposal practice was unearthed during the excavation of the influent-line trench from UC22 to the groundwater treatment plant.

From 1962 through 1965, no improvements were made on the Property. Historical aerial photographs for this interval, however, reveal a significant amount of surface disturbance, such as excavation, debris piling and surface staining. In particular, an aerial photograph taken in 1964 shows soil disturbances and what appears to be soil-stained areas emanating from the northeast corner of the Property to the south and west. The location and areal extent of this soil staining has been superimposed, via aerial photographic interpretation, onto a base map depicting the current land-use features of the Property, and is shown on Figure 2-2. This information, including the 1964 photograph, was provided to the EPA in the November 13, 1992 Pre-Design Work Plan. The discovery of contaminated unconsolidated deposits believed to be associated with this staining is discussed in section 3.3.4.

Building A, as depicted on Figure 2-1, was constructed in November 1965. This building and property were leased to Interstate Uniform Service Corporation (IUS, which changed its corporate name to UniFirst Corporation in 1986). An aerial photograph from 1966 shows Building A on the Property. The pavement configuration at that time extended in front of the building and as a narrow strip (one to two car widths) along the west and back sides of the building. The area immediately to the east of Building A was vacant.

The "Building B" addition was constructed in 1966. This addition is evident in a 1968 aerial photograph. Paved areas on the Property now extend in front of and behind the Building B addition. It is likely that this pavement corresponds to the buried pavement layer discovered at a depth of about one to two feet below the current surface pavement on the east end of the Property (see section 3.0 for additional discussion). In addition to completing construction of Building B in 1966, UniFirst installed two steel underground storage tanks. The tanks were used to store gasoline. REDACTED

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In 1970, UniFirst installed a third steel underground storage tank. This tank was used to store diesel fuel.

In 1978, IUS constructed a third building addition, "Building C," along the front of Building A.

Between approximately 1977 and 1982, IUS maintained a 5000-gallon indoor storage tank that was supported on two steel cradles above the concrete floor inside Building B at the east end of Building B. The tank was used principally to store PCE for occasional distribution to IUS' branch operations and retail launderers to take advantage of fluctuations in PCE wholesale costs. Small quantities (less than fifty gallons) of PCE at a time were reportedly pumped-off for distribution to IUS dry-cleaning plants at other locations. In addition, one load of TCA was reportedly

delivered to this tank. The fill pipe for the tank was located outside the building, within the former at-grade loading dock at the east end of the building.

In late 1979, a PCE spill of approximately 100 gallons of PCE occurred inside Building B. The spill reportedly occurred because a filter broke in the inlet line to the PCE storage tank. IUS personnel who were working near the tank at the time of the spill, immediately noticed the spill, and cleaned it up by placing garments on the floor to soak-up the PCE. The garments were put in barrels, placed in the breezeway in the loading dock, and shipped to IUS' Nashua, New Hampshire operation to recover the PCE. No PCE was reported to have exited the building via doors or other passage ways. In addition, no floor drains or weep holes existed in this portion of the building. The PCE was probably in contact with the floor for less than one hour. In either November 1982 or January/February 1983, the tank was permanently removed from the Property.

In the late 1970's, IUS completed the last major structural modification to the building. The loading dock at the east end of the property was upgraded and enclosed. This upgrade entailed transforming the loading dock from a ramped-down at-grade dock to an elevated and enclosed dock. Although no documentation is available, it is assumed that this construction event coincided with the construction of the second, upper layer of pavement at the current ground-surface grade in the northeast corner of the Property. In addition, the fill pipe to the above-ground, inside storage tank was relocated to its current position that is illustrated in Figure 2-1. As reported by ERT (1983), four areas of asphalt scarring, were visible in the area of the fill pipe. These scars were a few inches in diameter, and were believed to be attributable to small drips of solvents associated with transfer of solvents to the storage tank from truck tankers.

In 1986, UniFirst removed the two gasoline and diesel underground storage tanks. This work was supervised by ERT and inspected by the Woburn Fire Department and the DEP NERO. REDACTED

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In 1989, UniFirst Corporation ceased all business operations on the Property, and leased the Property to Woburn Storage Depot, Inc. The Storage Depot continues to lease the space. UniFirst continues to use the northeast corner of the building for housing and operation of the groundwater treatment plant, which is part of UniFirst's groundwater Remedial Action.

2.2 Site Description

The unconsolidated deposits beneath the Property consist of till and overlying artificial fill. Their total thickness varies considerably across the Property (Figure 2-3). In the northeast corner of the Property, bedrock is located at only a few feet below ground surface. The thickness of the unconsolidated deposits increases westward as the bedrock surface drops off towards the axis of a major bedrock valley underlying

the Aberjona River (Figure 1-1), and the unconsolidated deposits are at their thickest (approximately 75 feet) at the northwestern Property boundary.

With the exception of the narrow strip of land in the extreme northeast corner of the Property, where wells UC9, UC22, and UC23 are located (see Figure 2-3), the ground surface across almost the entire Property outside of the UniFirst building is paved. In the northeast corner of the Property, a second layer of pavement, associated with an earlier configuration of the UniFirst building (see Section 2.1), is located a foot or two below the current surface pavement. The parking-lot surface over Test Pits A, B, D and M and the UST removal areas has been restored by installation of "turfstone" pavement.

Beneath the eastern half of the Property, the till consists of a tan or brown to gray, poorly-sorted mixture of silt, sand, and gravel with boulders common, and has been referred to as an "ablation till" (Draft Pre-Design Work Plan, 1992). Locally (e.g., at UC8) a "lodgment till" unit approximately 1.5 feet thick overlies bedrock. The "lodgment till" is distinguished by its extreme density (e.g., 75 blows per 6 inches with a 300-pound hammer) and characteristic color and grain-size distribution (e.g., gray to green-gray, coarse to fine sand and gravel, little silt). The overlying artificial fill is generally described as a tan to brown sand and gravel with a minor silt-sized fraction. The contact of the till with overlying artificial fill is difficult to distinguish, likely because much of the artificial fill was derived from similar on-Property or local deposits. Beneath the western half of the Property, the ablation till is consistently underlain by a dense, gray to olive-green lodgment till which directly overlies bedrock. Bedrock underlying the Property is fractured crystalline rock of two distinct lithologies: pink and gray, granodiorite; and a dark, greenish-gray gabbrodiorite. The thickness of the unconsolidated-deposits units and the geologic sequence described above are illustrated on a series of cross sections that are aligned as illustrated on Figure 2.4. Cross sections A-A′ through E-E′ are included as Figures 2-5 through 2-9.

On the east end of the Property, where thirteen test pits have been excavated (eleven to the top of bedrock) and two bedrock borings have been cored, the nature of the bedrock surface was examined directly. In the vicinity of the east end of the UniFirst building, the contact between the unconsolidated deposits and bedrock is distinct and irregular. For example the bedrock (granodiorite) surface exposed in Test Pit A had approximately two feet of irregular relief. The surface and near-surface bedrock is generally slightly weathered (Core Logging Committee, 1978). That is, the joint faces are typically coated with what appear to be iron and other metallic oxides. In addition, calcium carbonate coatings are typical. The gabbrodiorite is often more weathered and fractured than the granodiorite. For example, the recesses in the granodiorite surface exposed in Test Pit A were capable of holding water without any noticeable leakage into the bedrock. The gabbrodiorite exposed in Pits C, D, and E, however, was medium to highly weathered—that is, slight discoloration extends from fracture planes through the greater part of the rock to friable with original texture mainly preserved (Core Logging Committee, 1978). The degree of weathering

of the gabbrodiorite appears to be local and decreases (i.e., the rock becomes more competent) quickly with depth. For example, the gabbrodiorite exposed in Test Pit M, which is adjacent to Test Pit D, was as closely to very closely (Core Logging Committee, 1978) fractured as that exposed in Test Pits C, D and E (approximately five to ten fractures per linear foot across the exposed surface), but only slightly weathered. Similarly, the boring for well UC8 encountered lodgment till directly overlying slightly weathered and highly fractured (RQD 16 per cent) gabbrodiorite. The granodiorite is similarly highly fractured. For example, the first two core runs in the boring for well UC5, which ran from 9.0 to 11.0 and 11.0 to 14.0 feet below ground surface, produced RQD of 0 per cent. The granodiorite, unlike the gabbrodiorite, was only slightly weathered near the bedrock surface at each location encountered. The joint dips are generally subvertical, but range in dip from 10° to 80°. The fractures in the bedrock (for both rock types) surface were typically filled with silt from the overlying till.

The photographs of the bedrock surfaces from Test Pits A and Test Pit E illustrate the difference in the closeness of jointing and the openness of the joints between the two bedrock types (Figures 2-10 and 2-11). Test Pit A manifests a granodiorite surface that is of high relief and slightly weathered, and the joints, although spaced at approximately 2 to 3 per foot, are relatively tight based on the puddling of water in the recesses. The gabbrodiorite surface depicted in Figure 2-11 (Test Pit E) is also of high relief, but it is moderately weathered and highly fractured. In addition, the joints in the surface gabbrodiorite appear open.

Generally, the bedrock surface in the vicinity of the east end of the Property is closely to very closely fractured, slightly to highly weathered and of high relief. In addition, the shallow bedrock cored borings for wells UC4, UC5 and UC8 manifest permeable jointing, as evidenced by the metallic oxide joint-face coatings, throughout their depth.

The water table in the unconsolidated deposits underlying the Property fluctuates seasonally approximately 4 feet with a water table depth between 10 and 14 feet below ground surface. Figures 2-12, 2-13 and 2-14 present cross sections A-A', B-B' and E-E' which show the range of water-table fluctuations between November 1992, a seasonal low, and May 1994, when water levels are seasonally high. Based on the data presented on these two cross sections of unconsolidated-deposit water-table wells as representative of seasonally high and low water tables, Figure 2-15 shows the area of saturation for the unconsolidated deposits beneath the Property. Figure 2-15 shows that the unconsolidated deposits beneath the eastern end of the Property remain unsaturated throughout the year. However, water levels in the shallow bedrock wells at the eastern end of the property (UC4, UC5, UC8, UC17 and UC20) have been measured above the bedrock surface. Currently, no monitoring wells are screened in the unconsolidated deposits adjacent to these shallow bedrock wells to determine if saturation occurs in the unconsolidated deposits when these shallow bedrock water levels are above the bedrock surface. In addition, these high water

levels also indicate that the groundwater pumping currently in progress at UC22 does not permanently dewater the shallow bedrock at the east end of the Property.

The general lateral direction of shallow groundwater flow within the unconsolidated deposits during nonpumping conditions is to the southwest as shown on Figure 2-16. As the second annual report regarding the UniFirst groundwater monitoring and capture system performance for the RD/RA will show, all areas of contaminated groundwater beneath the Property are apparently captured by the UC22 pumping well. In the report, UniFirst will recommend VOC monitoring to confirm if a reduction in VOC concentrations in the unconsolidated-deposits groundwater is occurring along the western boundary of the Property.

2.3 Chronology and Regulatory Framework

2.3.1 Introduction and Summary.

As a result of recent dispute-resolution discussions between the EPA and UniFirst, UniFirst agreed to provide this report and to include in this report a chronology of the genesis of SVE as the EPA's preferred remedial alternative for the unconsolidated deposits beneath the Property and the subsequent interactions between the EPA and UniFirst. The following chronology is organized in a regulatory framework. Therefore, the descriptions of events formally reference many of UniFirst's formal submittals, letters and presentations to the EPA and the EPA's formal documents and letters. To facilitate the reader's appreciation of the major points that are to be derived from the subsequent detailed sections, a summary is provided first.

In short, according to the decision documents, the sole goal for any remediation of the unconsolidated deposits beneath the Property is groundwater protection. Clean-up levels for volatile organic compounds (VOC) in unconsolidated deposits beneath the Property were meant to reflect concentrations which, if present in the unconsolidated deposits, might leach into groundwater, thereby causing exceedances of the relevant water quality standards, i.e., maximum contaminant levels (MCL). No other risks associated with soil contamination were identified at the Property. Further, the decision documents recognize that remediation of contaminated unconsolidated deposits must be sequenced to occur at an appropriate time after groundwater remediation has reduced the likelihood of recontamination of the unconsolidated deposits; they do not set forth any other mandate concerning the appropriate time to study or commence SVE.

SVE was first mentioned for the Property during negotiations in 1990 and was not subjected to appropriate feasibility studies for the Property before it was adopted as a remedial alternative in the Statement of Work (SOW) (incorporated by reference into the Wells G & H Consent Decree (the Consent Decree)). Although UniFirst

believes that the "appropriate time" for addressing soil contamination beneath the Property has not occurred, and will not occur in the foreseeable future, shortly after the Decree was lodged, at the EPA's request, UniFirst began evaluating the feasibility of implementing SVE at the Property. Continuously since then, as described in Section 3, UniFirst has performed numerous site-characterization and contaminant-distribution activities that led to the conclusions stated in this report. The following paragraphs recount the steps in the technical and regulatory dialogue between UniFirst and the EPA REDACTED REDACTED REDACTED REDACTED

2.3.2 January 1989: EPA's Proposed Remedial Action Plan. REDACTED REDACTED

In January 1989, EPA proposed a remedial action plan (RAP) affecting remediation of unconsolidated deposits at four of the five source area properties in the Wells G & H Site. The RAP called for excavation and incineration of certain unconsolidated deposits affected by VOC contamination, namely, an estimated 150 cubic yards of soil beneath the Property, believed to be contaminated by PCE in excess of 36.7 µg/kg. For the Property, the goal of this remedial approach was protecting groundwater from concentrations of tetrachloroethene (PCE) that might leach from the unconsolidated deposits and contaminate groundwater in excess of 5 µg/L, the MCL for PCE. For VOC found in unconsolidated deposits, the RAP stated that clean-up levels would be set based on consideration of the only exposure pathway found to pose a risk for VOC, that is, migration of contamination from unconsolidated deposits into the groundwater. (RAP pp. 7-8.) Although direct contact exposure pathways for certain other soil contaminants elsewhere on the Wells G & H Site were found to occasion unacceptable risks, no unacceptable risk was expected to result from direct contact with VOC in the unconsolidated deposits beneath the Property. REDACTED

2.3.3 March 1989: UniFirst Corporation's Comments on the Proposed Remedial Action Plan.

In response to the EPA's proposed plan to require incineration of unconsolidated deposits excavated from the Property, UniFirst submitted comments in a Technical Report authored by Dr. John Cherry and others in March 1989. The report concluded that the low to moderate concentrations of PCE found in shallow unconsolidated deposits beneath the Property were the result of upward vapor migration from contaminated groundwater. (Cherry et al., 1989 pp. 73-76). This conclusion was based largely on vapor-migration measurements beneath the Property, as explained in Section 3 below. Vapor-diffusion modeling further supported these findings. It was concluded that the concentrations of PCE found in shallow unconsolidated deposits "did not represent soil contaminated by past practices, but rather that the contamination is the result of upward vapor migration." (Cherry et al., p. 76)

2.3.4 September 1989: Record of Decision.

With an important modification based on UniFirst's comments, the EPA selected excavation and incineration as the remedy for the contaminated unconsolidated deposits beneath the Property, as well as other source areas, in the Record of Decision (ROD) issued in September 1989. (ROD pp. 31-32.) The EPA estimated that there were 150 cubic yards of PCE-contaminated unconsolidated deposits to be addressed beneath the Property. (ROD p. 32.) The ROD set forth "soil clean-up goals" for several VOC, including PCE, which were based on the paradigm that contamination in the unconsolidated deposits would leach into groundwater: "For volatile organic compounds detected in the soil and the groundwater, and which pose a substantial risk of exposure via groundwater, a leaching model was used to calculate a level in the soil that is protective of groundwater. These chemicals and their respective target soil concentrations are presented in Table 5." (ROD p. 29.) The "action level" or "target soil concentration" for PCE set forth in Table 5 is 36.7 µg/kg. A footnote to Table 5 in the ROD describes these levels as "Action levels based on the attainment of a target risk level in unconsolidated deposits which corresponds to the attainment of ARARs [applicable or relevant and appropriate requirements, i.e. MCLs] in groundwater." The 36.7 µg/kg goal was not meant to be rigid; the ROD anticipated that the actual fraction of organic carbon (foc) value would be used to modify volumes of unconsolidated deposits requiring remediation and clean-up goals as necessary. In direct response to UniFirst's comments in its 1989 Technical Report, the ROD states:

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> *Consideration will be given to the sequencing of the soil and groundwater components of the remedy to avoid recontamination of treated soil by volatilization of contaminated groundwater.* This is of special interest at the UniFirst property due to the presence of dense, non-aqueous phase liquids [DNAPLs] which have the potential to volatilize and recontaminate the soils.

(ROD p. 32.) (Emphasis added.) Thus, although the EPA retained the originally proposed remedy for unconsolidated deposits in the ROD, the EPA recognized that the presence of DNAPL in the bedrock beneath the Property made it essential for the EPA and UniFirst to consider sequencing remediation attempts for the unconsolidated deposits with remediation of the underlying ground water.

2.3.5 1990: Consent Decree Negotiations.

EPA first suggested that SVE be substituted for excavation and incineration of contaminated unconsolidated deposits beneath the Property in July 1990, during the final stages of the special-notice negotiations that resulted in a settlement in the early fall of 1990. UniFirst immediately objected because its scientists did not believe that vapor extraction from the unsaturated zone beneath the Property could usefully

abate contamination in the unconsolidated deposits as long as contamination persisted in the underlying groundwater. They believed that the high levels of contamination known to be present in the underlying groundwater would continuously and indefinitely recontaminate the unconsolidated deposits. During the negotiations, the EPA requested, and UniFirst provided, a memorandum explaining the technical basis for UniFirst's position. (S. Feenstra, Memorandum, July 31, 1990.) After recapitulating the investigation described in the 1989 Technical Report, which stated that contamination migrated upwards from the groundwater, UniFirst proposed the following remediation sequence:

1. Pump groundwater to control migration from the source area and retrieve contaminated groundwater from on-site areas;

2. When monitoring of groundwater quality in the site area indicates that groundwater quality has reached a concentration that will not cause recontamination of the unsaturated zone, begin vapor extraction from the unsaturated zone; and

3. When monitoring of unsaturated zone vapor indicates that remediation is complete, cease vapor extraction and continue extraction of groundwater.

At that time, Stanley Feenstra, UniFirst's lead scientist for this matter, performed one-dimensional vapor-transport modeling to estimate the maximum PCE concentration in the groundwater which would not be expected to cause recontamination of shallow unconsolidated deposits to levels that would exceed the clean-up standard. The preliminary results of that modeling, as reported in the technical memorandum, indicated that PCE in the groundwater would have to be reduced to a concentration of less than about 85 µg/L to avoid recontamination of unsaturated unconsolidated deposits to concentrations above the clean-up standard; this concentration came to be referred to, during these negotiations, as "Feenstra's Number." It was hoped that changes in concentrations in groundwater pumped from UC22 (to be tested later that year) might provide an estimate of the time required to achieve that concentration. (Unfortunately, as will be described in Section 4, after almost two years of operating the UC22 extraction and treatment system, the PCE concentrations in the groundwater pumped from UC22 have remained constant at approximately 1,500 µg/L. The groundwater concentrations in the influent to UC22 are not expected to reach Feenstra's Number in the foreseeable future, i.e., for decades or more.)

2.3.6 Consent Decree Statement of Work.

The Statement of Work (SOW), which was incorporated by reference into the settlement Consent Decree, calls for use of SVE at the Property to attain a clean-up level for PCE of 36.7 µg/kg based on the leaching model. (SOW pp. 5-6.) The SOW indicates that the soil clean-up level could be modified based on site-specific data:

"the clean-up level may be modified based on revised input to the leaching model used in the Feasibility Study incorporating measured soil properties derived from the Source Area properties." (SOW p. 5.) Because the feasibility of implementing SVE on the Property was not evaluated as a remedial alternative for the Property prior to its selection as the remedy for the contaminated unconsolidated deposits, the SOW called for "a pilot scale test for in-situ volatilization to insure effectiveness and optimization of the extraction systems and the emission treatment systems." (SOW p. 15.) It explains: "The results of these studies shall determine, at a minimum, the exact location and depth of extraction wells, sizing, efficiency of the emissions treatment systems, effectiveness of achieving clean-up levels, and ability to meet ARARs." (SOW p. 15.) In consideration of UniFirst's position during negotiations that clean-up of the contaminated unconsolidated deposits should not be undertaken at the Property until groundwater ceases to contaminate the overlying unconsolidated deposits, the SOW also calls for *"a study that evaluates the optimum sequencing of groundwater and soil treatment at each Source Area property in order to optimize total contaminant removal, and to avoid recontaminating with contaminated groundwater or volatilization of contamination in the groundwater."* (SOW p. 17.) (Emphasis added.)

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The unconventional manner in which SVE was nominated to replace soil excavation and incineration without initial screening or feasibility consideration has resulted in confusion as to the nature of UniFirst's commitments under the Consent Decree. Any undertaking by UniFirst as to remediation of the unconsolidated deposits on the Property must be understood to be conditioned on two findings: (1) that SVE would be feasible and (2) that SVE would, at some later time, serve to protect groundwater.

2.3.7 December 21, 1990: Letter from EPC to EPA.

In late 1990, in response to a request by Barbara Newman, Timothy Cosgrave of EPC forwarded to EPA the field and laboratory data supporting the position taken by UniFirst in the July 31, 1990 letter.

2.3.8 April 1991: Explanation of Significant Differences.

In April, 1991, more than half a year after negotiations were concluded, the EPA issued an Explanation of Significant Differences (ESD) which identified the replacement of incineration of contaminated unconsolidated deposits beneath the Property with in-situ volatilization (SVE) as a "significant change." The ESD explained that "[a] review of recently gathered data on the UniFirst property shows that the soil on the UniFirst property is, in part, being recontaminated by the upward migration of VOC vapors from the highly contaminated groundwater beneath the pavement of the UniFirst property. In-situ volatilization . . . can be applied *at an appropriate point* during groundwater remediation . . . ." (ESD pp. 3-4.)

(Emphasis added.) Thus, the language of the ESD reaffirms the reasoning presented on behalf of UniFirst during negotiations of the Consent Decree SOW to the effect that only after groundwater concentrations were low enough so that the groundwater would no longer constitute a threat to recontaminate the soil, i.e., only when Feenstra's Number were to be achieved, might the time be appropriate to implement in-situ volatilization. REDACTED

2.3.9 Summary of Decision Documents and Agreements.

In sum, according to the ROD, the Consent Decree SOW, and the ESD, the 36.7 µg/kg PCE soil clean-up level for contaminated unconsolidated deposits at the Property was adopted solely to protect groundwater. These documents confirm that the remedy of the contaminated unconsolidated deposits should be implemented at some time after the groundwater remedy had progressed sufficiently to avoid recontamination of the unconsolidated deposits. None of these documents contains any requirement to perform SVE if infeasible, nor do they set any other mandate for the time to commence SVE. REDACTED

2.3.10 September 1991: Negotiations.

At a September 17, 1991 meeting of technical representatives and counsel for EPA and UniFirst, UniFirst and EPA recognized that the Consent Decree SOW did not provide a mechanism for "Design" for RD/RA for the unconsolidated deposits beneath the Property. It was noted that Section VII.D of the Consent Decree SOW, which requires preparation of a Pre-Design Work Plan is, in effect, "preempted" by the 1988 Administrative Order on Consent (AOC) previously entered by the parties. (SOW p. 1.) Despite this discrepancy, and although UniFirst did not believe that the "appropriate time" to evaluate the feasibility and potential effectiveness of SVE for the soils at the Property had occurred, UniFirst nonetheless agreed at this meeting to present remedial hypotheses for the unconsolidated deposits as a section of the October 22, 1991 *Remedial Design Investigation Report* for groundwater that was planned to be submitted under the AOC.

2.3.11 October 22, 1991: *Draft Remedial Design and Investigation Report and Final Design*: Chapter 6, Appendix Q.

As promised, UniFirst presented a conceptual model and remedial hypotheses for the unconsolidated deposits beneath the Property in the *Draft Remedial Design Investigation Report* (RDI Report) which was submitted on October 22, 1991. Chapter 6 of that report concludes that "[t]he source of soil contamination and the nature of the unconsolidated deposits render soil vapor extraction inefficient, and, if at all appropriate, limited to a strict sequencing of implementation." (RDI Report p. 6-10.) UniFirst reported in Section 6 that, based on then available information, two highly

experienced vendors of SVE equipment, Vapex and Terra Vac, had informed UniFirst that if SVE were implemented, they would anticipate "a very short 'puff' of elevated vapor concentrations that would be followed by extremely low-level concentrations that would be sustained and governed by the rate of diffusion of compounds from the dissolved state within bedrock fractures across the limited cross-sectional area defined by the intersection of the bedrock joints and fractures with the overlying unsaturated, unconsolidated deposits." (RDI Report, p. 6-10.)

In this submission, UniFirst proposed to test a sequenced remedial approach that might actually be more aggressive than SVE and that might actually mitigate the phenomenon of contaminated groundwater recontaminating the unconsolidated deposits. Specifically, UniFirst proposed to use infiltration of water through the unconsolidated deposits until the 85 µg/L steady state groundwater concentration calculated by Mr. Feenstra was achieved in groundwater. UniFirst proposed to pump treated water through porous pipe galleries within the area in which unconsolidated deposits affected by concentrations over the action level had been encountered. It was anticipated that, as infiltration proceeded, "contaminants in the unconsolidated deposits would be flushed downward into the groundwater and diffusion of additional contaminants from the source and the contaminated groundwater would be prevented from diffusing upward." Questions about the then-unknown (but now confirmed, see Section 2.2 above) ability of the UC22 extraction well to capture all shallow, and thus all infiltrated water, led the EPA to ask for further assessment of this remedial alternative.

2.3.12 February 1992: Engagement of Dr. McWhorter; November 13, 1992: *Pre-Design Work Plan Remedial Design and Remedial Action for the Unconsolidated Deposits beneath the UniFirst Property* (1992 Pre-Design Work Plan); Force Majeure Letter.

In response to the EPA's and UniFirst's mutual concerns about the viability of infiltration for the Property, in February 1992, UniFirst retained Dr. David McWhorter, an expert on remediation of unconsolidated deposits, to work with Dr. Cherry to evaluate the potential applicability of both SVE and infiltration at the Property and to recommend an approach to respond to the EPA's and UniFirst's concerns. Drs. McWhorter and Cherry were asked to determine whether the 36.7µg/kg clean-up goal would be achievable by either infiltration or SVE. Dr. McWhorter's investigations included: a literature and file review; soil moisture content tests; hydraulic conductivity analyses; establishing the fraction of organic carbon ("foc"); testing of PCE concentrations by vapor probes; soil borings; test pits; and bedrock-surface observations in the bottom of test pits. He also compared methanol preservation to the EPA's standard methodology for VOC analysis of unconsolidated deposit samples. Coincidentally, as described in section 3.3 below, shortly after Dr. McWhorter's field investigations were completed, an area of previously undetected contamination, consisting of waste oil containing PCE, petroleum products and polynucleararomatic hydrocarbons (PAH), was discovered

on August 31, 1992, during excavation to install the influent pipe and utility conduits from well UC22 to the groundwater treatment plant. This information was taken into account in Dr. McWhorter's conclusions.

Dr. McWhorter presented his calculations and interpretations in the November 1992 *Pre-Design Work Plan* (1992 Work Plan). Dr. McWhorter's findings were: (1) the clean-up level for PCE of 36.7 µg/kg, which was originally derived from a leaching model and assumed higher foc than actually measured foc, is too high, based solely on that original approach to the leaching calculation; (2) not even the 36.7 µg/kg clean-up goal is achievable or measurable; and (3) the presence of waste-oil contamination containing PAH further complicates the situation because the presence of these compounds would impair the effectiveness of SVE, even if SVE were otherwise viable. (1992 Work Plan pp. 3-46 to 3-54, 5-1 to 5-4.)

In its November 13 transmittal letter of the 1992 Work Plan, UniFirst notified EPA that a force majeure event had occurred. Referring to Dr. McWhorter's findings, and knowing that UniFirst could neither achieve the clean-up level nor even successfully measure that level, UniFirst's project coordinator, Mr. Jeffrey Lawson, advised the EPA that UniFirst "will be unable to perform remediation of the unconsolidated deposits on the Property according to technology set forth in the ESD and the Decree" due to "causes beyond the control of UniFirst".

2.3.13 March 30, 1993: U.S. EPA Letter to Mr. Lawson.

In March 1993, Ms. Newman forwarded comments received by the EPA from Dr. Ryan DuPont concerning the 1992 Pre-Design Work Plan, at the same time objecting to UniFirst's notice of force majeure. Ms. Newman asserted that "it is clear to the reviewers of the above work plan, EPA, DEP, Ebasco, Pine & Swallow, and Dr. DuPont that it is certainly premature to claim that there are causes 'beyond your control' which prevent your preceding with pre-design work for in-situ volatilization." (Dr. DuPont's and Pine & Swallow's comments were provided to UniFirst.) She further stated: "The agency feels that there is insufficient site data to indicate that SVE would not be effective in achieving the goals of the Consent Decree" and asked for the following additional studies:

1. Source area characterization of the overburden to determine lateral and vertical extent, and concentrations of contamination including beneath the building;

2. Dynamic tests such as field scale in-situ permeability test, and identification of the nature of vapor migration using multi-level probes;

3. Based on information from 1 & 2 above, a Feasibility Study that looks at time vs. effectiveness issues for SVE.

2.3.14 April 14, 1993: UniFirst Letter Deferring Notice of Force Majeure and Dispute Resolution.

Responding to Ms. Newman's letter by a letter dated April 14, 1994, UniFirst's attorney, Jeffrey C. Bates, advised the EPA's attorney, Gretchen Muench, that "[i]n the spirit of cooperation that has characterized the working relations among the parties," UniFirst would defer to EPA's determination and would perform further investigations, hoping to achieve consensus. Accordingly, UniFirst did not, at this time, give notice to the EPA of the existence of a dispute.

2.3.15 July 12, 1993: U.S. EPA Letter to Mr. Lawson from Ms. Fitzsimmons.

Following a technical team meeting on May 7, 1993, attended by Drs. Cherry and McWhorter and Mr. Feenstra, as well as a smaller follow-up meeting involving attorneys on June 30, the EPA acknowledged UniFirst's doubts as to the need for, and practicability of, the use of SVE to remediate the unconsolidated deposits at its property. Ms. Paula Fitzsimmons stated in her July 12, 1993 letter to Mr. Lawson: "EPA appreciates your concern regarding possible limitations of the technology and the uncertainty inherent in its ability to achieve the clean-up levels specified in the Record of Decision." Reiterating the three tasks that Barbara Newman had mentioned in her March letter, she stated: "If the results of the pilot are not promising, EPA remains willing to discuss the practicability of SVE at the Property upon the completion of this additional pre-design work."

2.3.16 October 28, 1993: Letter to Mary Garren from Jeff Lawson.

In response to Ms. Fitzsimmons letter, UniFirst agreed to undertake further investigations. Specifically, UniFirst agreed to perform further studies to address Ms. Fitzsimmons' first concern, source-area characterization. UniFirst wanted to refine its knowledge about the nature and extent of contamination in order to find a location at which it might make sense to perform the second requested item, a permeability test. Responding to Ms. Fitzsimmons' letter, Mr. Lawson outlined tasks that UniFirst would undertake "in the spirit of continued cooperation." He also presented a schedule for field work and for submitting reports. The letter described several tasks that UniFirst planned to perform (and has performed) to refine its understanding of the nature and extent of contamination in the unconsolidated deposits, and its effect, if any, on shallow ground water. These tasks include: excavation and inspection of test pits; soil borings; shallow well installations; analyses of physical and chemical characteristics of unconsolidated deposits samples; and chemical analyses of groundwater. The letter also proposed that an in-situ permeability test would follow the completion and review of the excavation, boring, and well installation program. The test was to be located "based on the results of the source-area characterization so as to be representative of the type of setting in which

SVE might be focused." The letter set forth a schedule committing UniFirst to submit a full report on the source definition part of the project to the EPA in August, 1994. Having performed the source characterization investigations proposed in October 1993, UniFirst informed the EPA of the findings of the investigations by submitting interim reports on January 28, 1994, March 11, 1994, and June 13, 1994 and this final report.

2.3.17 March 17, 1994: Letter from Ms. Garren to Mr. Lawson.

By a letter dated March 1, 1994, Ms. Garren responded to UniFirst's interim data reports. Ms. Garren expressed uncertainty as to the relevance of the interim data reports to the remedial design for the unconsolidated deposits on the Property. She also expressed concern that UniFirst's schedule would not permit performance of an SVE pilot test in 1994.

2.3.18 April 29, 1994: Letter from Mr. Feenstra to Ms. Garren Regarding Evaluation of SVE—Clarification to EPA, UniFirst Property.

By a letter dated April 29, 1994, Mr. Feenstra responded to Ms. Garren's letter on behalf of UniFirst. After reviewing the schedule according to which UniFirst had been proceeding since October with no comment from the EPA, he provided a revised "working conceptual model" based on the new data. He also explained the relevance of the data to the source-area characterization exercise in which UniFirst was engaged.

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2.3.19 June 13, 1994: Meeting and Presentation by Mr. Feenstra; Issuance of Stop Work Order.

At a June 13, 1994 meeting with EPA's technical representatives, as requested by the EPA, Mr. Feenstra presented his conclusions. The conclusions are discussed in detail in Section 4. According to Mr. Feenstra, based on the various site investigations UniFirst has performed in the unconsolidated deposits, there is no location at which it would be appropriate to perform either a pneumatic permeability test or a pilot test.

At the June 13 meeting, Ms. Garren hand-delivered to Mr. Lawson a letter which directed UniFirst "to cease all field work at the site associated with the investigation of the unconsolidated deposits." The letter ordered UniFirst to continue monitoring groundwater as usual and to submit, within fourteen days, "a workplan proposing dynamic tests, such as field-scale in-situ permeability tests," and within thirty days of completion of the permeability test, "a workplan detailing a feasibility study, namely a pilot test, that examines the time versus effectiveness for remediation of the unconsolidated deposits using SVE."

2.3.20 Dispute Resolution.

On June 21, 1994, counsel and project managers for UniFirst and the EPA met to discuss the status of the remedial design for the unconsolidated deposits on the Property. On June 27, 1994, Mr. Lawson submitted on UniFirst's behalf, a work plan for the pneumatic permeability test and, at the same time, revived UniFirst's notice of the existence of force majeure conditions. By a June 27, 1994 letter to the EPA's attorney Gretchen Muench, Mr. Bates invoked the dispute resolution provisions of Section XX of the Consent Decree, stating that UniFirst disputed "the lawfulness, timing, appropriateness, necessity and reasonableness of assertions and directives contained in the June 13, 1994 letter."

Authorized by attorney Muench to communicate directly, Ms. Fitzsimmons and Deirdre Menoyo, UniFirst's assistant counsel, negotiated a resolution to the dispute, which was memorialized in a July 21, 1994 letter from Ms. Menoyo to Ms. Fitzsimmons. The resolution provided that, in lieu of further compliance with the EPA's June 13, 1994 directives, UniFirst would submit this report to EPA on or about August 31, 1994. It was agreed that the report would include: a comprehensive presentation and interpretation of all the data concerning the unconsolidated deposits beneath the Property that UniFirst had previously presented in interim reports; an explanation and justification of the conclusions concerning the need for, and the viability of, implementing SVE on the Property; a summary of UniFirst's interpretation of the references in the relevant decision documents to soil remediation; and a proposal to address any significant risks posed by contaminants remaining in the unconsolidated deposits beneath the Property, including an evaluation of the potential for infiltration of potassium permanganate as an alternative to SVE. Ms. Menoyo noted that, as to the infiltration technology, UniFirst's consultants had not concluded one way or the other whether the potassium permanganate infiltration technology may be potentially useful at the Property, but that, in any event, UniFirst hoped to be able to propose remediation of soil concentrations of PCE to 10 mg/kg, based on the rationale provided by the EPA's proposed corrective action rule, as a conservative cleanup level meant to protect endpoints other than groundwater.

This report is submitted in satisfaction of UniFirst's undertakings as conveyed by Ms. Menoyo.

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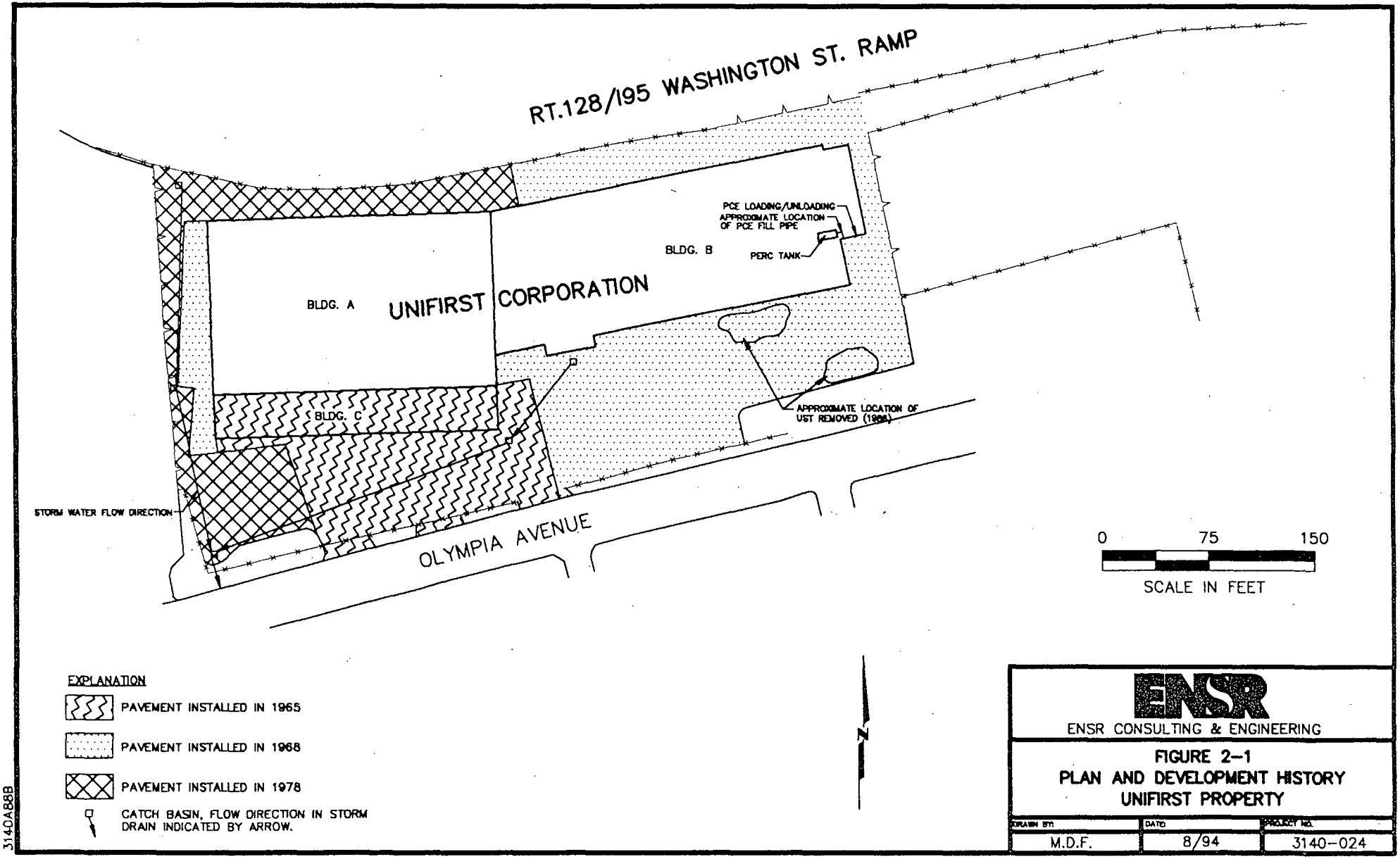
RT.128/195 WASHINGTON ST. RAMP
PCE LOADING/UNLOADING
APPROXIMATE LOCATION OF PCE FILL PIPE
PERC TANK
BLDG. B
BLDG. A
UNIFIRST CORPORATION
BLDG. C
APPROXIMATE LOCATION OF UST REMOVED (1988)
STORM WATER FLOW DIRECTION
OLYMPIA AVENUE
0
75
150
SCALE IN FEET
EXPLANATION
PAVEMENT INSTALLED IN 1965
PAVEMENT INSTALLED IN 1968
PAVEMENT INSTALLED IN 1978
CATCH BASIN, FLOW DIRECTION IN STORM DRAIN INDICATED BY ARROW.
N
ENSR
ENSR CONSULTING & ENGINEERING
FIGURE 2-1
PLAN AND DEVELOPMENT HISTORY
UNIFIRST PROPERTY
DRAWN BY:
M.D.F.
DATE:
8/94
PROJECT NO.
3140-024
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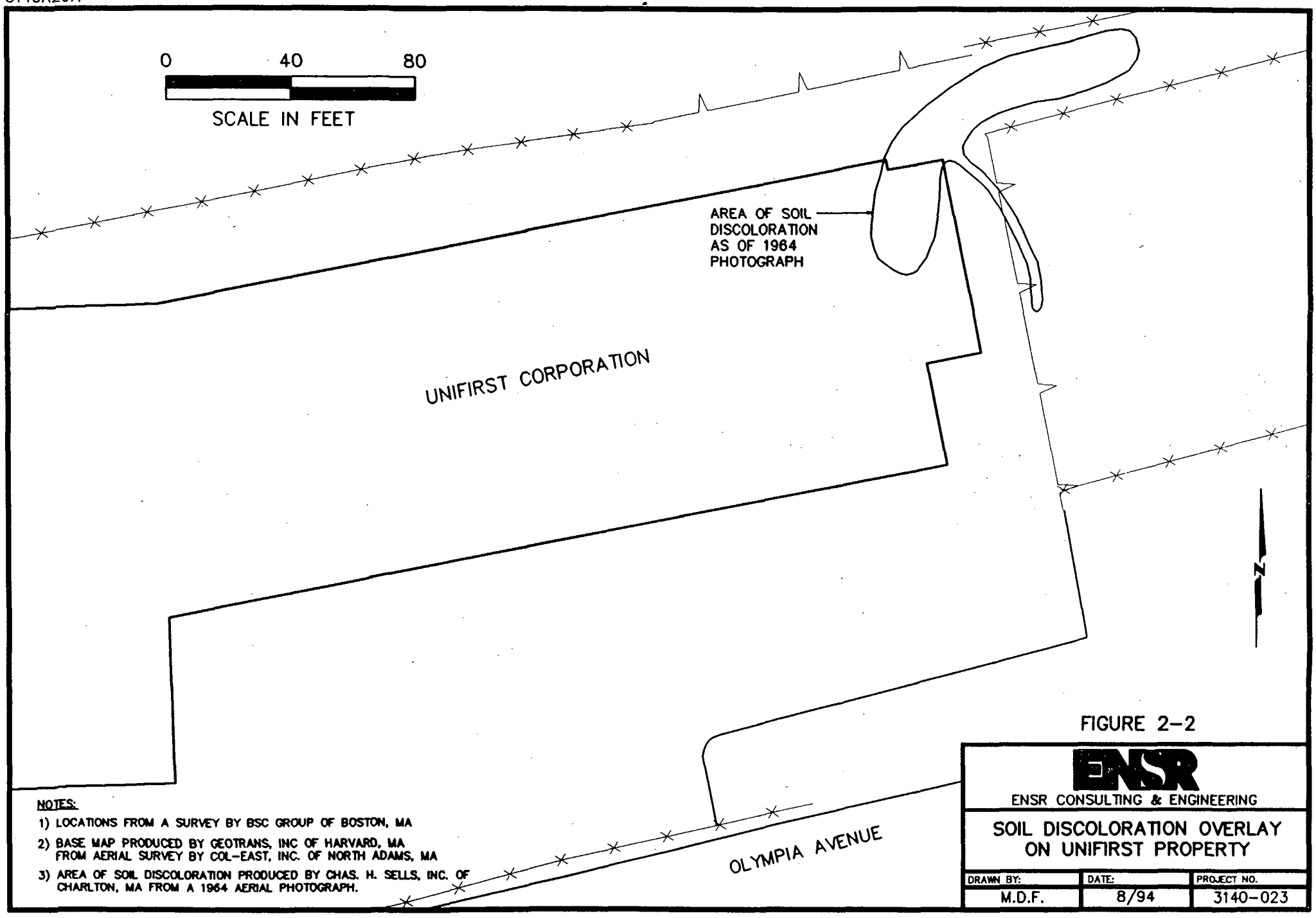
3140A29A



NOTES:

1) LOCATIONS FROM A SURVEY BY BSC GROUP OF BOSTON, MA
2) BASE MAP PRODUCED BY GEOTRANS, INC OF HARVARD, MA FROM AERIAL SURVEY BY COL-EAST, INC. OF NORTH ADAMS, MA
3) AREA OF SOIL DISCOLORATION PRODUCED BY CHAS. H. SELLS, INC. OF CHARLTON, MA FROM A 1964 AERIAL PHOTOGRAPH.

FIGURE 2-2

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SOIL DISCOLORATION OVERLAY ON UNIFIRST PROPERTY

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M.D.F.	8/94	3140-023

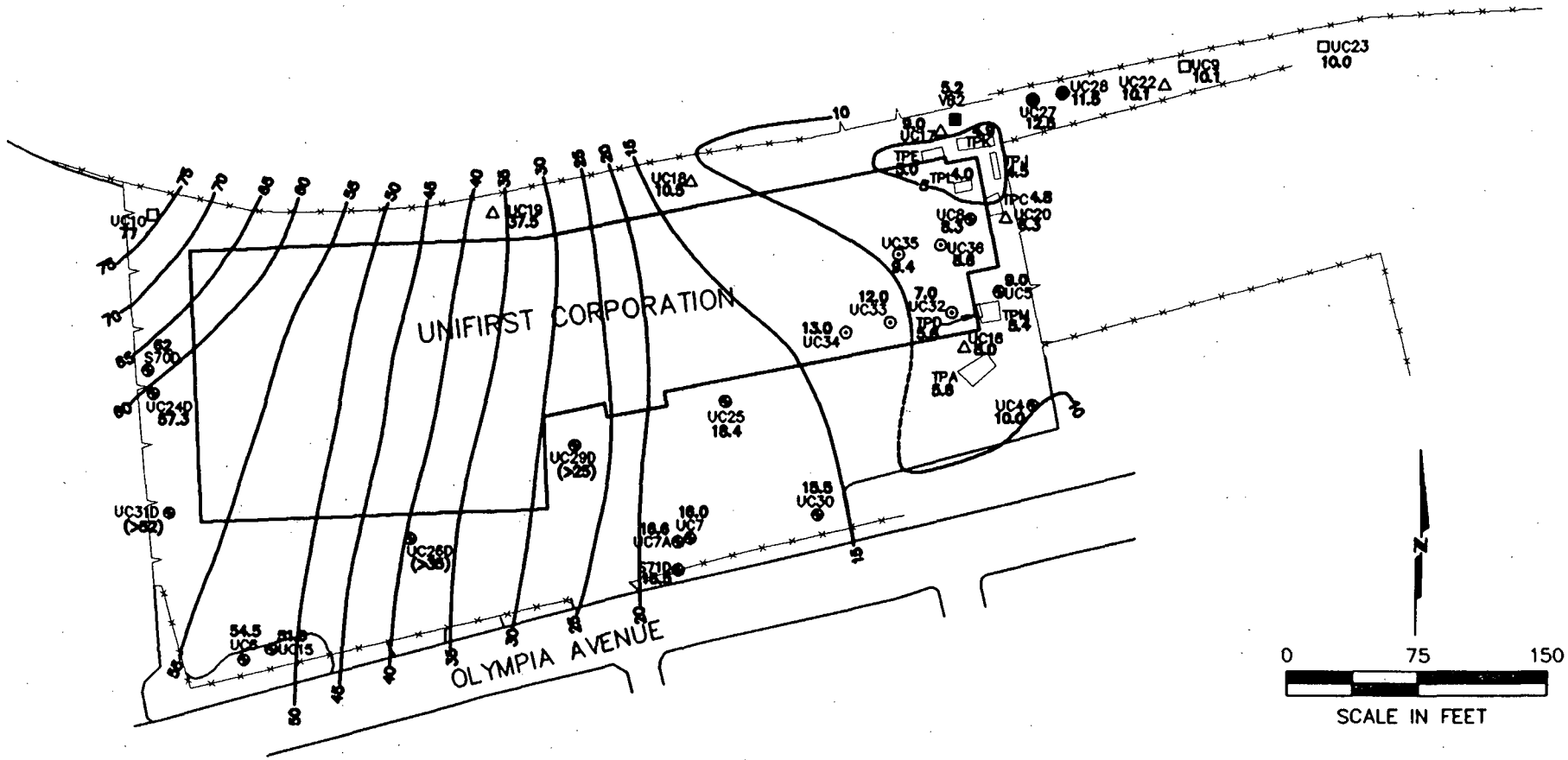

FIGURE 2-3

EXPLANATION

- TPR — TEST PIT
- □ MULTI-LEVEL BEDROCK MONITORING WELL
- ● SOIL BORING
- ⊙ 1 INCH MONITORING WELL
- ⊕ 2 INCH MONITORING WELL, S70 AND S71 ARE 1.5 INCH
- ■ VAPOR BORING (WINTER 1989)
- △ 6-INCH WELL OPEN IN ROCK; UC22 IS AN 8-INCH WELL
- • APPROXIMATE LOCATION

NOTES:

1) LOCATIONS FROM A SURVEY BY BSC GROUP OF BOSTON, MA.
2) WELL TYPES FROM DRAWINGS BY ENSR CONSULTING & ENGINEERING
3) BASE MAP PRODUCED BY GEOTRANS, INC OF HARVARD, MA FROM AERIAL SURVEY BY COL-EAST, INC. OF NORTH ADAMS, MA.

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ISOPACH OF UNCONSOLIDATED DEPOSITS UNIFIRST PROPERTY (THICKNESS IN FEET)

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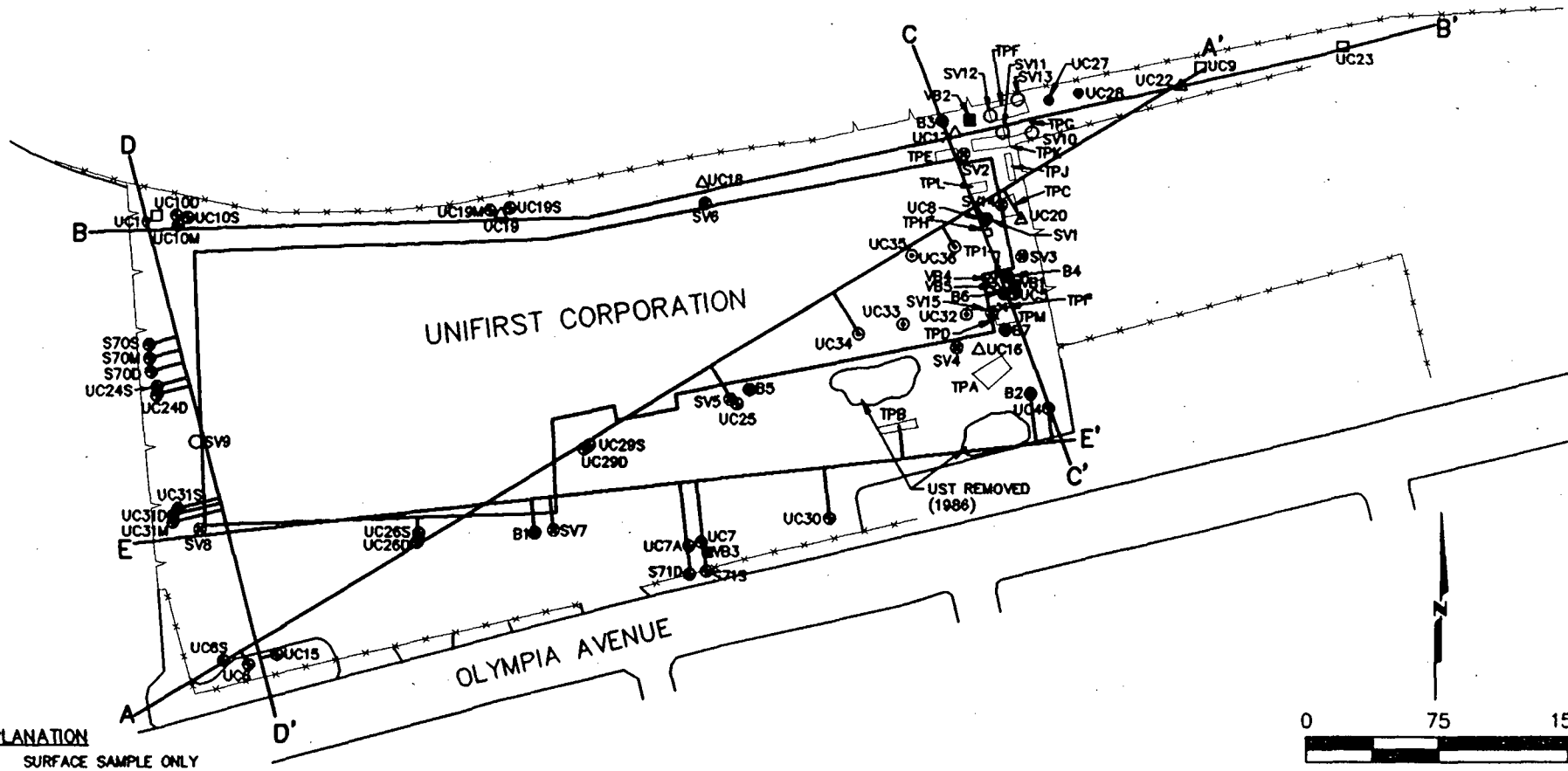

EXPLANATION

- × SURFACE SAMPLE ONLY
- TPB TEST PIT
- □ MULTI-LEVEL BEDROCK MONITORING WELL
- ● SOIL BORING
- ⊗ DRIVE POINT VAPOR PROBE LOCATION
- ○ FORMER DRIVE POINT VAPOR PROBE LOCATION
- ⊕ 2 INCH MONITORING WELL, S70 AND S71 ARE 1.5 INCH
- ■ VAPOR BORING (WINTER 1989)
- △ 6-INCH WELL OPEN IN ROCK; UC22 IS AN 8-INCH WELL
- ⊙ 1 INCH MONITORING WELL
- • APPROXIMATE LOCATION

NOTES:

1) LOCATIONS FROM A SURVEY BY BSC GROUP OF BOSTON, MA.
2) WELL TYPES FROM DRAWINGS BY ENSR CONSULTING & ENGINEERING
3) BASE MAP PRODUCED BY GEOTRANS, INC OF HARVARD, MA FROM AERIAL SURVEY BY COL-EAST, INC. OF NORTH ADAMS, MA.

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FIGURE 2-4
CROSS-SECTION ALIGNMENT MAP
UNIFIRST PROPERTY

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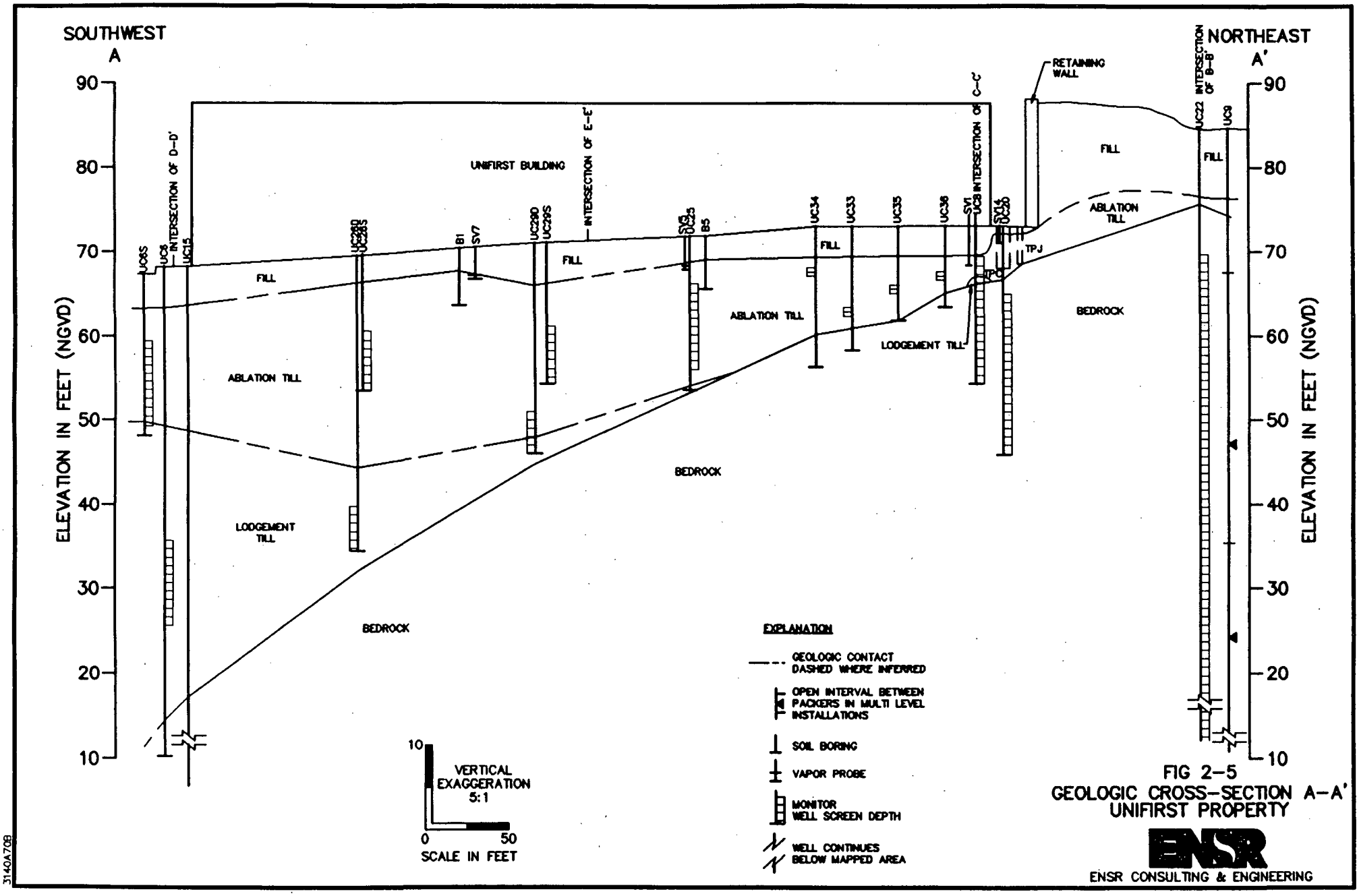

FIG 2-5
GEOLOGIC CROSS-SECTION A-A'
UNIFIRST PROPERTY

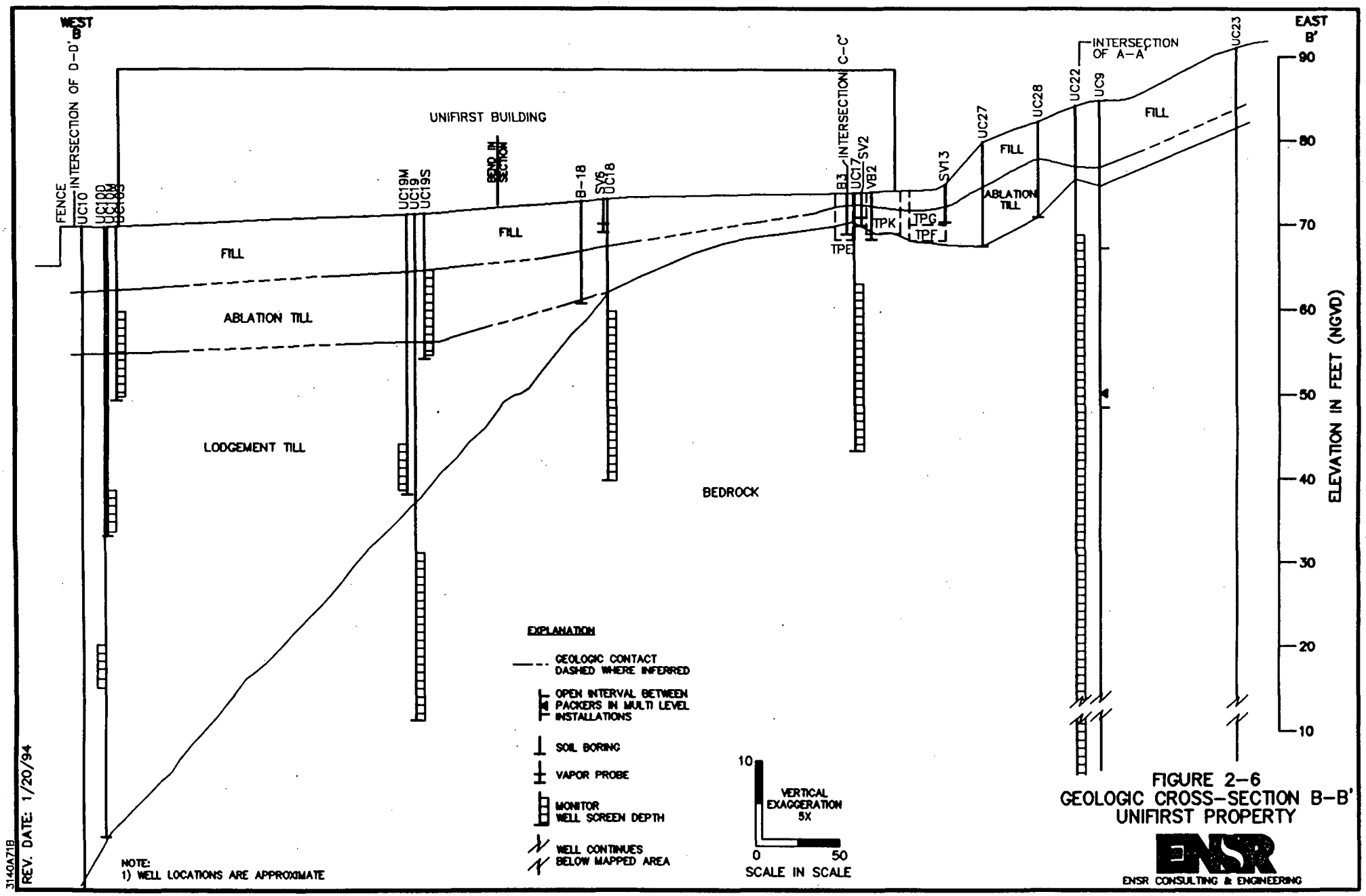

FIGURE 2-6
GEOLOGIC CROSS-SECTION B-B'
UNIFIRST PROPERTY

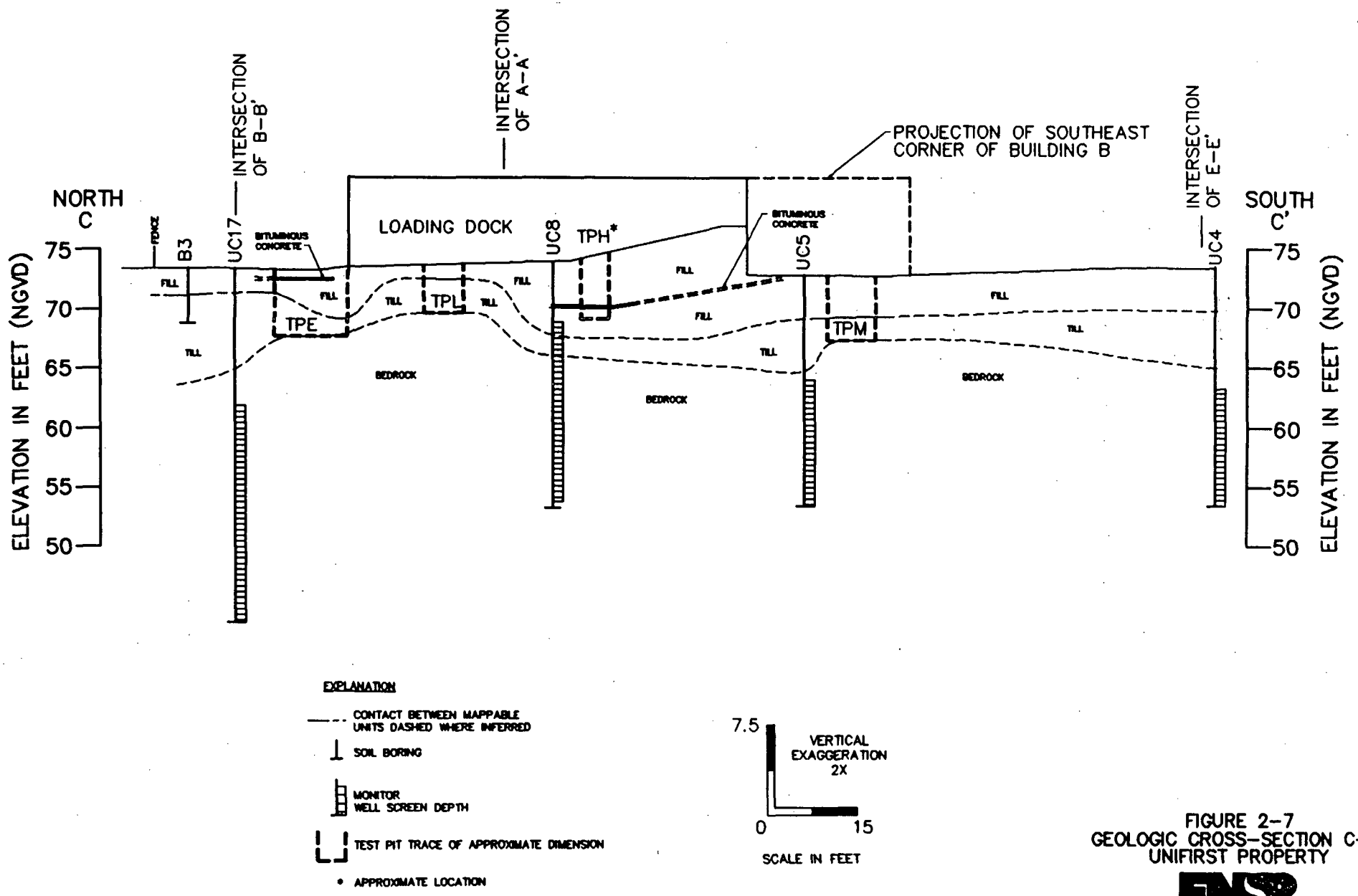

FIGURE 2-7
GEOLOGIC CROSS-SECTION C-C'
UNIFIRST PROPERTY

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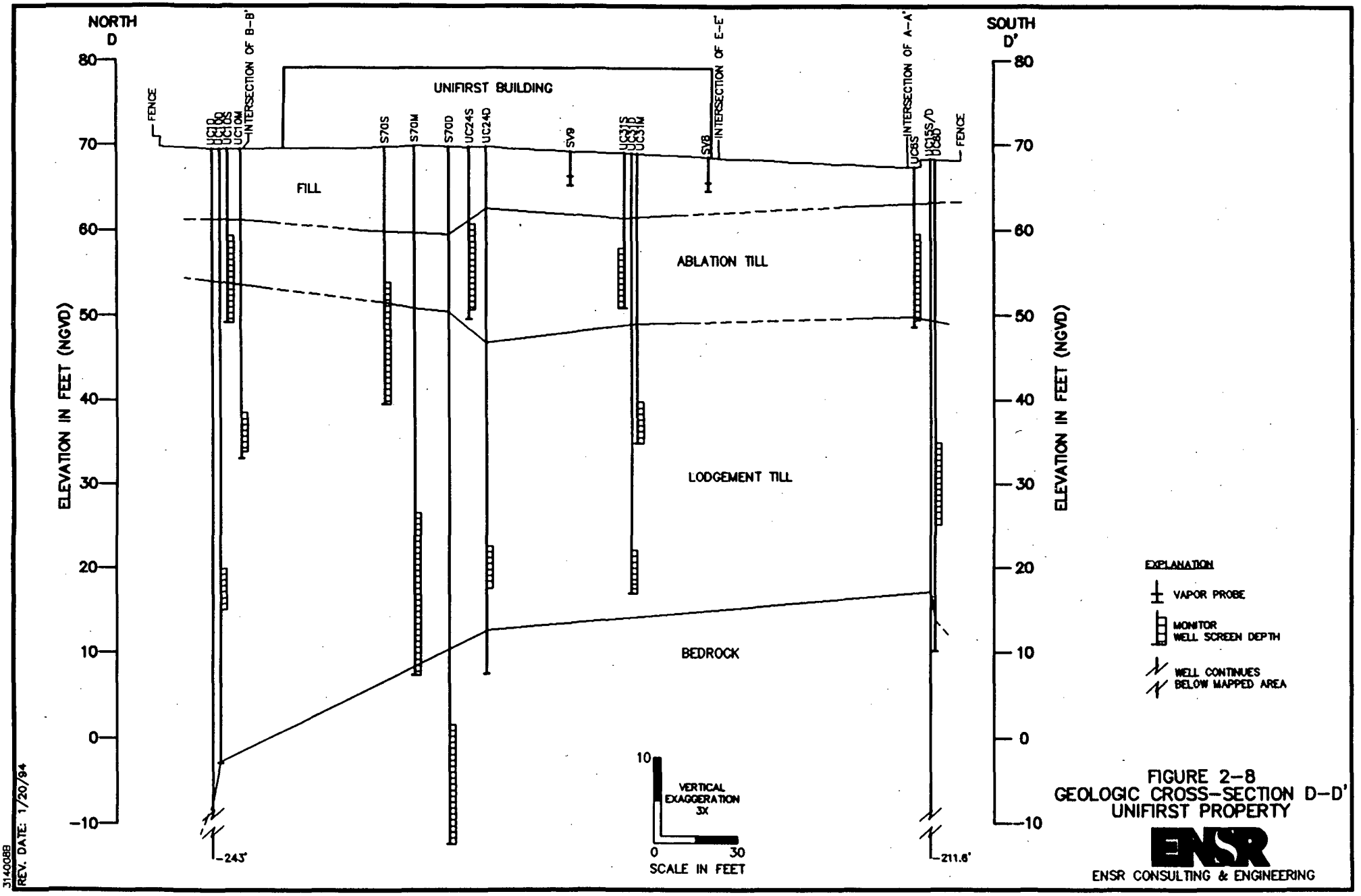

FIGURE 2-8
GEOLOGIC CROSS-SECTION D-D'
UNIFIRST PROPERTY

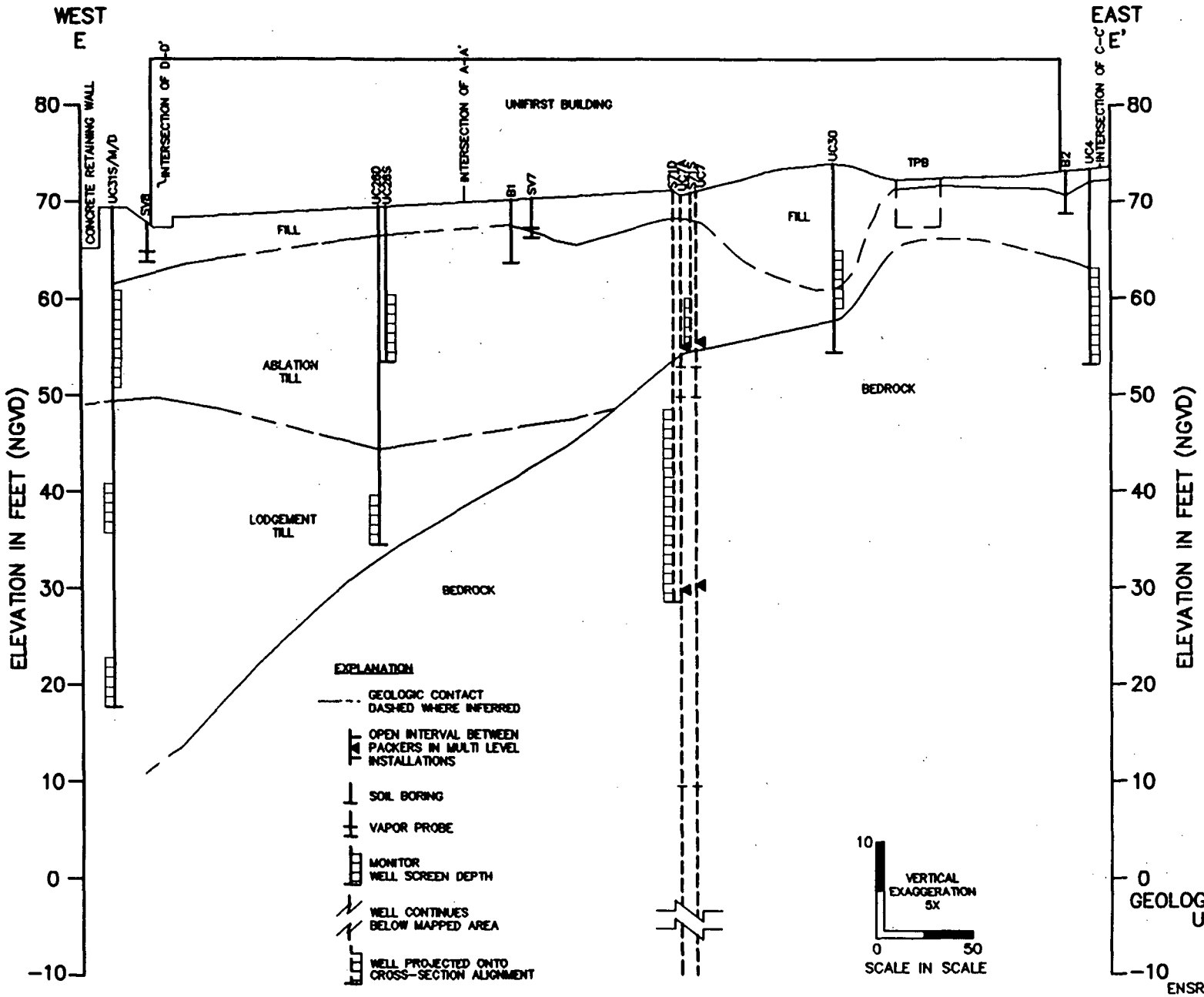

FIGURE 2-9
GEOLOGIC CROSS-SECTION E-E'
UNIFIRST PROPERTY

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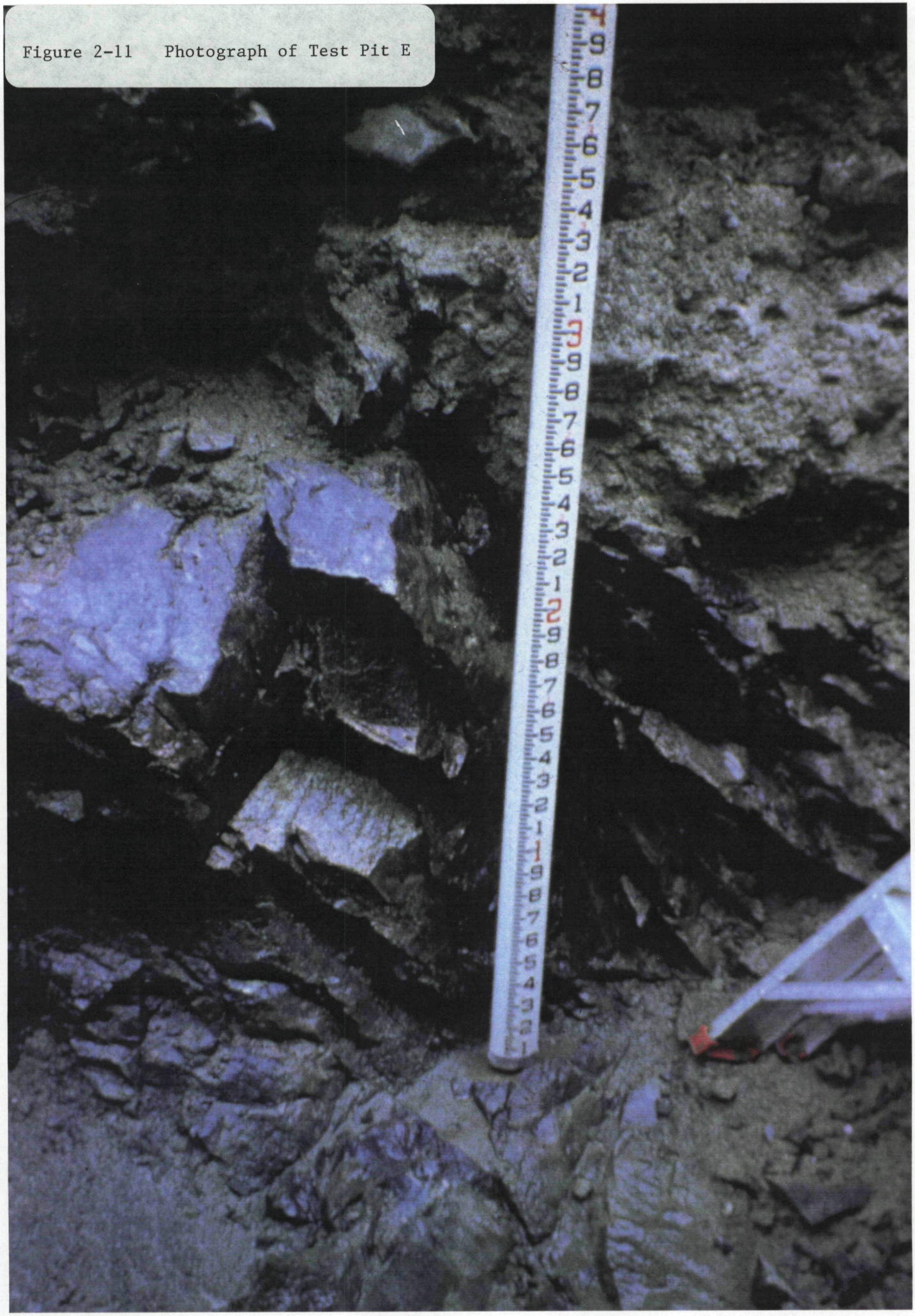
Figure 2-10 Photograph of Test Pit A

Figure 2-11 Photograph of Test Pit E



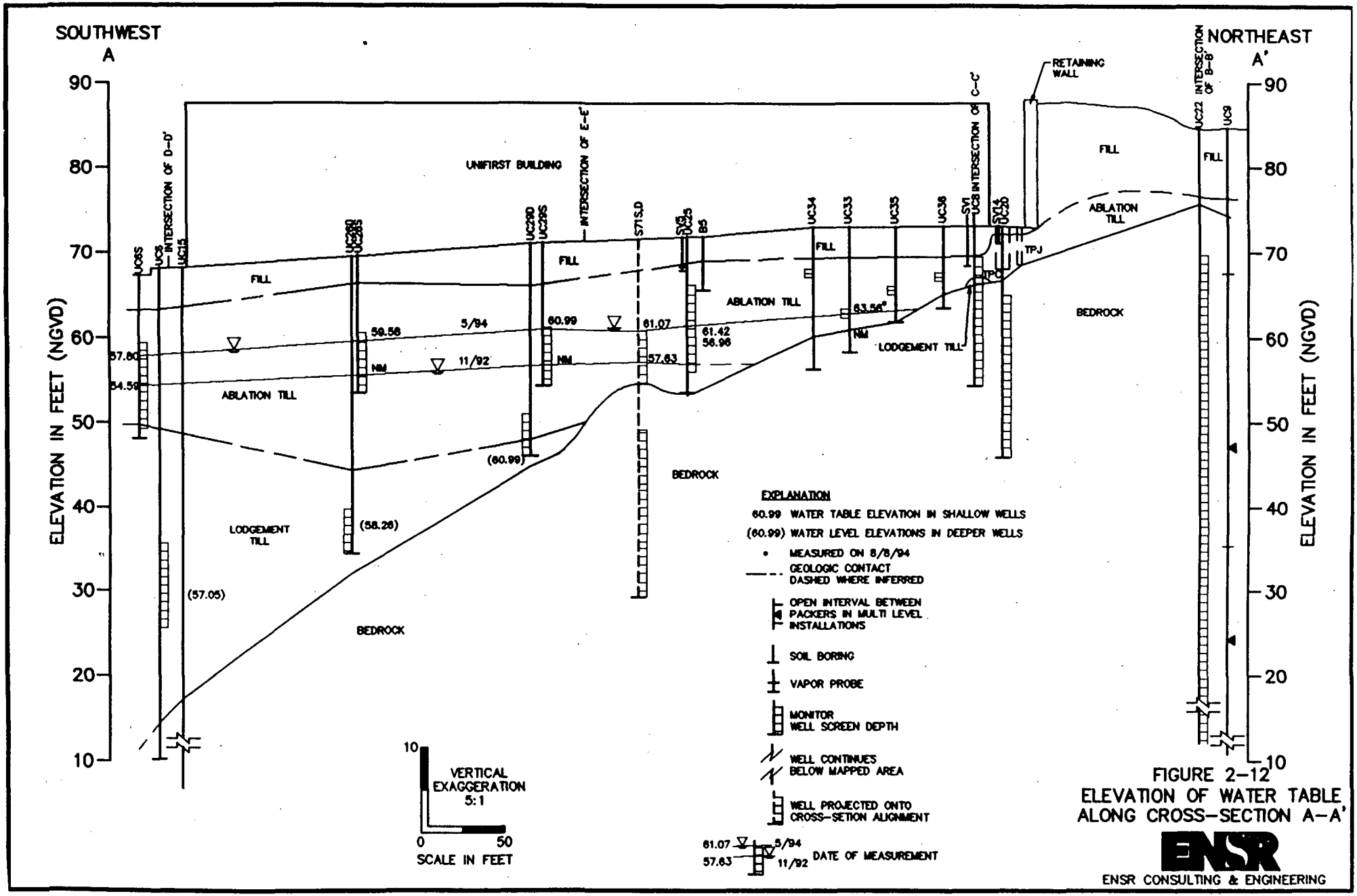


FIGURE 2-12
ELEVATION OF WATER TABLE ALONG CROSS-SECTION A-A'

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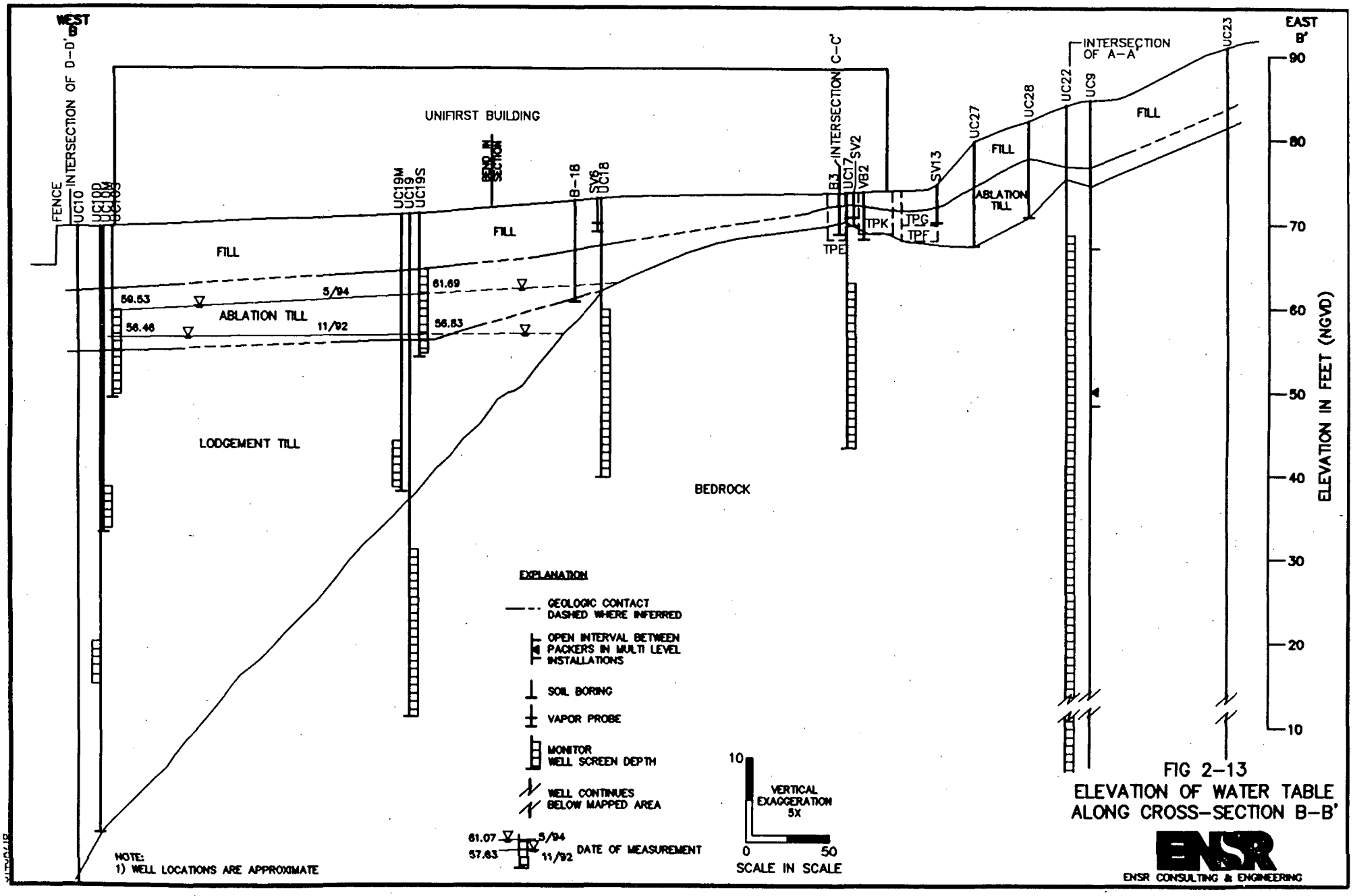

FIG 2-13
ELEVATION OF WATER TABLE ALONG CROSS-SECTION B-B'

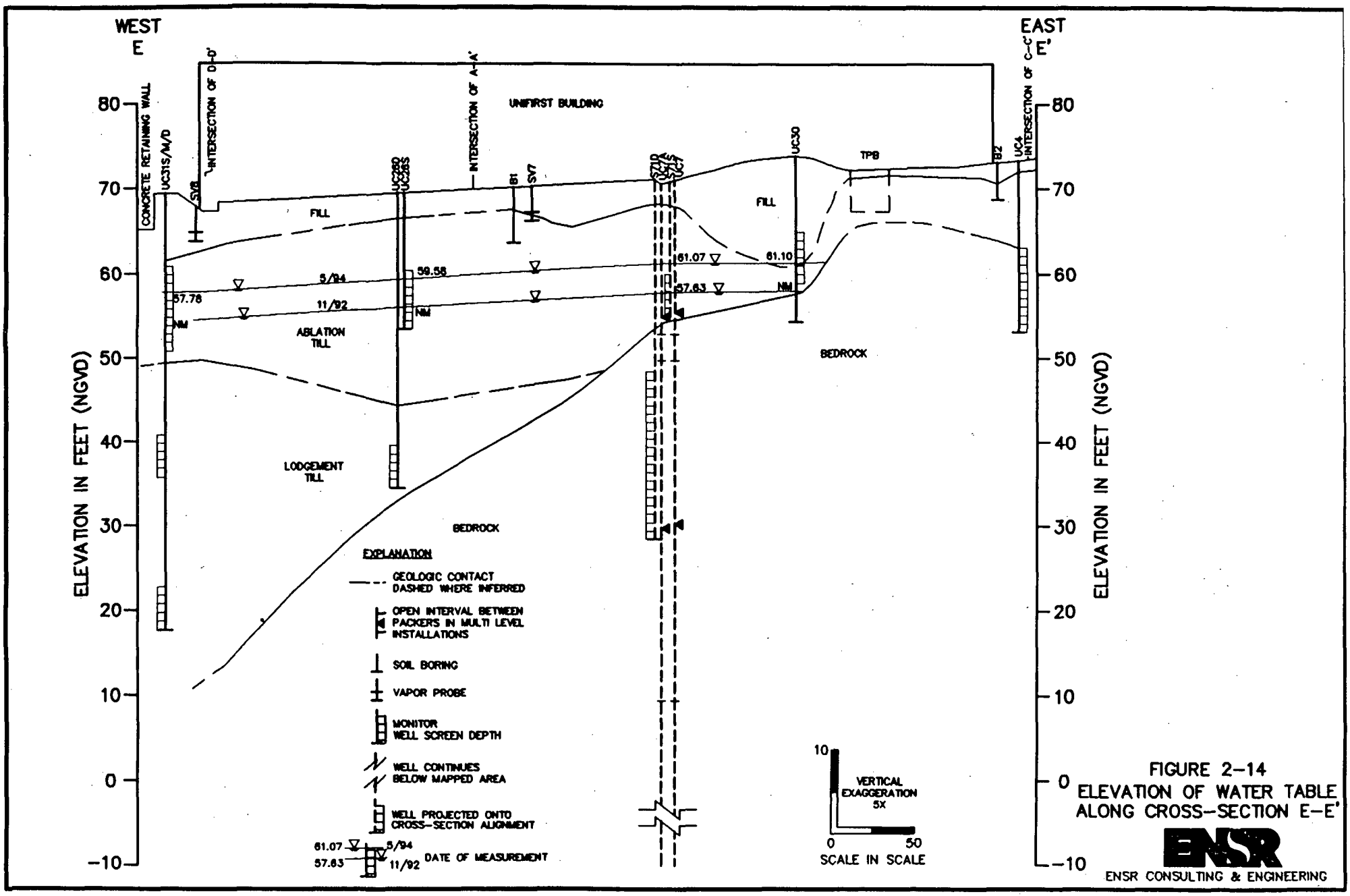

FIGURE 2-14
ELEVATION OF WATER TABLE ALONG CROSS-SECTION E-E'

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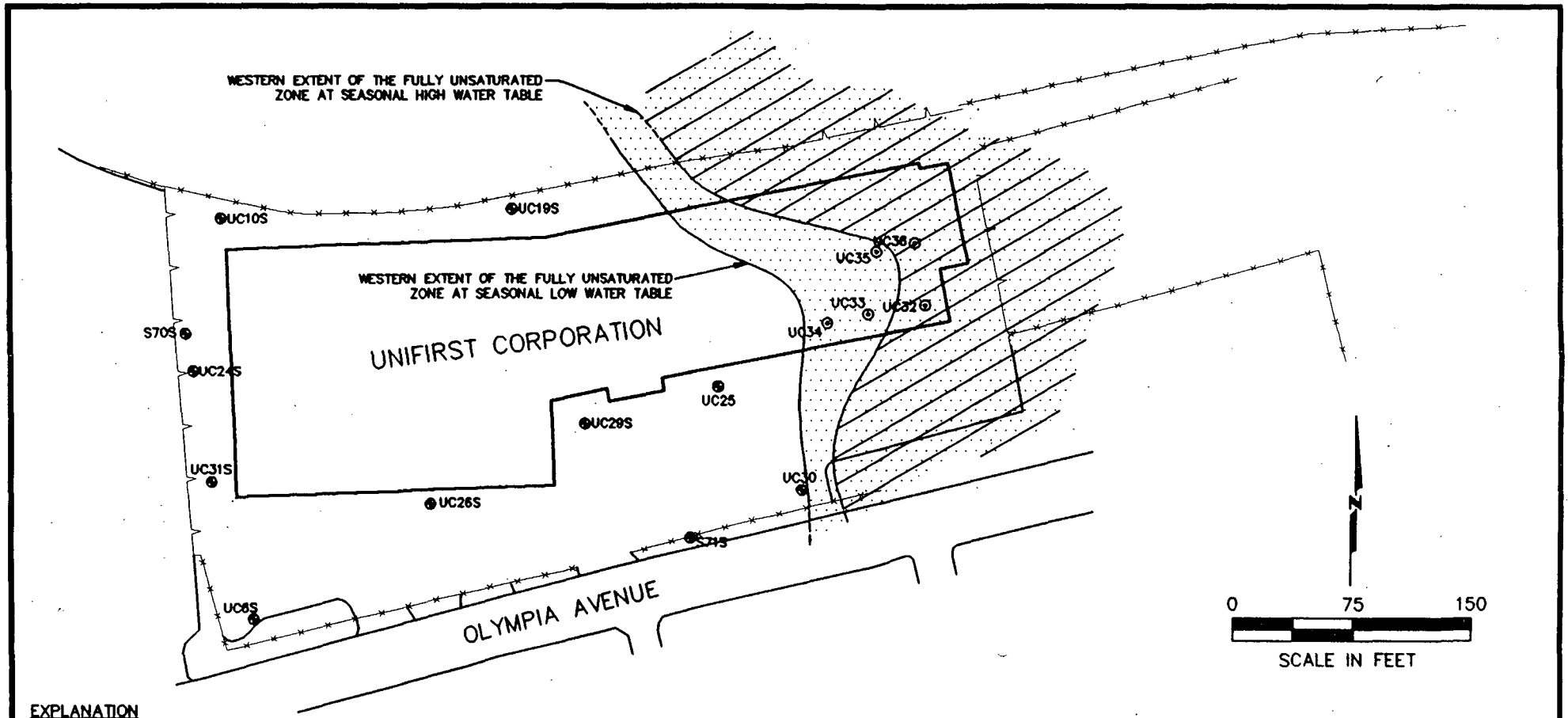

EXPLANATION

- 2 INCH MONITORING WELL, S70 AND S71 ARE 1.5 INCH
- 1 INCH MONITORING WELL
- -- 11/92
- -- 5/94

NOTES:

1) LOCATIONS FROM A SURVEY BY BSC GROUP OF BOSTON, MA.
2) WELL TYPES FROM DRAWINGS BY ENSR CONSULTING & ENGINEERING
3) BASE MAP PRODUCED BY GEOTRANS, INC OF HARVARD, MA FROM AERIAL SURVEY BY COL-EAST, INC. OF NORTH ADAMS, MA.

FIGURE 2-15

ENSR CONSULTING & ENGINEERING

EXTENT OF THE ZONE WHERE UNCONSOLIDATED DEPOSITS ARE FULLY UNSATURATED AT SEASONAL HIGH AND LOW WATER TABLE

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M.D.F.	8/94	3140-024

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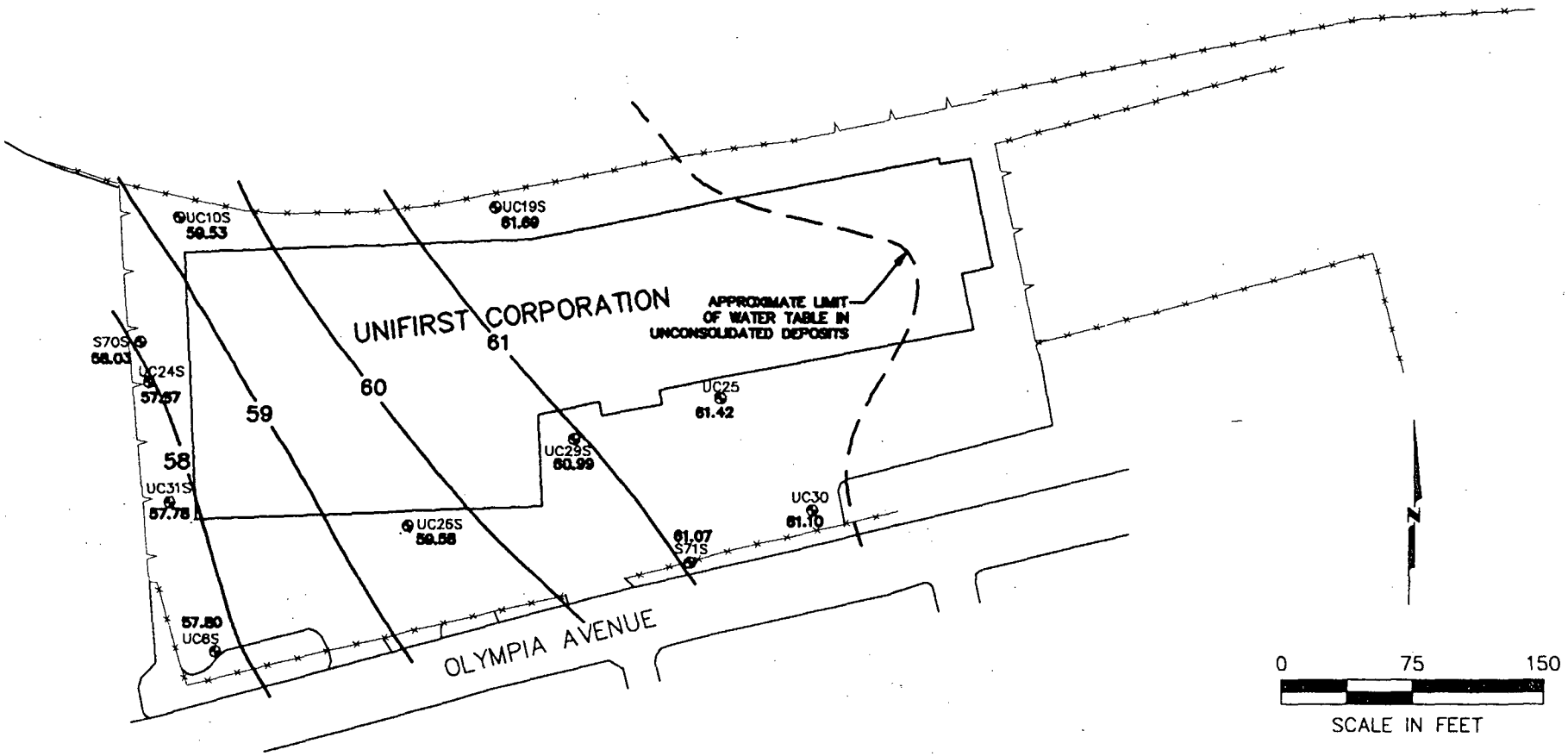

FIGURE 2-16

EXPLANATION

- 2 INCH MONITORING WELL, S70 AND S71 ARE 1.5 INCH
- 59.58 WATER TABLE ELEVATION IN FEET (ABOVE MEAN SEA LEVEL)
- APPROXIMATE LIMIT OF WATER TABLE IN UNCONSOLIDATED DEPOSITS

NOTES:

1) LOCATIONS FROM A SURVEY BY BSC GROUP OF BOSTON, MA.
2) WELL TYPES FROM DRAWINGS BY ENSR CONSULTING & ENGINEERING
3) BASE MAP PRODUCED BY GEOTRANS, INC OF HARVARD, MA FROM AERIAL SURVEY BY COL-EAST, INC. OF NORTH ADAMS, MA.

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ELEVATION OF WATER TABLE IN UNCONSOLIDATED DEPOSITS MAY, 1994

DRAWN BY	DATE	PROJECT NO.
M.D.F.	8/94	3140-024

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3.0 Unconsolidated-Deposits Investigations

Since unconsolidated-deposits contamination was first detected in 1985, numerous investigations have been focused on the subsurface beneath the Property. These investigations have been conducted in a series of logical steps to: locate and define areas of contamination within the unconsolidated deposits; continually refine the conceptual model for the Property; provide data necessary for the Property-specific consideration of the feasibility of successful remediation; and respond to specific requests by the EPA. The following discussion summarizes the nature and basic findings of all the unconsolidated-deposits investigations that have taken place to date, all of which have been included in earlier submittals, along with all the raw data. The purpose of the following discussion is to provide the context necessary to understand the purposes and significance of each investigation undertaken at the Property, and to clarify the evolution of the conceptual model for the Property described in Section 4.0.

3.1 Overview and Data Summaries

The locations of all subsurface investigations and monitoring installations at the Property are shown in Figure 3-1. The Property is approximately four acres, and investigations have been conducted across the entire Property. The most intensive investigations have been conducted on the east end of the Property in an area that is only about 150 feet square (0.4 acres) where the only indications of significant contamination have been found. In addition to those monitoring installations that were installed as part of the unconsolidated-deposits investigations, monitoring wells installed in the underlying bedrock across the Property, in support of the groundwater investigation and remediation activities at the Site, have also contributed to the development of the conceptual model (RDI/FD Report, October 22, 1991).

The unconsolidated-deposits investigations undertaken at the Property have included: geologic logging and sampling of 32 soil borings; excavation of a total of 13 test pits; and installation of 14 drive-point soil-vapor probes, 3 large-diameter (4-inch i.d.) and 5 small-diameter (1-inch i.d.) vapor-monitoring wells, and 21 groundwater monitoring wells. Analyses of samples collected during the unconsolidated-deposits investigations have included: chemical analysis of over 140 unconsolidated-deposits samples; physical-properties characterization of approximately 60 samples; separate analysis of 29 unconsolidated-deposits samples and bituminous-concrete pavement samples for petroleum-hydrocarbon characterization of the asphalt binder; and chemical analysis of approximately 30 soil-vapor samples. Table 3-1 is a sampling inventory that summarizes all the samples collected at the Property and the chemical and physical properties for which they were analyzed.

Two methods have been used to analyze for VOC in the unconsolidated deposits during the on-Property investigations. Originally, samples were collected using the EPA's standard sampling method, in which samples are transferred directly into standard, 40-ml vials with Teflon septa. In 1989, UniFirst adopted a modified sampling protocol, in which the samples are collected into 500-ml sample jars containing methanol in the field to minimize volatile losses and increase the extraction of organic compounds. Since 1989, the majority of the samples collected for VOC analysis for characterization of the nature and extent of contamination have been field-preserved in methanol, although some standard samples were also collected in 1992 and 1993 for purposes of method comparison. Comparison of the results for the methanol-preserved samples to those collected by the standard protocol confirmed that a significantly greater recovery of volatile contaminants was achieved for the methanol-preserved samples (Pre-Design Work Plan, 1992, section 3.3). Therefore, samples collected by the methanol method are deemed to be more representative of actual field conditions.

Results of laboratory VOC analyses for selected chlorinated organic compounds are summarized for all samples of unconsolidated deposits collected on the Property by the methanol-preserved method in Table 3-2, and by the standard (non-preserved) method in Table 3-3. Results for analyses for semi-volatile-organic compounds (SVOC) and polychlorinated biphenyl (PCB)/pesticide analyses are not summarized in table format, but are discussed in the text for those few instances where these substances were found. Table 3-4 summarizes the results of the physical analyses of unconsolidated-deposits samples including bulk density, grain-size distribution, moisture content and hydraulic conductivity. Results of soil-gas analyses are summarized in Table 3-5. Copies of all test-pit field logs, as well as schematics indicating the location of samples for chemical analysis collected from test pits TPC through TPH and TPJ through TPM, are included in Appendix A. Boring logs for the Property are provided in Appendix B.

3.2 Chronology of Investigative Phases

The basic chronology of the unconsolidated-deposits investigations conducted on the Property is presented in Table 3-6, and a brief discussion of each investigation is provided below. A more detailed account of the methodologies, results, and conclusions for each of the investigations summarized below can be found in the reports indicated in Table 3-6.

For the purpose of discussion, the unconsolidated-deposits investigations undertaken at the Property can be divided into five major chronological "phases", each of which is characterized by a major investigative focus or response to a specific investigative goal or a directive from the EPA. Significant overlap exists, however, regarding the utility of data generated

during each phase to the questions addressed in others. The re-evaluation and refinement of the conceptual model for the Property is the main objective of every phase, undertaken every time new data are generated for the Property. The major phases of investigation at the Property are:

- **1983-1987** Initial investigations by the EPA and UniFirst to locate potential sources of contamination in support of the Remedial Investigations and Feasibility Study (i.e., prior to the ROD and Decree) for the Wells G&H Site.

- **1989-1990** Field investigations to enable UniFirst to evaluate and comment on the EPA's Proposed Remedy for the Wells G&H Site (pre-ROD), and modeling investigations regarding the potential for recontamination of unconsolidated deposits during negotiations of the Consent Decree Statement of Work (SOW) REDACTED REDACTED

- **1992** Field studies to assess the feasibility of achieving cleanup of contaminated unconsolidated deposits or protection of groundwater by SVE or infiltration.

- **1992-1993** Discovery and investigation of the waste-oil-contamination area during trenching for the Groundwater Remedial Action.

- **1993-1994** Final site-characterization work and assessment of the feasibility of SVE in response to requests by EPA. REDACTED

REDACTED

3.3 Description of Unconsolidated-Deposits Investigations

3.3.1 Initial Investigations by the EPA and UniFirst, 1983–1987

Investigations of the unconsolidated deposits beneath the Property were initially undertaken by both the EPA and UniFirst in an effort to identify potential sources of groundwater contamination that was detected during the Remedial Investigation (RI) (ERT, 1984; NUS, 1986) and Supplemental Remedial Investigation and Feasibility Study (Ebasco, 1988) for the Wells G&H Site. Field-screening and analysis of unconsolidated-deposits ("soil") samples collected during installation of monitoring wells IUS1, IUS2 and IUS3 (immediately north and west of the Property), and S70, S71, UC4 through UC7 and UC15 through UC20 (on the Property), during the period 1983 through 1987, indicated the presence of low levels of contamination by volatile organic compounds in the upper few feet of unconsolidated deposits on the east half of the Property (UC4, UC5, UC7, and UC17). No unconsolidated-deposits contamination was detected on the west half of the

Property. VOC analyses of samples collected from borings on the Property indicated that the principal unconsolidated-deposits contaminant detected was tetrachloroethene (PCE), with a low level of 1,1,1-trichloroethane (TCA) reported in the upper 2 feet of boring UC5.

Once EPA's broad investigations during the RI had indicated the presence of PCE on the Property (NUS, 1986), further investigations were focused on the most likely locations of potential releases of PCE. In December 1986, a test pit (TP1) was excavated adjacent to the fill pipe from the former PCE storage tank in an area outside the current loading dock where some scarring of the surface pavement had been noted. A solvent-like odor was noticed upon breaching of the pavement, but it quickly dissipated (Cherry *et al.*, 1989; EPC, March, 1991). Analysis of soil gas collected from two pipes driven horizontally in the walls of the test pit did not detect any contamination. (Feb. 1987 letter to G. Ruta of EPA).

DNAPL was encountered, however, in 1987, in the shallow fractured bedrock beneath the Property after installation of monitoring well UC8 in 1987 inside the UniFirst loading dock (ERT, 1988). UC8 was drilled close to the reported former location of a dry well, which was constructed in the base of the loading "pit" that existed at the east end of the building from the mid-1960's to the late 1970's. It was hypothesized at the time that any PCE that may have been released in the loading-dock area, by spills during PCE transfer to the storage tank, might have run downslope along the surface of the pavement toward REDACTED the dry well and thence into the underlying unconsolidated deposits and bedrock. The free-phase DNAPL that accumulated in the well following construction of UC8 was removed using a bailer. Initial analysis of the DNAPL sample indicated the presence of PCE with minor amounts of bis(2-ethylhexyl)phthalate and napthalene (ERT, 1988). In addition to these compounds, subsequent analysis of the DNAPL also indicated the presence of petroleum hydrocarbons (January 1994 interim report).

Wells UC16 through UC20 were installed around the east end of the UniFirst building in the fall of 1987 to determine the extent of the DNAPL migration and accumulation in the shallow bedrock around UC8 (ERT, 1988). No additional free-phase DNAPL was encountered in any of the wells, and the unconsolidated-deposits contamination encountered was relatively modest, with the highest PCE concentration reported of 290 µg/kg in the unconsolidated deposits at UC17 (Ebasco, 1988).

In April 1989, the Massachusetts Department of Public Health (DPH) released its draft report on its review of health and safety issues related to the Wells G&H Site. In response to concerns about possible migration of vapors from the groundwater through the soil and into the basements of nearby homes, two surveys of indoor-air quality were conducted simultaneously: one by EPA; and a companion study by UniFirst and Grace Corporations. Indoor-air

quality measurements were made by UniFirst and Grace inside the UniFirst and Grace buildings, as well as by UniFirst, Grace, and the EPA in nearby homes. UniFirst's survey also included outdoor air samples in addition to those indoor locations collected simultaneously with the EPA. UniFirst also provided long-term sampling results (ENSR, July and August, 1989 letters to Mary Kay Voytilla).

The levels of PCE, TCE, and 1,1,1-TCA detected in these studies were all near the median values obtained for these compounds in an EPA study of typical indoor-air quality in areas not impacted by soil or groundwater contamination. One home southeast of the UniFirst Property REDACTED REDACTED exhibited TCA levels slightly higher than those encountered in the other two homes, but within the maximum levels determined in EPA's background indoor-air quality survey. Air quality results at that location were attributed to the presence of containers of paints, paint thinners, and other chemical products stored in the basement.

UniFirst engaged Dr. Rudolph Jaeger and Dr. Warner North to perform a risk assessment for exposures within its building. Their findings of no risk were provided to EPA under a cover letter from Mr. Bates (UniFirst's counsel) to Mr. Conway (EPA) dated July 24, 1989.

3.3.2 Pre-ROD Response to the EPA's Preferred Alternative and Pre-Consent Decree Investigations to Evaluate the Potential for Groundwater to Cause Recontamination of the Unconsolidated Deposits.

To evaluate the utility of the EPA's initially-proposed remedy for the unconsolidated deposits on the Property (excavation and incineration) UniFirst performed studies in 1989 and 1990 to refine further the conceptual model for contamination of the unconsolidated deposits beneath the Property. Low levels of PCE contamination were found in the unconsolidated deposits outside the immediate area of the loading dock (UC7 and UC17). There had been no expectation that releases had occurred outside the immediate area of the loading dock, based on the known Property history, nor had indications of a significant DNAPL source in the unconsolidated deposits been found there. Consequently, further consideration as to the possible source of that contamination was necessary.

Two facts prompted evaluation of an hypothesis that volatilization from contaminated groundwater was the source of contamination detected in the unsaturated zone at UC7 and UC17. Both DNAPL and high levels of dissolved PCE contamination in groundwater had been encountered in the shallow bedrock beneath the east end of the Property. Also, the water table in this area is located at a relatively shallow depth, less than 10 feet below

ground surface. Therefore, the hypothesis was advanced that, in the absence of evidence of any significant surface release of solvents on the Property, and given the very high dissolved concentrations in groundwater, the underlying contaminated groundwater could act as the main source of contamination to the overlying unconsolidated deposits by partitioning of the contamination to the soil gas and upward migration of the VOC vapors.

This hypothesis of upward migration of VOC vapors held considerable significance for the proposed remedy. That is, removal of contamination from the unconsolidated-deposits in the unsaturated zone would not abate a source of contamination to groundwater, because DNAPL in the groundwater zone itself, rather than the unsaturated, unconsolidated deposits, constituted the main source of contamination. Furthermore, under the scenario presented by this hypothesis, excavation and replacement of the contaminated unconsolidated deposits on the east end of the Property would not constitute a successful, permanent remedy as long as groundwater contamination persisted, since upward migration of VOC vapors would continue, resulting in recontamination of the unsaturated zone, possibly at lower levels, but still in excess of cleanup requirements. Consequently, UniFirst undertook to test the hypothesis of upward migration of contaminants from the groundwater to the overlying unsaturated zone. REDACTED REDACTED

Borings and Vapor Probes REDACTED

In 1989, two shallow vapor borings (VB4 and VB5) were drilled in the area of test pit TP1, which had been excavated and backfilled just 2 years earlier, to test the current concentrations of VOC in this area. In addition, three borings (VB1, VB2 and VB3) were drilled and instrumented with vapor probes adjacent to wells UC5, UC17, and UC7, respectively, to test whether soil-gas concentrations at depth might result in upward vapor migration sufficient to contaminate the overlying unsaturated zone (Cherry *et al.*, 1989; EPC, July 1990). During the sampling of these borings in 1989, UniFirst commenced the practice of field-preserving samples in methanol to improve the recovery and extraction of any VOC present. REDACTED

Analysis of samples from borings VB4 and VB5 in the immediate vicinity of the backfilled TP1 confirmed PCE concentrations at 6,500 µg/kg and 23,000 µg/kg of PCE, respectively, in the upper two feet of unconsolidated deposits. (The borings could not be augered to depths greater than about 3 to 4 feet because of the presence of large boulders in that location; TP1 exposed a large, approximately 4-feet diameter boulder.) Analyses of samples from these two borings also indicated the presence of 1,1,1-trichloroethane (TCA) at 200 µg/kg to 3,000 µg/kg.

Analysis of samples from borings VB1 and VB2, which were advanced to refusal at 3.3 feet and 5.3 feet, respectively, also confirmed the presence of PCE contamination in the upper few feet of unconsolidated deposits (as indicated earlier by the UC5 and UC17 borings) at levels up to 2,500 µg/kg. However, at location VB3 to the southwest, which was advanced to refusal (13 feet) one foot below the water table, PCE contamination was encountered, not in the shallowest deposits, but at depths below 4.5 feet depth. The highest concentration encountered was for a sample taken right at the water table, consistent with the predominant chemical gradient being upward. In addition to PCE, low levels of TCE were also reported from the boring samples from locations VB2 and VB3.

To test further the hypothesis of upward VOC migration, a vapor probe was installed in each of borings VB1, VB2, and VB3. The probes consisted of a length of 4-inch PVC blank pipe which was grouted in place and extended to a depth just above refusal for VB1 and VB2 (3.3 feet and 5 feet respectively), and just above the water table (10 feet) for VB3. Therefore, soil-gas vapors could enter the pipes only from the portion of the unconsolidated deposits at depth adjacent to the open bottom of the pipe and not the overlying, shallower, unconsolidated deposits. Vapor samples were collected from each of these vapor wells one week after installation. The measured PCE vapor concentrations within the pipes were 34 parts per million by volume (ppmv), 22 ppmv and 6 ppmv at VB1, VB2, and VB3 respectively, indicating that a significant source of contaminant vapors existed at depth at each location.

Results from these studies, particularly in the location of VB3 and UC7, supported the hypothesis that upward migration of VOC vapors could be occurring from underlying, VOC-contaminated groundwater. At the east end of the Property, where bedrock is located at a shallow depth and the water table is generally below bedrock surface, results indicated that significant vapor levels existed near the base of the unconsolidated deposits.

Numerical Modeling

The field results obtained from the 1989 borings and vapor probes were augmented by numerical modeling using Property-specific parameters (Feenstra, 1989) to determine whether the process of upward migration of vapors from the contaminated groundwater was capable of contaminating (or recontaminating) overlying unconsolidated deposits to significant levels. This modeling demonstrated that the process of vapor diffusion, originating from partitioning from groundwater contaminated by 1,500 µg/L of PCE, could contaminate overlying unconsolidated deposits to levels in excess of the cleanup target of 36.7 µg/kg in several years or less.

Additional interpretation of the modeling results was conducted in July, 1990 (Feenstra, 1990) in support of discussions about appropriate sequencing of the groundwater and unconsolidated-deposits remedial technologies. The purpose of the second study was to determine to what level the PCE concentrations in groundwater beneath the Site would need to decline, due to the groundwater remediation system, to ensure that the overlying unsaturated, unconsolidated deposits would not be subject to recontamination above the cleanup targets following implementation of an unconsolidated-deposits remedy. This study yielded a groundwater target concentration of 85 µg/L to ensure that the unconsolidated deposits would not be contaminated above the cleanup level of 36.7 µg/kg for PCE.

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The following observations informed the conceptual model put forward by UniFirst's consultants in 1989 and 1990, which called for sequencing of remedial actions at the Property: no indications of DNAPL had been found within the unconsolidated deposits beneath the Property that would act as a significant source of contamination to groundwater; DNAPL, as found in UC8, was known to exist within the bedrock beneath the water table and was associated with high dissolved PCE concentrations in groundwater; and evidence from on-Property investigations that recontamination of remediated unconsolidated-deposits, due to upward migration of vapors from shallow, contaminated groundwater, was a plausible mechanism worthy of consideration in remedial design.

3.3.3 Investigations to Address the Feasibility of Achieving Cleanup with SVE or Infiltration.

On October 22, 1991, UniFirst and Grace submitted the Draft Remedial Design Investigation Report and Final Design (RDI Report) for the Northeast Quadrant of the Wells G&H Site to the EPA. That report principally addressed the proposed design of the groundwater remedy for beneath the northeast quadrant of the Wells G&H Site, including the UniFirst and Grace Source-Area Properties. As discussed in Section 2.3, however, at the request of the EPA, a section dealing with remedial hypotheses for the unconsolidated deposits beneath the UniFirst Property was also included in the report (RDI Report, Section 6.0). This section described: the then current conceptual model for contamination beneath the UniFirst Property; the pertinent parts of that conceptual model with relation to sequencing of groundwater and unconsolidated-deposits remediation as recognized in the Explanation of Significant Differences (ESD); and possible remedial alternatives for dealing with the unconsolidated deposits and dewatered bedrock.

In discussion of the unconsolidated deposits beneath the Property at that time, UniFirst submitted that the prognosis for effective remediation of the Property by SVE was very poor, and that, furthermore, application of SVE or

other unconsolidated-deposits remedies prior to cleanup of the underlying groundwater, would be inefficient, based on geological conditions at the Property and consideration of the potential for recontamination as indicated by field demonstrations and the conceptual model. In consideration of the most appropriate sequencing of the unconsolidated deposits and groundwater remedies, an alternative "phased" remediation strategy was proposed for consideration, in which infiltration of clean water from the treatment plant effluent would be applied to the unconsolidated deposits via porous pipes to mitigate the effects on the unconsolidated deposits of upward migration of vapors from groundwater while the groundwater remedy was being implemented. Infiltration could be continued until attainment of contaminant levels of less than 85 µg/L PCE in the groundwater, and could then be followed by SVE in any remaining "hot spot" areas, should it be feasible and warranted based on a continuing threat to groundwater contamination.

In response to the EPA's concerns about the proposed remedial strategies, UniFirst undertook, in 1992, further studies to evaluate the feasibility of not only mitigating upward migration of vapors from the groundwater, as proposed in the report, but of achieving a cleanup goal of 36.7 µg/kg PCE by either infiltration or soil-vapor extraction. To conduct this evaluation, field investigations were performed that included soil borings, excavation of test pits, and installation of soil-vapor probes, to collect physical- and chemical-analysis samples to provide realistic, Property-specific numbers for calculations, and to refine further the nature and extent of contamination and the conceptual model for the Property. These investigations were reported in the Pre-Design Work Plan for the Unconsolidated Deposits beneath the UniFirst Property, submitted to EPA on November 13, 1992 (Pre-Design Work Plan, 1992).

Test-Pits A and B—May, 1992

In May 1992, two test pits (TPA and TPB) were excavated in front of the UniFirst building to examine, in a larger scale and by a method that eliminated problems of sample recovery from borings, the physical nature of the unconsolidated deposits and their contact with the underlying bedrock. The test pits were excavated in the area where it had been proposed previously that an area of porous pavement might be placed as part of the infiltration system (RDI Report 1991, Figure 6.3-1). Samples of unconsolidated deposits were collected from these test pits for physical analyses to provide measured parameter values for use in calculations to evaluate the proposed remedial options for the Property. Of particular interest was the collection of samples for permeameter analysis to provide an indication of how the permeability of the unsaturated-zone deposits beneath the Property might affect the performance of either an infiltration system or a SVE remedy.

Excavation of these test pits confirmed in large scale (*vis a vis* borings) the geologic section consisting of, from top to bottom: bituminous concrete pavement; artificial fill; till (naturally occurring); and bedrock. Both the till and artificial fill consisted of poorly sorted mixtures of sand, gravel, and silt with significant spatial variability in grain-size distribution and moisture contents. Visual inspection of the variability of texture of deposits in the test pits suggested that significant spatial variability in permeability to air or water movement would be expected. Samples for permeameter analysis could be collected only in areas where the coring device could be successfully driven into the finer-grained matrix of the cobbly/bouldery till, and a sample extracted that was sufficiently cohesive to yield representative *in-situ* bulk-density measurements. This is a typical problem sampling till. The matrix of the till, however, not the boulders, determines the permeability of the till. Permeabilities determined from permeameter analysis of samples collected with the coring devices yielded a range of values of hydraulic conductivities REDACTED from 2×10^{-5} cm/s to 4×10^{-4} cm/s. REDACTED

In TPA, close examination of the bedrock surface indicated a fairly sharp contact of the overlying till with a relatively smooth, but undulating (several feet of relief) pink, slightly weathered, granodiorite bedrock surface. The small depressions on the bedrock surface often had fine silt or clay surface coatings at the base of the till and local closure on the depressions were such that small volumes (1 to 2 liters) of water could pool within them when poured into the test pit; the test pit itself was dry, indicating that the water table, at that time, was located below the top of bedrock. The TPA bedrock surface, in contrast to the highly fractured and slightly weathered gabbrodiorite top of bedrock reported for UC8, led to interest in closer examination of the bedrock contact in the more immediate area of UC8 and the loading dock, where it was thought that PCE might have entered the subsurface, as discussed below. If the bedrock surface was more like that at TPA in the vicinity of UC8, it would suggest that small volumes of DNAPL might have accumulated on the bedrock surface in the close vicinity of the release area.

Soil-Vapor Probes —May, 1992

In May 1992, in addition to excavation of TPA and TPB, nine soil-vapor probes (SV1—SV9) were installed at the Property to assist in defining better the extent of contamination in the unsaturated zone, to compare results to those obtained in the 1989 recontamination studies, and to locate previously undetected zones of DNAPL in the unconsolidated deposits that would act as a vapor source. The probes were installed at three locations: inside the loading dock, around the east end of the UniFirst building; and on the west half of the Property in a direction roughly hydraulically downgradient of the loading dock area.

The probes indicated much decreased concentrations of PCE in the soil gas, 0.002 to 4.2 ppmv relative to the results obtained from the 1989 vapor recontamination experiments. This difference may be due to the fact that these probes were sampled immediately and the probes in 1989 were allowed to equilibrate for one week before sampling. Concentrations, although low, were highest in the vicinity of the northeast corner of the Property and extending to the southwest in the general direction of groundwater flow (see Figure 3-2). Although the absolute concentration results were much lower than expected, the general pattern of concentrations was consistent with a contaminant source on the east end of the Property. The correspondence of the center of an elongated vapor plume with the downgradient direction of groundwater flow was consistent with the theory of upward migration of vapors from shallow, contaminated groundwater.

Soil Borings—June, 1992

To investigate further the nature and extent of contamination beneath the Property, seven borings were advanced and sampled during June 1992. Five borings (B2, B3, B4, B6 and B7) were located around the east end of the building where contamination had previously been reported, and two borings (B1 and B5) were located further west adjacent to soil-vapor probes installed in May. Samples from these borings were collected for VOC analysis by both the standard and methanol-preserved methods, both to provide a comparison of the methodologies, and to allow comparison to earlier sample results that had been collected using the standard method. The methanol-preserved samples consistently showed higher recoveries than the standard sampling method, supporting the enhanced representativeness, and therefore the preference for using methanol-preserved sample results in interpretations whenever available.

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Samples from the immediate vicinity of the east end of the UniFirst building exhibited highly variable PCE concentrations ranging from non-detect to a high of 59,000 µg/kg; whereas, samples to the south and southwest exhibited contaminant levels which were all below 600 µg/kg, at least two orders of magnitude lower than the maximum of the unconsolidated deposits from the vicinity of the current loading dock. In addition to PCE, some of the samples from the area south of the current loading dock (B4 and B7) indicated the presence of TCA, consistent with the earlier detection of that compound in nearby borings VB4, VB5 and UC5.

Near the east end of the building, the highest concentrations were detected in the shallow unconsolidated deposits, within 2.5 feet beneath the surface pavement, although immediately south of the loading dock in the vicinity of earlier TP1, VB4 and VB5, deeper samples could not be obtained due to

shallow auger refusal on boulders. The sample results in the vicinity of the current loading dock exhibited a very high degree of spatial variability in distribution of contamination both laterally and vertically. Over three orders-of-magnitude difference in concentrations was obtained for shallow samples that were separated by only a few feet (B4 and B6). Boring B5 to the southwest showed contamination levels that were seven times higher (580 µg/kg) at depth (4.5 to 6.5 feet) than the shallow sample. By contrast, B1, the furthest boring to the southwest showed the highest concentration in the shallower sample (330 µg/kg), although the difference in concentrations was less than a factor of three.

Whereas no obvious indications of significant DNAPL contamination were seen in these samples, or earlier samples from the close vicinity, the occurrence of the high value in the shallow unconsolidated deposits at B4 suggested that some residual was likely present at that location. Based on equilibrium calculations, a soil concentration of 60,000 µg/kg PCE has been proposed for the Property as a concentration above which it is likely some immiscible phase is present in the sample (Pre-Design Work Plan, 1992, p. 3-56). The absence of high concentrations only a few feet away from B4, at location B6, however, suggests that the residual has very limited lateral extent. REDACTED

The results of the soil-vapor survey and borings confirmed that: the highest contamination levels beneath the Property were limited to the east end of the Property and that the contamination was principally PCE, with some TCA also present in the area to the south of the current loading dock. To the southwest of the loading dock area, contaminant concentrations were moderately low and the patterns were generally consistent with the hypothesis of upward migration of contamination from the shallow groundwater.

In the vicinity of the east end of the building, however, the conceptual model required some refinement. Whereas, previous studies had found no indication of DNAPL contamination within the unconsolidated deposits themselves, results suggested that, in the vicinity of the south end of the loading dock, very small, discontinuous areas of DNAPL residual existed in the shallow unconsolidated deposits beneath the pavement. Outside of these small areas of suspected "blebs" of residual, it was thought that the somewhat higher concentrations at shallow depths below the pavement might be the result of preferential vapor transport and accumulation in more permeable artificial fill deposits immediately beneath the pavement.

Test Pits C, D, and E—July-August, 1992

Following the results obtained from the borings and soil-gas work, additional investigations were undertaken on the east end of the Property to refine further the conceptual model for contaminant distribution. Test pits were used, as opposed to soil borings, due to: the high degree of heterogeneity of both the contaminant concentrations and the texture of the unconsolidated deposits; poor sample recovery obtained by split-spoon sampling; the necessity to collect undisturbed samples for bulk-density and permeameter analyses; a desire to make the best effort to find any DNAPL accumulations in the unconsolidated deposits; the need to examine, characterize, and sample directly the unconsolidated deposits at the bedrock contact; and the need to examine in appropriate scale the variable bedrock surface. Use of test pits provided: a much better indication of the spatial variability of deposits both vertically and laterally; the opportunity to screen a large area with an organic vapor analyzer for indications of significant contamination; and optimization of sidewall sampling locations based on visual evidence and field screening.

Consistent with the applicable work plans and regulatory requirements, any manifestly contaminated unconsolidated deposits were segregated from the test-pit spoil, staged on plastic sheeting until a roll-off container was brought to the site for final storage, sampled and analyzed, and disposed of off-Property consistent with the applicable regulations. Any volume deficit during backfilling was made up with clean bank-run gravel supplied from a sand and gravel quarry.

Test pits C, D and E were excavated in locations on three different sides of the east end of the UniFirst building within distances of only approximately 10 to 35 feet from UC8. Test pit D was located within about 25 feet of boring location B4. In particular, these test pits were excavated to examine and sample the unconsolidated deposits very close to the bedrock contact. If DNAPL had been released in the vicinity of UC8, as hypothesized, and bedrock conditions were like those exhibited in TPA, there was a potential that DNAPL reaching the bedrock surface may have migrated a short distance laterally along the bedrock surface until its volume was exhausted by occupying the available soil-pore volume within the till-filled, closed depressions on the bedrock surface. Therefore, the contact was examined closely, field screened, and sampled in each case to look for any evidence of very high concentrations or other indications of residual DNAPL.

In all three of the test pits, the upper surface of the bedrock (mostly gabbrodiorite) was, unlike TPA, highly fractured and, in many places, highly weathered clasts of bedrock existed near the top of the bedrock contact that were separated by sand infilling. These observations are consistent with the highly fractured and slightly weathered gabbrodiorite cored in the boring for UC8. The bedrock exposed in Test Pits C, D, and E was predominantly

greenish dark-gray/brown gabbrodiorite layered with less prevalent pink granodiorite. Field screening gave no indication of significant contamination or likely DNAPL near the bedrock contact, or at shallower depths, and analysis of samples collected from these three test pits yielded concentrations ranging from non-detect to a high of 810 µg/kg PCE. Concentrations in TPD exhibited a weak trend of increasing concentrations with depth; whereas, TPC and TPE did not exhibit a consistent trend with depth. All three test pits exhibited a high degree of spatial variability of texture of the unconsolidated deposits consistent with earlier observations. Variations in contaminant concentrations may have been more closely related to spatial variations in characteristics, such as soil moisture, which were not correlated to depth.

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The nature of the bedrock contact in the vicinity of UC8 and the loading dock suggested that any DNAPL reaching the bedrock surface in that area would easily have entered into the highly fractured bedrock, and would be unlikely to have migrated any significant distance laterally on the bedrock surface. The absence of any indication of DNAPL accumulations or residual near the bedrock contact within a short distance of the suspected release area was consistent with this hypothesis. With the exception of a sample collected from boring B4, no indication of DNAPL residual was found within the unconsolidated deposits in the vicinity of the east end of the building, and sample analyses indicated that unconsolidated-deposits contamination was generally low to moderate (less than 2000 µg/kg PCE). A high degree of spatial variability of soil texture and contaminant concentrations was characteristic of all investigations. Visible changes in the grain-size distribution and moisture content of the unconsolidated deposits were on the order of a few inches, and lateral continuity of zones of distinct texture was rarely as much as a few feet, suggesting that significant lateral transport of a DNAPL along confining lenses following a release was highly unlikely.

Installation of Additional Water-Level Monitoring Wells —September, 1992

In September 1992, nine unconsolidated-deposits wells were installed at 5 locations (UC6, UC10, UC19, UC24, UC25) to augment the existing water-level monitoring network on the Property (Pre-Design Work Plan, 1992). These wells were installed to improve the density of hydraulic data points within the unconsolidated deposits to support clear interpretation of the influence of pumping UC22 for the groundwater remedy on groundwater in the unconsolidated deposits. The groundwater remedy had commenced with startup of pumping from well UC22 on September 30, 1992. Monitoring of water levels on and in the vicinity of the Property have indicated that the contaminated groundwater within the unconsolidated deposits beneath the Property is within the zone of capture of well UC22. Details regarding the hydraulics and capture of groundwater as they relate the unconsolidated

deposits will be dealt with in the second annual report for the operation of the groundwater remediation system, which is due for submittal to the EPA in November, 1994.

3.3.4 Discovery and Investigation of Waste-Oil-Contamination Area

Excavation of Treatment Plant Influent Trench—August 31, 1992

On August 31, 1992, pursuant to the Remedial Action Work Plan for Ground Water, a trench was excavated from well UC22 to the groundwater treatment room in the northeast corner of the UniFirst building for emplacement of the discharge line (i.e., influent to the treatment plant) and electrical conduits from UC22 to the treatment plant. As the trench was excavated, debris and contaminated soil were exhumed that included: used framing lumber; reinforced concrete slabs; a patch of black charcoal-like material intermingled with disaggregated fire bricks; and a volume of discolored, odorous, unconsolidated deposits. The debris and contaminated soil were first encountered about 50 feet west of well UC22. The discolored unconsolidated deposits occurred approximately 30 feet farther west along the trench adjacent to the edge of the pavement, and occurred as a roughly lens-shaped accumulation of distinctly bright medium-grey, slightly plastic, silty, coarse to fine sand (Pre-Design Work Plan, 1992).

A solvent-like odor and strong response on the field-screening instrument were noted upon the excavation of the area of the bright-grey material and associated contaminated gravel and sand (collectively referred to as the "waste-oil contamination"). These materials were excavated and removed from the trench to a sufficient degree to reduce breathing-zone concentrations to safe levels for workers. The location of the trench and extent of additional excavation in the vicinity of the grey material are shown in Figure 3-3.

Three samples of the contaminated grey material (SS1SA, SS1SMA, SS1SMB) were collected from the excavated spoil and analyzed for a variety of parameters. Analyses of these samples indicated contamination to be predominantly petroleum compounds with significant amounts of PCE (130,000 to 460,000 µg/kg), and more minor amounts bis(2-ethylhexyl)phthalate, pesticides and PCB. As discussed further below, additional analyses were performed on these samples to determine, more fully, their chemical character, and to investigate the likelihood that the PCE contamination detected in these samples was related to the DNAPL sampled from UC8.

Based on research concerning use of the Property prior to UniFirst's ownership, examining historical aerial photographs, and reviewing Massachusetts Highway Department files, it was determined that much of the

construction debris encountered in the trench excavation was left over from large-scale roadway construction (improvements to the Route 128–Washington Street interchange) immediately adjacent to the Property in 1961 and 1962. Based on evidence of surface-soil staining detected in a 1964 aerial photograph, which depicted a clear superposition of this staining with the location of the waste-oil contamination (see Figure 2-2), it was hypothesized that the origin of the waste-oil contamination was some kind of surface release that had occurred about the time of the Route 128 road work. Thus, the immediate area of the excavated grey material and the area of the surface staining noted in the 1964 photograph became the focus of further investigations, as discussed below.

Soil-Vapor Survey and Excavation of Test Pits F&G—September, 1992

Due to the suspicion that the low soil-gas survey results in May 1992 could have been unrepresentative of site conditions and the discovery of the waste-oil contamination during trenching, an additional soil-gas survey was conducted in September 1992. Although the waste-oil contamination (which was not known of in May) was located less than 30-feet away from soil vapor probe SV2, no indication of a nearby vapor source zone was evident from the vapor-survey results. To understand better the influence of this zone on the soil-gas conditions, four additional vapor probes (SV10–SV13) were first installed immediately adjacent to the area where the waste-oil contamination had been encountered in the trench, and in the location where two additional test pits were to be excavated. A Property-wide soil-gas survey was then conducted including the new soil-gas probes as well as previously-installed probes including vapor probes VB2 and VB3.

Concentrations of PCE in the soil gas from the new probes, which had been placed essentially within a known area of significant contamination, the waste-oil contamination, were quite high (75 to 435 ppmv). Vapor concentrations, however, dropped off by about 2 orders of magnitude within a distance of 10-feet to VB2. Examination of the Property-wide soil-vapor concentrations showed higher concentrations than reported for the May 1992 round, but the pattern of soil contamination was similar. Vapor concentrations in excess of 50 ppmv were limited to the probes within the waste-oil contamination area. The remaining results exhibited a trend of decreasing concentrations to the southwest as shown in Figure 3-4.

Two test pits (TPF and TPG) were excavated immediately adjacent to the backfilled area of the trench where the waste-oil contamination had been discovered to look for additional signs of contamination and provide additional samples for chemical characterization. No large continuous areas of DNAPL contamination, as identifiable by appearance, odor, or field screening, were found in either test pit, but two very small lenses

(approximately 1 foot by 0.5 ft in size in size) of grey medium to coarse sand were identified in the two test pits. The small lens of grey sand in TPF exhibited obvious contamination as indicated both by odor and field screening. These two small lenses were selectively sampled (samples TPF1A and TPG1A) and additional unconsolidated-deposits samples were collected along vertical profiles from each end of both test pits.

Both methanol-preserved and standard samples were collected for VOC analyses for all samples for comparison, and samples were also collected for SVOC analyses from the two lenses of grey sand. Concentrations of PCE in excess of 60,000 µg/kg, which are indicative of residual DNAPL, were only indicated in two samples (TPF1A and TPG7A) in the immediate area of where the waste-oil contamination had been discovered. Concentrations in the remaining samples ranged from non-detect to 47,000 µg/kg PCE (Figures 3-5 and 3-6). For samples TPF1A and TPG1A, higher concentrations (35,000,000 µg/kg and 14,000 µg/kg) were obtained for the standard, rather than methanol-preserved samples. This is believed to reflect the effect of spatial variability in the presence of residual in pore spaces on sampling and analysis. Hypothetically, by analyzing a 5-gram subsample collected by the standard method, which actually happens to contain a residual DNAPL film, a higher concentration may result than by extracting the entire sample in methanol which, in effect, averages any residual DNAPL liquid present over the entire 250-gram soil sample. For all other samples, the methanol-preserved method resulted in greater contaminant recovery. The PCE concentrations summarized in Figures 3-5 and 3-6 represent the results for the methanol-preserved samples, but the results for the standard samples for TPFIA and TPGIA are also shown since they were higher than the methanol result in those two cases.

Initial analyses of TPF1A and TPG1A for semi-volatile organics indicated the presence of bis(2-ethylhexyl)phthalate. Subsequently, a subset of samples from these test pits along with the waste-oil contamination sample SS1SA were re-analyzed for semi-volatile compounds, pesticides and PCB. Detectable concentrations of bis(2-ethylhexyl)phthalate were reported for 7 samples, and detectable PCB concentrations were reported for 5 samples.

The waste-oil contamination area, although not large, was the first evidence of an area on the Property that might have represented a release area for a significant amount of PCE and constituted a source of contamination to the unconsolidated deposits. This discovery necessitated re-examination of the conceptual model for the Property. The presence of the waste-oil contamination area led to further questions about the possibility that the release area for the DNAPL detected previously in UC8 was actually within the waste-oil contamination area and a result of the release that caused the waste-oil contamination, instead of previously-hypothesized releases into the dry well that was located in the old loading pit near UC8. The dry well had

been tentatively identified as the most likely point of entry of DNAPL to the bedrock absent any indications of surface releases outside the loading dock. Discovery of an apparent surface release area in the northeast corner of the Property resulted in a reassessment of the conceptual model for contaminant distribution.

Test Pit H, Surface Sample TPI, and Petroleum-Hydrocarbon Characterization Study: July 1993—January 1994.

A comparison of the results of the chemical analyses of samples from the waste-oil contamination area to an earlier analysis of a sample of DNAPL recovered from UC8 indicated a marked chemical similarity between the samples from the two locations. Therefore, a program was undertaken in the summer of 1993 to determine whether the contamination in the waste-oil contamination area was more likely the source of the DNAPL encountered in UC8 rather than previously-hypothesized releases into the old dry well. The program consisted of test-pit excavation and sampling, and an analytical program that included a detailed characterization of the petroleum-hydrocarbon fractions of unconsolidated deposits, samples of bituminous-concrete pavement, and an archived sample of the UC8 DNAPL (January and March 1994 Interim Data Reports). The purpose of the program was to determine: if any evidence existed for a surface release of DNAPL in the immediate vicinity of UC8, as had been initially hypothesized; if a chemical similarity existed between the UC8 DNAPL and samples from the waste-oil contamination area, based on characterization of the petroleum hydrocarbons; and if the character of the asphalt from the bituminous-concrete pavement in the area of the former loading dock was such that the presence of petroleum compounds detected in the UC8 DNAPL could have been derived from percolating through it or across it and into the dry well.

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Test pit H (TPH) was excavated within the loading dock immediately adjacent to UC8 to observe and sample, with greater clarity than provided in UC8, the unconsolidated deposits in the vicinity of the dry well between the current loading dock floor and the pavement of the former loading pit, and immediately under this pavement. The second purpose of the test pit was to allow collection of a sample of the now buried bituminous-concrete pavement layer. To investigate the possibility that a surface release may have occurred in the vicinity of the PCE-tank fill pipe and may have migrated to UC8, a sample of the current surface pavement layer was also collected at location TPI in front of the current loading dock. The TPI sample was collected from one of the remaining scars in the pavement, similar to that at location Test Pit 1 (TP1). An unconsolidated-deposits sample from immediately beneath the pavement at location TPI was also submitted for VOA analysis.

Field screening of TPH and laboratory analyses of unconsolidated-deposits samples collected from the artificial fill between the current loading-dock floor and the former loading-pit pavement, and from immediately below this pavement, provided no indication of DNAPL residual within the unconsolidated deposits, which would indicate an unsaturated-zone release at the former loading dock. The test pit was excavated to a total depth of 5.5 feet, just below the approximate depth of the seasonal high for the water table. Contamination by PCE was indicated, but at low to moderate levels (approximately 270 µg/kg to 3400 µg/kg) and exhibited a general trend of increasing concentration with depth, consistent with a source of this contamination within the shallow groundwater zone.

A comparison of the results of the petroleum-hydrocarbon-characterization ("fingerprinting") analyses for unconsolidated-deposits samples from the waste-oil contamination and the UC8 DNAPL indicated that they had the same chemical signature. Furthermore, a comparison of these results to the analysis of the pavement samples from TPH and location TPI indicated that the asphaltic fraction of the hydrocarbons in the unconsolidated deposits in the waste-oil-contamination area, and the UC8 DNAPL sample were not derived from leaching through the on-Property pavement (January 1994 Interim Data Report).

At location TPI, the sample of the artificial fill from immediately beneath the pavement layer yielded a PCE concentration (120,000 µg/kg) indicative of residual DNAPL. The fact that DNAPL had not been detected based on visual staining, odor, or field screening, and no similar concentrations were detected in TPD approximately 10 feet away, suggests that the amount of residual present was probably quite small with little lateral extent. The vertical extent of this contamination was subsequently investigated further, as discussed below, by means of excavation and sampling Test Pit M.

In addition to the PCE detected in the TPI samples, it is significant that TCA was also detected at an appreciable concentration (8500 µg/kg). The presence of TCA in this sample was consistent with the finding of TCA in other samples from the area immediately south of the current loading dock, as discussed earlier. TCA was not detected, however, in any of the unconsolidated deposits from other parts of the Property including the waste-oil contamination area and TPH. Re-analysis of the UC8 DNAPL sample indicated that TCA was present only in minute quantities. Thus, whereas the UC8-DNAPL and waste-oil contamination showed matching chemical signatures, the chemical signature of PCE associated with TCA is unique to the area in front of the current loading dock.

The findings from these investigations following discovery of the waste-oil contamination area, taken together with the information already generated, provided for a logical revision of the conceptual model for contamination at

the Property from that originally proposed. The absence of an indication of any surface release in the unconsolidated deposits adjacent to UC8, the presence of a known release area of the same chemical character in the waste-oil contamination area, and the absence of a similarity of chemical signature to contaminated samples south of the current loading dock provided strong indication that the source of the DNAPL within the fractured bedrock at UC8 was the material released in the waste-oil contamination area. The indication of small, discontinuous occurrences of DNAPL residual in the area immediately south of the current loading dock, with a distinctive signature of TCA associated with PCE contamination, suggested that a separate release occurred in that location.

3.3.5 Additional Site Characterization and Assessment of Prognosis for SVE

Following the unanticipated discovery of the waste-oil contamination area in August, 1992, and its correspondence to a location of surface staining appearing on a 1964 aerial photograph, an extensive review of all available historical aerial photographs was undertaken to determine if any other areas of potential surface releases might be present on the Property. No other areas were identified, and excavation of a continuous trench along the entire length of the north and west Property boundaries, for installation of the discharge lines from the treatment plant to the municipal sewer, failed to encounter any additional zones of contamination.

In 1993, as important refinements to the conceptual model for source areas and the nature of contamination at the Property discussed above were emerging in light of the findings of the petroleum-hydrocarbon-characterization study and the excavation of TPH, UniFirst presented these findings in meetings with the EPA. At that time UniFirst re-asserted its opinion that it was not practicable to achieve the specified remediation of the contaminated unconsolidated deposits beneath the Property using soil-vapor extraction. In response to requests from the EPA to develop more detailed Property-specific information, UniFirst undertook additional studies in late 1993 and in the spring of 1994 to develop the necessary information to support its opinions further and satisfy the EPA's requests (March and June 1994 Interim Data Reports).

REDACTED

These additional investigations focused on: refining further the understanding of the nature and extent of contamination on the Property; providing more Property-specific data on characteristics such as permeability, bulk density and moisture content; and attempting to locate an area on the Property where it would be useful to undertake a pneumatic permeability test and subsequently a pilot-scale SVE test.

Borings and Test Pits J, K, and L—December 1993

To investigate further the potential extent of contamination within the waste-oil contamination area, two borings (UC27 and UC28) were augered and three test pits (TPJ, TPK, and TPL) were excavated within the portion of the stained area appearing on the 1964 photograph that had not already been investigated, excavated during the treatment plant construction, or excavated during construction of the loading dock east of building B or the retaining wall. The three test pits were located between the identified waste-oil-contamination area and UC8, including one location (TPL) inside the loading dock. All three test pits were excavated to the top of bedrock. One of the purposes of these test-pits was to determine whether there was any evidence suggesting that the DNAPL detected in the waste-oil-contamination area had migrated laterally within the unconsolidated deposits, or on top of the bedrock surface towards the location of UC8. That is, the excavations were designed to determine whether it was reasonable to infer that residual DNAPL that might represent an appropriate "target" for SVE existed within a more-or-less continuous zone between the waste-oil contamination area and UC8.

No obvious signs of DNAPL contamination based on field-screening, odors, or visual evidence were encountered in any of the test pits. VOC analysis of samples from the three test pits also confirmed very low levels of PCE contamination, ranging from non-detect to 170 µg/kg. PCE was reported at below the detection limit for boring UC28. The only elevated PCE concentration reported for these investigations was from a sample at 3.5 to 4.0 feet depth in boring UC27, immediately adjacent to the area of waste-oil contamination previously excavated from the influent-line trench from UC22. A sample near the top of bedrock at this location (10 to 11 feet depth) exhibited a concentration of only 620 µg/kg.

Geologic logging of the test pits demonstrated the same extreme spatial variability in the character of the unconsolidated deposits as seen in previous explorations beneath the Property. Vertical and lateral sequences of samples were collected for physical analyses including permeameter analyses, moisture content, grain-size distribution and specific gravity (grain density). The significance of the results of these analyses to the prognosis for soil-vapor extraction is discussed in Section 5.0.

The results of these borings and test pits provided no evidence of lateral transport of DNAPL within the unconsolidated deposits or along the top of the bedrock surface toward UC8, and no continuous zone of soil contamination extending from the previously excavated waste-oil-contamination area was identified. The only significant contaminant levels were obtained from an area immediately adjacent to the original influent

trench excavation where it is likely that some small areas of contaminated material, such as seen in test pits F and G, still exist. Therefore, consistent with the expectations based on the lack of laterally continuous confining layers in the unconsolidated deposits, and the fractured nature of the upper bedrock in the area, the conceptual model was refined to reflect the opinion that the DNAPL had penetrated into the fractured bedrock in the immediate area beneath the waste-oil contamination area and had migrated to the location of UC8 within the highly fractured bedrock.

Installation and Sampling of Groundwater Monitoring Wells —December 1993 to February 1994

Eight groundwater monitoring wells were installed at four locations (UC26, UC29, UC30, and UC31) in the unconsolidated deposits in December, 1993 to augment the existing network of monitoring wells that would allow for monitoring of water levels and water-quality sampling. Split-spoon samples collected during the borings for these installation were field screened for the presence of volatile organic compounds and none were indicated.

One purpose for installation of these wells was to permit better control on mapping the extent of the shallow, groundwater-contaminant plume beneath the Property. By determining the extent of shallow groundwater contamination on the Property, potential areas that might be acting as a source of that contamination could be identified. This rationale was used to allow selection of the most logical places beneath the UniFirst building to advance borings in search of any indications of DNAPL sources in the unsaturated deposits underlying the building, as discussed below. Sampling of the newly-installed wells was conducted in January and February of 1994 (March 1994 Interim Data Report).

Analysis of the groundwater samples from the shallow, unconsolidated-deposits wells indicated a southwest-trending contaminant plume. The PCE concentrations obtained from the 1994 groundwater sampling generally decreased from a high of 1000 µg/L in well UC25 southwestward across the Property to a low of 2 µg/L in well UC31S (Figure 3-7). The shallow plume results are consistent with a source of contamination in the bedrock in the vicinity of the east end of the UniFirst building/loading dock areas. No other areas of contamination acting as a source to groundwater were suggested by these results.

Beneath the Building Borings —March-April, 1994.

Results from excavation of December 1993 test pits TPK and TPL provided no indication of contamination extending beneath the UniFirst building from

the waste-oil contamination area. Furthermore, the pattern of contamination exhibited in shallow groundwater, including a level of 1000 µg/L in UC25, suggested a hydraulically upgradient source of PCE contamination consistent with the area on the east end of the Property containing DNAPL within the fractured bedrock at a shallow depth below the water table. To test the conceptual model further, however, additional borings were drilled beneath the UniFirst building to look for any evidence of unsaturated zone DNAPL sources that might be contributing to groundwater contamination. Therefore, in March and April, 1994, five borings (UC32 through UC36) were advanced beneath the building upgradient of the shallow plume of groundwater concentrations mapped within the unconsolidated deposits, between the east end of the UniFirst building and UC25.

These borings were continuously sampled by driving a split spoon ahead of the casing. All split-spoon samples were field-screened by headspace analysis using an OVM. In addition, 17 samples were selected, based on field screening results or proximity to the bedrock contact and submitted for laboratory analysis for VOC. Samples collected from the borings were also submitted for moisture-content and grain-size-distribution analyses to expand the database of Property-specific physical parameters to locations beneath the building. Following completion of the borings, narrow-diameter monitoring wells (1-inch i.d.) were installed within the borings for possible use as vapor monitoring points or ground-water monitoring wells, depending on the level of the water table, should they be required at a later date.

PCE concentrations obtained from these laboratory analyses ranged from non-detect to 8,900 µg/kg. No samples were obtained from these borings that, based on field screening of the split-spoon samples or laboratory analysis, provided indication of the presence of DNAPL beneath the building. Furthermore, the highest concentrations of PCE in the borings were obtained from locations UC34 and UC35, which are located along a line between UC25 and UC8 where high groundwater concentrations of PCE are expected to exist.

Excavation of Test Pit M—April, 1994

Having failed to find a substantial zone of DNAPL contamination remaining in the waste-oil-contamination area, and having failed to find indications of DNAPL residual or accumulations beneath the UniFirst building, further investigation was conducted in the area to the south of the current loading dock. In April 1994, a test pit was excavated in the location of the TPI sample, which had indicated the presence of a small amount of DNAPL residual, to determine if that contamination persisted with depth or over any significant lateral area that might be amenable to SVE.

Following removal of the surface pavement over the test pit, a small stained area of soil was identified. Sampling and laboratory analysis of the material excavated from this shallow zone (sample TPM1A) yielded a concentration of 2,500,000 µg/kg. Other samples from the test pit ranged in PCE concentration from approximately 88 µg/kg to 320,000 µg/kg, with the samples exhibiting concentrations in excess of 60,000 µg/kg being limited to the upper 8 inches below the pavement. The compound TCA was also detected in two of the samples. Three samples were also collected for physical analysis (moisture content, permeameter analysis, bulk-density measurements, and grain-size distribution) from locations coincident with chemical analysis samples TPM2A, TPM3A, and TPM4A.

The results of the samples from TPM are consistent with earlier findings from the area in front of the loading dock. Small amounts of residual DNAPL appear to be present within the small area immediately in front of the current loading dock, particularly in the shallow unconsolidated deposits beneath the pavement, but distribution of the contamination is very discontinuous and likely represents an extremely small volume of immiscible liquid.

3.4 Summary of Investigations

As described in the foregoing sections, an extensive series of investigations has been undertaken beneath the Property since contamination was first detected in the unconsolidated deposits in 1985. Initial studies focused on the vicinity of the loading dock on the east end of the Property and the reported location of a dry well associated with a loading dock that was part of an earlier configuration of the UniFirst building. Based on the known history of the Property, these areas had been identified as the most reasonable areas to look for evidence of possible surface releases that may have resulted in the noted unconsolidated-deposits contamination. However, while moderate soil contamination was encountered around the east end of the building, no indications of accumulations of residual DNAPL in the unconsolidated deposits was identified.

The lack of indications of surface release areas, the finding of free-phase DNAPL in the shallow bedrock at the location of UC8, and the existence of high levels of dissolved PCE in the shallow groundwater beneath the Property led to formulation of a new hypothesis: that the main source of VOC contamination to the unconsolidated deposits was the upward migration of contaminant vapors which partition from the contaminated groundwater underlying the Property. This conceptual model was supported by both on-Property testing and numerical modeling. During the on-Property investigations, UniFirst commenced the practice of methanol-preservation of unconsolidated-deposits to improve the recovery of VOC and, therefore, the representativeness of sample results.

REDACTED

Results of the numerical modeling study demonstrated that contamination of shallow groundwater in excess of 85 µg/L PCE could result in upward migration of vapors that could contaminate the unconsolidated deposits to the specified cleanup target within a period of a few years or less. This led to subsequent discussions between UniFirst and EPA regarding the concept of the appropriateness of sequencing of remedial actions for groundwater and the unconsolidated deposits beneath the Property and a "phased" remedy was proposed in the October 22, 1991 RDI Report.

Further phases of investigation within the unconsolidated deposits were undertaken, beginning in 1992, in response both to concerns expressed by the EPA, and to UniFirst's desire to expand further its conceptual model for contamination beneath the Property and address more fully questions of feasibility of remediation. These investigations incorporated a number of investigative techniques, but reflected an increased reliance on the use of test pits since they provided a means superior to borings or non-invasive techniques for identifying pertinent characteristics and collecting representative samples. Results of the investigations undertaken between 1992 and 1994 provided extensive and consistent evidence that the unconsolidated deposits beneath the Property are characterized by a high degree of spatial heterogeneity in texture, moisture content, and associated properties such as permeability. REDACTED REDACTED

Discovery of an area of debris and contamination during trenching in the northeast corner of the Property, and detection of some very high levels of PCE contamination at the south end of the current loading dock, resulted in the recognition that some residual DNAPL did occur in the unconsolidated deposits. Two small, separate and chemically-distinct release areas were identified: the waste-oil contamination area and the area south of the loading dock. Furthermore, chemical fingerprinting methods revealed that the DNAPL encountered in UC8 was derived from the waste-oil contamination area. Characterization of conditions near the bedrock (gabbrodiorite) surface revealed that in the vicinity of the east end of the Property where the release areas were located, the bedrock surface was irregular, slightly to highly weathered, and highly fractured. No evidence of significant migration or accumulation along the top of the bedrock surface was found. An extension of the investigations to the interior of the loading-dock area and beneath the UniFirst building found no indications of additional areas containing DNAPL. REDACTED REDACTED

Both physical and chemical characterization of the unconsolidated deposits was undertaken for the purpose of providing the data necessary to assess the prognosis for remedial activities, specifically SVE and infiltration. As

discussed in Section 5.0, these studies confirmed that a considerable degree of spatial variability of both physical properties and contaminant distribution existed that were deemed to be problematic for remediation.

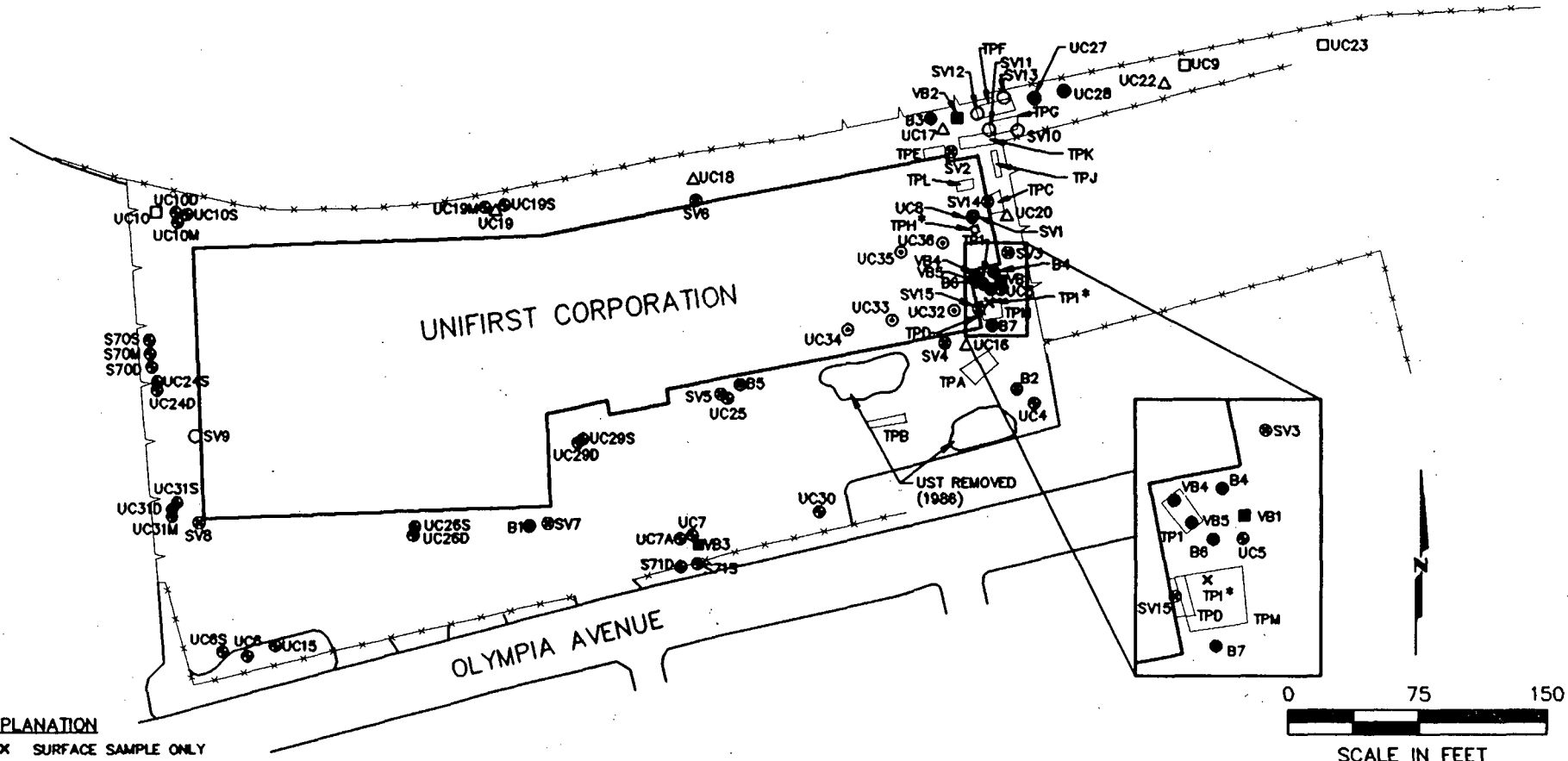


FIGURE 3-1

EXPLANATION

- × SURFACE SAMPLE ONLY
- TPB TEST PIT
- ● SOIL BORING
- □ MULTI-LEVEL BEDROCK MONITORING WELL
- ⊗ DRIVE POINT VAPOR PROBE LOCATION
- ○ FORMER DRIVE POINT VAPOR PROBE LOCATION
- ⊕ 2 INCH MONITORING WELL, S70 AND S71 ARE 1.5 INCH
- ■ VAPOR BORING (WINTER 1989)
- △ 6-INCH WELL OPEN IN ROCK; UC22 IS AN 8-INCH WELL
- ⊙ 1 INCH MONITORING WELL
- • APPROXIMATE LOCATION

NOTES:

1) LOCATIONS FROM A SURVEY BY BSC GROUP OF BOSTON, MA.
2) WELL TYPES FROM DRAWINGS BY ENSR CONSULTING & ENGINEERING
3) BASE MAP PRODUCED BY GEOTRANS, INC OF HARVARD, MA FROM AERIAL SURVEY BY COL-EAST, INC. OF NORTH ADAMS, MA.

ENSR

ENSR CONSULTING & ENGINEERING

BORING, VAPOR PROBE MONITORING WELL AND TEST-PIT LOCATIONS UNIFIRST PROPERTY

DRAWN BY:	DATE:	PROJECT NO.
M.D.F.	8/94	3140-024

3140A55B

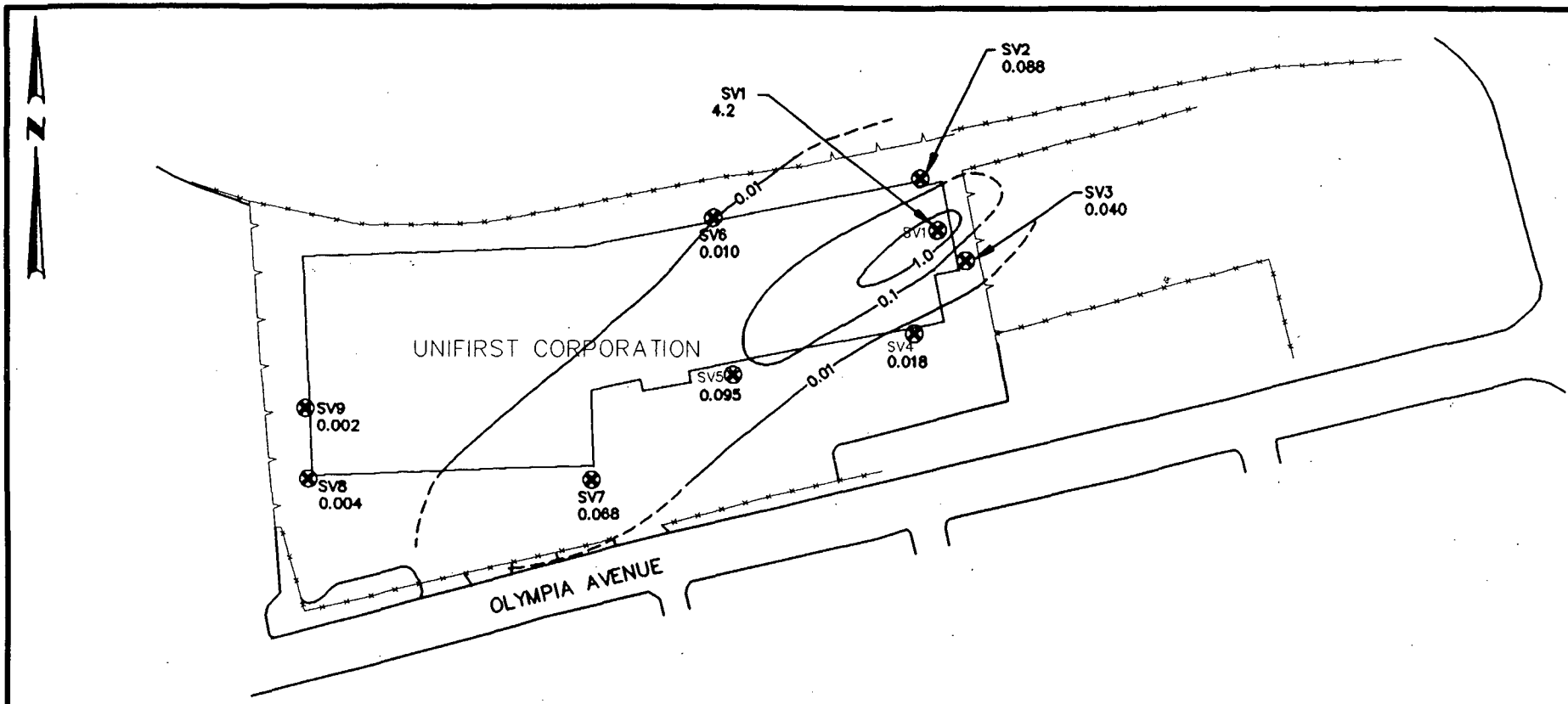


FIGURE 3-2

REV. 3-11/11/92 UD-MAP 12 BY: FD

ENSR CONSULTING & ENGINEERING

SHALLOW SOIL VAPOR PCE CONCENTRATIONS MAY 1992 UNIFIRST PROPERTY

DRAWN BY:	DATE:	PROJECT NO.
M.D.F.	8/94	3140-023

EXPLANATION

P-4.15 TETRACHLOROETHENE CONCENTRATION (PPMv)

⊗ DRIVE POINT VAPOR PROBE LOCATION

NOTES: 1) LOCATIONS FROM A SURVEY BY BSC GROUP OF BOSTON, MA.
2) WELL TYPES FROM DRAWINGS BY ENSR CONSULTING & ENGINEERING
3) BASE MAP PRODUCED BY GEOTRANS, INC OF HARVARD, MA FROM AERIAL SURVEY BY COL-EAST, INC. OF NORTH ADAMS, MA.
4) SOIL GAS CONTOURS IN CONCENTRATIONS OF PCE IN (ppmv)

0 75 150

SCALE IN FEET

3140A92B

3140A27A

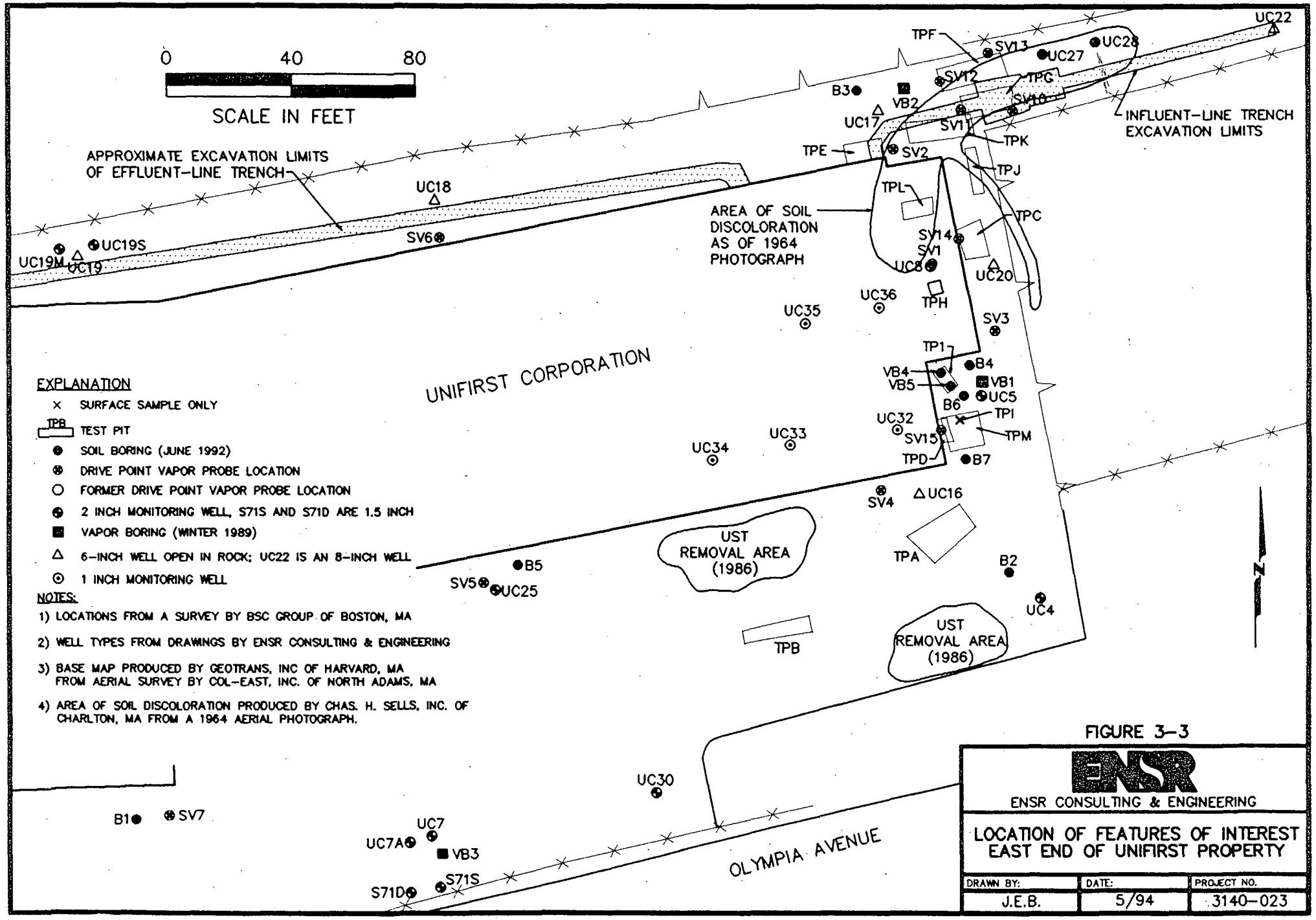
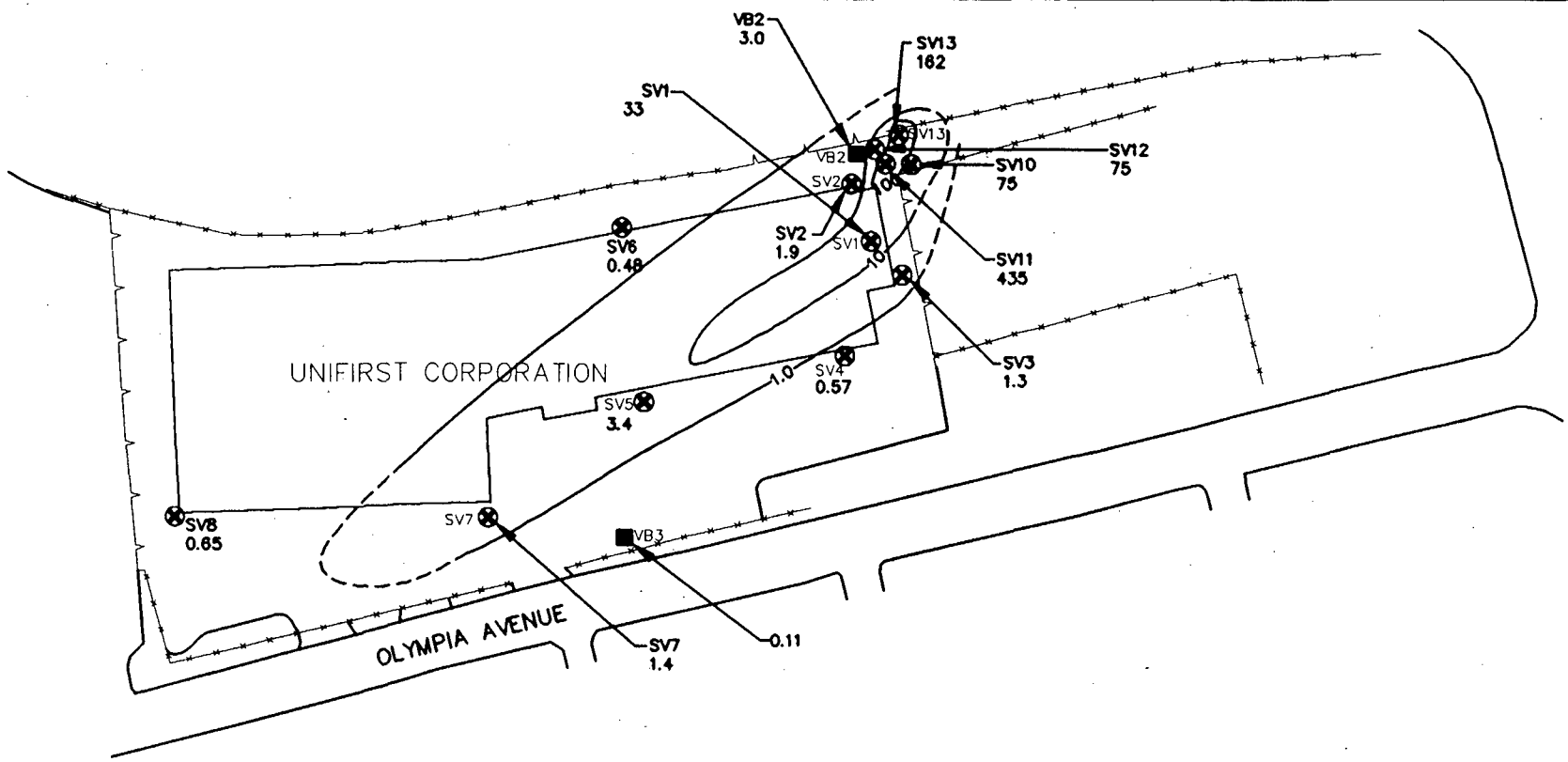


FIGURE 3-3



EXPLANATION

0.85 AVERAGED TETRACHLOROETHENE CONCENTRATION (PPMv)

⊗ DRIVE POINT VAPOR PROBE LOCATION

■ VAPOR BORING

NOTES: 1) LOCATIONS FROM A SURVEY BY BSC GROUP OF BOSTON, MA.
2) WELL TYPES FROM DRAWINGS BY ENSR CONSULTING & ENGINEERING
3) BASE MAP PRODUCED BY GEOTRANS, INC OF HARVARD, MA FROM AERIAL SURVEY BY COL-EAST, INC. OF NORTH ADAMS, MA.
4) SOIL-GAS CONTOURS IN CONCENTRATION IN (ppmv)

0 75 150
SCALE IN FEET

FIGURE 3-4

REV. 3-11/11/92 UD-MAP 15 BY: FD

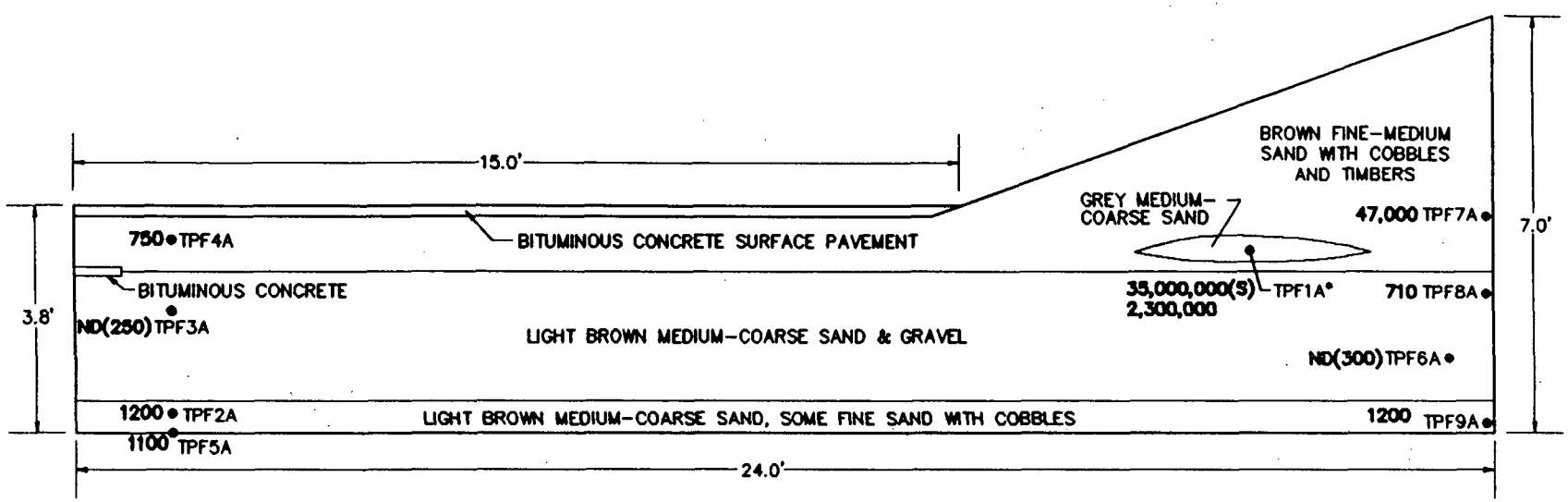
ENSR CONSULTING & ENGINEERING

SHALLOW SOIL VAPOR PCE CONCENTRATIONS SEPTEMBER 1992 UNIFIRST PROPERTY

DRAWN BY:	DATE:	PROJECT NO.
M.D.F.	8/94	3140-023

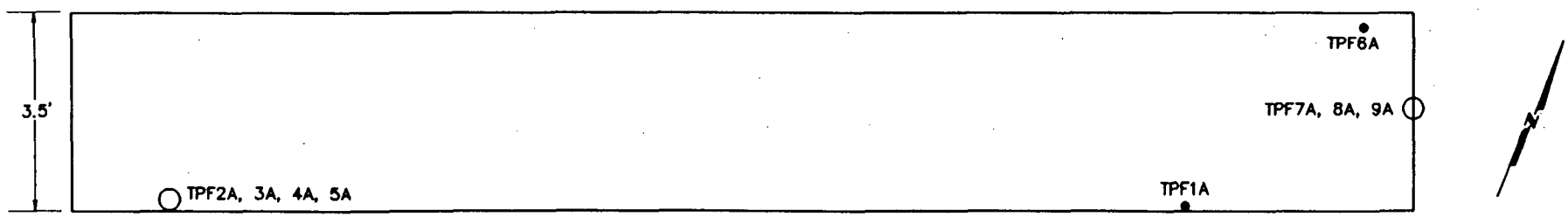
3140A91B

3140A33A



PROFILE VIEW

* OVM READING OF 50 IN AREA OF TPF1A



PLAN VIEW

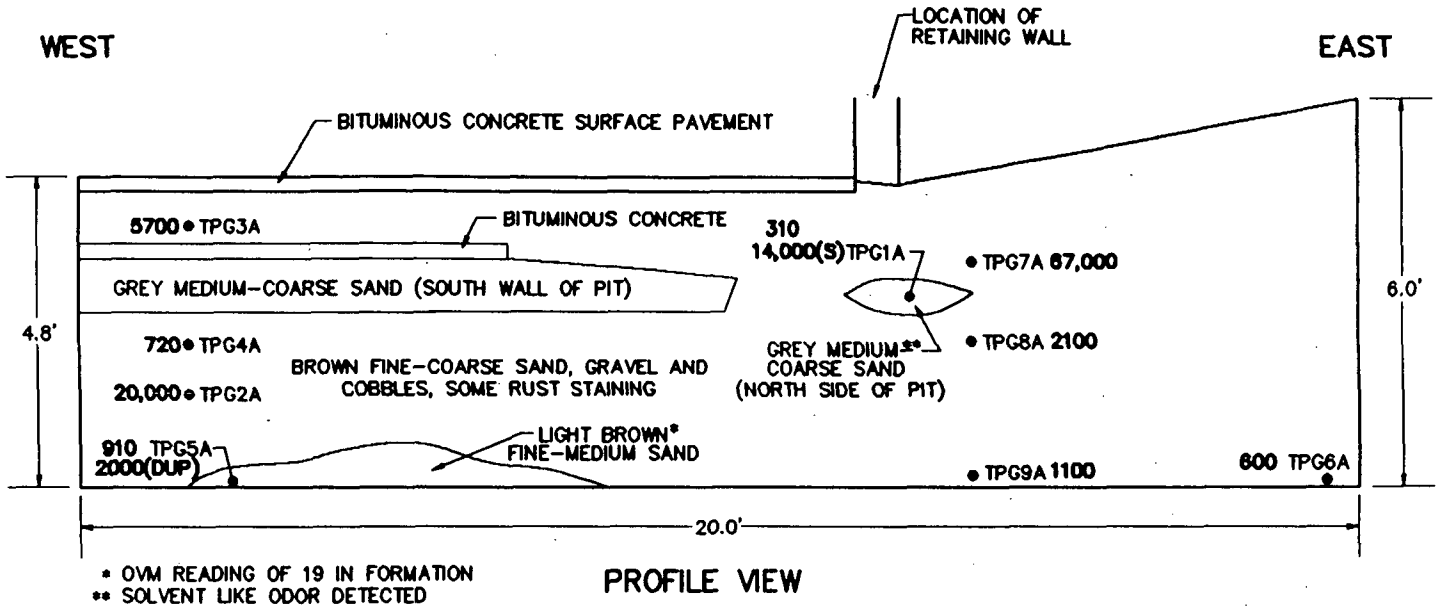
SCALE IN FEET
VERTICAL EXAGGERATION
1:1

NOTES:
1) ALL CONCENTRATIONS REPORTED IN ug/kg.
2) (S) -- RESULTS FOR (NON-METHANOL) METHOD.
3) ND(300) NON-DETECT AT A DETECTION LIMIT OF 300ug/kg.

FIGURE 3-5
PCE CONCENTRATIONS IN SAMPLES FROM TEST PIT F (ug/kg)

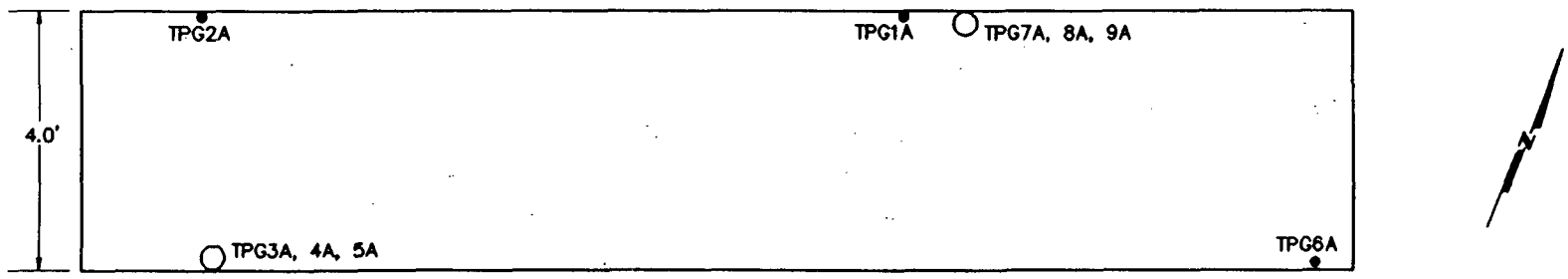
ENSR CONSULTING & ENGINEERING

3140A32A

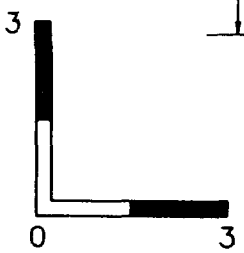


* OVM READING OF 19 IN FORMATION
** SOLVENT LIKE ODOR DETECTED

PROFILE VIEW



PLAN VIEW



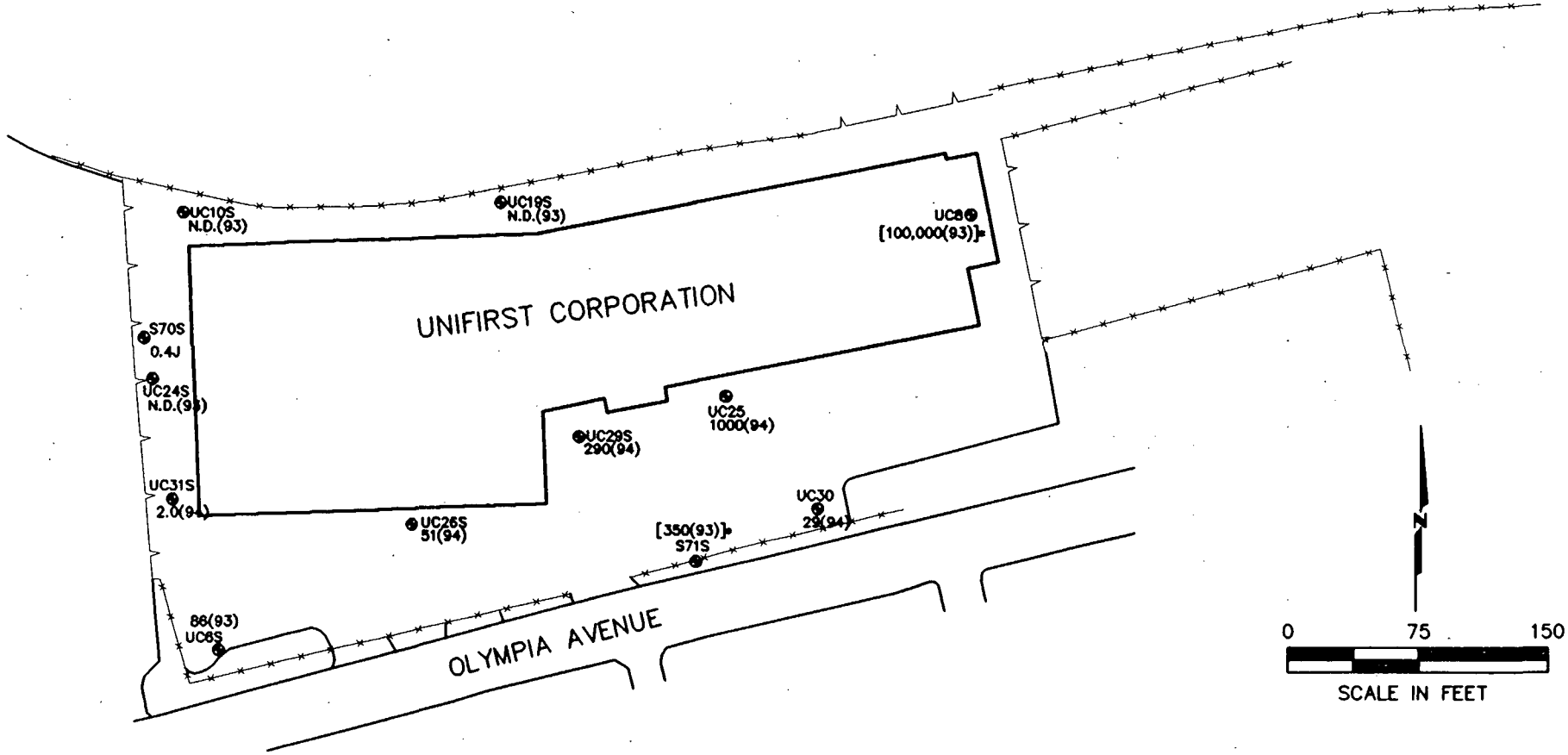
SCALE IN FEET
VETICAL EXAGGERATION
1:1

NOTES:

1) ALL RESULTS REPORTED IN ug/kg
2) (S) -- RESULT FOR STANDARD (NON-METHANOL) METHOD.

FIGURE 3-6
PCE CONCENTRATIONS IN SAMPLES FROM TEST PIT G (ug/kg)

ENSR CONSULTING & ENGINEERING



* WATER LEVEL NEAR OR BELOW TOP OF BEDROCK

FIGURE 3-7

ENSR CONSULTING & ENGINEERING

PCE CONCENTRATIONS IN SHALLOW, UNCONSOLIDATED DEPOSITS GROUNDWATER (ug/L) UNIFIRST PROPERTY

DRAWN BY:	DATE:	PROJECT NO.
M.D.F.	8/94	3140-024

EXPLANATION

⊕ 2 INCH MONITORING WELL, S70 AND S71 ARE 1.5 INCH
5(93) CONCENTRATION PCE IN ug/l (ppb), SAMPLED AUGUST 1993
5(94) CONCENTRATION PCE IN ug/l (ppb), SAMPLED JAN-FEB 1994

NOTES:

1) LOCATIONS FROM A SURVEY BY BSC GROUP OF BOSTON, MA.
2) WELL TYPES FROM DRAWINGS BY ENSR CONSULTING & ENGINEERING
3) BASE MAP PRODUCED BY GEOTRANS, INC OF HARVARD, MA FROM AERIAL SURVEY BY COL-EAST, INC. OF NORTH ADAMS, MA.

3140A90B

TABLE 3-1
UNIFIRST PROPERTY
UNCONSOLIDATED DEPOSITS
SAMPLING INVENTORY

Location	Sample I.D.	Depth (feet)	Date of Collection	Chemical Analyses							Physical Analyses					
				Standard VOC*	MeOH-Pres. VOC**	Semi-VOA	PCB/ Pesticide	Pet HC Fprint	Soil Vapor VOA	VOA by Field GC	% Organic Carbon	Specific Gravity	Grain-Size	Falling-Head Permeameter	Bulk Density	Moisture Content
SOIL BORINGS																
VB1	VB1-1	0.25-2.25	Feb-23-89	#	*											
	VB1-2	2.25-3.25	Feb-23-89	*	*											
VB2	VB2-1	0.25-2.25	Feb-23-89	#	*											
	VB2-2	2.25-4.25	Feb-23-89	#	*											
	VB2-3	4.25-5.25	Feb-23-89	#	*											
VB3	VB3-1	0.25-2.25	Feb-23-89	#	*											
	VB3-2	2.25-4.25	Feb-23-89	#	*											
	VB3-3	4.25-6	Feb-23-89	#	*											
	VB3-4	8-10	Feb-23-89	#	*											
	VB3-5	10-12	Feb-23-89	*	*											
	VB3-6	12-13	Feb-23-89	#	*											
VB4	VB4-1M	0.5-2	Mar-02-89		*											
	VB4-1	0.5-2	Mar-02-89	#												
	VB4-2M	2-3.75	Mar-02-89		*											
	VB4-2	2-3.75	Mar-02-89	#												
VB5	VB5-1M	0.5-2	Mar-02-89		*											
	VB5-1	0.5-2	Mar-02-89	#												
	VB5-2M	2-3	Mar-02-89		*											
	VB5-2	2-3	Mar-02-89	#												
B1	B1SAA	.05-2.5	Jun-18-92	*												
	B1MAA	.05-2.5	Jun-18-92		*											
	B1SBA	4.5-6.5	Jun-18-92	*												
	B1MBA	4.5-6.5	Jun-18-92		*											
B2	B2SAA	.05-2.5	Jun-18-92	*												
	B2MAA	.05-2.5	Jun-18-92		*											
	B2SBA	3.0-4.5	Jun-18-92	*												
	B2MBA	3.0-4.5	Jun-18-92		*											
B3	B3SAA	.05-2.5	Jun-18-92	*												
	B3MAA	.05-2.5	Jun-18-92		*											
	B3SBA	2.5-4.5	Jun-18-92	*												
	B3MBA	2.5-4.5	Jun-18-92		*											
B4	B4SAA	.05-2.5	Jun-18-92	*												
	B4MAA	.05-2.5	Jun-18-92		*											
B5	B5SAA	.05-2.5	Jun-19-92	*												
	B5MAA	.05-2.5	Jun-19-92		*											

* no methanol preservation
** samples preserved in the field in methanol
\# sample submitted to laboratory but not analyzed
| field GC analysis of headspace over a groundwater sample

TABLE 3-1
UNIFIRST PROPERTY
UNCONSOLIDATED DEPOSITS
SAMPLING INVENTORY

Location	Sample I.D.	Depth (feet)	Date of Collection	Chemical Analyses							Physical Analyses					
				Standard VOC*	MeOH-Pres. VOC**	Semi-VOA	PCB/ Pesticide	Pet HC Fprint	Soil Vapor VOA	VOA by Field GC	% Organic Carbon	Specific Gravity	Grain-Size	Falling-Head Permeameter	Bulk Density	Moisture Content
	B5SBA	4.5-6.5	Jun-19-92	*												
	B5MBA	4.5-6.5	Jun-19-92		*											
B6	B6SAA	.05-2.5	Jun-19-92	*												
	B6MAA	.05-2.5	Jun-19-92		*											
B7	B7SAA	.05-2.5	Jun-19-92	*												
	B7MAA	.05-2.5	Jun-19-92		*											
	B7SBA	2.5-3.7	Jun-19-92	*												
	B7MBA	2.5-3.7	Jun-19-92		*											
S71	SS-2	10-12	Feb-01-85							*						
	SS-3	15-17	Feb-01-85							*						
UC4	UC4-SS-1	0-2	Nov. '86	*												
UC5	UC5-SS-1	0-2	Nov. '86	*												
	UC5-SS-2	4-6	Nov. '86													
UC6	UC6-SS-1	0-2	Nov. '86	*												
	UC6-SS-2	2-4	Nov. '86	*												
	UC6-SS-3	4-6	Nov. '86	*												
	UC6-SS-4	18-20	Nov. '86	*												
UC7	UC7-SS-1A	2-4	Nov. '86	*												
	UC7-SS-2	4-6	Nov. '86	*												
	UC7-SS-3	6-6.5	Nov. '86	*												
UC15		5-10	Sept. '87	*												
UC16		2-5	Sept. '87	*												
UC17		2-5	Oct. '87	*												
UC18		2-10	Oct. '87	*												
UC19		3-6	Oct. '87	*												
UC20		3-6	Oct. '87	*												
UC27	C273A	4-6	Dec-03-93		*											
	C276A	10-12	Dec-03-93		*	*	*									
UC28	C281A	0-2	Dec-06-93		*											
	C284A	6-8	Dec-06-93		*	*	*						*			*
UC29	29D1A	0-2	Dec-07-93		*	*	*									
	29D3A	2-4	Dec-07-93		*	*	*									
	29D5A	8-10	Dec-07-93		*	*	*									
	29D5B	8-10	Dec-07-93		*											
UC30	C301A	0-2	Dec-08-93		*											
	C303A	4-6	Dec-08-93		*											
	C305A	8-10	Dec-08-93		*											

* no methanol preservation
** samples preserved in the field in methanol
\# sample submitted to laboratory but not analyzed
| field GC analysis of headspace over a groundwater sample

TABLE 3-1
UNIFIRST PROPERTY
UNCONSOLIDATED DEPOSITS
SAMPLING INVENTORY

Location	Sample I.D.	Depth (feet)	Date of Collection	Chemical Analyses							Physical Analyses					
				Standard VOC*	MeOH-Pres. VOC**	Semi-VOA	PCB/ Pesticide	Pet HC Fprint	Soil Vapor VOA	VOA by Field GC	% Organic Carbon	Specific Gravity	Grain-Size	Falling-Head Permeameter	Bulk Density	Moisture Content
	C307A	12-14	Dec-08-93		*											
UC32	32S1A	0.5-2	Mar-30-94													*
	32S2A	2-3.5	Mar-30-94										*			*
	32S3A	3.5-5.5	Mar-30-94													*
	32S4A	5.5-6.8	Mar-30-94													*
	C321A	0.5-2	Mar-30-94		*											
	C322A	2-3.5	Mar-30-94		*											
UC33	33S1A	0.5-2	Apr-4-94													*
	33S2A	2-3.5	Apr-4-94										*			*
	33S3A	3.5-5.5	Apr-4-94													*
	33S4A	5.5-7.5	Apr-4-94													*
	33S5A	7.5-9.0	Apr-5-94													*
	33S6A	9.0-10.5	Apr-5-94													*
	33S7A	10.5-11.25	Apr-5-94													*
	C331A	2-3.5	Apr-4-94		*											
	C332A	5.5-7.5	Apr-5-94		*											
	C333A	9-10.5	Apr-5-94		*											
	C334A	10.5-11.25	Apr-5-94		*											
UC34	34S1A	3-4.5	Apr-7-94										*			*
	34S2A	4.5-6	Apr-7-94													*
	34S3A	6-8	Apr-7-94													*
	34S4A	9-11	Apr-7-94										*			*
	34S5A	11-12.9	Apr-7-94													*
	C341A	3-4.5	Apr-7-94		*											
	C342A	9-11	Apr-7-94		*											
UC35	35S1A	0.5-2	Apr-12-94										*			*
	35S2A	2-3.5	Apr-12-94													*
	35S3A	3.5-5.5	Apr-12-94													*
	35S4A	5.5-7	Apr-12-94										*			*
	35S5A	7.5-8.5	Apr-12-94													*
	35S6A	8.5-9.35	Apr-13-94													*
	C351A	0.5-2	Apr-12-94		*											
	C352A	2-3.5	Apr-12-94		*											
	C352B	2-3.5	Apr-12-94		*											
	C353A	5.5-7	Apr-12-94		*											
	C354A	8.5-9.35	Apr-13-94		*											
UC36	36S1A	0.5-2	Apr-13-94													*

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TABLE 3-1
UNIFIRST PROPERTY
UNCONSOLIDATED DEPOSITS
SAMPLING INVENTORY

Location	Sample I.D.	Depth (feet)	Date of Collection	Chemical Analyses							Physical Analyses					
				Standard VOC*	MeOH-Pres. VOC**	Semi-VOA	PCB/ Pesticide	Pet HC Fprint	Soil Vapor VOA	VOA by Field GC	% Organic Carbon	Specific Gravity	Grain-Size	Falling-Head Permeameter	Bulk Density	Moisture Content
	36S2A	2-3.5	Apr-13-94										*			*
	36S3A	3.5-5	Apr-13-94													*
	36S4A	5-6.5	Apr-13-94										*			*
	36S5A	6.5-7.7	Apr-13-94													*
	C361A	0.5-2	Apr-13-94		*											
	C362A	3.5-5	Apr-13-94		*											
	C363A	5-6.5	Apr-13-94		*											
	C364A	6.5-7.7	Apr-13-94		*											
WASTE-OIL CONTAMINATION																
	SS1MA	spoil pile	Aug-31-92		*											
	SS1MB	spoil pile	Aug-31-92		*											
	SS1SA	spoil pile	Aug-31-92	*		*		*								
TEST PITS																
TP1		3	Dec-4-86													
TPA	TPA27	2.25	May-13-92								*			*		*
	TPA37	3.08	May-13-92								*			*		*
	TPA44	3.67	May-13-92								*			*		*
	TPA74	6.17	May-13-92								*					
TPB	TPB27	2.25	May-13-92								*			*		*
	TPB37	3.08	May-13-92								*			*		*
	TPB44	3.67	May-13-92								*			*		*
TPC	TPC1A	4.8	Jul-31-92		*											
	TPC2A	4.6	Jul-31-92		*											
	TPC3A	2.2	Jul-31-92		*											
	TPC4A	3.8	Jul-31-92		*											
TPD	TPD1A	5.2	Jul-31-92		*											
	TPD1B	5.2	Jul-31-92		*											
	TPD2A	3.9	Jul-31-92		*											
	TPD3A	2.5	Jul-31-92		*											
TPE	TPE1A	3.7	Aug-24-92		*											
	TPE2A	3.7	Aug-24-92		*											
	TPE3A	2.45	Aug-24-92		*											
	TPE4A	1	Aug-24-92		*											

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TABLE 3-1
UNIFIRST PROPERTY
UNCONSOLIDATED DEPOSITS
SAMPLING INVENTORY

Location	Sample I.D.	Depth (feet)	Date of Collection	Chemical Analyses							Physical Analyses					
				Standard VOC*	MeOH-Pres. VOC**	Semi-VOA	PCB/ Pesticide	Pet HC Fprint	Soil Vapor VOA	VOA by Field GC	% Organic Carbon	Specific Gravity	Grain-Size	Falling-Head Permeameter	Bulk Density	Moisture Content
	TPE4B	1	Aug-24-92		*											
	TPE5A	3.7	Aug-24-92		*	*										
TPF	TPF1A	2.5	Sep-22-92	*	*	*		*								
	TPF2A	3.5	Sep-22-92	*	*											
	TPF3A	1.7	Sep-22-92	*	*											
	TPF4A	0.6	Sep-22-92	*	*											
	TPF5A	3.9	Sep-22-92	*	*											
	TPF6A	5.5	Sep-22-92	*	*											
	TPF7A	3.5	Sep-22-92	*	*											
	TPF8A	4.5	Sep-22-92	*	*											
	TPF9A	6.9	Sep-22-92	*	*											
TPG	TPG1A	2	Sep-22-92	*	*	*		*								
	TPG1B	2	Sep-22-92			*		*								
	TPG2A	3.3	Sep-22-92	*	*			*								
	TPG3A	0.8	Sep-22-92	*	*			*								
	TPG4A	2.6	Sep-22-92	*	*			*								
	TPG5A	4.8	Sep-22-92	*	*			*								
	TPG5B	4.8	Sep-22-92	*	*			*								
	TPG6A	6	Sep-22-92	*	*			*								
	TPG7A	1.5	Sep-22-92	*	*			*								
	TPG8A	2.9	Sep-22-92	*	*			*								
	TPG9A	7.3	Sep-22-92	*	*			*								
TPH	TPH1A	0.5	Jul-24-93		*											
	TPH1B	0.5	Jul-24-93			*		*								
	TPH2A	4.6	Jul-24-93		*											
	TPH2B	4.6	Jul-24-93			*		*								
	TPH3B	4.6	Jul-24-93					*								
	TPH4B	4.6-4.8	Jul-24-93					*								
	TPH5B	4.6-4.8	Jul-24-93					*								
	TPH6B	4.6-4.8	Jul-24-93					*								
	TPH7B	4.6-4.8	Jul-24-93					*								
	TPH8B	4.8	Jul-24-93			*		*								
	TPH9A	4.8	Jul-24-93		*											
	TPH10B	5.5	Jul-24-93			*		*								
	TPH11A	5.5	Jul-24-93		*											
TPI	TPI1A	0.5	Jul-24-93		*											
	TPI1B	SURFACE	Jul-24-93					*								

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TABLE 3-1
UNIFIRST PROPERTY
UNCONSOLIDATED DEPOSITS
SAMPLING INVENTORY

Location	Sample I.D.	Depth (feet)	Date of Collection	Chemical Analyses							Physical Analyses					
				Standard VOC*	MeOH-Pres. VOC**	Semi-VOA	PCB/ Pesticide	Pet HC Fprint	Soil Vapor VOA	VOA by Field GC	% Organic Carbon	Specific Gravity	Grain-Size	Falling-Head Permeameter	Bulk Density	Moisture Content
	TPI2B	SURFACE	Jul-24-93					*								
	TPI3B	SURFACE	Jul-24-93					*								
	TPI4B	0.3	Jul-24-93					*								
	TPI5B	0.5	Jul-24-93			*		*								
	TPI6B	0.2	Aug-04-93					*								
	TPI7B	0.2	Aug-04-93					*								
TPJ	TPJ1A	3	Dec-02-93		*							*	*	*	*	*
	TPJ2A	3	Dec-02-93										*	*		*
	TPJ3A	4.5	Dec-02-93										*			*
TPK	TPK1A	1.8	Dec-02-93										*	*	*	*
	TPK2A	2.8	Dec-02-93										*	*	*	*
	TPK3A	3.3	Dec-02-93									*	*	*	*	*
	TPK4A	4.1	Dec-02-93										*	*	*	*
	TPK5A	4.8	Dec-02-93										*	*	*	*
	TPK6A	2	Dec-02-93									*	*		*	*
	TPK7A	4	Dec-02-93										*		*	*
	TPK8A	1.5	Dec-02-93										*		*	*
	TPK9A	3.8	Dec-02-93										*		*	*
	PK10A	4.4	Dec-03-93		*	*	*					*	*	*	*	*
	PK10B	4.4	Dec-03-93		*	*	*									
	PK11A	2.9	Dec-03-93		*								*	*		*
	PK12A	1.9	Dec-03-93		*								*	*		*
TPL	TPL1A	3.2	Dec-03-93		*								*	*	*	*
	TPL2A	1.8	Dec-03-93										*	*		*
	TPL3A	1.4	Dec-03-93									*	*	*	*	*
	TPL4A	2.1	Dec-03-93		*	*	*						*	*	*	*
	TPL5A	3.7	Dec-03-93		*											
TPM	TPM1A	0.5-1.2	Apr-25-94		*	*										
	TPM2A	4	Apr-25-94		*								*	*	*	*
	TPM3A	2	Apr-25-94		*								*	*	*	*
	TPM4A	0.06	Apr-25-94		*								*	*	*	*
	TPM4B	0.06	Apr-25-94		*											
	TPM5A	0.5	Apr-25-94		*											
	TPM6A	2	Apr-25-94		*											
	TPM7A	4	Apr-25-94		*											

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TABLE 3-1
UNIFIRST PROPERTY
UNCONSOLIDATED DEPOSITS
SAMPLING INVENTORY

Location	Sample I.D.	Depth (feet)	Date of Collection	Chemical Analyses							Physical Analyses					
				Standard VOC*	MeOH-Pres. VOC**	Semi-VOA	PCB/ Pesticide	Pet HC Fprint	Soil Vapor VOA	VOA by Field GC	% Organic Carbon	Specific Gravity	Grain-Size	Falling-Head Permeameter	Bulk Density	Moisture Content
SOIL-VAPOR PROBES																
VB1	3289-3	3.25	Mar-02-89						*							
VB2	3289-4	5	Mar-02-89						*							
	VB2	5	Sep-23-92						*							
VB3	3289-5	10	Mar-02-89						*							
	3289-6	10	Mar-02-89						*							
VB3	VB3	10	Sep-23-92						*							
SV1	SV1A	2	May-22-92						*							
	SV1B	4	May-22-92						*							
	SV1B	4	Sept-21-92						*							
	SV1C	6	May-22-92						l							
SV2		4	May-27-92						*							
		4	Sept-21-92						*							
SV3		4	May-27-92						*							
		4	Sept-22-92						*							
SV4		4	May-27-92						*							
		4	Sept-22-92						*							
SV5		4	May-27-92						*							
		4	Sept-22-92						*							
SV6		4	May-27-92						*							
		4	Sept-22-92						*							
SV7		4	May-27-92						*							
		4	Sept-22-92						*							
SV8		4	May-27-92						*							
		4	Sept-22-92						*							
SV9		4	May-27-92						*							
SV10		6	Sept-21-92						*							
SV11		3.5	Sept-21-92						*							
SV12		4.5	Sept-21-92						*							
SV13		6	Sept-21-92						*							

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** samples preserved in the field in methanol
# sample submitted to laboratory but not analyzed
l field GC analysis of headspace over a groundwater sample

TABLE 3-2

UNIFIRST PROPERTY

UNCONSOLIDATED-DEPOSITS RESULTS FOR SELECTED VOC

METHANOL-PRESERVED SAMPLES

Location	Sample I.D.	Depth (ft)	Date of Collection	Lab Method	Concentrations (ug/kg)							
					PCE	TCE	1,1,1-TCA	cis-DCE	t-DCE	1,1-DCA	1,2-DCA	VC
SOIL BORINGS												
B1	B1MAA	.05-2.5	Jun-18 -92	8010	330	43 U	43 U	43 U	43 U	43 U	43 U	43 U
	B1MBA	4.5-6.5	Jun-18 -92	8010	120	45 U	45 U	45 U	45 U	45 U	45 U	45 U
B2	B2MAA	.05-2.5	Jun-18 -92	8010	120	41 U	41 U	41 U	41 U	41 U	41 U	41 U
	B2MBA	3.0-4.5	Jun-18 -92	8010	44 U	44 U	44 U	44 U	44 U	44 U	44 U	44 U
B3	B3MAA	.05-2.5	Jun-18 -92	8010	1400	89 U	89 U	290	89 U	89 U	89 U	89 U
	B3MBA	2.5-4.5	Jun-18 -92	8010	42 U	42 U	42 U	42 U	42 U	42 U	42 U	42 U
B4	B4MAA	.05-2.5	Jun-18 -92	8010	59,000	1500	4600	360 U	360 U	360 U	360 U	360 U
B5	B5MAA	.05-2.5	Jun-19-92	8010	82	47 U	47 U	47 U	47 U	47 U	47 U	47 U
	B5MBA	4.5-6.5	Jun-19-92	8010	580	47 U	47 U	47 U	47 U	47 U	47 U	47 U
B6	B6MAA	.05-2.5	Jun-19-92	8010	51	46 U	46 U	46 U	46 U	46 U	46 U	46 U
B7	B7MAA	.05-2.5	Jun-19-92	8010	1700	280 U	12,000	280 U	280 U	280 U	280 U	280 U
	B7MBA	2.5-3.7	Jun-19-92	8010	48 U	48 U	48 U	48 U	48 U	48 U	48 U	48 U
VB1	VB1-1	.25-2.25	Feb-23-89	3580/8000	580	38 U	38 U	NA	NA	NA	95 U	NA
	VB1-2	2.25-3.25	Feb-23-89	3580/8000	2500	500 U	8.6 U	NA	NA	NA	21 U	NA
VB2	VB2-1	.25-2.25	Feb-23-89	3580/8000	1200	640	34 U	NA	NA	NA	85 U	NA
	VB2-2	2.25-4.25	Feb-23-89	3580/8000	82	17	9.4 U	NA	NA	NA	24 U	NA
	VB2-3	4.25-5.25	Feb-23-89	3580/8000	57	13 U	13 U	NA	NA	NA	33 U	NA
VB3	VB3-1	.25-2.25	Feb-23-89	3580/8000	22 U	22 U	22 U	NA	NA	NA	56 U	NA
	VB3-2	2.25-4.25	Feb-23-89	3580/8000	16 U	16 U	16 U	NA	NA	NA	500	NA
	VB3-3	4.25-6.0	Feb-23-89	3580/8000	79	13 U	13 U	NA	NA	NA	580	NA
	VB3-4	0.25-2.25	Feb-23-89	3580/8000	11 U	11 U	11 U	NA	NA	NA	11 U	NA
	VB3-5	2.25-4.25	Feb-23-89	3580/8000	54	9.5 U	9.5 U	NA	NA	NA	430	NA
	VB3-6	4.25-6.0	Feb-23-89	3580/8000	110	73	7.8U	NA	NA	NA	7.8U	NA
VB4	VB4-1M	0.5-2	Mar-2-89	3580/8000	6500	1400 U	220	NA	NA	NA	36 U	NA
	VB4-2M	2-3.7	Mar-2-89	3580/8000	700 U	1400 U	3000	NA	NA	NA	36 U	NA

TABLE 3-2

UNIFIRST PROPERTY

UNCONSOLIDATED-DEPOSITS RESULTS FOR SELECTED VOC

METHANOL-PRESERVED SAMPLES

Location	Sample I.D.	Depth (ft)	Date of Collection	Lab Method	Concentrations (ug/kg)							
					PCE	TCE	1,1,1-TCA	cis-DCE	t-DCE	1,1-DCA	1,2-DCA	VC
VB5	VB5-1M	0.5-2	Mar-2-89	3580/8000	23,000	1400 U	800	NA	NA	NA	36 U	NA
	VB5-2M	2-3.7	Mar-2-89	3580/8000	1200	1400 U	1200	NA	NA	NA	36 U	NA
UC27	C273A	3.5-4.0	Dec-3-93	8240	20,000	600 U	600 U	NA	600 U	600 U	600 U	1200 U
	C276A	10.0-11.0	Dec-3-93	8240	620	140 U	140 U	NA	140 U	140 U	140 U	290 U
UC28	C281A	0-1.0	Dec-6-93	8240	110 J	140 U	140 U	NA	140 U	140 U	140 U	280 U
	C284A	6.0-8.0	Dec-6-93	8240	160 U	160 U	160 U	NA	160 U	160 U	160 U	320 U
UC29D	29D1A	0-2.0	Dec -7-93	8240	190 U	190 U	190 U	NA	190 U	190 U	190 U	380 U
	29D3A	2.0–4.0	Dec -7-93	8240	180 U	180 U	180 U	NA	180 U	180 U	180 U	360 U
	29D5A	8.0–10.0	Dec -7-93	8240	38 J	170 U	170 U	NA	170 U	170 U	170 U	330 U
	29D5B	8.0–10.0	Dec -7-93	8240	100 J	210 U	210 U	NA	210 U	210 U	210 U	430 U
UC30	C301A	0-2.0	Dec-8-93	8240	240 U	240 U	240 U	NA	240 U	240 U	240 U	490 U
	C303A	4.0-6.0	Dec-8-93	8240	160 U	160 U	160 U	NA	160 U	160 U	160 U	310 U
	C305A	8.0–10.0	Dec-8-93	8240	170 U	170 U	170 U	NA	170 U	170 U	170 U	350 U
	C307A	12.0-14.0	Dec-8-93	8240	230 U	230 U	230 U	NA	230 U	230 U	230 U	450 U
UC32	C321A	2.0-3.5	Mar-30-94	8240	260U	260U	260U	NA	260U	260U	260U	260U
	C322A	5.5-6.8	Mar-30-94	8240	50J	270U	270U	NA	270U	270U	270U	270U
UC33	C331A	2.0-3.5	Apr-4-94	8240	200U	200U	200U	NA	200U	200U	200U	200U
	C332A	5.5-7.5	Apr-5-94	8240	220U	220U	220U	NA	220U	220U	220U	220U
	C333A	9.0-10.5	Apr-5-94	8240	220U	220U	220U	NA	220U	220U	220U	220U
	C334A	10.5-11.25	Apr-5-94	8240	110J	340U	340U	NA	340U	340U	340U	340U
UC34	C341A	3.0-4.5	Apr-7-94	8240	4400	230U	230U	NA	230U	230U	230U	230U
	C342A	9.0-11.0	Apr-7-94	8240	230U	230U	230U	NA	230U	230U	230U	230U
UC35	C351A	0.5-2.0	Apr-12-94	8240	8900D	220U	220U	NA	220U	220U	220U	220U
	C352A	2.0-3.5	Apr-12-94	8240	2000	220U	220U	NA	220U	220U	220U	220U
	C352B	2.0-3.5	Apr-12-94	8240	1000	260U	260U	NA	260U	260U	260U	260U
	C353A	5.5-7	Apr-12-94	8240	73J	230U	230U	NA	230U	230U	230U	230U
	C354A	8.5-9.35	Apr-13-94	8240	590	220U	220U	NA	220U	220U	220U	220U

TABLE 3-2

UNIFIRST PROPERTY

UNCONSOLIDATED-DEPOSITS RESULTS FOR SELECTED VOC

METHANOL-PRESERVED SAMPLES

Location	Sample I.D.	Depth (ft)	Date of Collection	Lab Method	Concentrations (ug/kg)							
					PCE	TCE	1,1,1-TCA	cis-DCE	t-DCE	1,1-DCA	1,2-DCA	VC
UC36	C361A	0.5-2.0	Apr-13-94	8240	130J	230U	230U	NA	230U	230U	230U	230U
	C362A	3.5-5.0	Apr-13-94	8240	84J	200U	200U	NA	200U	200U	200U	200U
	C363A	5.0-6.5	Apr-13-94	8240	290	200U	200U	NA	200U	200U	200U	200U
	C364A	6.5-7.7	Apr-13-94	8240	300	180U	180U	NA	180U	180U	180U	180U
WASTE OIL CONTAMINATION												
	SS1MA		Aug-31-92	8240	210,000	14,000 U	14,000 U	NA	14,000 U	14,000 U	14,000 U	27,000 U
	SS1MB		Aug-31-92	8240	130,000	14,000 U	14,000 U	NA	14,000 U	14,000 U	14,000 U	27,000 U
TEST PITS												
TPC	TPC-1A	4.8	Jul-31-92	8240	580	280 U	280 U	NA	280 U	280 U	NA	550 U
	TPC-2A	4.8	Jul-31-92	8240	210 J	280 U	280 U	NA	280 U	280 U	NA	560 U
	TPC-3A	2.2	Jul-31-92	8240	180 J	280 U	280 U	NA	280 U	280 U	NA	560 U
	TPC-4A	3.8	Jul-31-92	8240	680	260 U	260 U	NA	260 U	260 U	NA	520 U
TPD	TPD-1A	5.2	Jul-31-92	8240	810	280 U	280 U	NA	280 U	280 U	NA	570 U
	TPD-1B	5.2	Jul-31-92	8240	350	310 U	310 U	NA	310 U	310 U	NA	610 U
	TPD-2A	3.9	Jul-31-92	8240	250 U	250 U	250 U	NA	250 U	250 U	NA	500 U
	TPD-3A	2.5	Jul-31-92	8240	150 J	290 U	290 U	NA	290 U	290 U	NA	570 U
TPE	TPE-1A	3.7	Aug-24-92	8240	450 U	450 U	450 U	NA	450 U	450 U	NA	900 U
	TPE-2A	3.7	Aug-24-92	8240	410 J	540 U	540 U	NA	540 U	540 U	NA	1100 U
	TPE-3A	2.5	Aug-24-92	8240	800 U	800 U	800 U	NA	800 U	800 U	NA	1600 U
	TPE-4A	1.0	Aug-24-92	8240	580	440 U	440 U	NA	170 JX	440 U	NA	880 U
	TPE-4B	1.0	Aug-24-92	8240	450 J	560 U	560 U	NA	560 U	560 U	NA	1100 U
	TPE-5A	3.7	Aug-24-92	8240	140 J	450 U	450 U	NA	450 U	450 U	NA	900 U
TPF	TPF1A	2.5	Sep-22-92	8240	2,300,000	5,0000 U	5,0000 U	NA	5,0000 U	5,0000 U	NA	1,00000 U
	TPF2A	3.5	Sep-22-92	8240	1200	250 U	250 U	NA	250 U	250 U	NA	500 U
	TPF3A	1.7	Sep-22-92	8240	250 U	250 U	250 U	NA	250 U	250 U	NA	500 U

TABLE 3-2
UNIFIRST PROPERTY
UNCONSOLIDATED-DEPOSITS RESULTS FOR SELECTED VOC
METHANOL-PRESERVED SAMPLES

Location	Sample I.D.	Depth (ft)	Date of Collection	Lab Method	Concentrations (ug/kg)							
					PCE	TCE	1,1,1-TCA	cis-DCE	t-DCE	1,1-DCA	1,2-DCA	VC
	TPF4A	0.6	Sep-22-92	8240	750	290 U	290 U	NA	290 U	290 U	NA	580 U
	TPF5A	3.9	Sep-22-92	8240	1100	360 U	360 U	NA	360 U	360 U	NA	720 U
	TPF6A	5.5	Sep-22-92	8240	300 U	300 U	300 U	NA	300 U	300 U	NA	600 U
	TPF7A	3.5	Sep-22-92	8240	47,000	2800 U	2800 U	NA	2800 U	2800 U	NA	5500 U
	TPF8A	4.5	Sep-22-92	8240	710	300 U	300 U	NA	300 U	300 U	NA	590 U
	TPF9A	6.9	Sep-22-92	8240	1200	280 U	280 U	NA	280 U	280 U	NA	570 U
TPG	TPG1A	2.0	Sep-22-92	8240	310	160 U	160 U	NA	160 U	160 U	NA	310 U
	TPG2A	3.3	Sep-22-92	8240	20,000	490 U	490 U	NA	490 U	490 U	NA	980 U
	TPG3A	0.8	Sep-22-92	8240	5700	280 U	280 U	NA	280 U	280 U	NA	570 U
	TPG4A	2.6	Sep-22-92	8240	720	280 U	280 U	NA	280 U	280 U	NA	570 U
	TPG5A	4.8	Sep-22-92	8240	910	310 U	310 U	NA	310 U	310 U	NA	620 U
	TPG5B	4.8	Sep-22-92	8240	2,000	280 U	280 U	NA	280 U	280 U	NA	570 U
	TPG6A	6.0	Sep-22-92	8240	600	280 U	280 U	NA	280 U	280 U	NA	550 U
	TPG7A	1.5	Sep-22-92	8240	67,000	5,000 U	5,000 U	NA	5,000 U	5,000 U	NA	1,0000 U
	TPG8A	2.9	Sep-22-92	8240	2100	320 U	320 U	NA	320 U	320 U	NA	630 U
	TPG9A	7.3	Sep-22-92	8240	1100	300 U	300 U	NA	300 U	300 U	NA	590 U
TPH	TPH1A	0.5	Jul-24-93	8240	270 J	310 U	310 U	NA	310 U	310 U	NA	620 U
	TPH2A	4.6	Jul-24-93	8240	360	170 U	170 U	NA	170 U	170 U	NA	340 U
	TPH9A	4.8	Jul-24-93	8240	3400	37 J	170 U	NA	62 J	170 U	NA	340 U
	TPH11A	5.5	Jul-24-93	8240	2800	170 U	170 U	NA	64 J	170 U	NA	340 U
TPI	TPI1A	0.5	Jul-24-93	8240	120,000	86 J	8500	NA	170 U	170 U	NA	350 U
TPJ	TPJ1A	3.0	Dec-02-93	8240	42J	110U	110U	NA	110U	110U	110U	210U
TPK	PK10A	4.4	Dec-03-93	8240	36J	110U	110U	NA	110U	110U	110U	230U
	PK10B	4.4	Dec-03-93	8240	37J	100U	100U	NA	100U	100U	100U	200U
	PK11A	2.9	Dec-03-93	8240	93U	93U	93U	NA	93U	93U	93U	190U
	PK12A	1.9	Dec-03-93	8240	140	96U	96U	NA	96U	96U	96U	190U
TPL	TPL1A	2.1	Dec-03-93	8240	50J	91U	91U	NA	91U	91U	91U	180U

TABLE 3-2

UNIFIRST PROPERTY

UNCONSOLIDATED-DEPOSITS RESULTS FOR SELECTED VOC

METHANOL-PRESERVED SAMPLES

Location	Sample I.D.	Depth (ft)	Date of Collection	Lab Method	Concentrations (ug/kg)							
					PCE	TCE	1,1,1-TCA	cis-DCE	t-DCE	1,1-DCA	1,2-DCA	VC
	TPL4A	2.1	Dec-03-93	8240	170	130U	130U	NA	130U	130U	130U	260U
	TPL5A	3.7	Dec-03-93	8240	110U	110U	110U	NA	110U	110U	110U	220U
TPM	TPM1A	0.0-1.0	Apr-25-94	8240	2,500,000B	140,000U	140,000U	NA	140,000U	140,000U	140,000U	140,000U
	TPM2A	4	Apr-25-94	8240	230J	390U	390U	NA	390U	390U	390U	390U
	TPM3A	2	Apr-25-94	8240	3700B	370U	370U	NA	370U	370U	370U	370U
	TPM4A	0.8	Apr-25-94	8240	220,000	14,000U	14,000U	NA	14,000U	14,000U	14,000U	14,000U
	TPM4B	0.8	Apr-25-94	8240	320,000B	18,000U	18,000U	NA	18,000U	18,000U	18,000U	18,000U
	TPM5A	0.5	Apr-25-94	8240	73,000	5100U	3300J	NA	5100U	5100U	5100U	5100U
	TPM6A	2	Apr-25-94	8240	88BJ	430U	430U	NA	430U	430U	430U	430U
	TPM7A	4	Apr-25-94	8240	620B	370U	92J	NA	370U	370U	370U	370U

NOTES:

ND = not detected

NA = not analyzed

U = indicates that the compound was not detected at the detection limit indicated by the preceding number

J = indicates an estimated concentration

D = indicates a diluted sample

B = indicates compound detected in blank sample

X = indicates manual edit to reporting software

PCE = tetrachloroethene

TCE = trichloroethene

1,1,1-TCA = 1,1,1-trichloroethene

cis-DCE = cis-1,2-dichloroethane

t-DCA = trans-1,2-dichloroethene or 1,2-dichloroethene(total) where cis-DCE is NA

1,1-DCA = 1,1-dichloroethane

1,2-DCA = 1,2-dichloroethane

VC = Vinyl Chloride

TABLE 3-3
UNIFIRST PROPERTY
UNCONSOLIDATED-DEPOSITS RESULTS FOR SELECTED VOC
STANDARD (NON-PRESERVED) SAMPLES

Location	Sample I.D.	Depth (feet)	Date of Collection	Lab Method	Concentrations (ug/kg)							
					PCE	TCE	1,1,1-TCA	cis-DCE	t-DCE	1,1-DCA	1,2-DCA	VC
SOIL BORINGS												
B1	B1SAA	.05-2.5	Jun-18-92	8010	17	2.0 U	2.0 U	2.0 U	2.0 U	2.0 U	2.0 U	2.0 U
	B1SBA	4.5-6.5	Jun-18-92	8010	2.1 U	2.1 U	2.1 U	2.1 U	2.1 U	2.1 U	2.1 U	2.1 U
B2	B2SAA	.05-2.5	Jun-18-92	8010	120	4.0 U	4.0 U	4.0 U	4.0 U	4.0 U	4.0 U	4.0 U
	B2SBA	3.0-4.5	Jun-18-92	8010	2.0 U	2.0 U	2.0 U	2.0 U	2.0 U	2.0 U	2.0 U	2.0 U
B3	B3SAA	.05-2.5	Jun-18-92	8010	64	3.8 U	3.8 U	5.4	3.8 U	3.8 U	3.8 U	3.8 U
	B3SBA	2.5-4.5	Jun-18-92	8010	2.0 U	2.0 U	2.0 U	2.0 U	2.0 U	2.0 U	2.0 U	2.0 U
B4	B4SAA	.05-2.5	Jun-18-92	8010	2600	86 U	86 U	86 U	86 U	86 U	86 U	86 U
B5	B5SAA	.05-2.5	Jun-19-92	8010	5.4	2.2 U	2.2 U	2.2 U	2.2 U	2.2 U	2.2 U	2.2 U
	B5SBA	4.5-6.5	Jun-19-92	8010	20	3.8 U	3.8 U	3.8 U	3.8 U	3.8 U	3.8 U	3.8 U
B6	B6SAA	.05-2.5	Jun-19-92	8010	2.0 U	2.0 U	2.0 U	2.0 U	2.0 U	2.0 U	2.0 U	2.0 U
B7	B7SAA	.05-2.5	Jun-19-92	8010	37	3.0 U	8.0	3.0 U	3.0 U	3.0 U	3.0 U	3.0 U
	B7SBA	2.5-3.7	Jun-19-92	8010	1.9 U	1.9 U	1.9 U	1.9 U	1.9 U	1.9 U	1.9 U	1.9 U
VB1	VB1-2	2.25-3.25	Feb-23-89	3580/8000	150	19 U	19 U	NA	NA	NA	48 U	NA
VB3	VB3-5	10.0-12.0	Feb-23-89	3580/8000	28 U	28 U	28 U	NA	NA	NA	70 U	NA
UC4	UC4-SS-1	0-2.0	Nov-86		8.8	NA	NA	NA	NA	NA	NA	NA
UC5	UC5-SS-1	0-2.0	Nov-86		170	NA	12	NA	NA	NA	NA	NA
	UC5-SS-2	4.0-6.0	Nov-86		ND	NA	ND	NA	NA	NA	NA	NA
UC6	UC6-SS-1	0-2.0	Nov-86		ND	NA	ND	NA	NA	NA	NA	NA
	UC6-SS-2	2.0-4.0	Nov-86		ND	NA	ND	NA	NA	NA	NA	NA
	UC6-SS-3	4.0-6.0	Nov-86		ND	NA	ND	NA	NA	NA	NA	NA
	UC6-SS-4	18-20	Nov-86		ND	NA	ND	NA	NA	NA	NA	NA
UC7	UC7-1	1.0	Nov-86		61	NA	ND	NA	NA	NA	NA	NA
	UC7-2	2.0	Nov-86		-	NA	ND	NA	NA	NA	NA	NA
	UC7-2D	2.0	Nov-86		10	NA	ND	NA	NA	NA	NA	NA
	UC7-SS-1A	2.0-4.0	Nov-86		NA	NA	NA	NA	NA	NA	NA	NA
	UC7-SS-2	4.0-6.0	Nov-86		NA	NA	NA	NA	NA	NA	NA	NA
	UC7-SS-3	6-6.5	Nov-86		NA	NA	NA	NA	NA	NA	NA	NA
UC15		5.0-10.0	Sep-87		ND	ND	ND	ND	ND	NA	NA	NA
UC16		2.0-5.0	Sep-87		ND	ND	ND	ND	ND	NA	NA	NA
UC17		2.0-5.0	Oct-87		290	ND	ND	ND	ND	NA	NA	NA
UC18		2.0-10.0	Oct-87		ND	ND	ND	ND	ND	NA	NA	NA
UC19		3.0-6.0	Oct-87		ND	ND	ND	ND	ND	NA	NA	NA
UC20		3.0-6.0	Oct-87		ND	ND	ND	ND	ND	NA	NA	NA

TABLE 3-3
UNIFIRST PROPERTY
UNCONSOLIDATED-DEPOSITS RESULTS FOR SELECTED VOC
STANDARD (NON-PRESERVED) SAMPLES

Location	Sample I.D.	Depth (feet)	Date of Collection	Lab Method	Concentrations (ug/kg)							
					PCE	TCE	1,1,1-TCA	cis-DCE	t-DCE	1,1-DCA	1,2-DCA	VC
WASTE OIL CONTAMINATION												
	SS1SA	Spoil pile	Aug-31-92	5030/8240	460,000	14,000 U	14,000 U	NA	14,000 U	14,000 U	14,000 U	27,000 U
TEST PITS												
TPF	TPF1A	2.5	Sep-22-92	8240	35,000,000	650,000 U	650,000 U	NA	650,000 U	650,000 U	NA	1,300,000 U
	TPF2A	3.5	Sep-22-92	8240	5.5 U	5.5 U	5.5 U	NA	5.5 U	5.5 U	NA	11 U
	TPF3A	1.7	Sep-22-92	8240	5.0 U	5.0 U	5.0 U	NA	5.0 U	5.0 U	NA	10 U
	TPF4A	0.6	Sep-22-92	8240	110	6.0 U	6.0 U	NA	6.0 U	6.0 U	NA	12 U
	TPF5A	3.9	Sep-22-92	8240	5.5 U	5.5 U	5.5 U	NA	5.5 U	5.5 U	NA	11 U
TPF	TPF6A	5.5	Sep-22-92	8240	26 U	26 U	26 U	NA	26 U	26 U	NA	53 U
	TPF7A	3.5	Sep-22-92	8240	9200	1300 U	1300 U	NA	1300 U	1300 U	NA	2600 U
	TPF8A	4.5	Sep-22-92	8240	5.5 U	5.5 U	5.5 U	NA	5.5 U	5.5 U	NA	11 U
	TPF9A	6.9	Sep-22-92	8240	5.5 U	5.5 U	5.5 U	NA	5.5 U	5.5 U	NA	11 U
TPG	TPG1A	2.0	Sep-22-92	8240	14,000	1700	650 U	NA	1600	650 U	NA	1300 U
	TPG2A	3.3	Sep-22-92	8240	2700	750 U	750 U	NA	750 U	750 U	NA	1500 U
	TPG3A	0.8	Sep-22-92	8240	760	28 U	28 U	NA	28 U	28 U	NA	55 U
	TPG4A	2.6	Sep-22-92	8240	36	5.5 U	5.5 U	NA	5.5 U	5.5 U	NA	11 U
	TPG5A	4.8	Sep-22-92	8240	5.5 U	5.5 U	5.5 U	NA	5.5 U	5.5 U	NA	11 U
	TPG5B	4.8	Sep-22-92	8240	5.5 U	5.5 U	5.5 U	NA	5.5 U	5.5 U	NA	11 U
	TPG6A	6.0	Sep-22-92	8240	5.5 U	5.5 U	5.5 U	NA	5.5 U	5.5 U	NA	11 U
	TPG7A	1.5	Sep-22-92	8240	22,000	3100 U	3100 U	NA	3100 U	3100 U	NA	6200 U
	TPG8A	2.9	Sep-22-92	8240	5.0 U	5.0 U	5.0 U	NA	5.0 U	5.0 U	NA	10 U
	TPG9A	7.3	Sep-22-92	8240	10 U	10 U	10 U	NA	10 U	10 U	NA	21 U

NOTES:
ND = not detected
NA = not analyzed
U = indicates that the compound was not detected at the detection limit indicated by the preceding number
J = indicates an estimate concentration
- = not reported

PCE = tetrachloroethene
TCE = trichloroethene
1,1,1-TCA = 1,1,1-trichloroethene
cis-DCE = cis-1,2-dichloroethane
t-DCA = trans-1,2-dichloroethene or 1,2-dichloroethene(total) where cis-DCE is NA
1,1-DCA = 1,1-dichloroethane
1,2-DCA = 1,2-dichloroethane
VC = Vinyl Chloride

TABLE 3-4
UNIFIRST PROPERTY
UNCONSOLIDATED-DEPOSITS ANALYSES
PHYSICAL-PROPERTIES RESULTS

Location	Sample I.D.	Depth (feet)	Date of Collection	Dry Bulk Density (g/cc)	Specific Gravity	Fraction Organic Carbon (%)	Moisture Content (%)	Grain Size			Permeameter Hydraulic Cond. (cm/s)
								Gravel (%)	Sand (%)	Fines (%)	
BORINGS											
UC28	C284A	6-8	12/6/93				6.5	5.7	68.6	25.7	
UC32	32S1A	0.5-2.0	3/30/94				5.30				
	32S2A	2.0-3.5	3/30/94				3.13	45.9	41.4	12.7	
	32S3A	3.5-5.5	3/30/94				9.20				
	32S4A	5.5-6.8	3/30/94				13.35				
UC33	33S1A	0.5-2.0	4/4/94				4.25				
	33S2A	2.0-3.5	4/4/94				2.48	37.5	48.6	13.9	
	33S3A	3.5-5.5	4/4/94				2.93				
	33S4A	5.5-7.5	4/4/94				7.63				
	33S5A	7.5-9.0	4/5/94				6.84				
	33S6A	9.0-10.5	4/5/94				9.94				
	33S7A	10.5-11.25	4/5/94				0.72d				
UC34	34S1A	3.0-4.5	4/7/94				15.26	16.5	43.0	40.5	
	34S2A	4.5-6.0	4/7/94				5.16				
	34S3A	6.0-8.0	4/7/94				5.26				
	34S4A	9.0-11.0	4/7/94				6.80	36.3	52.6	11.1	
	34S5A	11.0-12.9	4/7/94				8.15				
UC35	35S1A	0.5-2.0	4/12/94				9.62	27.3	44.3	28.4	
	35S2A	2.0-3.5	4/12/94				2.52				
	35S3A	3.5-5.5	4/12/94				1.22				
	35S4A	5.5-7	4/12/94				7.23	50.1	36.1	13.8	
	35S5A	7.5-8.5	4/12/94				10.55				
	35S6A	8.5-9.35	4/13/94				10.32				
UC36	36S1A	0.5-2.0	4/13/94				6.40				
	36S2A	2.0-3.5	4/13/94				9.80	10.4	77.6	12.0	
	36S3A	3.5-5.5	4/13/94				5.28				

TABLE 3-4
UNIFIRST PROPERTY
UNCONSOLIDATED-DEPOSITS ANALYSES
PHYSICAL-PROPERTIES RESULTS

Location	Sample I.D.	Depth (feet)	Date of Collection	Dry Bulk Density (g/cc)	Specific Gravity	Fraction Organic Carbon (%)	Moisture Content (%)	Grain Size			Permeameter Hydraulic Cond. (cm/s)
								Gravel (%)	Sand (%)	Fines (%)	
	36S4A	5.0-6.5	4/13/94				2.87	42.0	46.2	11.8	
	36S5A	6.5-7.7	4/13/94				7.78				
TEST PITS											
TPA	TPA27	2.25	5/13/92			0.028	5.06				1.14X10-4
	TPA37	3.08	5/13/92			0.033	4.47				4.11X10-4
	TPA44	3.67	5/13/92			0.051	5.82				2.2X10-4
	TPA74	6.17	5/13/92			0.056	NA				NA
TPB	TPB27	2.25	5/13/92			0.036	8.80				3.2X10-5
	TPB37	3.08	5/13/92			0.039	5.10				5.36X10-5
	TPB44	3.67	5/13/92			0.072	6.72				2.08X10-5
TPJ	TPJ1A	3	12/2/93	1.72	2.68		8.8	0.1	72.9	27.0	6.6x10-5
	TPJ2A	3	12/2/93				3.7	56.7	37.5	5.8	6.7x10-4
	TPJ3A	4.5	12/2/93				10.2	1.3	89.0	9.7	
TPK	TPK1A	1.8	12/2/93	1.94			5.5	26.6	58.8	14.6	6.4x10-5
	TPK2A	2.8	12/2/93	1.76			7.3	7.1	68.9	24.0	5.6x10-4
	TPK3A	3.3	12/2/93	2.17	2.69		8.2	4.4	61.6	34.0	3.5x10-5
	TPK4A	4.1	12/2/93	1.94			8.7	15.6	61.1	23.3	1.4x10-5
	TPK5A	4.8	12/2/93	1.86			7.1	0.6	82.4	17.0	9.3x10-5
	TPK6A	4.1	12/2/93	1.99	2.67		9.5	5.7	63.0	31.3	
	TPK7A	4.1	12/2/93	1.80			6.5	2.1	80.4	17.5	
	TPK8A	4.1	12/2/93	1.57			7.3	12.5	69.3	18.2	
	TPK9A	4.1	12/2/93	1.82			8.3	8.9	71.3	19.8	
	PK10A	4.4	12/2/93	1.76	2.67		7.5	1.6	81.9	16.5	2.5x10-4
	PK11A	4.4	12/3/93				3.0	36.2	57.1	6.7	3.5x10-4
	PK12A	1.9	12/3/93				5.6	23.9	60.5	15.6	1.7x10-4
TPL	TPL1A	3.2	12/3/93	1.74			5.6	8.3	74.2	17.5	2.3x10-3
	TPL2A	1.8	12/3/93				4.2	15.9	66.3	17.8	6.2x10-4

TABLE 3-4
UNIFIRST PROPERTY
UNCONSOLIDATED-DEPOSITS ANALYSES
PHYSICAL-PROPERTIES RESULTS

Location	Sample I.D.	Depth (feet)	Date of Collection	Dry Bulk Density (g/cc)	Specific Gravity	Fraction Organic Carbon (%)	Moisture Content (%)	Grain Size			Permeameter Hydraulic Cond. (cm/s)
								Gravel (%)	Sand (%)	Fines (%)	
	TPL3A	14	12/3/93	1.56	2.68		6.0	0.7	75.2	24.1	3.3x10-3
	TPL4A	2.2	12/3/93	1.59			5.5	20.7	59.4	19.9	3.9x10-3
TPM	TPM2A	4	4/25/94	1.84			5.91	35.1	51.5	13.4	2.2x10-4
	TPM3A	2	4/25/94	1.85			6.37	24.8	62.6	12.6	2.8x10-4
	TPM4A	0.8	4/25/94	1.86			15.78	0.0	56.9	43.1	2.7x10-3

1) Gravel>4.75mm.
2) 4.75>Sand>0.074mm.
3) 0.074mm>Fines.

d = Sample appeared dry. Available mass less than minimum recommended

Table 3-5
UNIFIRST PROPERTY
SOIL-GAS SAMPLING RESULTS

Location	Sample I.D.	Depth (feet)	Date of Collection	Concentrations (ppmv)			
				PCE	TCE	TCA	1,2-DCE
TP1	Test Pipe #1	~1.5	Dec-04-86	ND	ND	ND	ND
	Test Pipe #2	~1.5	Dec-04-86	ND	ND	ND	ND
VB1	3289-3	3.25	Mar-02-89	34	NA	NA	NA
VB2	3289-4	4.8	Mar-02-89	22	NA	NA	NA
VB2	VB2	4.8	Sept-23-92	3.0	0.13	NA	0.16
VB3	3289-5	10	Mar-02-89	6.02	NA	NA	NA
VB3	3289-6	10	Mar-02-89	4.9	NA	NA	NA
VB3		10	Sept-23-92	0.11	NA	NA	NA
SV1A		2	May-22-92	NA	NA	NA	NA
SV1B		4	May-28-92	4.2	NA	NA	NA
SV1B		4	May-29-92	1.7	0.06	NA	NA
SV1B		4	Sept-21-92	33	1.1	NA	0.61
SV2		4	May-27-92	0.088	ND	NA	NA
SV2		4	Sept-22-92	1.9	NA	NA	NA
SV3		4	May-27-93	0.04	ND	NA	NA
SV3		4	Sept-22-92	1.3	NA	NA	NA
SV4		4	May-27-92	0.018	ND	NA	NA
SV4		4	Sept-22-92	0.57	NA	NA	NA
SV5		4	May-27-92	0.095	ND	NA	NA
SV5		4	Sept-22-92	3.4	NA	NA	NA
SV6		4	May-27-92	0.01	ND	NA	NA
SV6		4	Sept-22-92	0.48	NA	NA	NA
SV7		4	May-27-92	0.068	ND	NA	NA
SV7		4	Sept-22-92	1.4	NA	NA	NA
SV8		4	May-27-92	0.004	ND	NA	NA
SV8		4	Sept-22-92	0.65	NA	NA	NA
SV9		4	May-27-92	0.002	ND	NA	NA
SV10		6	Sept-21-92	75	NA	NA	NA
SV11		3.5	Sept-21-93	435	NA	NA	NA
SV12		4.5	Sept-21-94	75	1.2	NA	0.3
SV13		6	Sept-21-95	162	NA	NA	NA

NA = Not analyzed for compound indicated
ND = Not detected

PCE = tetrachloroethylene
TCE = trichloroethylene
TCA = 1,1,1-trichloroethane
1,2-DCE = 1,2-dichloroethylene

Table 3-6
Chronology of Unconsolidated Deposits Investigations
UniFirst Property

Investigation	Purpose/Findings	Date Performed	Report
Installation of monitoring wells IUS1, IUS2, IUS3 north of the UniFirst Facility (in accordance with the first Consent Order)	To determine if sources of PCE ground water contamination existed upgradient to the Property. No contamination indicated in soil samples from well borings.	November,1983	ERT (1984)
Installation of EPA wells S70 and S71 on the Property as part of Wells G&H RI.	Field screening of samples from boring for S71 indicated contamination of the unconsolidated deposits by VOC.	February,1985	Ebasco (1988)
Installation of wells UC4–UC7 by UniFirst. Borings sampled by the EPA as part of Supplementary RI/FS for Wells G&H Site.	Analysis of samples from borings indicated low levels of PCE contamination in shallow unconsolidated deposits on east end of Property.	November, 1986	Ebasco (1988)
Test-Pit TP1 excavated by UniFirst in front of current loading dock near fill-pipe area for removed PCE storage tank.	Solvent-like odor noted upon breaching pavement, no DNAPL encountered, soil-gas measurements in side walls of pit did not indicate PCE contamination.	December, 1986	March 1991 letter from EPC (T. Cosgrave) to EPA (B. Newman)
Shallow bedrock well UC8 installed by UniFirst inside the current Loading Dock.	DNAPL encountered in UC8	January, 1987	ERT(1988)
Wells UC15–UC20 installed by UniFirst. Borings sampled as part of the EPA's Supplementary RI/FS for Wells G&H Site.	Analysis of borings samples indicated PCE contamination only in UC17.	September-October, 1987	ERT (1988); Ebasco (1988)
Borings VB1, VB2 and VB3 drilled adjacent to UC5, UC17 and UC7, respectively. Shallow borings VB4 and VB5 advanced in backfill at location of TP1	UniFirst begins use of methanol preservation method for VOC analysis. PCE contamination detected in unconsolidated deposits in borings VB3, VB4, and VB5, (TCA also detected in VB4 and VB5).	February, 1989	Cherry et al., 1989; July 31, 1990 letter report from EPC to EPA (B. Newman)

Table 3-6
Chronology of Unconsolidated Deposits Investigations
UniFirst Property

Investigation	Purpose/Findings	Date Performed	Report
Soil-gas samples collected from installations in VB1, VB2 and VB3.	Samples indicated PCE contamination of vapor up to 34 ppmv (indicating potential for upward migration of vapors and recontamination of unsaturated zone).	March, 1989	Cherry et al., 1989; July 31, 1990 letter report from EPC to EPA (B. Newman)
First Numerical Modeling Study to investigate the potential impact of vapor diffusion from groundwater on overlying unconsolidated deposits	Study indicated that on-Property groundwater contamination could give rise to recontamination of overlying unconsolidated deposits	March, 1989	Feenstra (1989); July 31, 1990 letter from EPC to EPA (B. Newman)
Indoor air-quality surveys performed by EPA and UniFirst/Grace	No indication of groundwater causing air contamination or exposure risk in nearby homes or in the Grace or the UniFirst buildings.	April, 1989	ENSR Letters to EPA, July, 1989 and August, 1989; July 20, 1989 letter from Drs. North and Jaeger to J. Bates (GP&H) enclosed in July 24, 1989 letter from J. Bates to EPA (T. Conway).
(Record of Decision Issued for the Site)		September, 1989	
Second Numerical Modeling Study to determine most appropriate sequencing of unconsolidated-deposits and groundwater remedies.	Results indicated that a cleanup of underlying groundwater to 85 µg/L would be required to protect against recontamination of unconsolidated deposits following a remedy	July, 1990	July 31, 1990 letter report from EPC to EPA (B. Newman)

Table 3-6
Chronology of Unconsolidated Deposits Investigations
UniFirst Property

Investigation	Purpose/Findings	Date Performed	Report
(Consent Decree executed)		September, 1990	
(ESD issued for Site)		April, 1991	
(Consent Decree Entered)		October, 1991	
Excavation of Test Pit A and Test Pit B.	Samples collected for physical analysis, and nature of the unconsolidated-deposits/bedrock contact examined.	May, 1992	Draft Pre-Design Work Plan (1992)
Soil Vapor Probes SV1–SV9 installed and sampled.	Low levels of vapor contamination detected, highest concentrations detected along a zone trending southwest from the loading dock area.	May, 1992	Draft Pre-Design Work Plan (1992)
Soil Borings B1–B7.	PCE concentrations >1000 µg/kg limited to east end of UniFirst Property. Probable residual DNAPL in sample from B4. Highest PCE concentrations, (and some TCA) detected in upper 2.5 feet south of loading dock (B4 and B7).	June, 1992	Draft Pre-Design Work Plan (1992)
Test Pits C , D, and E Excavated.	Only moderate levels of PCE detected (ND to 810 µg/kg). Bedrock contact found to be fractured and weathered.	July-August, 1992	Draft Pre-Design Work Plan (1992)
Excavation of trench for influent lines for groundwater extraction system from UC22 to treatment room.	Discovery of the waste-oil-contamination area. Samples of contaminated materials analyzed for VOC, SVOC, Pesticides, PCB and petroleum-hydrocarbon fingerprinting.	August, 1992	Draft Pre-Design Work Plan (1992); January 1993 Interim Data Report

Table 3-6
Chronology of Unconsolidated Deposits Investigations
UniFirst Property

Investigation	Purpose/Findings	Date Performed	Report
Installed vapor probes SV10–SV13 in waste-oil-contamination area, and conducted Property-wide soil-vapor survey.	Highest vapor concentrations in immediate vicinity of the waste-oil contamination, concentrations decrease in a southwesterly direction.	September, 1992	Draft Pre-Design Work Plan (1992)
Excavation and Sampling of Test Pits F and G in waste-oil contamination area.	Small, discontinuous zones with residual DNAPL sampled in TPF and TPG. (PCE concentrations vary from non-detect to 2,300,000 µg/kg over distances of less than a few feet).	September, 1992	Draft Pre-Design Work Plan (1992); January 1994 Interim Data Report
Installation of 9 unconsolidated-deposits monitoring wells on Property (at new and existing locations UC6, UC10, UC19, UC24 and UC25).	Installed to allow for water-level-monitoring in the unconsolidated deposits to determine effects of UC-22 pumping system on unconsolidated deposits.	September, 1992	Draft Pre-Design Work Plan (1992)
(Startup of UC22 Groundwater Treatment System)		September 30, 1992	
Excavation of Test Pit H and collection of surface sample TPI.	Bituminous–concrete pavement samples collected for petroleum-hydrocarbon fingerprinting; unconsolidated-deposits samples collected for VOC analysis. PCE and TCA contamination in shallow subsurface near TPI, low levels of PCE contamination at TPH.	July, 1993	January 1994 Interim Data Report; March 1994 Interim Data Report
Petroleum-Hydrocarbon-Characterization Analyses performed on waste-oil contamination, soil samples, UC8 DNAPL, and pavement samples.	Similarity in chemical character found between waste-oil contamination and UC8 DNAPL. No evidence for DNAPL to have leached asphaltic components from on-Property pavement.	July 1993–December 1993	January 1994 Interim Data Report

Table 3-6
Chronology of Unconsolidated Deposits Investigations
UniFirst Property

Investigation	Purpose/Findings	Date Performed	Report
Excavation of Test Pits J, K, and L to investigate possible extent of the waste-oil contamination area and collect data on physical properties.	Samples analyzed for physical characteristics and chemical contamination. No indication of DNAPL or significant lateral spreading in the unconsolidated deposits. Extreme variability in physical characteristics.	December, 1993	March 1994 Interim Data Report
Borings UC26 through UC31 drilled and sampled. Installed 8 unconsolidated-deposits monitoring wells (new locations UC26, UC29, UC30, UC31).	Borings consistent with earlier findings regarding nature and extent of contamination; contamination found in immediate vicinity of previous waste-oil contamination and low levels at water table in middle of Property.	December, 1993	March 1994 Interim Data Report
Groundwater sampling of new unconsolidated-deposits monitoring wells and UC25.	Shallow, unconsolidated deposits groundwater contamination limited to area directly downgradient of east end of the UniFirst building. No other sources indicated.	January–February 1994	March 1994 Interim Data Report
Borings UC32–UC36 drilled beneath the UniFirst building.	Boring samples analyzed for VOC and physical properties. Low to moderate PCE contamination found. No indications of DNAPL.	March–April 1994	June 1994 Interim Data Report
Excavation and Sampling of Test Pit M	Local, shallow area of contaminated unconsolidated deposits excavated, no continuous zones of mappable contamination evident and no continuous zones noted at depth. Physical samples also collected.	April, 1994	June 1994 Interim Data Report

4.0 Conceptual Model for Nature and Extent of Contamination

The current conceptual model for the nature and extent of contamination in the unconsolidated deposits underlying the UniFirst Property has evolved through a process of continual testing and refinement with the completion of each new phase of investigation, as described in Section 3.0 above. The following paragraphs summarize the present conceptual model regarding conditions within the unconsolidated deposits beneath the Property and the nature and extent of contamination within those deposits. The conceptual model for the Property described below represents a coherent account of all the findings at the Property to date. The relevance of specific aspects of the conceptual model to the prognosis for remediation is presented in a general context in this section. The specific relevance of the pertinent features of the conceptual model to the prognosis for SVE as a remediation technology is discussed in Section 6.0.

4.1 Nature of Contamination and Conceptual Model for Transport

4.1.1 Release Areas

Investigations across the entire UniFirst Property have identified only two locations of limited areal extent on the east end of the Property to which chlorinated solvents apparently were released at the ground surface. These two areas, the waste-oil-contamination area and an area immediately to the south of the current loading dock, correspond to those areas on the Property where the only high concentrations of PCE in unconsolidated deposits have been found. Probable releases at these two locations are indicated by the occurrence of individual samples at scattered locations within these two areas that exhibit concentrations in excess of 60,000 µg/kg PCE, as well as, in some cases, by obvious staining or odor, indicative of residual DNAPL. Contaminant levels in the immediate vicinity (within a few feet) of these release areas are highly variable, ranging from non-detect to tens of thousands of µg/kg. The lateral extents of these release areas are shown in Figure 4-1. REDACTED

Releases in the area of the waste-oil contamination pre-date acquisition of the site by UniFirst in 1965, as discussed in Section 2.0 above. It is not possible to determine when any releases in the area of the current loading dock may have occurred, but any such releases must pre-date 1983, when pavement scarring was documented in this area and no scarring after that date has been observed. The area in the vicinity of the dry well in the former loading dock and near UC8, where it had been originally hypothesized that a release may have occurred, does not now appear to be an area of solvent release to the unconsolidated deposits or bedrock. REDACTED REDACTED REDACTED

 REDACTED

Waste-Oil - Contamination Area—UC8 DNAPL

Chemical characterization of petroleum-hydrocarbon compounds in the UC8 DNAPL, and of samples from the unconsolidated deposits from the waste-oil-contamination area, the pavement of the former loading dock, and the intervening unconsolidated deposits, has provided convincing evidence that the UC8 DNAPL was derived from a surface release of solvents and other contaminants in the zone of waste-oil contamination, and not from releases at the former loading dock, as had been previously hypothesized. A strong chemical similarity was found between both the light and heavy petroleum-hydrocarbon fraction found in both the UC8 DNAPL and unconsolidated-deposits samples from the zone of waste-oil contamination. The presence of compounds such as bis(2-ethylhexyl) phthalate in both the UC8 DNAPL and the zone of waste-oil contamination also indicated a common chemical source. In contrast, comparison of the chemical signatures of these samples to analyses of pavement samples from the former loading dock area indicated that the petroleum hydrocarbons fraction of the UC8 DNAPL could not have been derived from dissolution of the hydrocarbons in the bituminous-concrete pavement of the former loading dock. In other words, these findings disprove the earlier hypothesis that the UC8 DNAPL had penetrated through, or run along the surface of the former loading dock pavement and drained into the dry well. REDACTED

Two samples within the waste-oil contamination area that were selectively collected from the odorous grey material uncovered during excavation of the influent-trench from UC22, and from, or adjacent to, stained, odorous lenses of dark grey unconsolidated deposits in TPF and TPG, exhibited PCE concentrations sufficiently high (>60,000 µg/kg) to indicate the presence of residual DNAPL in this area. These samples, indicative of a DNAPL release area, were all collected within a small area immediately adjacent to the edge of the pavement layer outside the northeast corner of the building. REDACTED

As mandated by the site Health & Safety Plan and applicable regulations, all such contaminated material encountered during these excavations was removed, containerized, and later shipped to a licensed off-site facility for disposal consistent with chemical analyses of the material and applicable regulations.

Samples taken from outside of those areas where indications of DNAPL were found, but from within close proximity (5 to 10 feet) to them, exhibited highly variable concentrations from non-detect (<200 µg/kg) to 8,900 µg/kg PCE, but the majority indicated moderate contamination in the range of 1,000 µg/kg to 5,000 µg/kg PCE.

South End of Current Loading Dock

A total of 6 samples collected from the upper 3 feet of unconsolidated deposits underlying the pavement in an area immediately south of the current loading dock have also exhibited PCE concentrations that exceed the threshold indicative of DNAPL (i.e., >60,000 µg/kg). The residual DNAPL in this area indicative of a release does not appear to be laterally continuous within the approximately 20 by 35-feet area from which these samples were contained. PCE concentrations ranging from less than 100 µg/kg to 23,000 µg/kg were found in samples located within a few feet of, and between, those samples indicative of residual DNAPL. In addition to PCE, 1,1,1-trichloroethane (TCA) was found in the unconsolidated-deposits samples from the south end of the loading dock in concentrations of up to 12,000 µg/kg. This level of TCA distinguishes this release area somewhat from any other areas of contamination on the Property. No detectable concentrations of TCA have been found in unconsolidated-deposits samples from the zone of waste-oil contamination or from the vicinity of UC8. Only very low levels of TCA were found in the UC8 DNAPL. These data strongly indicate that separate releases occurred in the waste-oil contamination area and the current loading dock area. TCA is not otherwise discussed in this report because no cleanup levels or ARARs for TCA are exceeded.

REDACTED

REDACTED

REDACTED

REDACTED

UC8 Area

REDACTED

Unconsolidated-deposits samples collected immediately adjacent to UC8 and the former loading-dock area showed relatively low VOC concentrations (<3,400 µg/kg PCE). These data, together with the association of the UC8 DNAPL with the zone of waste-oil contamination, indicate that the immediate area around the former loading dock close to UC8 is not a zone of solvent release, but rather that the DNAPL encountered in UC8 originated from the material uncovered in the waste-oil-contamination area.

REDACTED

4.1.2 Migration Pathways in the Unconsolidated Deposits

The geological structure and hydrogeological properties of the unconsolidated deposits will control the migration of DNAPL, vapor and water through the unconsolidated deposits. The unconsolidated deposits outside the building have a variable, but generally low, permeability. Tests of undisturbed core samples yielded a range in hydraulic conductivity of 4×10^{-3} cm/s to 7×10^{-6} cm/s with an overall geometric mean of 2×10^{-4} cm/s (see Table 4-1). The unconsolidated deposits outside the building have a variable, but generally high, moisture content. Tests of core samples yielded a range in water saturation (per cent of porosity filled by water) of 22 per cent to 96 per cent with an overall geometric mean of 39 per cent.

The unconsolidated deposits are highly variable both laterally and vertically. Hydraulic conductivity can vary by several orders of magnitude over a distance of a foot or two. Although the unconsolidated deposits are variable, they do not exhibit significant horizontal layering. The highly variable geological structure in the unconsolidated deposits is illustrated by photographs from test pit TPK shown in Figures 4-2a and 4-2b. In the areas of the postulated releases, the unconsolidated deposits range from about 4 feet to 10 feet in thickness.

DNAPL from either release area would be expected to migrate predominantly downward following localized pathways represented by the zones of highest permeability (Poulsen and Kueper, 1992; Kueper et al., 1993). These pathways may be measured on the scale of inches and may be highly variable. However, aside from spreading, which might occur on the ground surface at the release area, the degree of lateral spreading of DNAPL within the unconsolidated deposits would be expected to be relatively small, because of the lack of horizontal layering in the geological structure.

Upon encountering the bedrock surface, DNAPL would continue to migrate downward wherever it could penetrate into the bedrock. The finding of DNAPL in UC8 and the magnitude and persistence of high dissolved concentrations in the groundwater in the bedrock beneath the Property indicate that DNAPL has in fact penetrated deep into the bedrock. DNAPL may also migrate laterally near the surface of the bedrock for some short distance depending on the volume released, the slope and shape of the bedrock surface, and the nature of the fractures present. However, attempts to find evidence of lateral DNAPL migration along or near the bedrock contact, by excavation of test pits and screening and sampling along the bedrock contact, both in the immediate vicinity of the waste-oil contamination area and other locations on the east end of the Property, found no evidence of such migration within the unconsolidated deposits.

Based on the highly fractured and slightly to highly weathered nature of the bedrock surface encountered in test pits and borings in the immediate vicinity of the two release areas, it is also reasonable to expect that DNAPL could penetrate rather easily into the bedrock. Once within the bedrock below the water table, however, locally significant (tens of feet) lateral migration of the DNAPL may have occurred, as evidenced by the presence of DNAPL from the waste-oil contamination area at UC8. The migration of DNAPL through the highly fractured and variably weathered bedrock will be controlled by the permeability (aperture and degree of filling), orientation and interconnection of the fractures. DNAPL migration pathways through the bedrock are expected to be highly variable, as evidenced by the fact that free-phase DNAPL has not been found in any other borings around the waste-oil contamination area. Small accumulations of free-phase DNAPL, such as that intersected by UC8, are most likely to occur in zones of closely fractured and weathered bedrock, but will also be variable in size and location.

The zones within the unconsolidated deposits through which DNAPL has migrated and left behind residual DNAPL will exhibit the highest concentrations of VOC in soil samples. Further migration of contamination from these areas can be expected to occur by vapor migration and, outside the building and paved areas, by infiltration of precipitation. These processes will generally tend to redistribute VOC and cause lower-level contamination of the unconsolidated deposits in irregular diffuse zones surrounding DNAPL release areas. The actual size of these diffuse zones, and their geometry with relation to the area of residual, will be strongly controlled by factors such as: the total volume and distribution of the residual; the moisture content and permeability of the deposits; the amount of infiltration; and the length of time the contaminant has been in the ground. In particular, the spatial variability in moisture content and porosity will control vapor migration and result in diffuse zones that are variable in size and shape.

Vapor migration through the unconsolidated deposits will be relatively slow and will not likely be able to redistribute VOC effectively over distances greater than about 10 to 20 feet because of the high water content in most areas within the unconsolidated deposits. This expectation is consistent with the actual experience on the Property that soil-vapor probes did not detect DNAPL within 20 to 30-feet of where residual DNAPL was eventually found to be present.

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Because the pathways followed by DNAPL through the unconsolidated deposits may be small in size, and the volume of residual DNAPL also small, DNAPL within a release area may actually disappear over a period of many years as a result of vaporization and dissolution as it is redistributed within the soil gas, pore water, and soil solids surrounding the original release area.

In addition to migration of vapors away from residual DNAPL in the unsaturated zone, there will also be vapor migration upward from areas of contaminated groundwater which will also cause low to moderate contamination of the unconsolidated deposits.

Although the capacity for vapor migration beneath the Property is not sufficient to permit large diffuse zones laterally out from the release areas, it would allow for vapor migration and resultant contamination of unconsolidated deposits to occur over short distances, such as the distance upward through the 4- to 10-feet typical thickness of unconsolidated deposits from underlying contaminated groundwater. Upward vapor migration from shallow groundwater contamination is now recognized as an important factor to consider for VOC (US EPA, 1993). Upward migration of chlorinated solvent vapors from shallow groundwater contamination has been documented in field experiments (Rivett, 1994; see Appendix G) and at actual field sites. At the Picatinny Arsenal in New Jersey (Smith et al., 1990), substantial levels of soil contamination were attributed

to upward migration of TCE (trichloroethene) vapor from the shallow groundwater.

Spatial variability in moisture content and porosity in the unconsolidated deposits will cause irregularity in the pattern of vertical migration of vapor upward from the groundwater, and the resultant contaminant concentrations in the unconsolidated deposits. A consistent trend of decreasing soil concentration upward from the water table, such as observed in the sand aquifer at the Picatinny Arsenal, would not be expected in till and artificial fill such as found on the UniFirst Property. In variable deposits, the vertical profile of vapor and soil concentrations will likely reflect both upward migration and lateral migration of vapor along the most favorable pathways. This could result in a pattern at some locations where the highest soil concentrations occur at elevations well above the water table. There will also be spatial variability in the pattern of vapor and soil contamination resulting from upward vapor migration from the groundwater due to variability in the pattern of contamination and concentrations in the shallow groundwater.

Because of the limited influence of lateral vapor migration from the release areas and the small size of the two release areas, the low to moderate (up to several thousand µg/kg) concentrations of PCE that are found in the largest volume of contaminated unconsolidated deposits beneath the Property are inferred to be caused by upward migration of vapor from the contaminated groundwater. The zone of this diffuse contamination is shown in Figure 4-1.

4.2 Extent of Contamination in the Unconsolidated Deposits

4.2.1 Distribution of Contamination

The majority of the contaminant mass in the unconsolidated deposits occurs on the east end of the Property, but low to moderate contamination also occurs over an area extending southwestward from the east end of the Property in the general direction of groundwater flow (see Figure 4-1). The general extent and distribution of this contamination can be best understood in the context of the probable pathways for migration, discussed above, as they relate to the occurrence of both the postulated release areas in the unconsolidated deposits, and the shallow groundwater contamination beneath the Property that arises from DNAPL that has penetrated beneath the water table and into the bedrock.

The highest VOC concentrations encountered in the unconsolidated deposits are located in two small areas within the immediate vicinity of the waste-oil contamination and near the south end of the current loading-dock. These two release areas and their relation to the general mechanisms for contaminant transport in the unconsolidated deposits are illustrated in Figure 4-3. In the

waste-oil-contamination area, contamination consists principally of petroleum hydrocarbons and PCE. At the south end of the loading dock, contamination consists principally of PCE with a distinguishing TCA component.

Evidence from numerous test pits and borings confirms that high levels of contamination are not continuous between the two release areas; that is, the two are separate and distinct within the unconsolidated deposits. Furthermore, the results of test pits outside and inside the building indicate that DNAPL from the zone of waste-oil contamination does not extend underneath the building within the unconsolidated deposits.

The two release areas are each characterized by small, discontinuous zones, which contain residual DNAPL with concentrations in excess of 60,000 µg/kg PCE, and the contiguous areas of diffuse contamination caused by vapor migration from the residual DNAPL. These zones of diffuse contamination are found within approximately 10 feet to 20 feet of the residual DNAPL, and exhibit moderate PCE contamination (up to several thousand µg/kg).

Over the remainder of the east end of the Property, outside of the release areas, as well as some distance to the southwest, contamination of the unconsolidated deposits by PCE occurs at low to moderate levels. The principal source of this contamination is likely upward migration of vapors from the underlying contaminated groundwater. Although PCE contamination levels caused by upward migration from the contaminated groundwater are not as high generally as those found immediately around the release areas, the volume of unconsolidated deposits affected in this way is larger.

4.2.2 Estimate of Contaminant Mass Remaining in the Unsaturated Zone

Despite the fact that over 100 samples of unconsolidated deposits from the east end of the Property have been analyzed, it is not possible to calculate the chemical mass in the unconsolidated deposits precisely, both because the spatial distribution of PCE is extremely variable due to geological variability, and because the release areas are so small. Nonetheless, it is instructive to provide a plausible upper bound estimate of the chemical mass that might have been contained, and still remains, in the release areas. Such estimates of the mass of contaminant contained within the release areas prior to and following construction and exploration activities in these areas are provided below.

For the waste-oil contamination area, all five unconsolidated-deposits samples that exceed about 10,000 µg/kg PCE are clustered in a small area in the immediate vicinity of test pits TPF, TPG and boring UC27. This zone is also where the most odorous materials were found during excavation of the effluent trench from UC22 (influent line to the treatment plant). This is the zone where DNAPL is most likely to have been present as a result of the postulated release. A

concentration level of 10,000 µg/kg was chosen to define this zone, rather than 60,000 µg/kg, so as to estimate contaminant mass generously. That is, the actual contaminant mass is likely to be smaller than the estimated contaminant mass.

The zone delineated by the findings in TPF, TPG and UC27 can be enclosed in an area measuring about 15 feet by 35 feet in size. The vertical distribution of contaminants observed during the construction of the UC22 effluent trench and the exploration test pits, indicated that even within the defined release area, the zones of highest concentration are discontinuous over distances of a few feet laterally and a foot or two in thickness. The average PCE concentration in this zone is about 500,000 µg/kg. PCE concentrations within this area range from non-detect to 2,500,000 µg/kg.

It should be recognized that the average PCE concentration calculated for the release zone is probably higher than the actual conditions because the samples of the unconsolidated deposits were collected selectively from the most contaminated zones based on field OVA readings and visual inspection. REDACTED

Using these dimensions for the entire area defined as the waste-oil contamination release area (15 feet x 35 feet by 2 feet) and average concentration (500,000 µg/kg), and a bulk density of 1.86 g/cm^3, the mass of PCE that could have been present in the waste-oil contamination area, prior to construction and exploration activities is generously estimated to be about 60 pounds (equivalent to about 4.5 gallons of PCE).

As a result of construction of the influent trench from UC22 and the exploration test pits TPF and TPG, some of the most contaminated material in this area has been removed. Based on the defined size of the waste-oil contamination release area and the observations during construction and exploration of the area, it is estimated that more than 50 per cent of the most contaminated material (i.e., that likely containing residual DNAPL) has been removed representing more than 30 pounds of PCE. REDACTED REDACTED

On consideration of these calculations, it is estimated that less than 30 pounds of PCE (or about 2 gallons) may remain in the unconsolidated deposits in the waste-oil contamination area. Because of the conservative nature of the calculations, the actual mass that remains should be much less.

A comparable calculation can be made for the area of the current loading dock. Six samples of unconsolidated deposits in which PCE concentrations exceeded 10,000 µg/kg are clustered in a small area in the vicinity of B4, VB5, TPI and TPM. Again, DNAPL is most likely to be present in this zone. As in the waste-oil contamination area, samples of the unconsolidated deposits were collected selectively from the most contaminated zones based on field OVA readings and

visual inspection. As a result, the average PCE concentration calculated for the current loading dock is again probably higher than the actual conditions.

The zone delineated by the findings in B4, VB5, TPI and TPM can be enclosed in an area measuring about 20 feet by 35 feet in size. Based on the vertical distribution of contaminants observed in the test pits and trenching operations, even within the defined release area, the zones of highest concentration are discontinuous over distances of a few feet laterally and a foot or two in thickness. The average PCE concentration in this zone is about 500,000 µg/kg. PCE concentrations within this area range from 51 µg/kg to 2,300,000 µg/kg.

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Using the dimensions of the defined release area (20 feet by 35 feet by 2 feet) and average concentration (500,000 µg/kg), and a bulk density of 1.86 g/cm^3, the mass of PCE that could have been present in the current loading-dock area is generously estimated to be about 80 pounds (equivalent to about 6 gallons of PCE). In comparison to the waste-oil contamination area, a smaller portion of the most contaminated material has been removed as a result of exploration activities. Based on defined size of the release area and visual observation during excavation of test pit TPM, it is estimated that only about 10 per cent of the contaminant mass in the current loading dock area may have been removed by these activities.

The chemical mass in the unconsolidated deposits outside the release areas can be calculated in a similar fashion. The low concentrations found in this diffuse zone likely result almost entirely from upward migration from contaminated groundwater at the water table, but may also be influenced to some degree by vapor migration laterally from the release areas. The zone of diffuse contamination extends from east end of the Property and covers about 13,000 ft^2 in area and varies in thickness from about 4 to 10 feet in thickness. Concentrations within this zone range from non-detect up to about 9,000 µg/kg with an average PCE concentration of about 1,100 µg/kg. Using the dimensions for the entire diffuse zone (13,000 ft^2 by 7 feet), the average concentration (1,100 µg/kg), and a bulk density of 1.86 g/cm^3, the estimated mass of PCE outside the release areas is about 12 pounds (equivalent to approximately 1 gallon of PCE).

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These estimated masses of PCE presently in the unconsolidated deposits in the release areas and diffuse zone are small relative to the mass of PCE removed from the bedrock and resulting zone of capture by pumping of UC22. During 20 months of operation, 550 pounds of PCE have been removed from the bedrock groundwater. The monthly mass removal rate from UC22 has been relatively stable at 25 to 30 pounds/month since pumping began. The trend in mass removal rate is shown in Figure 4-4. Based on the magnitude and distribution of PCE concentrations in the deep bedrock, the mass of PCE already removed, and the stability in the rate of PCE removal from UC22, it is likely that the bedrock,

both on Property and off-Property, contains a minimum of several thousand pounds of PCE compared to the estimated mass of less than approximately one hundred pounds contained presently in the unconsolidated deposits.

Not only is the estimated mass of PCE in the unconsolidated deposits very small compared to the mass likely present in the bedrock, but also the relative contribution of dissolved PCE to the groundwater from the unconsolidated deposits will be negligible in comparison to the contribution from DNAPL present in the bedrock or other off-Property sources. This will be discussed further in section 4.4.

4.3 Summary of Nature and Extent of Contamination

In summary, there are two separate areas from which releases of solvent are believed to have occurred on the UniFirst Property: the zone of waste-oil contamination, and immediately south of the current loading-dock. These release areas contain discontinuous zones of residual DNAPL and represent the areas of highest VOC contamination found in the unconsolidated deposits. It is generously estimated that about 60 pounds of PCE may have been formerly present in the waste-oil contamination area and that about 50 per cent has already been removed as a result of construction of the influent line trench for UC22 and exploration test pits. It is generously estimated that about 80 pounds of PCE may be present in the area of the current loading dock. Some of this area also has been removed by excavation of test pits. Zones of lower-level contamination surrounding these releases areas resulting primarily from lateral vapor transport away from the postulated release areas are relatively small (within about 10 to 20 feet).

Outside of the release areas, zones of lower-level contamination occur in the unconsolidated deposits across much of the east end of the Property, and extending southwestward across the middle of the Property coincident with the location of a shallow groundwater contamination. These areas of lower-level contamination are the result of vapor migration upward from groundwater contamination at the water table. The PCE mass associated with the unconsolidated deposits outside the release zones is estimated to be about 12 pounds

Because samples of unconsolidated deposits for chemical analysis were collected selectively from the most contaminated zones, the average PCE concentrations calculated for the various areas are likely higher than the actual conditions. As a result, the estimated PCE masses represent maximum values.

Despite this fact, the estimated mass of PCE of less than approximately one hundred pounds probably remaining in the unconsolidated deposits is a very

small relative to the likely mass of several thousand pounds or more present in the bedrock both on Property and off-Property.

4.4 Contribution of the Unconsolidated Deposits to Groundwater Contamination

The contribution of the unconsolidated deposits to contamination of the underlying groundwater has been negligible because of the small size of the releases areas, the location of the release areas at shallow depth above the water table, the relatively low permeability of the unconsolidated deposits, and the fact that the current loading-dock area has been covered by pavement, preventing significant infiltration through that zone. That small contribution of contamination of the unconsolidated deposits to underlying groundwater will also have been attenuated even further by the removal of a substantial portion of the contaminated materials during excavation of the influent-line trench and test pits. Any small contribution of contamination from the unconsolidated deposits to underlying groundwater (the amount of mass moving downward to the water table) is derived primarily from the release areas. In the area of diffuse contamination, particularly beneath the building, contamination in the unconsolidated deposits is likely the result of upward vapor migration from the groundwater. There is no contribution of contamination to the groundwater from the area of diffuse contamination.

To consider the potential impact of the contaminated unconsolidated deposits in the release areas on the underlying groundwater (the flux downward), the magnitude of the chemical mass loading of PCE to the groundwater can be estimated based on the rate of water infiltration and size of the release areas.

The waste-oil contamination area has been defined as approximately 15 feet by 35 feet in size. Most of this zone is not covered by pavement so that the rate of infiltration into the fill and till materials can be estimated to be about 8 inches/year. This rate represents about 20 per cent of rainfall and is regarded as typical for New England till. With these values, the volume of water that would percolate through the release area would be very small, about 2,600 gallons/year (0.005 gpm).

Any water percolating through this zone that contacts residual DNAPL will acquire a dissolved PCE concentration which may approach maximum solubility of about 200,000 µg/L. However, based on OVA readings, visual observation and chemical analyses, it is known that the distribution of residual DNAPL, even within the release area, is highly discontinuous. As a result, only a small portion of the water percolating through the release zone will contact DNAPL. If 10 per cent of the percolating water contacts DNAPL and reaches solubility concentrations and the remainder reaches only much lower levels, the PCE loading to the groundwater would be 0.43 pounds/year (about 0.5 cups/year) or 0.04 pounds/month. This estimate is probably the upper limit. If only 1 per cent

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of the percolating water contacts DNAPL and reaches solubility concentrations, the PCE loading to the groundwater would be 0.043 pounds/year (about 0.05 cups/year) or 0.004 pounds/month.

A comparable calculation can be performed for the current loading-dock area. The current loading dock release area has been defined to measure about 20 feet by 35 feet in size. Most of this zone is covered by pavement so that infiltration into the fill and till materials will be limited to that amount of precipitation and runoff that can penetrate through cracks or joints in the pavement. The area of test pit TPM was not repaved but covered with permeable "turfstone." The average infiltration for the current loading dock area is estimated to be about 2 inches/year, a rate that represents about 25 per cent of the rate of infiltration for uncovered areas. With these values, the volume of water that would percolate through the release area would be very small, about 860 gallons/year (0.0016 gpm).

As was the case for the waste-oil contamination area, based on OVA readings, visual observation and chemical analyses, it is known that the distribution of residual DNAPL in the current loading dock area is highly discontinuous. As a result, only a small portion of the water percolating through the release zone will contact DNAPL. If 10 per cent of the percolating water contacts DNAPL and reaches solubility concentrations and the remainder reaches only much lower levels, the PCE loading to the groundwater would be 0.14 pounds/year (about 0.16 cups/year) or 0.012 pounds/month. This estimate is probably the upper limit. If only 1 per cent of the percolating water contacts DNAPL and reaches solubility concentrations, the PCE loading to the groundwater would be 0.014 pounds/year (about 0.016 cups/year) or 0.0012 pounds/month.

The estimated flux of PCE to the groundwater from the release areas would have been very small in any event, and must have been further limited due to removal of portions of the PCE mass in the release areas as a result of construction and exploration activities.

The estimated rates of PCE flux to the groundwater from the unconsolidated deposits are extremely small in comparison to the mass removal rates of contamination from pumping well UC22. The monthly mass removal rate from UC22 has been relatively stable at 25 to 30 pounds/month since pumping began. Based on the conservative calculations described above the flux to the groundwater from the unconsolidated deposits would contribute, at most, only 0.2 per cent to 0.02 per cent to the PCE removed from UC22.

The analysis of groundwater water levels indicates that any contaminated water resulting from percolation through the release areas would be captured by the pumping of UC22. The present PCE concentrations in the effluent from UC22 are relatively stable at about 1,600 µg/L. Based on the PCE flux calculations described above, in the hypothetical situation where the release areas in the

unconsolidated deposits were the only contributor of the PCE found in UC22, the resultant PCE concentrations in UC 22 would range from 0.3 to 3 μg/L, less than the MCL for PCE. This hypothetical calculation indicates that the likely contribution of PCE to the groundwater from the release areas in the unconsolidated deposits is low in absolute terms, in addition to being very low in comparison to the contribution from DNAPL in the bedrock or other off-Property sources.

Outside of the release areas, the low-level of PCE contamination in the unconsolidated deposits does not likely contribute any measurable chemical mass loading to the groundwater. Beneath the building there can be no infiltration of water through the unconsolidated deposits, and outside of the building where groundwater contamination is present at the water table, the net flux of PCE is upward from the groundwater.

4.5 Implications of Conceptual Model for Remediation

The conceptual model for conditions beneath the Property and contamination in the unconsolidated deposits provides the basis for conclusions as to whether remedial measures for the unconsolidated deposits are necessary to control the effects of the contamination present, and also provides the basis for the evaluation and design of prospective remedial measures.

The following points summarize the key features of the Property's conditions that are relevant to the consideration of remedial measures for the unconsolidated deposits.

With regard to the release areas:

1. There are two areas in which PCE was released to the ground surface: the waste-oil contamination area and the one in front (immediately to the south) of the current loading dock.
2. The release areas are small in lateral extent with the waste-oil contamination area measuring about 15 feet by 35 feet, and the current loading-dock area measuring about 20 feet by 35 feet.
3. Evidence of residual DNAPL has been found only in small discontinuous zones within the release areas.
4. The migration of vapors from the release zones has not resulted in contamination of the unconsolidated deposits significantly beyond the release zones.
5. The mass of PCE estimated to remain in the release areas is small, less than approximately one hundred pounds, a small fraction of the several thousand pounds or more likely present in the bedrock or from other off-Property sources. REDACTED

6. The flux of PCE to the groundwater from the release areas is very small, 0.05 pounds/month (0.066 cups/month) or less, due to the small size of the release areas and the relatively low permeability of the unconsolidated deposits. The calculated PCE flux to the groundwater from the unconsolidated deposits is about 0.02 per cent to 0.2 per cent of the 25 to 30 pounds/month of PCE removed by the pumping of UC22.

With regard to the zone of diffuse contamination:

7. The zone of diffuse contamination extends from the east end of the Property measuring about 13,000 ft^2 in area. REDACTED EDACTED
8. Low to moderate concentrations of PCE result predominantly from vapor migration upward from the contaminated groundwater.

With regard to the groundwater contamination:

9. The presence of DNAPL in the shallow bedrock is indicated by the findings in UC8. The magnitude of dissolved PCE concentrations and the persistence of high concentrations in UC22 indicate the presence of DNAPL in the deep bedrock and from off-Property sources.
10. Groundwater contamination is expected to persist indefinitely because of the presence of DNAPL in the bedrock.

As recounted above in section 2.3, regulatory decision and settlement documents associated with the remediation of the contaminated unconsolidated deposits beneath the Property clearly established that the sole goal for any such remedial efforts is the protection of groundwater. The clean-up level for contaminated unconsolidated deposits of 36.7 µg/kg PCE specified in the 1989 ROD was meant to reflect the concentration, that, if present in unconsolidated deposits, would leach to the groundwater and cause exceedance of the MCL for PCE (5 µg/L). The 1989 ROD and 1991 ESD further indicate that the remedy for the contaminated unconsolidated deposits should commence at some appropriate time during operation of the groundwater remedial measures so as to avoid recontamination of the unconsolidated deposits.

At the time these decisions were made, several aspects of the Property conditions were uncertain. The location and mass of PCE in the unconsolidated deposits was not known. The relative contributions of the unconsolidated deposits and the DNAPL in the bedrock to the groundwater contamination was not known. Also, it was not known how long significant groundwater contamination in the bedrock might persist. With respect to the selection of SVE as a cleanup remedy, there was little quantitative information concerning the physical properties of the unconsolidated deposits. REDACTED REDACTED

Since the time that the decisions outlined in the 1989 ROD and 1991 ESD were made, however, a much greater understanding has been gained of the nature

and extent of PCE contamination in the unconsolidated deposits and the underlying bedrock.

The site conditions described in this report provide the basis for present conclusions as to whether remedial measures for the unconsolidated deposits are necessary or useful to protect groundwater.

Groundwater contamination is expected to persist indefinitely because of the likely mass of PCE in the bedrock as indicated by the persistent high concentrations of PCE in UC22, and the slow rate of PCE removal by UC22. The contribution of PCE from the unconsolidated deposits to the groundwater is negligible in comparison to the contribution from DNAPL present in the bedrock. Consequently, there would be no measurable improvement in groundwater quality as a result of even complete elimination of the small mass of PCE present in the unconsolidated deposits.

In addition, because groundwater contamination beneath the Property is expected to persist for decades or more, it is likely that vapor migration upward from the contaminated groundwater will cause recontamination of the overlying unconsolidated deposits or artificial fill placed if any remedial measures were implemented in the contaminated unconsolidated deposits. The level of contamination caused by vapor migration from the groundwater would be lower than the levels found currently in the release areas, but would be comparable to those found in the zone of diffuse contamination.

Because of these conditions, no measurable benefit in terms of groundwater protection could result from remediation of the unconsolidated deposits in the foreseeable future. In the event that restoration of the contamination in the groundwater is achieved at some time in the distant future, it is possible that no further remediation would be required in the unconsolidated deposits in order to protect groundwater. Because the contribution of PCE to the groundwater from the unconsolidated deposits is estimated to be so small, the presence of a small mass of PCE in the unconsolidated deposits may not have any significant effect on potential drinking water supplies in the underlying groundwater. Future groundwater monitoring will determine this possibility.

If, despite their known inability to achieve measurable benefit, remedial measures were to be considered for the unconsolidated deposits, the conditions found at the Property must also be evaluated with regard to their influence on the effectiveness of various potential remedies. The effectiveness of potential remedies undertaken while DNAPL persists in the bedrock will be limited by the effect of recontamination from the underlying contaminated groundwater.

Any remedies involving removal or treatment of the contaminants in situ will be impaired by the spatial variability in the distribution and relatively small mass of contaminants, particularly in the form of DNAPL. Soil-vapor extraction

or other in situ remedies will be substantially impaired because the unconsolidated deposits have a relatively low permeability. This condition results in low rates of flow of air, water or other solutions through the subsurface.

The unconsolidated deposits also exhibit a high spatial variability in soil properties such as permeability and moisture content. Soil-vapor extraction and other in situ remedies all depend on close contact between the zones of contamination and the flowing air, water, or other solution. The spatial variability in permeability will create preferential pathways for flow so that many contaminated zones within the subsurface may be bypassed. The rate of removal of contaminants from the bypassed zones will depend on vapor-phase or aqueous-phase diffusion, and removal to low concentrations levels could take many years depending on the initial concentrations and the distances over which diffusion must occur. As a result, even remedies considered to be active cleanup measures may require application for many years to approach cleanup to low concentration levels in variable media such as the unconsolidated deposits. REDACTED

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In summary, because of the expected persistence of groundwater contamination in the bedrock and the potential for recontamination, no benefit in terms of groundwater protection can result from remediation of the unconsolidated deposits. Even if remedial measures were to be applied to the unconsolidated deposits, the relatively low permeability and spatial variability in soil properties at the Property would severely limit the effectiveness of various potential remedies.

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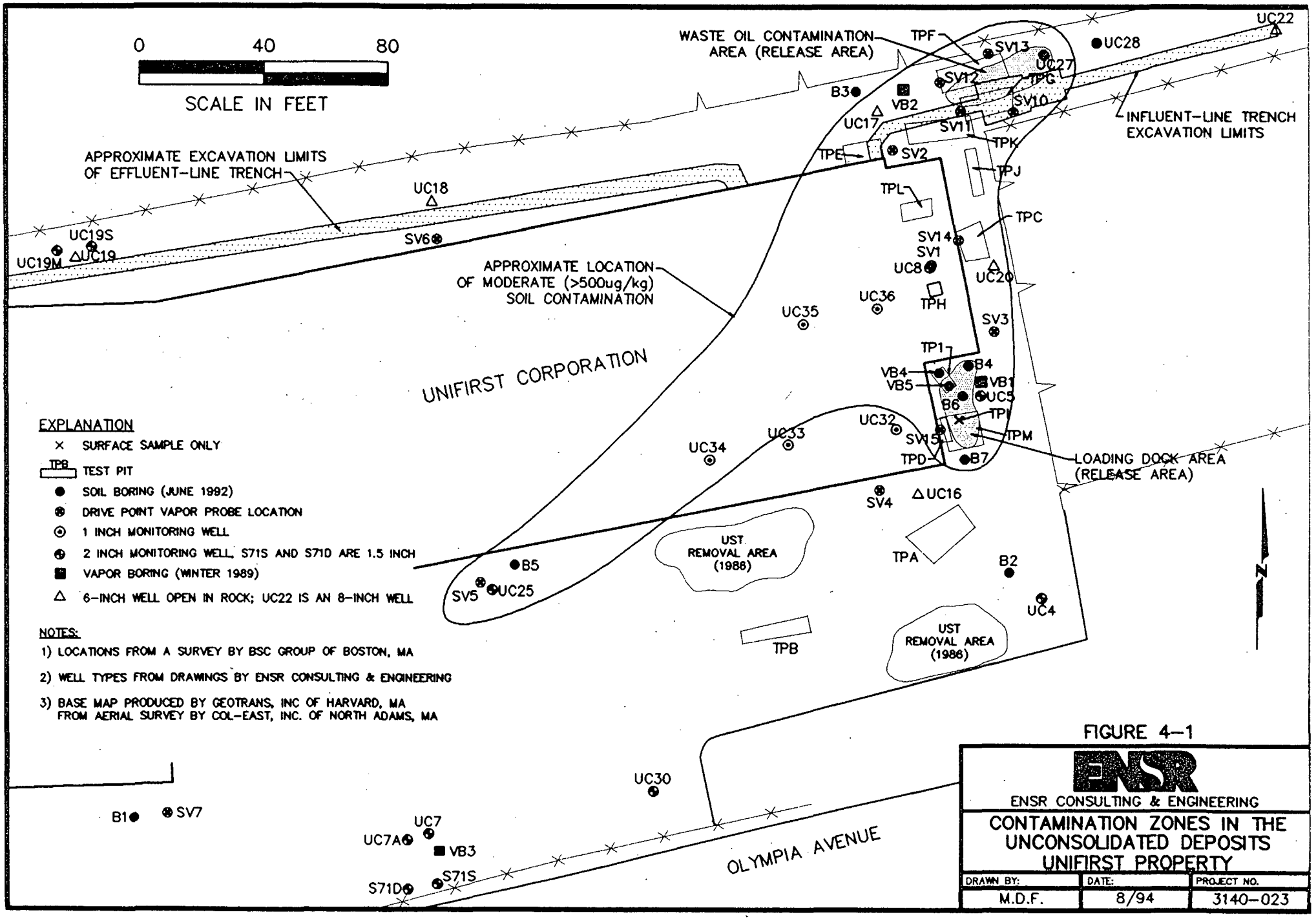

EXPLANATION

× SURFACE SAMPLE ONLY

TPB TEST PIT

● SOIL BORING (JUNE 1992)

⊛ DRIVE POINT VAPOR PROBE LOCATION

⊙ 1 INCH MONITORING WELL

⊕ 2 INCH MONITORING WELL, S71S AND S71D ARE 1.5 INCH

■ VAPOR BORING (WINTER 1989)

△ 6-INCH WELL OPEN IN ROCK; UC22 IS AN 8-INCH WELL

NOTES:

1) LOCATIONS FROM A SURVEY BY BSC GROUP OF BOSTON, MA

2) WELL TYPES FROM DRAWINGS BY ENSR CONSULTING & ENGINEERING

3) BASE MAP PRODUCED BY GEOTRANS, INC OF HARVARD, MA FROM AERIAL SURVEY BY COL-EAST, INC. OF NORTH ADAMS, MA

FIGURE 4-1

ENSR CONSULTING & ENGINEERING

CONTAMINATION ZONES IN THE UNCONSOLIDATED DEPOSITS UNIFIRST PROPERTY

DRAWN BY:	DATE:	PROJECT NO.
M.D.F.	8/94	3140-023

Figure 4-2a. Photograph illustrating the geological variability at the west end of test pit TPK centered at a depth of about 3 feet.

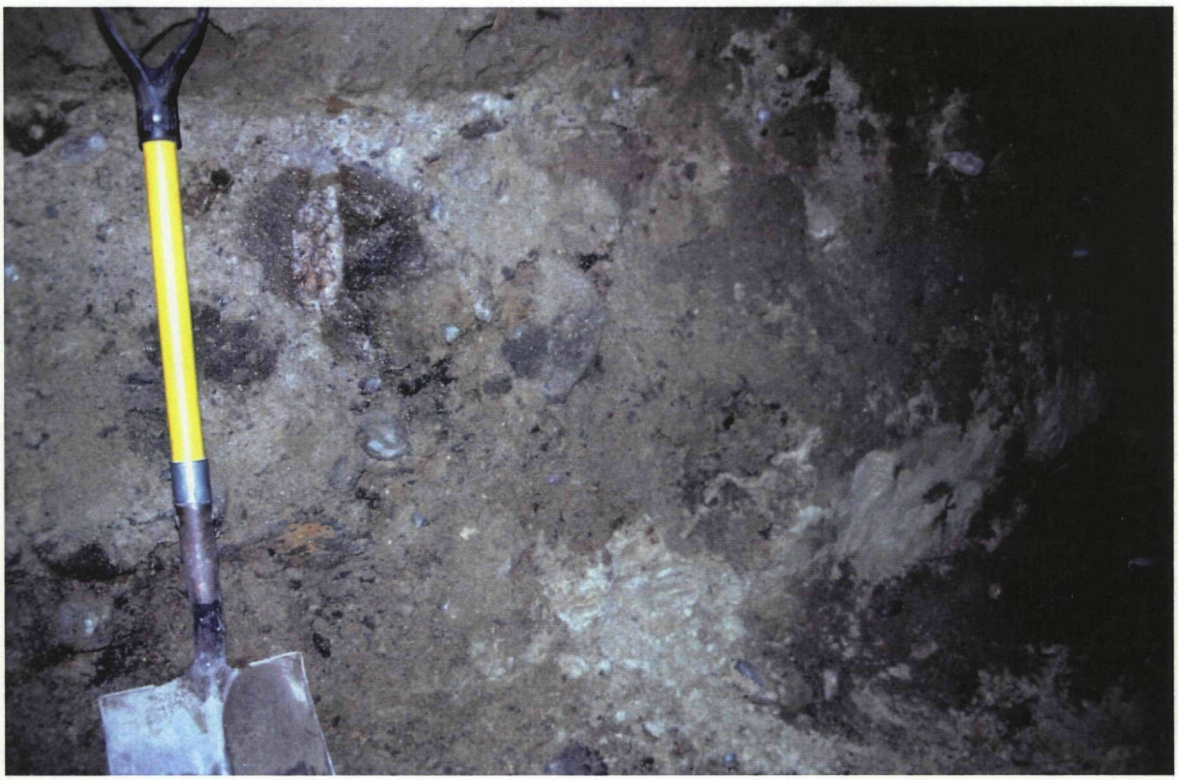

Figure 4-2b. Photograph illustrating the geological variability near the middle of test pit TPK centered at a depth of about 2 feet.

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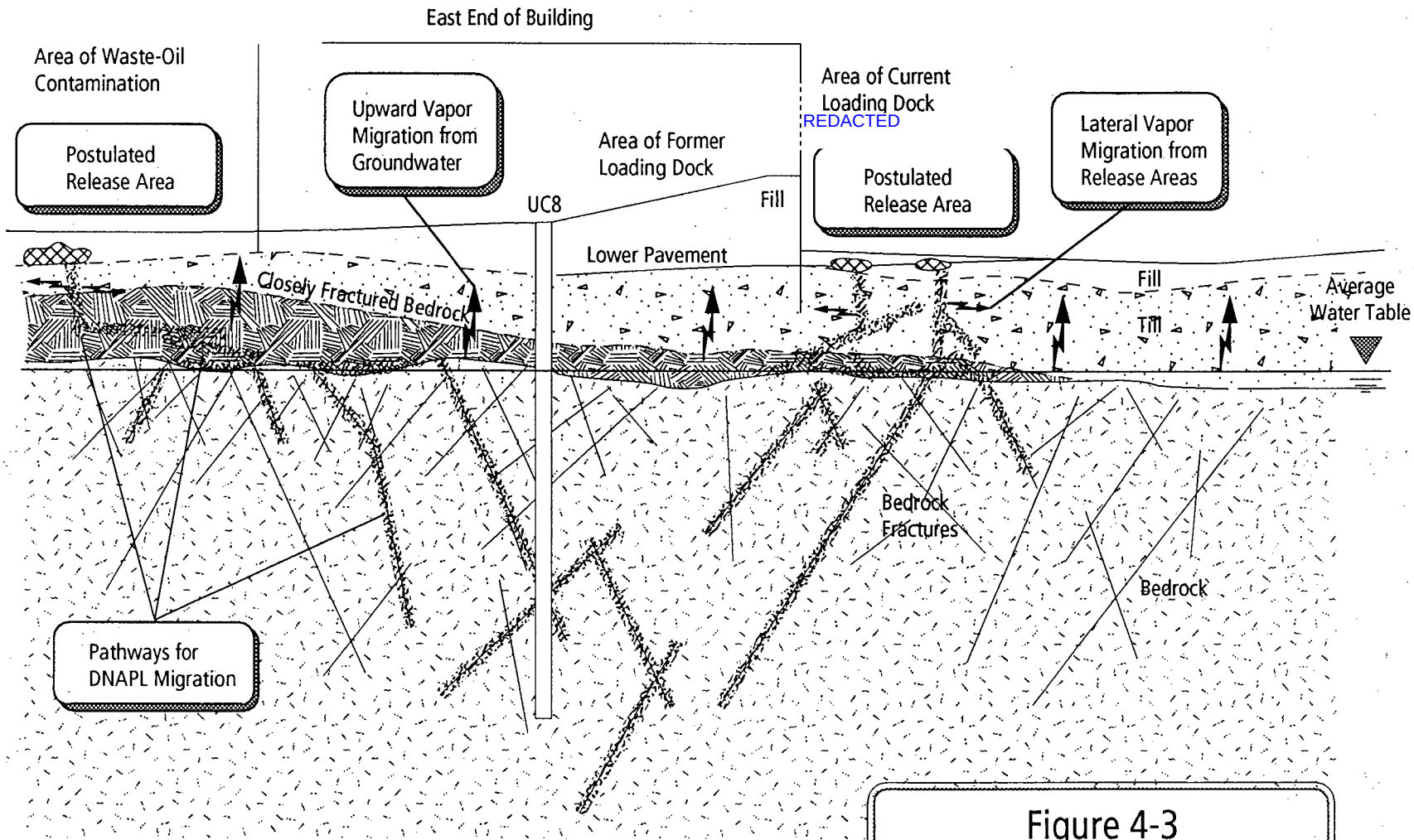

Not to scale
Illustrates postulated release areas and hypothetical migration pathways, not present-day contaminant concentrations or precise locations

Figure 4-3
Working Conceptual Model for Nature of Subsurface Contamination

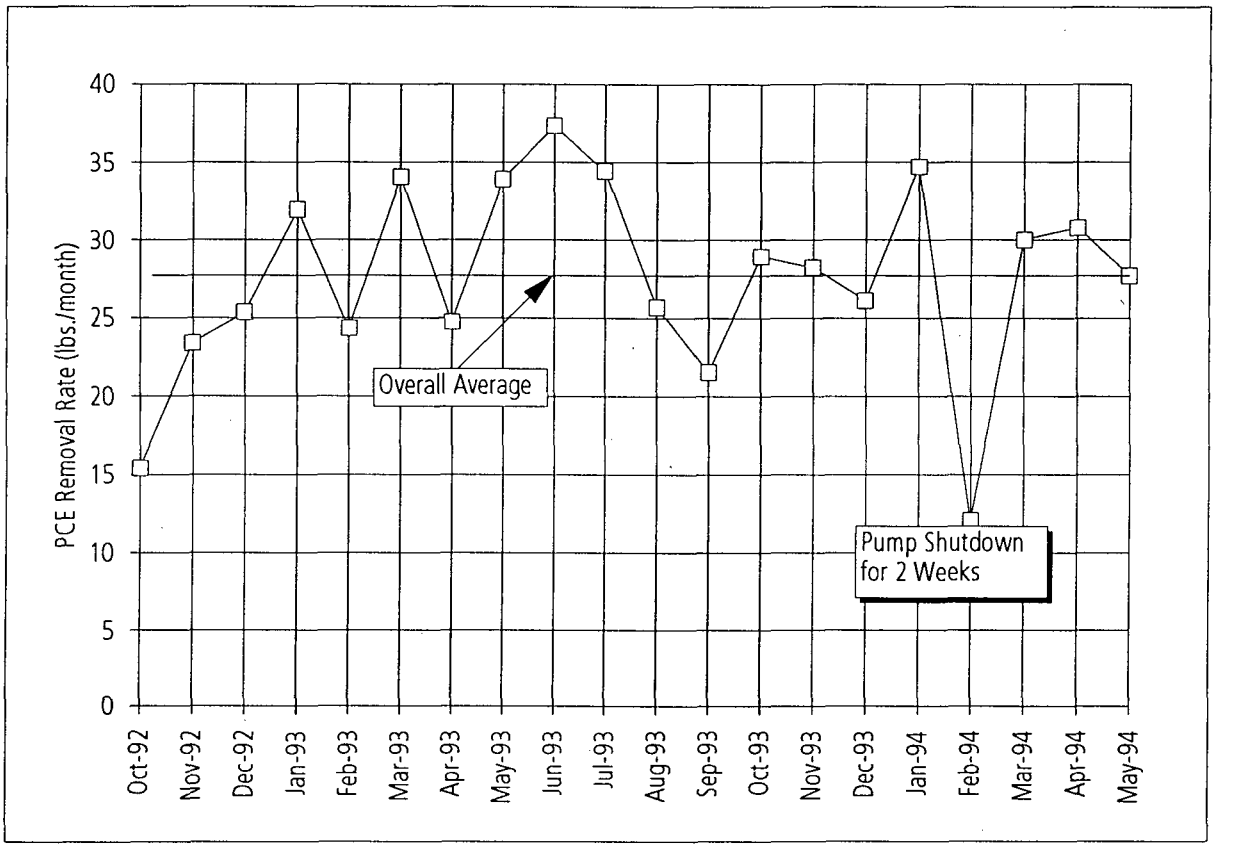

Figure 4-4. PCE mass removal rate from pumping of UC22.

Table 4-1 Summary of measured hydraulic conductivity and porosity values for the unconsolidated deposits.

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Sample	Depth (ft.)	Porosity (%)	Hydraulic Conductivity (cm/s)
TPA 27	2.25	-	1.14×10^{-4}
TPA 37	3.08	-	4.11×10^{-4}
TPA 44	3.67	-	2.20×10^{-4}
TPB 27	2.25	-	3.20×10^{-5}
TPB 37	3.08	-	5.36×10^{-5}
TPB 44	3.67	-	2.08×10^{-5}
TPJ 1A	1.9	36	6.60×10^{-6}
TPK 1A	1.8	28	6.40×10^{-5}
TPK 2A	2.8	34	5.60×10^{-4}
TPK 3A	3.3	29	3.50×10^{-5}
TPK 4A	4.1	28	1.40×10^{-5}
TPK 5A	4.8	31	9.30×10^{-5}
TPK 10A	4.4	34	2.50×10^{-4}
TPM 2A	4.0	31	2.20×10^{-4}
TPM 3A	0.8	31	2.80×10^{-3}
TPM 4A	3.0	36	2.70×10^{-3}
TPL 1A	3.2	35	2.30×10^{-3}
TPL 3A	1.4	42	3.30×10^{-3}
TPL 4A	2.2	41	3.90×10^{-3}
	Geometric Mean	33	2×10^{-4}

5.0 Feasibility of Soil-Vapor Extraction (SVE)

5.1 Basis for Assessment

SVE was specified in the 1991 ESD as the selected remedy for remediation of the unconsolidated deposits. SVE was selected at a time when there was little quantitative information of the physical properties of the unconsolidated deposits beneath the Property. At that time, SVE was not subjected to the remedy screening and feasibility testing prior to selection that is now standard procedure as set out in EPA guidance documents.

The results of the detailed investigations conducted at the UniFirst property during 1992 - 1994 make it now possible for UniFirst to assess the feasibility of SVE for future remediation of the unconsolidated deposits in a way that was not possible when the remedy was selected in 1991.

It is now normal practice to assess the feasibility of remedial technologies using a three-tiered approach that consists of: remedy screening, remedy selection and remedy design. The application of these steps in the evaluation of SVE is described in the US EPA Guide for Conducting Treatability Studies under CERCLA - Soil Vapor Extraction (EPA 540-2-91-019A) dated September 1991. The following section provides an evaluation of the feasibility of SVE for remediation of the unconsolidated deposits at the UniFirst Property according to the remedy screening criteria outlined in this EPA guidance.

5.2 Screening of SVE Remedy

EPA guidance for assessing the feasibility of SVE recommends consideration of a variety of factors related to the characteristics of the contaminant, the soil, and the site at which SVE might be implemented. In particular, factors are considered that may have a negative effect on the performance of SVE. A listing of the factors specified in Table 2-1 of the EPA guidance document is reproduced here in Table 5-1.

In general, the principal contaminant (PCE) at the Property meets the characteristic of the group of contaminants that are generally amenable to SVE, but the specific conditions at the Property will create numerous critical limitations to the effective application of SVE. Almost all of the soil and site characteristics noted in the EPA guidance as having a negative effect on the performance of SVE are found at the UniFirst Property. Among the factors likely to severely impair the performance of SVE are: the low air permeability, high moisture content; small quantity of contaminants located at shallow depth; and highly variable soil characteristics. The following discussion reviews these factors as applied to the UniFirst Property.

5.2.1 Contaminant Characteristics

Based on its vapor pressure, Henry's Constant and experience with SVE at other sites, PCE would be considered as amenable to removal from the subsurface by SVE. However, another factor noted in the EPA guidance is high density. PCE is a DNAPL that will tend to migrate into the saturated zone where it will not be accessible for removal by SVE. This is clearly the case at the UniFirst Property where migration of PCE as DNAPL has caused the vast majority of the PCE mass to migrate downward into the saturated zone and the bedrock.

5.2.2 Soil Characteristics

Low Air Permeability

Low air permeability in soil will impair the performance of SVE because it will limit the rate of air flow through the subsurface. At the time that SVE was specified as the remedy for the unconsolidated deposits, there had been no measurements of hydraulic conductivity or estimates of air permeability made for the UniFirst Property. However, the investigations during 1992 - 1994 included the collection and analysis of samples of the unconsolidated deposits to characterize the magnitude of the air permeability and the spatial variability in the air permeability.

A total of 10 samples of the unconsolidated deposits from outside the building and 3 samples from beneath the building have been tested to calculate air permeability. Undisturbed samples of unconsolidated deposits were collected from test pits and analyzed for bulk density, moisture content and hydraulic conductivity. These properties were used to calculate the air permeability. Details of the calculation methods are found in Appendix C. The results of the unconsolidated-deposits analyses and the calculated air permeability are shown in Table 5-2.

Hydraulic conductivity, a measure of the permeability of the sample to water flow under saturated conditions, was found to range from a high of 4×10^{-3} cm/s to a low of 7×10^{-6} cm/s, with an overall geometric mean of 2×10^{-4} cm/s. This represents a variability of about three orders of magnitude. Air permeability is dependent on both the hydraulic conductivity (permeability) of the unconsolidated deposits themselves as well as the moisture content. For a geologic medium of any given hydraulic conductivity, the higher the moisture content, the lower the air permeability. Because unconsolidated deposits with the lowest hydraulic conductivity will also have the highest moisture content, the contrast in air permeability will tend to be greater than the contrast in hydraulic

conductivity. By adjusting the hydraulic conductivity values for moisture content, as shown on Table 5-2, the air permeability values generated range from 3 darcys (3×10^{-8} cm^2) to 0.0005 darcys (5×10^{-12} cm^2) with an overall geometric mean of 0.06 darcys (6×10^{-10} cm^2).

The air permeability values are low in comparison to values preferred for the application of SVE. The overall geometric mean air permeability for the Property is 0.06 darcys (6×10^{-10} cm^2). EPA guidance suggests that 0.01 darcys (10^{-10} cm^2) is the lower practical limit for the application of SVE. Four out of 10 of the samples from outside the building had an air permeability of less than the suggested lower limit of 0.01 darcys. The general areas in which the lowest air permeabilities are found corresponds to the release areas in which the highest PCE concentrations are found.

Results from these samples reflect the permeability values for discrete samples which are averaged over a few inches, the cross-sectional size of the sample collected. Based on examination of the test pits, significant variability in texture of the unconsolidated deposits sufficient to cause highly variable permeability to air flow occurs over a scale of several inches to a foot or two. However, as discussed in section 3.0, these samples may well underestimate the total range in permeability of deposits beneath the Property, since samples from the test pits were collected only from those locations where a representative sample could be successfully obtained using the sidewall coring device.

These results indicate that the air permeability of the unconsolidated deposits over much of the Property is low, particularly outside the building in the release areas, and is frequently less than the practical lower limit for SVE suggested by EPA guidance.

High Humic Content

The presence of high concentrations of non-volatile organic material such as humic substances in the unconsolidated deposits would impair the performance of SVE because volatile organic compounds tend to sorb preferentially to this organic material. The organic carbon content has been measured in 12 samples of the unconsolidated deposits from outside the two release areas. The organic carbon content ranged from 0.01 per cent to 0.072 per cent with a geometric mean of 0.03 per cent. These values are low and would not likely impair the performance of SVE. However, samples from test pits TPF and TPG in the waste-oil contamination area were found to have petroleum hydrocarbon concentrations ranging from approximately 1 mg/kg up to 3,800 mg/kg. The highest value would represent an organic carbon content of about 0.3 per cent. At this level or higher, sorption of PCE on the organic carbon would have a negative effect on the performance of SVE.

High Moisture Content

High moisture content in soil will impair the performance of SVE by limiting the rate of air flow through the subsurface. Moisture content of a soil sample is typically expressed as weight of water as a percent of the weight of the dry soil. The water saturation is the percentage of the porosity filled by water, and can be determined from the moisture content and the porosity or dry density. The water saturation in the unsaturated zone of a typical sandy soil in which SVE is commonly applied would be about 20 per cent or less. Moisture contents of this magnitude would not impair the performance of SVE significantly.

Water saturations have been calculated for 13 samples of unconsolidated deposits for which both moisture content and dry density were measured (see Table 5-2). Water saturations range from 22 per cent to 96 per cent with an overall geometric mean of 39 per cent. The water saturations are generally higher near the release areas outside the building than beneath the building. These results indicate that the moisture content of the unconsolidated deposits is much higher than that of typical sandy soil. As described above, these high water saturations combine with the relatively low hydraulic conductivity of the unconsolidated deposits to yield low values for air permeability.

Low Temperature

Low temperature can impair the performance of SVE because both vapor pressure and Henry's Constants for most volatile organics are about 2 times lower at 0°C compared to 10°C. At sites where soil contamination exists at 15 feet or more below the ground surface, seasonal fluctuations in temperature are reasonably small and subsurface temperatures tend to approximate the average annual air temperature for the area. At the UniFirst Property, the temperature at depths of 15 feet or more would be expected to be approximately 10°C.

At most sites at which SVE is applied, the zones of soil contamination to be treated exist at depths of 10 feet or more and are not subjected to very low temperature or large seasonal reductions in temperature. However, at the UniFirst Property, all of the PCE contamination exists at a depth of less than 10 feet. In the release areas, some of the highest concentrations exist at less than 3 feet. Frost penetration at the UniFirst Property would typically be about 2 feet. At these shallow depths, low temperatures during winter will reduce the effectiveness of SVE substantially. REDACTED

High Clay Content

High clay content in soil is generally related to low permeability and high moisture content. As a result, soils having a high clay content generally have a low air permeability. Although the unconsolidated deposits do not have a high clay content, the relatively low hydraulic conductivity and high moisture content combine to have the same effect as high clay content on the performance of SVE.

Low Porosity

Low porosity in soil will impair the performance of SVE by limiting the rate of air flow through the subsurface. The total porosity in the unconsolidated deposits at the UniFirst Property range from 28 per cent to 42 per cent with an overall geometric mean of 33 per cent. Total porosity values are generally lower near the release areas outside the building than beneath the building. This range in values is typical for sandy soils. Total porosity values in this range will not, in themselves, impair the effectiveness of SVE. The critical parameter that will control air flow during SVE is the air-filled porosity. Because of high moisture content, the air-filled porosity of the unconsolidated deposits at the UniFirst Property is sufficiently low to impair the performance of SVE.

5.2.3 Site Characteristics

Distribution and Quantity of Contaminants

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The distribution and quantity of contaminants in the subsurface are important factors in assessing the feasibility of SVE and determining whether other remedial technologies might be preferable. EPA guidance states that "Soil excavation and treatment are probably more cost effective when only a few hundred cubic yards (yd^3) of near surface soil are contaminated. If the spill has penetrated more than 20 or 30 feet, has spread through an area of several hundred square feet (ft^2) at a particular depth, or has contaminated a soil volume of 500 yd^3, excavation costs begin to exceed those associated with an SVE system."

At the UniFirst Property, the total mass of PCE in the unconsolidated deposits is estimated to be less than approximately one hundred pounds (about 11.4 gallons). This mass is small compared to the mass of PCE estimated to be present in the bedrock either on or off the Property. In addition, even within the release areas or the zone of diffuse contamination, PCE concentrations are highly variable over distances of a foot or two.

None of the contaminated unconsolidated deposits in either the release areas or the zone of diffuse contamination are deeper than 10 feet. In the release areas, the zones of highest concentration are generally found at less than 3 feet. SVE is seldom, if ever, applied to contamination found only at these shallow depths. Air extraction wells installed and operated at such shallow depths will be prone to excessive leakage of air from the ground surface. Such leakage will reduce substantially the lateral zone of influence of the wells (Beckett and Huntley, 1994).

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The contaminated unconsolidated deposits in the release areas cover an area of about 1,200 ft^2 but because of the shallow depth, this represents only about 225 yd^3. SVE is seldom, if ever, applied to zones of contamination of this size. The zone of diffuse contamination covers a larger area of about 13,000 ft^2 and a volume of about 3,400 yd^3, but average PCE concentration in this zone is 1,100 µg/kg and the PCE mass contained in this area is small, estimated to be at most 12 pounds.

Based simply on the shallow depth and small volume of contaminated unconsolidated deposits found in release areas, SVE is not considered to be a feasible technology. SVE is seldom, if ever, applied in such circumstances. Although the volume of contaminated unconsolidated deposits associated with the zone of diffuse contamination is larger than the release areas, depths are also shallow and PCE concentrations much lower.

Variable Soil Characteristics, Lithology, Heterogeneity

Spatial variation in soil characteristics may impair severely the performance of SVE. Variability in properties such as moisture content and air permeability will cause air to flow preferentially through the most permeable zones and to bypass other zones.

The effect of geological variability on the effectiveness of SVE is recognized in general terms in the EPA guidance. However, only recently has research been conducted to attempt to relate the effectiveness of SVE to the magnitude and the spatial scale of the geological variability.

During SVE operation, air flow through the subsurface will occur through the zones of highest air permeability and bypass the zones of lower permeability. Volatile contaminants residing in the zones of lower permeability can be removed by SVE only if they are able to migrate by diffusion to the zones through which air flow occurs. If the lower permeability zones have a low moisture content, migration of volatiles will occur via vapor-phase diffusion through the air-filled pore space and be relatively rapid. If the moisture content of the lower permeability zones is high, vapor-phase diffusion will be greatly

reduced and cleanup of these zones by SVE will be much slower. If the pore spaces in the lower permeability zones are almost fully saturated with water, migration of volatiles will occur by aqueous-phase diffusion at rates even lower than would occur by vapor-phase diffusion.

Theoretical calculations of the rate of cleanup of such lower permeability zones by vapor-phase and aqueous-phase diffusion for conditions comparable to the UniFirst Property are shown in Appendix D. These calculations illustrate that it would take many years of SVE operation to achieve low level cleanup targets when the presence of lower permeability zones cause contaminants to travel distances of more than one or two foot by diffusion.

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REDACTED As discussed in a preceding section, air permeability was calculated for 13 samples of unconsolidated deposits based on measured values of hydraulic conductivity, dry density and moisture content. The calculated air permeability from these samples is strongly correlated with the moisture content. These results are shown in Figure 5-1. With this relationship it is possible to estimate the air permeability for another 36 samples from the borings and test pits for which only moisture content was measured. These data are found in Table 5-4 REDACTED and are summarized in Figure 5-2.

For the samples of unconsolidated deposits from outside the building, the measured and estimated air permeabilities range from <0.001 to >5 darcys. Eight of 25 samples or about 32 per cent yield an air permeability less than 0.01 darcys, EPA's suggested practical lower limit for SVE. For samples from beneath the building, measured and estimated air permeabilities range also from <0.001 to >5 darcys. However, air permeabilities are slightly higher with only 5 of 24 or about 21 per cent less than a value of 0.01 darcys.

The only systematic pattern observed in the measured or estimated air permeability is that values are slightly higher beneath the building. This finding is likely the result of lower moisture contents from the lack of infiltration of precipitation. The air permeability was found to vary by a factor of about 1,000 times over a distance of several feet or less. This variation is illustrated in Figure 5-3 which shows the measured and estimated air permeability values obtained for test pit TPK. This variation in air permeability will result in highly localized pathways for air flow and the bypassing of zones of lower permeability.

Based on the information available for the Property, it is not possible to correlate REDACTED the level of PCE contamination with the air permeability of the unconsolidated deposits. Only a few of the samples selected for analysis of physical properties were found to exhibit PCE contamination. In addition, the magnitude and scale of the spatial variability in both PCE concentrations and physical properties would likely obscure any close correlation in measured values. However, high concentrations of PCE are found in less permeable zones in the unconsolidated deposits. For example, sample TPM4A had a calculated air permeability of

0.0005 darcys which was the lowest measured at the Property. This sample had a PCE concentration of 220,000 µg/kg. In contrast, samples TPM 2A and TPM 3A collected nearby each had an air permeability of about 0.1 darcys and PCE concentrations of 230 and 3,700 µg/kg respectively. The presence of high concentrations of PCE in such lower permeability layers will severely impair the performance of SVE at the UniFirst Property.

Buried Debris

The presence of buried debris and fill may impair the performance of SVE by disrupting air flow patterns. In the waste-oil contamination release area, buried construction debris was encountered. In addition, the backfill material placed in the trench for the pipe from UC22 and the exploration test pits would also tend to disrupt air flow patterns if SVE were applied in the area. The backfill material placed in the exploration test pits in the current loading dock release areas could cause similar disruptions in air flow. REDACTED REDACTED

5.2.4 Conclusion on Feasibility of SVE REDACTED

Almost all of the various factors identified in EPA guidance that might have a negative impact on the performance of SVE apply to varying degrees to the PCE contamination found in the unconsolidated deposits at the UniFirst Property. As a result, it is concluded that SVE would not be a feasible technology for application at the UniFirst Property.

The conditions of greatest significance, confirmed by detailed investigations of the UniFirst Property, are:

1. The shallow depth of contamination in both the release areas and the zone of diffuse contamination REDACTED
2. The small volume of contaminated unconsolidated deposits associated with the release areas. REDACTED
3. The generally low air permeability in the unconsolidated deposits.
4. The extreme spatial variability in air permeability and contamination concentrations in the unconsolidated deposits.

SVE can never contribute to protection of groundwater while contaminated groundwater persists and allows upward migration of vapors. At the Gemeinhardt Superfund site in Elkhart, Indiana, US EPA permitted the termination of an SVE remedy after 15 months of operation when the soil cleanup target of 1,000 µg/kg PCE could not be achieved throughout the soil. This was concluded to be due to on-going contributions of PCE to the soil from the underlying contaminated groundwater (see ENSR Report to US EPA dated January 1992 found in Appendix E). REDACTED REDACTED REDACTED

REDACTED

REDACTED

Thus, based on the conditions at the Property, it is unlikely that protection of groundwater could be achieved practicably by SVE, even if applied following remediation of the underlying contaminated groundwater at some time in the future. Because of the site conditions, an SVE system implemented for the protection of groundwater would require very closely spaced air extraction wells and would require many years of operation after restoration of the groundwater. Other remedial technologies would likely be more cost effective than SVE for part or all of the contamination that might remain in the unconsolidated deposits at that time in the future. REDACTED REDACTED

The highest PCE concentrations in the unconsolidated deposits are found only in the two release areas. These release areas are small in volume and the contaminated material occurs at a depth of 5 feet or less. If remediation efforts were to be applied to only the areas of highest concentrations where residual DNAPL might be present, other remedial technologies are likely to be more cost effective than SVE for treatment of such small and shallow zones.

In summary, it is concluded that SVE would not be a feasible remedy for the unconsolidated deposits at the UniFirst Property to achieve protection of groundwater either now or in the future when the groundwater remediation is complete, or for treatment of the highest PCE concentrations found in the release areas. As a result, the further study of SVE by means of field pneumatic testing or pilot testing is not warranted. Neither pneumatic testing nor short duration SVE pilot testing could provide more definitive information on the factors most critical to the effectiveness of SVE, namely, the effect of diffusion out of lower permeability zones which are known to exist and the length of time that an SVE system would need to operate to achieve any specific cleanup target. REDACTED

5.3 Results of SVE Research on the Effect of Variable Soil Characteristics

Because conclusions regarding the practicability of SVE at the UniFirst Property depend in large part on the effect of variable soil characteristics, UniFirst provided funding to investigate further the influence of spatial variability in chemical concentrations and permeability on the effectiveness of SVE through a detailed field experiment conducted by the University of Waterloo. This experiment was described by Flynn et al. (1994). A copy of this paper is included in Appendix F. REDACTED REDACTED

This experiment was conducted in a sandy aquifer having conditions much more favorable to SVE than those in the unconsolidated deposits at the UniFirst Property. REDACTED

This SVE experiment was performed inside a 29.5 feet by 29.5 feet test cell isolated from the surrounding aquifer by steel sheet piling walls. The cell extends to the

base of the aquifer and is about 11 feet deep. This cell creates a 350 cubic yard block of natural sandy aquifer. The aquifer material is fine to medium sand that exhibits visible horizontal bedding. The hydraulic conductivity of the different beds varies by a factor of about 10 to 50 times. The overall hydraulic conductivity for the SVE experiment is much higher, and the range in hydraulic conductivity is much smaller than that measured at the UniFirst Property.

In the Waterloo experiment in July 1991, 203 gallons of PCE were released to the aquifer in a controlled experiment when the water table in the cell was close to the ground surface. The principal purpose of this experiment was to evaluate the REDACTED effectiveness of geophysical methods for identifying DNAPL occurrence in the subsurface. The PCE migrated into the aquifer and became distributed in numerous accumulations or pools at various elevations in the aquifer and at the bottom of the cell. Information on the spatial distribution of contamination was derived from the geophysical monitoring during the release and by core sampling after the release. The layout of the test cell and core locations are shown in Figure 5-4. The level of detail obtained on the spatial distribution of contamination is much greater than could be derived at any real site. Later that year, the water table inside the cell was lowered and about 46 gallons of PCE were removed from the pool at the bottom of the cell.

Before the SVE experiment began, 6 soil cores were collected and analyzed at 10 cm intervals to characterize the PCE distribution. Figure 5-5 shows the results of several of these cores. The SVE experiment began in July 1993. The SVE system included 3 extraction wells on one side of the cell and 3 passive air inlet wells on the other side. The air flow rate ranged from 25 scfm to 7.5 scfm. The system was monitored using a detailed array of soil-gas probes, pressure transducers, and thermocouples. During the first 50 days of operation, PCE concentrations in the effluent air declined from about 5,000 ppmv to less than 500 ppmv. This represents the time period during which the majority of the chemical mass was removed. Little additional mass has been removed during the following 150 days. The decline in PCE concentration in the extracted air is shown in Figure 5-6. This decline in concentrations is proportional to the decline in the rate of mass removal.

In January 1994, 8 additional soil cores were collected and analyzed at 5 cm interval to characterize the distribution of PCE that remained in the cell. Figure 5-7 shows the PCE concentration profiles in several of these cores. These results show that several layers of DNAPL PCE remain in several areas of the cell.

Figure 5-8 shows that the zones of highest PCE concentration or DNAPL layers remaining in the cell are associated with zones of higher water saturation in the middle part of the aquifer, and the higher water saturation at the bottom of the cell in the capillary fringe immediately above the water table.

These DNAPL layers will persist for long period because the rate of mass removal by the SVE system has declined to a constant low level. The removal of PCE from these DNAPL layers is likely controlled by slow diffusion through zones of higher water content into the zones through which air flow occurs.

The geological variability exhibited by the sands in the Waterloo experiment is small in comparison to that present in the unconsolidated deposits at the UniFirst site. As a result, the effectiveness of SVE at the UniFirst Property would be expected to be impaired by geological variability to a much greater degree than for the Waterloo experiment. In addition, PCE in the Waterloo experiment had resided in the subsurface for less than 3 years. During this time, there would have been far less opportunity for contaminants to diffuse into less permeable zones than is the case of the unconsolidated deposits at the UniFirst site where some of the PCE may have existed in the subsurface for 30 years. The longer that contaminants have to diffuse into less permeable zones, the longer will be the time required to remove them. Based on the slow constant mass removal rate and large amount of mass remaining, many more years of SVE operation would be required to remove further significant quantities of PCE from the Waterloo experiment.

The spatial scale of chemical and geological variability exhibited in the Waterloo experiment would result in diffusion distances of about a foot or less. Comparable diffusion distances would be expected for the UniFirst site based on the geological variability observed in test pits. As a result of the low air permeability and extreme geological variability at the UniFirst Property, the effectiveness of SVE at the Property would be expected to be impaired to a much greater degree than that observed in the Waterloo experiment.

5.4 Summary and Conclusions

The feasibility of SVE for remediation of the unconsolidated deposits at the UniFirst Property has been assessed on the basis of the remedy screening factors set out in EPA guidance. Although the PCE at the UniFirst Property would be amenable to removal by SVE if only its vapor pressure and Henry's Constant were considered, almost all the factors related to soil characteristics and site characteristics that can have a negative effect on the performance of SVE are applicable at the UniFirst Property. These factors include:

1. High density of PCE has caused most of the mass of PCE to migrate downward into the saturated zone and into the bedrock.
2. Low air permeability found generally across the Property will hinder air flow. In the vicinity of release areas outside the where PCE are highest, 32 per cent of the soil samples indicate an air permeability of 0.01 darcys or less, which is noted in EPA guidance as the practical lower limit for SVE. REDACTED

3. High humic (organic carbon) content resulting from petroleum hydrocarbons in the waste-oil contamination area will cause high sorption of PCE and hinder removal.
4. High moisture content found in many areas will cause low air permeability.
5. Low temperature during the winter will lower vapor pressure and Henry's Constant, and thus, the rate of removal for the PCE contamination found at shallow depth. REDACTED REDACTED
6. PCE contamination is shallow in both the release areas and the zone of diffuse contamination, and the volume of contaminated unconsolidated deposits associated with the release areas is small.
7. The extreme spatial variability in air permeability will cause air to flow preferentially through the most permeable zones and bypass the less permeable zones.
8. Buried debris and backfill from the construction of the effluent trench for UC22 and exploration test pits is present and will cause disruption of air flow patterns. REDACTED REDACTED

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Although all these factors will have a negative effect of the performance of SVE the most significant are: the shallow depth of contamination in both the release areas and the zone of diffuse contamination; the small volume of contaminated unconsolidated deposits associated with the release areas; the low air permeability in the unconsolidated deposits; the extreme spatial variability in air permeability and contamination concentrations in the unconsolidated deposits. REDACTED REDACTED

SVE can never contribute to the protection of groundwater while contaminated groundwater persists and allows upward migration of vapors. It is unlikely that protection of groundwater could be achieved practicably by SVE, even if applied following restoration of the underlying contaminated groundwater at some time in the future. Other remedial technologies would likely be more cost effective than SVE for part or all of the contamination that might remain in the unconsolidated deposits at that time in the future.

If remediation efforts were to be applied to only the zones of high concentrations in the release areas, other remedial technologies are likely to be more cost effective than SVE for treatment of such small and shallow zones.

In summary, it is concluded that SVE would not be a feasible remedy for the unconsolidated deposits at the UniFirst Property either to achieve protection of groundwater, or for treatment of the highest PCE concentrations found in the release areas. As a result, the further study of SVE by means of field pneumatic testing or pilot testing is not warranted. Neither pneumatic testing nor short duration SVE pilot testing could provide more definitive information on the factors most critical to the effectiveness of SVE, namely, the effect of diffusion

out of lower permeability zones which are known to exist, and the length of time that and SVE system would need to operate to achieve any specific cleanup target.

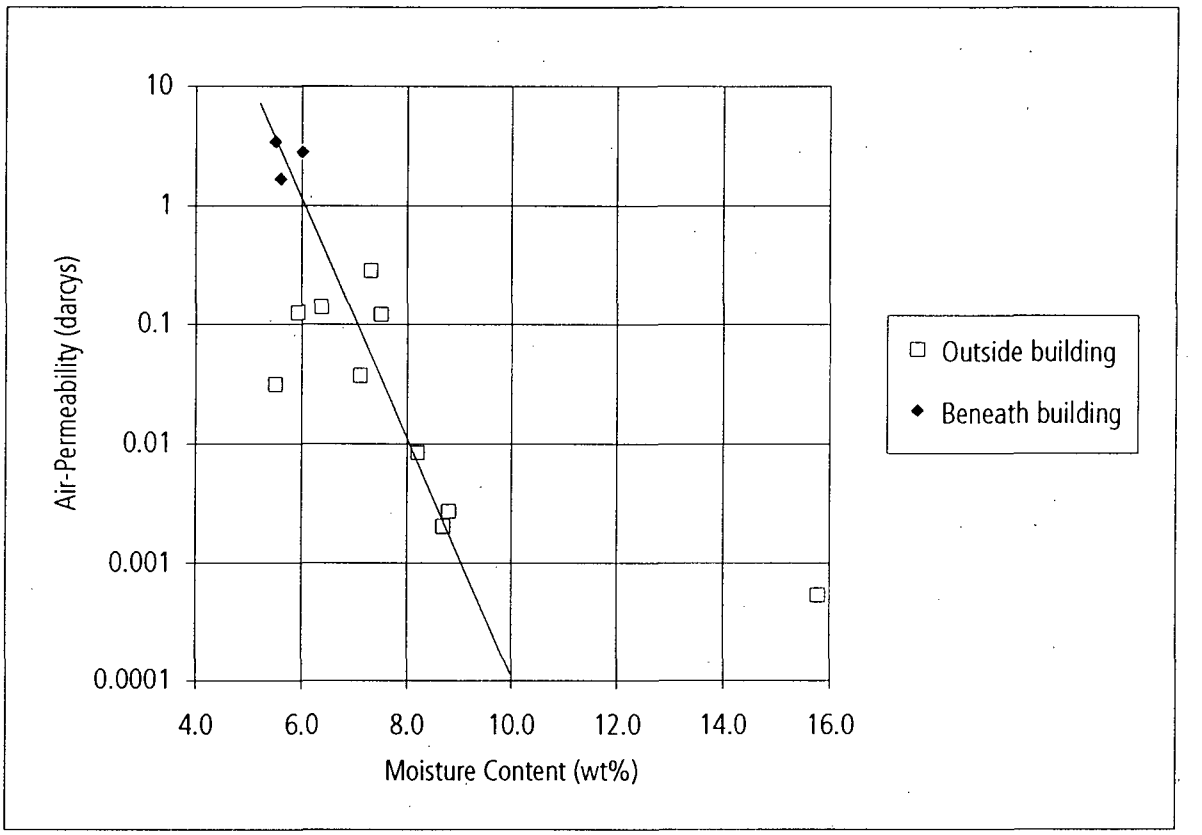


Figure 5-1. Relationship between calculated air permeability and measured moisture content.

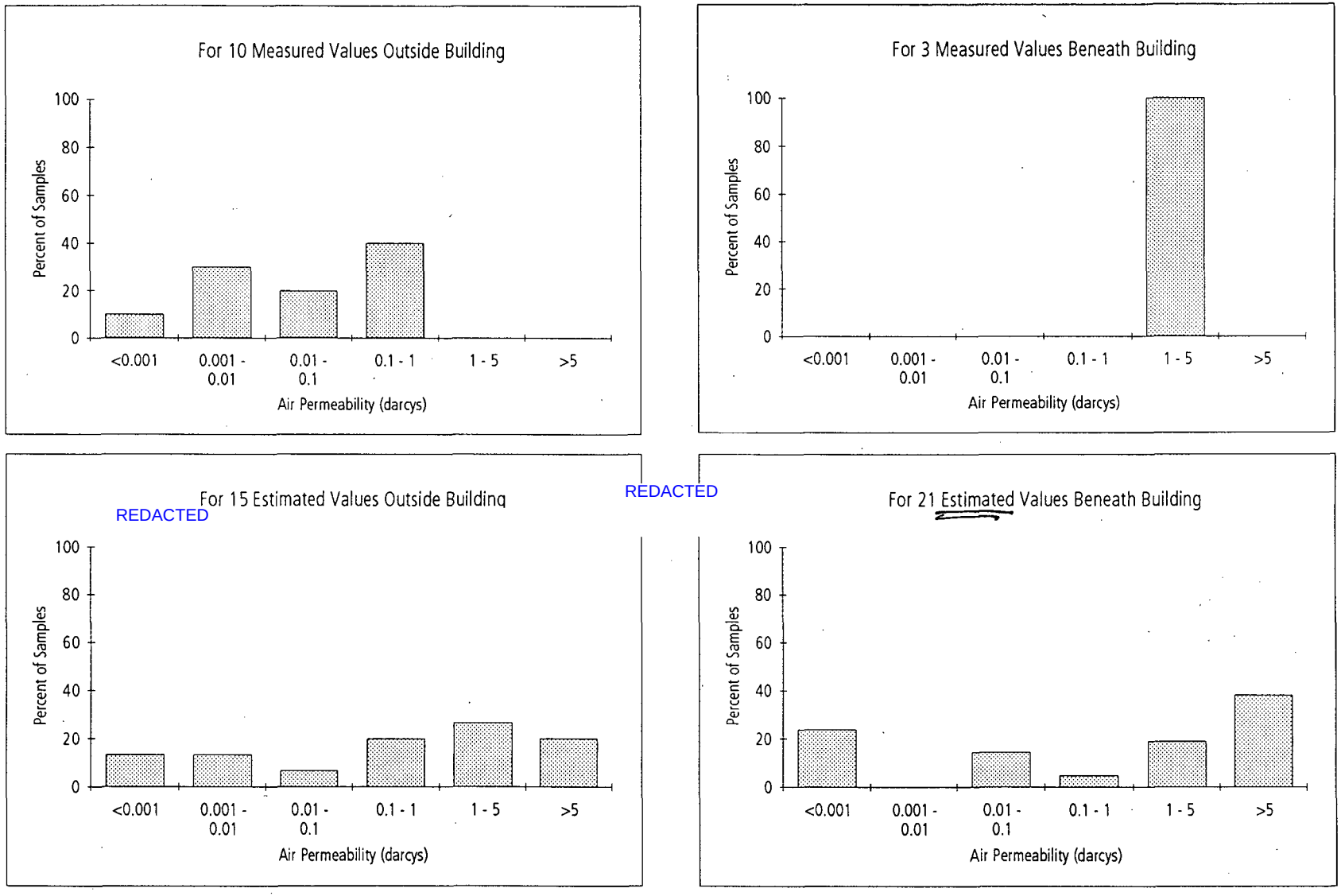
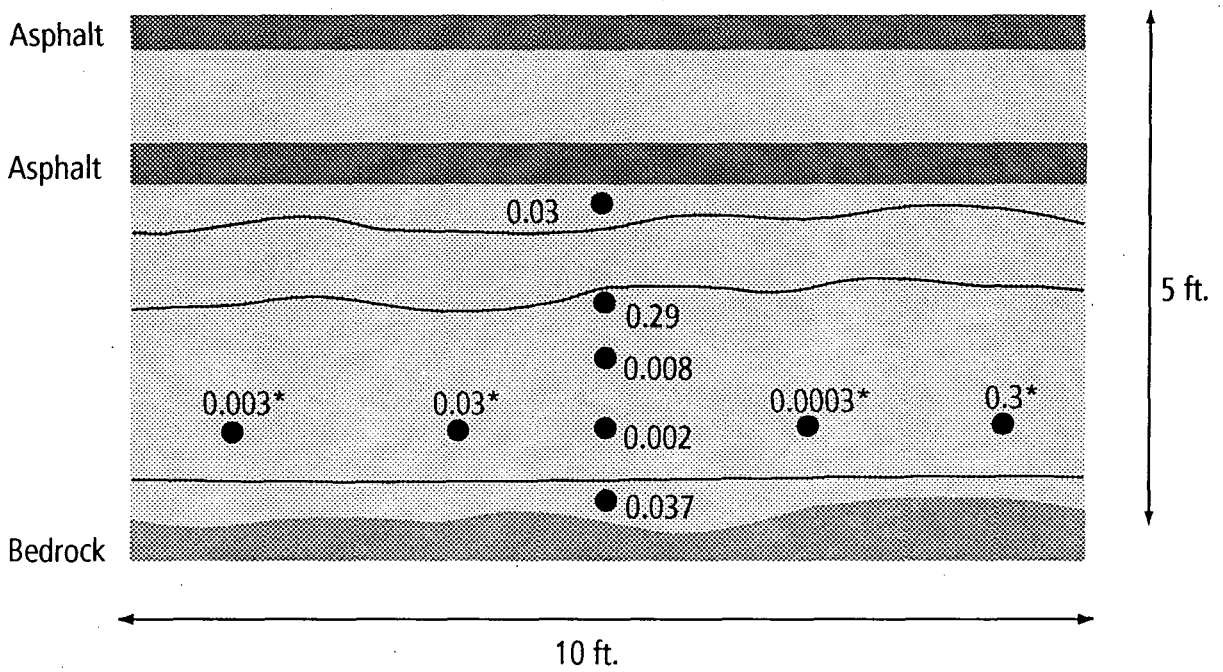


Figure 5-2. Histograms of calculated and estimated air permeability values for the areas outside and beneath the building.



Air-Permeability (darcys) calculated from hydraulic conductivity and moisture content.

*Air-Permeability (darcys) estimated from moisture content.

Figure 5-3. Section view of test pit TPK showing variation in calculated and estimated air permeability values.

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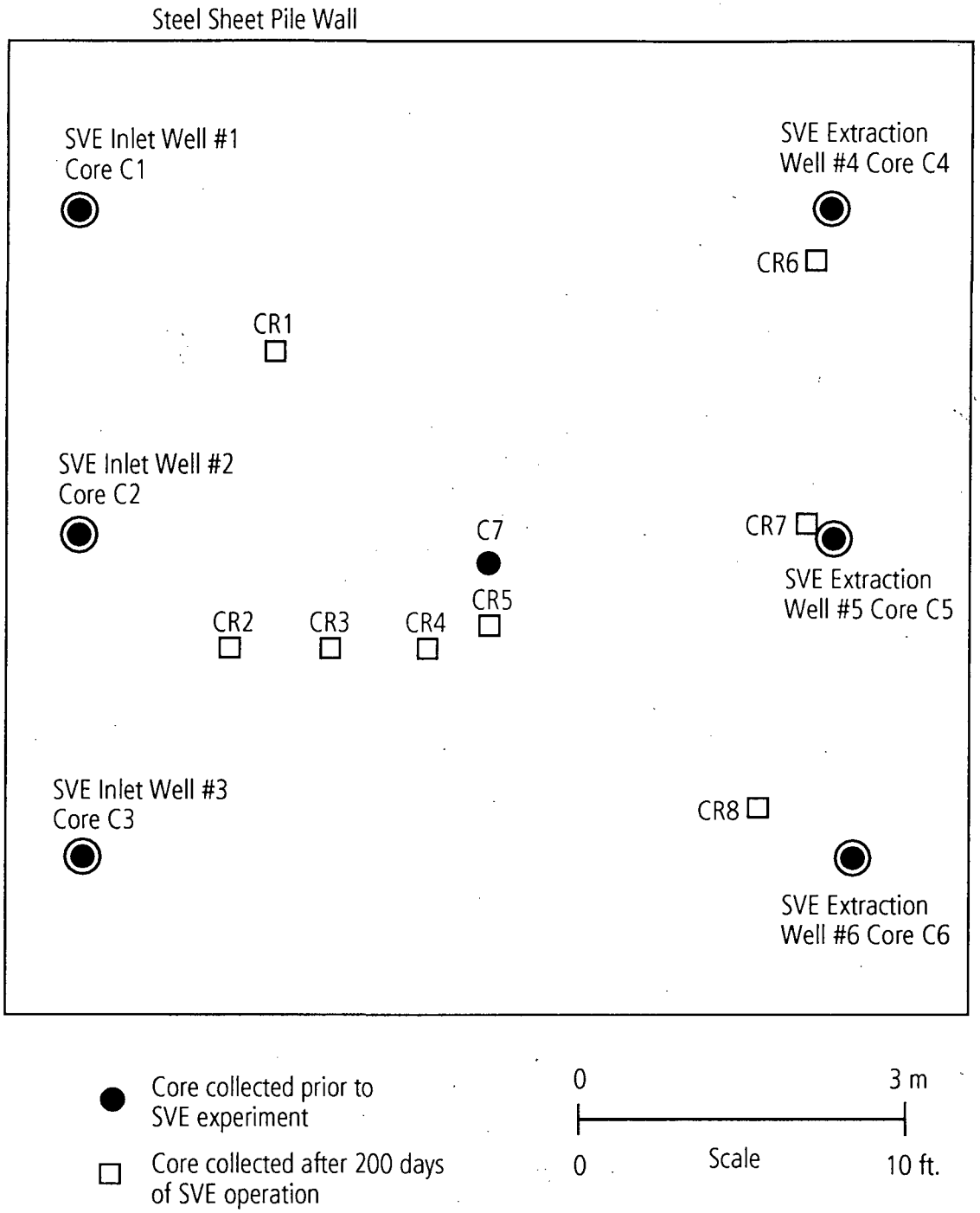

Figure 5-4. Layout of test cell for SVE experiment and location of cores.

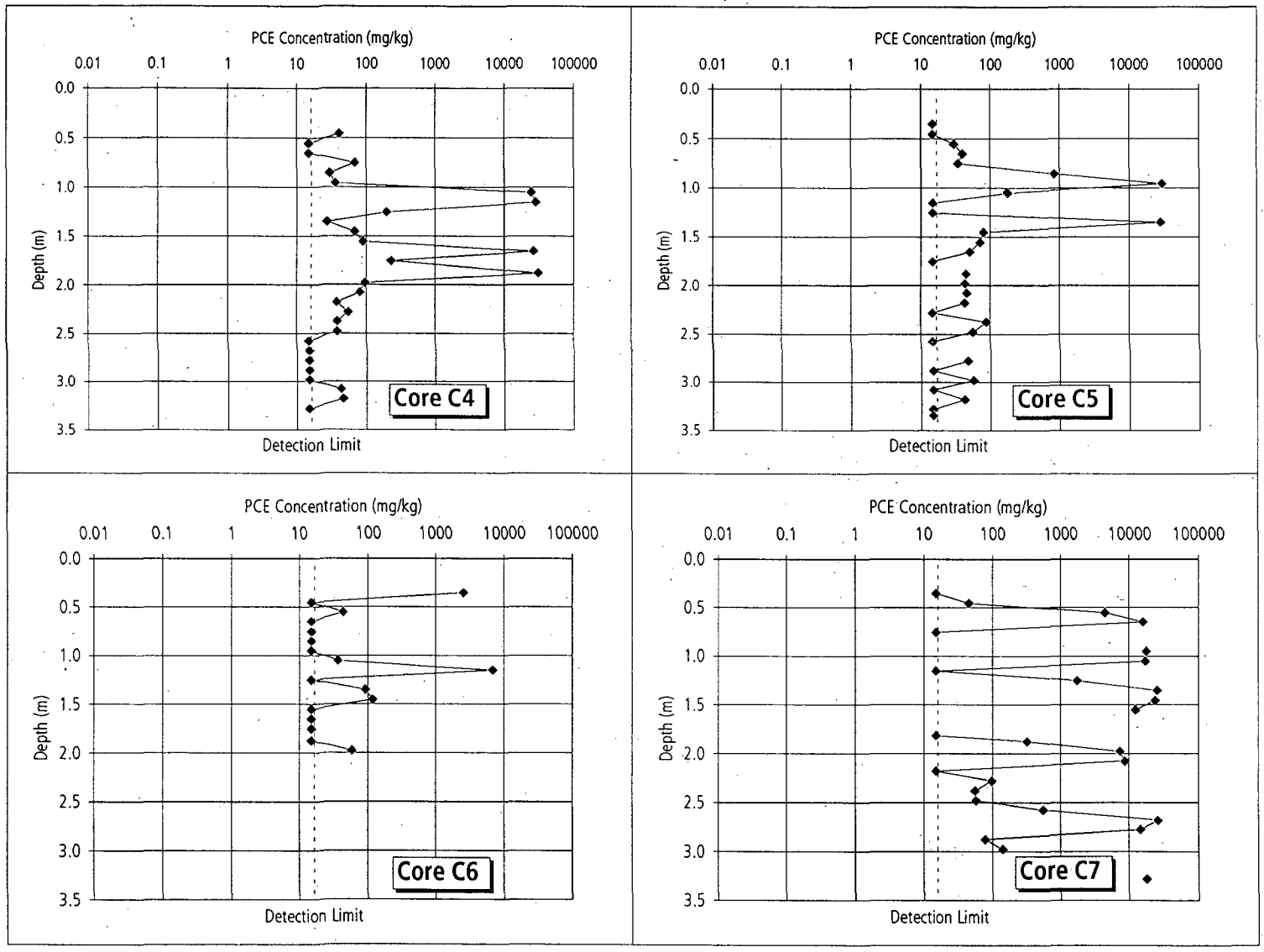

Figure 5-5. Results of soil samples from cores collected prior to the SVE experiment.

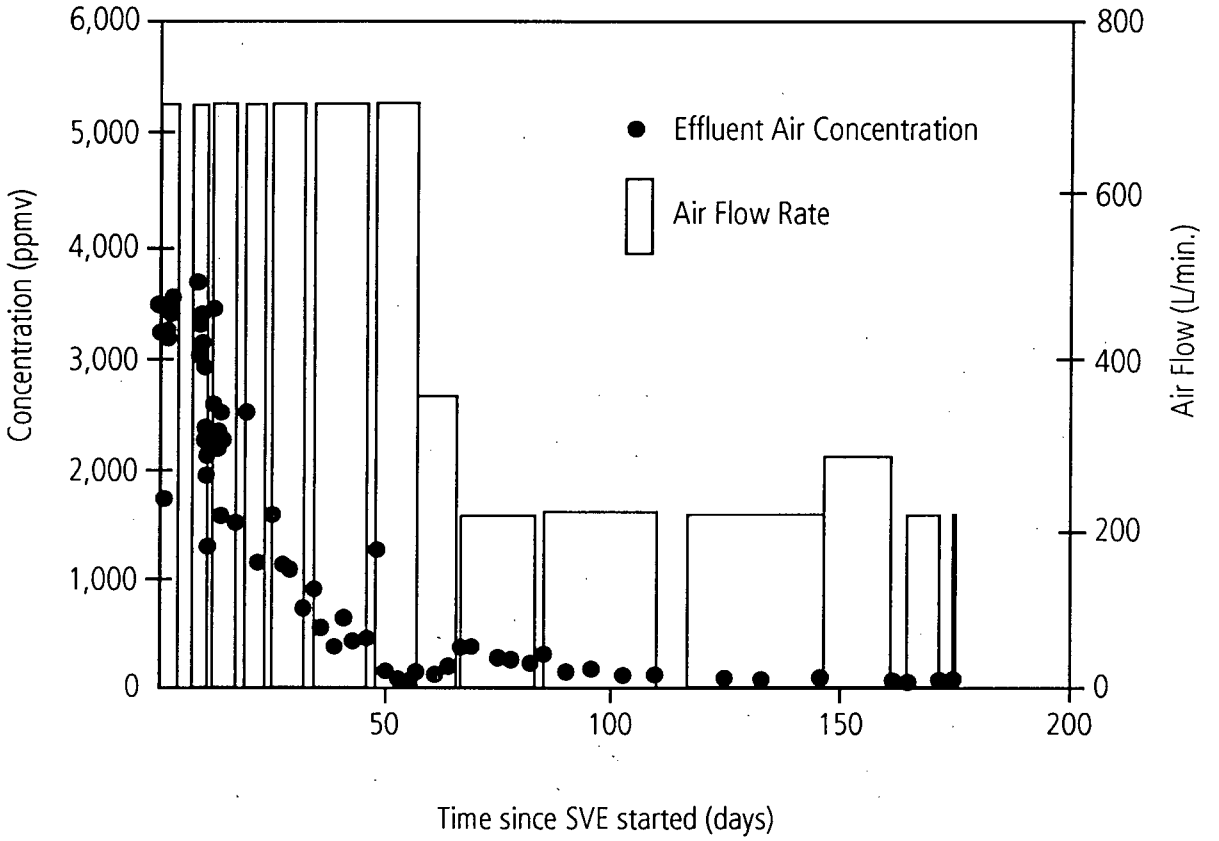

Figure 5-6. Trend in effluent air concentration during SVE experiment.

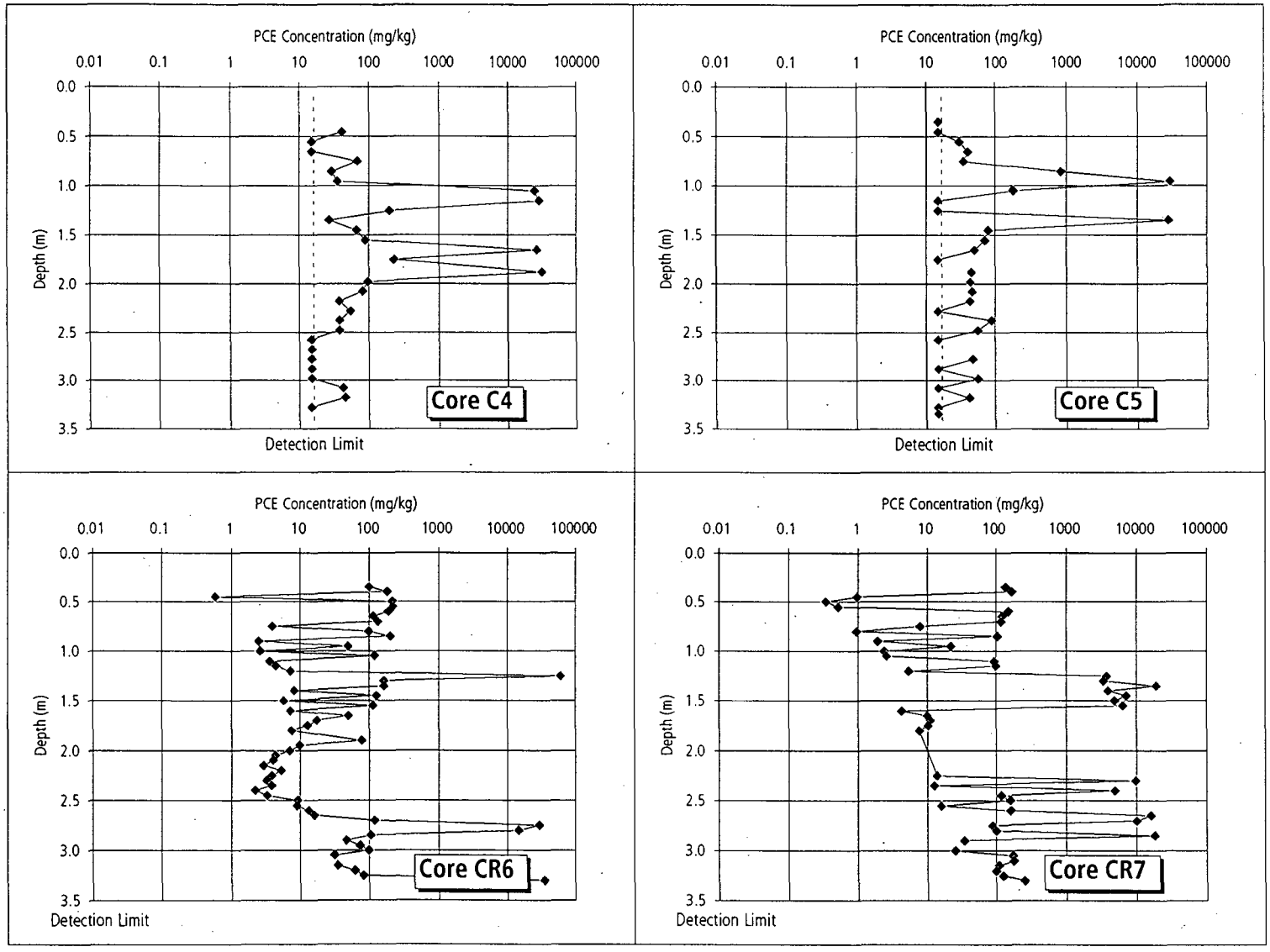

Figure 5-7. Results of soil samples from adjacent cores collected before the SVE experiment and after 200 days.

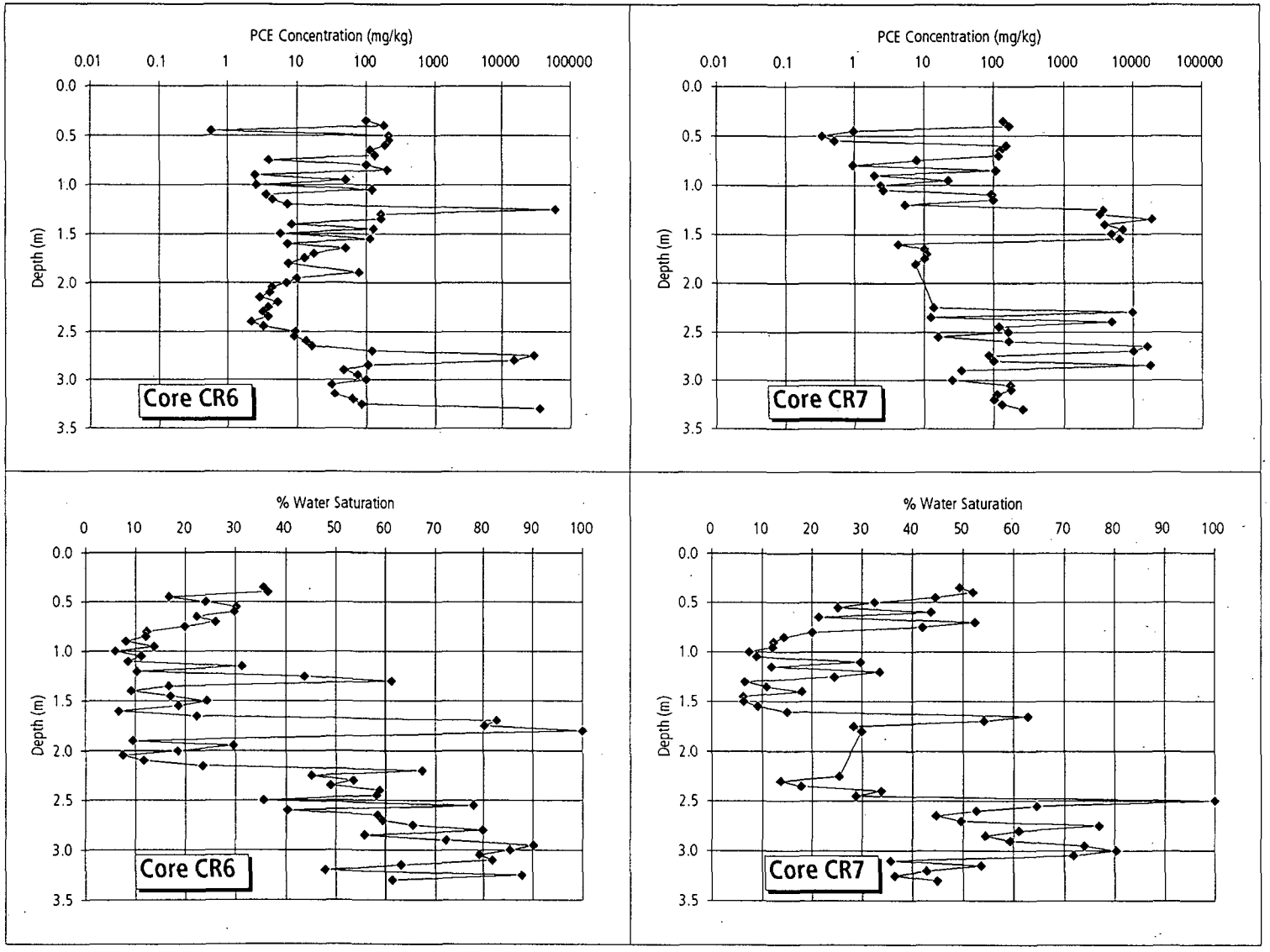

Figure 5-8. PCE in soil samples from cores collected after the SVE experiment compared to water saturation.

Table 5-1 Site characteristics that impact SVE process feasibility. From US EPA (1991).

Characteristic	Potential Negative Impact
Contaminant	
Type	Unsuitable if non-volatile
Low Volatility	Unsuitable if vapor pressure is too low
High Density, High Water Solubility	Contaminants tend to migrate into the saturated zone
Soil	
Low air permeability	Hinders air flow
High humic content	Causes high sorption
High moisture content	Hinders air flow
Low temperature	Lowers vapor pressure and Henry's Constant
High clay content	Hinders air flow
Low porosity	Hinders air flow
Site	
Distribution and quantity of contaminants	May not be cost effective if quantity is small (<several hundred cubic yards) or if contaminants are shallow (<20 ft.)
Variable soil characteristics	Bypassing of contaminated zones by air flow
Lithology, heterogeneity	Affects well design and placement
Buried debris	Inconsistent removal rates

Table 5-2. Calculated air permeability for samples of the unconsolidated deposits. Water saturation calculated from porosity and water content. REDACTED REDACTED

Sample	Depth (ft.)	Water Saturation (%)	Air Permeability (darcys)	Air Permeability (cm^2)
TPJ 1A	1.9	42	0.0027	2.7×10^{-11}
TPK 1A	1.8	39	0.031	3.1×10^{-10}
TPK 2A	2.8	37	0.29	2.8×10^{-9}
TPK 3A	3.3	53	0.0085	8.3×10^{-11}
TPK 4A	4.1	61	0.0020	2.0×10^{-11}
TPK 5A	4.8	43	0.037	3.7×10^{-10}
TPK 10A	4.4	39	0.12	1.2×10^{-9}
TPM 2A	4.0	35	0.12	1.2×10^{-9}
TPM 3A	0.8	38	0.14	1.4×10^{-9}
TPM 4A	3.0	96	0.0005	5.4×10^{-12}
TPL 1A	3.2	28	1.7	1.6×10^{-8}
TPL 3A	1.4	22	2.8	2.8×10^{-8}
TPL 4A	2.2	22	3.4	3.4×10^{-8}
	Geometric Mean	39	0.06	6×10^{-10}

Table 5-3 Summary of foc (fraction organic carbon) and petroleum hydrocarbon analyses for the unconsolidated deposits.

Sample	Depth (ft.)	foc (wt. %)	Total Petroleum Hydrocarbons (mg/kg)
TPA 27	2.25	0.028	-
TPA 37	3.08	0.033	-
TPA 44	3.67	0.051	-
TPA 74	6.17	0.056	-
TPB 27	2.25	0.036	-
TPB 37	3.08	0.039	-
TPB 44	3.67	0.072	-
VB1 2	2.25 - 3.25	0.02	-
VB2 2	2.25 - 4.25	0.03	-
VB3 2	2.25 - 4.25	0.03	-
VB3 4	8.0 - 10.0	0.01	-
VB3 6	12.0 -13.0	0.02	-
TPF 1A	2.5	-	3850
TPG 1A	2.0	-	260
TPG 2A	3.3	-	120
TPG 3A	0.8	-	47
TPG 4A	2.6	-	12
TPG 5A	4.8	-	7.4
TPG 6A	6.0	-	6.4
TPG 7A	1.5	-	200
TPG 8A	2.9	-	1.1
TPG 9A	7.3	-	4.3
TPG 5B	4.8	-	3.1
TPG 1B	2.0	-	260
SS1SA	Excavation spoil	-	260

Table 5-4. Estimated air permeability for samples of the unconsolidated deposits for which only moisture content was measured.

Outside Building

Sample	Depth (ft.)	Water Content (wt. %)	Estimated Air Permeability (darcys)	Calculated Air Permeability (darcys)
TPA 27	2.25	5.1	3	-
TPA 37	3.08	4.5	>5	-
TPA 44	3.67	5.8	3	-
TPB 27	2.25	8.8	0.003	-
TPB 37	3.08	5.1	3	-
TPB 44	3.67	6.7	0.6	-
TPJ 1A	3.0	8.8	-	0.0027
TPJ 2A	3.0	3.7	>5	-
TPJ 3A	4.5	10.2	0.0005	-
TPK 1A	1.8	5.5	-	0.03
TPK 2A	2.8	7.3	-	0.29
TPK 3A	3.3	8.2	-	0.0085
TPK4A	4.1	8.7	-	0.002
TPK 5A	4.8	7.1	-	0.037
TPK 6A	4.1	9.5	0.0005	-
TPK 7A	4.1	6.5	0.6	-
TPK 8A	4.1	7.3	0.03	-
TPK 9A	4.1	8.3	0.007	-
TPK 10A	4.4	7.5	-	0.12
TPK 11A	4.4	3.0	>5	-
TPK 12A	1.9	5.6	3	-
TPM 2A	4.0	5.9	-	0.12
TPM 3A	2.0	6.4	-	0.14
TPM 4A	0.8	15.8	-	0.0005
UC28 C284C	6.0 - 8.0	6.5	0.6	-

Table 5-4 (cont.). Estimated air permeability for samples of the unconsolidated deposits for which only moisture content was measured.

Beneath Building

Sample	Depth (ft.)	Water Content (wt. %)	Estimated Air Permeability (darcys)	Calculated Air Permeability (darcys)
TPL 1A	3.2	5.6	-	1.6
TPL 2A	1.8	4.2	>5	-
TPL 3A	1.4	6.0	-	2.8
TPL 4A	2.2	5.5	-	3.4
UC32 1A	0.5 - 2.0	5.3	3	-
UC32 2A	2.0 - 3.5	3.1	>5	-
UC32 3A	3.5 - 5.5	9.2	0.0005	-
UC32 4A	5.5 - 6.8	13.3	0.0005	-
UC33 1A	0.5 - 2.0	4.3	>5	-
UC33 2A	2.0 - 3.5	2.5	>5	-
UC33 3A	3.5 - 5.5	2.9	>5	-
UC33 4A	5.5 - 7.5	7.6	0.03	-
UC34 1A	3.0 - 4.5	15.3	0.0005	-
UC34 2A	4.5 - 6.0	5.2	3	-
UC34 3A	6.0 - 8.0	5.3	3	-
UC35 1A	0.5 - 2.0	9.6	0.0005	-
UC35 2A	2.0 - 3.5	2.5	>5	-
UC35 3A	3.5 - 5.5	1.2	>5	-
UC35 4A	5.5 - 7.0	7.2	0.06	-
UC36 1A	0.5 - 2.0	6.4	0.6	-
UC36 2A	2.0 - 3.5	9.8	0.0005	-
UC36 3A	3.5 - 5.0	5.3	3	-
UC36 4A	5.0 - 6.5	2.9	>5	-
UC36 5A	6.5 - 7.7	7.8	0.02	-

6.0 Alternate Remedial Measures for the Unconsolidated Deposits

6.1 Alternate Cleanup Target

Given the conclusion that remedial measures applied to the unconsolidated deposits would not protect groundwater, it is useful to ask if there are other exposure endpoints affected by contaminated unconsolidated deposits at the Property that could be addressed. As noted above in Section 2.3, the original Endangerment Assessment ("EA") found none on the UniFirst Property. Furthermore, in 1989, EPA and UniFirst conducted outdoor and indoor air sampling studies in both the UniFirst building and nearby residences. A risk assessment conducted at that time showed no risks.

When the decisions outlined in the 1989 ROD and 1991 ESD were made, however, there was little information on the nature and extent of contamination in the unconsolidated deposits. There had been no indication of residual DNAPL in the unconsolidated deposits. Since that time, the waste-oil-contamination release area was discovered and the contamination in the current loading-dock area has been delimited. Although these areas are relatively small in size and are conservatively estimated to contain less than approximately one hundred pounds of PCE, concentrations in samples of the unconsolidated deposits indicate discontinuous zones of residual DNAPL. In view of the finding of these release areas, it is appropriate to consider alternate soil cleanup targets intended to protect against exposures via other pathways.

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The highest concentrations of PCE in the unconsolidated deposits occur outside the building at a relatively shallow depth. All PCE concentrations exceeding about 10,000 µg/kg are found in the waste-oil contamination area and the vicinity of the current loading dock. The volume of contaminated unconsolidated deposits in these areas is small, about 100 to 200 yd^3.

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All such findings occur in areas covered by pavement or several feet of uncontaminated deposits, and, as a result, access to the contaminated zones can be gained only by purposeful excavation.

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As an appropriate proxy cleanup standard to protect non-groundwater endpoints at the Property, UniFirst proposes to utilize the action level for PCE that the EPA has set out in the proposed RCRA rule titled "Corrective Action for Solid Waste Management Units (SWMUs) at Hazardous Waste Management Facilities," which, UniFirst understands, is currently being utilized in Region 1. As the most stringent soil standard where groundwater protection is not at issue, the EPA proposed an "action level" for PCE concentrations in unconsolidated deposits of 10 mg/kg (10,000 µg/kg). The

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following quoted and paraphrased discussion of the action level is taken from 55 Federal Register 30798–30820, July 27, 1990.

The 10 mg/kg PCE standard was derived for a scenario that assumed a residential use pattern, with long-term direct contact and soil ingestion by children. "Action levels for soil would typically be measured on the surface (generally the upper two feet of earth)." The EPA further noted that its exposure assumptions were:

> . . . reflective of a conservative average scenario in which children ages 1-6 years (i.e. the time period during which children exhibit the greatest tendency for hand-to-mouth activity) are assumed to ingest an above-average amount of soil on a daily basis. The exposure levels estimated in this manner are calculated to keep exposures well below the population threshold for toxic effects. . . . [The] recommendations are based on the conservative assumptions that 100 percent of the ingested non-carcinogenic and carcinogenic soil contaminants are absorbed across the gastrointestinal tract and that ingestion occurs 365 days/year, regardless of climatic conditions or age.

It is important to note that, an "action level" is not a *cleanup* standard, but rather, a "trigger", that will merely indicate the need for a "Corrective Measure Study" ("CMS"). "Contamination exceeding action levels indicates a potential threat to human health or the environment which may require further study." Exceedance of an action level allows, but does not require, EPA to require a CMS; in other words, it creates only a rebuttable presumption that a CMS is necessary.

In addition to being supported by EPA's risk reduction strategy, reliance on the surrogate "cleanup goal" of 10 mg/kg (10,000 µg/kg) of PCE in the top 3 feet of unconsolidated deposits is also technically justified and highly protective given the nature of the Property. A level of 10 mg/kg PCE in the unconsolidated deposits represents a contaminant concentration which, based on observations at the Property, is not likely to be exceeded by recontamination due to upward migration of vapors from groundwater beneath the Property. That is, where contamination in excess of 10 mg/kg PCE in the release areas is removed, recontamination of the unconsolidated deposits by upward vapor migration from the underlying contaminated groundwater will occur, but at levels below the 10 mg/kg target. Thus, for a 10 mg/kg goal, a "permanent remedy" is feasible. REDACTED

Practically speaking, the only conceivable mechanism of exposure to contaminated unconsolidated deposits would be by purposeful excavation. UniFirst has already excavated in the most seriously affected soils when it installed the influent line trench through the waste-oil contamination, which REDACTED

contained the highest PCE concentration beneath the Property. At no time during this excavation were conditions measured that warranted implementation of any health and safety measures beyond normal construction requirements according to the approved Health and Safety Plan.

Cleanup to the 10 mg/kg level would require removal of the waste-oil contamination area and the area of the current loading dock. This action, if effective, would remove about 90 per cent of the less than approximately one hundred pounds of PCE estimated to be present in the unconsolidated deposits. After this action, the PCE contamination remaining in the unconsolidated deposits would be limited to low to moderate levels of contamination situated principally beneath the building. Removal from the release areas in this way would also increase the likelihood that no further remediation of the unconsolidated deposits would be required to protect groundwater at some time in the distant future if groundwater remediation ever were completed.

In summary, UniFirst proposes that a PCE concentration of 10 mg/kg (10,000 µg/kg) be applied as an alternate cleanup target for the top three feet of the unconsolidated deposits in order to protect against the risk of direct exposure to contamination close to the ground surface. (The material that presently exceeds the alternate cleanup target is found only at shallow depth in the release areas.) Cleanup to this alternate target would constitute a permanent remedy that would not be negated by the effect of vapor migration upward from the underlying contaminated groundwater. This action would remove about 90 per cent of the less than approximately one hundred pounds of PCE estimated to be present in the unconsolidated deposits and would increase the likelihood that no further remediation of the unconsolidated deposits would be required to protect groundwater, at some time in the distant future if groundwater remediation ever were to be completed.

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6.2 Remedial Measures for the Alternate Cleanup Target

6.2.1 Objective

Remedial measures to achieve the alternate cleanup target will focus on the small volume of contaminated unconsolidated deposits found at shallow depth in the waste-oil contamination area and the vicinity of the current loading dock. These are the only areas in which PCE concentrations exceed 10,000 µg/kg.

Because of the small volume and shallow depth of the contaminated unconsolidated deposits, and the geological variability, in situ removal or treatment technologies such as SVE, water flushing and surfactant flushing

are not feasible. Excavation is probably the most suitable technology for remediation in this situation. However, in situ oxidation by permanganate infiltration also deserves consideration because this in situ treatment technology may not be limited by geological variability to the same degree as technologies such as SVE. Excavation and in situ oxidation by permanganate infiltration are discussed in the following sections.

6.2.2 Excavation

The detailed investigations of the unconsolidated deposits conducted during 1992 through 1994 have defined the areas of highest PCE concentrations in the waste-oil contamination area and the vicinity of the current loading dock. All unconsolidated deposits exceeding 10,000 µg/kg are found outside the building at shallow depth.

For a cleanup target of 10,000 µg/kg, the implementation and costing of an excavation remedy can be well defined. Past experience at the Property has shown that concentrations of 10,000 µg/kg PCE in unconsolidated deposits can be readily detected by field screening methods using a portable OVA (organic vapor analyzer). This approach would allow confirmation of the extent of contamination during the excavation activities to ensure appropriate materials are removed. Upon excavation, all materials would be containerized, manifested and shipped off site for appropriate disposal or treatment.

UniFirst proposes to prepare a plan for implementation and preliminary costs for an excavation remedy.

6.2.3 In Situ Oxidation by Permanganate Infiltration

The use of in situ oxidation of PCE in the unconsolidated deposits by infiltration with a solution of potassium permanganate may have advantages over other in situ removal or treatment technologies such as SVE, water flushing or surfactant flushing because it may be less impaired by the effects of geological variability. In addition, in situ oxidation would not require shipment of contaminated soil off site for treatment or disposal.

Potassium permanganate ($KMnO_4$) is a strong oxidizing agent that has been used in the field of water and wastewater treatment for the destruction of organic contaminants for decades. Potassium permanganate is stable in water and soluble in water to concentrations of about 36 g/L. Permanganate reacts with chlorinated ethenes such as PCE or TCE to form harmless by-products: carbon dioxide, chloride and manganese dioxide. The oxidation reaction

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occurs mostly in the aqueous phase, rather than by direct attack of PCE in the form of DNAPL. REDACTED

Permanganate infiltration is an experimental technology that has undergone laboratory and small-scale field testing for the in situ oxidation of PCE and TCE (see Schnarr and Farquhar, 1992 in Appendix G). These studies have shown permanganate to be capable of almost complete destruction of PCE in the form of residual and pooled DNAPL in sandy aquifer materials. Permanganate concentrations of 1 g/L to 10 g/L have been studied. The effective destruction of PCE in the form of DNAPL is believed to occur as a result of greatly accelerated dissolution of the DNAPL caused by rapid oxidation of the PCE in the aqueous phase.

Most other in situ removal or treatment technologies such as SVE, water flushing or surfactant flushing require intimate contact between the air, water or surfactant solution flowing through the subsurface in order to be effective. Where geological variability causes permeable pathways for preferential flow, areas of lower permeability are by-passed. Contaminants residing in such lower permeability zones can be removed only by slow diffusion of the contaminants out of the lower permeability zones into the higher permeability zones.

Because of the nature of the permanganate behavior and the oxidation reaction, permanganate infiltration may be less impaired by geological variability than other in situ technologies. When permanganate solution migrates along the more permeable pathways in a variable geological unit, REDACTED permanganate will diffuse out into less permeable zones. Because the infiltrating solution contains a high permanganate concentration, diffusion out into less permeable zones will be substantial. At the same time, PCE in the less permeable zones will tend to diffuse out of the less permeable zones. Permanganate diffusing into these zones will oxidize the dissolved PCE as it diffuses out, thereby maintaining both a high rate of PCE diffusion out and permanganate diffusion into the less permeable zones.

This dual-direction diffusion of oxidant in and contaminant out should result in more rapid contaminant removal from less permeable zones than any other in situ technology. This capability would be well suited to the geological variability found in the unconsolidated deposits at the UniFirst Property.

Another potential benefit of permanganate infiltration is that any permanganate reaching the groundwater zone and encountering PCE will continue to oxidize the contaminants. This would be an advantage over technologies such as SVE which are limited to contaminant removal from only the unsaturated zone.

Permanganate infiltration is an innovative technology that has not yet undergone field-scale pilot tests at actual sites of PCE contamination, nor has it been implemented as a full-scale remedy at any site. Likewise, permanganate infiltration has not been applied in till such as that found at the UniFirst Property.

As a first stage in the evaluation of permanganate infiltration, UniFirst proposes to assess the site conditions at the Property and information available from experimental testing of the technology in order to develop a conceptual remedial design and preliminary costing. The expected effectiveness of the technology and possible cost would then be compared to an excavation remedy.

If it is determined that permanganate infiltration may be comparable in effectiveness and cost to excavation, laboratory treatability testing would be proposed. Such testing would likely involve batch tests to confirm the oxidation of PCE in the soil matrix found at the UniFirst Property and determine the degree of permanganate consumption by the soil matrix.

7.0 Summary and Conclusions

Detailed investigations conducted during 1992 through 1994 have led to the formulation of a comprehensive conceptual model for the nature and extent of PCE contamination in the unconsolidated deposits at the UniFirst Property. This conceptual model provides the basis for conclusions as to whether remedial measures for the unconsolidated deposits are necessary to control the effects of the contamination present, and also provides the basis for the evaluation of prospective remedial measures.

7.1 Site Conditions

The following points summarize the key features of the Property's conditions that are relevant to the consideration of remedial measures for the unconsolidated deposits. REDACTED REDACTED

1. There are two areas in which PCE was released to the ground surface: the waste-oil contamination area and the area to the south of the current loading dock.
2. The release areas are small in lateral extent with the waste-oil contamination area measuring about 15 feet by 35 feet, and the current loading-dock area measuring about 20 feet by 35 feet.
3. Evidence of residual DNAPL has been found only in small discontinuous zones within the release areas.
4. The migration of vapors from the release zones has not resulted in contamination of the unconsolidated deposits significantly beyond the release zones.
5. The mass of PCE estimated to remain in the release areas is small, less than approximately one hundred pounds, a small fraction of the several thousand pounds or more likely present in the bedrock or other off-Property sources. REDACTED
6. The flux of PCE to the groundwater from the release areas is very small, 0.05 pounds/month (0.066 cups/month) or less, due to the small size of the release areas and the relatively low permeability of the unconsolidated deposits. The calculated PCE flux to the groundwater from the unconsolidated deposits is about 0.02 per cent to 0.2 per cent of the 25 to 30 pounds/month of PCE removed by the pumping of UC22.
7. A zone of diffuse contamination extends from the east end of the Property measuring about 13,000 ft^2 in area. Low to moderate concentrations of PCE in this area result from vapor migration upward from the contaminated groundwater.
8. The presence of DNAPL in the shallow bedrock is indicated by the findings in UC8. The magnitude of dissolved PCE concentrations

and the persistence of high concentrations in UC22 indicate the presence of DNAPL in the deeper bedrock.

10. Groundwater contamination is expected to persist indefinitely, decades or longer, because of the large mass of PCE estimated to exist in the bedrock or other off-Property sources, and the rate of removal by pumping of UC22.

7.2 Remedial Measures Specified in the ROD and ESD

According to the regulatory decision and settlement documents concerning the remediation of the contaminated unconsolidated deposits beneath the Property, the sole goal for any such remedial efforts is the protection of groundwater. The clean-up level for contaminated unconsolidated deposits of 36.7 μg/kg PCE specified in the 1989 ROD was meant to reflect the concentration, that, if present in unconsolidated deposits, would leach to the groundwater and cause exceedance of the MCL for PCE (5 μg/L).

The 1991 ESD specified soil vapor extraction (SVE) as the remedy for the unconsolidated deposits. The ROD, the Consent Decree State of Work (SOW) and ESD all indicate that the remedy for the contaminated unconsolidated deposits at the UniFirst Property should commence at some appropriate time during operation of the groundwater remedial measures so as to avoid recontamination of the unconsolidated deposits.

At the time these decisions were made, several aspects of the Property conditions were uncertain. The distribution and mass of PCE in the unconsolidated deposits was not known. In particular, the waste-oil contamination area had not been discovered. The relative contributions of the unconsolidated deposits and the DNAPL in the bedrock to the groundwater contamination was not known. Also, it was not known how long significant groundwater contamination in the bedrock might persist.

It can now be concluded that groundwater contamination will persist for decades or longer because of the large mass of DNAPL in the bedrock. The contribution of PCE from the unconsolidated deposits to the groundwater is negligible in comparison to the contribution from DNAPL present in the bedrock. Consequently, there would be no measurable improvement in groundwater quality as a result of even complete elimination of the small mass of PCE present in the unconsolidated deposits.

In addition, because groundwater contamination beneath the Property is expected to persist for decades or longer, it is likely that vapor migration upward from the contaminated groundwater will negate the effectiveness of remedial measures implemented in the unconsolidated deposits. The level of contamination caused by vapor migration from the groundwater would be

lower than the levels found currently in the release areas, but would be comparable to those found in the zone of diffuse contamination.

Because of these conditions, no measurable benefit in terms of groundwater protection could result from remediation of the unconsolidated deposits in the foreseeable future. In the event that restoration of the groundwater is achieved at some time in the distant future, it is possible that no further remediation would be required in the unconsolidated deposits in order to protect groundwater. Because the contribution of PCE to the groundwater from the unconsolidated deposits is estimated to be so small, the presence of a small mass of PCE in the unconsolidated deposits may not have any significant effect on potential drinking water supplies in the underlying groundwater. Future groundwater monitoring will determine this possibility.

Irrespective of whether any potential benefit with regard to groundwater protection could be derived from remediation of the unconsolidated deposits, the small size and shallow depth of the contaminated areas, the relatively low permeability, and the spatial variability in soil properties at the Property would severely limit the performance of most in situ treatment of removal remedies.

7.3 Feasibility of SVE

SVE was selected in the 1991 ESD at a time when there was little quantitative information on the distribution of contaminants or the physical properties of the unconsolidated deposits. Based on the understanding gained from the detailed investigations conducted during 1992 - 1994, the feasibility of SVE for remediation of the unconsolidated deposits at the UniFirst Property was assessed according to the remedy screening factors set out in EPA guidance.

Although the PCE at the UniFirst Property would be amenable to removal by SVE if only its vapor pressure and Henry's Constant were considered, almost all the factors related to soil characteristics and site characteristics that can have a negative effect on the performance of SVE are applicable at the UniFirst Property. These factors include:

1. High density of PCE has caused most of the mass of PCE to migrate downward into the saturated zone and into the bedrock.
2. Low air permeability found generally across the Property will hinder air flow. In the vicinity of the release areas outside the building the where PCE concentrations are highest, 32 per cent of the soil samples indicate a very low air permeability of 0.01 darcys or less, which is noted in EPA guidance as the practical lower limit for SVE. REDACTED

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3. High humic (organic carbon) content resulting from petroleum hydrocarbons in the waste-oil contamination area will cause high sorption of PCE and hinder removal.
4. High moisture content found in many areas will cause low air permeability.
5. Low temperature during the winter will lower vapor pressure and Henry's Constant, and thus, the rate of removal for the PCE REDACTED contamination found at shallow depth. REDACTED
6. PCE contamination is shallow in both the release areas and the zone of diffuse contamination, and the volume of contaminated unconsolidated deposits associated with the release areas is small.
7. The extreme spatial variability in air permeability will cause air to flow preferentially through the most permeable zones and bypass the less permeable zones. REDACTED
8. Buried debris and backfill from the construction of the effluent trench for UC22 and exploration test pits is present and will cause disruption of air flow patterns. REDACTED

Although all these factors will have a negative effect on the performance of SVE, the most significant are:

- the shallow depth of contamination in both the releases areas and the zone of diffuse contamination;
- the small volume of contaminated unconsolidated deposits associated with the release areas;
- the low air permeability in the unconsolidated deposits;
- the extreme spatial variability in air permeability and contamination concentrations in the unconsolidated deposits.

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SVE can never contribute to the protection of groundwater while contaminated groundwater persists and allows upward migration of vapors. It is unlikely that protection of groundwater could be achieved practicably by SVE, even if remediation of the unconsolidated deposits were to be required following restoration of the underlying contaminated groundwater at some time in the future. Other remedial technologies would likely be more cost effective than SVE for part or all of the contamination that might remain in the unconsolidated deposits at that time in the future.

If remediation efforts were to be applied to only the zones of high concentrations in the release areas, other remedial technologies are likely to be more cost effective than SVE because of the small size and shallow depths of these zones.

In summary, it is concluded that SVE would not be a feasible remedy for the unconsolidated deposits at the UniFirst Property either to achieve protection of groundwater, or for treatment of the highest PCE concentrations found in

the release areas. As a result, the further study of SVE by means of field pneumatic testing or pilot testing is not warranted. Neither pneumatic testing nor short duration SVE pilot testing could provide more definitive information on the factors most critical to the effectiveness of SVE, namely, the effect of diffusion out of lower permeability zones which are known to exist, and the length of time that and SVE system would need to operate to achieve any specific cleanup target.

7.4 Alternate Cleanup Target

When the decisions outlined in the 1989 ROD and 1991 ESD were made, there was little information on the nature and extent of contamination in the unconsolidated deposits. There had been no indication of residual DNAPL in the unconsolidated deposits. Since that time, the waste-oil-contamination release area was discovered and the contamination in the current loading-dock area has been delimited. PCE concentrations in samples of the unconsolidated deposits indicate discontinuous zones of residual DNAPL, but these areas are small in size, are at shallow depth, and are generously estimated to contain less than approximately one hundred pounds of PCE. In view of the finding of these release areas, it is appropriate to consider alternate soil cleanup targets intended to protect against exposures via other pathways.

UniFirst proposes to utilize the action level for PCE that the EPA has set out in the proposed RCRA rule titled "Corrective Action for Solid Waste Management Units (SWMUs) at Hazardous Waste Management Facilities," which, UniFirst understands, is currently being utilized in Region I. As the most stringent soil standard where groundwater protection is not at issue, the EPA proposed an "action level" for PCE concentrations in unconsolidated deposits of 10 mg/kg (10,000 μg/kg).

UniFirst proposes that a PCE concentration of 10 mg/kg (10,000 μg/kg) be applied as an alternate cleanup target for the unconsolidated deposits in order to protect against the risk of direct exposure to contamination close to the ground surface. The material that presently exceeds this alternate cleanup target is found only at shallow depth in the release areas. All PCE concentrations exceeding about 10,000 μg/kg are found in the waste-oil contamination area and the vicinity of the current loading dock. The volume of contaminated unconsolidated deposits in these areas is small, about 100 to 200 yd^3.

Cleanup to this alternate target would constitute a permanent remedy that would not be negated by the effect of vapor migration upward from the underlying contaminated groundwater. Evidence from the Property indicates

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that PCE contamination of the unconsolidated deposits by upward vapor migration from the groundwater should not exceed 10,000 µg/kg REDACTED

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Cleanup to this alternate target would remove about 90 per cent of the less than approximately one hundred pounds of PCE estimated to be present in the unconsolidated deposit source area and would increase the likelihood that no further remediation of the unconsolidated deposits would be required to protect groundwater, at some time in the distant future if groundwater REDACTED remediation ever were completed. REDACTED

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7.5 Alternate Remedial Measures

Remedial measures to achieve the alternate cleanup target will focus on the small volume of contaminated unconsolidated deposits found at shallow depth in the waste-oil contamination area and the vicinity of the current loading dock. Excavation is probably the most suitable technology for remediation in this situation. However, in situ oxidation by permanganate infiltration also deserves consideration because this in situ treatment technology may not be limited by geological variability to the same degree as technologies such as SVE. Excavation and in situ oxidation by permanganate infiltration are discussed in the following sections.

7.5.1 Excavation

For a cleanup target of 10,000 µg/kg, the implementation and costing of an excavation remedy can be well defined. Past experience at the Property has shown that concentrations of 10,000 µg/kg PCE in unconsolidated deposits can be readily detected by field screening methods using a portable OVA (organic vapor analyzer). This approach would allow confirmation of the extent of contamination during the excavation activities to ensure appropriate materials are removed. Upon excavation, all materials would be containerized, manifested and shipped off site for appropriate disposal or treatment.

UniFirst proposes to prepare a plan for implementation and preliminary costs for an excavation remedy.

7.5.2 In Situ Oxidation by Permanganate Infiltration

The use of in situ oxidation of PCE in the unconsolidated deposits by infiltration with a solution of potassium permanganate may have advantages over other in situ removal or treatment technologies such as SVE because it may be less impaired by the effects of geological variability. In addition, in situ

oxidation would not require shipment of contaminated soil off site for treatment or disposal.

As a first stage in the evaluation of permanganate infiltration, UniFirst proposes to assess the site conditions at the Property and information available from experimental testing of the technology in order to develop a conceptual remedial design and preliminary costing. The expected effectiveness of the technology and possible cost would then be compared to an excavation remedy.

References

The references cited in the preceding text are listed below in a manner that is intended to facilitate the reader's ability to find the reference and determine the nature of the reference. The references are categorized below accordingly: 1) UniFirst's submittals to the EPA in performance of its Source Area RD/RA for the unconsolidated deposits—many of which have multiple authors; 2) Reports that antedate the Consent Decree ; 3) Correspondence between UniFirst and its technical and legal representatives, and the EPA; and 4) Technical publications.

1) UniFirst's Submittals to the EPA in performance of its Source Area RD/RA for the unconsolidated deposits.

Draft Remedial Design Investigation Report (1991)
Draft Remedial Design Investigation Report and Final Design, Northeast Quadrant of the Wells G&H Site, Woburn, Massachusetts, Prepared by Environmental Project Control, Inc., October 22, 1991.

Draft Pre-Design Work Plan (1992).
Draft Pre-Design Work Plan, Remedial Design and Remedial Action for the Unconsolidated Deposits Beneath the UniFirst Property, Prepared by Water Waste & Land, Inc., ENSR Consulting and Engineering, Gradient Corporation, and Environmental Project Control, Inc. November 13, 1992.

Interim Data Report (January, 1994)
Analyses for Petroleum-Hydrocarbon Characterization of Unconsolidated Deposits, DNAPL, and Bituminous Concrete from the UniFirst Property, Prepared by J. P. Maney and S. Feenstra, January 28, 1994.

Interim Data Report (March, 1994)
Monitoring-Well Installations and Sampling of Groundwater and Unconsolidated Deposits, July 1993-February, 1994, UniFirst Property, Woburn, Massachusetts, Prepared by Stan Feenstra, March 11, 1994.

Interim Data Report (June, 1994)
Analyses of Unconsolidated Deposits from Borings and a Test Pit, April, 1994, UniFirst Property, Woburn, Massachusetts, Prepared by S. Feenstra, June 13, 1994.

2) Reports submitted to or prepared on behalf of the EPA that antedate the Decree.

Cherry et al. (1989)
Technical Report on the Woburn, Massachusetts Wells G&H Site, Prepared by J. A. Cherry, M.L. Johnson, and R. J. Jaeger, March, 1989.

E&E (1982). *Field Investigations of Uncontrolled Hazardous Waste Sites, Chlorinated Solvent Contamination of the Groundwater, East Central Woburn, Massachusetts. Task Report to EPA,* Prepared by Ecology and Environment, Inc., 1982.

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NUS (1986). *Wells G&H Site Remedial Investigation Report Part I, Volumes I-IV,* October 17, 1986.

3)Correspondence between UniFirst and its technical and legal representatives, and the EPA.

UniFirst's Responses to the EPA's "104(e) requests":
February 17, 1987 Letter from Ronald D. Croatti to EPA Gwen Ruta
February 19, 1987 Letter from Ronald D. Croatti to EPA Gwen Ruta
February 25, 1987 Letter from Jeffrey C. Bates to EPA Gwen Ruta
April 11, 1988 Letter from Ronald D. Croatti to EPA Barbara Newman

July 20, 1989. Letter from Warner North and Rudolph Jaeger to Jeffrey Bates memorializing their interpretation of the risk associated with exposure to concentrations of "target compounds" measured in dwellings near the Property and in the building on the UniFirst Property.

July 21, 1989. Letter and report from Douglas G. Smith, Sc.D. and John D. Spengler, Ph.D., describing the indoor-air-quality analyses performed in dwellings nearby the UniFirst Property and in the building on the UniFirst Property.

July 21, 1989. Letter from Douglas G. Smith, Sc.D. and John D. Spengler, Ph.D., to Mary Kay Voytilla (EPA): Residential Indoor-Air Sampling Results: Dewey Avenue Neighborhood, Wells G&H Superfund Site.

July 24, 1989. Letter from Jeffrey Bates to Tim Conway conveying July 20, 1989 letter from Warner North and Rudolph Jaeger to Jeffrey Bates cited above (July 20, 1989).

July 31, 1990. Letter from Timothy M. Cosgrave to Barbara Newman memorializing the major reasons why UniFirst maintains that SVE will not effectively remediate the unconsolidated deposits as presented on July 25, 1990 by UniFirst's consultants to the EPA.

March 14, 1991. Letter from Timothy M. Cosgrave to Barbara Newman clarifying the relative locations of Test Pit 1 and soil-vapor-collection devices VB1, VB2 and VB3 and the findings therefrom.

March 17, 1994. Letter from Mary Garren to Jeffrey Lawson providing the EPA's comments on: UniFirst's January 28, 1994 Interim Data Report, and letters from Jeffrey Lawson to Paula Fitzsimmons and Mary Garren of October 28, 1993 and March 4, 1994, respectively.

June 13, 1994. Letter from Mary Garren to Jeff Lawson directing UniFirst to cease all field work at the UniFirst Property and submit a work plan for a pneumatic permeability test.

June 27, 1994. Letter from Jeffrey Lawson to Mary Garren accompanying a work plan for a pneumatic permeability test and notifying the EPA that UniFirst would also send a notice of dispute and revive its notice of *force majeure* conditions.

June 27, 1994. Letter from Jeffrey Bates to Gretchen Muench giving notice of the existence of a dispute.

July 21, 1994. Letter from Deirdre Menoyo to Paula Fitzsimmons regarding proposed report from UniFirst in resolution of the dispute. Report promised on or about August 31, 1994.

July 22, 1994. Letter from Deirdre Menoyo to Paula Fitzsimmons acknowledging the termination of the dispute resolution process.

4) Technical Publications.

Core Logging Committee, South Africa Section, AEG, *A Guide to Core Logging for Rock Engineering*, Bulletin of the Associated Engineering Geologists, Vol. XV, No. 3, 1978.

G.D. Beckett and David Huntley, 1994. *Characterization of Flow Parameters Controlling Soil Vapor Extraction*, Ground Water, Vol. 32, No. 2, March, April 1994.

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Poulsen, M.M. and B.H. Kueper, 1992. *A field experiment to study the behavior of tetrachloroethylene in unsaturated porous media.* Environmental Science and Technology, v. 26, no. 5, p. 889-895.

Rivett, M. O., 1994. *Soil-gas signatures from chlorinated solvents: Borden field experiments.* Accepted for publication in Ground Water.

Schnarr, M.J. and G.J. Farquhar, 1992. *An In-Situ Oxidation Technique to Destroy Residual DNAPL from Soil.* Paper presented at the May 1992 IAH Conference "Modern trends in Hydrogeology", Hamilton, Ontario, Canada.

Smith, J. A., C. T. Chiou, J. A. Kammer and D. E. Kile, 1990. *Effect of soil moisture on the sorption of trichloroethene vapor to vadose-zone soil at Picatinny Arsenal, New Jersey.* Environmental Science and Technology, v. 24, no. 5, p. 676-683.

U.S. EPA, 1993. *Seminar on Characterizing and Remediating Dense Nonaqueous Phase Liquids at Hazardous Sites: Presentation Outlines and Slide Copy.* EPA Publication EPA/600/K-93/003.

U.S. EPA, 1991. *Guide for Conducting Treatability Studies Under CERCLA: Soil Vapor Extraction Interim Guidance.* EPA Report #EPA5402-91019A, September, 1991.

Appendix A

Appendix A

Test-Pit Schematics and Test-Pit Logs

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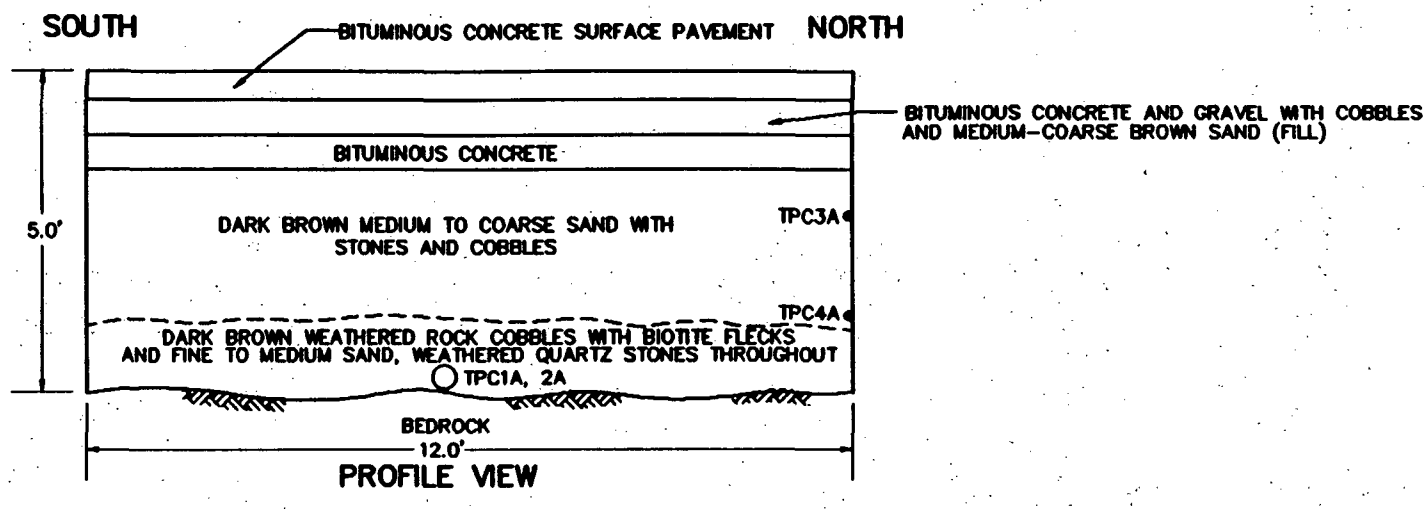
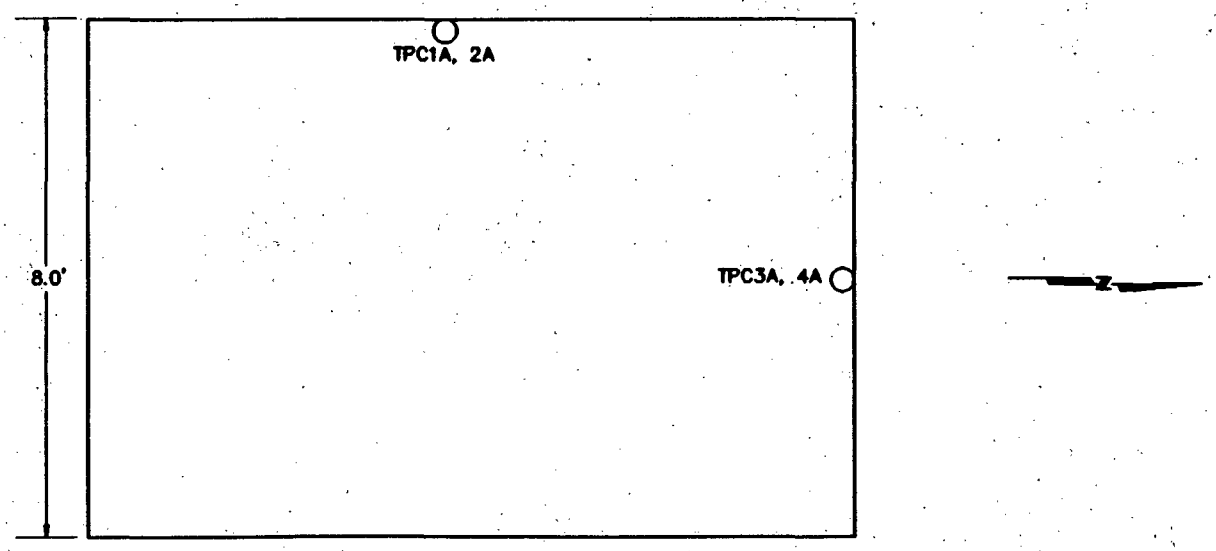
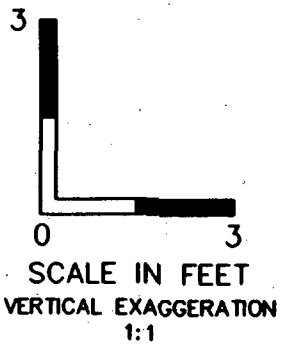


PROFILE VIEW



PLAN VIEW

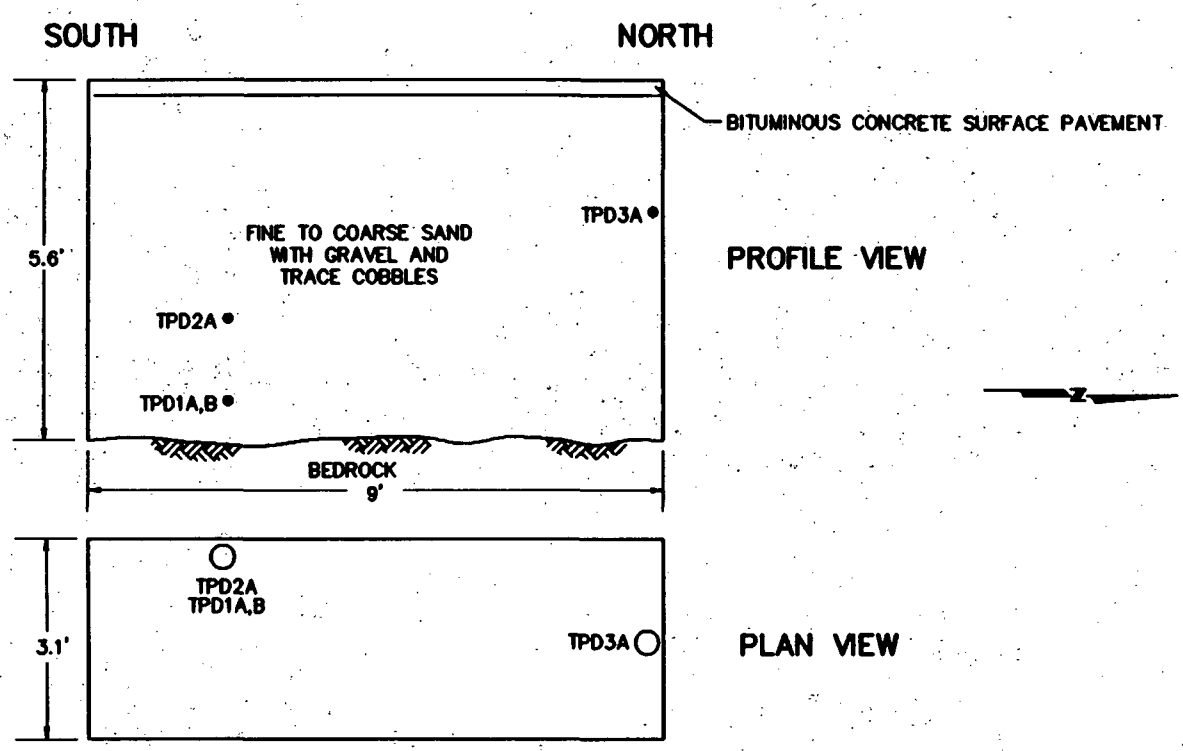


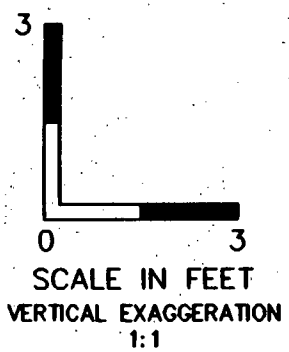
SCALE IN FEET
VERTICAL EXAGGERATION
1:1

SCHEMATIC OF SAMPLING LOCATIONS
TEST PIT C
UNIFIRST PROPERTY

ENSR CONSULTING & ENGINEERING

3140A30A

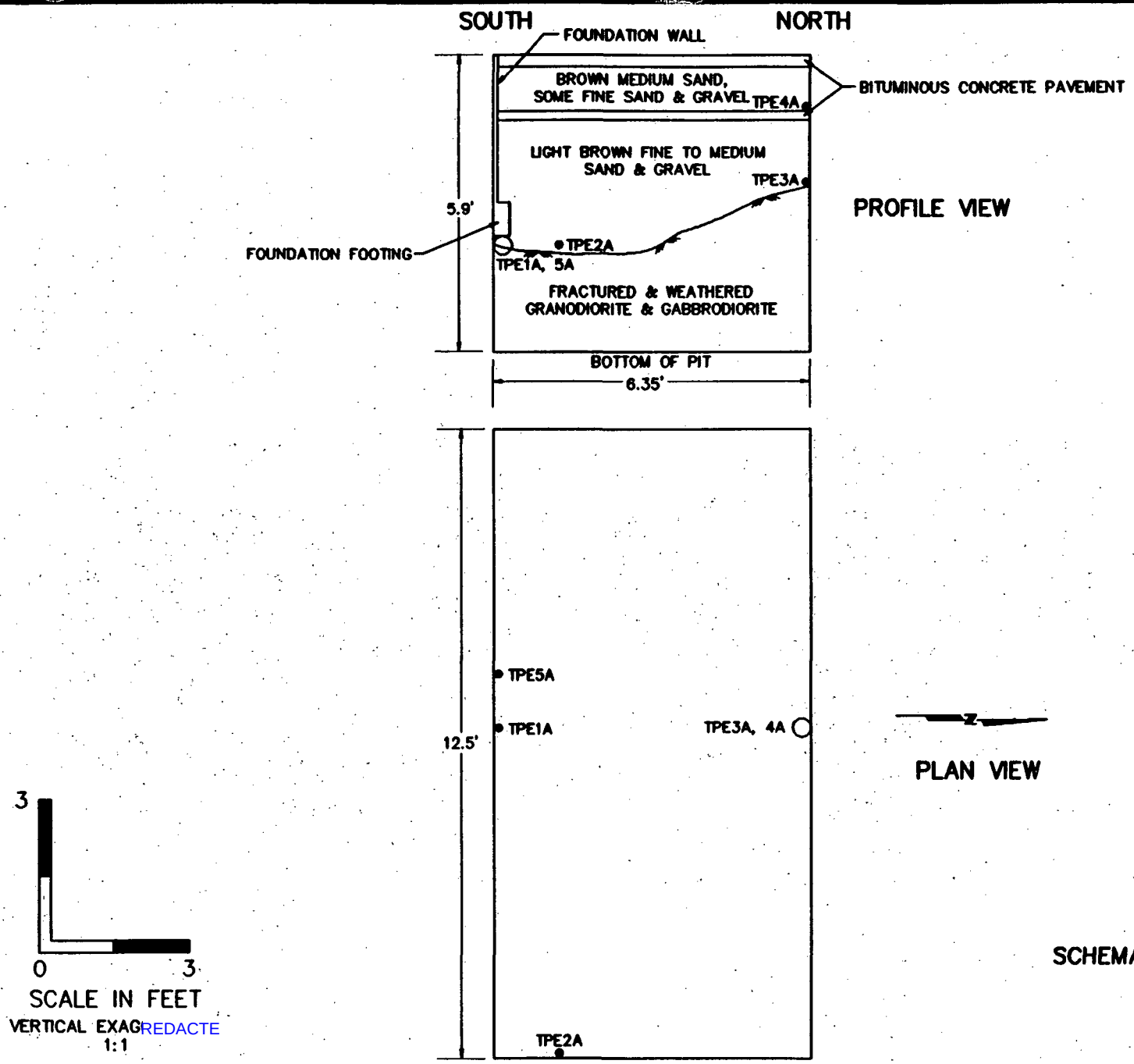




SCHEMATIC OF SAMPLING LOCATIONS
TEST PIT D
UNIFIRST PROPERTY

ENSR CONSULTING & ENGINEERING

3140A26A

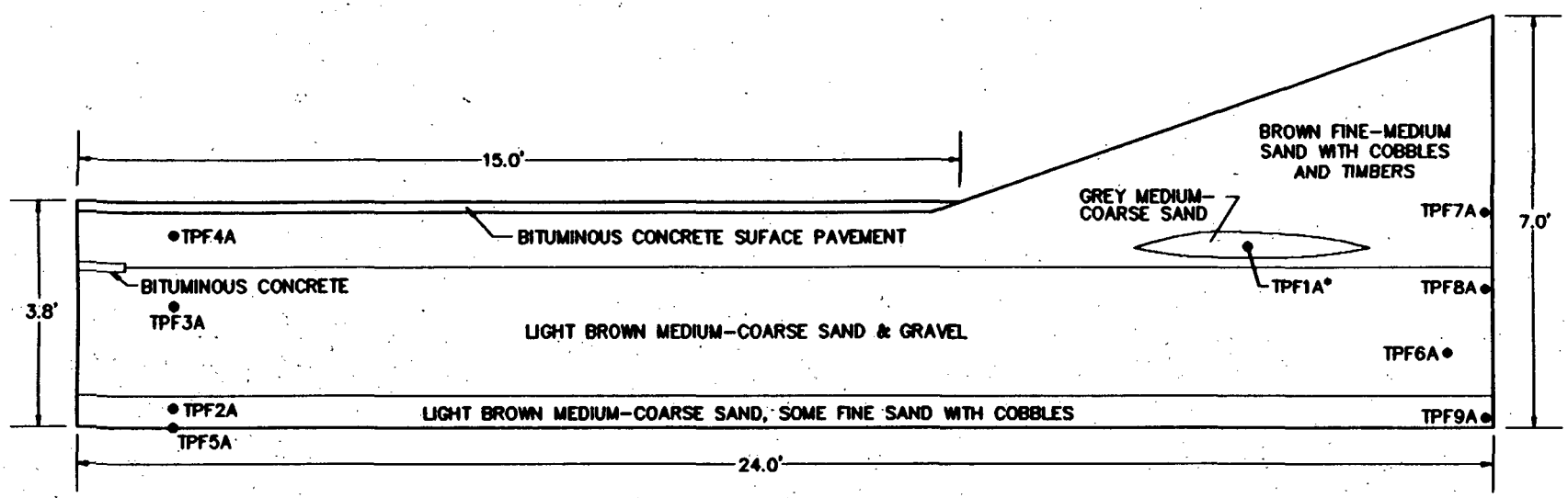


REDACTE

SCHEMATIC OF SAMPLING LOCATIONS
TEST PIT E
UNIFIRST PROPERTY

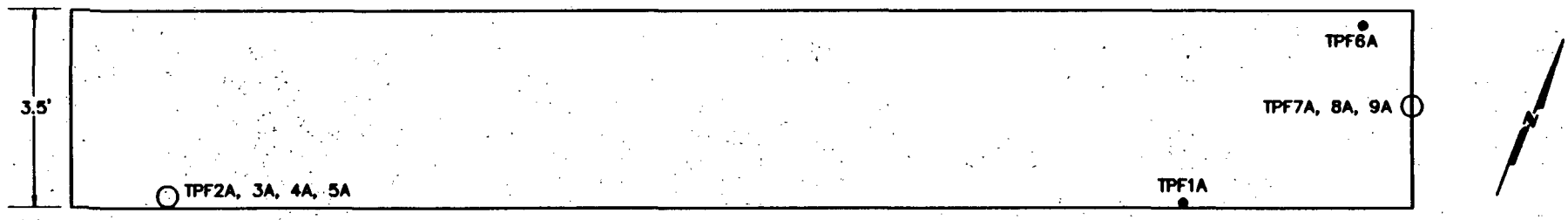
ENSR CONSULTING & ENGINEERING

3140A17A

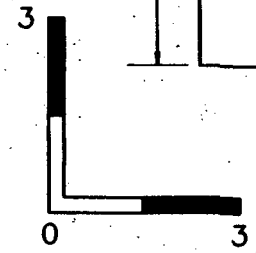


PROFILE VIEW

* OVM READING OF 50 IN AREA OF TPF1A



PLAN VIEW

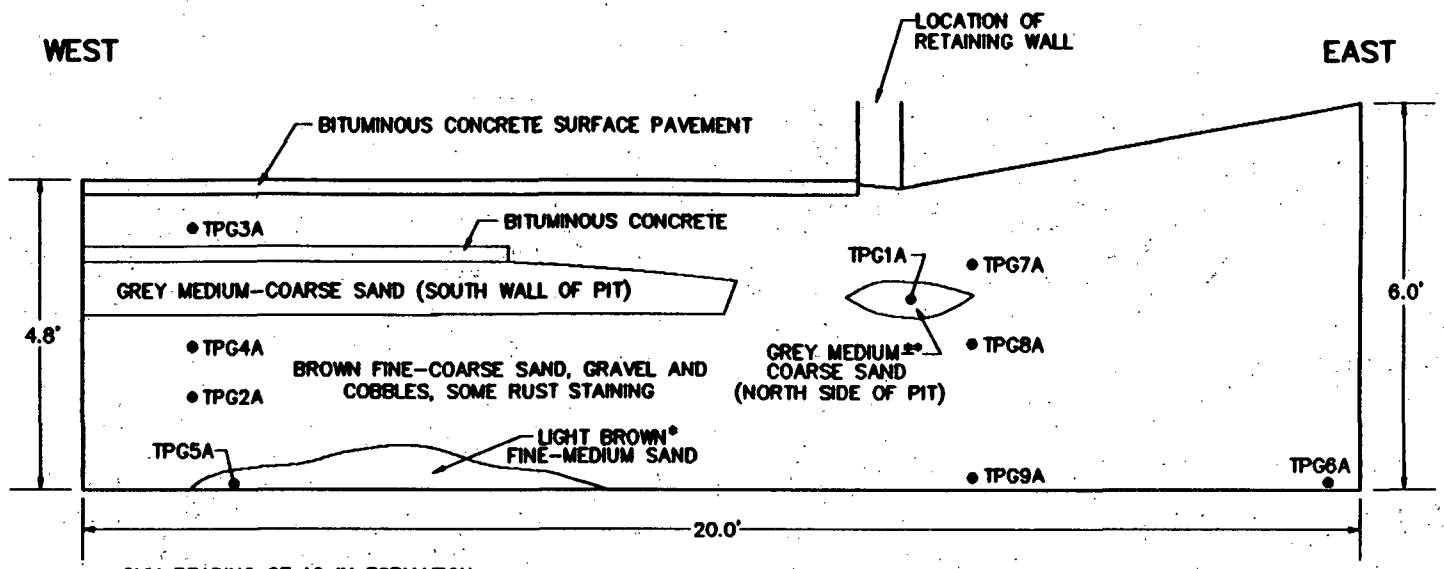


SCALE IN FEET
VERTICAL EXAGGERATION
1:1

SCHEMATIC OF SAMPLING LOCATIONS
TEST PIT F
UNIFIRST PROPERTY

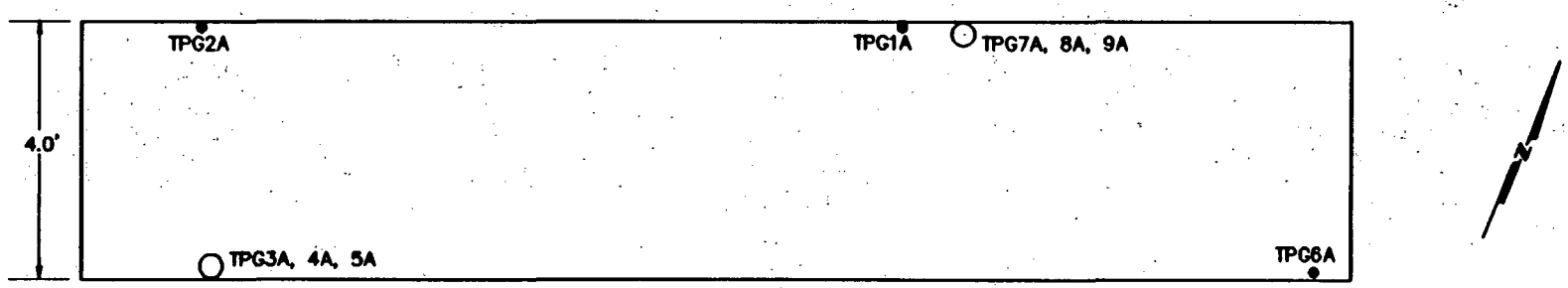
ENSR CONSULTING & ENGINEERING

3140A16A

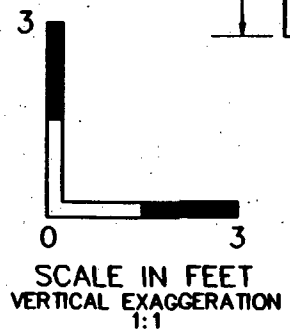


* OVM READING OF 19 IN FORMATION
** SOLVENT-LIKE ODOR DETECTED

PROFILE VIEW



PLAN VIEW

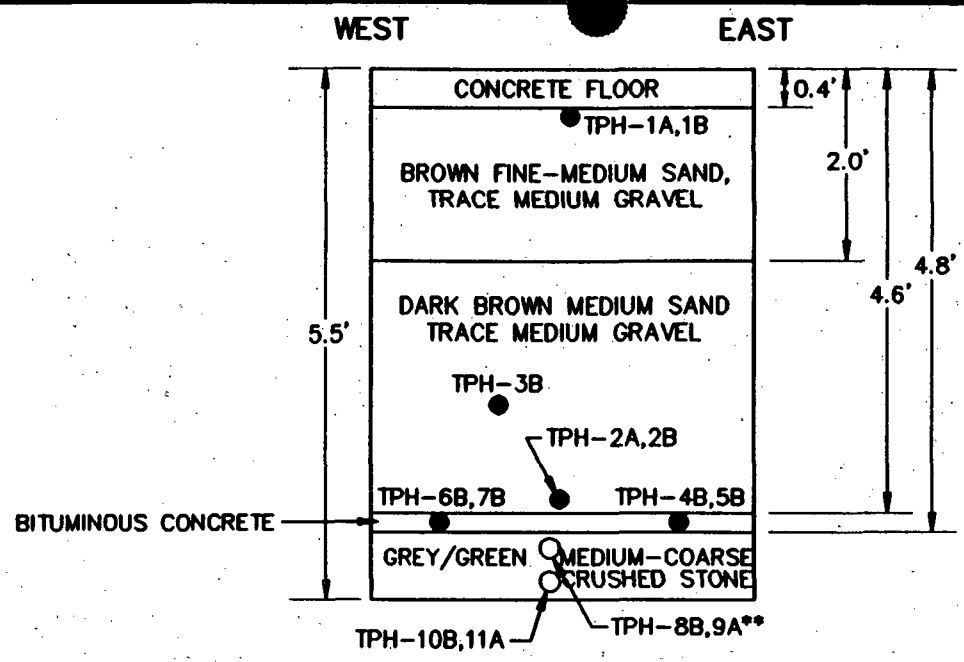


SCHEMATIC OF SAMPLING LOCATIONS
TEST PIT G
UNIFIRST PROPERTY

ENSR

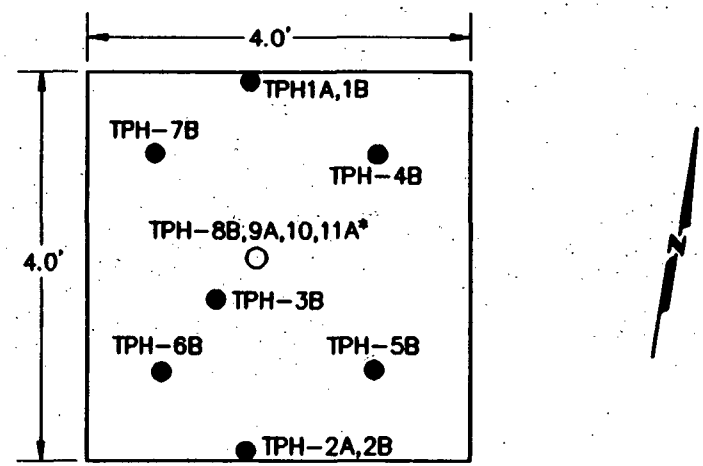
ENSR CONSULTING & ENGINEERING

3140A20A



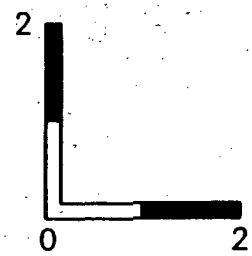
PROFILE VIEW

**NOTE: OVM READING OF 60-80 IN AREA OF TPH-9A.



PLAN VIEW

*NOTE: SAMPLES TPH-8B,9A,10B,11A WERE COMPOSITE SAMPLES TAKEN FROM LOCATIONS DISTRIBUTED ACROSS THE BOTTOM OF TEST PIT.

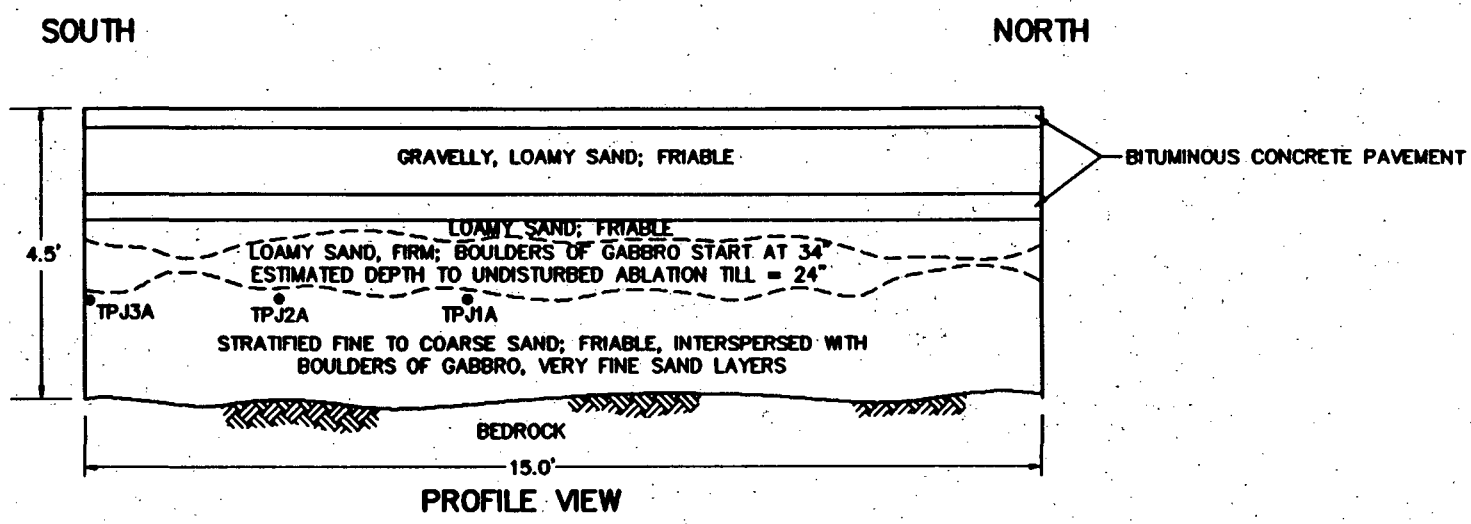


SCALE IN FEET
VERTICAL EXAGGERATION 1:1

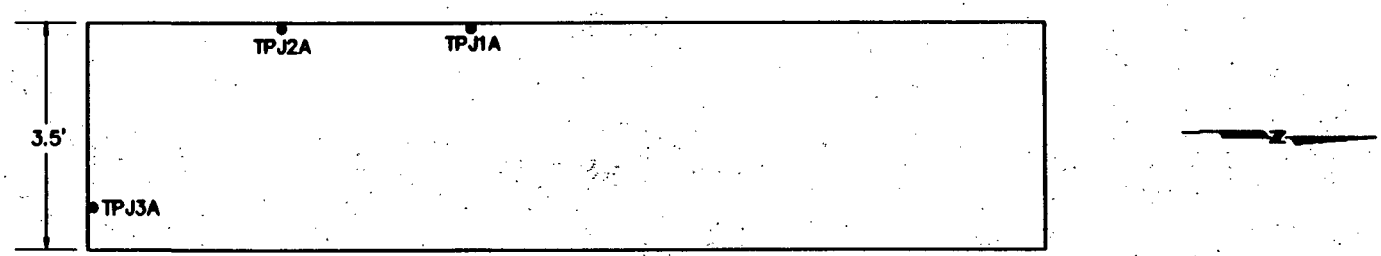
SCHEMATIC OF SAMPLING LOCATIONS
TEST PIT H
UNIFIRST PROPERTY

ENSR CONSULTING & ENGINEERING

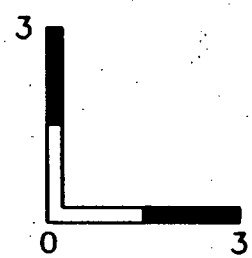
3140A21A



PROFILE VIEW



PLAN VIEW

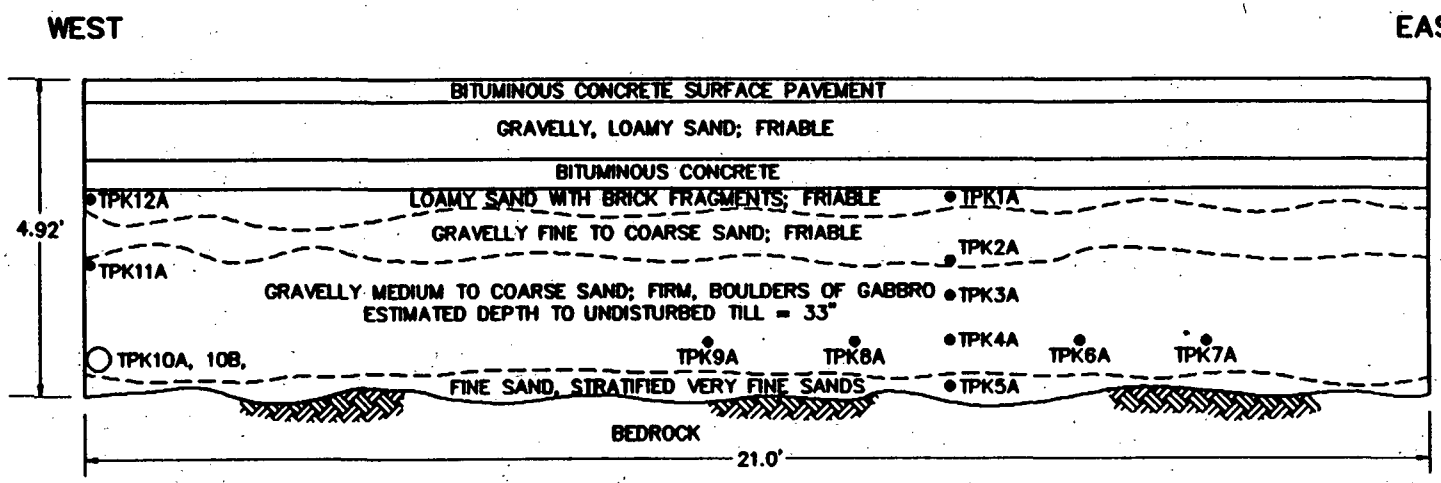


SCALE IN FEET
VERTICAL EXAGGERATION
1:1

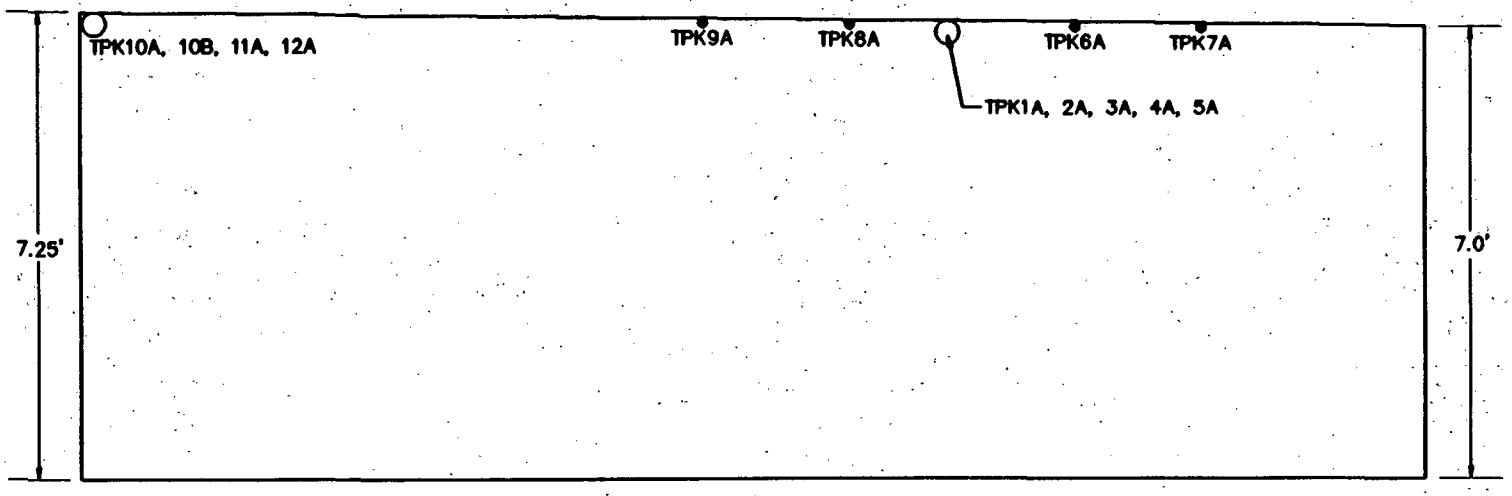
SCHEMATIC OF SAMPLING LOCATIONS
TEST PIT J
UNIFIRST PROPERTY

ENSR CONSULTING & ENGINEERING

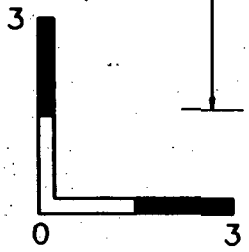
3140A22A



PROFILE VIEW



PLAN VIEW

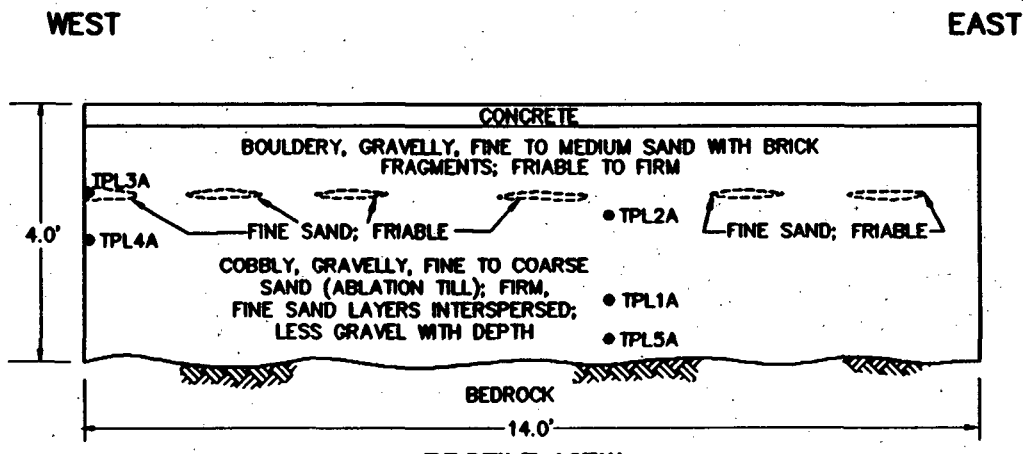


SCALE IN FEET
VERTICAL EXAGGERATION
1:1

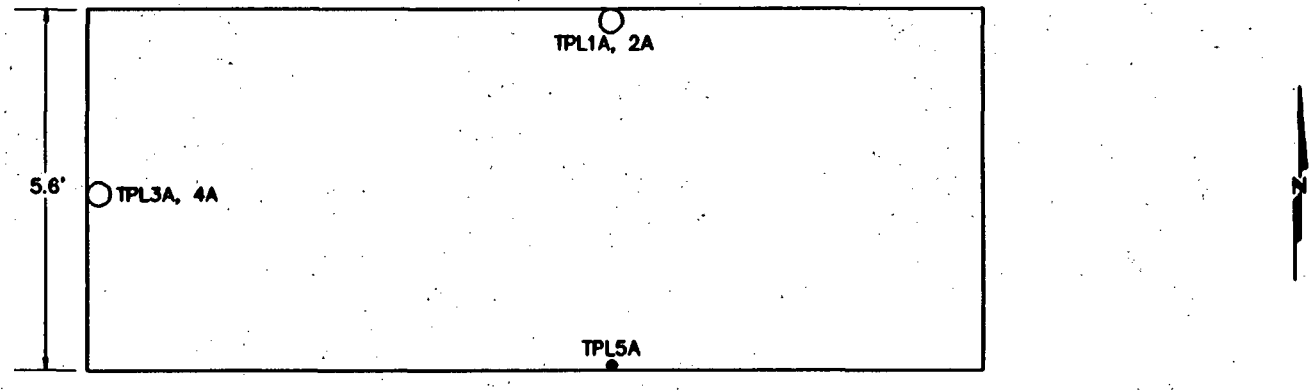
SCHEMATIC OF SAMPLING LOCATIONS
TEST PIT K
UNIFIRST PROPERTY

ENSR CONSULTING & ENGINEERING

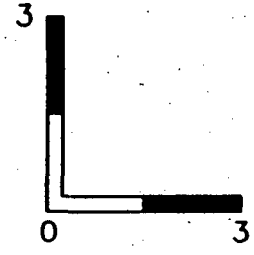
3140A23A



PROFILE VIEW



PLAN VIEW

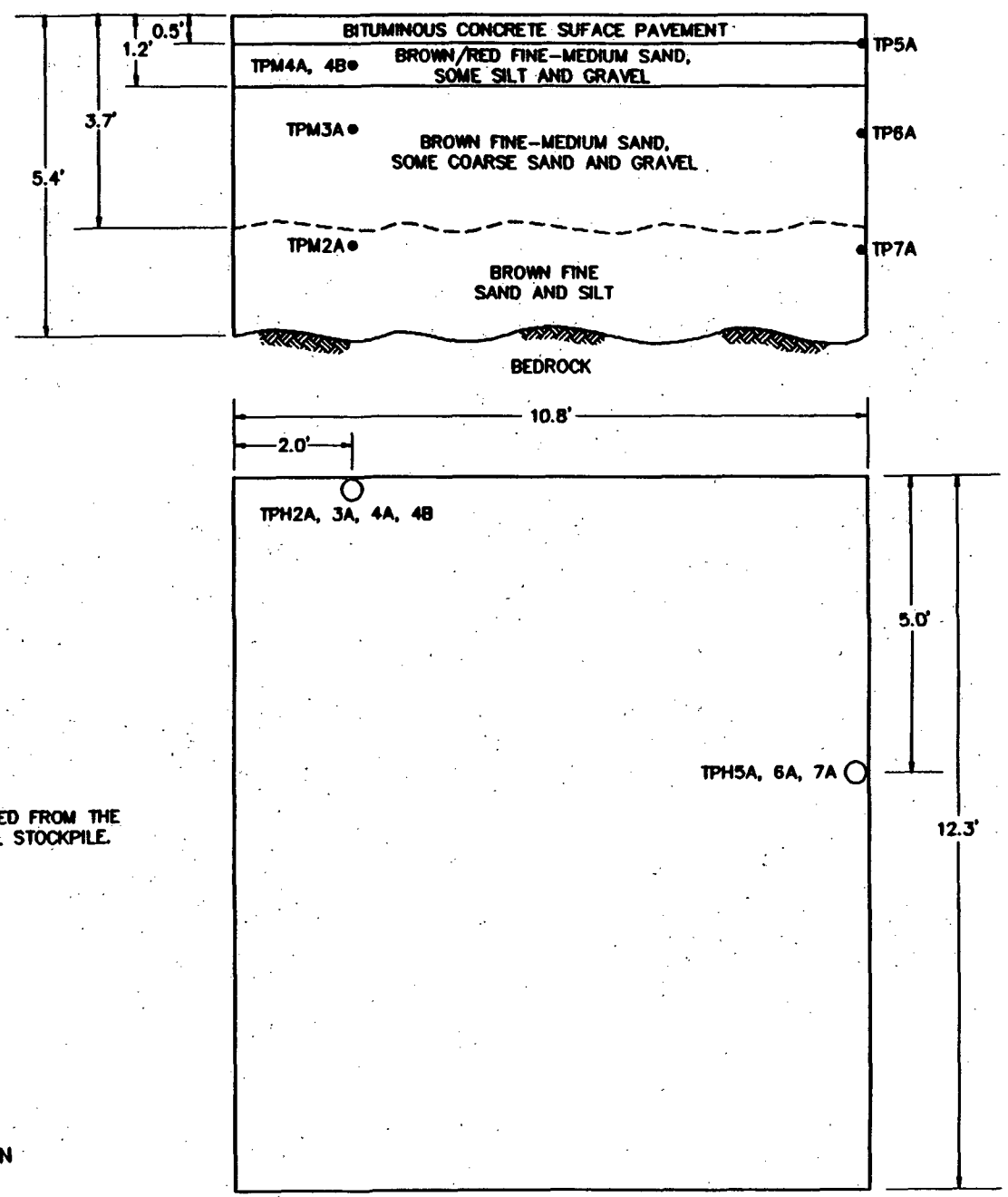


SCALE IN FEET
VERTICAL EXAGGERATION
1:1

SCHEMATIC OF SAMPLING LOCATIONS
TEST PIT L
UNIFIRST PROPERTY

ENSR CONSULTING & ENGINEERING

3140A28A



PROFILE VIEW

PLAN VIEW

NOTE: TPM1A WAS COLLECTED FROM THE EXCAVATED MATERIAL STOCKPILE.

3

0 3

SCALE IN FEET

VERTICAL EXAGGERATION 1:1

SCHEMATIC OF SAMPLING LOCATIONS
TEST PIT M
UNIFIRST PROPERTY

ENSR

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Project UNIFIRST Site WOBURN **TEST PIT** 1 Sh ___ of ___

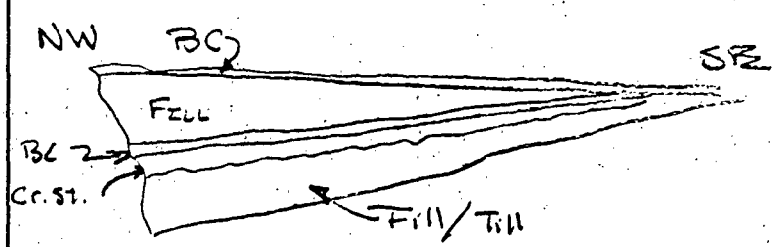
Date 12/4/86 Location ___ Ground Elevation ___

Total Depth 3.0 Contractor MT Construction Corp

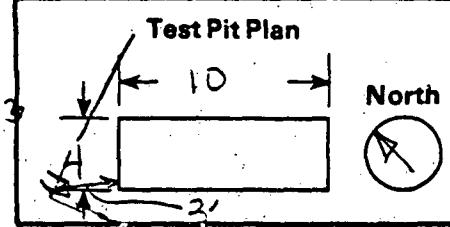
Equipment Used Komatsu PC 220LC Logged by J. T. Lawson

Remarks ___

Elev. Feet	Depth Feet	Sample Type & No.	Sample Depth Range	Soil & Rock Description & Comments
				Northeast Corner
				0.0-0.2 Bituminous Concrete Pavement
	1			0.2 - 1.5 Tan to yellow-tan crs-f SAND & GRAVEL trace silt, lightly stained on surface in contact with bit-con. light "perc." odor below lower pavement
	2			
	3			
	4			1.5- 1.7 Bituminous Concrete Pavement
				1.7-2.0 3/4-1 in crushed stone
				2.0-3.0 Tan to Yellow-tan crs-f SAND & GRAVEL trace silt
				3.0 ft large > 3ft pink granite boulder machine refusal
				ambient HNU Readings / HS jar
				0.0'-1.5': 0-5 / <50
				1.7'-2.0': <10 / <100
				>2.0': 5-8 / <50



Test Pit Plan



Groundwater

Date	Time (Hours After Completion)	Depth (Feet)
12/4/86		Dry

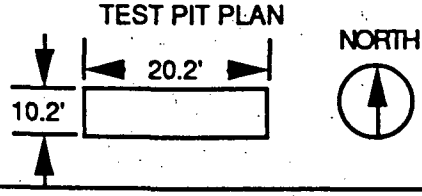
1913 (1/81)

ERT
ENVIRONMENTAL RESEARCH & TECHNOLOGY, INC.

PROJECT 3140-016 SITE UNIFIRST **TEST PIT** TP-A SH 1 OF 1
DATE 5/13/92 LOCATION WOBURN, MA GROUND ELEVATION
TOTAL DEPTH 74" CONTRACTOR FRANKLIN ENVIRONMENTAL
EQUIPMENT USED CASE BACK-HOE LOGGED BY R. BAKER
REMARKS Material identified as ablation till, getting somewhat firmer with depth. No obvious stratification, macropores or roots observed. Slight and moderate dampness observed in horizons C3 and C4 respectively.

ELEV. FEET	DEPTH (IN)	HORIZON	SAMPLE DEPTH RANGE	SOIL DESCRIPTION TEXTURE	CONSISTENCE	COLOR	COMMENTS
				ASPHALT			
	5–10			gravelly sandy loam (fill)	friable	7.5YR4/2 brown to dark brown	
	15–20	C1		cobbly gravelly coarse sand	firm in place	10YR4/4 dark yellowish brown	
	25–30	C2	TPA-27"	sandy loam	firm in place	10YR5/3 brown	mottles - 10YR6/2 common, medium, faint
	35	C3	TPA-37"	gravelly loamy sand	friable	10YR5/3 brown	mottles - 7.5YR4/4 and 10YR6/2, few, medium, distinct
	40–45	C4	TPA-44"	cobbly gravelly sandy loam	firm in place	10YR4/4 dark yellowish brown	mottles - 7.5YR4/4, few, fine, faint
	50–60						
	65–70		TPA-74"	soil gleyed and nearly saturated 1"- 2" above bedrock surface; immediately above bedrock depressions is approximately 1" of dense silty clay.			
				BOTTOM OF PIT @ 60"-74" COMPETENT GRANODIORITE BEDROCK			
	75–85			Collect undisturbed and composite samples at 27", 37" and 44" below the ground surface. Collect additional composite sample at 74" below the ground surface. TPA-44 was collected approximately 3'-4' southwest of TPA-27, TPA-37 and TPA-74, which were within the described profile. The profile at TP-44 was very similar to the described profile with the exception of cobbly sandy loam in horizons C2 and C4.			

TEST PIT PLAN



GROUNDWATER		
DATE	TIME (HOURS AFTER COMPLETION)	DEPTH (FEET)

ENSR CONSULTING & ENGINEERING

DRAFT

PROJECT 3140-016 SITE UNIFIRST **TEST PIT** TP-B SH 1 OF 1

DATE 5/13/92 LOCATION WOBURN, MA GROUND ELEVATION

TOTAL DEPTH 55" CONTRACTOR FRANKLIN ENVIRONMENTAL

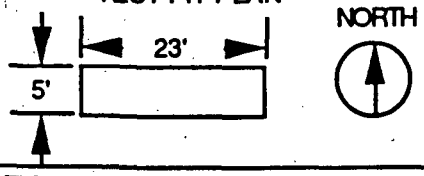
EQUIPMENT USED CASE BACK-HOE LOGGED BY R. BAKER

REMARKS Angular coarse fragments observed during excavation were identified as Granodiorite weathered in place.

ELEV. FEET	DEPTH (IN)	HORIZON	SAMPLE DEPTH RANGE	SOIL DESCRIPTION TEXTURE	CONSISTENCE	COLOR	COMMENTS
				ASPHALT			
	5–10			sandy loam (fill)	friable	10YR5/3 brown	mottles - 10YR6/3, common, medium, faint
	15–20	C1		stoney loamy sand, angular coarse fragments throughout	firm in place	10YR5/3 brown	mottles - 10YR6/3, common, medium, faint
	25–30	C2	TPB-27"	stoney gravelly loamy fine sand, angular coarse fragments throughout	firm in place	10YR5/3 brown	mottles - 10YR6/3, common, medium, faint
	35	C3	TPB-37"	same with lenses of fine sand 34"-38"	firm in place	2.5Y5/2 grayish brown	mottles - 10YR5/3, common, fine, faint
	40–50	C4	TPB-44"	stoney sandy loam, angular coarse fragments throughout	firm in place	2.5Y5/2 grayish brown	mottles - 2.5YR4/8, common, fine, distinct
	55–85			BOTTOM OF PIT @ 55" COMPETENT GRANODIORITE BEDROCK			

Collected composite samples at 27", 37" and 44" below the ground surface.

TEST PIT PLAN



GROUNDWATER		
DATE	TIME (HOURS AFTER COMPLETION)	DEPTH (FEET)

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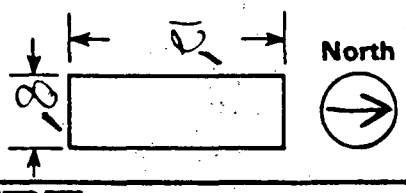
Project Wells G+H Site UniFirst Property **TEST PIT** C Sh 1 of 1
Date 7/31/92 Location Adjacent to East Wall Ground Elevation
Total Depth 5.0' Contractor Franklin
Equipment Used Backhoe Logged by M. Moore
Remarks Samples recorded went to lab for analysis VOC. Others taken for screening recorded in field book # 0592A0368

Elev. Feet	Depth Feet	Sample to lab Type & No.	Sample to lab Depth Range	Soil & Rock Description & Comments
				Fill
	0.5			at 0.5 feet mixed asphalt and gravel with cobbles and medium to coarse brown sand. Cobbles rounded
	1			
	1.5			from 0.5 to 1.0 a second layer of Asphalt 0.5 feet thick over a hard packed fill
	2	TPC3A	2.2'	1-4' medium to course sand with stones & cobbles, dark brown
	2.5			
	3			
				Biotite
	4	TPC4A	3.8'	4-5 Mottled mix of ~~wea~~ dark brown
		TPC1A	4.8'	weathered rock cobbles w/ ~~pyrite~~ flecks and
		TPC2A	4.8'	fine to medium sand filling in between. weath.
	5			Quartz stones throughout
				End of TP 5.0 feet
	6			
	7			
	8			

Test Pit Plan



Groundwater None

Date	Time (Hours After Completion)	Depth (Feet)

1813 (1/81)

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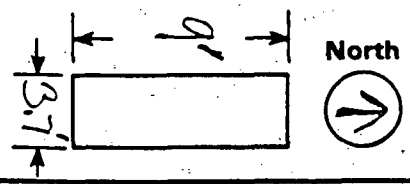
Project Well GtH Site UniFirst Property **TEST PIT** D Sh 1 of 1
Date 7/31/92 Location East Wall in Front of Loading Dock Ground Elevation
Total Depth 5.6' Contractor Franklin
Equipment Used Backhoe Logged by M. Moore
Remarks

Elev. Feet	Depth Feet	Sample Type & No.	Sample Depth Range	Soil & Rock Description & Comments
	0.5			0-0.4' = Asphalt
	1			0.4 — 5.6' Uniform mixture of fine to coarse sand with gravel and trace of cobbles
	2			
		TPD3A	2.5' North wall	on ~~E~~ West side of pit the foundation wall goes down to 2.9'
	3			
	4	TPD2A	3.9 west wall	
	5	TPD1A	5.2 west wall	
		TPD1B Dup		
	6			End 5.6' Gabbrodiorite Bedrock = Fractured heavily to the point of crumbling apart when tapped with a hammer

Test Pit Plan



Groundwater None

Date	Time (Hours After Completion)	Depth (Feet)

1913 (1/81)

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DRAFT

Project Unifirst U.Z. Site Unifirst **TEST PIT TPE** Sh 1 of 1

Date 8/24/92 Location Woburn, MA Ground Elevation —

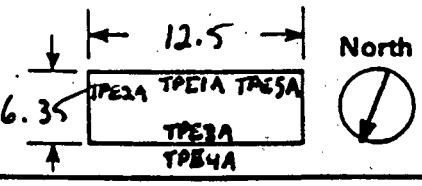
Total Depth 5.9' Contractor Franklin Environmental

Equipment Used John Deere 710 B Logged by L. Hogan

Remarks Log description is a cross section of the pit from South to North

Elev. Feet	Depth Feet	Sample Type & No.	Sample Depth Range	Soil & Rock Description & Comments (S — N)
				Bituminous Concrete
				Brown Med SAND, some Fine Sand and Gravel — TPE4A(1')
	1			Bituminous Concrete
	2			Light Brown Fine to Med. SAND and GRAVEL — TPE3A (2.4'
	3			Foundation Wall; Footing — TPE2A(3.7')
	4			TPE1A (3.7') — TPE5A (3.7') 1 foot east of TPE1A — Fractured and weathered Granodiorite and Gabbro Diorite
	5			
	6			5.9' Bottom of Pit
	7			

Test Pit Plan



Groundwater

Date	Time (Hours After Completion)	Depth (Feet)
8/24/92	2 Hours	No Ground Water

ENSR

Figure 1 Test Pit Log

DRAFT

Project 3140-016-516 Site UniFirst **TEST PIT F** Sh 1 of 1

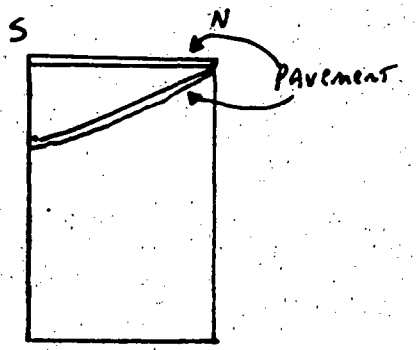
Date 9/22/92 Location Woburn, MA Ground Elevation

Total Depth 3.8 - 7' Contractor Franklin Environmental

Equipment Used John Deere 710B Logged by L. Hogan

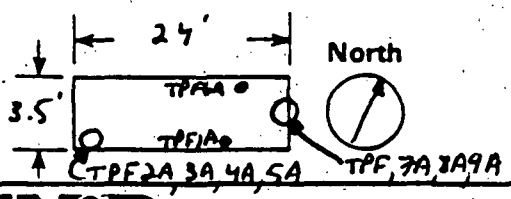
Remarks Ground surface slopes downward from East to West. Log is drawn as a longitudinal X-section, no horizontal scale

Elev. Feet	Depth Feet	Sample Type & No.	Sample Depth Range	Soil & Rock Description & Comments
	1			W. E.
	2			17.8'
	3			2.5' Surface pavement 15' Brown F-M SAND with cobbles and timbers
	4			TPF4A; Grey M-C SAND; H.MU-SOMA TPF1A; TPF7A; 7.0
	5			TPF3A; Lt. Brown M-C SAND & GRAVEL; TPF8A; 3.8
	6			TPF6A
	7			TPF2A; Lt. Brown M-C SAND some F. sand w/ cobbles; TPF9A; TPF5A; Bottom of Pit
	8			



View of the West End of the Test Pit

Test Pit Plan



Groundwater

Date	Time (Hours After Completion)	Depth (Feet)

ENSR

Figure 1 Test Pit Log

DRAFT

Project 3140-016-516 Site UNIFIRST **TEST PIT** G Sh 1 of 1

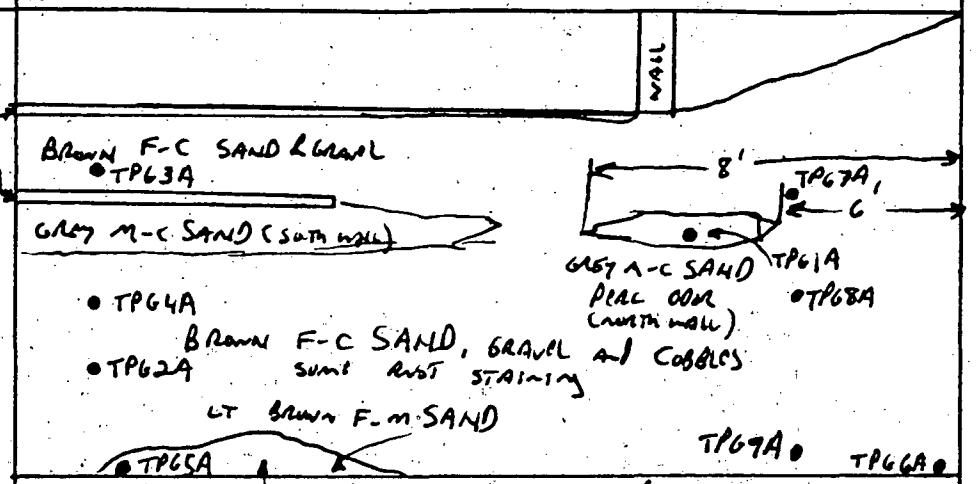
Date 9/22/92 Location Woburn, MA Ground Elevation

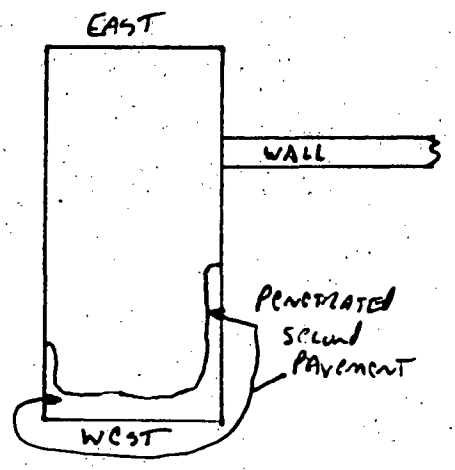
Total Depth 4.8 - 6' Contractor Franklin Environmental

Equipment Used John Deere 710B Logged by L. Hogan

Remarks Ground surface slopes downward from east to west. Log is drawn as a x-section, no horizontal scale.

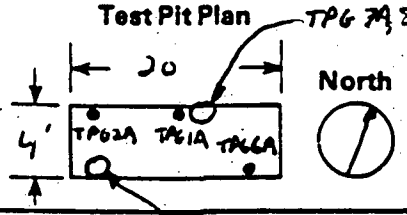
Elev. Feet	Depth Feet	Sample Type & No.	Sample Depth Range	Soil & Rock Description & Comments
	1		1	W — E
	2		Pavement	Brown F-C sand & gravel • TP63A
	3			Grey M-C sand (south wall)
	4			• TP64A
	5			• TP62A
	6			• TP65A
	7			





Top view of test pit

Test Pit Plan



Groundwater		
Date	Time (Hours After Completion)	Depth (Feet)

ENSR

Figure 1 Test Pit Log

DRAFT

Project Unifirst Site Wells G+H **TEST PIT** H Sh 1 of 1

Date 7/24/93 Location Woburn, MA Ground Elevation

Total Depth 66" Contractor Franklin Environmental

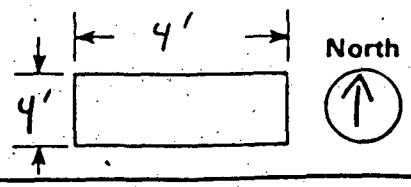
Equipment Used concrete saw, bobcat, shovel Logged by A.R. Khiel

Remarks No odor noticed in pit, fill was uniform, Asphalt on old dock level was in good condition.

Elev. Feet	Depth Feet	Sample Type & No.	Sample Depth Range	Soil & Rock Description & Comments
			0-5"	reinforced concrete
	.5	TPH-1A (VOC) TPH-1B (SVOC)	5"-24"	brown fine and medium SAND with trace medium gravel. NOTE: Samples were taken just below the concrete.
	1			
	1.5			
	2		24-55"	dark brown medium SAND with 10% medium rounded gravel
	2.5			
	3			
	3.5			
	4	TPH-2A (VOC) TPH-2B (SVOC)		Note: Samples were taken just above the asphalt.
	4.5			
		See NOTE below	55-58"	Asphalt (former dock level) good condition - solid
	5	TPH-9A,11A (VOC) TPH-8B,10B (SVOC)	58-66"	gray/green medium and coarse GRAVEL (clean - No sand intermixed)
	5.5			bottom of pit: 66"

NOTE: Samples of Asphalt taken: TPH-4B, TPH-5B, TPH-6B, TPH-7B — HC Fprint (SVOC)

Test Pit Plan



Groundwater		
Date	Time (Hours After Completion)	Depth (Feet)

ENSR

Figure 1 Test Pit Log

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ENSR

TEST PIT LOG

Project No. 3140-024-050 Date 12/2/93 Test Pit TPJ

Project Name Unifirst/UCD RI/RA Location NE corner of bldg, near TPC Ground Elev.

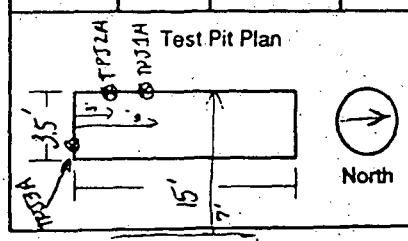
Total Depth 54" Contractor Franklin Environmental

Equipment Used backhoe Logged By J. Loseman

Remarks maximum HNU reading = 5 ppm just below surface of asphalt, no groundwater encountered

Elev. Feet	Depth Feet	Sample Type & No.	Sample Depth Range (in)	Soil & Rock Description & Comments
			0-4	asphalt
	1		4-16	gravelly loamy sand 2.5Y 6/4 friable
			16-20	asphalt
	2		20-24	loamy sand 2.5Y 3/2 friable
			24-34	loamy sand 2.5Y 5/4 firm; boulders of gabbro start @ 34"
	3		34-54	estimated depth to undisturbed ablation till - 34" stratified fine to coarse sand, friable 2.5Y 7/2 interspersed w/ boulders of gabbro, very fine sand layers
	4			Sample TPJ1A, undisturbed, collected @ 36" for bulk density, additional sample collected for moisture content, grain size and permeatry (will be repacked), VOC CLP (methanol)
	5			Sample TPJ2A, also collected @ 36", between gabbro boulders, for grain size, moisture content, permeatry (repacked)
				Sample TPJ3A, weathered (firm) gabbro, for moisture content and grain size

Test Pit Plan



Groundwater

Date	Time (Hrs. after Completion)	Depth (Feet)

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TEST PIT LOG

Project No. 3140-024-050 Date 12/2/93 Test Pit TPK

Project Name Unifirst/UCD RD/RA Location NE corner of bldg; near TPE Ground Elev.

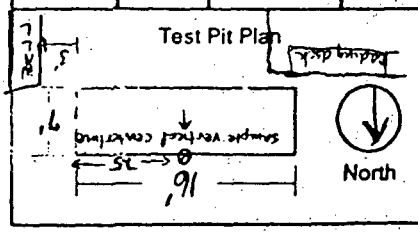
Total Depth 59" Contractor Franklin Environmental

Equipment Used backhoe Logged By J. Wiseman

Remarks materials w/ Hnu reading greater than 10 ppm segregated (~3 yds³), greatest reading was 79 ppm @ 3.5' b.g.s. Only physical samples collected today. No groundwater encountered.

Elev. Feet	Depth Feet	Sample Type & No.	Sample Depth Range (in)	Soil & Rock Description & Comments
			0-4	asphalt
	1		4-6	gravelly loamy sand 2.5Y 6/4 friable
			16-20	asphalt
	2		20-24	loamy sand w/ brick fragments friable 2.5Y 3/2 Sample TPK1A collected for bulk density (undisturbed) moisture content, grain size, permeametry at 22"
			24-33	gravelly fine to coarse sand, friable 2.5Y 5/4 Sample TPK2A collected for bulk density (undisturbed) moisture content, grain size, permeametry @ 33"
	3		33-56	gravelly medium to coarse sand firm, 2.5Y 6/2, boulders of gabbro Sample TPK3A collected, same parameters as above @ 40" Sample TPK4A collected, same parameters as above @ 49" estimated depth to undisturbed till - 33" ~~sample~~
	4			
	5		56-59	fine sand, stratified very fine sands Sample TPK5A collected @ 57", same parameters as above
				Sample TPK6A collected 24" east of 4A, same parameters as above except permeametry
				Sample TPK7A collected 48" east of 4A, same parameters as above except permeametry
				Sample TPK8A collected 18" west of 4A, same parameters as above except permeametry
				Sample TPK9A collected 45" west of 4A, same parameters as above except permeametry

Test Pit Plan



Groundwater

Date	Time (Hrs. after Completion)	Depth (Feet)

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ENSR

TEST PIT LOG

Project No. 3140-024-050 Date 12/3/93 Test Pit TPK

Project Name Unifirst/UCD RD/RA Location NE Corner of bldg; Near TPE Ground Elev.

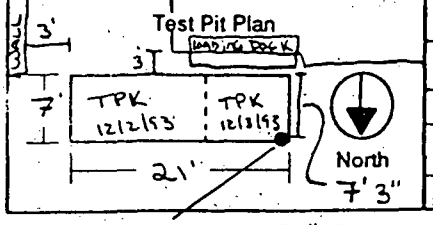
Total Depth 59" Contractor Franklin Environmental

Equipment Used backhoe Logged By J. Wiseman

Remarks TPK 12/2/93 extended 5' west on 12/3/93. Samples Collected 21' west of east pit wall, Sample South wall of P.t. No Hnu readings detected above background (0.0 units), No groundwater encountered.

Elev. Feet	Depth Feet	Sample Type & No.	Sample Depth Range (in)	Soil & Rock Description & Comments
				Refer to Test Pit Log TPK 12/2/93
	1			
	2		23"	Sample PK12A 23" bgs for falling head permeameter, Sieve and hydrometer, Moisture Content, Voc (CLP) Methanol preserved
	3		35"	Sample PK11A 35" bgs for falling head permeameter, Sieve and hydrometer, moisture Content, Voc (CLP) Methanol preserved
	4			
			53"	Bottom of Test Pit at 53"
	5			Sample PK10A 53" BGS for falling head permeameter, Bulk Density, Sieve and hydrometer, moisture Content, Voc (CLP) Methanol preserved, Pesticide, PCB, SVOC (CLP)
				Sample PK10B 53" BGS for Voc (CLP) Methanol preserved, Pesticide, PCB, SVOC (CLP)
				Sample PK10C 53" BGS for Pesticide, PCB, SVOC (CLP)
				Sample PK10Q 53" BGS for Voc (CLP) Methanol preserved
				Sample PK10T 53" BGS for Voc (CLP) Methanol preserved.

Test Pit Plan



Groundwater

Date	Time (Hrs. after Completion)	Depth (Feet)

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TPK10 53" BGS
TPK11 35" BGS
TPK12 23" BGS

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TEST PIT LOG

Sheet 1 of 1

Project No. 3140-024-050 Date 12/3/93 Test Pit TPIL Jan 1.3.1994

Project Name Unifirst/UCD RD/12A Location inside bldg, loading dock area Ground Elev.

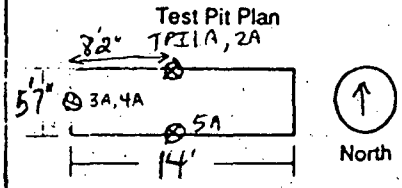
Total Depth 48" Contractor Franklin Environmental

Equipment Used bobcat Logged By J. Wiseman

Remarks

Elev. Feet	Depth Feet	Sample Type & No.	Sample Depth Range (in)	Soil & Rock Description & Comments
			0-4	concrete
	1		4-16	bouldery, gravelly fine to medium sand w/ brick fragments 2.5Y 5/4 friable to firm
			16-17	fine sand 5Y 7/3 friable
	2		17-48	cobbly, gravelly fine to coarse sand (ablation till) 5Y 6/1 firm fine sand layers interspersed; less gravel w/ depth
	3			Sample TPI1A, 38" below concrete surface for VOC-CLP, Bulk density, moisture content, grain size, permeametry Sample TPI2A, 21" below concrete surface for permeametry moisture content, grain size Sample TPI3A, bulk density, ~17" below concrete in sand layer permeametry, grain size, moisture content Sample TPI4A, bulk density, permeametry, moisture content grain size, below 3A, 26" below concrete surface VOC-CLP, Pest/PCB, SVOC Sample TPI5A, 44" below concrete surface, on top of gabbro for VOC
	4			

Test Pit Plan



Groundwater

Date	Time (Hrs. after Completion)	Depth (Feet)

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ENSR TEST PIT LOG

Project No. 3140-023-240 Date 4/25/94 Test Pit TPM

Project Name Unifirst/UCD RD/RA Location SE Corner of bldg; near TPI Ground Elev.

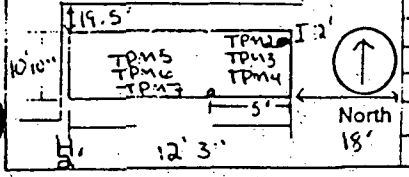
Total Depth 65" Contractor Franklin Environmental Services

Equipment Used John Deere 710B Backhoe Logged By J. Powers/S. Farnsworth

Remarks All S.I. Samples Collected from TPM sidewall with the exception of TPM1 which was excavated from 6-14" bgs excavation pile, eastern half of TPM. Exposed bedrock surface along center of TPM, granodiorite becomes less fractured/weathered moving north along base of TPM.

Elev. Feet	Depth Feet	Sample Type & No.	Sample Depth Range (in)	Soil & Rock Description & Comments
			0-6	ASPHALT SURFACE
	1	TPM1 TPM4 TPM5	6-14	brown fine to medium SAND, some silt and gravel; disturbed, dry — brown/red color, slight cohesion and sweet odor in eastern half of test pit, 2500 ppm OVM readings
	2	TPM3 TPM6	14-44	brown fine to medium SAND, some coarse sand and gravel, moist, dense, OVM readings decrease with depth in eastern half of test pit, ~20 ppm at 42" bgs
	3			
	4	TPM2 TPM7	44-65	brown fine SAND and SILT, moist
	5			brown/pink GRANODIORITE, weathered, trimble silt in fractures, bottom of TPM @ 65" bgs.
	6			TPM1A Collected from excavation pile 6-14" bgs for VOC, SVOC TPM1C equipment blank SVOC TPM1F Collection blank VOC TPM2A Collected 4' bgs for VOC, Physical parameters TPM3A Collected 2' bgs for VOC, Physical Parameters TPM4A Collected 10" bgs for VOC, Physical Parameters TPM4B Collected 10" bgs for VOC (collected) TPM5A Collected 6" bgs for VOC TPM6A Collected 2' bgs for VOC TPM7A Collected 4' bgs for VOC

Test Pit Plan



Groundwater

Date	Time (Hrs. after Completion)	Depth (Feet)
4/25/94	No Standing Groundwater observed	65"

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Appendix B

Appendix B

Boring Logs

EMSK

Project No. 3140-016-519 Date - Start 6/18/92 Finish 6/18/92 Boring B1

Project Name Unifirst Drilling Co. Geologic

Location outside Ryder office - near SV-7 Drilling Method HSA

Total Depth 6.5' Inspector J. Wiseman Reviewer

Remarks

Depth Feet	Sample Type & No.	Sample Blows per 6 In.	Sample Depth Range	Sample Rec.	Graphic Log	Lithologic Description	OVM ppm Equipment Installed
		(140 lb hammer)				4" asphalt	
1							
	S-1	24-98-60-20	6"-2.5'	6"		brown, gravelly med. SAND samples 10:30 B1MAA (202.4g soil) B1SAA	Ø
2							
3							
	S-2	14-10-12-16	2.5'-4.5'	12"		tan, moist, v.f. SAND, br & bl striations sample - foc, grain size	325
4							
5							
	S-3	15-24-90-120	4.5'-6.5'	11"		tan, moist, v.f. SAND, refusal on boulder samples 10:45 B1MBA (200.3g soil) B1SBA	455
6							
7						End of Boring @ 6.5' on boulder (?)	

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Project No. 3140-016-519 Date - Start 6/18/92 Finish 6/18/92 Boring B2

Project Name Unifirst Drilling Co. GeoLogic

Location near UC4 Drilling Method HSA

Total Depth 4.5' Inspector J. Wiseman Reviewer

Remarks Switched to 300lb hammer on S-2

Depth Feet	Sample Type & No.	Blows per 6 In.	Depth Range	Rec.	Graphic Log	Lithologic Description	OVM ppm Equipment Installed
						3" asphalt	
1							
	S-1	28-26-48-55	6"-2.5'	10"		brown, gravelly f. to c. SAND, trace silt Samples B2MAA (204.7g soil) 11:45 B2SAA refusal @ 2'7", moved 4' and augered to 2'6", used 300lb hammer from now on.	1344
2							
3	S-2	18(140lb) 35-65-80 (300lb)	25'-45'	8"		gravelly, f. to c. SAND, weathered & unweathered rock fragments Sample - foc & grain size refusal @ 4'9" (till + rock in spoon tip) moved and augered to 3.0'	75
4							
5	S-3	29-52-120	3'-4.5'	7"		till and rock fragments, bouncing @ 4.5' Samples B2MBA (194.0g soil) 12:30 B2SBA	75
						End of Boring @ 4.5'	

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Sheet 1 of 1

Project No. 3140-016-579 Date - Start 6/18/92 Finish 6/18/92 Boring B3

Project Name Unifirst Drilling Co. Geologic

Location near UC17 Drilling Method HSA

Total Depth 4'7" Inspector J. Wiseman Reviewer

Remarks Switched to 300lb hammer on S-1

Depth Feet	Sample Type & No.	Blows per 6 In.	Depth Range	Rec.	Graphic Log	Lithologic Description	OVM ppm Equipment Installed
						3" asphalt	
1							
	S-1	55(140lb) 18-20-22 (300lb)	6"-2.5"	8"		rock frag's, some gravel, f. to c. SAND samples: B3MAA (197.5g soil) 14:00 B3SAA	455
2							
3							
	S-2	88-95-66-97	25'-45'	10"		gravelly f. to c. SAND, trace silt samples: B3MBA (195.9g soil) 14:20 B3SBA foc, grain size	Ø
4							
	S-3	100/1"	46"-47"	Ø		rock in tip of spoon	
5						End of Boring @ 4'7"	

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Project No. 3140-016-519 Date - Start 6/18/92 Finish 6/18/92 Boring B4

Project Name Unifirst Drilling Co. Geologic

Location near UC5 and loading dock Drilling Method HSA

Total Depth 2.5' Inspector J Wiseman Reviewer

Remarks note hammer usage

OVM ppm

Depth Feet	Sample Type & No.	Sample Blows per 6 In.	Sample Depth Range	Sample Rec.	Graphic Log	Lithologic Description	Equipment Installed
						3" concrete	
						bouncing at 8", ~~[illegible]~~ switched to 300 lb hammer, stik bounced and moved	
1							
	S-1	18 (140 lb) 22-25-36 (300 lb)	6"-2.5'	10"		gravelly, f. to c. SAND, asphalt chunks Samples: B4MAA (241.0g soil) 15:15 B4SAA foc & grain size	"over range" (5 times tested)
2							
3		50/bouncing		Ø		End of Boring @ 2.5'	

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Project No. 3140-016-519 Date - Start 6/19/92 Finish 6/19/92 Boring B5

Project Name Unifirst Drilling Co. Geologic

Location near SV5 Drilling Method HSA

Total Depth 6.5' Inspector J. Wiseman Reviewer

Remarks

Depth Feet	Sample Type & No.	Blows per 6 In.	Depth Range	Rec.	Graphic Log	Lithologic Description	OVM ppm Equipment Installed
		(140 lb)				3" asphalt	
1							
	S-1	24-25-17-18	6"-2.5'	6"		brown, gravelly f. to c. SAND and silt samples 7:15 B5MAA (188.0g soil) B5SAA	Ø
2							
3							
	S-2	6-5-4-4	2.5'-4.5'	Ø		brown, moist, gravelly f. to c. SAND and silt took sample from spoon tip for foc and grain size	275
4							
5	S-3	4-18-22-30	4.5'-6.5'	5"		brown, moist, gravelly f. to c. SAND and silt samples 7:30 B5MBA (190.3g soil) B5SBA	175
6							
						End of Boring @ 6.5'	

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Sheet 1 of 1

Project No. 3140-016-519 Date - Start 6/19/92 Finish 6/19/92 Boring B6

Project Name Unifirst Drilling Co. Geologic

Location near UC5 Drilling Method HSA

Total Depth 2.5' Inspector J. Wiseman Reviewer

Remarks note switch to 300 lb hammer

Depth Feet	Sample Type & No.	Blows per 6 In.	Depth Range	Rec.	Graphic Log	Lithologic Description	OVM ppm / Equipment Installed
						4" asphalt	
1	S-1	24-55-84 (140 lb) -48 (300 lb)	6"-2.5'	10"		lt. brown, gravelly f. to c. SAND and trace silt samples 9:40 B6MAA (192.1g Soil) B6SAA foc, grain size bouncing @ 2.5', moved over and augered to 2.5', again it bounced	Ø
2							
3		31 (300 lb)		Ø			
						End of Boring @ 2.5'	

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Project No. 3140-016-519 Date - Start 6/19/92 Finish 6/19/92 Boring B7

Project Name Unifirst Drilling Co. Geologic

Location corner of building, end of concrete Drilling Method HSA

Total Depth 3.7' Inspector J. Wiseman Reviewer

Remarks note switch to 300 lb hammer

OVM ppm

Depth Feet	Sample Type & No.	Sample Blows per 6 In.	Sample Depth Range	Sample Rec.	Graphic Log	Lithologic Description	Equipment Installed
						3" asphalt	
1	S-1	24-55-90 (140 lb) 18/300 lb	6"-2.5'	7"		gravelly, f. to c. SAND trace silt samples 10:45 B7MAA (150.8 g soil) B7SAA	75
2							
3	S-2	13-24-28-44	2.5-3.7'	6"		gravelly, f. to c. SAND, trace silt rock in tip samples 10:50 B7MBA (178.4 g soil) B7SBA foc, grain size	Ø
4						End of Boring @ 3.7'	

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Project	TDD No.	Sheet	Hole
Wells G & H Remedial Investigation	F1-8409-01	1 of 3	S

Location	Angle from Horiz.
25' West of Unifirst BLDG	Vertical

Begun	Completed	Driller	Drill Make & Model	Hole Dia.	Overburden (ft)	Rock (ft)	Total D
17 DEC 83		NEBC	Mobile B-53	3.5"	62'	20'	82'

Core Recovery (ft)	Core Bxs	Samples	El. Top of Casing	Ground El.	Depth to Top of Rc
20'	2	12			62'

Sample Hammer Weight/Fall	Casing	NUS Inspector
140 lbs/30"	Solid: Sch 80 PVC 1.5" I.D. Screen: 0.010 slot	Golden

Depth	Sample No.	ROCK Core/Rec (in)	ROCK RQD	SOIL Pen/Rec (in)	SOIL Depth Interval (ft)	SOIL Blows/6"	Well Construction	Stratum Description
	01			24/4	0-2	4/5/6/7		Fill: F SAND, SO C Sand, SO F/M Gravel
5	02			24/15	5-7	10/26/42/80		Fill: F SAND, SO C Sand, SO F/M Gravel
10	03			10/9	10-12	28/100.3 R		GR-Green F SAND, SO F Sand and Silt, TR TR Clay, TR F Gravel
15	04			24/17	15-17	28/28/42/51		GR-Green M SAND, SO F Sand and Silt, TR Gravel, TR Clay
20	05			12/8	20	33/133/R		Sandy Till highly compact F SAND, Silt and Clay
25	06			8/8	25	33/100.2 R		GR-Green Sandy Till - sand percentage decreasing with depth
30								

GRANULAR SOILS Blows/Ft	Density	PROPORTIONS USED		ABBREVIATIONS
0-4	V. Loose	Trace (TR)	0-10%	F-Fine
4-10	Loose	Little (LI)	10-20%	M-Medium
10-30	M. Dense	Some (SO)	20-35%	C-Coarse
30-50	Dense	And	35-50%	F/M-Fine to Medium
>50	V. Dense			F/C-Fine to Coarse
				V-Very
				GR-Gray
				BN-Brown
				YEL-Yellow

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Project	TDD No.	Sheet	Hole No.
Wells G & H Remedial Investigation	F1-8409-01	2 of 3	S70

Location: Unifirst Parking Lot

Depth	ROCK Sample No.	ROCK Core/Rec (in)	ROCK RQD	SOIL Pen/Rec (in)	SOIL Depth Interval (ft)	SOIL Blows/6"	Well Construction	Stratum Description
	07			5/3	35	120.5		Sandy Till
40	08			6/6	40	120		S70M Top of Ottawa 40' Sandy Till S70M Top of screen 42'
45	09			3/3	45	120		Sandy Till
50	10			4/2	50	120		Sandy Till
55	12			6/2	55	120		Sandy Till
60	13			3/3	60	120		Sandy Till Bedrock at 62' S70M Bottom of screen 62'
		60/60						Highly fractured felds-pathic granite
65		60/60						S70D Top of Ottawa SAND 65' S70D Top of screen 67'

REMARKS:

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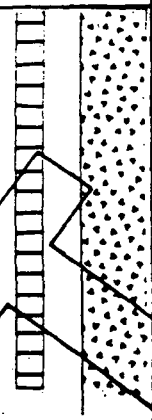
Project	TDD No.	Sheet	Hole No.
Wells G & H Remedial Investigation	F1-8409-01	3 of 3	570

Location: Unifirst Parking Lot

Depth	ROCK Sample No.	ROCK Core/Rec (in)	ROCK RQD	SOIL Pen./Rec (in)	SOIL Depth Interval (ft)	SOIL Blows/6"	Well Construction	Stratum Description	No
70								Less fractured Dedham (Granodiorite)	
		60/60						highly fractured granite	
75								highly fractured granite	
		60/60							
80								570D Bottom of screen 82' EOB - 82'	
85									



REMARKS:

All wells sealed with cement/bentonite slurry from top of sand to GS.

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A Halliburton Company

Project	TDD No.	Sheet	Hole No.
Wells G & H Remedial Investigation	F1-8409-01	1 of 2	S71

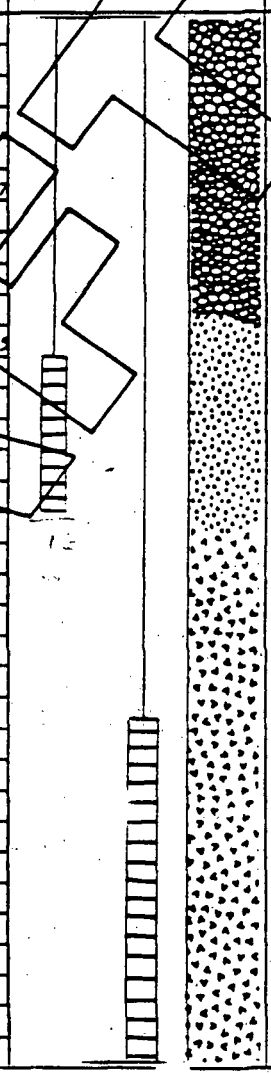
Location	Angle from Horiz.
Unifirst (front gate) Parking Lot	Vertical

Begun	Completed	Driller	Drill Make & Model	Hole Dia.	Overburden (ft)	Rock (ft)	Total Depth
1 Feb 85		NEBC	Mobile B-53	3.5"	16.5	26.2	42.7

Core Recovery (ft)	Core Box	Samples	El. Top of Casing	Ground El.	Depth to GW/Time	Depth to Top of Rock
25	2	2				16.5

Sample Hammer Weight/Fall	Casing	NUS Inspector
140 lbs/30"	Solid: Sch 80 PVC 1.5" I.D. Screen: 0.010 slot	Radville

Depth	Sample No.	ROCK Core/Rec (in)	ROCK RQD	SOIL Pen/Rec (in)	SOIL Depth Interval (ft)	SOIL Blows/6"	Well Construction	Stratum Description	Note
5	01			24/24	5-7	37/67/77/87		BN F/C GRAVEL, SO F/M Sand, TR Silt	
10	02			13/11	10-12	19/19/17/25		S71S Top of Ottawa Sand 9' S71S Top of screen 11' C SAND, SO F/C Gravel, TR Silt	1
15		60/60						S71S Bottom of screen 16' Roller bitted from 16 1/2' to 20' expecting Boulders Bedrock at 16.5'	2
20		60/60						S71D Top of Ottawa Sand 20' S71D Top of screen 22.7' Dedham Granodiorite moderately fractured, some fractures are mineralized	
25		60/60							
30		60/60							



GRANULAR SOILS Blows/Ft	Density	PROPORTIONS USED		ABBREVIATIONS
0-4	V. Loose	Trace (TR)	0-10%	F-Fine
4-10	Loose	Little (LI)	10-20%	M-Medium
10-30	M. Dense	Some (SO)	20-35%	C-Coarse
30-50	Dense	And	35-50%	F/M-Fine to Medium
>50	V. Dense			F/C-Fine to Coarse
				V-Very
				GR-Gray
				BN-Brown
				YEL-Yellow

1.) S71S sealed in overburden with cement/bentonite slurry from 9' to GS
2.) S71D sealed in bedrock with cement/bentonite slurry from 22.7 to GS

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Project	TDD No.	Sheet	Hole No.
Wells G & H Remedial Investigation	F1-8409-01	2 of 2	S71

Location: Unifirst (front gate) Parking Lot

Depth	ROCK Sample No.	ROCK Core/Rec. (in)	ROCK RQD	SOIL Pen/Rec. (in)	SOIL Depth Interval (ft)	SOIL Blows/6"	Well Construction	Stratum Description	No.
		60/60						Dedham Granodiorite	
40								EOB 42.7'	

REMARKS:

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UC4

Project UNIFIRST Site WOBURN **BORING** ~~UC4~~ Sh 1 of 2
Date Started 11/3/86 Completed 11/4/87 Ground Elevation
Total Depth 20.0 Location Logged by J. T. LAWSON
Casing I.D. 3¾in HSA/4in/3in Contractor GUZLO DRILLING CO.
Remarks

Elev. Feet	Depth Feet	Sample Type & Number	Sample Blows per 6 In.	Sample Depth Range	Sample Rec.	Graphic Log	Sample Description	Equipment Installed
	1	SS 1		0.0 to 1.2	0.8		0.0 - 0.2 Bituminous Concrete Pavement	Flush road box; cement and bentonite
	2						0.2 - 1.2 Light brown - tan SAND & GRAVEL, little silt	
	3						HNU jar headspace 10-15	
	4						1.2 - 6.0 Boulders; auger refusal; roller bit and advance 4in. casing to 6.0; attempt sample at 5.0, no penetration	bentonite pellets 3.0' to 6.0'
	5							
	6	SS2		6.0 to 7.2	0.7		6.0 - 7.2 Light - brown - tan SILT & SAND, trace gravel (Till)	top of silica sand pack 6.0'
	7							
	8						Spoon refusal at 7.2	
	9						roller bit to 10.0 at which cuttings become consistently pink-gray and rig vibration becomes steady	
	10		RQD					
	11			10.0			10.0 Top of Sound Rock	
	12	NX 1	70%	to	4.5		10.0 - 11.0 Gray and pink coarse-grained grano-diorite	9.9' 0.01" slot screen
	13			15.0				
	14						11.0 - 16.0 Dark green to gray fine-grained gabbro-diorite; joints 40°-60° to core axis, some joints ⊥ to core axis;	
	15							
	16	NX 2	30%	15.0 to 18.0	2.8			
	17							

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Project UNIFIRST Site WOBURN **BORING UC4** Sh 2 of 2

Elev. Feet	Depth Feet	Sample Type & Number	Sample Blows per 6 In.	Sample Depth Range	Sample Rec.	Graphic Log	Sample Description	Equipment Installed
	18	NX 3	RQD 80%	18.0 to 20.0	2.4		joint faces slightly weathered	Screen tip @ 19.85'
	19						16.0 to 19.0 Gabbrodiorite, increased fracture frequency; joint faces coated with calcite, FeO, MnO	
	20						Bottom of Boring 20.0	

Notes:

1.) Well constructed of Schedule 40 2 in. ID PVC with O-ring sealed threaded joints

2.) Blow counts not recorded. Split spoon was advanced with a 140 lb. hammer falling greater than 30 in. or with a 300 lb. hammer.

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UC5

Project UNIFIRST Site WOBURN **BORING** UC5 Sh 1 of 2

Date Started 11/4/86 Completed 11/4/86 Ground Elevation

Total Depth 19.5 ft Location Logged by J.T. Lawson

Casing I.D. 3¼ HSA/4in/3in Contractor Guild Drilling Co.

Remarks

Elev. Feet	Depth Feet	Sample Type & Number	Blows per 6 In.	Sample Depth Range	Sample Rec.	Graphic Log	Sample Description	Equipment Installed
	1	SS1		0.0 to 2.0	1.5		0.0 - 0.2 Bituminous Concrete Pavement	flush road box
	2	SS2		2.0 to 3.0	1.0		0.2 - 2.6 Tan SAND & GRAVEL trace silt (Fill) HNU ~50 in jar head space, ~100 in open boring	neat cement
	3						2.6 - 3.0 Pink - tan pulverized rock HNU ~2 in jar head space	bentonite pellets 3.0 to 5.0
	4							
	5							top of silica sand pack 5.0'
	6						3.0 auger refusal; roller bit to 9.0; boulders; rig "stands up"; ~7.5-7.9 rods advance quickly, wash turns from gray to tan, 7.9 boulders HNU ~0 wash water	
	7							
	8							
	9						9.0 Top of sound rock	
	10	NX 1	RQD 0%	9.0 to 11.0	2.0			
	11						Pink & gray coarse grained granodiorite; vertical, close spaced joints; joint faces lightly weathered, FeO, MnO & calcite coated; 11.0-11.4 slickensides	
	12	NX 2	0%	11.0 to 14.0	2.1			
	13							9.9' 0.01" slot screen
	14							
	15	NX 3	38%	14.0 to 17.5	3.9		Core barrel jambs at 11.0 & 14.0	
	16							
	17							

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Project UNIFIRST Site WOBURN **BORING UC5** Sh 2 of 2

Elev. Feet	Depth Feet	Sample Type & Number	Sample Blows per 6 in.	Sample Depth Range	Sample Rec.	Graphic Log	Sample Description	Equipment Installed
	18	NX 4	RQD 44%	17.5 to 19.5	1.8		HNu ~0 in open casing	Screen tip at 18.78'
	19							
	20						Bottom of Boring 19.5	

Notes:

1.) Well constructed of Schedule 40 2in. ID PVC with O-ring sealed threaded joints

2.) Blow counts not recorded. Split spoon was advanced with a 140 lb. hammer falling greater than 30 in. or with a 300 lb. hammer

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6C6

Project UNIFIRST Site WOBURN **BORING** [illegible] Sh 1 of 3
Date Started 11/5/86 Completed 11/14/86 Ground Elevation
Total Depth 58.0 ft Location Logged by J.T. Lawson
Casing I.D. 3¾ HSA/4in/3in Contractor Guild Drilling Co.
Remarks

Elev. Feet	Depth Feet	Sample Type & Number	Blows per 6 In.	Sample Depth Range	Sample Rec.	Graphic Log	Sample Description	Equipment Installed
							0.0 - 0.2 TOPSOIL	Road Box
	1	SS1		0.0 to 2.0	1.5		0.2 - 1.1 Tan coarse SAND & GRAVEL trace silt	
	2						1.1 - 2.0 Tan fine SAND trace silt; HNU no response in jar or open boring	
	3	SS2		2.0 to 4.0	1.0		2.0 - 4.5 Tan coarse to fine SAND & GRAVEL trace silt, pebble plugs shoe; HNU no response in jar or open boring	
	4	SS3		4.0 5.0	1.0			
	5							
	6						4.5 - 5.0 Gray coarse to fine SAND & GRAVEL little silt (Till); HNU no response in jar or open boring	
	7							Cement Bentonite
	8	SS4		8.0 - 8.5	0.5			
	9						5.0 - 8.0 BOULDERS	
	10						8.0 - 8.5 Tan and gray coarse to fine SAND & GRAVEL trace silt (Till); HNU no response in jar	2 in ID Sch 40 PVC O-Ring sealed threaded joints
	11						8.5 Auger refusal	
	12						8.5 - 14.0 BOULDERS	
	13							
	14						14.0 - 16.0 Green - Tan coarse to fine SAND & GRAVEL little silt (Till); HNU no response from opened spoon, ~50 in jar	
	15	SS5		14.0 to 16.0	0.9			
	16							
	17							

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Project UNIFIRST Site WOBURN **BORING UC6** Sh 2 of 3

Elev. Feet	Depth Feet	Sample Type & Number	Blows per 6 In.	Depth Range	Rec.	Graphic Log	Sample Description	Equipment Installed
	18							
	19	SS6		19.0-20.0	0.8		19.0-20.0 Gray coarse to fine SAND & GRAVEL little silt (Till); HNU ~1-2 in opened spoon, ~40 in jar	
	20						20.0 spoon refusal	
	21							Cement Bentonite
	22							
	23							
	24	SS7		24.0-24.5	0.4		24.0-24.5 Gray fine SAND some gravel trace silt (Till)	
	25						24.5 spoon refusal, 300 lb. hammer	
	26							
	27							
	28						29.0-29.4 boulder	bentonite pellets 29.2'-29.5'
	29							
	30	SS8		29.5-30.0	0.5		29.5-30.0 Gray coarse to fine SAND and SILT trace gravel (Till); HNU ~5-10 in open boring	top of silica sand pack 29.5'
	31							
	32						30.0 spoon refusal, 300 lb hammer	
	33							
	34	SS9		34.0-34.5	0.2		34.0-34.5 Same as SS8, pebble block shoe	9.9' 0.01" slot screen
	35						34.5 spoon refusal, 300 lb hammer	
	36							
	37							
	38						39.0-39.7 Gray coarse to fine SAND & SILT trace gravel & clay (Till)	
	39	SS10		39.0-39.7	0.7		39.7 spoon refusal, 300 lb hammer	

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Project UNIFIRST Site WOBURN **BORING UC6** Sh 3 of 3

Elev. Feet	Depth Feet	Sample Type & Number	Sample Blows per 6 in.	Sample Depth Range	Sample Rec.	Graphic Log	Sample Description	Equipment Installed
	40						39.7 - 44.0 Boulders	Screen tip at 43.0'
	41							
	42							
	43							
	44	SS11		44.0-44.5	0.5		44.0 - 44.5 Gray coarse to fine SAND & SILT trace gravel & clay (Till) HNu response ~100 in jar	Cement Bentonite 43.0'-58.0'
	45							
	46							
	47						44.5 spoon refusal, 300lb hammer	
	48							
	49	SS12		49.0-49.5	0.2		49.0 - 49.5 Same as SS11; HNu response ~150 in jar	
	50						49.5 spoon refusal, 300lb hammer	
	51							
	52							
	53							
	54	SS13		54.0-54.5	0.4		54.0 - 54.5 Gray CLAY & SILT trace gravel HNu response ~25	
	55							
	56	NX 1	RQD 20%	56.0 to 58.0	1.4		54.5 spoon refusal, 300lb hammer, Top of Rock	
	57						54.5 - 56.0 Smooth roller bit action	
	58						56.0 - 58.0 Pink coarse grained granodiorite	
	59							
	60						Vertical joint 56.6 - 56.8	
	61						Bottom of Boring 58.0 ft	

Note: Blow counts not recorded. Split spoons were advanced with a 140lb hammer falling greater than 30 in or with a 300lb hammer.

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BORING LOG

ENSR

Sheet 1 of 1

Project No. 11 Date - Start 9/23/92 Finish 9/23/92 Boring UCGS

Project Name Uniform Drilling Co. DL MAHER

Location Woburn, MA Drilling Method 6" Cased Air Rotary

Total Depth 18.9' Inspector JP Reviewer JP

Remarks

Depth Feet	Sample Type & No.	Sample Blows per 6 In.	Sample Depth Range	Sample Rec.	PID readings	Lithologic Description	Water Table
			0'-3'			brown f-m SAND, some silt	
			3'-15'			tan f-c SAND, some gravel + Rx frags	
5							
10							
15			15'-17.5'			tan f-m Sand, some gravel + silt	
			17.5-18'			gray f-m SAND, some silt - gravel	
20						EOB 18.9'	
25							
30							
35							

MD A 14 11

UC7

Project UNITFIRST Site WOBURN **BORING** ~~UC7~~ Sh 1 of 7

Date Started 11/17/86 Completed 11/24/86 Ground Elevation

Total Depth 148.0 Location Logged by J. T. Lawson

Casing I.D. 3¾ ID HSA/4in/3in Contractor Guild Drilling Co

Remarks

Elev. Feet	Depth Feet	Sample Type & Number	Blows per 6 In.	Depth Range	Rec.	Graphic Log	Sample Description	Equipment Installed
		S1		0.4			2 ft diameter manhole installed; rim 0.1 above grand, base 2.2 below grand	
	1							
	2	S2		2.2			Samples S1 and S2 are grab samples taken during installation of manhole	
	3	SS1		2.3 to 4.3	1.8		0.0 - 0.4 Bituminous Concrete Pavement; 0.4 HNU response in jar headspace ~700	
	4							
	5	SS2		4.3 to 5.8	1.1		0.4 - 2.2 Yellow-tan coarse to fine SAND & GRAVEL trace silt trace brown sand, silt & clay agglomerations ~4" max. dimension, slightly plastic (Fill); 2.2 HNU response in jar headspace ~400, in open excavation no response	
	6	SS3		6.0 - 6.4	0.4			
	7							
	8							
	9							
	10							
	11	SS4		10.0 to 12.0	1.1		2.2 - 6.4 Tan-gray coarse to fine SAND & GRAVEL	
	12							
	13						4.3 - 5.8 HNU response in jar ~20 6.0 - 6.4 HNU response in jar ~10 7.0 auger refusal Boulders	
	14							
	15						10.0 - 12.0 Tan medium to fine SAND some fine gravel HNU response in jar ~0	
	16	SS5		15.0 - 16.0	0.7		15.0 - 16.0 Gray-brown coarse to fine SAND & GRAVEL, fine granodiorite	
	17							

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Project UNIVERST Site WOBURN **BORING UC7** Sh 2 of 7

Elev. Feet	Depth Feet	Sample Type & Number	Blows per 6 in.	Depth Range	Rec.	Graphic Log	Sample Description	Equipment Installed
	18		RQD	17.5			fragments in shoe, wet HNu response in jar ~1-2	
	19	NX 1	50%	to	4.0		16.0 Top of Rock 3in casing spun to 17.5	
	20						16.0 - 19.5 Pink & gray coarse grained grano-diorite	
	21			22.0				
	22							
	23			22.0			19.5 - 20.0 weathered zone, tools advance rapidly, slight change in wash color, @ 19.5 open FeO stained joints 30° from core axis	
	24	NQ 1	62%	to	4.9			
	25							
	26			27.0			22.0 - 28.0 Mixed pink & gray granodiorite and gray gabbrodiorite	
	27	NQ 2	40%	27.0 - 28.0	1.0		22.2 - 23.2 joint 10° from core axis	
	28							
	29			28.0			24.0 weathered joint 60° from core axis; joints generally planar to wavy, FeO & Calcite coated	
	30	NQ 3	0%	to	3.5		27.4 joints 50° from core axis	
	31						28.0 - 33.0 fractured gabbro diorite	
	32							
	33			33.0			29.5 - 30.2 quart vein, sub-vertical	
	34	NQ 4	40%	33.0 to 35.0	2.2		33.0 - 48.0 mixed granodiorite and gabbrodiorite; joints 10° - 50° from core axis, planar to wavy, FeO & calcite coated	
	35							
	36	NQ 5	0%	35.0 to	2.8			
	37							
	38			38.0				
	39	NQ 6	35%	38.0 to 41.0	2.9			

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Project UNIFIRST Site WOBURN **BORING UC7** Sh 3 of 7

Elev. Feet	Depth Feet	Sample Type & Number	Sample Blows per 6 In.	Sample Depth Range	Sample Rec.	Graphic Log	Sample Description	Equipment Installed
	40	NQ 6	RQD 35%	38.0 to 41.0	2.9			
	41							
	42	NQ 7	68%	41.0 to 46.0	5.0			
	43							
	44							
	45							
	46	NQ 8	80%	46.0 to 48.0	2.0			
	47							
	48	NQ 9	68%	48.0 to 53.0	5.0		48.0 - 85.6 Dark gray fine-grained gabbrodiorite, joints 10°-90° from core axis, planar calcite coated 52.2 - 52.8 calcite filled joint, 10° from core axis	
	49							
	50							
	51							
	52							
	53	NQ 10	58%	53.0 to 58.0	5.0		53.0 - 58.0 intersecting joint sets, 45° and 70° from core axis, some joints calcite filled, others manifest no calcite	
	54							
	55							
	56							
	57							
	58	NQ 11	38%	58.0 to 63.0	5.0			
	59							
	60							
	61							

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Project UNI[illegible]RST Site WOBURN **BORING** UC7 Sh 4 of 7

Elev. Feet	Depth Feet	Sample Type & Number	Sample Blows per 6 In.	Sample Depth Range	Sample Rec.	Graphic Log	Sample Description	Equipment Installed
	62		RQD					
	63							
	64	NQ 12	62%	63.0 to 68.0	5.0		67.8 intersecting joint sets 40° & 90° to core axis, planar, calcite coated	
	65							
	66							
	67							
	68							
	69	NQ 13	74%	68.0 to 73.0	5.0		48.0-85.6 Dark gray fine-grained gabbrodiorite, joints 10°-90° to core axis, planar, calcite coated	
	70							
	71							
	72							
	73							
	74	NQ 14	16%	73.0 to 78.0	4.9		73.0-83.0 intersecting joint sets 10° & 20° to core axis, slickensides, calcite coating	
	75							
	76							
	77							
	78							
	79	NQ 15	16%	78.0 to 83.0	5.0		82.0-83.0 joint 0° to core axis	
	80							
	81							
	82							
	83							

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Project UNIFIRST Site WOBURN BORING UC7 Sh 5 of 7

Elev. Feet	Depth Feet	Sample Type & Number	Sample Blows per 6 in.	Sample Depth Range	Sample Rec.	Graphic Log	Sample Description	Equipment Installed
	84		RQD	83.0				
	85	NQ	50%	to	5.0		85.6 - 90.8 Pink medium-grained granodiorite; joints 10° - 90° from core axis, calcite coated, many joints manifest slickensides	
	86	16						
	87			88.0				
	88							
	89			88.0				
	90	NQ	50%	to	5.0		90.8 - 133.0 Dark gray fine-grained gabbro diorite, locally contains 5% - 10% pink feldspar, joints 15° - 90° from core axis, planar occasionally wavy, calcite coated	
	91	17						
	92			93.0				
	93			93.0				
	94							
	95	NQ	61%	to	4.9		93.0 - 98.0 joints 15° - 80° from core axis, calcite coated planar, slickensides	
	96	18						
	97			98.0				
	98			98.0				
	99							
	100	NQ	86%	to	5.0			
	101	19						
	102			103.0				
	103							
	104							
	105							

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Project UNIFIRST Site WOBURN **BORING UC7** Sh 6 of 7

Elev. Feet	Depth Feet	Sample Type & Number	Blows per 6 In.	Sample Depth Range	Rec.	Graphic Log	Sample Description	Equipment Installed
	106, 107, 108	NQ 20	RQD 100%	103.0 to 108.0			103.0-108.0 ~5% pink feldspar 107.6 intersecting joints 30° & 40° from core axis planar, FeO stained	
	109, 110, 111, 112, 113	NQ 21	88%	108.0 to 113.0	5.0		108.0-109.2 ~10% pink feldspar 108.6-109.2 intersecting joints, 50° from core axis	
	114, 115, 116, 117, 118	NQ 22	84%	113.0 to 118.0	5.0		114.3-114.4 fractured zone, 90° from core axis, FeO staining 90.8-133.0 Dark gray fine-grained gabbro diorite locally contains 5%-10% pink feldspar; joints 15° & 90° from core axis, planar occasionally wavy, calcite coated	
	119, 120, 121, 122, 123	NQ 23	94%	118.0 to 123.0	5.0		118.0-123.0 joints planar to rough, calcite coated, FeO staining 120.4-121.6 quartz and calcite filled vein, minor pyrite	
	124, 125, 126, 127	NQ 24	94%	123.0 to 128.0	4.9		127.0 calcite filled vug	

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Project UA IRST Site WOBURN BORING UC7 Sh 7 of 7

Elev. Feet	Depth Feet	Sample Type & Number	Blows per 6 in.	Sample Depth Range	Rec.	Graphic Log	Sample Description	Equipment Installed
	128		RQD				128.0-133.0 increasing pink feldspar content	
	129	NQ 25	76%	128.0 to 133.0	5.1		131.8 lost drill water, regain half flow by 133.0	
	130						131.7-132.9 fractured zone, calcite and FeO coating	
	131							
	132							
	133	NQ 26	88%	133.0 to 138.0	4.9		133.0-140.3 Mixed dark gray fine-grained gabbro-diorite and pink medium grained granodiorite, joints 40° to 90° from core axis	
	134							
	135							
	136						133.0-148.0 no drill water return	
	137							
	138	NQ 27	32%	138.0 to 143.0	5.1		137.5-138.0 fracture zone FeO staining	
	139							
	140						140.6-141.0 fracture zone	
	141							
	142							
	143	NQ 28	94%	143.0 to 148.0	5.0		140.3-148.0 Dark gray-green gabbrodiorite, dense network of tight, calcite filled joints, major joints 70°-90° to core axis	
	144							
	145							
	146							
	147							
	148						Bottom of Boring 148.0	

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UC7A

Project VolFirs Site Warren **BORING** Sh 1 of 5
Date Started 11/25/86 Completed 12/1/86 Ground Elevation
Total Depth 137.0 Location Logged by J. T. Lawson
Casing I.D. 3¾ ID HSA Contractor Guild Drilling
Remarks

Elev. Feet	Depth Feet	Sample Type & Number	Blows per 6 In.	Depth Range	Rec.	Graphic Log	Sample Description	Equipment Installed
	1						0.0-0.4 Bituminous Concrete Pavement	
							0.4-2.3 Yellow-tan crs-f sand & gravel tr. silt Fill trace brown sand, silt & clay agglomerations, slightly plastic	
	2						2 ft ø manhole installed	
							Auger to 7.0	
	7	SS1	Jar head-space HNu (max.) ~1-2	7.0-9.0	1.5'		Gray crs-fine SAND & GRAVEL tr silt Till 8.9-9.0 wet in ss shoe	
							≤ 8.9 → probably artificially high from drilling UC7	
	9	SS2	~2	9.0-11.0	1.8'		Tan med-f. SAND tr f. gravel wet ~med. compact, lot < dense than SS1	
	11	SS3	~7-8	11.0-13.0	1.4'		Same as above Spin HW Casing to 13.0'	
	13	SS4	~8	13.0-15.0	0.8'		Same as above Spin HW to 15.0	
							HNu response rapidly dissipated w/in 15 sec to background	

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Elev. Feet	Depth Feet	Sample Type & Number	Blows per 6 In.	Sample Depth Range	Sample Rec.	Graphic Log	Sample Description	Equipment Installed
				15.0-16.7	0.9		open starts bouncing @ ~16.5'	
		SS5					same as above, pink granite rock fragment at 16.5'	
	16						hammer HW to 15.5 then to 16.0 spin NW to 17.8	
							Top of Rock 16.5	
	17						roller bit to 19.0 barrel drops to 17.7	
			RQD				~19.5 ft soft seam, quick advance ~0.2	
	20	NQ 1	37%	18.0-22.6	3.9		granodiorite (Salem Gabbrodiorite) ~5% pink kspar fracture zones 18.6-19.1, 19.4-19.7 20.3-20.8, jts 20°-90° to core axis	
	25	NQ 2	50%	22.6 to 27.0	4.3		same as above jts 10°-20° to axis	
	30	NQ 3	72%	27.0 to 32.0	5.1		same as above above w/ zones 30.3-30.4, 31.5-31.6	
		NQ 4	65%	32.0-33.9	1.8		granodiorite 32.6-32.9 crushed zone jts 20° core axis	
	35	NQ 5	38%	33.9-38.0	4.1		granodiorite w/ bands of pink granite jts 10° to core axis, planar FeO & CaCO3 coated	
	40	NQ 6	74%	38.0 to 43.0	5.0		pink crs & fine grained granite (Redham Granodiorite) 41.5 granodiorite - fractured - RQD 0% jts 40°-90° to core axis planar, [illegible]	
	45	NQ 7	70%	43.0 to 48.0	5.0		granodiorite bands of pink granite jts 55°-90° to core axis CaCO3	

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Project Unit First Site Woburn BORING NUCFA 3 of 5

Elev. Feet	Depth Feet	Sample Type & Number	Blows per 6 In.	Sample Depth Range	Rec.	Graphic Log	Sample Description	Equipment Installed
			RQD					
	50	NQ 8	80%	48.0 to 53.0	5.0		granodiorite, 48.4 - 49.1 pink granite jts 20°-80° to core axis planar to wavy $CaCO_3$	
	55	NQ 9	70%	53.0 to 58.0	5.0		granodiorite, 56.5 - 58.4 frax. zone jts 0°-80° to core axis, $CaCO_3$	
	60	NQ 10	46%	58.0 to 63.0	5.0		61.3 - 63.0 frax. zone jts 40°-60° to core axis, $CaCO_3$	
☆	65	NQ 11	46%	63.0 to 68.0	5.0		jts 0°-90° to core axis, $CaCO_3$ 64.0-64.3 vertical jt, 64.6-64.7 crushed zone	
	70	NQ 12	60%	68.0 to 73.0	5.0		68.3 jt 35° to core axis, slks, $CaCO_3$ jts planar to wavy 71.0 - 71.4 vertical jt. 72.0 - 72.4 jts 30° to core axis	
	75	NQ 13	16%	73.0 to 78.0	5.0		jts 10°-90° to core axis, slks, planar-wavy $CaCO_3$	
	80	NQ 14	30%	78.0 to 83.0	5.0		core barrel jamming, pull string jts 45°-90° to core axis	
	85	NQ 15	20%	83.0 to 88.0	4.9		jts. 10°-90° to core axis planar, some slks, $CaCO_3$ 84.5 - frax. frequent leave 4.0 ft [illegible]	

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Proj. [illegible] Sheboygan [illegible] 7A Sh. 1 of 3

Elev. Feet	Depth Feet	Sample Type & Number	Blows per 6 in.	Depth Range	Rec.	Graphic Log	Sample Description	Equipment Installed
			RQD					
	90	NQ 16	56%	88.0 to 93.0	5.0		To recover core dropped from NQ #5, spinned barrel over dropped core	
	95	NQ 17	46%	93.0 to 98.0	5.0		90.0 - 91.0 fine grained pink granite 91.0 - 92.0 granodiorite 92.0 - f.gr. pink granite - jts 40° to core axis closely spaced, crumbled during removal from shoe	
drill slows	100	NQ 18	94%	98.0 to 103.0	5.0		94.4 granodiorite jts 35° - 80° planar to wavy coated	
	105	NQ 19	95%	103.0 to 107.4	4.2		100.3 - 101.5 pink med. gr. granite jts 80° - 90° to core axis planar - wavy CaCO3	
		NQ 20	100%	107.4 - 108.0	0.6		Pink & gray granodiorite; bit worn stop run. Pull string & replace bit	
	110	NQ 21	78%	108.0 to 113.0	5.0		111.9 - 112.8 ∩ jts 10° & 20° to core axis planar FeO, CaCO3	
	115	NQ 22	88%	113.0 to 118.0	4.9		~113.0 change to greenish granodiorite with pink K spar phenocrysts 117.5 - 118.0 open jt 0° to core axis jts planar - wavy FeO, CaCO3 0° to 20° to core axis strong fabric, filled jts	
	120	NQ 23	82%	118.0 to 123.0	5.0		Same as above, qtz & CaCO3 vein 124.0 crushed zone 125.7 - 125.8 jt 0° 120.0 - 121.4; jts 0° - 90° to core axis	
	130	NQ 24	72%	123.0 to 128.0	4.9		Pink K spar increases to ~70 - 80% 124.3 - 124.6 close spaced jts 60° - 90° to core axis, fine grained, filled qtz & CaCO3	

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4.3

Elev. Feet	Depth Feet	Sample Type & Number	Blows per 6 in.	Sample Depth Range	Sample Rec.	Graphic Log	Sample Description	Equipment Installed
	125		RQD					
	130	NQ 25	86%	128.0 to 133.0	5.0		Same as above, jts 90°-90° to core axis FeO, CaCO3 coating; vert jt healed	132.6-132.9
	135	NQ 26	82%	133.0 to 138.0	5.0		Same as above, 133.2-139.8 ⊓ jts w/ to core axis 137.0-137.1 open FeO w/ jt; 137.9 close spaced frac, crushed upon removal from shoe; lose water ~137	137.5-
	140	NQ 27	44%	138.0 to 143.0	3.7		no water return; core slips, dry block attempt — sand blows into barrel & jams it — mistakes barrel pushed up into rod & jammed w/ sand, trans- pull string; core removed from outer barrel	
	145	NQ 28	75%	143.0 to 147.0	4.2		138.5-139.1 close spaced frac 139.6-140.1 " 141.6-141.0 "	
	150						switch to std. barrel to reduce problems w/ sand blocking 146.3 greenish granodiorite jts. 45°-90° to core axis planar - wavy, $CaCO_3$ sand lightly blown up into barrel 147.0 End of Boring	

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Project UNIFIRST Site WOBURN **BORING UC8** Sh 1 of 2

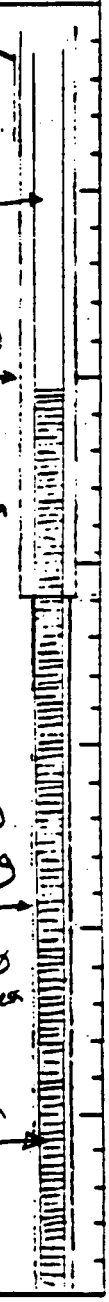
Date Started 1/6/87 Completed 1/8/87 Ground Elevation

Total Depth 30.8 Location Logged by J.T. Lawson

Casing I.D. 4in, 2in riser Contractor Guild Drilling Co.

Remarks See Notes at end of log

Elev.	Depth Feet	Sample Type & Number	Blows per 6 in.	Depth Range	Rec.	Graphic Log	Sample Description	Equipment Installed Road Box
	1, 2	SS1	2/1.5	0.7 to 2.2	0.2		0.0 - 0.45 Concrete Floor Cored with 12in thin-wall HNu no response below floor soil settles to 0.7 during removal of concrete core	2in Ø stainless steel blank riser
	3	SS2	1/1.5	2.2 to 3.7	0.1		0.7 - 2.2 Brown medium to fine SAND trace silt HNu no response in jar	4in steel casing
	4, 5	SS3	14-9-5	3.7 to 5.2	1.0		2.2 - 3.7 Pebble blocked auge	
	6	SS4	7-6-15	5.2 to 6.7	1.2		3.7 - 3.9 Bituminous Concrete Pavement	
	7	SS5	See Note 1	6.7 - 7.7	0.8		3.9 - 4.2 1/4 in Crushed Stone	bottom of casing 7.9'
	8	SS6	See Note 1	7.7 - 8.0	0.3		4.2 - 6.4 Brown coarse to fine SAND & GRAVEL HNu response ~250 in jar	
	9	SS7	See Note 1	8.2 - 8.3	0		6.4 - 6.7 Black fine SAND HNu response in jar: 5.7-6.4 ~30 6.4-6.7 ~5	
	10, 11, 12	NQ 1	RQD 16%	8.3 to 12.8	2.7		5.7 - 6.7 Slow roller-bit advance, metal "flakes" in wash	NQ Cored Boring
	13, 14, 15, 16, 17	NQ 2	92%	12.8 to 16.8	3.8		6.7 - 7.7 Gray - green gray coarse to fine SAND some silt trace gravel (Till) HNu response in jar ~2	2in Ø stainless steel 10 mil slot screen
							7.7 - 8.0 Gray - green gray coarse to fine SAND & GRAVEL little silt	



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ENSR

Sheet 1 of 1

Project No. 01.03 Date - Start 4/12/94 Finish 4/13/94 Boring UC35

Project Name Unifirst Corp. Property Investigation Drilling Co. Guild

Location Wells G+H Site, Woburn Drilling Method Wash & Drive

Total Depth 11.35' Inspector J. Howe Reviewer

Remarks background = 1.1 parts, ☆ = sample taken for VOC, core size NW-2
S-3 was 2" spoon all others were 3"

Depth Feet	Sample Type & No.	Blows per 6 In.	Depth Range	Rec.	PID Graphic Log OVM	Lithologic Description	Equipment Installed Samples
☆	S-1	15-20-29	.5-2'	.9'	73	.37' concrete floor Dark br. f-m SAND, trace gravel and rx frags.	21:00 C351A
☆	S-2	26-31-39	2'-3.5'	1.1'	9.8	lt. Br. f-m SAND, some gravel, trace rx frags.	21:15 C352A,B,C,F
5	S-3	61-41-43-45	5.5-5.5'	2'	3.6	lt Br-gray f-m SAND and Rock frags. Subangular <1"-1"	5
☆	S-4	28-42-43	5.5-7'	.8'	4.4	br. f SAND and weathered rock, trace c sand and silt	23:10 C353A
	S-5	21-24-27	7'-8.5'	.8'	20.5	br. f SAND, some m-c sand and weathered rx	01:30
☆	S-6	27-100/4	8.5-9.35	1.0'	65	lt. br/Dk. br. interbedded f SAND, some c. sand and gravel	C354A
10	NW2-1	RQD 75%	9.4-11.4'	2.'	1.1	Top zone v. fr and weathered 9.7'-10.2' Granodiorite slightly weathered 10.1 Gabbodiorite fresh, broken, 45° angle to axis fracs.	10
						EOB 11.35'	
15							15

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ENSR

Sheet 1 of 1

Project No. 01.03 Date - Start 4/13/94 Finish 4/13/94 Boring VC36

Project Name Unifirst Corp. Property Investigation Drilling Co. Guild

Location Wells G+H Site, Woburn, MA Drilling Method Drive & Wash

Total Depth 9.7' Inspector J. Howe Reviewer

Remarks background reading = 0.0 parts ☆ = sample for VOC

using 300lb. hammer

Depth Feet	Sample Type & No.	Blows per 6 In.	Depth Range	Rec.	OVM ~~Graphic Log~~ PPM	Lithologic Description	Equipment Installed
☆	S-1	57-63-51	.5-2'	1.2'	23	.37' concrete floor br. f-m SAND, trace gravel and rx frags.	19:30 C361A
	S-2	37-120-51	2-3.5'	.4'	2.5	same	C362A 20:00
☆	S-3	31-55-36	3.5-5'	1.2'	35	lt br. same	
☆	S-4	31-27-21	5.0-6.5'	1.1'	111.0	lt br. f-m SAND, trace gravel and silt, moist	C363A 20:15
	S-5	41-55-120/2	6.5-7.7'	.9'	65	same	C364A 21:30
	WR2-1	RQD 86%	7.7'-9.7'	1.75		7.7-8.1' Broken, slightly weathered Gabbro diorite 8.1-9.45 Blocky, fresh Gabbro diorite 45° fracture at 9.5' trace silt	C364C
						EOB 9.7'	

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Project [illegible] Site [illegible]

BORING

Sh [illegible] of 2

Elev. Feet	Depth Feet	Sample Type & Number	Blows per 6 in.	Depth Range	Rec.	Graphic Log	Sample Description	Equipment Installed
							casing too high w/T to spin rods	
		SS-5	50 140# 75 300#	6.7 to 7.7	0.8		try washing w/ T in place, poor advancement remove T, allow water to wash back thru floo	
	8	SS6	300#	7.7 to 8.0	0.3		gray-greenish gray c-f sand some silt tr. gravel Till SS-5 HNU ~2	
	9	SS7	300#	8.2 to 8.3	0		gray-greenish gray c-f S & G little silt FeO stained pebbles SS-6 HNU <2	
							SS7 No Recovery, Rods bouncing	
							8.3 Top of Rock	
			RQD					
	10	NQ1	16%	8.3 to 12.8	2.7		8.3-10.3 black-green fine grained granodiorite highly frac. jts. 10°-90° to core axis coated CaCO3, light FeO	Salem Granodiorite
							NQ1 10.3- pink-gray granite unfrac.	Dedham Granodiorite
							boring caves @ 11.0 overnight - ream	1/8/87
		NQ2	92%	12.8 to 16.8	3.8		NQ2 pink granite becomes coarse grained jts 30°-80° to core axis FeO stained	
							boring continues to cave - ream	13.8-16.8
		NQ3	85%	16.8 to 20.8	4.1		NQ3 difficulty pulling rods, hole caving	
							same as above	
							20.8 End of boring	
		7' HW casing 0.5' hard shoe bottom of casing @ 7.7'					boring caves, push obstruction to 13.0	
							during installation of road box "solvent type" odor noted from standing water between casing and floor ~200 HNU response at water surface	

road box installed @ surface

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1812 (1/81)

UC9

Project UniFirst DUSS Site Woburn **BORING** [redacted] Sh 1 of 8

Date Started 4/28/87 Completed 5/12/87 Ground Elevation

Total Depth 23.0 Location Logged by J. T. Lawson

Casing I.D. NW in place, HW coal boring Contractor Guild Drilling Co. Daryl Greene

Remarks HNU 11.7 eV lamp

Elev. Feet	Depth Feet	Sample Type & Number	Blows per 6 in. / HNU	Sample Depth Range	Rec.	Graphic Log	Sample Description	Equipment Installed
		SS1	no response	0.0-2.0	1.4		No blows recorded, 140 lb drops >30 in.	
							0.0-0.4 brown silt & f. sand trace organic, grass, roots (Topsoil)	
	1						0.4-2.0 tan, fine sand little silt, tr. f. gravel (Fill)	
							~1.5 spoon deflects ~20° off boulder, attempt to drive	
	2						~1 ft away hit boulder again → go to spinning NW w/water	
		BOULDER		2-3'			→ NW spins hard @ ~1.6	
							spin HW to 2.5, roller bit to 3.0 thru boulder	
	3	SS-2		3.0-4.5	0.8		4.5 refusal – 300# hammer	
			0.4				3.0-4.5 brown c-f sand & f gravel trace silt, bituminous concrete fragments (Fill)	
	4						roller bit to 5.6	
							spin HW to 5.0	
				5.6 to 10.0	1.5		set spoon at 5.0 2 drives w/300# to 8.0	
	5	SS 3					overdrive to 10.0	
						8.0-8.7	~~5.6-6.3~~ tan-yellow silt trace roots	
						8.7-10.0	6.3-10.0? gray c-f SAND tr. gravel	
			0.1				5.6-8.0 void below boulder in fill	
							8.0-10.0 original soil	
	6							
							Was rig & tools steamed cleaned between holes? No rod dope used	

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UC9

Project UniFirst Site Woburn **BORING UC9** Sh 2 of 8

Elev. Feet	Depth Feet	Sample Type & Number	Sample Blows per 6 in.	Sample Depth Range	Sample Rec.	Graphic Log	Sample Description	Equipment Installed
			HWU				Use water upon starting casing advance from 5.0 ft – spin HW to 10.0, clean out 10.1 top of rock	
				10.0 – 10.1			Refusal Sonic hammer	
	10	SS3					roller bit to 12.0	
		~~NX1~~					NX1 std. barrel to confirm bedrock	
			RQD					
	10	NX1	28 34%	10.1 to 12.0 to 17.0	4.2		12.0 – 15.1 pink & gray granodiorite, m. grained jts. 50°-90° to core axis planar to wavy FeO, Mno coated	
	15						15.1 – 17.7 dk gray gabbrodiorite, f. grained jts. 80°-90° to core axis, FeO coated irregular surface, most spun & ground by core barrel	
4/23		NQ1	76%	17.0 to 22.0	5.2			
	20						12.5 ft NW casing & shoe spun into place bottom at 12.0, clean out w/ roller bit, no water return	
17.0		NQ2	66%	22.0 to 27.0	5.0		spin NW to 15.0 → no water return clean out w/ roller bit → no water return spin NW to 17.0 no water return clean out w/ roller bit → gd water back water down outside of casing & no water	
4/30	25	NQ3	32%	27.0 to 32.0	4.3		17.4 – 18.0 fran. zone, wavy – irregular jt. surfaces FeO coated	
	30	NQ4	46%	32.0 to 37.0	4.5		17.7 – 42.0 pink & gray m. grained granodiorite jts 0°-90° to core axis FeO, Mno, CaCO3 coating, vertical jt. 19.0 – 20.4 ; 21.8 – 22.6 closely spaced jts. FeO Mno coated ; 25.5 jts. w/ FeO Mno coated open	
	35						28.2 – 30.4 fine grained 30.9 – 31.4 vert jt. FeO CaCO3	
	40	NQ5	100%	37.0 to 42.0			NQ4 – NQ6 std. inner barrel 32.8 – 40 frac zone 37.7 – 37.9 20° to core axis, open jt. FeO CaCO3 coating	

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UC9

Project UniFirst Site Woburn **BORING UC9** Sh 3 of 8

Elev. Feet	Depth Feet	Sample Type & Number	Blows per 6 in.	Sample Depth Range	Rec.	Graphic Log	Sample Description	Equipment Installed
	40		RQD				47.0 – pink & gray m. grained granodiorite jts. 50 – 90° to core axis coated, FeO MnO CaCO3 surfaces planar & rough to wavy	
	45	15 6	96%	42.0 to 47.0	4.7			
	50	NQ 7	N/A	47.0 to 52.0	2.4		NQ7 core lifter slips NQ8 drill over w/ std. barrel; recover 0.2; pull drillstring	
check →		NQ8	N/A	52.0 – 53.0				
	55	NQ9	58%	53.0 to 58.0	4.8		53.6 – 54.0 frac. zone 54.6 – 55.0 frac zone	
511	60	NQ10	100%	58.0 to 63.0	5.0		60.5 – 60.7 qtz. vein ~80° to core axis 62.0 – 62.2 breccia?, gabbrodiorite intrusion w/ included granodiorite, slks, zone & open jt w/ slks 35° to core axis FeO, MnO, CaCO3 coating; @ 62.0 ∩ jt 25° to measures	
		NQ11	100%	63.0 to 65.0	2.0			
	65	NQ12	100%	65.0 to 68.0	3.0		less to no coating on jts 65.0 slks, barrel jambs, pull rod up short 64.0 – 65.0 brecciated fabric, rock has been dilated & injected	
	70	NQ 13	N/A	68.0 to 73.0	4.7		66.7 $CaCO_3$ filled jt. 55° to core axis NQ13 core lifter slips 68.9 – 73.0 redrilled	
	75	NQ 14	92%	73.0 to 78.0	5.0		74.0 – calcite veining and chlorite increases; FeO & MnO [illegible] to absent on jt faces, $CaCO_3$ [illegible] in veins only	
	80	NQ 15	98%	78.0 to 83.0	4.9		calcite veining ~10° to core axis core breaks & jts 70 – 90° to core axis	

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Project UniFirst Site Woburn MA **BORING** Sh 4 of 8

Elev. Feet	Depth Feet	Sample Type & Number	~~Blows per 6 in~~	Sample Depth Range	Rec.	Graphic Log	Sample Description	Equipment Installed
			RQD					
	85	NQ 16	90%	83.0 to 88.0	5.1		c-m grained pink & gray granodiorite jts. 30°-90° to core axis, decreasing chlorite & calcite veining	
5/5	90	NQ 17	98%	88.0 to 93.0	5.0		same as above 88.8-88.9 open FeO jts. 90° to core axis	
	95	NQ 18	100%	93.0 – 96.0	2.9		increasing $CaCO_3$ veining, light FeO staining; lost water ~95.0	
→		NQ 19	100%	96.0 – 98.0	2.0		no water return, decreasing $CaCO_3$ veining m.grained pink & gray granodiorite jts planar smooth 50°-60° to core axis	
	100	NQ 20	88%	98.0 to 103.0	4.9		102.2 - 102.3 open frac. FeO staining 80° to core axis ∩ 10° to core axis tight $CaCO_3$ filled jt.; jts 80-90° to core axis light coating	
→	105	NQ 21	64%	103.0 to 108.0	6.1		103.8 - 104.0 open FeO, $CaCO_3$ coated frac.	
	110	NQ 22	72%	108.0 to 113.0	4.9		106.0 - 106.4 open FeO $CaCO_3$ coated frac jts. 10°-90° core axis, rough to smooth, increased coating	
→							111.0 – 112.3 open jt/frac FeO $CaCO_3$ coated	
	115	NQ 23	86%	113.0 to 118.0	5.0		115.2 to 115.9 open planar rough FeO stained jt. ~60° to core axis	
	120	NQ 24	74%	118.0 to 123.0	5.0		118.9 - 119.[illegible] ∩ jts planar smooth [illegible] 122.4 - 123.5 open rough curved jt [illegible]	

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UC9

Project UniFirst Site Woburn MA **BORING** UC9 Sh 5 of 8

Elev. Feet	Depth Feet	Sample Type & Number	~~Blows per 6 in~~	Sample Depth Range	Sample Rec.	Graphic Log	Sample Description	Equipment Installed
	120		RQD					
	125	NQ 25	48%	123.0 to 128.0	5.0		little water return @ ~125, lost again completely ~125.5 123.9 – 124.1 jt. 0° to core axis Rough, FeO stained 124.6 – 125.7 closely spaced jts planar smooth to rough FeO stained	
	130	NQ 26	94%	128.0 to 133.0	4.9		126.9 – 127.7 closely spaced jts 20° to core axis – 90° FeO stained open 129.1 – 129.3 jts. ∩ 90° & 70° open light FeO stained	
	135	NQ 27	88%	133.0 to 138.0	4.9		130.6 f. grained pink & gray granodiorite 132.0 – 132.3 jts. ∩ 60° & 70° coated, smooth planar faces	
	140	NQ 28	88%	138.0 to 143.0	5.0	gd	135.6 – 136.1 jt. open 20° to core axis smooth planar → ~ contact between f. & c. granodiorite 136.6 – 136.8 green – dk gray gabbrodiorite jt 80° to core axis	
	145	NQ 29	86%	143.0 to 148.0	5.0	gbd	136.8 0.02 calcite vein 90° to core axis 137.2 open rough jt 80° to core axis 137.9 0.01 calcite vein 90° to core axis 139.4 – 139.5 gabbro diorite 70° to core axis jt @ upper contact	
	150						140.9 – 142.5 increase jt. frequency light FeO staining 80° – 90° to core axis	
	155						144.6 – 144.9 Calcite vein 80° to core axis 144.9 – 146.0 green – dk gray gabbrodiorite 146.0 – 146.5 f. grained pink granodiorite 146.5 – 149.8 green – dk gray gabbrodiorite pyrite on lower contact	
	160						147.9 0.05 calcite vein – CaCO3 increasing NQ 29 frax/jts along contacts of gabbrodiorite 145.1 – 145.3 frax zone FeO staining	

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UC9

Project UniFirst Site Woburn **BORING** UC9 Sh 6 of 8

Elev. Feet	Depth Feet	Sample Type & Number	Blows per 6 in.	Sample Depth Range	Rec.	Graphic Log	Sample Description	Equipment Installed
			PMD				147.6-148.4 brecciated & injected zone, 0.05 calcite veins	
	150	NQ 30	100%	148.0 to 153.0	5.0	gbd	green-dk gray lightly pink gabbrodiorite f. grained, jts 80°-90° to core axis irregular surface	
	155	NQ 31	100%	153.0 to 158.0	5.0		156.6-157.3 jts open Fe stained 20° & 90° to core axis	
	160	NQ 32	88%	158.0 to 163.0	5.0		159.4 2 ll open jts Fe stained 90° 159.8 & 160.0 open jts CaCO3, 70° 160.7 & 160.8 open jts coated CaCO3	
						grd	161.8 c-m grained pink granodiorite	
	165	NQ 33	96%	163.0 to 168.0	4.8	grd & gbd	163.0-167.7 mixed gabbrodiorite & granodiorite, jts 80°-90° irregular surfaces	
SB	170	NQ 34	100%	168.0 to 173.0	4.8	grd	167.7-173.4 pink & gray c-m grained granodiorite, jts 30°-90° to core axis light coating, planar to irregular smooth-rough parting & along gabbrodiorite? intrusions	
	175	NQ 35	70%	173.0 to 178.0	5.2	gbd	173.4- green-dk gray gabbrodiorite <5% granodiorite inclusions jts 30°-90° to core axis, smooth & planar to rough & irregular, calcite veining & coatings	
	180	NQ 36	58%	178.0 to 183.0	5.2		179.9-182 fract zone jts close 80° to core axis - drilling difficulty mark increase in fract/jt frequency in gabbrodiorite & calcite veining	
						grd		
	185	NQ 37	100%	183.0 to 184.5	1.5	gbd	182.2 f. grained pink granodiorite 183.0	
							183.0- green-dk gray f. grained gabbrodiorite, calcite veining ~50° to core axis, some chlorite in veins	

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• bit muds, heavy rod vibration pull run-pull stroke change bit

UC9

Project UniFirst Site Woburn **BORING** UCG Sh 7 of 8

Elev. Feet	Depth Feet	Sample Type & Number	Blows per 6 in.	Sample Depth Range	Rec.	Graphic Log	Sample Description	Equipment Installed
	185	NQ 38	97%	184.5 to 188.0	3.5	gbd	186.7 SKS 20° to core axis CaCO3 & chlorite 187+/- 0.1' CaCO3 vein	
	190	NQ 39	78%	188.0 to 193.0	5.0		green-dk gray f. grained gabbro diorite ~1% pink K-spar, jts 0°-90° to core axis CaCO3 chlorite filled & coated 189.0-189.4 SKS	
	195	NQ 40	100%	193.0 to 198.0	5.0		193.4-193.7 SKS 30° to core axis smooth curved CaCO3 chlorite	
	200	NQ 41	100%	198.0 to 203.0	5.0		m. grained green & dk gray gabbro diorite jts 30°-90° to core axis jts planar, wavy smooth calcite filled v. fast drilling 2 min/ft	
	205	NQ 42	100%	203.0 to 208.0	5.0		Breaks in core appear to be affected by drilling, partings ∥ to calcite veining 206.9-207.4 jt calcite filled 10° to core axis	
	210	NQ 43	100%	208.0 to 213.0	5.0		212.0-213.0 core breaks from drilling & core removal from lifter	
	215	NQ 44	96%	213.0 to 218.0	5.0		214.7-214.9 11 jts. 10°-20° to core axis calcite filled.	
	220	NQ 45	100%	218.0 to 223.0	5.0		221.4-222.4 core breaks from removal from lifter	
	225	NQ 46	100%	223.0 to 228.0	5.0		~0.1 pulverized & lost in process removal from lifter <1% pink K-spar	

5/10

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UCG

Project UNIFIRST Site WOBURN **BORING** UC9 Sh 8 of 8

Elev. Feet	Depth Feet	Sample Type & Number	~~Blows per 6 in.~~	Sample Depth Range	Sample Rec.	Graphic Log	Sample Description	Equipment Installed
	225							
			RQD					
	230	NQ 47	100%	228.0 to 233.0	5.0		M-f grained green & dk gray gabbro diorite calcite filled jts 0°-90° to concavity 232.7-233.0 frax. during removal from hole 233.7-234.2 curved calcite filled jt. 236.6-236.7 Calcite vein	
	235	NQ 48	96%	233.0 to 238.0	5.0			
5/11	240						End of Boring 2ft ϕ Manhole installed	

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UC9

Project UniFirst Site Wbb **BORING** JC10 Sh 1 of 2

Date Started 5/13/87 Completed 5/26/87 Ground Elevation

Total Depth Location Logged by T. T. Lawson

Casing I.D. HW, NW Contractor Guild Drilling Co. Daniel Green

Remarks

Elev. Feet	Depth Feet	Sample Type & Number	Sample Blows per 6 in.	Sample Depth Range	Sample Rec.	Graphic Log	Sample Description	Equipment Installed
			HNU				0.0-2.0 excavated for installation of manhole	
							0.0-0.4 bituminous concrete pavement	
							0.4-0.9 black oiled sand & gravel	
	1		bkgrd 0.5				0.9-2.1 yel-tan fine SAND, little gray silt	
		1.5	150				HNU 2.5' bkgrd 1.2 response none same for replicate	
	2						yel-tan f. SAND trace silt, gray	
		SS1	bkgrd 1.0 res. 3.0	2.0 to 4.0	2.0			
	3							
	4		bkgrd 0.8 response	4.0			same as above	
	5	SS2	3.5	to 6.0	2.0		~5.0 moist ~6.0 and below saturated storm drain w/in 10 ft STOS ∇ 10.5	
	6							

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Project UNIFIRST Site WOBURN **BORING** UC10 Sh 2 of 3

Elev. Feet	Depth Feet	Sample Type & Number	Blows per 6 in.	Sample Depth Range	Rec.	Graphic Log	Sample Description	Equipment Installed
	6		HW	6.0			2.0–8.0 SS1,2&3 press split w/ hyd. feed	
	7	SS3	bkgd 0.8 resp. 6.0	6.0 to 8.0	2.0		same as above	
							7.9 yel-tan f. SAND & SILT tr. gravel (Till?)	
	8	SS4	bkgd 0.7 resp. 2.5	8.0 to 10.0	0.3		Spin HW to 8.0 SS4 300# hammer ↳ toss gray c-f Sand & Gravel	
							HW casing -> boulder ~9.5 Spin HW to 14	
	10						Boulders, heavy drilling to 14 ft.	
	15	SS5	0.8 1.5	14.0 – 16.0	0.9		green-gray c-f SAND little silt, tr. gravel (Till)	
	20	SS6	0.9 NR	19.0 – 20.9	1.2		same as SS5 refusal @ 20.9	
	25	SS7	1.0 2.6	24.0 – 26.0	1.2		same as SS5	
	30	SS8	0 2.5	29.0 – 30.8	0.9		same as SS5, increasing gravel refusal @ 30.8	
							telescope to UW new shoe 0.45 ft	

scale skewed

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1812 (1/81)

UC10

Project UniFirst Site Woburn **BORING** UC10Sh 3 of 3

Elev. Feet	Depth Feet	Sample Type & Number	~~Blows per 6 in.~~	Depth Range	Rec.	Graphic Log	Sample Description	Equipment Installed
	30		HNU					
	35	SS9	1.0 3.4	34.0 - 35.0	0.8		Same as SS8 35.0 refusal	
	40	SS10	1.2 1.4	39.0 41.0	0.7		Same as SS8	
	45	SS11	N/A	44.0 44.2	0		44.2 refusal	
	50	SS12	1.0 NQ	49.0 - 51.0	1.2		Same as SS8	
	55	SS13	1.3 1.7	54.0 - 55.0	0.5		Same as SS8	
	60	SS14	1.3 1.5	59.0 - 61.0	1.0		Same as SS8	
	65	SS15	N/A	64.0 66.0	0		No Recovery	
	70	SS16	1.0 1.1	69.0 70.1	1.0		No Recovery 69.0 - 70.0 Redrive to 70.1 Refusal gray fine SAND tr. silt	

1012 (1/81)

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UCD

Project Unifight Site Woburn **BORING UC10** Sh 4 of 8

Elev. Feet	Depth Feet	Sample Type & Number	Sample Blows per 6 in.	Sample Depth Range	Sample Rec.	Graphic Log	Sample Description	Equipment Installed
	70		HNu					
5/15/87	75	SS17	1.3 1.8	74.0 76.0	1.2		green-gray c-f sand & gravel trace silt	
			RQD				77.0 top of rock, spin NW casing to 79.0 roller bit & clean out	
	80	NX1	38%	79.0 to 84.0	3.7		~80 wash turns brown, ~81 back to lt-gray NX-1 std. barrel ~83 wash turns dk brown, then brown, dk brown → produces sheen	
	85	NX2	66%	84.0 to 89.0	4.7		no odor HNU bkgrd - 0 response; NR 79.8 – ~80.8 wx & frac zone (measured from top of run) FeO heavy staining ~80.8 black soft wx rock → core loss ~83.1-88.2 measured from bottom of run wx & frac zone heavy FeO & MnO coating	
	90						most core loss begins @ 79.8 84.3 open jt MnO FeO CaCO3 coated 70° to core axis 85.0 open jt FeO CaCO3 coated 70° to core axis 85.9 jt CaCO3 coated 60° to core axis 88.2 jt CaCO3 coated 80° to core axis	
	95							
	100						79.0 – 79.6 CaCO3 filled frac. zone 82.0 – 84.0 " " "	
	105						79.0 – pink & gray m. grained granodiorite	
	110						Spin NW to 81.0	

1812 (1/91)

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UC10

Project Uni First Site Woburn **BORING** UC10 Sh 5 of 8

Elev. Feet	Depth Feet	Sample Type & Number	Sample Blows per 6 in.	Sample Depth Range	Sample Rec.	Graphic Log	Sample Description	Equipment Installed
	85		RMD					
							roller bit to 89.5 after reaming thru casing	
	90	NQ 1	51%	89.5 to 94.0	4.5	grd	pink/gray m-f grained granodiorite jts. 0°-90° to core axis MnO, Fe O, CaCO3 coating, closely spaced ~vertical jts - vertical jt. to 94.4	
	95	NQ 2	100%	94.0 to 98.0	3.9	gbd	96.5 green-dk gray gabbro diorite f. grained calcite veining 97.8 f. grained pink granodiorite	
	100	NQ 3	84%	98.0 to 103.0	5.0	grd gbd	100.0 green-dk gray f. grained gabbro chlorite CaCO3 veining jts. 0°-90° to core axis, planar rough-smooth variable light MnO & FeO coating 100.8 SKS 45° core axis	
→	105	NQ 4	68%	103.0 to 108.0	5.0		103.9-104.1 Quartz vein 50°-80° to core axis 104.6-106.3 frac zone, jts 0°-80° to core axis, light FeO, calcite coating	
	110	NQ 5	60%	108.0 to 113.0	4.9		111.5-112.7 closely spaced ∩ jts 20° to core axis planar smooth SKS, purple coating FeO CaCO3	
	115	NQ 6	60%	113.0 to 118.0	5.1		114.6-115.8 closely spaced ∩ jts 10°-30° to core axis planar smooth light MnO coating	
5/19/87	120	NQ 7	66%	118.0 to 123.0	5.0		119.3-119.8 same as above 120.3-120.5 "	
	125	NQ 8	74%	123.0 TO 128.0	4.6'		124.3-124.6 same as above 126.0-126.4 jt 20° to core axis wavey smooth light FeO, MnO & CaCO3 127.2-127.5 jt 30° to core axis planar smooth CaCO3 filled	

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UC 10

Project UniFirst Site Woburn **BORING UC10** Sh 6 of 8

Elev. Feet	Depth Feet	Sample Type & Number	Blows per 6 in.	Sample Depth Range	Rec.	Graphic Log	Sample Description	Equipment Installed
	125	NQ8		123 TO 128	4.6'		116.1 —	
						gbd	dk gray gabbro diorite <5% K spar	
	130	NQ9	100%	123 TO 130	7.4'	gbd	jts 20°-70° to core axis planar smooth	
		NQ10	67%	130 TO 133	3'		129.8 - 130.3 crs. grained pink & gray granodiorite	
	135	NQ11	84%	133 TO 138	5'		130.6 - 131.3 closely spaced ∩ jts. 10°-60° to core axis planar smooth to rough CaCO3 coated	
							134.2 - 137.1 closely spaced ∩ jts 0°-80° to core axis CaCO3 coated, FeO	
	140	NQ12	66%	138 TO 143	4.9 5	gbd	138.9 - 139.5 - ∩ jts 0° & 60° to core axis curved somewhat rough light CaCO3 FeO	
							140.6 - 141.1 ∩ jts 20°-80° to core axis CaCO3	
	145	NQ13	76%	143 TO 148	5.1 5		145.2 - 145.9, 146.5 - 147.0 ∩ jts 0°-60° to core axis planar to curved, smooth - rough CaCO3 light FeO	
	150	NQ14	94%	148 TO 153	5'		jts 40°-80° to core axis, light CaCO3	
							154.4 - 155.0 pink f. grai	
	155	NQ15	74%	153 TO 158	4.7'	gbd	155.0 - 155.7 open closely spaced ∩ jts 20°-60° to core axis FeO, light CaCO3	
	160	NQ16	86%	158 TO 163	4.9 5	gbd	159.4 - 160.1 f. grained pink granodiorite jts 40°-60° to core axis CaCO3, light chlorite ∩ sets w/in grd	
	165	NQ17	100%	163 TO 168	5		165.[illegible] jt planar smooth calcite coated 40° to core axis	

5/24/87

1012 (1/91)

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UC10

Project UniFirst Site Woburn **BORING** UC10 Sh 7 of 3

Elev. Feet	Depth Feet	Sample Type & Number	Blows per 6 in.	Sample Depth Range	Rec.	Graphic Log	Sample Description	Equipment Installed
	160		RQD					
						gbd		
	170	NQ 18	90%	168.0 to 173.0	5.0		174.0 168.7 - pink f. grained granodiorite jts 40°-80° to core axis planar smooth CaCO3 & chlorite coated.	
	175	NQ 19	100%	173.0 to 178.0	5.0	gbd	174.0 gray f-m grained granodiorite calcite veining <5% K spar inclusions	
	180	NQ 20	94%	178.0 to 183.0	4.9		179.4 – 179.9 jts 20° & 60° to core axis smooth & rough, light CaCO3 coating	
	185	NQ 21	98%	183.0 to 188.0	4.9		core breaks @ CaCO3 filled jts 40°-60° to core axis	
	190	NQ 22	100%	188.0 to 193.0	5.0			
	195	NQ 23	92%	193.0 to 198.0	[illegible]	grd gbd	194.4 – 195.2 pink & gray f-grained granodiorite 197.3 0.05 CaCO3 vein	
	200	NQ 24	98%	198.0 to 203.0	5.0	gbd & grd	198.3 – gray f-m grained gabbrodiorite and pink c. grained granodiorite 201.7-201.8 open jt, 60° to core axis calcite coated	
5/21/87	205	NQ 25	99%	203.0 to 208.0	5.0		decreasing granodiorite → <5% jts, tight CaCO3 & chlorite coated 30° & 70° to core axis	

1012 (1/91)

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UC10

Project UNIFIRST Site WOBURN **BORING** UC10 Sh 8 of 8

Elev. Feet	Depth Feet	Sample Type & Number	Sample Blows per 6 in.	Sample Depth Range	Sample Rec.	Graphic Log	Sample Description	Equipment Installed
	205		2000					
	210	NQ 26	97%	208.0 to 213.0	4.9	gbd	gray, m-f grained gabbro diorite calcite filled jts 40°-80° to core axis chlorite coated jts grd intrusions 210.6-210.7, 211.4-211.8 change bit	
	215	NQ 27	98%	213.0 to 218.0	5.0		213.8 jt 30° to core axis $CaCO_3$ & chlorite coating	
	220	NQ 28	98%	218.0 to 223.0	4.9	grd	220.4-222.5 $CaCO_3$ filled 0° jt.	
	225	NQ 29	78%	223.0 to 228.0	5.1	gbd	224.0 — 225.5 pink f. grained granodiorite core breaks along contacts & jts w/in granodiorite, $CaCO_3$ & chlorite 50°-80° to core axis, smooth, planar to wavy	
	230	NQ 30	98%	228.0 to 233.0	4.9		229.3 jt 80° to core axis planar smooth $CaCO_3$ & chlorite	
	235	NQ 31	100%	233.0 to 238.0	5.0		237.0-240.0 Calcite filled 0° frac. 0.03 wide, pyrite thickens to full ø of core & chlorite manifest 238-239.4	
	240	NQ 32	99%	238.0 to 243.0	5.1		242.0 2 closely spaced jts 90° & 80° to core axis	
	245	NQ 33	100%	243.0 243.5	0.5		243.5 END OF BORING	drill working in dry

1812 (1/81)

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UC10

Log of UC-23

Casing screwed down to 23 ft

Starting to log open bedrock at 25'

25	water produced By Drill	12:40	down hole 10-31-90	start	
27	Water discharge low	≈ 5gpm		12 45	
29	water discharge curve back			12 50	
31					
33					
35	NO CHANGE	13 15		1 Rod, 37 ft	
* 37		13 33			
39		13 30	≈ 5gpm		
41					
43					
45		14 00		47 ft	
47					
49					
51					

Log of UC-23

	Geology/Water		Time	Comments
53	No change	H_2O ≈ 5gpm		Reading on OVM 3.0 ppm limestone
	GD w/ basalt (?)		14 20	
55				
* 57			14 40	2nd Rod down
			14 50	OVM backgrd 3.6 ppm Rod 3 started
59	GD	≈ 6gpm	15 00	2.9 ≈ 3.0 OVM
61				
63				
65	GD	≈ 4gpm	15 05	2.9 ≈ 3 OVM
67				
69	GD	≈ 3 gpm	15 25	3.0 ppm OVM
71				
73				
75				

	GD	≈ 4.5gpm well prod.	16 00	3.0 ≈ 3.6 ppm OVM
★ 77	GD	≈ 3 gpm	16 05	3rd rod down
			16 10	Start of 4th Rod
	GD Flags getting smaller	≈ 3gpm	16 15	3.0 ≈ 3.6 ppm, OVM
79				
81				
83	GD	≈ 5gpm	16 42	3.0 ≈ 3.6 ppm OVM
85				
87	GD	≈ 5gpm	17 05	2.4 ≈ 3.0 ppm OVM
89				
91				
93	GD	≈ 5gpm	17 30	Charged OVM No Reading
95				
★ 97	GD	≈	17 50	END of Rod 4
			17 55	start of Rod 5
			18 05	Too Dark to see cuttings
99	GD	≈ 7gpm	18 20	900 ft.
101				
103				
105				
107	GD	≈ 7gpm	18 56	No OVM Reading.
109				
111	GD	≈ 8 gpm	19 17	No OVM Reading
113				
115	GD	≈ 8gpm	19 45	No OVM Reading Can half fully H_2O,
★ 117	GD	≈ 8 gpm	19 53	End of Rod 5
			20 00	Start of Rod 6
119				
121	GD	≈ 8 gpm	20 24	
123				
125				
127				

David G. Oliveira 10-31-10

128			2:15	Shut down Palace 10-31-90
129			11:00	Start drilling 11-1-90
130				
132				
134				
136				
* 137			12:00	END Rod 6 11-1-90
			12:05	Start Rod 7. 21.4 ft Rod
138				
140				
142				
144				
146				
148				
150				
151			13:45	
152	GD	≈ 8 gpm	13:55	

10

20:38 MEASURE DISCHARGE PIPE

DEP 11/1/90 21.5 / 18.0 [240 ft Dishare Line]

11/1 127 St morning Author of Notes M. Moore

water level in open hole at 8:BAM was ~~14.5~~ feet after pulling out the drill hammer. 18'11" ~~14.5~~ from ground surface

Bottom of borehole = ≈

Water sampled with point source bailer at 8:30. Put sample into 8 oz (4) jars, cover with foil, capped, agitated for 3 min. ~~Sam~~ Analyzed 2 ~~no~~ jars with OVM after agitation & got no response. The OVM before reading was 003.0 ppm, during the reading it dropped to 001.0 ppm. The next 2 jars were placed on a car defrost heater for 10 minutes and agitated further & analyzed with OVA and OVM with no reaction. The OVA & OVM were checked with CAL Gas and in the emissions of the truck and they showed a reaction in the 10's of ppm = 20 to 30 ppm

Then we checked the samples again and got no response from the OVM.

	Biology & lithology changes	H_2O gpm	Time	Comments
154	Diorite(?) Blk	≈ 8 gpm	14 00	Litho change Blk alt of clay/Ind ill + H_2O
156				
* 158 / 158.4 ft / 158.7		≈ 8 gpm	15 10 / 15 25	End of Rod 7 START of Rod 8
160	Granodiorite			
162	Blk GD w/ Leucosome Diorite(?)	≈ 8 gpm	15 55	Rx Appears to be fractured see calcite druzeiss.
164				
166				
168				
169		≈ 8 gpm	17 15	Too dark
170	Blk Gabro/Diorite Produces alot of gray clay	≈ 8 gpm	18 15 / 08 30	End Day 11-1-90 170 TOC Continue w/ Rod 8 11-2-90 hammer bit to 230 ft
172				
174				

Drilling to 230 ft

Continue drill to -- 230 ft when at depth sample. Tell Mike results. If results are clean then Grout from 230 to 225 ft and Volclay (Peanut Butter) to 210 ft. If clean close to 400 ft. Sample. END of hole.

5 ft

15 ft of Volclay

If Sample is Dirty at 230 drill on 260 sample and let sit till morning, and sample again.

Letting Mike know all results.

12 ft

Rod # 7 is 21 ft 4 in Long. Adjust accordingly.

Volclay grout round hole

		H2O out	Time	Comments
176				
178	Gabro Diorite		09 15	END of Rod 8
			09 20	START of Rod 9
*178.4				
180				
182				
184				
186	Gabro w/ talcite cutting	≈ 9gpm	10 55	Not Monitoring OVM broken
188				
188.4				
190				
192				
194				
196				
198	GD/Gabro Diorite w/ $CaCO_3$ & Epidote	≈ 9gpm	12 40	≈ 198 ft End of Rod 9
*198.4			12 45	START of Rod 10
200				

		H2O out	Time	Comments
202				
204				
206	GD/Gabro Diorite	≈ 10gpm	14 05	Lithology includes Epidote/$CaCO_3$
			14 52	drilling H2O changes color from gray to DK Tan
208	GD/Gabro Diorite	≈ 8gpm	15 15	EVIRT Fnds 3 min. Latter
209.4				11-2-90 END of drilling Day
			09 00	Start of 11-5-90
210				
		≈ 80+gpm	09 30	Hit Fracture Zone
			12 15	well producing clear of H2O stop drilling to pump down.
212				
214				→ Resume drilling
	DG Gabro Diorite Mix	≈ 100gpm	12 35	drilling is getting
216				quicker.
218	SAME	≈ 100+	13 10	DG Gabrodiorite
			13 18	Mix is More
*219.4				FINE grained
220			14 15	→ End of Rod 9 start of Rod 10
222				
224				
	Same	≈ 100+	15 00	stop drilling for today
226			07 45	11-5-90 START 11-6-90

	172.0			
228				
229.4				
230 sample	Same	≈ 100+	0830	End of 10in hole. 11-6-90
			1120	start Gin Hammer. Will drill to 260: 11-8-90
232	(?)	≈ 80+gpm	1130	Started to produce good H_2O
234				
236		≈ 70gpm		Started to produce more H_2O
238				
* 239.4		≈ 100gpm	1140	Producing much more water stopped drilling.
240				drill string dropped from 236 to 239 Large Fracture.
242			1145	Resumed drilling
244				
246				
248				
250				
252				

Sample Any Time for Conv:

- When tooled out.
- In Morning Before drilling.
- Sample in

18[00] Samples taken UC-23 at 170 ft w/ Point Source Bailer (4) Jar filled half way w/ water.

18[30] Sound of Rushing water down hole, MADE US Investigate. Just below 10in Casing at ≈ 27 ft water was flowing into well at roughly 2.5 gpm.

18[45] Heating samples taken at 170ft. on the Night of 11-1-90 Thursday. w/ Point Source Bailer Will take Measurements ~~at~~ w/ OVA. → OVER

ENSR

BORING LOG

Project No. 3140-016 Date - Start 9/22/92 Finish _____ Boring UC10D

Project Name UniFirst /Cummings Drilling Co. D.L. Maher

Location Woburn, Ma. Drilling Method Air Rotary

Total Depth _____ Inspector T. Rice Reviewer _____

Remarks _____

Depth Feet	Sample: Type & No.	Sample: Blows per 6 in.	Sample: Depth Range	Sample: Rec.	Graphic Log	Lithologic Description	Equipment Installed
						Tan fine SAND, some silt	
5							
10						Tan fine to coarse SAND, some silt	
15						Gray medium SAND, little silt and gravel	
20							
						Gray/Tan fine SAND and silt	
25						Gray SILT, some fine sand, trace of clay	
30							
35						Gray SILT Rock Fragments	
40							

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BORING LOG (continued)

Project UniFirst Boring VC 10D Sheet 2 of 2

Depth Feet	Sample Type & No.	Blows per 6 In.	Depth Range	Rec.	Graphic Log	Lithologic Description	Equipment Installed
40						Gray/Tan fine to coarse SAND, Some silt, rock fragments	
45'							
50'							
55'							
60'						Fine to coarse SAND, with many rock fragments	
65'							
70'							
						EOB 72'	
75'							

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Project UNITERST Site WOE IRA **BORING** UC15 Sh 1 of ___

Date Started 9/29/92 Completed 9/25/92 Ground Elevation ___

Total Depth 79.0 ft Location ___ Logged by J. T. Lawson

Casing I.D. 6 in Contractor D.L. Maney; John Bowman Driver

Remarks Source advanced with a Barber air-rotary rig; no samples taken; boring left cased and locking head secured in a road box

Elev. Feet	Depth Feet	Sample: Type & Number	Sample: Blows per 6 In.	Sample: Depth Range	Sample: Rec.	Graphic Log	Sample Description	Equipment Installed
							cuttings dry	
	20							
	40							
							Top of Rock 51 ft casing installed to 54 ft 51 - 53.5 several soft zones [illegible] thick, rapid casing advance; boulders or fractured and weathered rock blow out well at 71 ft; < 1 [illegible] drill to 79 ft, blow out well, no [illegible]	
	60							
	80						Bottom of Boring 79.0 ft All rock cuttings are pink granodiorite and occasional dark gray gabbrodiorite	

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UC15

BORING UC 1b

Project UNITEST Site WOBURN Sh 1 of 1

Date Started 9/30/88 Completed 9/30/88 Ground Elevation

Total Depth 28.4 Location Logged by J. T. Lawson

Casing I.D. 6 inch Contractor D.L. Maher; John Bowen driller

Remarks boring advanced with a Barber air-rotary rig; no samples taken; boring left cased and open; head secured in a road box

Elev. Feet	Depth Feet	Sample Type & Number	Sample Blows per 6 in.	Sample Depth Range	Sample Rec.	Graphic Log	Sample Description	Equipment Installed
							0.0-0.2 bituminous concrete 3-4 ft pink granodiorite boulder; very hard drilling; pull casing back to inspect shoe; shoe ok 6-6.5 ft dark gray gabbrodiorite boulder	
	5							
							Top of Rock 8 ft 9 ft inject water to control dust 9.5 ft minor << 1 gpm water return 8-10.5 ft casing advances quickly; ⇒ broken/weathered rock water injected throughout rock drilling to control dust; <40 gallons injected finished hole blown out; negligible water return casing installed to 11 ft All rock cuttings are pink granodiorite and occasional dark gray gabbrodiorite	
	10							
	15							
	20							
	25							
	30						Bottom of Boring 28.4 ft	

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UC1b

Project UNITERST Site Wrbuch **BORING** UC17 Sh 1 of 1

Date Started 10/1/87 Completed 10/1/87 Ground Elevation

Total Depth 30.0 ft Location Logged by J.T. Lawson

Casing I.D. 6 in Contractor D.L. Maher; John Bower Driller

Remarks boring advanced with a Barber air rotary; no samples taken; boring left cased and open; head secured in road box

Elev. Feet	Depth Feet	Sample Type & Number	Sample Blows per 6 in.	Sample Depth Range	Sample Rec.	Graphic Log	Sample Description	Equipment Installed
							0.0-0.2 Bituminous concrete	
							3-4 ft pink granodiorite boulder inject water	
	5						6.5-8.5 dark gray gabbro diorite boulder	
	10						Top of Rock 9.0 ft	
							Casing installed to 11.7 ft	
							All rock cuttings pink granodiorite	
	15							
	20							
	25							
	30						Bottom of Boring 30.0 ft	

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UC17

Project UNITEIRST Site WOBURN **BORING** UC18 Sh 1 of 1

Date Started 10/2/87 Completed 10/2/87 Ground Elevation

Total Depth 33.0 ft Location Logged by J. T. Lawson

Casing I.D. 6 in Contractor D.L. Maher; John Bowen driller

Remarks boring advanced with a Barber air-rotary rig; no samples taken; boring left open and cased; head secured in a road box

Elev. Feet	Depth Feet	Sample Type & Number	Sample Blows per 6 in.	Sample Depth Range	Sample Rec.	Graphic Log	Sample Description	Equipment Installed
							0.0 - 0.2 Bituminous Concrete rapid casing advance	
	5						7.5 - 8.5 boulders rapid casing advance	
	10						Top of Rock 10.5 ft install casing to 13.4 ft	
	15						rock cuttings predominantly gray granodiorite to 20 ft pink granodiorite to end of boring	
	20							
	25							
	30							
							End of Boring 33.0 ft	

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Project UNITEST Site Woburn **BORING** JC19 Sh 1 of 1

Date Started 10/5/87 Completed 10/5/87 Ground Elevation

Total Depth 58.6 ft Location Logged by J. Lewis

Casing I.D. 6 in. Contractor D.L. Maher; Jon Bauer

Remarks boring advanced with a Barber air-rotary rig; no samples taken; boring left cased and open; head secured in a road box

Elev. Feet	Depth Feet	Sample: Type & Number	Sample: Blows per 6 in.	Sample: Depth Range	Sample: Rec.	Graphic Log	Sample Description	Equipment Installed
							0.0 - 0.2 Bituminous Concrete	
							~7 ft dark brown, medium to fine SAND, some silt, trace roots and twigs; old top soil	
	10						16.0 - 16.5 boulder	
	20							
	30						32.0 - 32.8 boulder	
	40						Top of Rock 37.5 rock cuttings dark gray granodiorite 39.0 ft inject water install casing to 40.3 ft	
	50						~45 pink granodiorite to ~50 dark gray granodiorite to end of boring ~53 water produced	
	60						End of Boring 58.6 ft Blow out well at 58.6 ft produced ~2 gpm for < 2 min. and << 1 gpm thereafter	

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JC19

ENSR

Sheet 1 of

Project No. 3140-016 Date - Start 9/22/92 Finish 9/22/92 Boring UC19M

Project Name Unifirst / Cummings Drilling Co. D.L. Maher

Location Woburn, ma. Drilling Method Air Rotary

Total Depth 33' Inspector T. Rice Reviewer

Remarks

39.2
11.9
25.4

Depth Feet	Sample Type & No.	Blows per 6 In.	Depth Range	Rec.	Graphic Log	Lithologic Description	Equipment Installed
						Fine Tan/Brown SAND and Gravel some silt	
5'						Tan/Brown Medium SAND, some gravel	
10'							
15'							
						Gray Fine SAND and silt, some gravel	
20'						Gray Coarse SAND and Gravel	
25'						Gray fine SAND and SILT, trace of clay	
30'						Gray SILT, some clay and gravel	
35'						Medium Gray SAND and Silt, some gravel. Rock Fragments	

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DIGITIZED

Project UNIFIRST Site WOBURN **BORING** UC20 Sh 1 of 1

Date Started 10/6/87 Completed 10/6/87 Ground Elevation

Total Depth 27.0 ft Location Logged by J. T. Lawson

Casing I.D. 6 in. Contractor D.L. Maher; John Bown Driller

Remarks boring advance with a Barber air-rotary rig; no samples taken; boring left cased and open; head secured in a road box

Elev. Feet	Depth Feet	Sample Type & Number	Sample Blows per 6 in.	Sample Depth Range	Sample Rec.	Graphic Log	Sample Description	Equipment Installed
							0.0 - 0.1 Bituminous Concrete	
	5							
							Top of Rock 6.3 ft rock cuttings dark gray gabbrodiorite to 7.0 ft pink and gray granodiorite install casing to 8.0 ft inject water at 8.0 ft well blown out at 27 ft << 1 gpm produced	
	10							
	15							
	20							
	25							
							Bottom of Boring 27.0 ft	
	30							

UC20

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UC22

BORING [redacted] Sh 1 of 2

Project UNITEST Site Woburn

Date Started 1/12/88 Completed 1/13/88 Ground Elevation

Total Depth 190' Location Fence line north east Logged by Wm. Henderson

Casing I.D. 8in Contractor D.L. Maher

Remarks Barber Air Rotary Down-the-hole hammer

Elev. Feet	Depth Feet	Sample Type & Number	Sample Blows per 6 in.	Sample Depth Range	Sample Rec.	Graphic Log	Sample Description	Equipment Installed
							UC9 bedrock 10.1	
							brown Sand fill	
5								0.0
							Bedrock 9'	
10							Start diorite grey water injection	0.0
15							-15' casing depth	0.0
							gabbro diorite alternating layers	
20								0.0
1/12/88 25								0.0
							end 1st day (27')	
1/13/88 30								
35								

1911 (1/81)

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Project Unifirst Site Woburn **BORING** 1022 Sh 2 of 2

Date Started 1/12/88 Completed 1/13/88 Ground Elevation

Total Depth 190' Location Logged by Uni Henderson

Casing I.D. 8" Contractor D.L. Maher

Remarks

Elev. Feet	Depth Feet	Sample Type & Number	Sample Blows per 6 In.	Sample Depth Range	Sample Rec.	Graphic Log	Sample Description	Equipment Installed
180								
185								
							E.O.B.	
190							Note: total depth 190', casing driven to 15', bedrock encountered at 9', water injection started at 9'	

1911 (1/81)

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BORING LOG

ENSR

Sheet 1 of 1

Project No. _____ Date - Start 9/22/92 Finish 9/22/92 Boring UC24D

Project Name Unifirst Drilling Co. DL MAHER

Location Woburn, MA Drilling Method Air Rotary 6" Casing

Total Depth _____ Inspector J. Powers Reviewer J. Powers

Remarks 9/22 - ENSR/DL MAHER on-site 07:00 2 Drillers, 2 Helpers Franklin - 3 Lab Tom Rice, James Powers. Complete UC24S (cleanup) 8:00 Begin boring UC24D

Depth Feet	Sample Type & No.	Blows per 6 in.	Depth Range	Rec.	OVA ~~PID~~ readings	Lithologic Description	Water Table
					0-7'	tan fine sand, some gravel and silt	
5							
					7'-10'	tan f-c sand and gravel some rx frags. (Boulder?) silt	
10					10'-23'	tan f-c. sand and gravel some silt	
					23'-40'	Gray fine sand + silt, some gravel	
15							
					~27'	encounter gray to black slight sheen in cuttings o Deflection of OVA (Rx flour?)	slight sheen (flurs) on cuttings water
20							
					40'-45'	Gray fine sand + silt, trace gravel	
25							
					45'-47'	Boulder (same) rx frags	
					47'-57'	Gray fine sand + silt, some gravel, rx frags	
30					57'3" -62'	Bedrock - frags (Gabbro Diorite)	
35						EOB 62' Bedrock Surface 57'3"	

DRAFT

BORING LOG

ENSR

Sheet 1 of 1

Project No. _____ Date - Start 9/23/92 Finish 9/23/92 Boring UC25

Project Name Uniform First Drilling Co. DL MAHER

Location Woburn MA Drilling Method 6" Cased Air Rotary

Total Depth _____ Inspector JP Reviewer JP

Remarks _____

Depth Feet	Sample Type & No.	Sample Blows per 6 in.	Sample Depth Range	Sample Rec.	PID readings	Lithologic Description	Water Table
					0'-7'	3" Asphalt brown f-m sand, some silt and gravel, some Rx frags	
5					7'-16'	tan f-m sand, some gravel and Rx frags, some silt	
10					16'-17.5'	tan f-c sand, some gravel + Rx frags	
					17.5-18.4	gray f sand + silt, trace gravel - Bottom fragments Gabbrodiorite	
15							
20						Bedrock 18.4'	
25							
30							
35							

DRAFT

BORING LOG

ENSR

Sheet 1 of 1

Project No. 05.01 Date - Start 12/1/93 Finish 12/3/93 Boring UC26D

Project Name Unifirst/UCD RD/RA Drilling Co. D.L. Maher

Location Unifirst site property Drilling Method 4¼" HSA

Total Depth 35' Inspector J. Howe Reviewer J. Powers

Remarks weather - clear 40°

* hit refusal at 10', assumed cobble - moved west 5', continue logging on same sheet

Depth Feet	Sample Type & No.	Blows per 6 in.	Depth Range	Rec.	OVA ppm	Lithologic Description	Equipment Installed
	S-1	21-30-21-20	0-2'	8"	0.0	5.5" concrete 8" Fill - f-m SAND, some gravel, cobbles DRY	
5'	S-2	8-11-18-100 for 4"	5-7'	18"	0.0	H. tan m SAND, trace cobbles and silt DRY refusal - assumed cobble	
Refusal * 10'	S-3	25-100 for 5"	10-12'	1"	0.0	brown m-c SAND some gravel moist, silt [illegible]	
15'	S-4	41-47-40-39	15-17'	16"	0.0	brown m/c SAND, some gravel, rock frags WET ~18' increased amount of large cobbles	
20'	S-5	100 for 5"	20-22'	5"	1.1 Background 0.4	3" grey f/m sand, some silt, cobbles WET 2" brown m/c SAND, some cobbles refusal on cobble	
25'	S-6	21-27-100 for 0"	25-27'	8"	2.2 0.6 backgr.	Basal till. grey silty f. SAND, trace gravel WET dense	
auger refusal start coring							
30						~29' 7" of boulder cored thru	
	S-7	from bottom of core	~29-31	24"	0.0	basal till, very dense grey silty f. SAND, cobbles WET	
	S-8	34-67-34-72	30-32'	21"	0.8	Same	
	S-9	30-53-50-96	33-35	20"	0.0	Same lodgement till	
35						EOB 35'	

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BORING LOG

Sheet 1 of 1

Project No. 01.03 Date - Start 12/3/93 Finish 12/6/93 Boring VC27

Project Name Unifirst UCD RD/RA Drilling Co. DL Maher

Location Unifirst Site Property Drilling Method 4 1/4" HSA

Total Depth 12.5' Inspector J. Wiseman Reviewer J. Hoste

Remarks 3" Split Spoon

Background: 0 ppm

Depth Feet	Sample Type & No.	Blows per 6 In.	Depth Range	Rec.	OVM ~~Graphic Log~~ PPM	Lithologic Description	Equipment Installed
	S-1	7-10-10-10	0-2'	20"	2.8	vegetated top soil - roots FILL - dark brown f/m SAND some cobbles MOIST	
	S-2	9-22-19-17	2-4'	9"	15.0	Same FILL	
5	S-3	10-13-17-50	4-6'	10"	87.4	concrete, same FILL	Sample C275 14:0
	S-4	23-35-29-30	6-8'	16"	38.7	brown f/m SAND, some gravel, trace cobbles MOIST	
10	S-5	23-25-50-68	8-10	12"	27.9	brown m SAND and GRAVEL, trace cobbles, mottling MOIST	
	S-6	11-27-40-44	10-12	20"	96.0	Same, moist	C276 14:35
	S-7	100 for 0"	12-14	5"	53.9	Auger material - gray silty SAND, some m sand + gravel	
						Auger refusal 12.5'	
15							
20							

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BORING LOG

Sheet 1 of 1

Project No. 01 03 Date - Start 12/6/93 Finish 12/7/93 Boring VC28

Project Name Unifirst/UCD RI/RA Drilling Co. D. L. Maher

Location Wells G+H, Woburn, MA Drilling Method 4 1/4" HSA

Total Depth _____ Inspector J. Howe Reviewer J. Powers

Remarks background 1.7 ppm

Depth Feet	Sample Type & No.	Blows per 6 In.	Depth Range	Rec.	DVM ~~Graphic Log~~ PPM	Lithologic Description	Equipment Installed
	S-1	5-10-18-17	0-2'	10"	1.7	FILL - asphalt, black tar-like material, concrete cobbles brown m SAND some cobbles, moist	10:0 C281
	S-2	7-6-8-6	2-4'	15"	1.0	reddish-brown m SAND, some fill-dark brown m sand with some black tar and asphalt moist	
5	S-3	13-31-36-25	4-6'	17"	0.0	brown f-m SAND and Gravel, some cobbles, trace rock frags. moist	
	S-4	20-28-27-27	6-8'	20"	1.0	same	S-4 C284 10:50
	S-5	15-37-100 for 4"	8-10'	12"	0.1	brown f-m SAND, trace silt + gravel, mottling moist	
10	S-6	19-77-100 for 0"	10-12'	8"	0.0	same	
						auger refusal 11.5'	
15							

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BORING LOG

Sheet 1 of 1

Project No. 05.01 Date - Start 12/7/93 Finish 12/8/93 Boring UC29D

Project Name Unifirst/UCM RD/RA Drilling Co. D.L. Maher

Location Wells G+H, Woburn, on-site Drilling Method 4¼" HSA

Total Depth 25' Inspector J. Howe Reviewer J. Powers

Remarks Background = 4 ppm

Refusal 5-8, gravel in shoe - Auger to 25' BGS, boring Complete.

Depth Feet	Sample Type & No.	Blows per 6 In.	Depth Range	Rec.	OVM Graphic Log ppm	Lithologic Description	Equipment Installed
	S-1	9-17-17-23	0-2'	10"	2.0	6" pavement Fill - brown m sand some gravel, asphalt	0-2' 29D1A 13:30
	S-2	24-52-33-25	2-4'	15"	0.0	same	2-4' 29D3A 14:00
5	S-3	20-24-46-25	4-6'	8.5"	0.0	same - fill	
	S-4	2-4-6-8	6-8'	19"	2.5	Brown fine Sand, trace silt, some mottling, moist	
	S-5	11-19-36-50	8-10'	16"	0.7	6" same brown m SAND, some gravel, trace cobbles WET mottled	8-10 29D5A 14:10 29D5G
10							
15	S-6	26-38-30-30	15-17'	4"	0.0	brown-gray f-m SAND, some c sand + gravel WET	
20	S-7	20-33-28-100 for 5"	20-22'	12"		brown f-m SAND, some c and f sand and gravel very wet	
	S-8	100 for 2"	23-25'	2"		refusal due to gravel Gray Fine SAND and SILT, some gravel, trace weathered Rx	
25						EOB at 25'	

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BORING LOG

Sheet 1 of 1

Project No. 05.01 Date - Start 12/8/93 Finish 12/9/93 Boring UC30

Project Name Unifirst/UCD RDRA Drilling Co. D.L. Maher

Location Unifirst Site Property Drilling Method 4¼" HSA

Total Depth _____ Inspector J. Howe Reviewer J. Powers

Remarks No background reading from OVM

NQ size core water encountered - silty grey

* This log represents the first boring - UC30 is installed in a boring 3' west, to a depth of 15'
This boring was grouted to surface

Depth Feet	Sample Type & No.	Blows per 6 In.	Depth Range	Rec.	OVM ~~Graphic Log~~ PPM	Lithologic Description	Equipment Installed	Sample for VOC's
	S-1	4-15-40-80	0-2'	15"	0.0	3" pavement FILL - brown m SAND some cobbles and gravel, asphalt, Dry		S-1 C301 14:3
	S-2	15-40-25-26	2-4'	17"	0.0	Brown f-m SAND, some coarse sand, trace gravel, and cobbles - fill, Dry		
5	S-3	32-21-16-29	4-6'	16"	9.7	same, dry		S-3 C303 14:5
	S-4	13-20-27-38	6-8'	18"	2.0	brown f-m SAND, some c. sand, trace gravel slightly moist		
	S-5	28-51-100 for 3"	8-10'	10"	3.1	brown f-m SAND, trace silt and gravel, dry		S-5 C305 16:0
10	S-6	14-21-22-25	10-12'	17"	0.9	brown f-m SAND, trace silt and gravel with pockets of dark brown f. sand, some m. sand - FILL dry		
FILL	S-7	24-43-100 for 0"	12-14'	12"	0.0	brown m SAND, some gravel, trace cobbles, moist		S-7 C307A 15:20
15	S-8		14-16'			Grinding on rock - no sample		
	RUN 1	RQD = 72.7%	15.5-19.5'	3.2'	0.0	15.5-16.4' pink c.grain GRANODIORITE, BR., fresh, low angle frac. trace f sand in fractures 16.4-17.0' gray/pink, f-m grained GABBRODIORITE, BR-V.BR., slightly weathered, low angle fractures, sharp contacts 17.0-19.5' pink c.grained GRANODIORITE, same		
20						EOB at 19.5'		

BORING LOG

ENSR

Project No. 05.01 Date - Start 10/13/93 Finish _____ Boring UC31D

Project Name Unifirst/VCS RI/RA Drilling Co. D. L. Maher

Location Wells G+H Site Woburn, MA Drilling Method 4 1/4" HSA

Total Depth _____ Inspector J. Howe Reviewer J. Powers

Remarks UC31M was intended to be the deep well, hence the first 35' are logged on the UC31M boring and from 40' on appear on UC31D

Depth Feet	Sample Type & No.	Sample Blows per 6 In.	Sample Depth Range	Sample Rec.	Graphic Log	Lithologic Description	Equipment Installed
5							
10							
						SEE UC31M FOR FIRST 35'	
15							
20							
25							
30							
35							

BORING LOG (continued)

ENSR Project Unifirst/UCD RD/RA Boring UC31D Sheet 2 of 2

Depth Feet	Sample Type & No.	Blows per 6 In.	Depth Range	Rec.	OVM ~~Graphic Log~~ ppm	Lithologic Description	Equipment Installed
	S-1	37-75-40-68	40-42'	8"	0.0	Grey fine SAND. Some silt and m sand, trace gravel - WET	
45	S-2	85-85-100 for 2"	45-47'	12"	6.8	Same	
50	S-3	36-100 for 5"	50-52'	10"	9.6	Same. more dense	
						EOB 52'	
55							

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BORING LOG

Sheet 1 of 1

Project No. 05.01 Date - Start 12/10/93 Finish 12/10/93 Boring UC 31M

Project Name Unifirst/UCD RD/RA Drilling Co. D. C. Maher

Location Wells G+H, Woburn MA, Unifirst Site Drilling Method 4 1/4" HSA

Total Depth 35.5' Inspector J. Howe Reviewer J. Powers

Remarks Background Reading = 0.0 ppm

Depth Feet	Sample Type & No.	Blows per 6 In.	Depth Range	Rec.	OVM ~~Graphic Log~~ ppm	Lithologic Description	Equipment Installed
	S-1	4-7-11-16	0-2'	10"	0.0	FILL - f SAND and SILT, some gravel, Dry	
5	S-2	8-26-41-53	5-7'	8"	0.0	2" Same 6" orange/brown, f SAND and SILT	
10	S-3	13-35-41-43	10-12'	14"	0.0	2" brown m SAND, some coarse, trace gravel, wet 12" m SAND, some c. sand, gravel and cobbles, mottled	
15	S-4	15-31-42-51	15-17'	18"	0.0	Running Sands - m SAND, some coarse, trace gravel V. WET	▼
20	S-5	35-75-50-80	20-22'	20"	0.0	Grey Fill - f-m SAND, trace gravel, damp, wet	
25	S-6	45-77-80-80	25-27'	12"	0.0	Same - very wet	
30	S-7	30-60-100 for 4"	30-32'	13"	0.0	Same	
35	S-8	40-100 for 0"	35-36'	6"	0.0	Same increasing fine	
						EOB at 35.5' Refusal	

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BORING LOG

Sheet 1 of 1

Project No. 01-03 Date - Start 8/29/94 Finish 4/1/94 Boring UC32

Project Name Unifirst UCD Drilling Co. Guild

Location Wells G+H Site, Woburn, MA Drilling Method Drive & Wash

Total Depth 9.0' Inspector J. Howe Reviewer

Remarks Background: 0.0-0.2 ppm

300lb. hammer Size NV2 core

Depth Feet	Sample Type & No.	Blows per 6 In.	Depth Range	Rec.	Graphic Log	Lithologic Description	Equipment Installed
			0-.4'		1.5	concrete	
	S-1	21-44-42	.5-2'	.7'	3.4	Brown f-m SAND some gravel	
	S-2	32-57-65	2-3.5'	1'	2.0		
	S-3	20-31-35-37	3.5-5.5	1.5'	6.1	Brown f-m SAND, trace coarse sand and gravel	
	S-4	57-185-65 for .3'	5.5-6.8	.8'	3.7		
	~~NV2-2~~ NV2-1	RQD 100%	7.0-8.5'	1.4'	2.0	pink m grained Granodiorite, fresh (2), blocky trace silt in fractures ~ 7.5', fractures 45-90°	
	NV2-2	NA	8.5-9'	.15'	1.5	same pink m grain Granodiorite	
						EOB 9'	

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Project No. 01.0yr 3 Date - Start 4/4/94 Finish 4/6/94 Boring UC33

Project Name Unifirst Property Investigation Drilling Co. Guild

Location Wells G+H Site, Woburn, MA Drilling Method Wash & Drive

Total Depth 15' Inspector J. Howe Reviewer

Remarks* using 300lb. hammer dropping about 1'

background reading w/OVM: 0.4-0.5

☆ = sample

Depth Feet	Sample Type & No.	Blows per 6 In. *	Depth Range	Rec.	OVM Graphic Log PPM	Lithologic Description	Equipment Installed
	S-1	100-100-100	.5-2.0	1.4'	3.2	6" concrete. Fill brown f-m SAND some gravel, rx frags.	21:20 C331 470.9
☆	S-2	102-98-100	2-3.5	1.5'	2.3	Fill brown f-m SAND some gravel and rock frags angular to subrounded 2 cm - 3"	
5	S-3	39-43-49-47	3.5-5.5	1.0'	5.2	Same	09:3
☆	S-4	67-75-81-52	5.5-7.5	.9'	4.4	Same, wet, mottled	C332 467.1
	S-5	62-71-84	7.5-9.0	1.0'	3.7	Same, wet, mottled	21:00 C333 466.1
10 ☆	S-6	72-103-127	9-10.5	1.2'	0.6	brown f-m SAND, trace coarse sand and gravel rx frags. angular, wet	
☆	S-7	57-62 for 3"	10.5-11.25'	.6'	26.0	Same	21:45 C334 465.9
	NX2-1	RQD 100%	12'-15'	2.7'	0.2	Pink medium grained monzonite, fresh rock, blocky trace silt in fractures ~2.15', 45°, calcite 1.25'-2.65' qtz veins	
						EOB 15'	

M890278

BORING LOG

ENSR

Sheet 1 of 1

Project No. 01.03 Date - Start 4/6/94 Finish 4/8/94 Boring UC34

Project Name Unifirst UCD Drilling Co. Guild

Location Wells G+H Woburn, MA Drilling Method Drive & Wash

Total Depth 17' Inspector J. Howe Reviewer

Remarks 300lb hammer

core size NV2, losing water while coring

Depth Feet	Sample Type & No.	Blows per 6 In.	Depth Range	Rec.	OVM Graphic ~~Log~~ PPM	Lithologic Description	Equipment Installed
					1.2	.2' concrete .46' c. sand for drainage	
						2.9' second layer concrete (staircase)	
	S-1	13-18-22	3-4.5'	1.2'	69	Grayish-Brown f-m SAND trace gravel and c. sand	
						Orange-Brown f SAND, some m sand, trace silt and gravel	
	S-2	22-27-38	4.5-6'	.9'	9.2	Buff, f-m SAND with trace f sand and silt, well sorted	
	S-3	19-26-22-28	6-8'	.7'	1.3	Grey-Brown f-m SAND trace gravel and sub-angular rx frags, mottled	
						Boulder	
	S-4	31-38-34-41	9-11'	.8'	2.2	Brown f-m SAND, trace c. Sand and gravel, sub-angular rx frags. .5-2"	
	S-5	27-52-61-100 for 4"	11-12.9'	1.2'	1.0		
	NV2-1	RQD 63%	13-17'	3.5'	1.2	EOB JH Pink m grained Granodiorite, top 6" weathered and v. Broken. Rest is broken and fresh, low angle fractures at 14'4", 14'9", 15'6" with calcite and silt, 45° fracture at 15'10"	
						EOB 17'	

M890278

Project UNIFIRST Site Woburn **BORING** VB-1 (B-5) Sh 1 of 1

Date Started 2/23/89 Completed 2/23/89 Ground Elevation

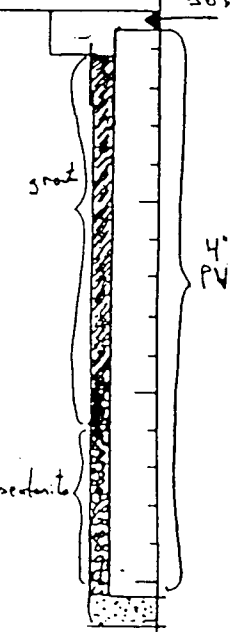
Total Depth 3' 3" Location Logged by Larry Pannell

Casing I.D. 4" PVC Contractor SOIL EX

Remarks

6¼" HSA installed 3' of 4" PVC

Elev. Feet	Depth Feet	Sample Type & Number	Sample Blows per 6 In.	Sample Depth Range	Sample Rec.	Graphic Log	Sample Description	Equipment Installed
							3" asphalt soil immediately beneath asphalt registered 60 on TIP.	road box grout 4" PV
1		SS-1	28-11 17-19	3"-2'3"	16"		Poorly sorted, light brown SAND, mostly fine-medium; trace coarse, some gravel	
2								
		SS-2	18-17 100/0	2'3"- 3'3"	6"		Poorly sorted light brown SAND; fine-coarse, trace very coarse, trace gravel. Refusal at 3'3"	bentonite
3								



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1911 (1/81)

Project UNIFIRST Site WOBURN **BORING** VB-2(B-17) Sh 1 of 1

Date Started 2/23/89 Completed 2/23/89 Ground Elevation

Total Depth 5' 5" Location Logged by Larry Pannell

Casing I.D. 4" Contractor SOIL EX

Remarks

6 1/4 HSA installed 4' 8" of 4" PVC pipe

Elev. Feet	Depth Feet	Sample Type & Number	Blows per 6 In.	Depth Range	Rec.	Graphic Log	Sample Description	Equipment Installed
							3" asphalt. soil directly beneath asphalt registered 5.7 on TIP	road box
1		SS-1	11-23 31-19	3"-2'3"	16"		poorly sorted brown SAND; fine - coarse, mostly medium; some gravel.	grout
2								
3		SS-2	17-30 41-47	2' 3"- 4' 3"	11"		8" Tan poorly sorted SAND; fine - coarse, some gravel over 3" brown SAND; fine - coarse, mostly fine-medium, some gravel.	bentonite
4								
5		SS-3	43-69 100/0	4' 3"- 5' 3"	10"		tan SAND; very fine - coarse, mostly v. fine - fine, Some gravel, trace weathered bedrock Refusal at 5' 3" Augered ~ 2" into bedrock. Finished hole at 5' 5". Set pipe at 5' 0".	11.5"

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1811 (1/8)

Project UNIFIRST Site WOBURN **BORING** VB-3 (B-7) Sh 1 of 1

Date Started 2/23/89 Completed 2/23/89 Ground Elevation

Total Depth 13' Location Logged by Larry Pannell

Casing I.D. 4" PVC Contractor Soil Ex

Remarks

6 1/4 HSA installed 10' of 4" PVC pipe

Elev. Feet	Depth Feet	Sample Type & Number	Blows per 6 In.	Depth Range	Rec.	Graphic Log	Sample Description	Equipment Installed
							3" asphalt	road box
		SS-1	23-11 17-28	3" - 2'3"	12"		Soil directly beneath asphalt registered 0.2 on TIP. Poorly sorted light brown SAND. v-fine - v. coarse, mostly med-coarse; some gravel.	
2								grout
		SS-2	29-38 46-50	2'3" - 4'3"	14"		light gray SAND; v-fine - v-coarse, mostly fine - coarse; some gravel	
4								
		SS-3	31-48 63-79/3"	4'3" - 6'0"	10"		" augered through refusal at 6'	
6							no sample from 6'-8'	
8		SS-4	7-9 9-11	8'-10'	18"		light gray-tan SAND. Fine - Coarse; trace gravel.	bentonite
10		SS-5	11-12 12-11	10'-12'	13"		"	
12		SS-6	15-18 100/0"	12'-13'	12"	▽	light gray-tan SAND. v-fine - Coarse; trace silt, some gravel. Water at ~ 12'.	
14							note: pipe set at just over 10'	

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1911 (1/81)

Project UNIFIRST Site WOBURN **BORING** VB-4 Sh 1 of 1

Date Started 3/7/89 Completed 3/7/89 Ground Elevation

Total Depth 3' 8" Location Old Test pit Logged by Larry Pannell

Casing I.D. none Contractor SOIL EX (Rich Benetti)

Remarks Hand driven spoon

~ 50 lb hammer with a 30" drop

Elev. Feet	Depth Feet	Sample Type & Number	Blows per 6 In.	Depth Range	Rec.	Graphic Log	Sample Description	Equipment Installed
							6" concrete with gravel on bottom	
	1	SS-1	18-22 34	6"-2'	8.5"		15" washed gravel over 6" poorly sorted grey SAND & GRAVEL. Mostly fine-med, some very coarse. 1" broken asphalt pieces.	
	2	SS-2	39-18 17-9/2"	2'-3'8"	4"		poorly sorted light brown SAND & GRAVEL; fine-v. coarse, little asphalt mixed throughout.	
	3						refusal at 3' 8"	
	4							

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Project UNIFIRST Site WOBURN **BORING** VB-5 Sh 1 of 1

Date Started 3/2/89 Completed 3/2/89 Ground Elevation

Total Depth 3' 0" Location Old Test Pit Logged by Larry Pannell

Casing I.D. none Contractor SOIL EX (Rich Bonetti)

Remarks Hand driven spoon
~ 50 lb hammer with a 30" drop

Elev. Feet	Depth Feet	Sample Type & Number	Blows per 6 In.	Depth Range	Rec.	Graphic Log	Sample Description	Equipment Installed
							6" concrete with gravel on bottom.	
	1	SS-1	31-31 30	6"-2'	11"		poorly sorted, light brown, fine-coarse SAND. Some gravel, trace asphalt.	
	2	SS-2	31-60 50/0"	2'-3'	7.5"		poorly sorted, light brown, SAND; mostly med-coarse; little asphalt.	
							Refusal at 3' 0"	
	3							

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1911 (1/81)

Appendix C

Appendix C

Diffusion control on PCE removal during SVE

Calculation of the Effect of Diffusion Control on the Performance of Soil Vapor Extraction (SVE)

The effect of diffusion-controlled mass transfer on the performance of SVE was calculated using a simple diffusive transport model. The general configuration and conditions for the diffusion model are shown in Figure 1. The model is based on a one-dimensional analytical solution described by Crank (1975) p. 47. The model reflects the condition where there is diffusive transport of PCE out of a low permeable layer into surrounding zones in which air flow occurs. It was assumed that the low permeability layer has a high water content and PCE migration is controlled by aqueous-phase diffusion. This would be the case for the zones of highest moisture content found in the unconsolidated deposits at the UniFirst Property.

General parameters for PCE used in the calculations are:

Henry's Constant	0.294
Organic carbon partition coefficient	364 REDACTED
Free-solution diffusion coefficient	6×10^{-6} cm^2/s

Site-Specific parameters used in the calculations are:

Total porosity	40% REDACTED
Water saturation	100%
Dry bulk density	1.62 g/cm^3
Initial PCE concentration	60 mg/kg

The effective diffusion coefficient for the soil is much lower than the value in free solution of water. The effective diffusion coefficient (D_e) of PCE in soil water is related to the "free-solution diffusion coefficient" (D) by:

$$D_e = D \ t^*$$

where t^* is the tortuosity. The tortuosity is a factor which accounts for the fact that diffusion can only occur through the water-filled pore spaces in the soil. Consequently, the effective diffusion coefficient is lower than the free-solution diffusion coefficient and is typically described empirically by:

$$t^* = \frac{\theta_w^{2.33}}{\theta_t^2}$$

For an water-filled porosity (θ_w) of 0.4 and a total porosity (θ_t) of 0.4, the effective tortuosity would be 0.73 and the resultant effective diffusion coefficient for TCE would be 4×10^{-6} cm^2/s.

The model calculates the change in relative concentration in the soil water with time as a result of aqueous-phase PCE diffusion out of the low permeability layer. It is assumed that the soil water is in equilibrium with the soil solids at all locations in the layer. Consequently, the shape of the profile of soil water concentrations through the layer will reflect the profile total soil concentrations. The soil concentrations and soil water concentrations were related to each other using the partitioning relationships described in Feenstra et al. (1991).

Calculations were performed for a layer about 1 ft. (30 cm) in thickness and for a layer about 2 ft. (60 cm) in thickness. The soil concentrations profiles for

these layers at three different times during SVE are shown in Figures 2 and 3 respectively.

Figure 2 illustrates that about 7 years are required to reduce the soil concentrations in the 1 ft. thick layer from 60 mg/kg down to low levels. Figure 3 illustrates that about 20 years are required to reduce the soil concentrations in the 2 ft. thick layer from 60 mg/kg down to low levels. For a case with higher initial concentrations, cleanup times would be even longer.

REDACTED

These simplified calculations indicate that the cleanup of high water content low pemeability zones of several feet in size such as found in the unconsolidated deposits at the UniFirst Property would require many years of SVE operation to remove PCE down to low concentration levels.

References

Crank, J. (1975). The Mathematics of Diffusion. Oxford University Press.

Feenstra, S., D. M. Mackay and J. A. Cherry (1991). A method for assessing residual NAPL based on organic chemical concentrations in soil samples. Ground Water Monitoring Review, v. XI, p. 128-136.

Figure 1. General configuration and conditions for diffusion model.

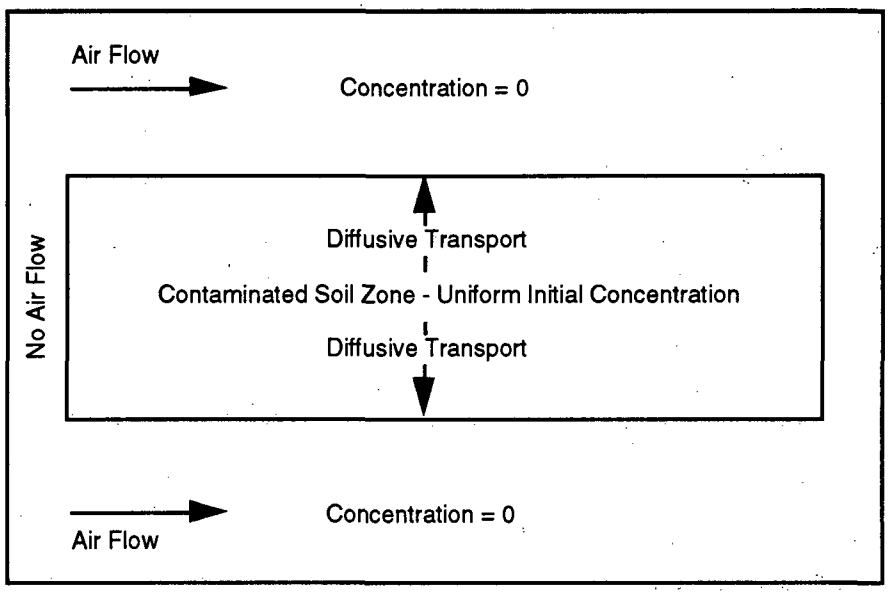


Figure 2. Model calculations for removal of PCE from a high water content layer about 1 ft. in thickness. Initial PCE concentration 60 mg/kg.

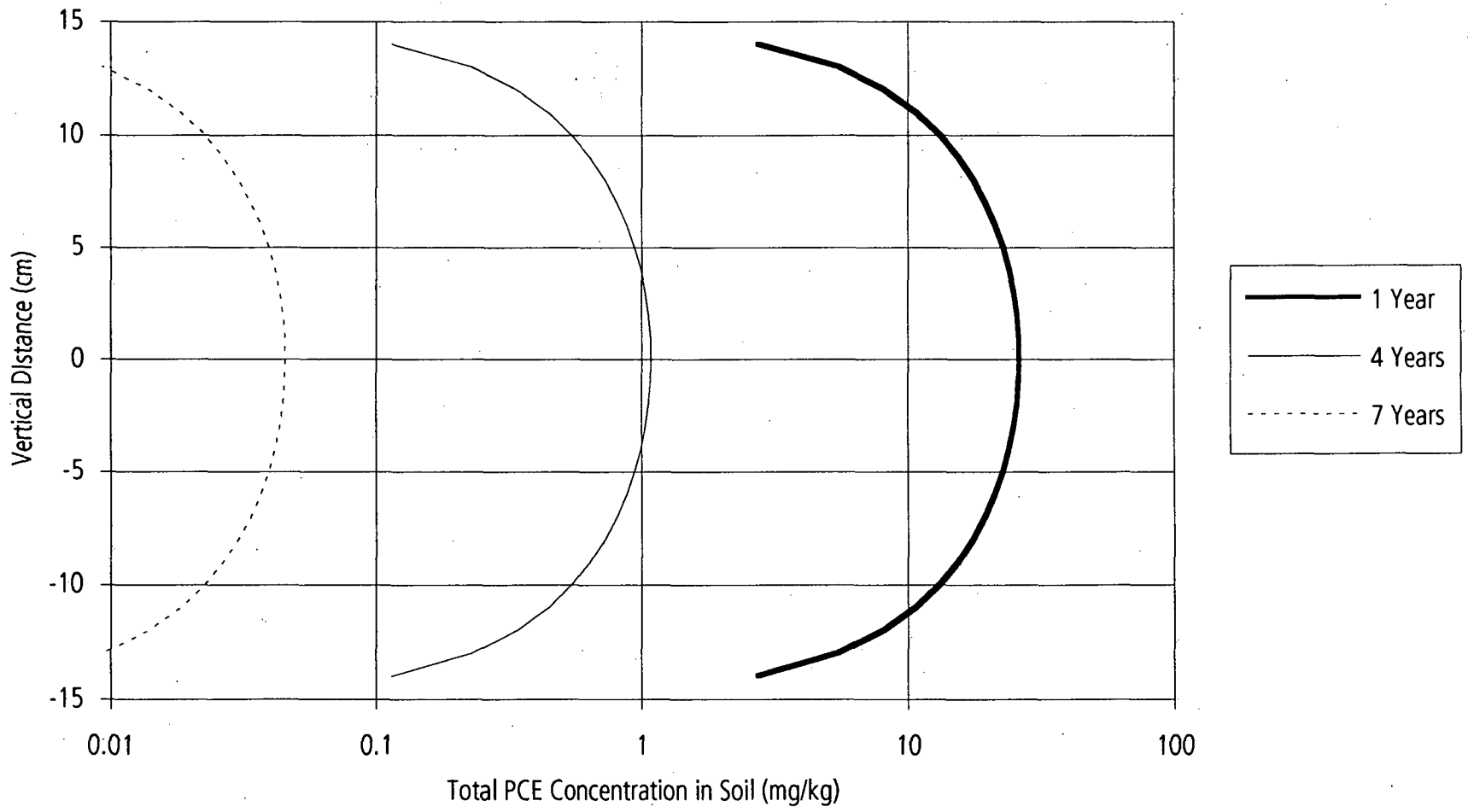
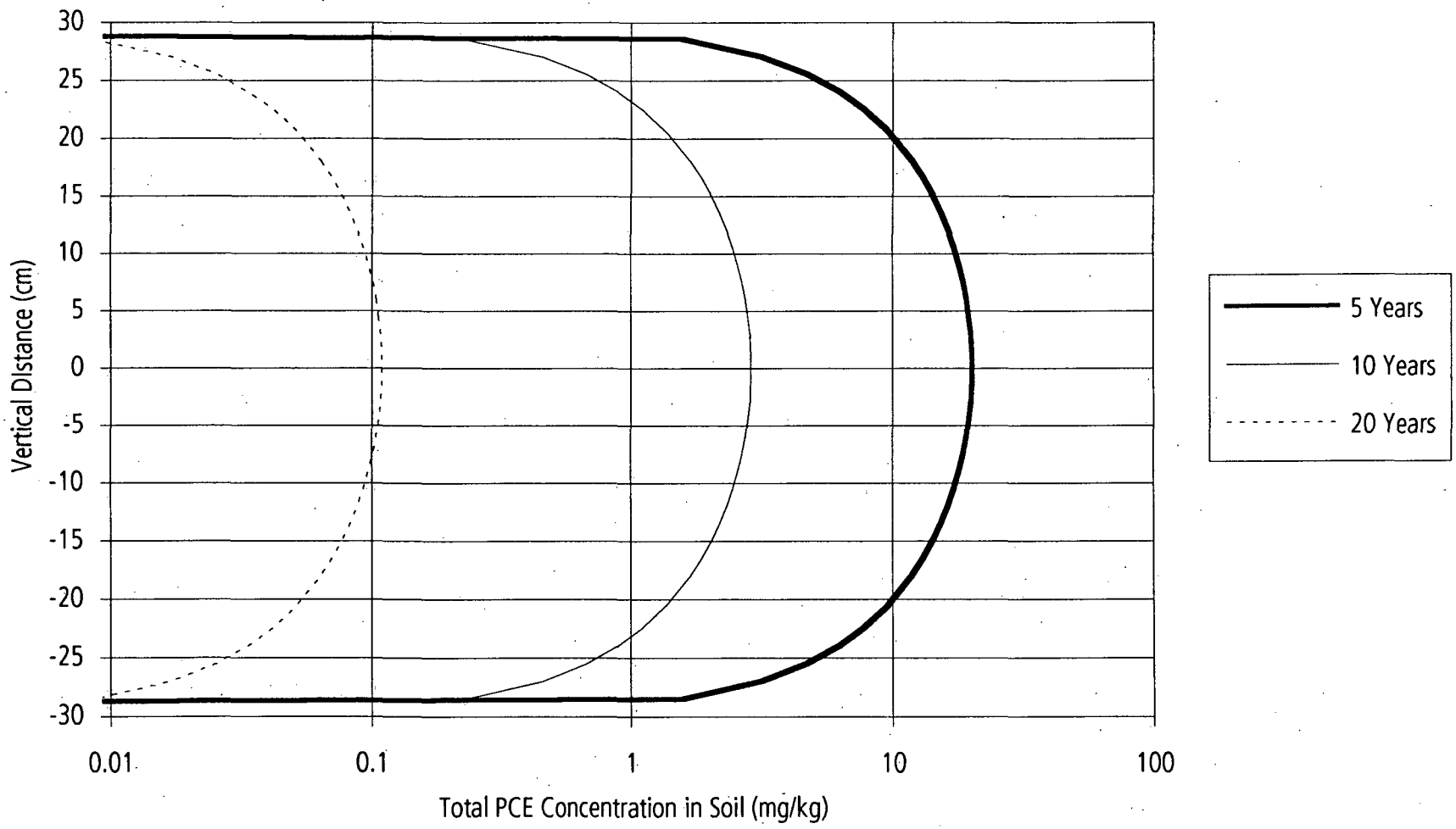


Figure 3. Model calculations for removal of PCE from a high water content layer about 2 ft. thick. Initial PCE concentration 60 mg/kg.



Appendix D

Appendix D

Calculation of Air Permeability

Calculation of Air Permeability

Air permeability was calculated for samples of the unconsolidated deposits based on the measured hydraulic conductivity and water saturation using the relationship of Brooks-Corey (1961). This method is described by DiGuilio (1992) with regard to the evaluation of soil vapor extraction (SVE).

The Brooks-Corey equation for the relative permeability of a non-wetting fluid such as air in soil is given by:

$$k_r = (1 - S_e)^2 \, (1 - S_e^{(2+\lambda/\lambda)})$$

where:
k_r *is the relative permeability*
S_e *is the effective saturation*
λ *is a pore size distribution parameter*

$$S_e = \frac{\left(\frac{\theta_w}{\theta_t} + \frac{\theta_r}{\theta_t}\right)}{\left(1 + \frac{\theta_r}{\theta_t}\right)}$$

where:
θ_w *is the water – filled porosity*
θ_r *is the residual water saturation*
θ_t *is the total porosity*

A total of 13 samples were tested for dry density, water content and hydraulic conductivity. Dry density was used to calculate the total porosity for each sample. The total porosity and water content were used to calculate the water-filled porosity for each sample. Values for the pore distribution index

and residual water saturation were assumed to be 2.5 and 0.06 respectively to be typical for a sandy granular soil.

The effective saturation was calculated for each sample based on the total porosity and water-filled porosity. The relative permeability was then calculated using the effective saturation.

The air permeability was calculated for each sample as the product of the relative permeability and the measured hydraulic conductivity.

The results of the air permeability calculations are shown in Table 1.

References

Brooks, R. H. and A. T. Corey (1964). Hydraulic Properties of Porous Media. Colorado State University, Fort Collins, CO, Hydrology Paper, No. 3, 27 p.

DiGuilio, D. C. (1992). Evaluation of soil venting application. US Environmental Protection Agency, EPA/540/S-92/004.

Sample	Depth (ft)	Silt and Clay (%)	Water Content (wt. %)	Dry Density (g/cm3)	Porosity (%)	Water Content (vol %)	Water Saturation (%)	Hydraulic Conductivity (cm/s)	Calculated Relative Air Permeability	Calculated Air Permeability (darcys)	Calculated Air Permeability (cm2)
Outside Building											
TPK 1A	1.8	14.6	5.5	1.94	28	10.7	39	6.40E-05	0.469	0.031	3.07E-10
TPK 2A	2.8	24.0	7.3	1.76	34	12.8	37	5.60E-04	0.493	0.286	2.82E-09
TPK 3A	3.3	34.0	8.2	1.90	29	15.6	53	3.50E-05	0.233	0.008	8.34E-11
TPK 4A	4.1	23.3	8.7	1.94	28	16.9	61	1.40E-05	0.140	0.002	2.00E-11
TPK 5A	4.8	17.0	7.1	1.86	31	13.2	43	9.30E-05	0.386	0.037	3.67E-10
TPK 10A	4.4	16.5	7.5	1.76	34	13.2	39	2.50E-04	0.467	0.121	1.19E-09
TPM 2A	4.0	13.4	5.91	1.84	31	10.9	35	2.20E-04	0.548	0.125	1.23E-09
TPM 3A	2.0	12.6	6.37	1.85	31	11.8	38	2.80E-04	0.480	0.139	1.37E-09
TPM 4A	0.8	43.1	15.78	1.86	31	29.4	96	2.70E-03	0.000	0.001	5.36E-12
TPJ 1A	3.0	27.0	8.8	1.72	36	15.1	42	6.60E-06	0.402	0.003	2.71E-11
Average		22.6	8.1	1.84	31	15	48	4.22E-04	0.362	0.075	7.43E-10
Median		20.2	7.4	1.86	31	13	40	1.57E-04	0.435	0.034	3.37E-10
Inside Building											
TPL 1A	3.2	17.5	5.6	1.74	35	9.7	28	2.30E-03	0.698	1.662	1.64E-08
TPL 3A	1.4	24.1	6	1.56	42	9.4	22	3.30E-03	0.823	2.812	2.78E-08
TPL 4A	2.2	19.9	5.5	1.59	41	8.7	22	3.90E-03	0.845	3.410	3.37E-08
Average		20.5	5.7	1.63	39	9.3	24	3.17E-03	0.789	2.628	2.59E-08
Median		19.9	5.6	1.59	41	9.4	22	3.30E-03	0.823	2.812	2.78E-08

Table 1. Calculation air permeability on samples of unconsolidated deposits.

Appendix E

Appendix E

Gemeinhardt Report

Gemeinhardt Site

Elkhart, Indiana

ENSR

Summary Report: Soil Remediation with Soil Vapor Extraction

ENSR Consulting and Engineering

Janaury 1992

Document Number 1287-002-025

CBS Project Number C-88-792

E000035

ENSR

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ENSR Document No.: 1287-002-025
ENSR Reference No.: 220-DBU-162

January 27, 1992

Mr. Ken Theisen
U.S. Environmental Protection Agency
Region V
230 South Dearborn Street
Chicago, IL 60604

Re: Gemeinhardt Site Soil Remediation
Summary Report

Dear Ken:

Enclosed is the summary report for the Gemeinhardt site soil remediation with soil vapor extraction. This report summarizes background information, site data, design and operating data, and shutdown justification for the system. The remediation was conducted under Administrative Order Docket No. V-W-85-C-003, signed March 7, 1985.

This report completes the effort on this soil remediation project. Please call me if you have any questions.

Very truly yours,

David B. Urban, P.E.
Senior Project Manager

cc: Joseph Horowitz, P.E. - CBS
Christopher P. Davis, Esq. - GPH
Robert Clemens - ENSR
John Wingard, P.E. - EIS

Gemeinhardt Site

Elkhart, Indiana

Summary Report: Soil Remediation with Soil Vapor Extraction

ENSR Consulting and Engineering

Janaury 1992

Document Number 1287-002-025

CBS Project Number C-88-792

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1.0 INTRODUCTION

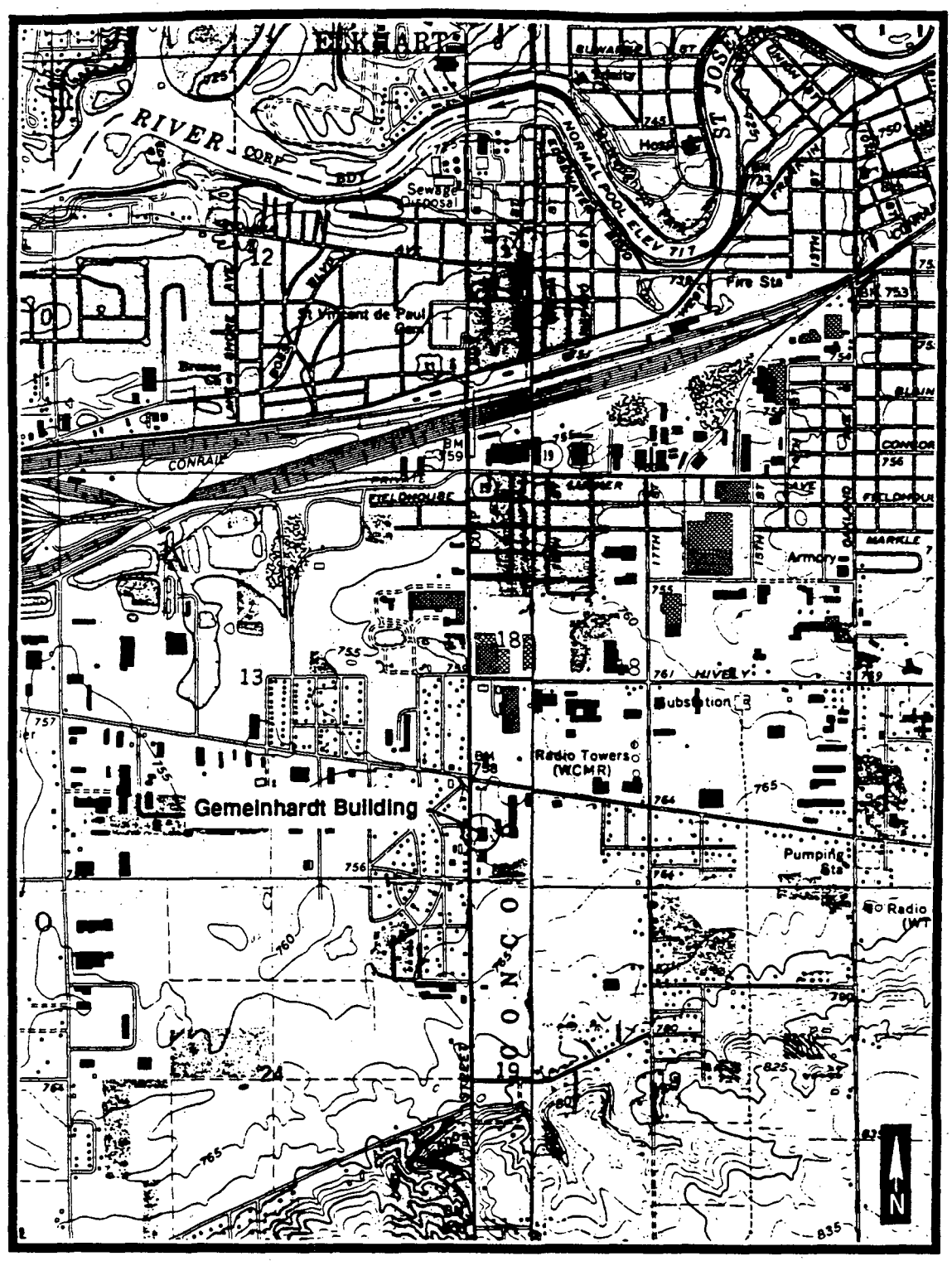
Soil contaminated with tetrachloroethylene (PCE) at the Gemeinhardt facility in Elkhart, Indiana was remediated with a soil vapor extraction system that was in operation from September 1989 through December 1990. At the request of EPA, this report was prepared to provide a brief history of the project by identifying major milestones and summarizing the major documents associated with the site. For sake of completeness, key documentation that had previously been issued has also been included in the appendices.

2.0 SUMMARY

The Gemeinhardt plant, located on State Route 19 southwest of Elkhart, Indiana (Figure 2-1), is a manufacturer of flutes and piccolos. The manufacturing processes generated wastewaters that in the past had contained low levels of the degreasing solvents tetrachloroethene (PCE), trichloroethene (TCE), and 1,1,1-trichloroethane (111-TCA). The wastewaters were discharged to five dry wells located on the site (Figure 2-2). In 1984, two of the dry wells and other contaminated soil were excavated and removed, as shown in Figure 2-2, and disposed of at a RCRA landfill. In late 1984, Gemeinhardt ceased discharge of process wastewater to the remaining dry wells.

Analyses of soil at the site indicated the presence of PCE at concentrations of up to 55 mg/kg. As a result of the Administrative Consent Order between the USEPA and Gemeinhardt (Ref. 1) and EPA's letter of April 26, 1988 (Ref. 2), a Soil Vapor Extraction (SVE) system was installed and operated at the site over a fifteen month period beginning in September, 1989 and ending in December, 1990. During that time, there were several stretches when the system was shut down because of cold temperatures, equipment failures and repairs, and to allow the soil to equilibrate prior to sampling.

The system met two of the three shutdown criteria established for the program. The third criterion, to achieve a maximum 1 mg/kg PCE concentration in the soils, was judged to be impractical to achieve with the SVE system, based on ENSR's analysis of the data and conclusion that the residual PCE vapors were primarily from PCE in the groundwater. As a result, EPA approval was obtained to shut down and dismantle the system.

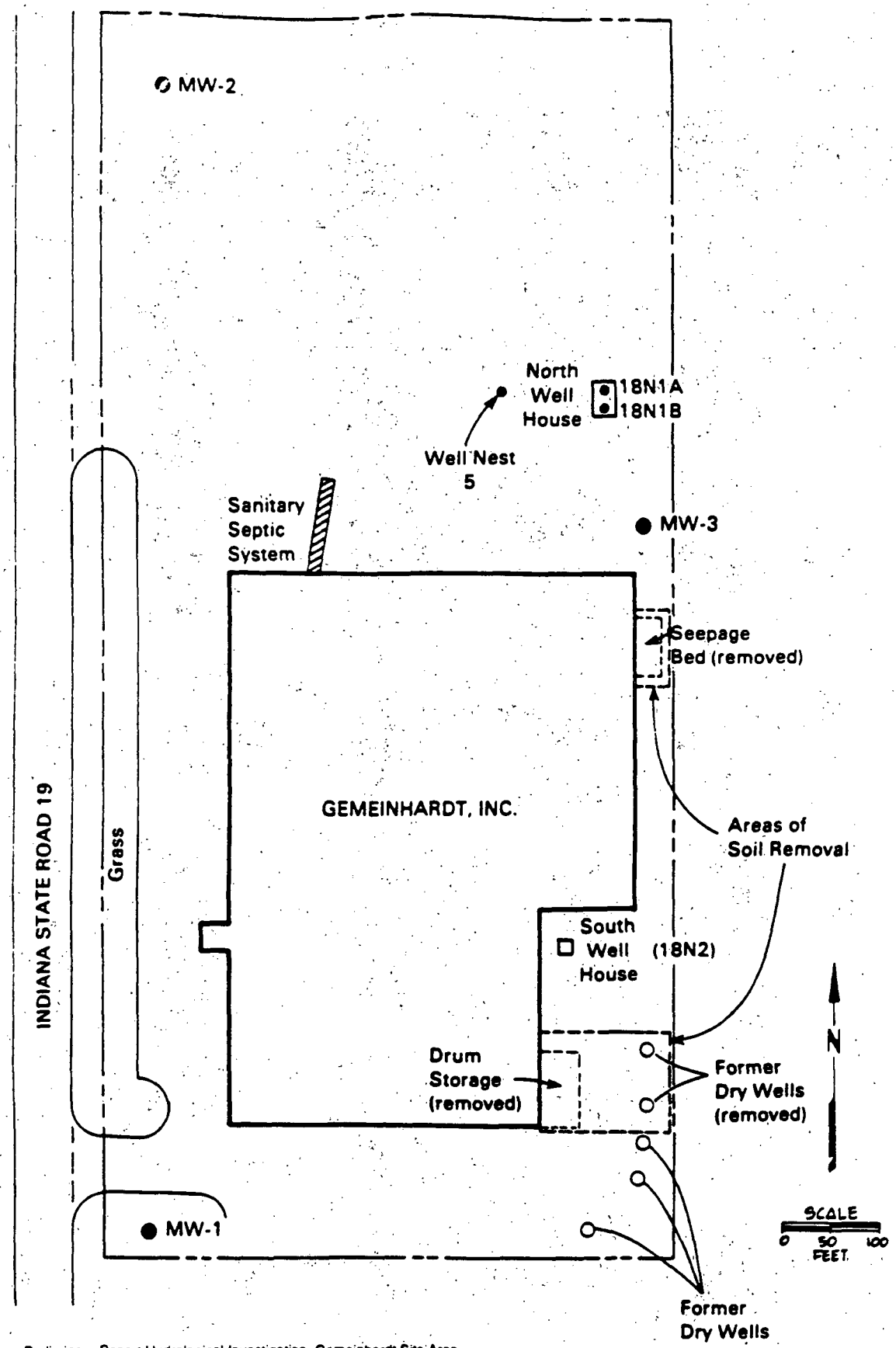


SOURCE:
USGS 7.5 Minute Topographic Series, 1980
Osceola and Elkhart, Indiana Quadrangle

0 .5 1 Mile

FIGURE 2-1

Gemeinhardt Site Location



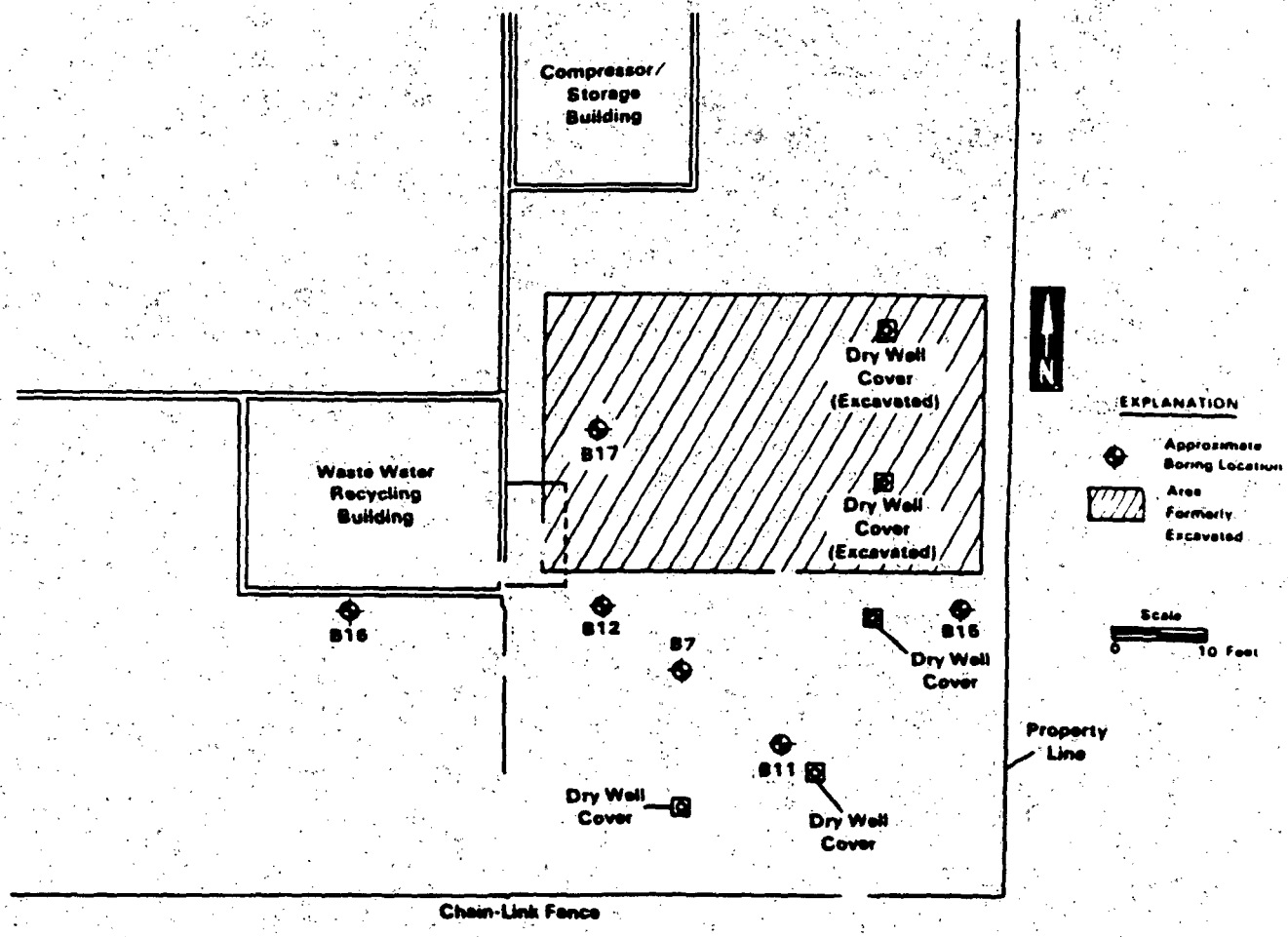
Source: Preliminary Report Hydrological Investigation, Gemeinhardt Site Area, Elkhart, Indiana; Volume I, ENSR Doc. 3140-002-011, June 1988.

FIGURE 2-2

Gemeinhardt Site Map, Dry Wells and Excavated Area

3.0 SITE INVESTIGATION

In 1984 soil samples were collected from borings at the Gemeinhardt site in the vicinity of the dry wells. Because of the high levels of VOC detected, contaminated soil near two of the five dry wells and other areas of the site (Figure 2-2) was excavated and disposed of off-site at a RCRA landfill. In 1985 additional soil samples were collected from borings near the remaining three dry wells (Ref. 3). In 1988, a third round of soil sampling was conducted to further delineate the extent of contamination and determine the applicability of soil vapor extraction (Ref. 4). Excavation of soils in this area was not feasible because of structural concerns with the existing building which was still in operation. The locations of the borings and previous excavation are shown in Figure 3-1. The results of the analyses are summarized in Table 3-1. A soil gas survey (Ref. 5) was conducted on the site in 1989 to supplement the soil data. This study showed no significant VOC contamination to a depth of 18 inches, indicating that the contamination was all at greater depths.



Source: Work Plan for Soil Sampling and Analysis,
Gemeinhardt Site, Elkhart, Indiana, ENSR Doc. No. 3140-008-003, Sept. 1988.

FIGURE 3-1

Gemeinhardt Soil Remediation, Soil Boring Locations

TABLE 3-1
GEMEINHARDT SOIL REMEDIATION
SOIL ANALYSES

Boring	Depth, ft	PCE Concentration, µg/kg 10/5/88[c]	"low level"[a] 7/85[d]	"medium level"[b] 7/85[d]
B7	3-4.5	14,000[g]	2,700	12,000
	6-7.5	310	3,800	4,600
	9-10.5	280	5,000	4,100
B11	3-4.5	ND[e]	NA[f]	7,900
	9-10.5	15	3,800	NA
	13.5-15	2,900[g]	NA	NA
B12	9-10.5	55,000[g]	25,000	13,000
B15	3-4.5	Nd	22	NA
	6-7.5	ND	1,100	NA
	9-10.5	52	NA	2,300
B16	9-10.5	630	NA	NA
	12-13.5	100	NA	NA
	13.5-15	2,300	NA	NA
B17	6-7.5	300	NA	NA
	13.5-15	710	NA	NA

Notes:
[a]"low level" = GC/MS with purge and trap.
[b]"medium level" = EPA methods 5030/8240; methanol extraction and GC/MS with purge and trap.
[c]Samples collected by ENSR (formerly ERT) and analyzed by E3I using EPA methods 5030/8240. Concentration reported is highest value measured for a given sample interval, regardless of whether sample was aerated or not aerated.
[d]Samples collected by ERT and EIS and analyzed by ERT Laboratory.
[e]ND = not detected.
[f]NA = not analyzed.
[g]Sample was analyzed using "medium-level" method.
Source: Reference 4.

4.0 LABORATORY TESTS

By their letter of April 26, 1988 (Ref. 2), EPA approved the use of SVE to remediate the soils at Gemeinhardt. During the round of sampling in October 1988 (Ref. 4), simple laboratory aeration tests were conducted on the soil samples. The tests indicated that soil vapor extraction would be an appropriate remediation technique for the site. Subsequently, a more rigorous laboratory study was conducted by Vapex Environmental Technologies of Canton, MA to determine the practical extent of treatment and to develop design parameters for the full-scale unit (Ref. 6). Although the VOC concentration in the untreated soil sample used in this test was less than 1 mg/kg, the results indicated that the VOC could be easily stripped within a reasonable amount of time, even at low concentrations.

5.0 SVE SYSTEM CONCEPTUAL DESIGN

Based on an evaluation of soil data and contaminant analyses, a conceptual design for the SVE system was developed by ENSR. The design considered contaminant depths and concentrations, soil permeability, water table, and existing site surface and subsurface conditions. The conceptual design, as shown in Figure 5-1, included six extraction wells, nine air injection wells, and vapor probes as necessary to monitor the effectiveness of the vacuum on the soil volume being treated. Offgas treatment was not required because the anticipated emission rates were below levels requiring treatment in Indiana. Details of the conceptual design are in Reference 7.

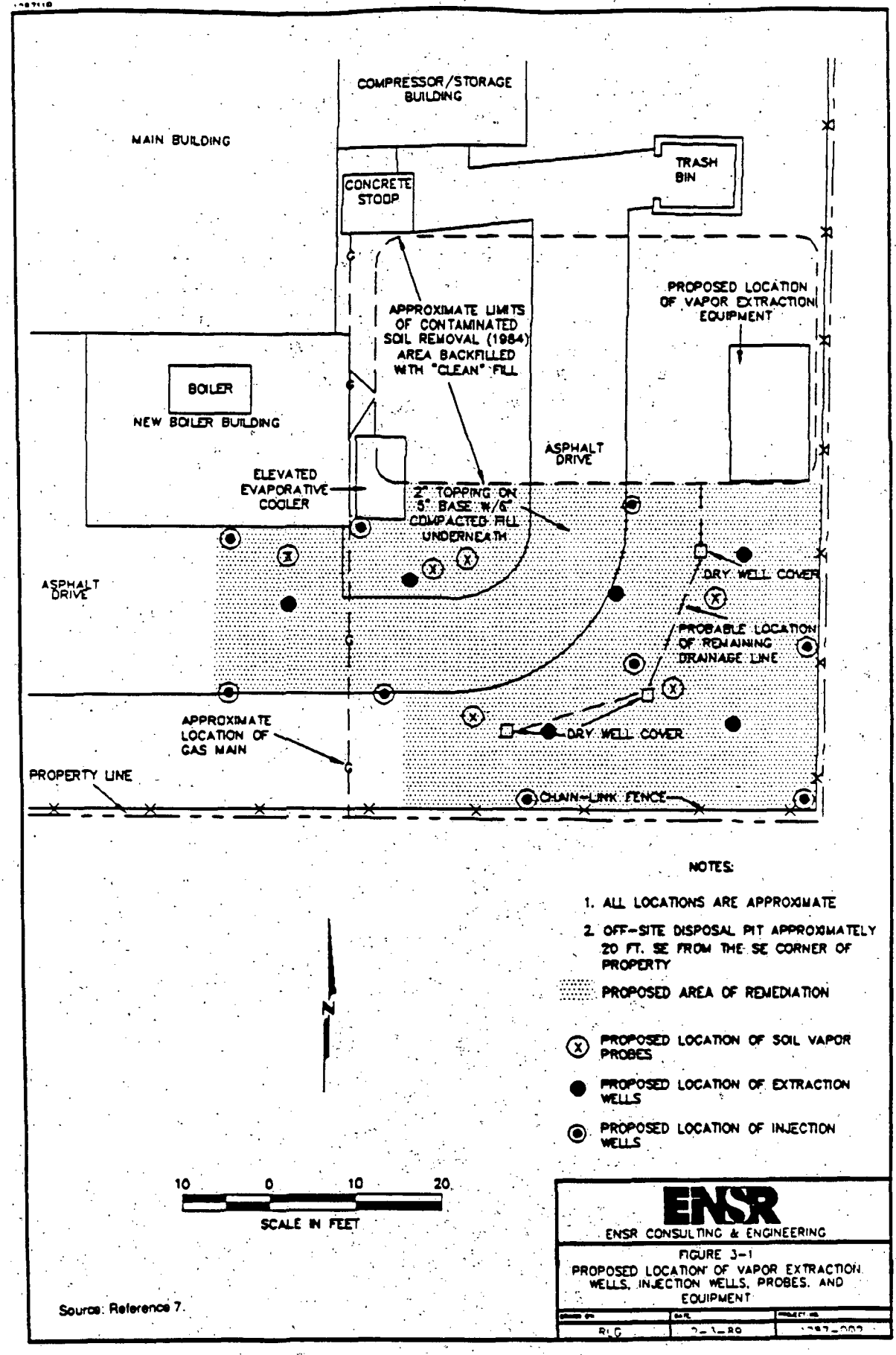

COMPRESSOR/STORAGE BUILDING
MAIN BUILDING
TRASH BIN
CONCRETE STOOP
PROPOSED LOCATION OF VAPOR EXTRACTION EQUIPMENT
APPROXIMATE LIMITS OF CONTAMINATED SOIL REMOVAL (1984) AREA BACKFILLED WITH "CLEAN" FILL
BOILER
NEW BOILER BUILDING
ASPHALT DRIVE
ELEVATED EVAPORATIVE COOLER
2" TOPPING ON 5" BASE W/6" COMPACTED FILL UNDERNEATH
DRY WELL COVER
ASPHALT DRIVE
PROBABLE LOCATION OF REMAINING DRAINAGE LINE
APPROXIMATE LOCATION OF GAS MAIN
DRY WELL COVER
PROPERTY LINE
CHAIN-LINK FENCE
NOTES:
1. ALL LOCATIONS ARE APPROXIMATE
2. OFF-SITE DISPOSAL PIT APPROXIMATELY 20 FT. SE FROM THE SE CORNER OF PROPERTY
PROPOSED AREA OF REMEDIATION
PROPOSED LOCATION OF SOIL VAPOR PROBES
PROPOSED LOCATION OF EXTRACTION WELLS
PROPOSED LOCATION OF INJECTION WELLS
N
10 0 10 20
SCALE IN FEET
ENSR
ENSR CONSULTING & ENGINEERING
FIGURE 3-1
PROPOSED LOCATION OF VAPOR EXTRACTION WELLS, INJECTION WELLS, PROBES, AND EQUIPMENT
RLG
Source: Reference 7.

FIGURE 5-1

6.0 ORIGINAL SHUTDOWN CRITERIA

Based on the soils analyses, laboratory tests, mass transfer considerations, and experience, the following three criteria were developed to determine the point at which the SVE system could be shut down:

Criterion No. 1: The soil vapor extraction system will be operated until VOC concentrations in the offgas discharged from the vacuum pump are reduced to a concentration of less than 1 percent of the initial VOC recovery concentrations in the soil. When this reduced concentration is achieved, the offgas will be resampled five days later, and if the concentration has either remained the same or decreased, then the first criterion has been met, and the system will be shut down.

Criterion No. 2: Vapor samples from the installed soil vapor monitoring probes will be analyzed immediately after shut-down, and again two days later to check for vapor diffusion and re-establishment of vapor equilibrium in the soil pore space. If the soil vapor concentrations remain the same or
decrease over the two day period, then the second criterion for shut-down has been met.

Criterion No. 3: If the second criterion has been met, two soil samples (one at 5 foot depth and one at 10 foot depth) will be collected from a soil boring adjacent to a soil vapor monitoring probe in the area of highest known VOC near former boring B12. If VOC soil concentrations below the soil treatment standard have been obtained then the third criterion has been met and the cleanup is complete. In the Conceptual Design Report, it is stated that "a cleanup criteri[on] of 1 milligram per kilogram (ppm) was selected, based on experience at similar sites, for a remedial action consisting of excavation, treatment by mechanical aeration, and soil replacement in the same location....The ability of this technology to meet the previously proposed 1 ppm criterion will be confirmed upon completion of a laboratory column test...If the results indicate that this criteri[on] cannot be met, an alternate level will be proposed." Based on the results of the laboratory column tests, it was concluded that the 1 ppm criterion was achievable (Ref. 8).

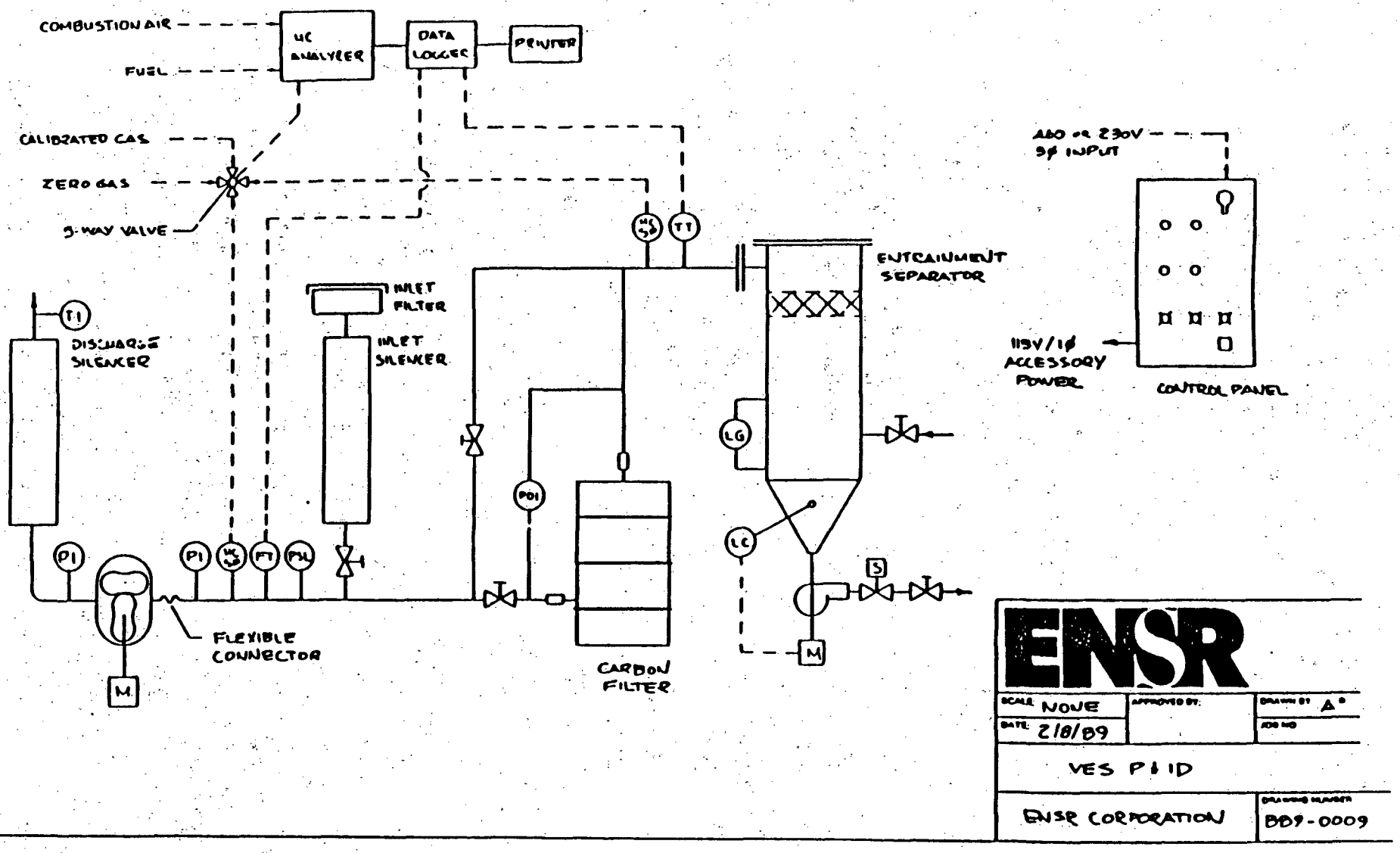
These three original criteria were included in the contract as conditions for the successful completion of the project.

7.0 SVE CONTRACTOR, SYSTEM DESIGN, AND INSTALLATION

ENSR Constructors of Houston, TX was contracted to design, install, and operate the SVE system on the Gemeinhardt site. System design was essentially as described in the Conceptual Design Report (Ref. 7). A schematic of the vacuum system is in Figure 7-1. Installation details are in Figure 7-2.

The SVE system included a monitoring system that recorded time, temperature in and out of the vacuum system, and off-gas VOC concentration (calibrated to PCE).

The entire system was installed in August, 1989.



Source: ENSR Constructors.

FIGURE 7-1

Gemeinhardt Soil Remediation, Schematic of SVE Vacuum System

8.0 SYSTEM OPERATION

A. Chronology

SVE system start-up was on September 14, 1989. Operational problems were encountered during the winter months. Power failures and cold weather caused automatic shutdown and/or damage to some critical components of the unit. To avoid further damage, the unit was idled in late December, 1989, continuing through January and February, 1990.

Based on routine measurements of soil vapors, it was determined that one of the dry wells at the site had high levels of PCE. Soil analysis indicated a maximum PCE concentration of 450 mg/kg. Therefore, in January, 1990, the dry well was excavated, and approximately 8 cubic yards of soil were disposed of.

The SVE system was restarted on March 1, 1990 and continued operation through May 10, 1990. The unit was shut down at that time to evaluate shutdown criteria, as discussed below. The system was restarted on June 20, 1990 and continued operating, with minor outages, while the justification for shutdown was being evaluated. Cold weather precluded sustained operation into the winter months without significant investment in weatherproofing; therefore, the unit was idled on December 26, 1990.

On February 13, 1991, EPA approved shutdown of the unit (Ref. 12). The SVE system was removed from the site in March, 1991.

Table 8-1 provides a summary of the operating periods and milestones. Overall, the unit was in normal operation for 319 of the 467 days of elapsed time from start-up through final shutdown.

B. Operating Parameters and Performance

Operating data were recorded and provided periodically by the contractor. The data included hourly and daily operating parameters and measurements, plots of the data, vacuum data on the vapor probes, and concentration data from the extraction wells and vapor probes. These data were sent to EPA periodically, with the final update in December, 1991 (Ref. 9). The air rate for the system was generally in the range of 260 to 280 CFM. Inlet and outlet temperature varied with ambient temperature. Inlet temperature ranged from 30 to 80 degrees F, while outlet temperature was generally about 20 degrees higher than that of the inlet.

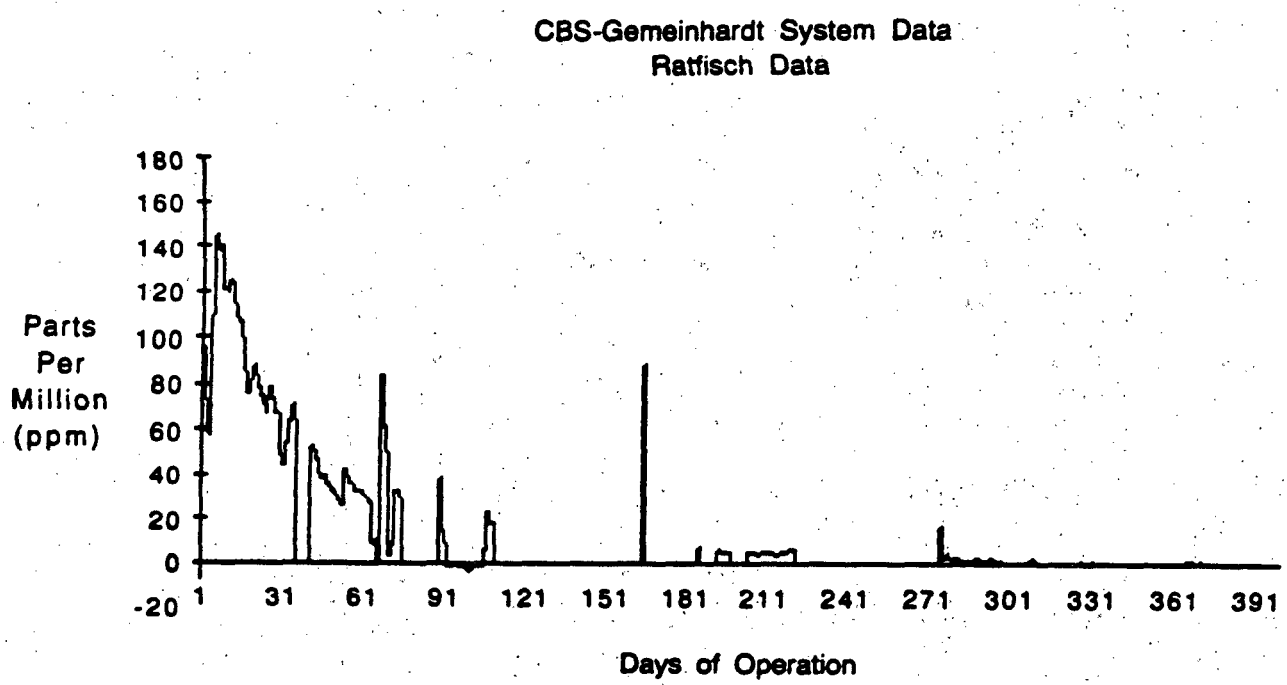
Table 8-1
Gemeinhardt Soil Remediation
SVE Operating Log Summary

Date	Days since Start	Activity	Comment
9/14/89	0	system startup	
9/18/89 through 10/17/89		periodic outages, all < 3 hr.	down total of ~0.5 day
10/19/89	36	system down	
10/25/89	42	restart	down 5 days
11/18/89	66	system down	
11/19/89	67	system up	down 1.25 days
11/27/89	75	system down	
12/12/89	90	restart	down 15 days
12/16/89	94	system down	
12/18/89	96	restart	down 2.25 days
12/26/89	104	winter shutdown	
1/23/90	131	dry well excavated	
3/1/90	164	restart	down 65 days
5/11/90	236	sampling shutdown	to evaluate criteria
6/20/90	275	restart	down 39 days
10/13/90	393	system down	
10/22/90	402	restart	down 9 days
11/10/90	421	system down	
11/21/90	432	restart	down 11 days
12/26/90	466	winter shutdown	
2/13/91	516	EPA approval for shutdown	

At start-up (after 20 minutes of operation), off-gas VOC concentration was 422 ppm, corresponding to a VOC removal rate of over 2 pounds per hour. Within 24 hours, the off-gas concentration fell to about 100 ppm, or approximately 0.5 pounds per hour. As the system continued to operate, off-gas concentration generally declined slowly. After one month of operation, offgas concentration was about 50 ppm. After two months, the concentration reduced to 30 ppm. The unit was shut down for the winter soon after.

Following the winter shutdown and removal of the "hot spot" (the highly-contaminated dry well), off-gas concentrations dropped to below 10 parts per million, and asymptotically approached zero during the remainder of the operation. Figure 8-1 provides a plot of measured offgas concentrations through October 1990.

Based on the off-gas concentrations and flow rates, the total PCE removed by the system was 661 pounds. Appendix A provides the data used to perform these mass calculations. There were several extended periods during which the off-gas monitor was not working, totaling 173 days out of 309 days of operation, as shown on Table 8-2. Most of those days were during the final days of operation when the offgas concentrations were very low. PCE removal rates during these periods were estimated based on the measured rates before and after the monitor down times. By this method, removal of an additional 60 pounds of PCE was calculated, and the total amount of PCE removed is estimated to be approximately 720 pounds. Table 8-2 and Appendix A provide details of these calculations.



Source: Reference 9.

FIGURE 8-1

Gemeinhardt Soil Remediation, Off-Gas VOC Concentrations

Table 8-2

Gemeinhardt Soil Remediation
SVE Operating Log Summary
Periods of Operation Without Data Collection

Dates	Elapsed Days	Estimated Daily PCE Removal rate lb/day	Estimated Total PCE Removal for Period, lb
10/2/89 - 10/2/89	0.05	11.5	0.5
3/3/90 - 3/30/90	27	0.9	24
4/4/90 - 4/11/90	7	0.75	5
4/28/90 - 5/10/90	12	0.9	11
7/16/90 - 7/24/90	8	0.15	1
7/25/90 - 8/10/90	16	0.15	2
8/16/90 - 9/17/90	32	0.15	5
9/24/90 - 10/12/90	18	0.15	3
10/22/90 - 11/9/90	18	0.15	3
11/21/90 - 12/26/90	35	0.15	5
Total	173	---	60

9.0 SVE SYSTEM SHUTDOWN

The three shutdown criteria described above were used to initiate the shutdown process. On May 10, 1990, the unit was stopped because the first criterion (off-gas concentration less than 1% of initial off-gas concentration) had been met. Subsequent monitoring of the VOC concentration in the vapor probes was judged to meet the requirements of the second shutdown criterion (no change in the VOC concentrations in the vapor probes). Soil samples were then taken and analyzed to determine if the third criterion (less than 1 ppm VOC in soil) had been met. Although there was a significant overall decrease in VOC in the soil, some of the samples exceeded this criterion, with VOC -in-soil concentrations as high as 15 ppm. It was concluded that the SVE system was no longer effectively removing VOC from the soil, but rather was drawing VOC from contaminated groundwater. ENSR recommended shutdown of the unit at that time. Documentation of this analysis (Ref. 10) is provided in Appendix B.

After EPA's review of this document, EPA requested further evaluation of the impact of contaminated groundwater on the off-gas concentrations. As a result, ENSR analyzed the data from the vapor probes during the remediation period and demonstrated that the groundwater was, in fact, diffusing into the soil and entering the SVE system. This documentation (Ref. 11) is provided in Appendix C. EPA agreed with the conclusions and authorized unit shutdown on February 13, 1991 (Ref. 12), included in Appendix D.

10.0 REFERENCES

1. EPA Document Number V-W-85-C-003, signed by EPA on 3/7/85.

2. Letter to Christopher P. Davis of Goodwin, Procter and Hoar from Charles McKinley of EPA, re: Gemeinhardt Soils Remedy, dated April 26, 1988.

3. "Recommendation for Remedial Action," ERT Document PD-657-004-1, September, 1985.

4. "Results of Soil Sampling and Analysis, Gemeinhardt Site, Elkhart, Indiana," ENSR Document Number 3140-008-006, February, 1989.

5. "Soil Vapor Survey, Gemeinhardt Site, Elkhart, Indiana," ENSR Document Number 1287-002-013, April, 1989.

6. Results of Laboratory Vent Test, VAPEX Project No. 89-041, letter from Peter E. Nangeroni and Michael C. Marley of VAPEX Environmental Technologies, Inc. to Raymond Ball of ENSR, March 15, 1989.

7. "Conceptual Design Report for Soil Vapor Extraction, Gemeinhardt Site, Elkhart, Indiana," ENSR Document 1287-002-008, February, 1989.

8. Letter from Raymond Ball of ENSR to Frank Rich of CBS, Inc., March 31, 1989.

9. "Gemeinhardt Site Soil Remediation, Operating Data Summary," letter from David Urban of ENSR to Ken Theisen of EPA, ENSR Reference No. 220-DBU-053, Dec. 20, 1990 with update in December, 1991.

10. "Gemeinhardt Soil Remediation, Justification for SVE System Shutdown," letter from David Urban of ENSR to Ken Theisen of EPA, ENSR Reference No. 220-DBU-036, August 16, 1990.

11. "Gemeinhardt Soil Remediation, Justification for SVE System Shutdown, Additional Data Analysis," letter from David Urban of ENSR to Ken Theisen of EPA, ENSR Reference No. 220-DBU-057, January 29, 1991.

12. "Gemeinhardt Soil Remediation, Justification for SVE System Shutdown," letter from Ken Theisen of EPA to David Urban of ENSR, February 13, 1991.

APPENDIX A

PCE REMOVAL RATES

CBS-Gemeinhardt
Daily Operation Averages

Temp in	Temp out	CFM	ppm cor	ppm	day of oper.	date	pounds/hour	pounds/day
71	87	252	168	168	1	9-14-89	0.9445	22.6684
68	70	253	95	95	2	9-15-89	0.5362	12.8693
64	88	258	72	72	3	9-16-89	0.4144	9.9463
65	88	260	58	58	4	9-17-89	0.3364	8.0744
66	85	261	110	110	5	9-18-89	0.6405	15.3725
67	88	260	145	145	6	9-19-89	0.8411	20.1861
68	90	261	138	138	7	9-20-89	0.8036	19.2855
68	91	259	141	141	8	9-21-89	0.8147	19.5537
70	90	257	121	121	9	9-22-89	0.6938	16.6506
65	84	260	120	120	10	9-23-89	0.6961	16.7057
65	90	261	125	125	11	9-24-89	0.7279	17.4687
65	84	260	123	123	12	9-25-89	0.7135	17.1234
64	85	262	114	114	13	9-26-89	0.6664	15.9925
63	84	264	108	108	14	9-27-89	0.6381	15.2665
63	86	262	106	106	15	9-28-89	0.6196	14.8702
64	86	260	99	99	16	9-29-89	0.5743	13.7822
64	86	262	85	85	17	9-30-89	0.4968	11.9242
64	88	259	76	76	18	10-01-89	0.4392	10.5396
66	84	261	82	82	19	10-02-89	0.4775	11.4595
64	82	263	88	88	20	10-03-89	0.5163	12.3922
63	80	262	84	84	21	10-04-89	0.4910	11.7840
64	78	259	79	79	22	10-05-89	0.4565	10.9556
64	82	260	75	75	23	10-06-89	0.4350	10.4411
62	80	263	71	71	24	10-07-89	0.4166	9.9983
61	78	261	67	67	25	10-08-89	0.3901	9.3632
60	78	262	74	74	26	10-09-89	0.4325	10.3811
61	80	261	79	79	27	10-10-89	0.4600	11.0402
62	81	262	74	74	28	10-11-89	0.4325	10.3811
63	83	262	67	67	29	10-12-89	0.3916	9.3991
62	82	262	66	66	30	10-13-89	0.3858	9.2588
64	86	260	48	48	31	10-14-89	0.2784	6.6823

CBS-Gemeinhardt
Daily Operation Averages

Temp in	Temp out	CFM	ppm cor	ppm	day of oper.	date	pounds/hour	pounds/day
64	85	258	44	44	32	10-15-89	0.2533	6.0783
64	83	261	54	54	33	10-16-89	0.3144	7.5465
60	77	266	64	64	34	10-17-89	0.3798	9.1153
58	75	264	71	71	35	10-18-89	0.4182	10.0363
57	73	260	64	64	36	10-19-89	0.3712	8.9097
0	0	0	0	0	37	10-20-89	0.0000	0.0000
0	0	0	0	0	38	10-21-89	0.0000	0.0000
0	0	0	0	0	39	10-22-89	0.0000	0.0000
0	0	0	0	0	40	10-23-89	0.0000	0.0000
0	0	0	0	0	41	10-24-89	0.0000	0.0000
65	86	260	53	53	42	10-25-89	0.3074	7.3784
62	81	265	51	51	43	10-26-89	0.3015	7.2365
62	81	265	47	47	44	10-27-89	0.2779	6.6689
62	80	266	40	40	45	10-28-89	0.2374	5.6971
62	80	264	38	38	46	10-29-89	0.2238	5.3715
62	81	263	40	40	47	10-30-89	0.2347	5.6328
60	77	262	36	36	48	10-31-89	0.2104	5.0503
59	76	265	34	34	49	11-01-89	0.2010	4.8243
58	74	264	32	32	50	11-02-89	0.1885	4.5234
57	73	266	30	30	51	11-03-89	0.1780	4.2728
56	73	262	28	28	52	11-04-89	0.1637	3.9280
58	76	261	26	26	53	11-05-89	0.1514	3.6335
58	76	264	32	32	54	11-06-89	0.1885	4.5234
57	76	263	42	42	55	11-07-89	0.2464	5.9145
57	76	261	39	39	56	11-08-89	0.2271	5.4502
56	74	258	36	36	57	11-09-89	0.2072	4.9732
55	73	264	35	35	58	11-10-89	0.2061	4.9475
56	74	259	32	32	59	11-11-89	0.1849	4.4377
56	74	266	32	32	60	11-12-89	0.1899	4.5577
58	77	263	32	32	61	11-13-89	0.1878	4.5063
58	78	262	30	30	62	11-14-89	0.1754	4.2086

CBS-Gemeinhardt
Daily Operation Averages

Temp in	Temp out	CFM	ppm cor	ppm	day of oper.	date	pounds/hour	pounds/day
57	76	258	29	29	63	11-15-89	0.1669	4.0062
52	69	256	27	27	64	11-16-89	0.1542	3.7010
51	67	258	8	8	65	11-01-89	0.0460	1.1051
52	68	263	10	10	66	11-18-89	0.0587	1.4082
0	0	0	0	0	67	11-19-89	0.0000	0.0000
54	74	255	84	84	68	11-20-89	0.4779	11.4691
52	72	257	61	61	69	11-21-89	0.3498	8.3941
51	70	259	50	50	70	11-22-89	0.2889	6.9339
50	68	254	3	3	71	11-23-89	0.0170	0.4080
49	69	256	8	8	72	11-24-89	0.0457	1.0966
51	72	255	33	33	73	11-25-89	0.1877	4.5057
52	72	256	32	32	74	11-26-89	0.1828	4.3863
51	73	254	29	29	75	11-27-89	0.1643	3.9441
0	0	0	0	0	76	11-28-89	0.0000	0.0000
0	0	0	0	0	77	11-29-89	0.0000	0.0000
0	0	0	0	0	78	11-30-89	0.0000	0.0000
0	0	0	0	0	79	12-01-89	0.0000	0.0000
0	0	0	0	0	80	12-02-89	0.0000	0.0000
0	0	0	0	0	81	12-03-89	0.0000	0.0000
0	0	0	0	0	82	12-04-89	0.0000	0.0000
0	0	0	0	0	83	12-05-89	0.0000	0.0000
0	0	0	0	0	84	12-06-89	0.0000	0.0000
0	0	0	0	0	85	12-07-89	0.0000	0.0000
0	0	0	0	0	86	12-08-89	0.0000	0.0000
0	0	0	0	0	87	12-09-89	0.0000	0.0000
0	0	0	0	0	88	12-10-89	0.0000	0.0000
0	0	0	0	0	89	12-11-89	0.0000	0.0000
40	45	261	38	38	90	12-12-89	0.2213	5.3105
46	65	260	14	14	91	12-13-89	0.0812	1.9490
44	64	263	8	8	92	12-14-89	0.0469	1.1266
43	62	270	0	-2	93	12-15-89	0.0000	0.0000

CBS-Gemeinhardt
Daily Operation Averages

Temp in	Temp out	CFM	ppm cor	ppm	day of oper.	date	pounds/hour	pounds/day	
42	64	264	0	-2	94	12-16-89	0.0000	0.0000	
17	16	0	0	0	95	12-17-89	0.0000	0.0000	
27	31	0	0	0	96	12-18-89	0.0000	0.0000	
46	68	252	0	-2	97	12-19-89	0.0000	0.0000	
44	65	257	0	-2	98	12-20-89	0.0000	0.0000	
40	80	227	0	-2	99	12-21-89	0.0000	0.0000	
40	96	166	0	-4	100	12-22-89	0.0000	0.0000	
41	132	159	0	-3	101	12-23-89	0.0000	0.0000	
42	120	181	0	-2	102	12-24-89	0.0000	0.0000	
40	129	94	0	-2	103	12-25-89	0.0000	0.0000	
31	30	12	0	-2	104	12-26-89	0.0000	0.0000	
32	32	12	0	-2	105	12-27-89	0.0000	0.0000	
38	41	12	6	6	106	12-28-89	0.0016	0.0386	Not included in total
44	44	13	23	23	107	12-29-89	0.0067	0.1601	
42	42	13	18	18	108	12-30-89	0.0052	0.1253	
43	43	13	18	18	109	12-31-89	0.0052	0.1253	
40	40	12	18	18	110	1-01-90	0.0048	0.1157	
0	0	0	0	0	111	1-02-90	0.0000	0.0000	
0	0	0	0	0	112	1-03-90	0.0000	0.0000	
0	0	0	0	0	113	1-04-90	0.0000	0.0000	
0	0	0	0	0	114	1-05-90	0.0000	0.0000	
0	0	0	0	0	115	1-06-90	0.0000	0.0000	
0	0	0	0	0	116	1-07-90	0.0000	0.0000	
0	0	0	0	0	117	1-08-90	0.0000	0.0000	
0	0	0	0	0	118	1-10-90	0.0000	0.0000	
0	0	0	0	0	119	1-11-90	0.0000	0.0000	
0	0	0	0	0	120	1-12-90	0.0000	0.0000	
0	0	0	0	0	121	1-13-90	0.0000	0.0000	
0	0	0	0	0	122	1-14-90	0.0000	0.0000	
8	0	0	0	0	123	1-15-90	0.0000	0.0000	
0	0	0	0	0	124	1-16-90	0.0000	0.0000	

CBS-Gemeinhardt
Daily Operation Averages

Temp in	Temp out	CFM	ppm cor	ppm	day of oper.	date	pounds/hour	pounds/day
10	0	0	0	0	125	1-17-90	0.0000	0.0000
11	0	0	0	0	126	1-18-90	0.0000	0.0000
12	0	0	0	0	127	1-19-90	0.0000	0.0000
13	0	0	0	0	128	1-20-90	0.0000	0.0000
14	0	0	0	0	129	1-21-90	0.0000	0.0000
15	0	0	0	0	130	1-22-90	0.0000	0.0000
16	0	0	0	0	131	1-23-90	0.0000	0.0000
17	0	0	0	0	132	1-24-90	0.0000	0.0000
18	0	0	0	0	133	1-25-90	0.0000	0.0000
19	0	0	0	0	134	1-26-90	0.0000	0.0000
20	0	0	0	0	135	1-27-90	0.0000	0.0000
21	0	0	0	0	136	1-28-90	0.0000	0.0000
0	0	0	0	0	137	1-29-90	0.0000	0.0000
0	0	0	0	0	137	1-30-90	0.0000	0.0000
0	0	0	0	0	139	1-31-90	0.0000	0.0000
0	0	0	0	0	140	2-01-90	0.0000	0.0000
0	0	0	0	0	141	2-02-90	0.0000	0.0000
0	0	0	0	0	142	2-03-90	0.0000	0.0000
0	0	0	0	0	143	2-04-90	0.0000	0.0000
0	0	0	0	0	144	2-05-90	0.0000	0.0000
0	0	0	0	0	145	2-06-90	0.0000	0.0000
0	0	0	0	0	146	2-07-90	0.0000	0.0000
0	0	0	0	0	147	2-08-90	0.0000	0.0000
0	0	0	0	0	148	2-10-90	0.0000	0.0000
0	0	0	0	0	149	2-11-90	0.0000	0.0000
0	0	0	0	0	150	2-12-90	0.0000	0.0000
0	0	0	0	0	151	2-13-90	0.0000	0.0000
0	0	0	0	0	152	2-14-90	0.0000	0.0000
0	0	0	0	0	153	2-15-90	0.0000	0.0000
0	0	0	0	0	154	2-16-90	0.0000	0.0000
0	0	0	0	0	155	2-20-90	0.0000	0.0000

CBS-Gemeinhardt
Daily Operation Averages

Temp in	Temp out	CFM	ppm cor	ppm	day of oper.	date	pounds/hour	pounds/day
0	0	0	0	0	156	2-21-90	0.0000	0.0000
0	0	0	0	0	157	2-22-90	0.0000	0.0000
0	0	0	0	0	158	2-23-90	0.0000	0.0000
0	0	0	0	0	159	2-24-90	0.0000	0.0000
0	0	0	0	0	160	2-25-90	0.0000	0.0000
0	0	0	0	0	161	2-26-90	0.0000	0.0000
0	0	0	0	0	162	2-27-90	0.0000	0.0000
0	0	0	0	0	163	2-28-90	0.0000	0.0000
0	0	0	0	0	164	3-01-90	0.0000	0.0000
39	60	290	88	88	165	3-02-90	0.5694	13.6644
0	0	0	0	0	166	3-03-90	0.0000	0.0000
0	0	0	0	0	167	3-04-90	0.0000	0.0000
0	0	0	0	0	168	3-05-90	0.0000	0.0000
0	0	0	0	0	169	3-06-90	0.0000	0.0000
0	0	0	0	0	170	3-07-90	0.0000	0.0000
0	0	0	0	0	171	3-08-90	0.0000	0.0000
0	0	0	0	0	172	3-09-10	0.0000	0.0000
0	0	0	0	0	173	3-10-90	0.0000	0.0000
0	0	0	0	0	174	3-11-90	0.0000	0.0000
0	0	0	0	0	175	3-12-90	0.0000	0.0000
0	0	0	0	0	176	3-13-90	0.0000	0.0000
0	0	0	0	0	177	3-14-90	0.0000	0.0000
0	0	0	0	0	178	3-15-90	0.0000	0.0000
0	0	0	0	0	179	3-16-90	0.0000	0.0000
0	0	0	0	0	180	3-17-90	0.0000	0.0000
0	0	0	0	0	181	3-18-90	0.0000	0.0000
0	0	0	0	0	182	3-19-90	0.0000	0.0000
0	0	0	0	0	183	3-20-90	0.0000	0.0000
0	0	0	0	0	184	3-21-90	0.0000	0.0000
0	0	0	0	0	185	3-22-90	0.0000	0.0000
44	66	288	7	7	186	3-23-90	0.0450	1.0794

CBS-Gemeinhardt
Daily Operation Averages

Temp in	Temp out	CFM	ppm cor	ppm	day of oper.	date	pounds/hour	pounds/day
0	0	0	0	0	187	3-24-90	0.0000	0.0000
0	0	0	0	0	188	3-25-90	0.0000	0.0000
0	0	0	0	0	189	3-26-90	0.0000	0.0000
0	0	0	0	0	190	3-27-90	0.0000	0.0000
0	0	0	0	0	191	3-28-90	0.0000	0.0000
0	0	0	0	0	192	3-29-90	0.0000	0.0000
47	68	284	6	6	193	3-30-90	0.0380	0.9124
50	71	274	5	5	194	3-31-90	0.0306	0.7336
52	72	278	5	5	195	4-01-90	0.0310	0.7443
48	66	281	5	5	196	4-02-90	0.0313	0.7523
47	65	280	5	5	197	4-03-90	0.0312	0.7496
44	62	280	5	5	198	4-04-90	0.0312	0.7496
0	0	0	0	0	199	4-05-90	0.0000	0.0000
0	0	0	0	0	200	4-06-90	0.0000	0.0000
0	0	0	0	0	201	4-07-90	0.0000	0.0000
0	0	0	0	0	202	4-08-90	0.0000	0.0000
0	0	0	0	0	203	4-09-90	0.0000	0.0000
0	0	0	0	0	204	4-10-90	0.0000	0.0000
48	62	284	5	5	205	4-11-90	0.0317	0.7603
46	65	287	4	4	206	4-12-90	0.0256	0.6147
49	70	286	4	4	207	4-13-90	0.0255	0.6125
48	68	282	3	3	208	4-14-90	0.0189	0.4530
48	70	282	4	4	209	4-15-90	0.0252	0.6040
50	70	282	4	4	210	4-16-90	0.0252	0.6040
46	66	288	4	4	211	4-17-90	0.0257	0.6168
49	69	288	4	4	212	4-18-90	0.0257	0.6168
51	73	284	4	4	213	4-19-90	0.0253	0.6083
54	77	280	3	3	214	4-20-90	0.0187	0.4498
57	80	284	3	3	215	4-21-90	0.0190	0.4562
56	81	283	4	4	216	4-22-90	0.0253	0.6061
64	86	278	5	5	217	4-23-90	0.0310	0.7443

CBS-Gemeinhardt
Daily Operation Averages

Temp in	Temp out	CFM	ppm cor	ppm	day of oper.	date	pounds/hour	pounds/day
64	86	276	5	5	218	4-24-90	0.0308	0.7389
67	89	277	6	6	219	4-25-90	0.0371	0.8899
66	88	277	6	6	220	4-26-90	0.0371	0.8899
67	88	277	6	6	221	4-27-90	0.0371	0.8899
0	0	0	0	0	222	4-28-90	0.0000	0.0000
0	0	0	0	0	223	4-29-90	0.0000	0.0000
0	0	0	0	0	224	4-30-90	0.0000	0.0000
0	0	0	0	0	225	4-31-90	0.0000	0.0000
0	0	0	0	0	226	5-01-90	0.0000	0.0000
0	0	0	0	0	227	5-02-90	0.0000	0.0000
0	0	0	0	0	228	5-03-90	0.0000	0.0000
0	0	0	0	0	229	5-04-90	0.0000	0.0000
0	0	0	0	0	230	5-05-90	0.0000	0.0000
0	0	0	0	0	231	5-06-90	0.0000	0.0000
0	0	0	0	0	232	5-07-90	0.0000	0.0000
0	0	0	0	0	233	5-08-90	0.0000	0.0000
0	0	0	0	0	234	5-09-90	0.0000	0.0000
0	0	0	0	0	235	5-10-90	0.0000	0.0000
0	0	0	0	0	236	5-12-90	0.0000	0.0000
0	0	0	0	0	237	5-13-90	0.0000	0.0000
0	0	0	0	0	238	5-14-90	0.0000	0.0000
0	0	0	0	0	239	5-15-90	0.0000	0.0000
0	0	0	0	0	240	5-16-90	0.0000	0.0000
0	0	0	0	0	241	5-17-90	0.0000	0.0000
0	0	0	0	0	242	5-18-90	0.0000	0.0000
0	0	0	0	0	243	5-19-90	0.0000	0.0000
0	0	0	0	0	244	5-20-90	0.0000	0.0000
0	0	0	0	0	245	5-21-90	0.0000	0.0000
0	0	0	0	0	246	5-22-90	0.0000	0.0000
0	0	0	0	0	247	5-23-90	0.0000	0.0000
0	0	0	0	0	248	5-24-90	0.0000	0.0000

CBS-Gemeinhardt
Daily Operation Averages

Temp in	Temp out	CFM	ppm cor	ppm	day of oper.	date	pounds/hour	pounds/day
0	0	0	0	0	249	5-25-90	0.0000	0.0000
0	0	0	0	0	250	5-26-90	0.0000	0.0000
0	0	0	0	0	251	5-27-90	0.0000	0.0000
0	0	0	0	0	252	5-28-90	0.0000	0.0000
0	0	0	0	0	253	5-29-90	0.0000	0.0000
0	0	0	0	0	254	5-30-90	0.0000	0.0000
0	0	0	0	0	255	5-31-90	0.0000	0.0000
0	0	0	0	0	256	6-01-90	0.0000	0.0000
0	0	0	0	0	257	6-02-90	0.0000	0.0000
0	0	0	0	0	258	6-03-90	0.0000	0.0000
0	0	0	0	0	259	6-04-90	0.0000	0.0000
0	0	0	0	0	260	6-05-90	0.0000	0.0000
0	0	0	0	0	261	6-06-90	0.0000	0.0000
0	0	0	0	0	262	6-07-90	0.0000	0.0000
0	0	0	0	0	263	6-08-90	0.0000	0.0000
0	0	0	0	0	264	6-09-90	0.0000	0.0000
0	0	0	0	0	265	6-10-90	0.0000	0.0000
0	0	0	0	0	266	6-11-90	0.0000	0.0000
0	0	0	0	0	267	6-12-90	0.0000	0.0000
0	0	0	0	0	268	6-13-90	0.0000	0.0000
0	0	0	0	0	269	6-14-90	0.0000	0.0000
0	0	0	0	0	270	6-15-90	0.0000	0.0000
0	0	0	0	0	271	6-16-90	0.0000	0.0000
0	0	0	0	0	272	6-17-90	0.0000	0.0000
0	0	0	0	0	273	6-18-90	0.0000	0.0000
0	0	0	0	0	274	6-19-90	0.0000	0.0000
74	94	284	17	17	275	6-20-90	0.1077	2.5851
69	87	284	2	2	276	6-21-90	0.0127	0.3041
72	91	283	4	4	277	6-22-90	0.0253	0.6061
69	87	284	2	2	278	6-23-90	0.0127	0.3041
72	91	285	2	2	279	6-24-90	0.0127	0.3052

CBS-Gemeinhardt
Daily Operation Averages

Temp in	Temp out	CFM	ppm cor	ppm	day of oper.	date	pounds/hour	pounds/day
74	95	288	2	2	280	6-25-90	0.0129	0.3084
73	93	287	2	2	271	6-26-90	0.0128	0.3073
77	97	284	2	2	282	6-27-90	0.0127	0.3041
76	96	285	1	1	283	6-28-90	0.0064	0.1526
75	95	288	1	1	284	6-29-90	0.0064	0.1542
78	100	283	1	1	285	6-30-90	0.0063	0.1515
78	98	283	1	1	286	7-01-90	0.0063	0.1515
78	98	274	1	1	287	7-02-90	0.0061	0.1467
79	99	272	2	2	288	7-03-90	0.0121	0.2913
84	105	270	2	2	289	7-04-90	0.0120	0.2891
80	100	280	1	1	290	7-05-90	0.0062	0.1499
77	96	274	1	1	291	7-06-90	0.0061	0.1467
76	95	277	1	1	292	7-07-90	0.0062	0.1483
82	102	272	2	2	293	7-08-90	0.0121	0.2913
83	104	271	2	2	294	7-09-90	0.0121	0.2902
78	98	274	1	1	295	7-10-90	0.0061	0.1467
73	92	273	1	1	296	7-11-90	0.0061	0.1462
74	93	273	1	1	297	7-12-90	0.0061	0.1462
71	89	276	0	0	298	7-13-90	0.0000	0.0000
73	92	272	0	0	299	7-14-90	0.0000	0.0000
74	93	274	0	0	300	7-15-90	0.0000	0.0000
0	0	0	0	0	301	7-16-90	0.0000	0.0000
0	0	0	0	0	302	7-17-90	0.0000	0.0000
0	0	0	0	0	303	7-18-90	0.0000	0.0000
0	0	0	0	0	304	7-19-90	0.0000	0.0000
0	0	0	0	0	305	7-20-90	0.0000	0.0000
0	0	0	0	0	306	7-21-90	0.0000	0.0000
0	0	0	0	0	307	7-22-90	0.0000	0.0000
0	0	0	0	0	308	7-23-90	0.0000	0.0000
80	103	277	2	2	309	7-24-90	0.0124	0.2968
72	92	279	1	1	310	7-25-90	0.0062	0.1494

CBS-Gemeinhardt
Daily Operation Averages

Temp in	Temp out	CFM	ppm cor	ppm	day of oper.	date	pounds/hour	pounds/day
0	0	0	0	0	311	7-26-90	0.0000	0.0000
0	0	0	0	0	312	7-27-90	0.0000	0.0000
0	0	0	0	0	313	7-28-90	0.0000	0.0000
0	0	0	0	0	314	7-29-90	0.0000	0.0000
0	0	0	0	0	315	7-30-90	0.0000	0.0000
0	0	0	0	0	316	7-31-90	0.0000	0.0000
0	0	0	0	0	317	8-01-90	0.0000	0.0000
0	0	0	0	0	318	8-02-90	0.0000	0.0000
0	0	0	0	0	319	8-03-90	0.0000	0.0000
0	0	0	0	0	320	8-04-90	0.0000	0.0000
0	0	0	0	0	321	8-05-90	0.0000	0.0000
0	0	0	0	0	322	8-06-90	0.0000	0.0000
0	0	0	0	0	323	8-07-90	0.0000	0.0000
0	0	0	0	0	324	8-08-90	0.0000	0.0000
0	0	0	0	0	325	8-09-90	0.0000	0.0000
78	103	280	1	1	326	8-10-90	0.0062	0.1499
73	95	282	0	0	327	8-11-90	0.0000	0.0000
72	95	281	0	0	328	8-12-90	0.0000	0.0000
71	94	282	0	0	329	8-13-90	0.0000	0.0000
72	96	283	1	1	330	8-14-90	0.0063	0.1515
72	96	284	0	0	331	8-15-90	0.0000	0.0000
0	0	0	0	0	332	8-16-90	0.0000	0.0000
0	0	0	0	0	333	8-17-90	0.0000	0.0000
0	0	0	0	0	334	8-18-90	0.0000	0.0000
0	0	0	0	0	335	8-19-90	0.0000	0.0000
0	0	0	0	0	336	8-20-90	0.0000	0.0000
0	0	0	0	0	337	8-21-90	0.0000	0.0000
0	0	0	0	0	338	8-22-90	0.0000	0.0000
0	0	0	0	0	339	8-23-90	0.0000	0.0000
0	0	0	0	0	340	8-24-90	0.0000	0.0000
0	0	0	0	0	341	8-25-90	0.0000	0.0000

CBS-Gemeinhardt
Daily Operation Averages

Temp in	Temp out	CFM	ppm cor	ppm	day of oper.	date	pounds/hour	pounds/day
0	0	0	0	0	342	8-26-90	0.0000	0.0000
0	0	0	0	0	343	8-27-90	0.0000	0.0000
0	0	0	0	0	345	8-28-90	0.0000	0.0000
0	0	0	0	0	346	8-29-90	0.0000	0.0000
0	0	0	0	0	347	8-30-90	0.0000	0.0000
0	0	0	0	0	348	8-31-90	0.0000	0.0000
0	0	0	0	0	349	9-01-90	0.0000	0.0000
0	0	0	0	0	350	9-02-90	0.0000	0.0000
0	0	0	0	0	351	9-03-90	0.0000	0.0000
0	0	0	0	0	352	9-04-90	0.0000	0.0000
0	0	0	0	0	353	9-05-90	0.0000	0.0000
0	0	0	0	0	356	9-06-90	0.0000	0.0000
0	0	0	0	0	357	9-07-90	0.0000	0.0000
0	0	0	0	0	358	9-08-90	0.0000	0.0000
0	0	0	0	0	359	9-09-90	0.0000	0.0000
0	0	0	0	0	360	9-10-90	0.0000	0.0000
0	0	0	0	0	361	9-11-90	0.0000	0.0000
0	0	0	0	0	362	9-12-90	0.0000	0.0000
0	0	0	0	0	363	9-13-90	0.0000	0.0000
0	0	0	0	0	364	9-14-90	0.0000	0.0000
0	0	0	0	0	365	9-15-90	0.0000	0.0000
0	0	0	0	0	366	9-16-90	0.0000	0.0000
0	0	0	0	0	367	9-17-90	0.0000	0.0000
70	89	292	1	1	368	9-18-90	0.0065	0.1563
69	88	290	1	1	369	9-19-90	0.0065	0.1553
69	90	292	1	1	370	9-20-90	0.0065	0.1563
68	88	290	0	0	371	9-21-90	0.0000	0.0000
66	86	294	0	0	372	9-22-90	0.0000	0.0000
64	83	293	1	1	373	9-23-90	0.0065	0.1569
0	0	0	0	0	374	9-24-90	0.0000	0.0000
0	0	0	0	0	375	9-25-90	0.0000	0.0000

CBS-Gemeinhardt
Daily Operation Averages

Temp in	Temp out	CFM	ppm cor	ppm	day of oper.	date	pounds/hour	pounds/day
0	0	0	0	0	376	9-26-90	0.0000	0.0000
0	0	0	0	0	377	9-27-90	0.0000	0.0000
0	0	0	0	0	378	9-28-90	0.0000	0.0000
0	0	0	0	0	379	9-29-90	0.0000	0.0000
0	0	0	0	0	380	9-30-90	0.0000	0.0000
0	0	0	0	0	381	10-01-90	0.0000	0.0000
0	0	0	0	0	382	10-02-90	0.0000	0.0000
0	0	0	0	0	383	10-03-90	0.0000	0.0000
0	0	0	0	0	384	10-04-90	0.0000	0.0000
0	0	0	0	0	385	10-05-90	0.0000	0.0000
0	0	0	0	0	386	10-06-90	0.0000	0.0000
0	0	0	0	0	387	10-07-90	0.0000	0.0000
0	0	0	0	0	388	10-08-90	0.0000	0.0000
0	0	0	0	0	389	10-09-90	0.0000	0.0000
0	0	0	0	0	390	10-10-90	0.0000	0.0000
0	0	0	0	0	391	10-11-90	0.0000	0.0000
0	0	0	0	0	392	10-12-90	0.0000	0.0000
0	0	0	0	0	393	10-13-90	0.0000	0.0000
0	0	0	0	0	394	10-14-90	0.0000	0.0000
0	0	0	0	0	395	10-15-90	0.0000	0.0000
0	0	0	0	0	396	10-16-90	0.0000	0.0000
0	0	0	0	0	397	10-17-90	0.0000	0.0000
0	0	0	0	0	398	10-18-90	0.0000	0.0000
0	0	0	0	0	399	10-19-90	0.0000	0.0000
0	0	0	0	0	400	10-20-90	0.0000	0.0000
0	0	0	0	0	401	10-21-90	0.0000	0.0000
0	0	0	0	0	402	10-22-90	0.0000	0.0000
0	0	0	0	0	403	10-23-90	0.0000	0.0000
0	0	0	0	0	404	10-24-90	0.0000	0.0000
0	0	0	0	0	405	10-25-90	0.0000	0.0000
0	0	0	0	0	406	10-26-90	0.0000	0.0000

CBS-Gemeinhardt
Daily Operation Averages

Temp in	Temp out	CFM	ppm cor	ppm	day of oper.	date	pounds/hour	pounds/day
0	0	0	0	0	407	10-27-90	0.0000	0.0000
0	0	0	0	0	408	10-28-90	0.0000	0.0000
0	0	0	0	0	409	10-29-90	0.0000	0.0000
0	0	0	0	0	410	10-30-90	0.0000	0.0000
0	0	0	0	0	411	10-31-90	0.0000	0.0000
0	0	0	0	0	412	11-01-90	0.0000	0.0000
0	0	0	0	0	413	11-02-90	0.0000	0.0000
0	0	0	0	0	414	11-03-90	0.0000	0.0000
0	0	0	0	0	415	11-04-90	0.0000	0.0000
0	0	0	0	0	416	11-05-90	0.0000	0.0000
0	0	0	0	0	417	11-06-90	0.0000	0.0000
0	0	0	0	0	418	11-07-90	0.0000	0.0000
0	0	0	0	0	419	11-08-90	0.0000	0.0000
0	0	0	0	0	420	11-09-90	0.0000	0.0000
0	0	0	0	0	421	11-10-90	0.0000	0.0000
0	0	0	0	0	422	11-11-90	0.0000	0.0000
0	0	0	0	0	423	11-12-90	0.0000	0.0000
0	0	0	0	0	424	11-13-90	0.0000	0.0000
0	0	0	0	0	425	11-14-90	0.0000	0.0000
0	0	0	0	0	426	11-15-90	0.0000	0.0000
0	0	0	0	0	427	11-16-90	0.0000	0.0000
0	0	0	0	0	428	11-17-90	0.0000	0.0000
0	0	0	0	0	429	11-18-90	0.0000	0.0000
0	0	0	0	0	430	11-19-90	0.0000	0.0000
0	0	0	0	0	431	11-20-90	0.0000	0.0000
0	0	0	0	0	432	11-21-90	0.0000	0.0000
0	0	0	0	0	433	11-22-90	0.0000	0.0000
0	0	0	0	0	434	11-23-90	0.0000	0.0000
0	0	0	0	0	435	11-24-90	0.0000	0.0000
0	0	0	0	0	436	11-25-90	0.0000	0.0000
0	0	0	0	0	437	11-26-90	0.0000	0.0000

CBS-Gemeinhardt
Daily Operation Averages

Temp in	Temp out	CFM	ppm cor	ppm	day of oper.	date	pounds/hour	pounds/day
0	0	0	0	0	438	11-27-90	0.0000	0.0000
0	0	0	0	0	439	11-28-90	0.0000	0.0000
0	0	0	0	0	440	11-29-90	0.0000	0.0000
0	0	0	0	0	441	11-30-90	0.0000	0.0000
0	0	0	0	0	442	12-01-90	0.0000	0.0000
0	0	0	0	0	443	12-02-90	0.0000	0.0000
0	0	0	0	0	444	12-03-90	0.0000	0.0000
0	0	0	0	0	444	12-04-90	0.0000	0.0000
0	0	0	0	0	445	12-05-90	0.0000	0.0000
0	0	0	0	0	446	12-06-90	0.0000	0.0000
0	0	0	0	0	447	12-07-90	0.0000	0.0000
0	0	0	0	0	448	12-08-90	0.0000	0.0000
0	0	0	0	0	449	12-09-90	0.0000	0.0000
0	0	0	0	0	450	12-10-90	0.0000	0.0000
0	0	0	0	0	451	12-11-90	0.0000	0.0000
0	0	0	0	0	452	12-12-90	0.0000	0.0000
0	0	0	0	0	453	12-13-90	0.0000	0.0000
0	0	0	0	0	454	12-14-90	0.0000	0.0000
0	0	0	0	0	455	12-15-90	0.0000	0.0000
0	0	0	0	0	456	12-16-90	0.0000	0.0000
0	0	0	0	0	457	12-17-90	0.0000	0.0000
0	0	0	0	0	458	12-18-90	0.0000	0.0000
0	0	0	0	0	459	12-19-90	0.0000	0.0000
0	0	0	0	0	460	12-20-90	0.0000	0.0000
0	0	0	0	0	461	12-21-90	0.0000	0.0000
0	0	0	0	0	462	12-22-90	0.0000	0.0000
0	0	0	0	0	463	12-23-90	0.0000	0.0000
0	0	0	0	0	464	12-24-90	0.0000	0.0000

CBS-Gemeinhardt
Daily Operation Averages

Temp in	Temp out	CFM	ppm cor	ppm	day of oper.	date	pounds/hour	pounds/day
0	0	0	0	0	465	12-25-90	0.0000	0.0000
0	0	0	0	0	466	12-26-90	0.0000	0.0000
0	0	0	0	0	467	12-27-90	0.0000	0.0000
0	0	0	0	0	468	12-28-90	0.0000	0.0000

Total Material Removed 661.289 Pounds

APPENDIX B

SHUTDOWN JUSTIFICATION
AUGUST 16, 1990
(REFERENCE 10)

ENSR

ENSR Consulting
and Engineering
35 Nagog Park
Acton, Massachusetts 01720
(508) 635-9500
(508) 635-9180 (FAX)

ENSR Reference No.: 220-DBU-036

August 16, 1990

Mr. Ken Theisen
U.S. Environmental Protection Agency
Region V
230 South Dearborn Street
Chicago, IL 60604

Re: Gemeinhardt Site Soil Remediation
Justification for SVE System Shutdown

Dear Ken:

The soil vapor extraction (SVE) system has been operating at the Gemeinhardt site in Elkhart, Indiana since September, 1989 and has removed a significant quantity of PCE from the soils in the area. The attached report prepared by ENSR Consulting and Engineering provides a review of site conditions, an analysis of the effectiveness of the remediation effort, and a justification for system shutdown.

To summarize the report, two out of the three shutdown criteria have been met. The third criterion (1 mg/kg PCE in soil) was not met, probably because of recontamination of the soil by contaminated groundwater. The calculated PCE removal rate dropped from an initial rate of 16 lb per day to the current rate of 0.3 lb/day. The current rate has been essentially constant over the past several weeks, leading us to believe that the system has reached its practical limits of effectiveness. Considering the large quantity of PCE removed (approximately 700 lb), we feel that effective remediation of the soil has been accomplished. Therefore, we recommend that the system be shut down.

Please call me if you have any questions.

Sincerely,

David B. Urban, P.E.
Senior Project Manager

ENSR

cc: J. Horowitz, P.E. - CBS
R. Clemens - ENSR
C. Davis, Esq. - GPH
J. Wingard, P.E. - EIS
J. Barbato - ENSR
J. Schiffgens - ENSR

attachment

ENSR

Gemeinhardt Site Soil Remediation
Justification for SVE System Shutdown

The soil vapor extraction (SVE) system has been operating at the Gemeinhardt site in Elkhart, Indiana since September, 1989 for the purpose of removing PCE from the soils in the area. This report provides a review of site conditions, an analysis of the effectiveness of the remediation effort, and a justification for system shutdown.

1. Pre-remediation Conditions

In October 1988, soils at the Gemeinhardt site near the southeast corner of the building were sampled for VOCs. Figure 1 shows the locations of the samples and Table 1 provides the results according to the depth of the sample. PCE was the only VOC found in significant quantities, with concentrations ranging from < 0.007 mg/kg to 55 mg/kg.

Figure 1 also shows the area to be remediated. Total area is approximately 2200 sq ft. Depth to groundwater is approximately 15 feet. The total volume to be remediated was 33,000 cu ft. Assuming a soil density of 96 lb/cu ft (Baumister, 1978), the mass to be remediated was 3.2 x 10^6 lb.

The arithmetic average of the PCE concentrations before remediation shown in Table 1 is 5.8 mg/kg. This average concentration corresponds to a total of 18 lb of PCE in the soil volume. (At a cleanup criterion of 1 mg/kg, 3 lb PCE would remain in the soils after remediation.)

2. SVE System Performance and Shutdown Criteria

The soil vapor extraction system was started on September 14, 1989 and ran through May 10, 1990 before final soil samples were taken. During this time, there were several periods when the unit was not operating as a result of mechanical problems, cold weather conditions, and other miscellaneous concerns. The unit was in normal operation for 132 days during this period out of a possible 235 days. The unit was restarted on June 20, 1990 and is currently operating normally.

The mass of PCE removed from the soil was calculated based on offgas VOC concentration, offgas flow rate, and a PCE/VOC correction factor. Total PCE removed during this period was calculated to be approximately 700 lb. Calculation procedures are attached. This amount does not include the 8 cubic yards of contaminated soil in the abandoned dry well that was removed in January, 1990. This contaminated soil had a PCE content of 447 ppm, amounting to a total of approximately 9 pounds of PCE.

Three shutdown criteria were defined in the Conceptual Design Report (ENSR Document Number 1287-002-008, February, 1989). The following describes these criteria and the performance of the system in relation to these criteria:

> Criterion No. 1: "The soil vapor extraction system will be operated until VOC concentrations in the offgas discharged from the vacuum pump are reduced to a

concentration of less than 1 percent of the initial VOC recovery concentrations in the soil. When this reduced concentration is achieved, the offgas will be resampled five days later, and if the concentration has either remained the same or decreased, then the first criterion has been met, and the system will be shut down."

Field experience: The unit offgas concentrations were less than 1% of the initial offgas concentrations. The initial offgas concentration on 9/14/89 was 422 ppm. The offgas concentrations from 4/12/90 through 4/22/90 were consistently 4 ppm and below, which meets the first criterion. The offgas concentrations from 4/23 through 4/27 were 4 to 7 ppm; the reason for the slight increase may be a result of higher ambient temperatures which increased the soil temperature and consequently the volatility of PCE in the soil. The unit continued to operate until 5/10/90, but no offgas data are available. The unit was shut down on 5/10 for other shutdown tests as described below. It was subsequently restarted on 6/20 and has been operating with offgas concentrations in the 1 to 2 ppm range, which is well below 1% of the initial concentration of 422 ppm.

Criterion No. 2: "Vapor samples from the installed soil vapor monitoring probes will be analyzed immediately after shut-down, and again two days later to check for vapor diffusion and re-establishment of vapor equilibrium in the soil pore space. If the soil vapor concentrations remain the same or
decrease over the two day period, then the second criterion for shut-down has been met."

Field experience: Vapor probes and extraction wells were monitored 1.5 hours after shutdown on 5/10/90 and again on 5/14/90. Low VOC concentrations were measured, in many cases below the detection limit of the analyzer. The 5/14/90 reading showed, in some cases, a slight increase in VOC concentration, and in other cases, a slight decrease. Based on these data, it was judged that the second shutdown criterion was met. (Data are in the unit operating log.)

Prior to the 6/20 restart, it was noted that the groundwater level had risen approximately two feet above normal, which was above the bottom of some of the extraction wells and vapor probes. Vapor phase VOC concentrations in these wells were found to be at elevated levels, as high as 100 ppm, compared to a maximum reading of 10 ppm on 5/14, when groundwater level was below the bottom of the wells. These high readings are evidence of the impact of VOCs in groundwater on the soil remediation. This groundwater effect is discussed later in this report.

On 8/10/90, the SVE unit was operating normally with an offgas PCE concentration of 2 ppm. A test was conducted during which each of the six extraction wells was shut off while the other five operated normally. The system was allowed to equilibrate, and an offgas reading was taken. With either well 3 or 4 shut off, offgas concentration rose to 3 ppm, indicating a smaller share of VOC from these wells. With any of the other wells shut off, offgas concentration remained constant at 2 ppm, indicating that none of the

wells contributed more than its proportional share of VOC to the offgas.

Criterion No. 3: "If the second criterion has been met, two soil samples (one at 5 foot depth and one at 10 foot depth) will be collected from a soil boring adjacent to a soil vapor monitoring probe in the area of highest known VOC near former boring B12. If VOC soil concentrations below the soil treatment standard have been obtained then the third criterion has been met and the cleanup is complete." In the Conceptual Design Report, it is stated that "a cleanup criteri[on] of 1 milligram per kilogram (ppm) was selected, based on experience at similar sites, for a remedial action consisting of excavation, treatment by mechanical aeration, and soil replacement in the same location....The ability of this technology to meet the previously proposed 1 ppm criterion will be confirmed upon completion of a laboratory column test...If the results indicate that this criteri[on] cannot be met, an alternate level will be proposed." Based on the results of the laboratory column tests (ENSR Document 56-RGB-013, March 31, 1989), it was concluded that the 1 ppm criterion was achievable.

Field experience: On May 18, 1990, soil samples were taken at three locations, as shown on the attached site layout drawing (Figure 1), at depths of 5 and 10 feet. The locations and depths chosen had the highest measured VOC concentrations at the site prior to remediation. Three sampling locations were chosen instead of only one, as specified in the shutdown criteria, in order to obtain a more representative indication of the effectiveness of the remediation. As reported to EPA previously, the soil analyses showed VOC concentrations as high as 15 ppm. Results are provided in Table 1.

3. Groundwater Data

Groundwater samples within the remediation area were taken on August 23, 1989 and June 13, 1990. PCE concentrations in the groundwater were 31 mg/l and 3.4 mg/l, respectively. The samples were taken from a piezometer which was installed within the remediation area near the building, as shown on Figure 1. Although the piezometer was not designed for groundwater sampling, it was judged to be adequate for obtaining samples for this purpose.

4. Observations and Analysis of Data

Several observations can be made with regard to the site contamination, SVE system operation, and soil and groundwater analyses:

- Based on offgas flow rates and PCE concentration, over 700 pounds of PCE were removed from the site. This is approximately 40 times the amount originally believed to be in the soil. The reasons for the discrepancy can be 1) the difficulty in getting representative soil samples, as evidenced by the fact that the existence of the dry well that was excavated was not known until the remediation was well underway; other

pockets of highly contaminated soil may also have existed in the area; and 2) groundwater contamination may have contributed to VOCs in the offgas.

- Looking at the soil analyses before and after remediation, and only at the areas that were sampled after remediation, the concentration of PCE in the soil has been reduced significantly, from an average of 10.4 ppm to an average of 5.6 ppm. Table 1 provides analyses of Borings 1, 2, and 3 and the corresponding borings B12, B7, and B11 from previous investigations.

- The site soils have not achieved the original cleanup goal of 1 mg/kg PCE, but this goal was chosen based on the results of a laboratory test. Since the laboratory test did not duplicate field conditions; the results may have overpredicted the removal effectiveness of SVE. The site average PCE concentration (using the latest soil data for the highly contaminated areas and 1988 data for the cleaner areas) is 3.0 mg/kg. Considering that the system is removing very little additional PCE from the site at this time, the current contaminant level appears to be a lower practical limit for remediation of these soils.

- Groundwater level in the area varies by over two feet, depending on season, rainfall, and other factors. As the level rises and then falls, contaminated groundwater remains in the capillary zone of the soil and can provide a large surface area for evaporation of groundwater and volatilization of PCE from the groundwater into the soil air.

- Under subsurface conditions, the equilibrium concentration of PCE in the vapor phase is 231 ppm at the current groundwater concentration of 3.4 ppm. At the initial measured concentration of 31 ppm PCE in groundwater, the equilibrium vapor phase concentration would have been 2100 ppm. Recent measurements of vapor concentrations in the extraction wells before unit re-start were as high as 100 ppm. Unsaturated zone soils may become recontaminated by PCE from the groundwater as the PCE vapors diffuse through the soils.

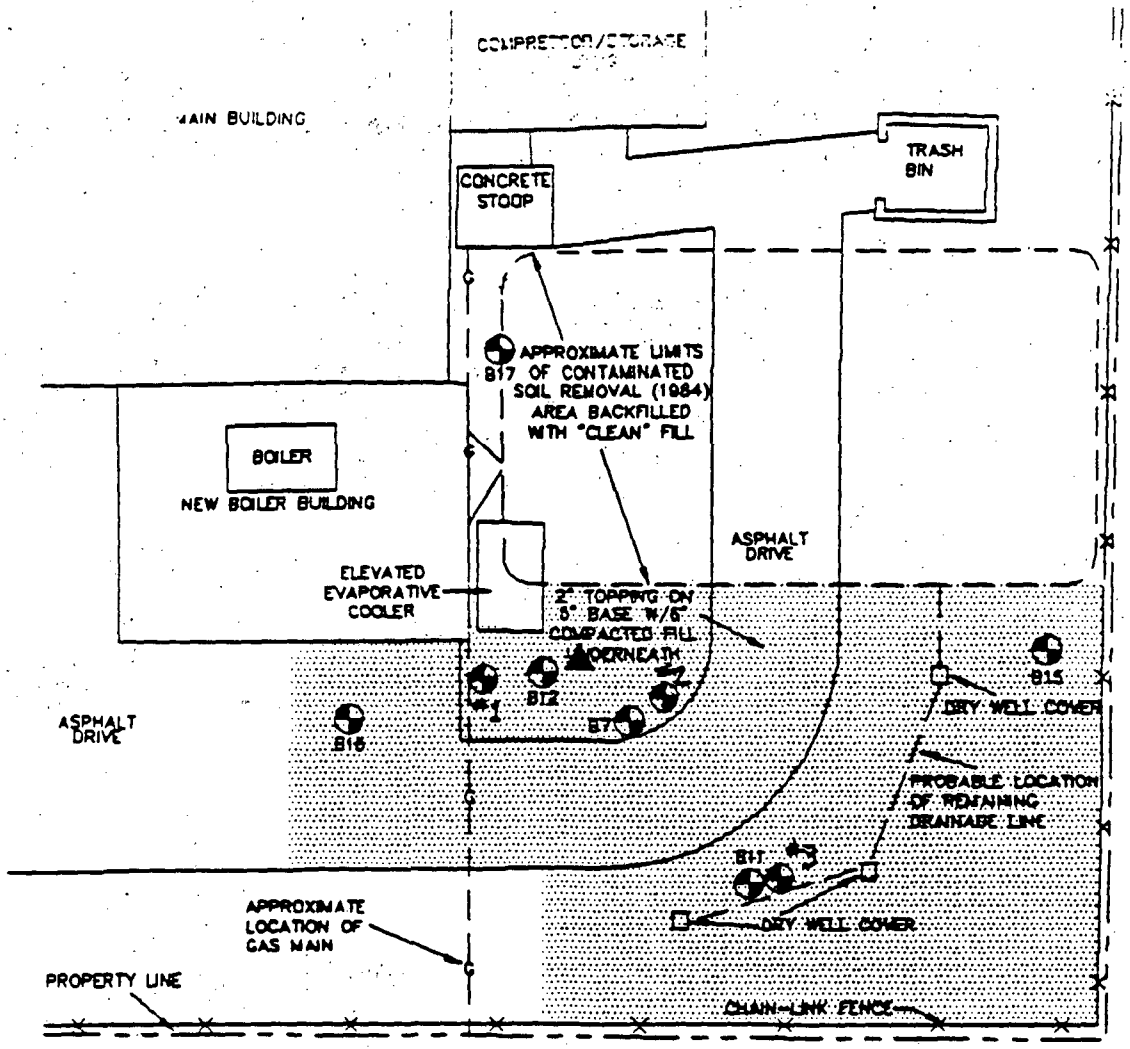
- Recent performance of the SVE system has shown offgas concentrations of 1 to 2 ppm, corresponding to removal rates of approximately 0.3 lb/day. Initial removal rates were on the order of 16 lb/day.

- A simplified empirical analysis: Assume the current removal rate of 0.3 lb/day is due entirely to PCE in groundwater; and that the groundwater contribution is proportional to PCE concentration. At the beginning of the remediation, the PCE removal rate due to groundwater would have been approximately 9 lb/day out of a total of 16 lb/day removed. If it is assumed that the groundwater concentration decreased linearly, then the average removal rate due to groundwater would have been approximately 4.6 lb/day over the course of the remediation. 132 days of operation would have resulted in removal of just over 600 lb of PCE. This amount, along with the amount of PCE removed from the soil, corresponds reasonably well with the total amount removed (700 lb) during the operation of the system.

- The test showing that each well was contributing a proportional share of VOC indicates that the source of VOC is widespread rather in concentrated pockets. Contaminated groundwater is a likely source of VOC.

5. Justification for Shutdown of Soil Vapor Extraction System

Based on the above observations and analyses, it can be concluded that the SVE system has removed a substantial quantity of PCE from the soil, and has now reached the practical limit of remediation for this system in this soil mass. The PCE currently being removed is likely derived from the contaminated groundwater that underlies the site. This groundwater will be remediated with a pump-and-treat system that is currently being designed and is scheduled to be implemented as soon as possible. Therefore, it is recommended that the soil vapor extraction unit be shut down and removed from the site at this time.



NOTES:

1. ALL LOCATIONS ARE APPROXIMATE
2. OFF-SITE DISPOSAL PIT APPROXIMATELY 20 FT. SE FROM THE SE CORNER OF PROPERTY

PROPOSED AREA OF REMEDIATION

BORING LOCATION

PIEZOMETER

N

10 0 10 20

SCALE IN FEET
1" = 10'-0"

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ENSR CONSULTING & ENGINEERING

FIGURE 1
SITE PLAN
GEMEINHARDT INCORPORATED
ELKHART, INDIANA

RLG/DU	1-20-89	1287-007

08/07/90

Table 1
Gemeinhardt Soil Remediation
Summary of Soil Sampling Results
1988 and 1990 Samples

1988 Samples			1990 samples		
Boring	Approx. Depth feet	PCE Conc. mg/kg	Equiv. Boring	Approx. Depth feet	PCE Conc mg/kg
B7	4	14	2	5	< 0.5
	7	0.31		10	15
	10	0.28			
B11	4	< .007	3	5	4.4
	10	0.015		10	2.6
	14	2.9			
B12	10	55	1	5	11
				10	< 0.3
B15	4	< .007			
	7	< .007			
	10	0.052			
B16	10	0.63			
	13	0.1			
	14	2.3			
Average:	B7, B11, B12:	10.4	Average:	1, 2, and 3	5.6
	B7, B11, B12, B15, B16	5.8		1, 2, 3, B15, B16	3.0

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ATTACHMENT

Calculation Procedure for PCE Removal Rate

$$M_p = C_p/10^6 \times Q_a \times \frac{1\,\text{mole}}{379\,\text{cu ft}} \times 166\ \text{lb PCE/mole} \times 1440\ \text{min/day}$$

Where:

M_p = mass of PCE in offgas, lb/day
C_p = Concentration of PCE in offgas, ppmv
Q_a = Air flow rate, cu ft/min

During the first day of operation:

C_p was approximately 100 ppmv
Q_a was approximately 260 cu ft/min

$$M_p = 100/10^6 \times 260 \times 1/379 \times 166 \times 1440$$

$$= 16.4\ \text{lb PCE/day}$$

Current operation:

C_p is approximately 2 ppmv
Q_a is approximately 280 cu ft/min

$$M_p = 2/10^6 \times 280 \times 1/379 \times 166 \times 1440$$

$$= 0.35\ \text{lb PCE/day}$$

Note: Gaseous molar volume of 379 cu ft was assumed. Actual may vary slightly, but error was considered inconsequential.

APPENDIX C

SHUTDOWN JUSTIFICATION
JANUARY 29, 1991
(REFERENCE 11)

ENSR

ENSR Consulting
and Engineering
35 Nagog Park
Acton, Massachusetts 01720
(508) 635-9500
(508) 635-9180 (FAX)

ENSR Reference No.: 220-DBU-057

January 29, 1991

Mr. Ken Theisen
U.S. Environmental Protection Agency
Region V
230 South Dearborn Street
Chicago, IL 60604

Re: Gemeinhardt Site Soil Remediation
Justification for SVE System Shutdown
Additional Data Analysis

Dear Ken:

Pursuant to our conference call of December 7, I have reviewed the available data from the Soil Vapor Extraction system at the Gemeinhardt site to develop additional justification for system shutdown. Details of this assessment are provided in the attachment.

Briefly, the available soil vapor probe data show the concentration gradient present in the soil and the effect of PCE in the groundwater on the soil concentrations. The concentration gradient is especially evident when the water table is higher than normal. Offgas data from individual extraction wells indicate little difference among the wells. The conclusions that can be drawn are that there are no significant hot spots in the soil and that the likely source of PCE is the groundwater. Equilibrium calculations indicate that the soil can become recontaminated by the PCE in groundwater to levels well above the remediation goal of 1 mg/kg.

The above conclusions, in conjunction with the conclusions presented in my letter of August 16, 1990 (ENSR Reference No. 220-DBU-036), provide adequate evidence that the SVE system has reached its limit of effectiveness and should therefore be shut down at this time.

Please call me if you have any questions.

Sincerely,

David B. Urban

David B. Urban, P.E.
Senior Project Manager

ENSR

cc: J. Horowitz, P.E. - CBS
R. Clemens - ENSR
C. Davis, Esq. - GPH
J. Wingard, P.E. - EIS
J. Barbato - ENSR
J. Schiffgens - ENSR

attachment

ENSR

ATTACHMENT

Gemeinhardt Site Soil Remediation
Additional Justification for SVE System Shutdown

The soil vapor extraction (SVE) system has been operating at the Gemeinhardt site in Elkhart, Indiana since September, 1989 for the purpose of removing PCE from the soils in the area. A report on the justification for shutdown was issued by ENSR on August 16, 1990 (ENSR Reference No. 220-DBU-036). A conference call was held on December 7, 1990 among Mr. Dom DiGiulio of EPA Kerr Laboratory, Mr. Ken Theisen of EPA Region V, and Mr. Dave Urban of ENSR to discuss the report, EPA's comments on that report, and remediation efforts at the site. The primary outcome of that discussion was that the data presented did not demonstrate to EPA's satisfaction that the groundwater was the primary source of PCE, and that a soil gas survey should be conducted to provide evidence of a soil vapor concentration gradient due to PCE in groundwater. ENSR investigated the logistics and possible results of a soil gas survey and concluded that a one-time survey could be misleading, especially considering the potential for interference from soil moisture on concentration measurements. Therefore, the soil gas survey was put on hold. Instead, available data obtained during 17 months of operation were reanalyzed to better understand the effectiveness of the SVE system. This report provides these additional analyses, which, in conjunction with the August 16 report, justify system shutdown at this time.

Soil Vapor Data

Soil vapor data that have been collected from the vapor probes at the site during SVE operation were tabulated and rearranged to show the effect of depth on concentration. These data are presented in Table 1. In this table, the concentration measurements are also averaged for 6-foot, 9-foot, 10-foot, and 12-foot depths. At a depth of 6 feet, measurements from Vapor Probes 2, 5, 7, 8, 9, 13, and 14 are included. The 9-foot probes include VP-12, VP-15, and VP-16. At 10 feet, measurements from Vapor Probes 1, 6, 10 and 11 are averaged; an adjusted 10-foot average is also presented in which the VP-11 measurements are not included. This probe had high concentrations because of the contaminated dry well nearby; the dry well and VP-11 were removed in March, 1990. The 12-ft values include measurements from VP-3 and VP-4. Figure 1 shows the locations of the vapor probes, as well as the injection wells, extraction wells, and borings.

Figure 2 is a plot of vapor probe concentrations over the operating period of the SVE system. Average concentrations at three depths are shown. Data from the 9-foot level are not shown because they were not available for the entire operation. The 10-foot data do not include VP-11 measurements.

Normal groundwater level at this site is approximately 14 feet below grade. The extraction wells and injection wells were installed such that the bottoms of the wells would be approximately 2 feet above the water table. On June 12 (267 days after startup), it was noted that the water table had risen to a level as much as 6 inches above the bottom of the injection wells; recent heavy rains were the probable cause. As noted on Figure 2, the high water table resulted in greatly increased vapor concentrations. It is not known how long the groundwater remained at the high level, because water table measurements were not a part of the routine monitoring of the operation. This figure shows some important data trends:

1. Since the start of site remediation, a soil vapor concentration gradient that increases with depth has existed; i.e., as the water table is approached, PCE concentration in the soil vapor increases.

2. Through May 14, soil vapor concentrations dropped steadily with time, indicating that the SVE system was removing PCE from the soils.

3. The dramatic increase in soil vapor concentration when groundwater level rose, along with the more pronounced concentration gradient with depth (Figure 2), confirms the impact of groundwater contamination on soil vapor concentrations.

In summary, the vapor probe data provide evidence that PCE in the groundwater does, in fact, migrate into the soil vapor.

Extraction Well Data

Extraction well vapor concentrations are provided in Table 2. These measurements were taken using the same procedures as for the vapor probe measurements, i.e., after the vacuum pumps were shut down and the vapors were allowed to equilibrate (approx. 2 hr). Extraction well averages are reported both with and without the readings from extraction well EW-6; the high levels due to the contaminated material near EW-6 that was subsequently excavated tend to mask the overall data trends. An important observation is that, after the bulk of the site contamination was removed, none of the wells had vapor concentrations significantly different from the others. This trend indicates that the source of PCE was uniform across the site. It can be concluded that groundwater is the likely source.

Table 3 provides the results of a test conducted on September 18, 1990, in which only one extraction well was being drawn from at a time. Unfortunately, extraction well EW-2 could not be shut off, and, therefore, remained open for all readings. These data indicate that all the wells are extracting approximately the same amount of PCE from the soil and groundwater. The highest reading occurred when EW-2 alone was operating, and PCE concentration reached 4 ppm. However, this reading may be misleading because, with all the air (approx. 280 CFM) being drawn through the one well, the air flow pattern around the extraction well would be expected to be quite different from the pattern that would develop when the flow is shared between EW-2 and each of the other wells. The vacuum readings at vapor probes VP-3 and VP-4, which are close to EW-2, were 3 to 4 times higher than normal during this test. These two probes are at a depth of 12 feet, which means that the air flow near the groundwater surface was higher than normal, causing the more concentrated soil vapor to be drawn into the system. The result is a slightly higher offgas concentration from this well compared to the concentrations from the other wells.

The fact that the concentrations from all of the wells were approximately the same indicates that the source of PCE is relatively constant across the site. Once again, it can be concluded that groundwater is the probable source.

Equilibrium considerations

Available data show the concentration of PCE in groundwater to range from 3 to 31 mg/l. Based on a Henry's Law constant of 0.7 at 25 deg C, the equilibrium vapor concentration of PCE is 231 and 2100 ppmv, respectively. As PCE in the groundwater transfers to the vapor phase, it will approach equilibrium with the soil and moisture in the unsaturated soils above the water table. The moisture equilibrium will be based on Henry's Law. The amount adsorbed to the soil particles will be based on the partition coefficient, K_d, for the soil-water system. Bishop, et al[1] report K_d = 1.2 for PCE in a sandy soil with organic carbon content of 0.12%. Although this K_d does not necessarily represent the Gemeinhardt soils, it provides an estimate of the equilibrium PCE levels that would be approached in the soils. Based on these values, the equilibrium PCE content in the soils would be roughly 4 to 40 mg/kg, well above the remediation goal of 1 mg/kg.

[1]D. J. Bishop, J. P. Knezovich, D. W. Rice, Jr., " Sorption Studies of VOCs Related to Soil/Ground Water Contamination at LLNL," NTIS DE89-016698, August, 1989.

This equilibrium analysis indicates that the PCE levels in the site soils may exceed the remediation goal due entirely to the diffusion of PCE from the groundwater. Although the analysis does not consider the rates of diffusion through the soils, it can be concluded that further remediation at this time with the soil vapor extraction system is not justified because, until the groundwater is remediated, the soil could eventually become recontaminated when the SVE system is shut down. As PCE is removed from the groundwater with the planned pump-and-treat system, equilibrium forces will result in the transport of PCE out of the soils via diffusion, infiltration, and water table fluctuations.

Justification for Shutdown of Soil Vapor Extraction System

Based on the above observations and analyses, it can be concluded that the SVE system has removed a substantial quantity of PCE from the soil, and has now reached the practical limit of remediation in this soil mass. The PCE currently being removed is likely derived from the contaminated groundwater that underlies the site, as evidenced by the analyses presented herein in conjunction with the evaluation provided in the initial justification for shutdown (letter of August 16). As part of the Consent Order of January 23, 1990, the contaminated groundwater will be remediated with a pump-and-treat system that is currently being designed and is scheduled to be implemented as soon as possible. Therefore, it is recommended that the soil vapor extraction unit be shut down and removed from the site at this time.

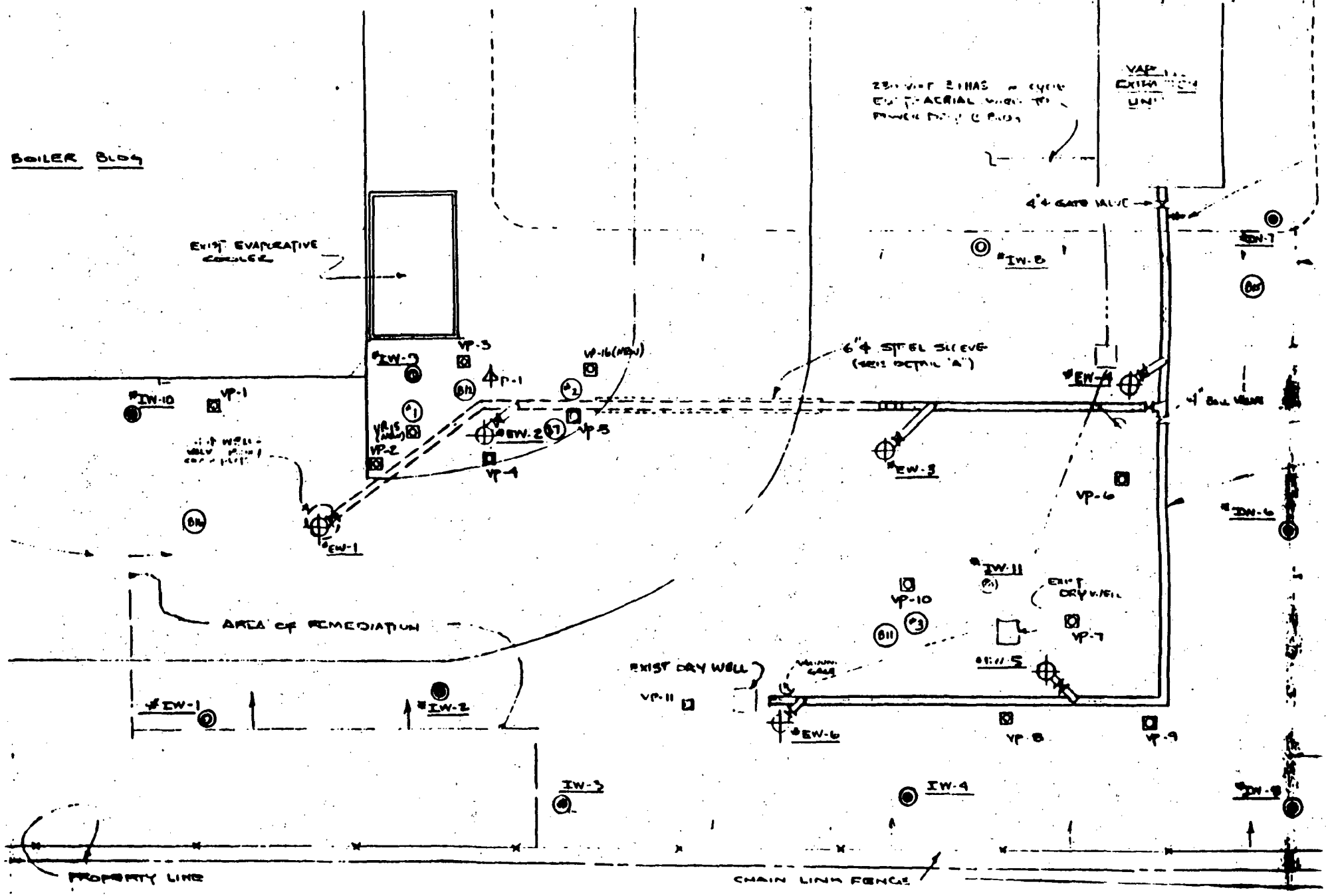


FIGURE 1

PLAN VIEW

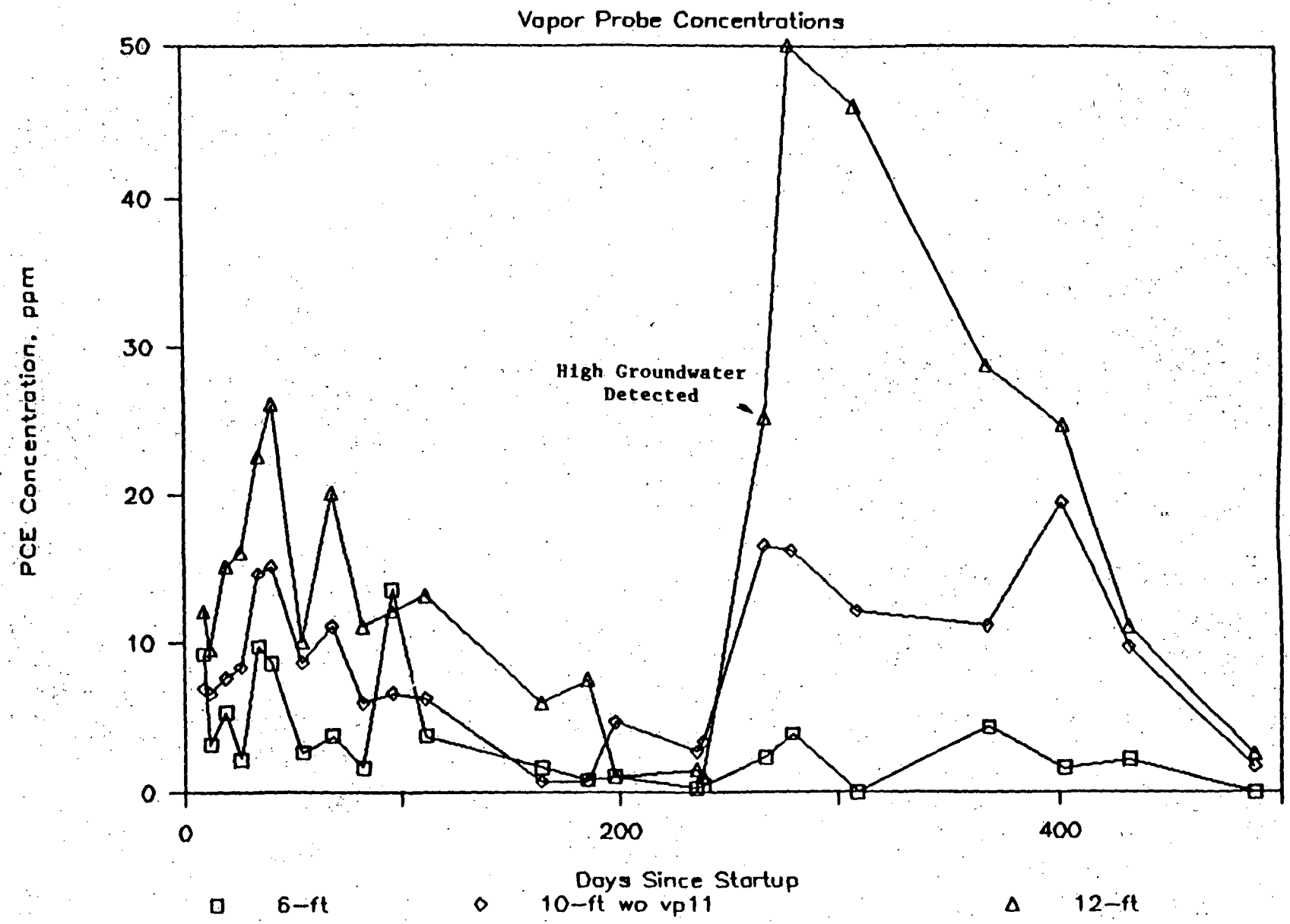
SCALE

LEGEND:

PRE-REMEDIATION BORING

SHUTDOWN BORING

FIGURE 2


Gemeinhardt Site
Vapor Probe Concentrations
PCE Concentration, ppm
50
40
30
20
10
0
0
200
400
Days Since Startup
High Groundwater Detected
6-ft
10-ft wo vp11
12-ft

APPENDIX D

EPA AUTHORIZATION FOR SHUTDOWN
(REFERENCE 12)

UNITED STATES ENVIRONMENTAL PROTECTION AGENCY
REGION 5
230 SOUTH DEARBORN ST.
CHICAGO, ILLINOIS 60604

REPLY TO ATTENTION OF:

February 13,1991

Mr. David Urban
Senior Project Manager
ENSR Consulting and Engineering
35 Nagog Park
Acton, Mass. 01720

Re: Gemeinhardt Site Soil Remediation
Justification for SVE Shutdown

Dear Dave:

I am in receipt of your correspondence of January 29, 1991 concerning your reanalyses of data pertaining to the shutdown of the Soil Vapor Extraction System. After reviewing your submittal, I have concluded that your argument why Criterion 3 cannot be met is valid and should be used as the basis for the system shutdown. Please consider this letter as the United States EPA's authorization to dismantle the system as a result of the shutdown criteria having been met.

I appreciate the effort that you have expended on this portion of the project and I am looking forward to working with you on the remaining aquifer remediation phase.

Sincerely,

Kenneth M Theisen

Kenneth Theisen, OSC Region V

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POLKST

ENSR

ENSR Consulting and Engineering

Alabama	Florence	(205) 740-8240
Alaska	Anchorage	(907) 561-5700
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	Camarillo	(805) 388-3775
	Newport Beach	(714) 476-0321
	San Francisco	(510) 865-1888
Colorado	Fort Collins	(303) 493-8878
Connecticut	Hartford	(203) 657-8910
Illinois	Chicago	(708) 887-1700
Massachusetts	Boston	(508) 635-9500
Minnesota	Minneapolis	(612) 924-0117
New Jersey	Mahwah	(201) 818-0900
	Mt. Laurel	(609) 234-5520
	Somerset	(908) 560-7323
North Carolina	Raleigh	(919) 571-0669
Pennsylvania	Pittsburgh	(412) 261-2910
South Carolina	Rock Hill	(803) 329-9690
Texas	Dallas	(214) 960-6855
	Houston	(713) 520-9900
Washington	Seattle	(206) 881-7700
Puerto Rico	San Juan	(809) 753-9509

Appendix F

Appendix F

Waterloo (Borden) SVE experiment: core data and technical paper

Background:

As part of a series of field experiments investigating the behaviour of chlorinated solvents in the subsurface, a block of the upper aquifer sands and silts at the Canadian Forces Base Borden field site has been hydraulically isolated using sealable sheet pile walls driven through the aquifer and keyed into the underlying aquitard. In July 1991, an experiment was conducted in this cell in which 770 litres (1250 kg) of perchloroethylene (PCE) was released in the centre of the cell and the movement of the solvent liquid was monitored using a variety of geophysical techniques. At the conclusion of the geophysical experimentation, the water level in the cell was lowered to the top of the aquitard and a conventional soil vacuum extraction (SVE) system was installed. The goal of the SVE trial was to evaluate the performance and efficiency of the SVE technology in a relatively homogeneous aquifer under "controlled" conditions. Some of the pertinent details of this SVE field trial are discussed in Attachment 1.

Pre-Remediation Soil Core Analyses:

To establish initial PCE soil conditions prior to the initiation of the SVE trial, two sets of soil cores were collected and analyzed for bulk PCE soil concentration using a methanol extraction method. The first set of eight cores was collected after the geophysical experiment was completed in the Fall of 1991 and were designated as CP-1 to CP-8 as shown in Figure 1. The second set of seven cores was collected when the SVE system was installed in the Fall of 1992 and these cores were identified as C1 to C7 as shown in Figure 1. The bulk soil concentration profiles from both of these sets of cores are presented in Figures 2 to 16.

Post-Remediation Soil Core Analyses:

Eight soil cores (identified as CR-1 to CR-8) were collected from the cell after approximately 185 days (January, 1994) from the start-up of the SVE system. At this point in the remediation process approximately 400 kg of PCE had been removed from the cell. The location of each of these cores (see Figure 1) was selected using the results of a soil gas survey performed in late December 1993. The collected cores spanned the range of soil gas concentrations measured during the soil gas survey. The rationale for the selection of each core is provided below:

CR-1:	This core was collected from an area where soil gas concentrations were between the high concentrations near the centre of the cell and relatively low concentrations at the edge of the cell.
CR-2, CR-3, CR-4:	These cores were collected one metre apart to investigate the bulk PCE soil concentrations from a zone of high soil gas concentrations to a zone of relatively low soil gas concentrations.
CR-5:	This core was collected adjacent to core C7 (a pre-remediation core).
CR-6:	This core was collected adjacent to core C4 (a pre-remediation core).

CR-7	This core was collected adjacent to core C5 (a pre-remediation core).
CR-8	This core was taken from an area that appeared relatively clean based on soil gas concentrations.

These soil cores were collected using a modified version of the coring technique described in Attachment 2. Each core was placed in a jig and the core tube was split longitudinally. A fine wire was used to divide the cores into semi-cylindrical halves. Two sub-samples were collected side-by-side every 5 cm along the core using a 2 mL sampler. One sample was placed into a pre-weighed dry vial for moisture content analysis, and the second sample was placed into a pre-weighed jar containing 10 mL of spectrophotometer grade methanol for PCE concentration analysis. The cores were split and sampled within one hour of collection to minimize volatilization losses.

A total of 888 sub-samples were extracted from the eight cores, 444 of these sub-samples were used to determine bulk PCE concentration (mass of PCE/mass of dry soil), and the remaining 444 sub-samples were used to determine the volumetric soil moisture content.

An aliquot of the methanol from each sample bottle was transferred into an autosampler vial and was initially screened on a gas chromatograph (GC) equipped with a flame ionization detector (FID). All samples that yielded a PCE concentration less than 25 mg of PCE/L of methanol were re-analyzed on a gas chromatograph equipped with an electron capture detector (ECD). The lower detection limit (LDL) on the GC/ECD was statistically determined (Greenberg *et al.*, 1992) as 0.4 µg of PCE/L of methanol. Considering the range of dry soil mass employed in each sample, the 0.4 µg/L LDL in methanol corresponds to an approximate bulk soil LDL of 0.002 mg of PCE/kg of dry soil.

The profiles of bulk soil concentration and moisture content for each post-remediation core are presented in Figures 17 to 24.

References:

Greenberg A. E., R.R. Trussell, and L.S. Clesceri, Standard Methods For the Examination of Water and Wastewater, America Public Health Association, 18 edition, 1992.

ATTACHMENT 1

Figure 1: Location of Soil Cores

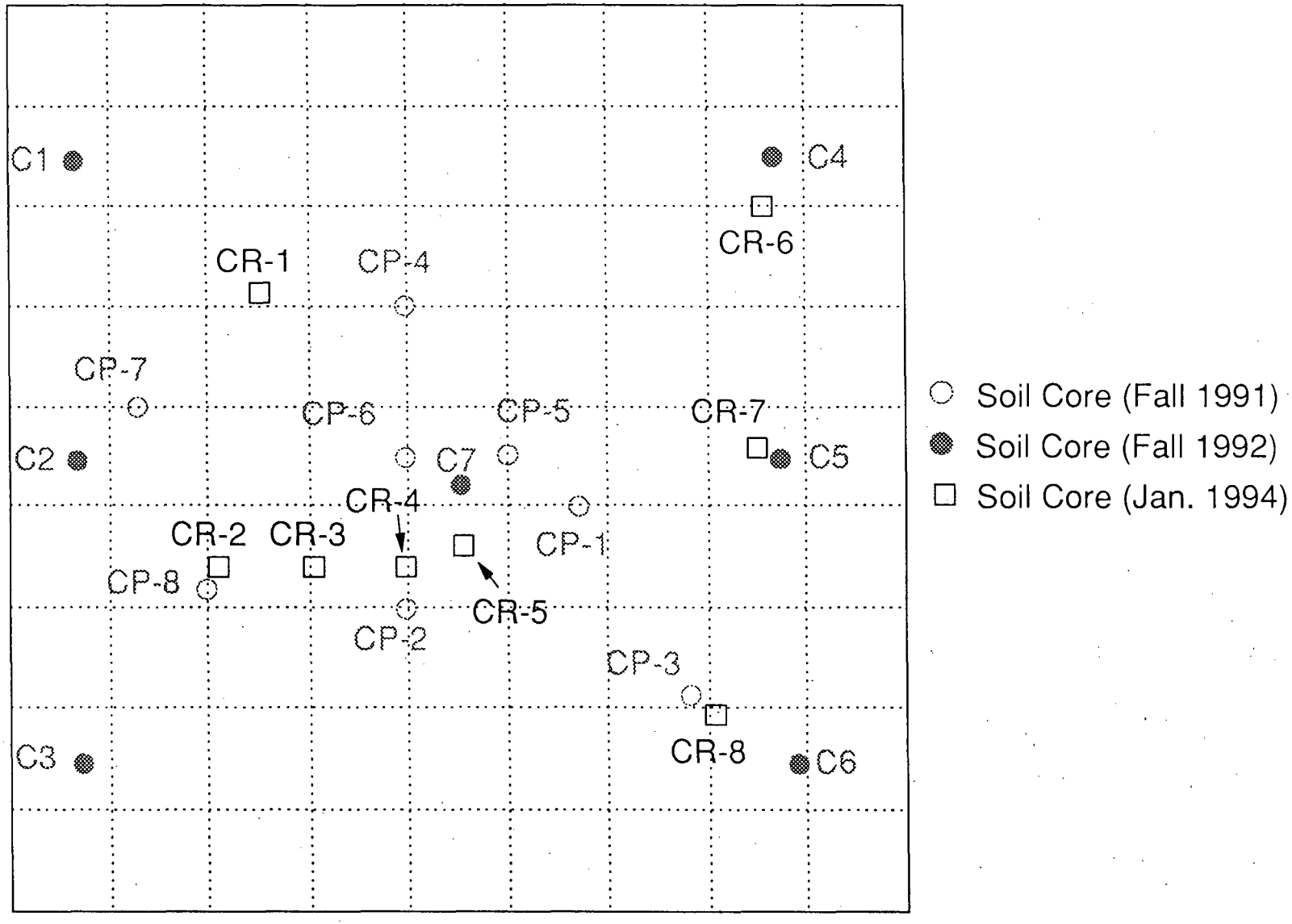


Figure 2: PCE Saturation Profile for Core CP-1

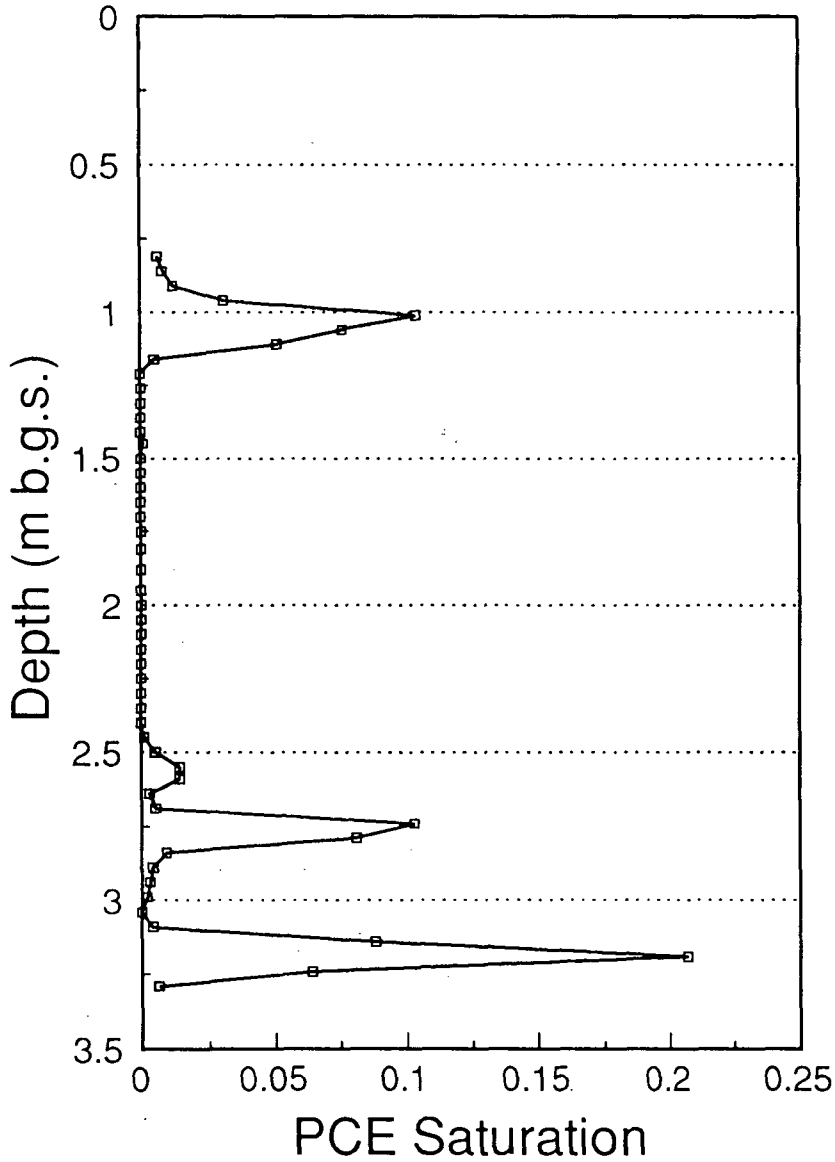


Figure 3: PCE Saturation Profile for Core CP-2

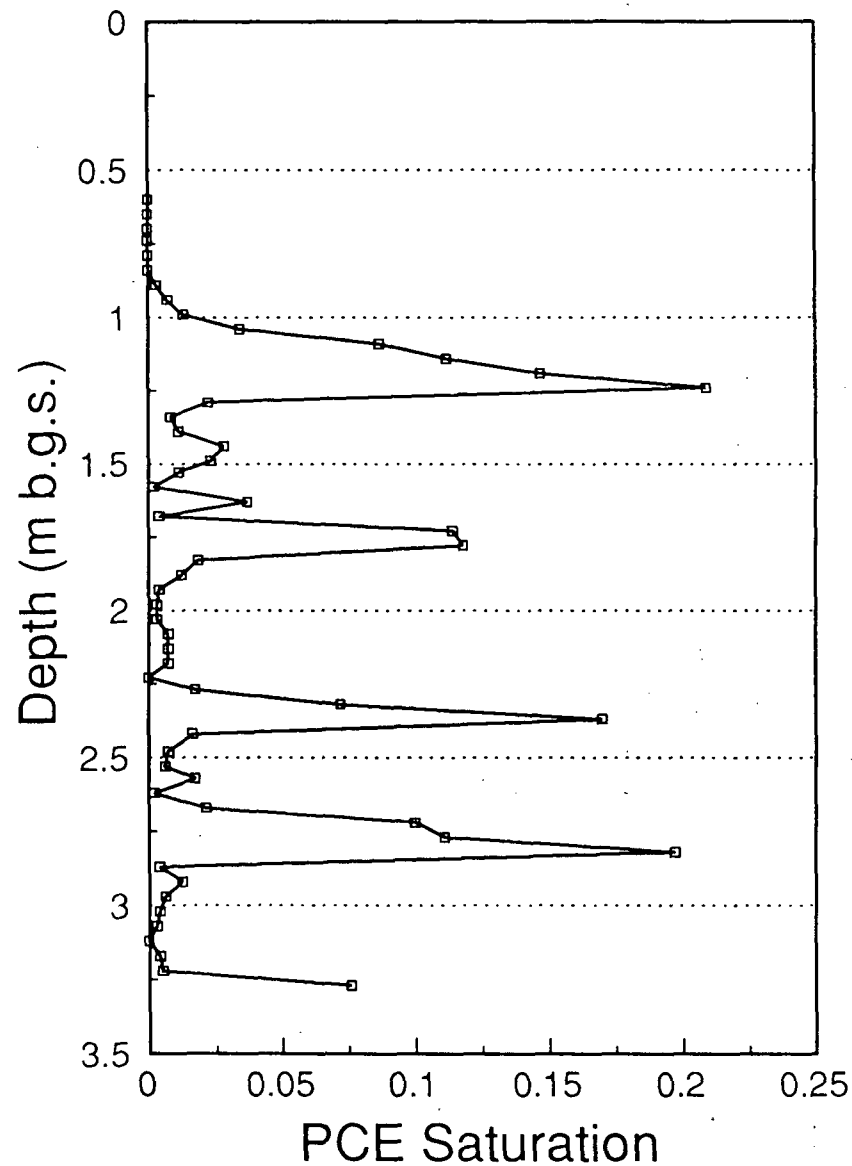


Figure 4: PCE Saturation Profile for Core CP-3

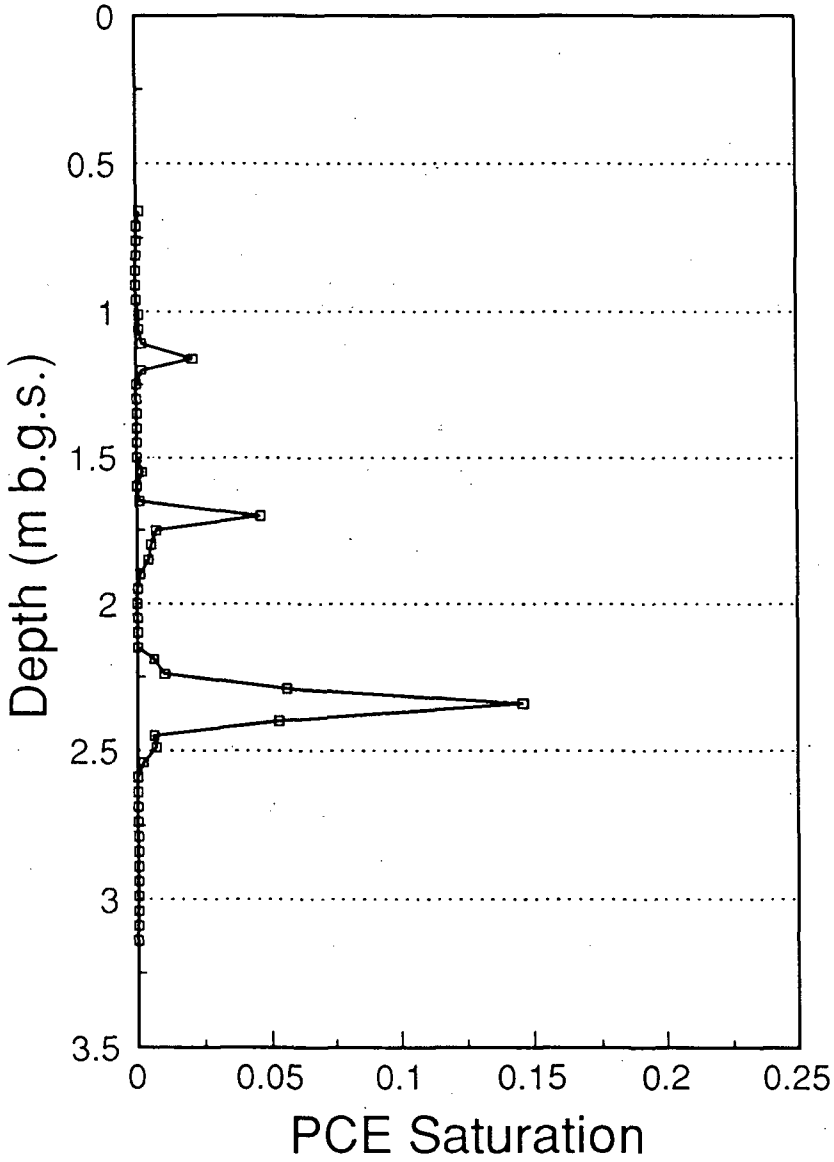


Figure 5: PCE Saturation Profile for Core CP-4

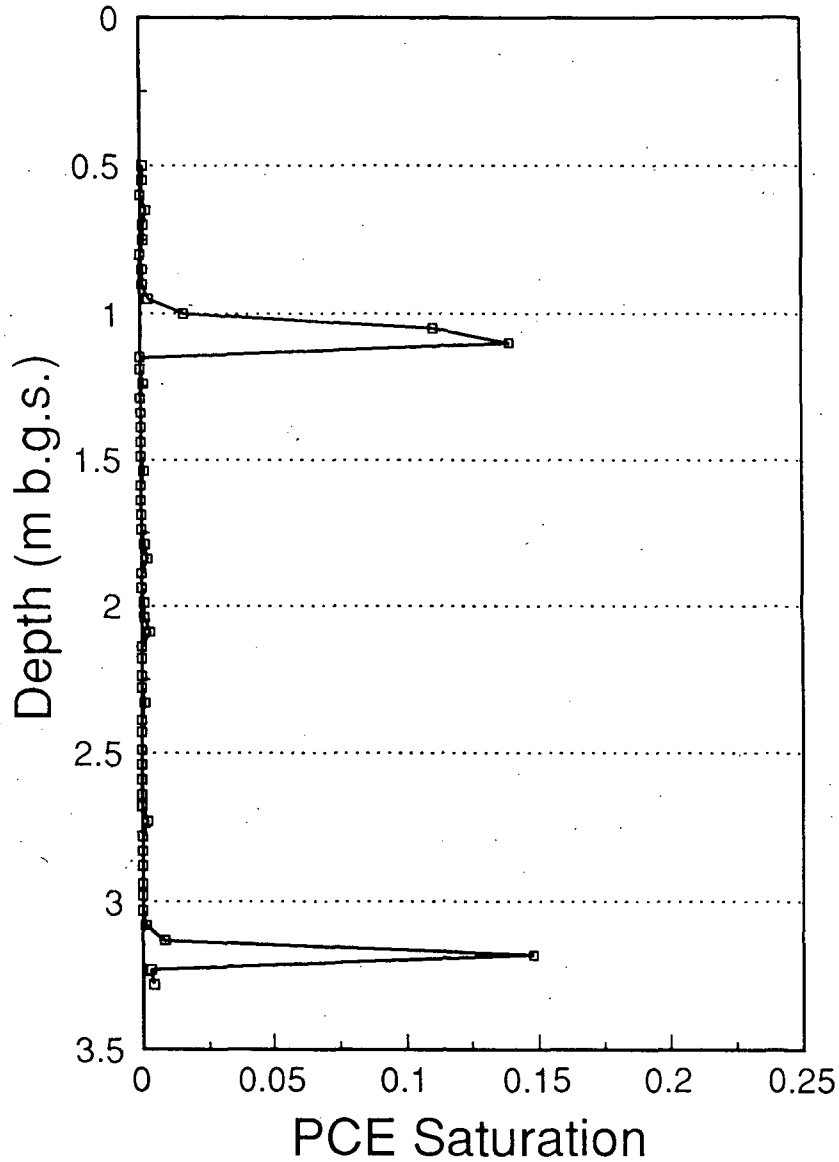


Figure 6: PCE Saturation Profile for Core CP-5

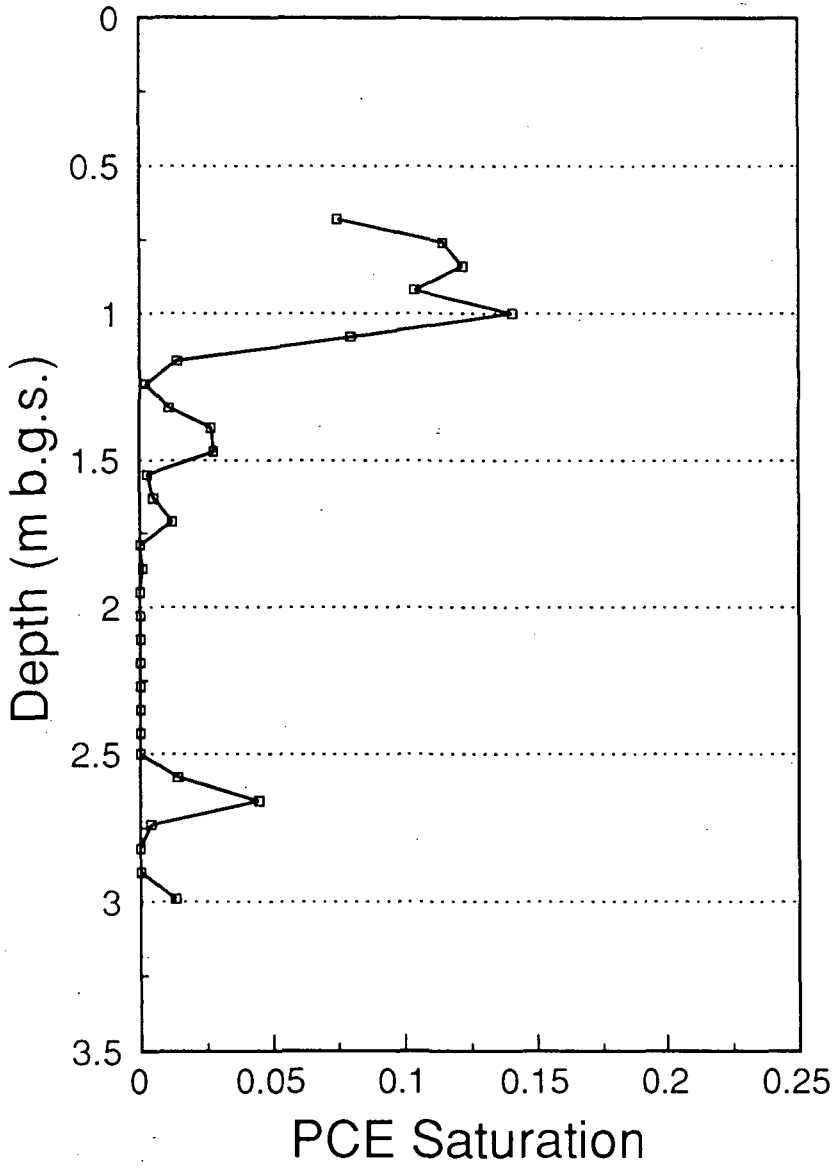


Figure 7: PCE Saturation Profile for Core CP-6

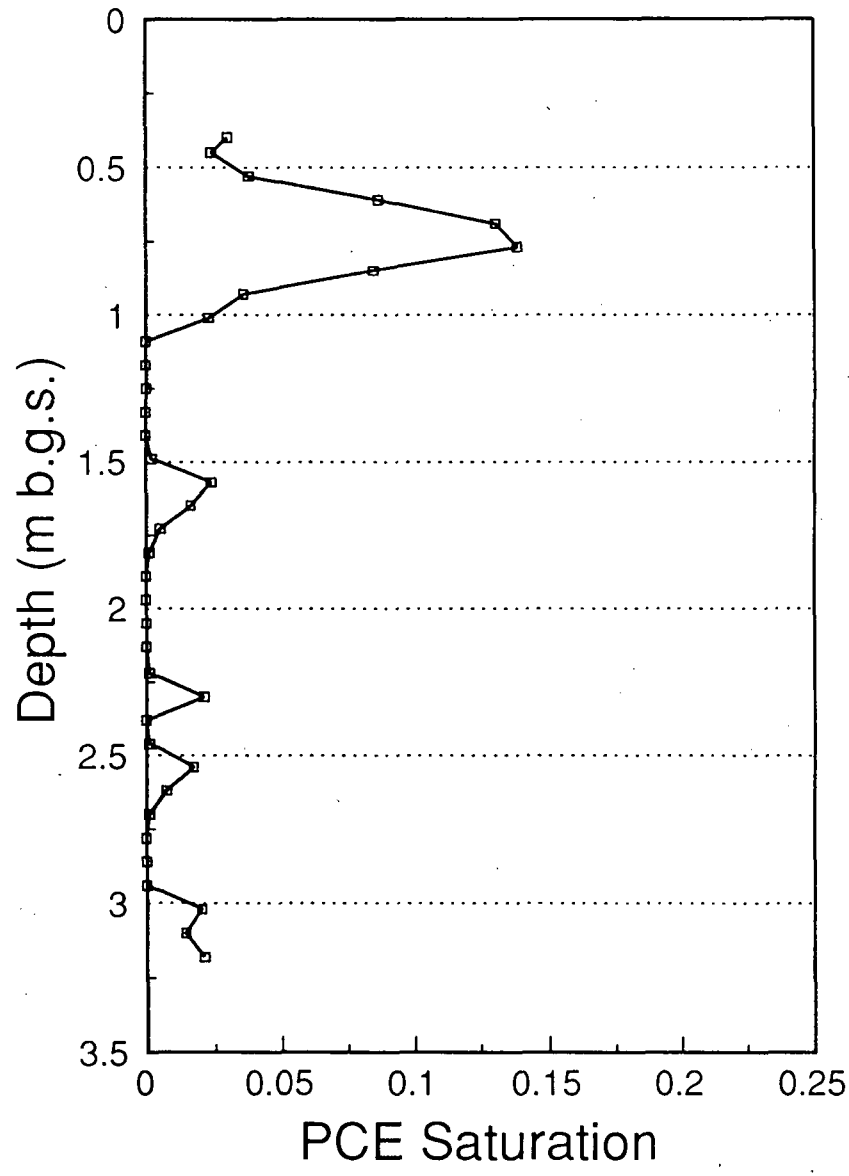


Figure 8: PCE Saturation Profile for Core CP-7

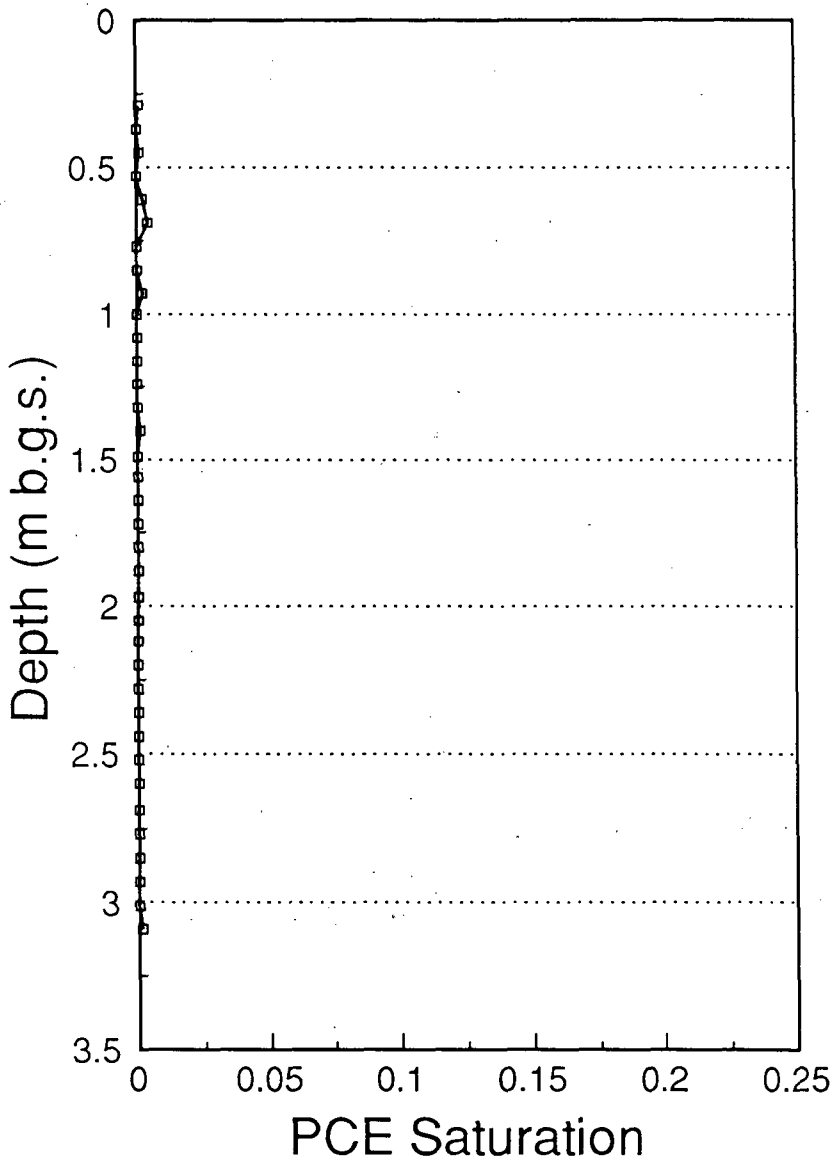


Figure 9: PCE Saturation Profile for Core CP-8

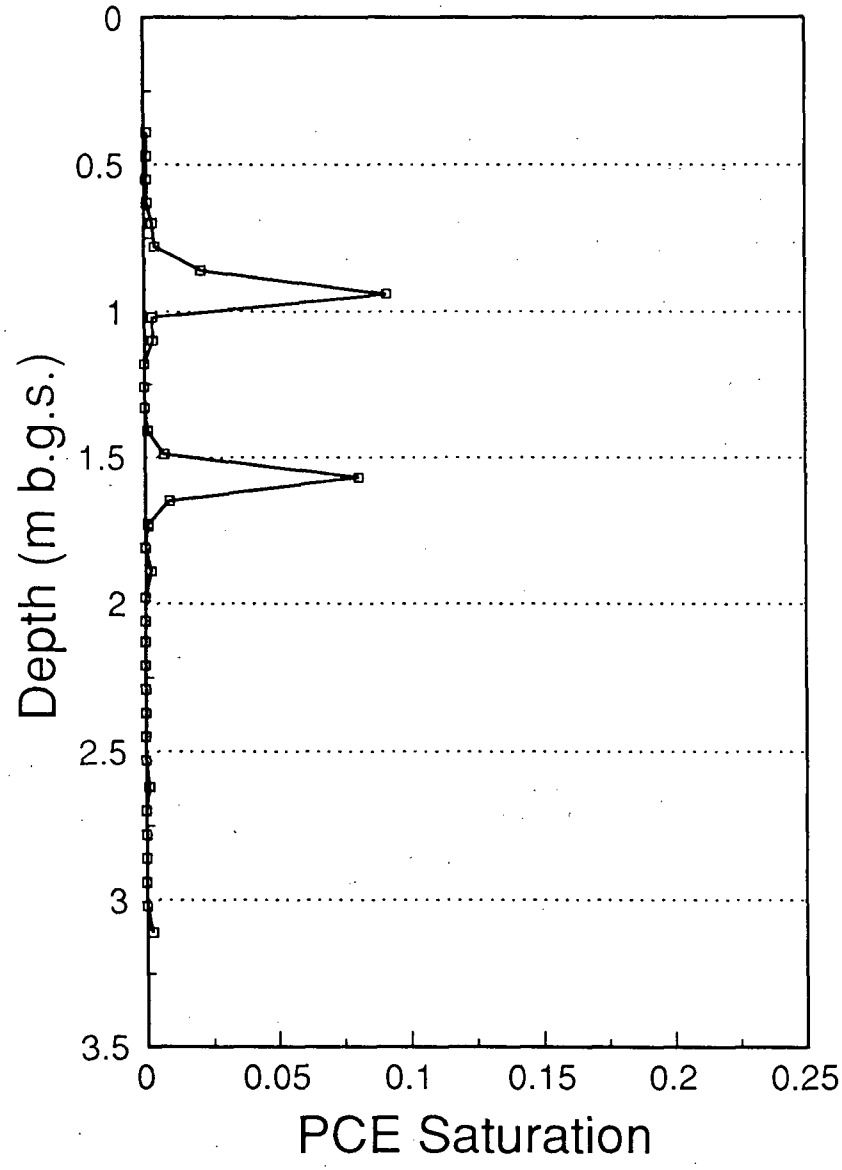


Figure 10: Soil Concentration Profile for Core C1

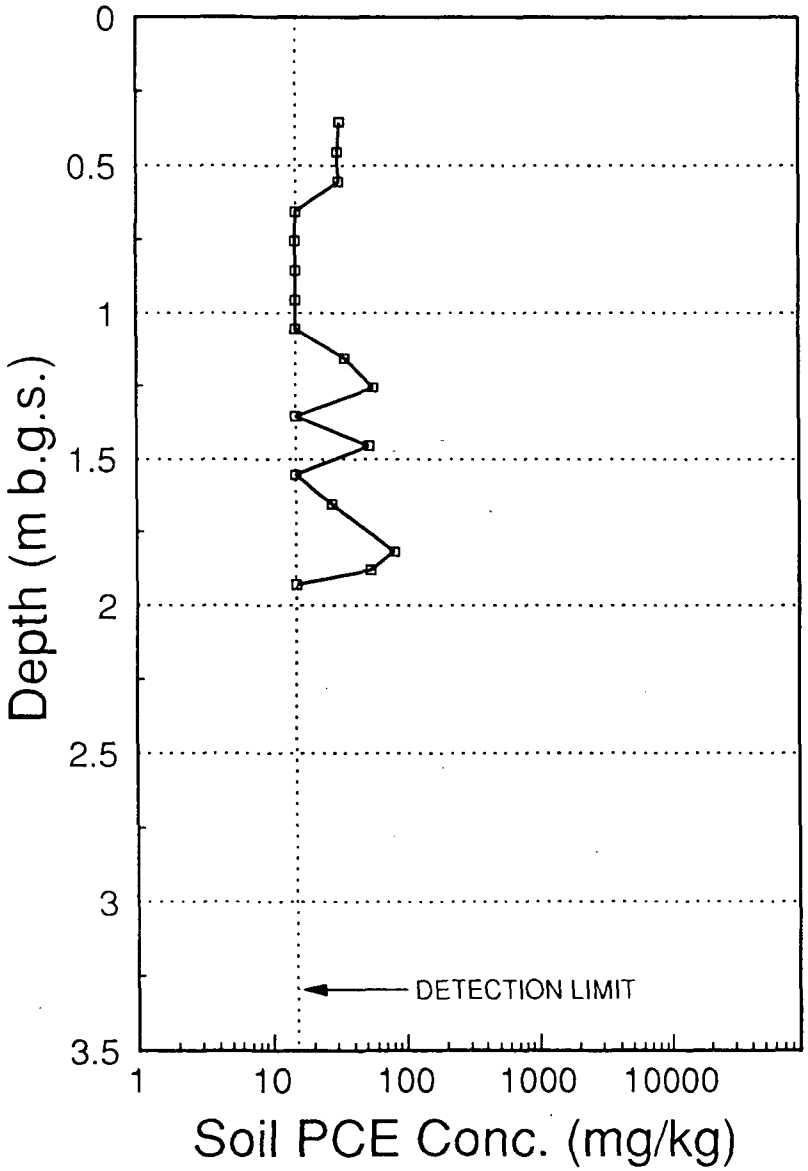


Figure 11: Soil Concentration Profile for Core C2

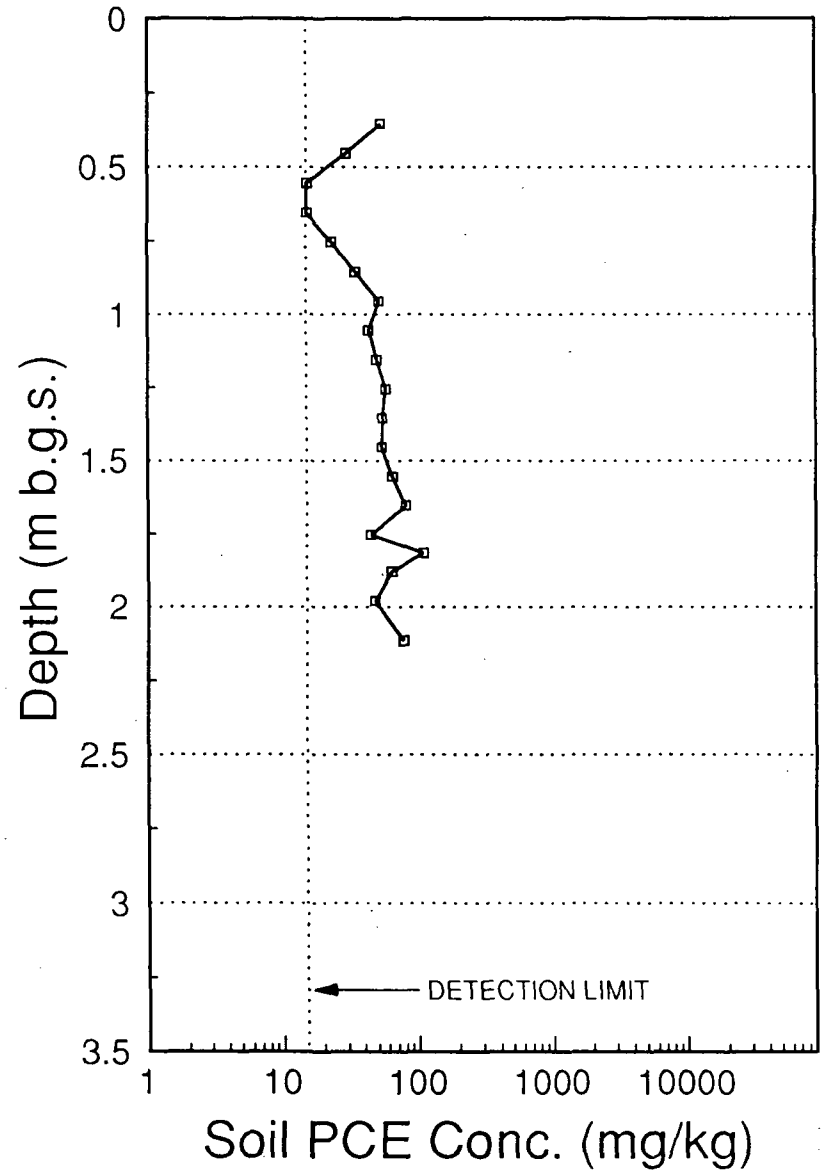


Figure 12: Soil Concentration Profile for Core C3

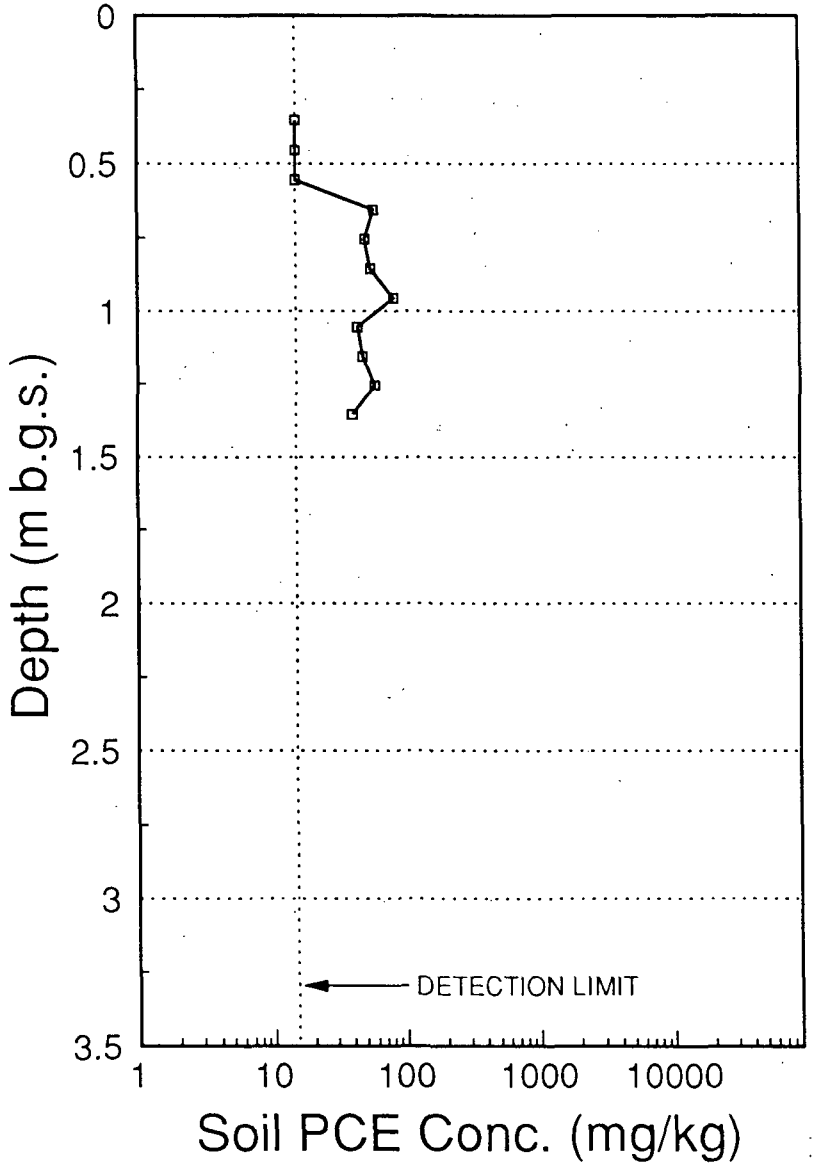


Figure 13: Soil Concentration Profile for Core C4

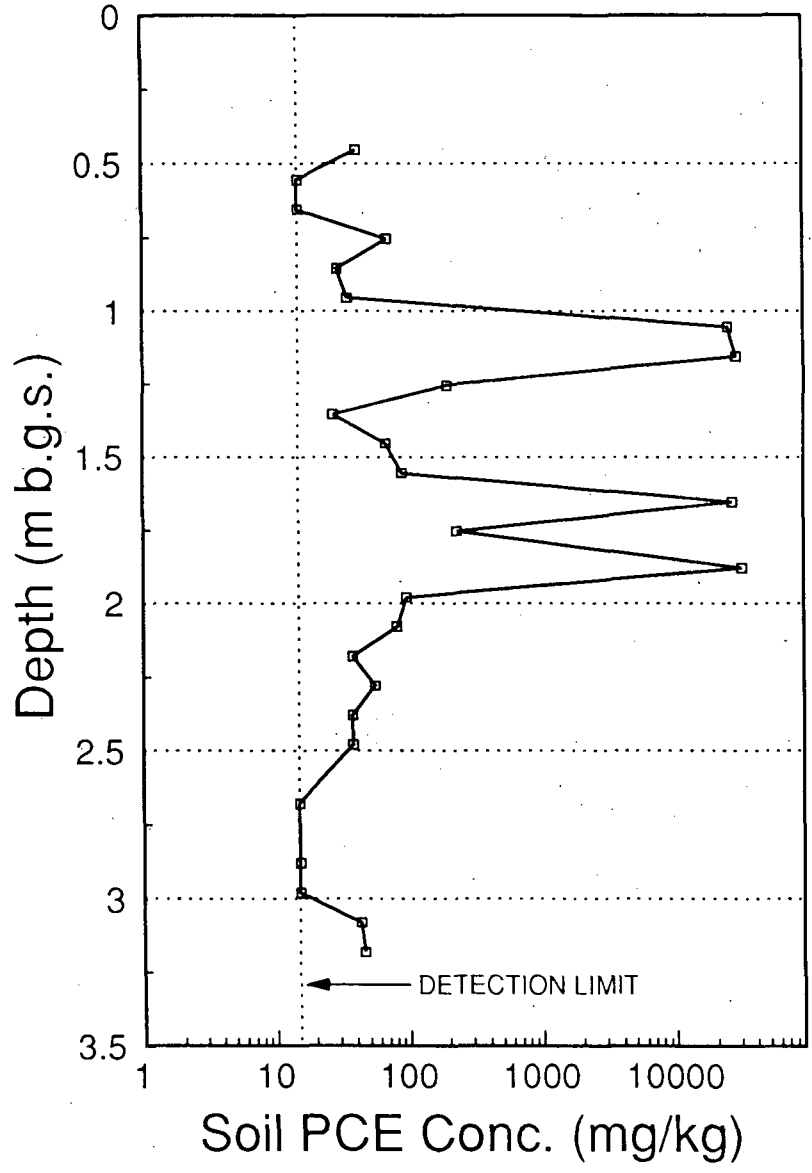


Figure 14: Soil Concentration Profile for Core C5

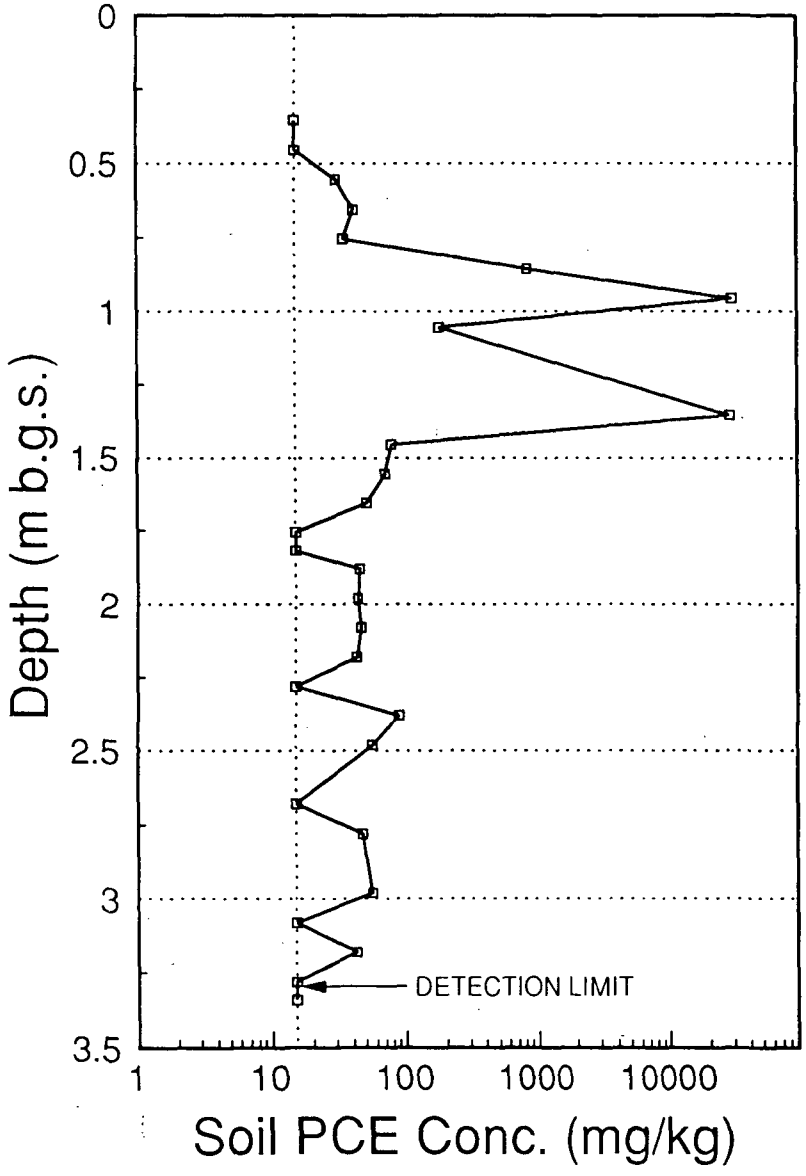


Figure 15: Soil Concentration Profile for Core C6

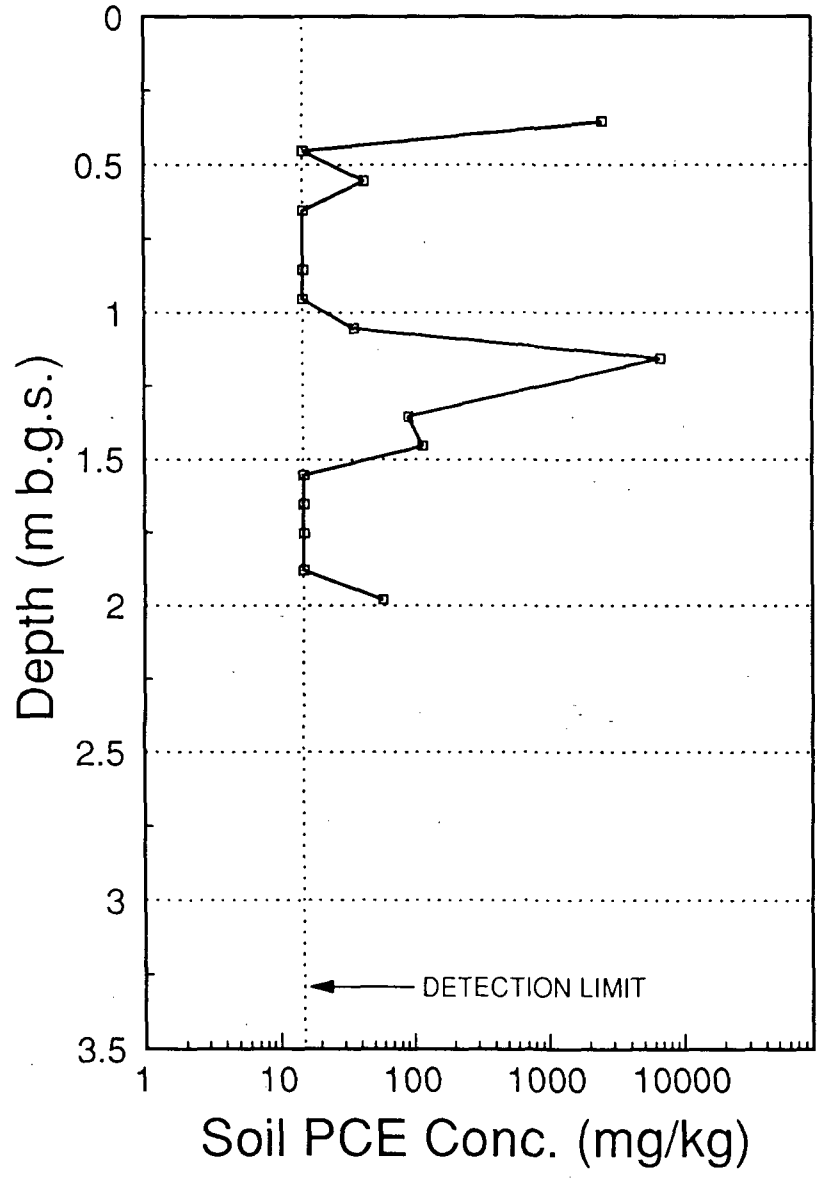


Figure 16: Soil Concentration Profile for Core C7

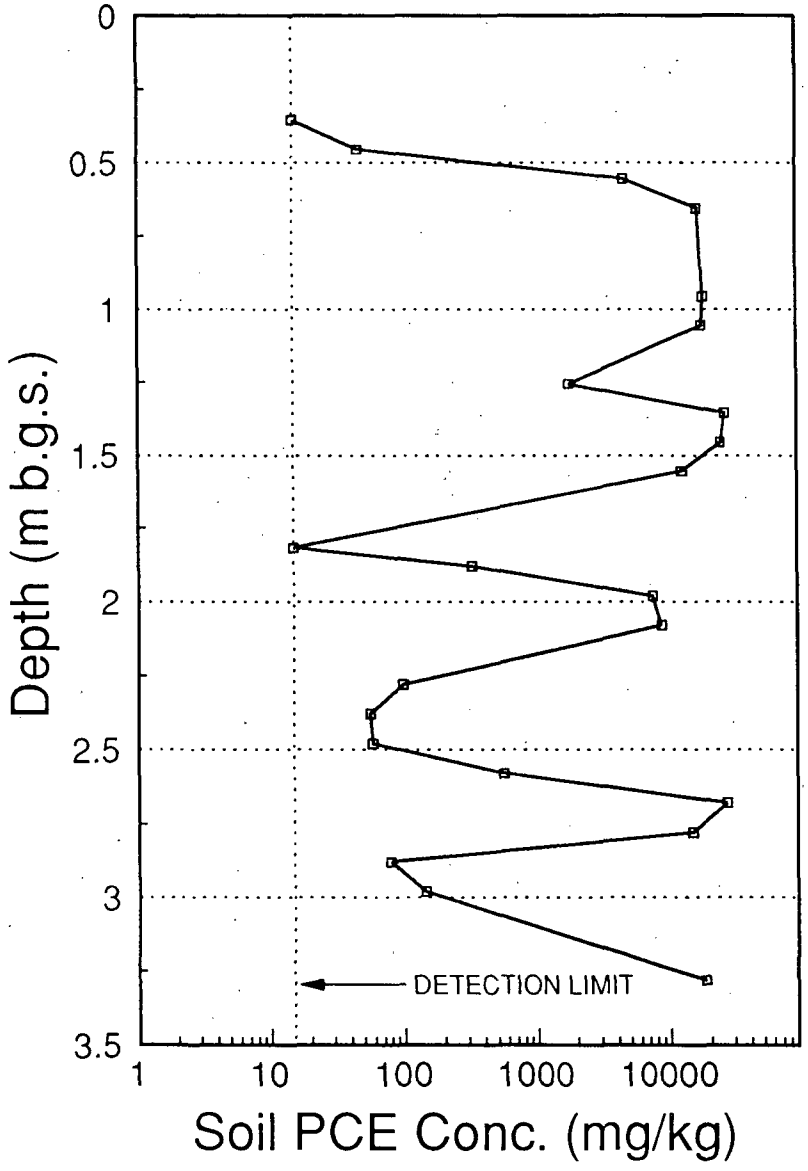


Figure 17: Soil Concentration and Moisture Content Profile for Core CR-1

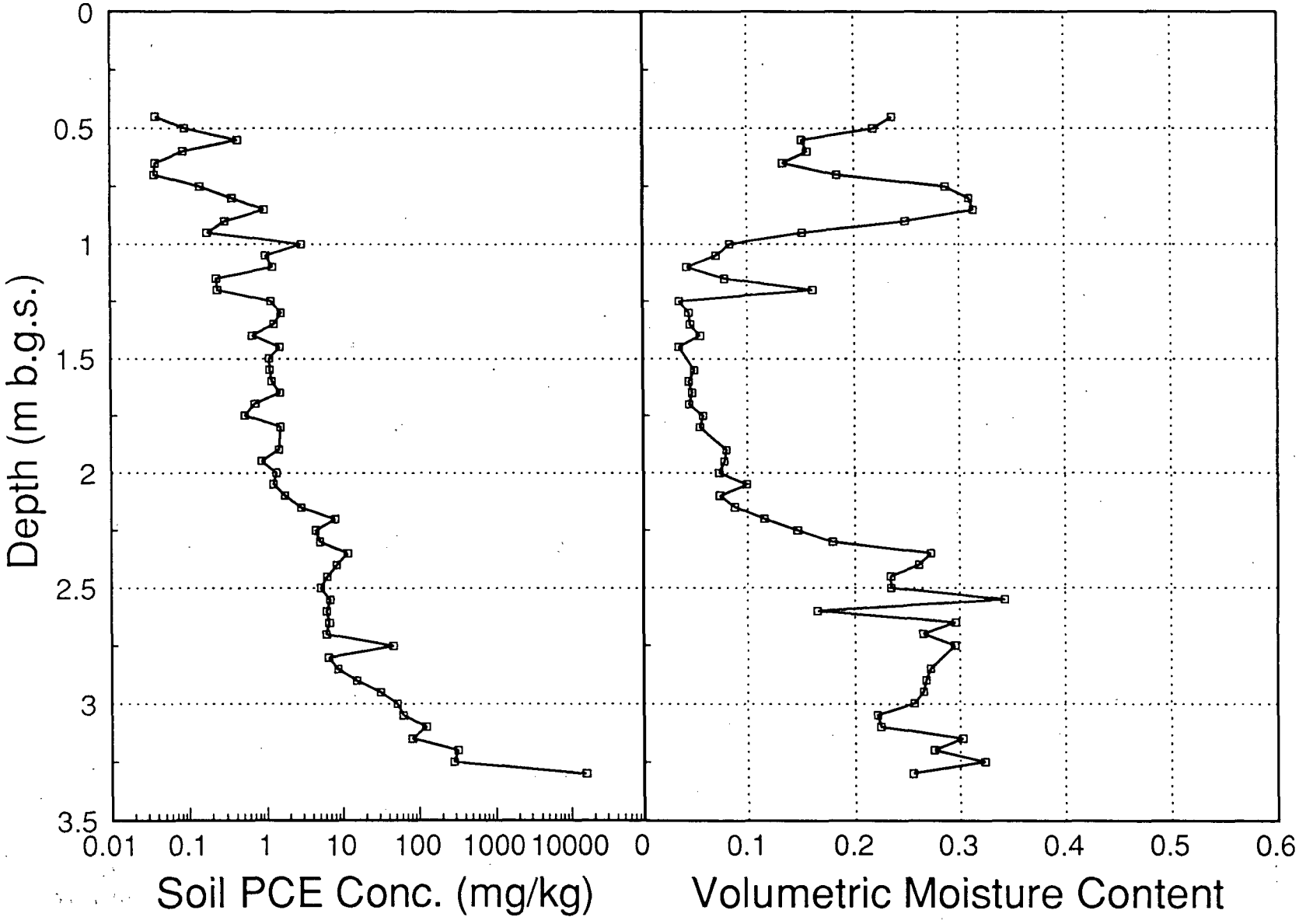


Figure 18: Soil Concentration and Moisture Content Profile for Core CR-2

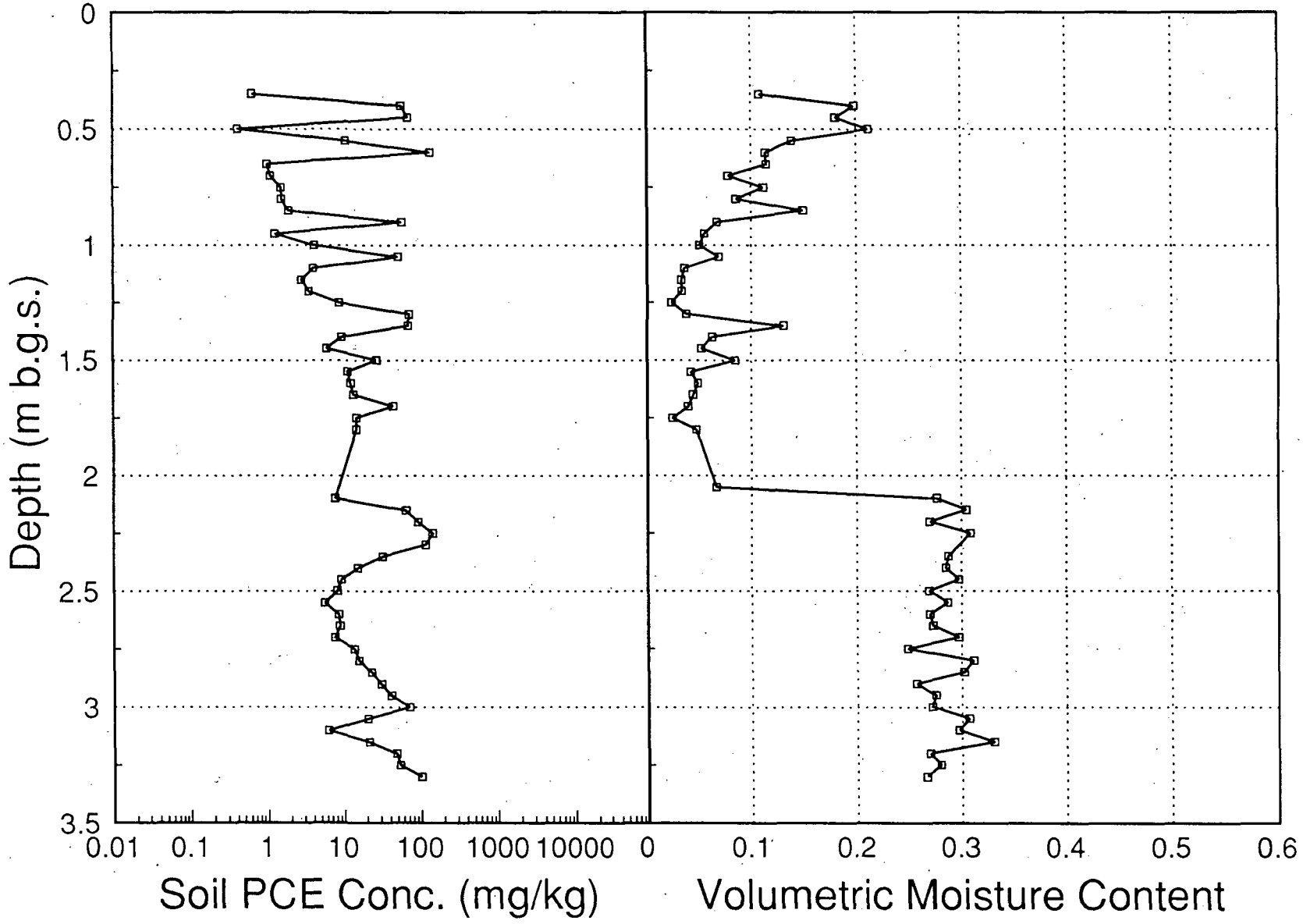


Figure 19: Soil Concentration and Moisture Content Profile for Core CR-3

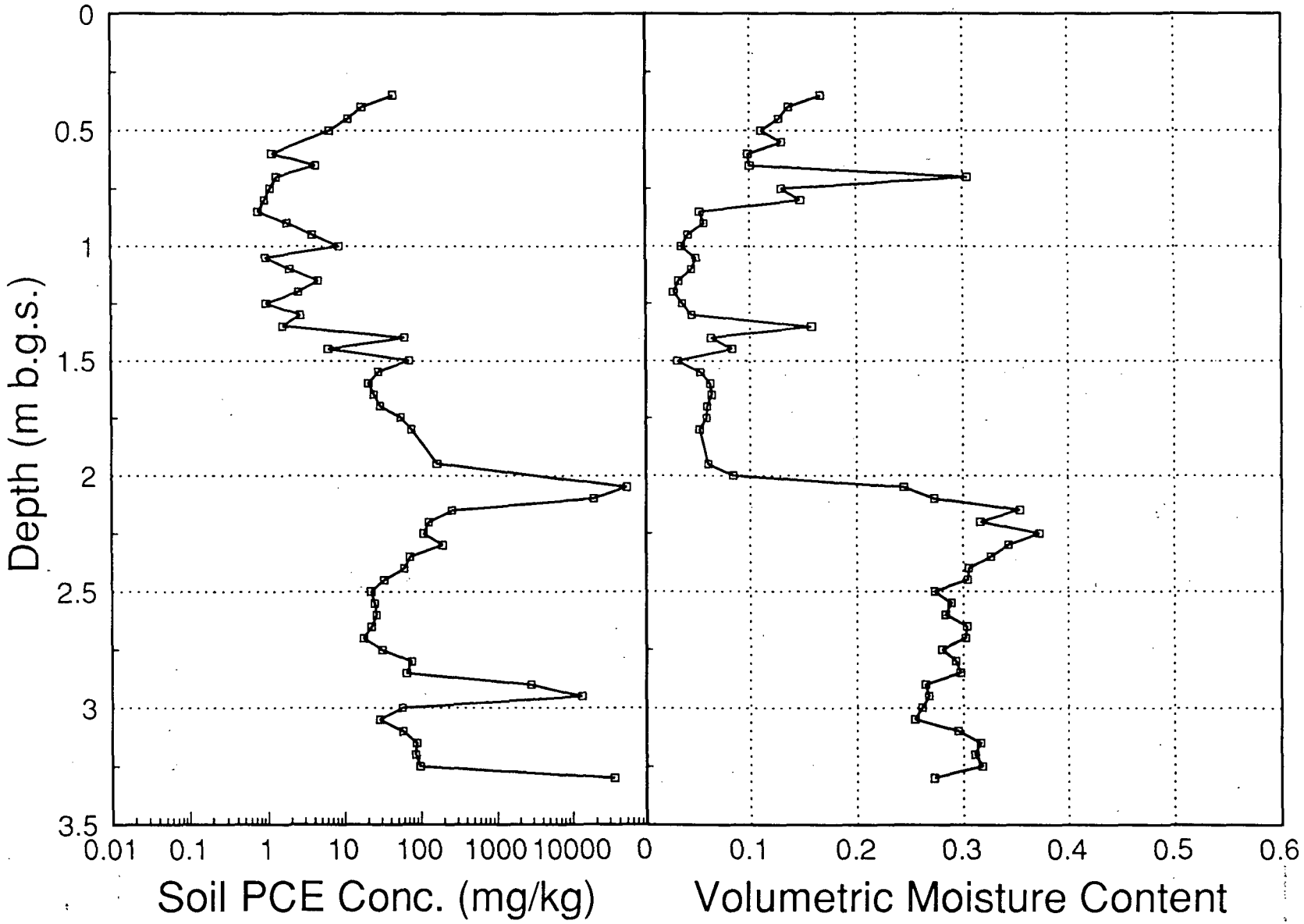


Figure 20: Soil Concentration and Moisture Content Profile for Core CR-4

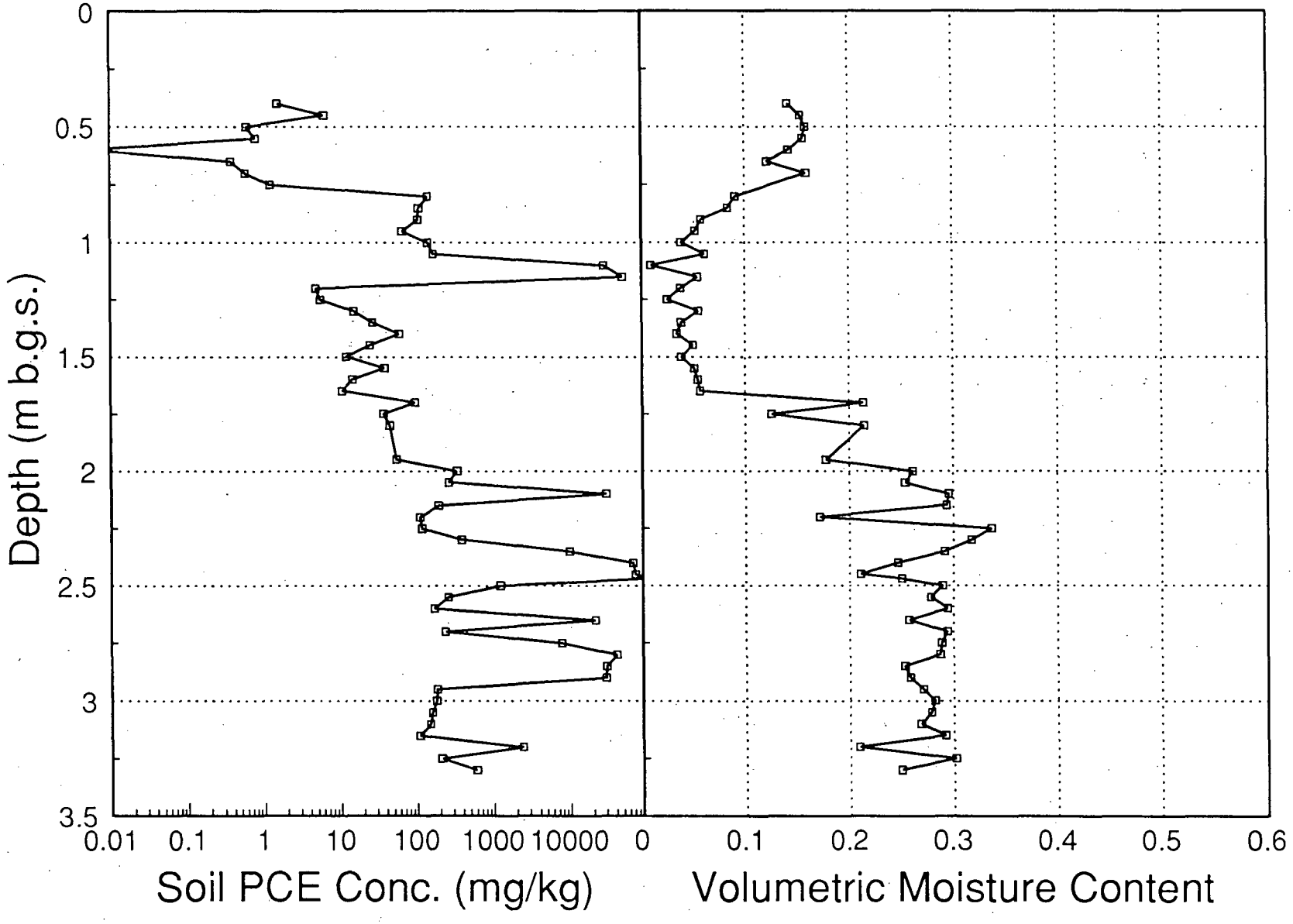


Figure 21: Soil Concentration and Moisture Content Profile for Core CR-5

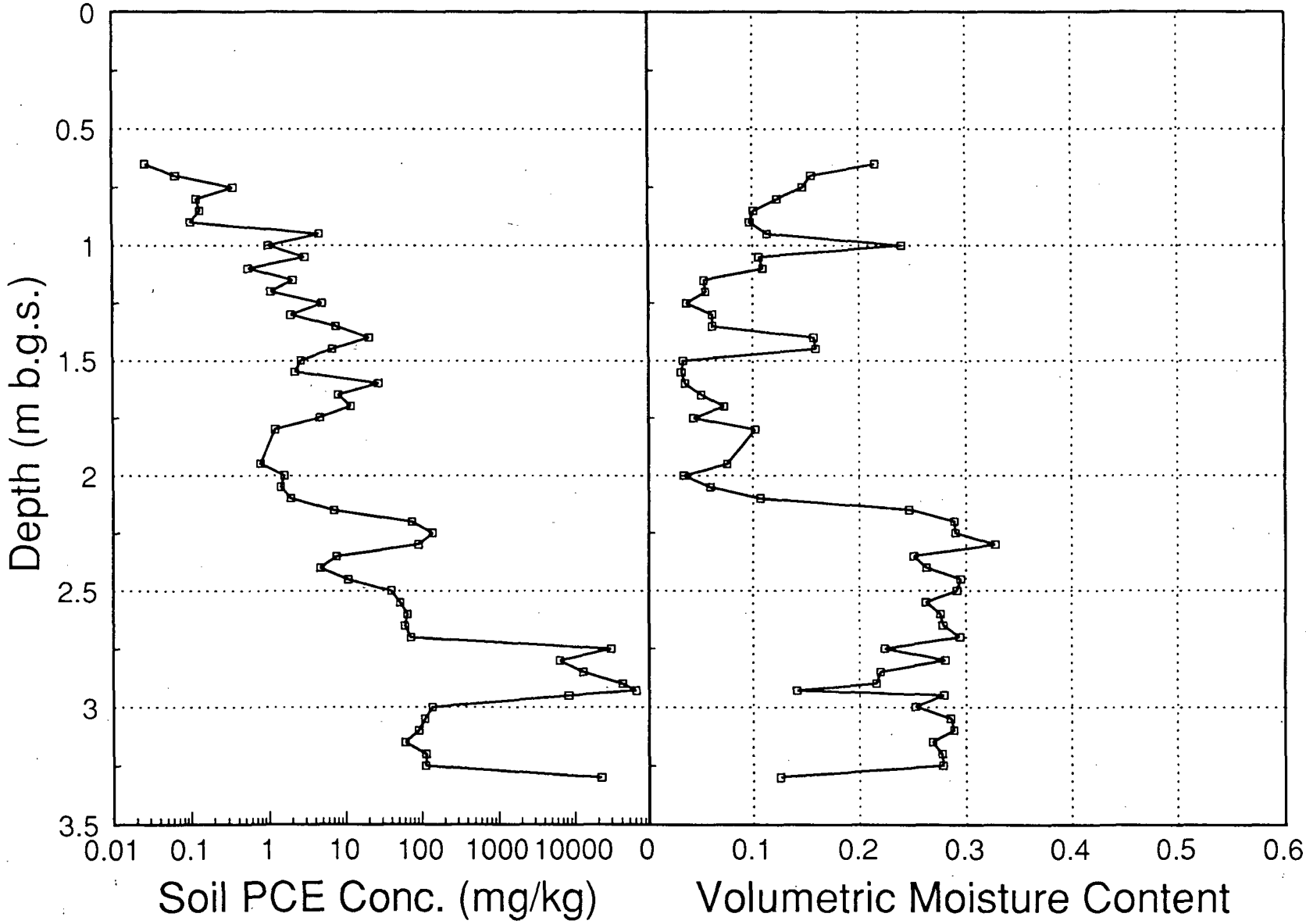


Figure 22: Soil Concentration and Moisture Content Profile for Core CR-6

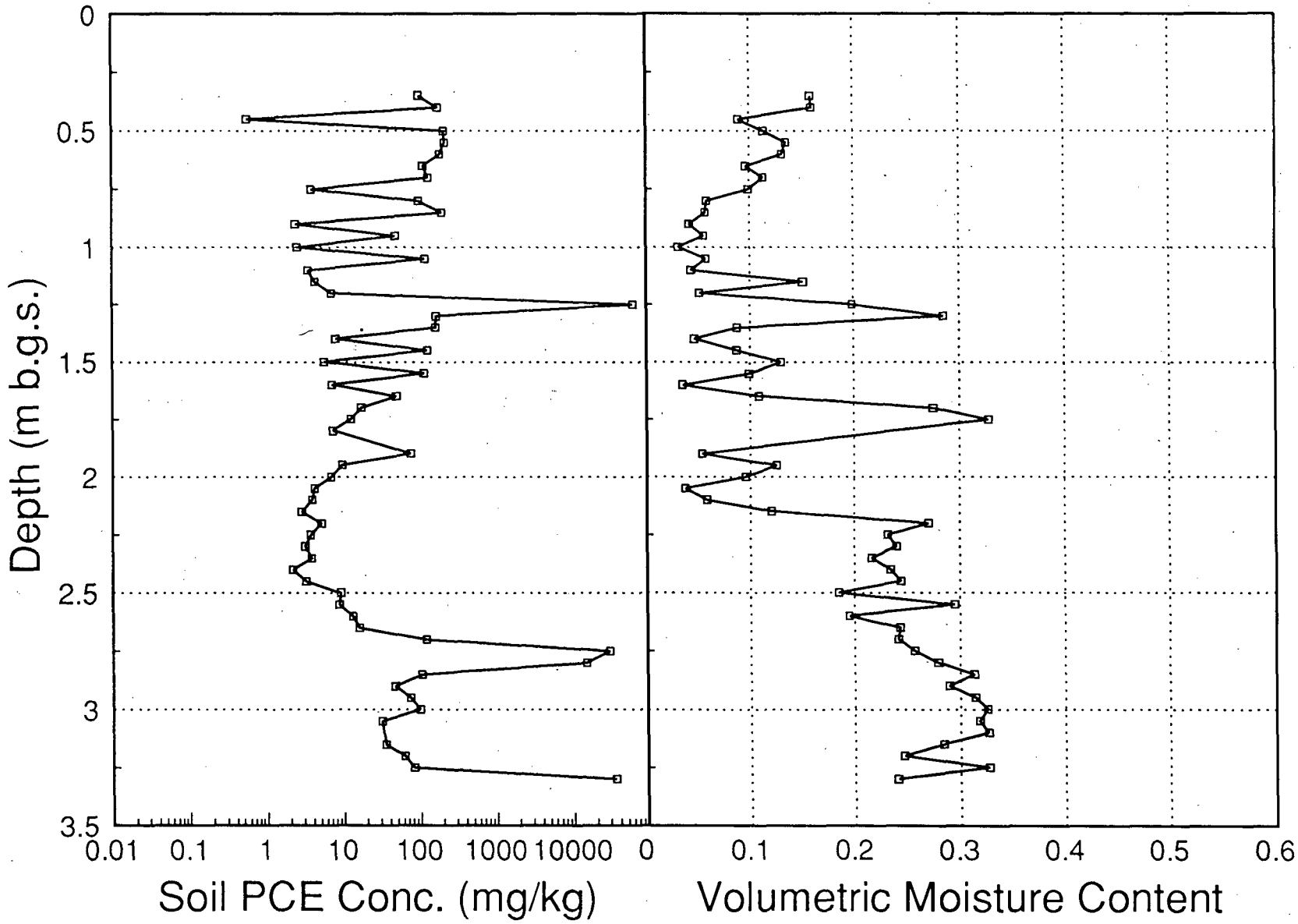


Figure 23: Soil Concentration and Moisture Content Profile for Core CR-7

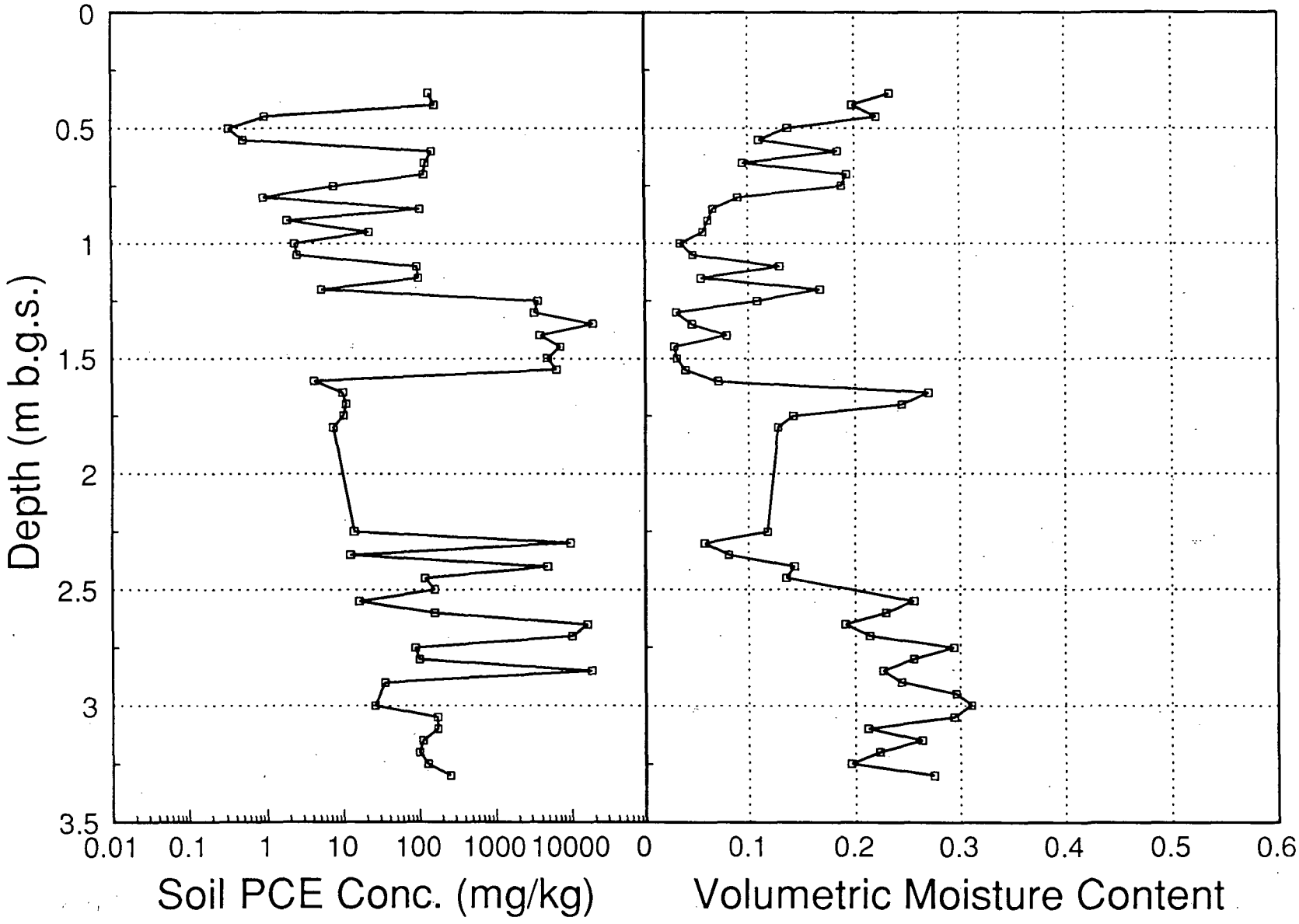
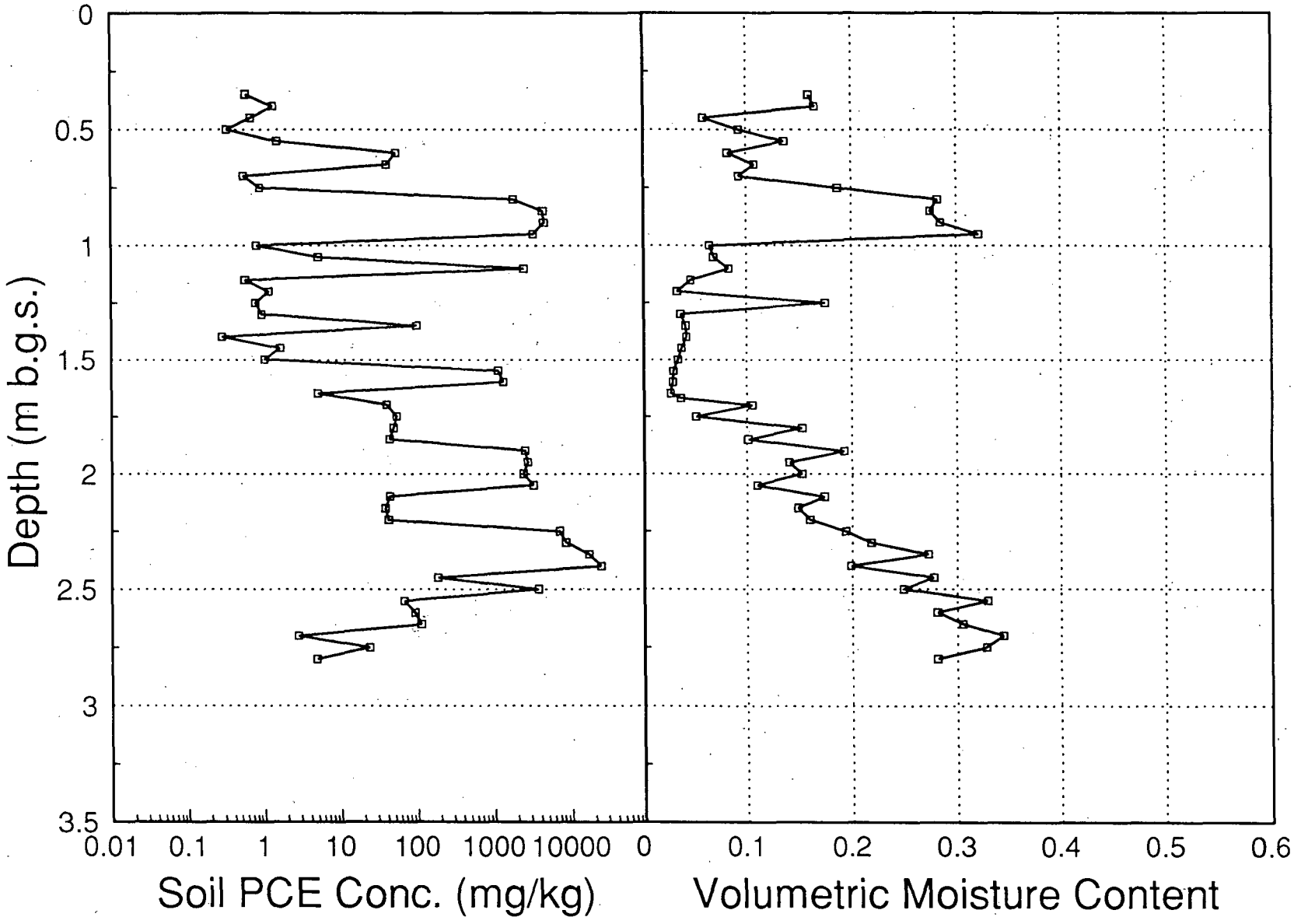


Figure 24: Soil Concentration and Moisture Content Profile for Core CR-8



The Influence of Heterogeneity on the Mass Removal Efficiency of Conventional Soil Vacuum Extraction Technology: A Field Study.

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Abstract

Soil vacuum extraction has been used in remediation programs at contaminated sites throughout Canada and the United States. Case studies have reported on the ability of this technology to remove large amounts of mass; however, soil clean-up levels are measured in terms of the mass remaining in the subsurface, not in terms of the mass removed. The heterogeneous nature of many subsurface environments results in rapid removal from higher permeability layers, followed by slow removal from lower permeability layers. Significant mass may be retained in the soil after mass removal rates become negligible. The quantification of the effects of heterogeneity on the efficiency of remediation would aid in the decision of whether or not to implement vacuum extraction as a remedial method at individual sites.

A large field scale experiment was performed in a 267 m^3 block of naturally heterogeneous aquifer. Perchloroethylene (PCE) was vacuum extracted from a test cell. The effluent concentration decreased to low levels after only 25% of the initial mass of PCE had been removed. The use of extensive *in situ* monitoring provided information on the effects of heterogeneity on the removal of PCE from the soil. The progress of the experiment was monitored at twenty-three monitoring nests, which allowed the measurement of several important parameters, including: soil gas concentration, soil gas pressure, temperature, and volumetric water content. The monitoring data revealed the

Presented at the NGWA Outdoor Action Conference, Minneapolis, MN, May 23-25, 1994.

location of areas exhibiting low remediation efficiency. Pre-cleanup and post-cleanup soil cores were collected and analyzed to estimate cleanup efficiency. Details of the findings of this field trial are presented, and the role of heterogeneities are elucidated.

Introduction

Soil vacuum extraction (SVE) has been a commonly applied remediation technology at many sites throughout North America. Several authors have reported its use to remediate (with varying success) soils contaminated by petroleum hydrocarbons and volatile organic chemicals (VOC's) (e.g., *Conner, 1988; Ardito et al., 1990*).

While a great number of case studies of SVE have been reported, very few have been instrumented enough to gain insights into the processes involved and the efficiency of various venting configurations. In addition, few case studies have reported the degree of success of the remediation in terms of soil concentration. Success has mainly been judged in terms of mass removal. The properties of non-aqueous phase liquids (NAPL's) require almost complete removal of the contaminating chemicals from the vadose zone before a site could be considered remediated. This is because their solubilities can be thousands of times higher than the maximum concentration levels (MCL's) set by the United States Environmental Protection Agency (USEPA). Table 1 lists the aqueous phase solubilities and USEPA MCL's for drinking water for several volatile NAPL's, as well as their aqueous solubilities.

Table 1: Aqueous Solubilities and Drinking Water Limits

Chemical	Aqueous Solubility (mg/L) (25 °C)	USEPA MCL[a] (mg/L)	Solubility/ MCL
Perchloroethylene (PCE)	150[b]	0.005	30000
Trichloroethylene (TCE)	1100[b]	0.005	220000
1,1,1 Trichloroethane (1,1,1 TCA)	720[c]	0.2	3600
Benzene	1780[c]	0.005	356000
Toluene	515[c]	2	258
o-Xylene	175[c]	0.440	398

Notes:

a US Environmental Protection Agency Maximum Concentration Limits for Drinking Water
b *Horvath (1982)*
c *MacKay and Shiu (1982)*

As can be seen from the solubility/MCL ratios in this table, small amounts of NAPL can result in significant volumes of contaminated ground water.

The purpose of this field experiment was to investigate SVE at the field scale in a naturally heterogeneous soil in terms of both **mass removal performance** and **soil clean-up performance**.

Heterogeneity

Since all natural soils are heterogeneous to some extent, it would be useful to quantify the effects of these heterogeneities on SVE. Soil heterogeneity will have several effects the are relevant to SVE. From the moment a NAPL is released into the environment, the degree of heterogeneity of the underlying soil will affect its distribution. *Poulsen and Kueper (1992)* demonstrated that NAPL movement will be controlled by heterogeneity even in weakly heterogeneous soils (permeability variations over vertical distances of centimetres). As the NAPL moves along tortuous paths through the porous medium the zones containing residual NAPL and pools of NAPL, will be non-uniformly distributed throughout the zone of contamination.

Non-uniform NAPL distributions have been shown to slow the removal of a NAPL from the subsurface. For example, *Benson (1990)* performed laboratory experiments that showed that mass removal from a non-uniform NAPL distribution was slower than from a uniform NAPL distribution.

Laboratory and field studies have also shown that soil heterogeneity will have a great influence on subsurface gas flow. *Ho and Udell (1992)* found that the time required to remove a NAPL trapped in a lower permeability layer will increase as the difference in permeability between the lower permeability layer and an adjacent higher permeability layer increases. *Chambers and Hennier (1991)* performed a pneumatic test in a complex layered system for the design of an SVE system, and found very little response in a low permeability layer even when the vacuum well was only screened across that layer.

The experimental program discussed herein included a heterogeneous porous medium, a non-uniform NAPL distribution, and a non-uniform soil moisture content. The effects of these on the performance of the SVE system were considered.

Experimental Background

An experiment investigating SVE at the field scale was performed at CFB Borden, Alliston, Ontario. The experiment was performed in a block of surficial aquifer located approximately 750 m northeast of the site of the Stanford tracer experiment (*Mackay et al., 1986*). The site was previously used for a geophysics experiment (*Brewster et al., 1992*).

While the sand in the upper aquifer is considered to be a fairly homogeneous, clean, well sorted fine-medium grained sand, observation of core samples showed distinct horizontal layering. *Mackay et al. (1986)* described the texture of the individual beds and laminae as varying from silt to coarse sand with occasional pebbles. Falling head permeameter tests performed on samples from the upper Borden aquifer revealed

permeability variations on the millimetre scale (*Poulsen and Kueper, 1992; Sudicky, 1986*). The layers typically differed in permeability by a factor of 1.7.

The research area was a block of the surficial sand aquifer measuring 9 m x 9 m in plan and approximately 3.3 m deep. The block was isolated by double sheet pile walls which were pneumatically driven through the aquifer and keyed into the clay aquitard, forming an impermeable base. In order to prevent leakage through the walls into the aquifer, the joints between the wall sections were sealed using a bentonite grout (*Starr et al., 1992*).

The cell was initially used for a geophysics experiment. The purpose of this study was "to evaluate the effectiveness of several different geophysical techniques for observing the presence of organic solvents in the subsurface" (*Brewster and Redman, 1991*). In July, 1991, seven hundred and seventy litres of perchloroethylene (PCE), commonly used as a dry cleaning solvent, was injected into the cell at a constant head of 123 cm of PCE (198 cm of water). The injection occurred 60 cm below ground surface (b.g.s.). At the time of the injection the water level in the cell was maintained at 15 cm b.g.s., ensuring that the cell was fully saturated (the upper 15 cm was tension saturated).

PCE movement was monitored for over a month using an array of geophysical technologies. Several geophysical technologies successfully monitored the movement of the DNAPL, including time domain reflectometry (TDR), neutron logging and ground penetrating radar (GPR) (*Brewster and Redman, 1991*). After 984 hours (41 days), the DNAPL appeared to be immobile since there were no longer observable changes between the elapsed time geophysical data (*Brewster, 1993*).

Once the geophysical experimentation was completed, the cell was de-watered in preparation for the SVE experiment. The water table in the cell was lowered to approximately 3.0 m b.g.s. in order to create as much of an unsaturated zone as possible. While de-watering the cell, 174 L of pure phase PCE was removed.

Monitoring Equipment

In order to investigate the performance of the SVE system, it was necessary to carefully and comprehensively monitor the progress of the experiment. The parameters monitored for this experiment were soil gas concentration, *in situ* gas pressure, soil temperature, volumetric moisture content, effluent concentration, flow rate, line pressure, barometric pressure, and ambient temperature. The spatial variability of the soil and NAPL distribution necessitated a large network of instrumentation to properly assess the remediation progress. Figure 1 shows the locations of the monitoring installations. Before any monitoring equipment was installed, the surface of the cell was covered with 2 layers of 6 mil vapour barrier to prevent the infiltration of rainwater, and to help control the airflow by preventing atmospheric air from being drawn through the ground surface.

Many of the performance measurement parameters were measured at seventeen multi-level sampling nests distributed throughout the cell. Nests S1 to S16 had two or three

samplers each, installed to nominal depths of one, two, and three metres, and nest S17 had six samplers installed at half-metre intervals. The samplers were entirely constructed of stainless steel, with the exception of Teflon™ Mininert™ valves that were used to seal the samplers from the atmosphere (see Figure 2 for the construction of the samplers).

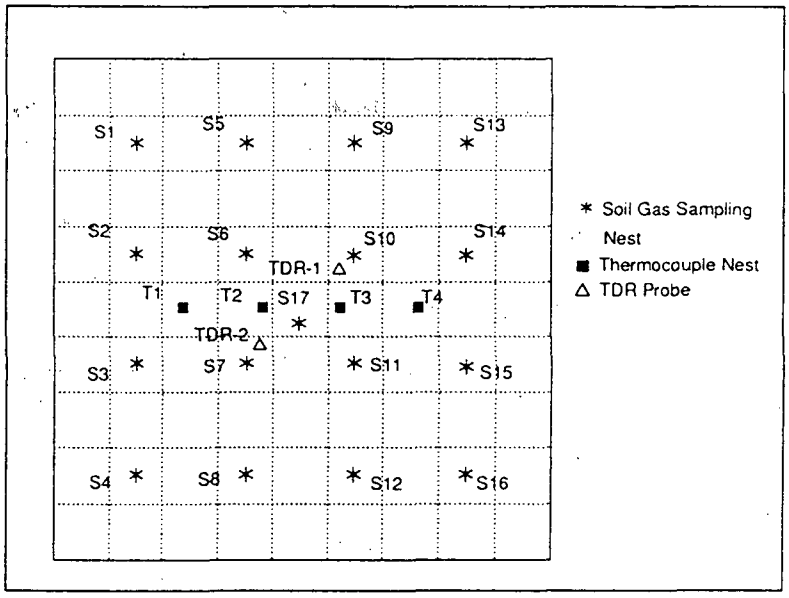

Figure 1: Location of Monitoring Equipment

One of the most useful tools for evaluating the success of SVE at meeting site clean-up goals is soil gas concentration. This parameter has been used in several field trials of SVE as an indication of the progress of the remediation program (e.g., *Stinson, 1989; Robitaille and Walen, 1988*). Soil gas measurements were made at each of the multi-level sampling nests before and at various times during the field trial.

In addition to soil gas concentration measurement, the multi-level samplers were used to measure the *in situ* gas pressure, which provided information on the pressure distribution throughout the cell. These measurements were performed by connecting a handheld pressure transducer to each sampler.

Finally, the multi-level sampling nests were used as electrodes for TDR, which is a method of non-destructively measuring the volumetric moisture content of the soil. Measurements made at each multi-level sampling nest allowed contour maps of the average moisture content from 0 m to 1 m b.g.s., and from 1 m to 2 m b.g.s. to be made. This provided an indication of the spatial variability of the volumetric moisture content.

These measurements were complemented by moisture content profiles measured at *in situ* TDR probes at locations TDR-1 and TDR-2 (see Figure 1). These probes allowed the measurement of the moisture content over 16 cm lengths from the ground surface to the aquitard. Moisture content profiles were measured each time that the spatial variation in moisture content was measured using the multi-level nests.

The subsurface temperature was measured at four nests of thermocouples installed in a line across the centre of the cell. Each nest contained three thermocouples installed to depths of 1, 2, 3 m b.g.s. The temperature was monitored using a datalogger system in order to provide a detailed record of temperature fluctuations.

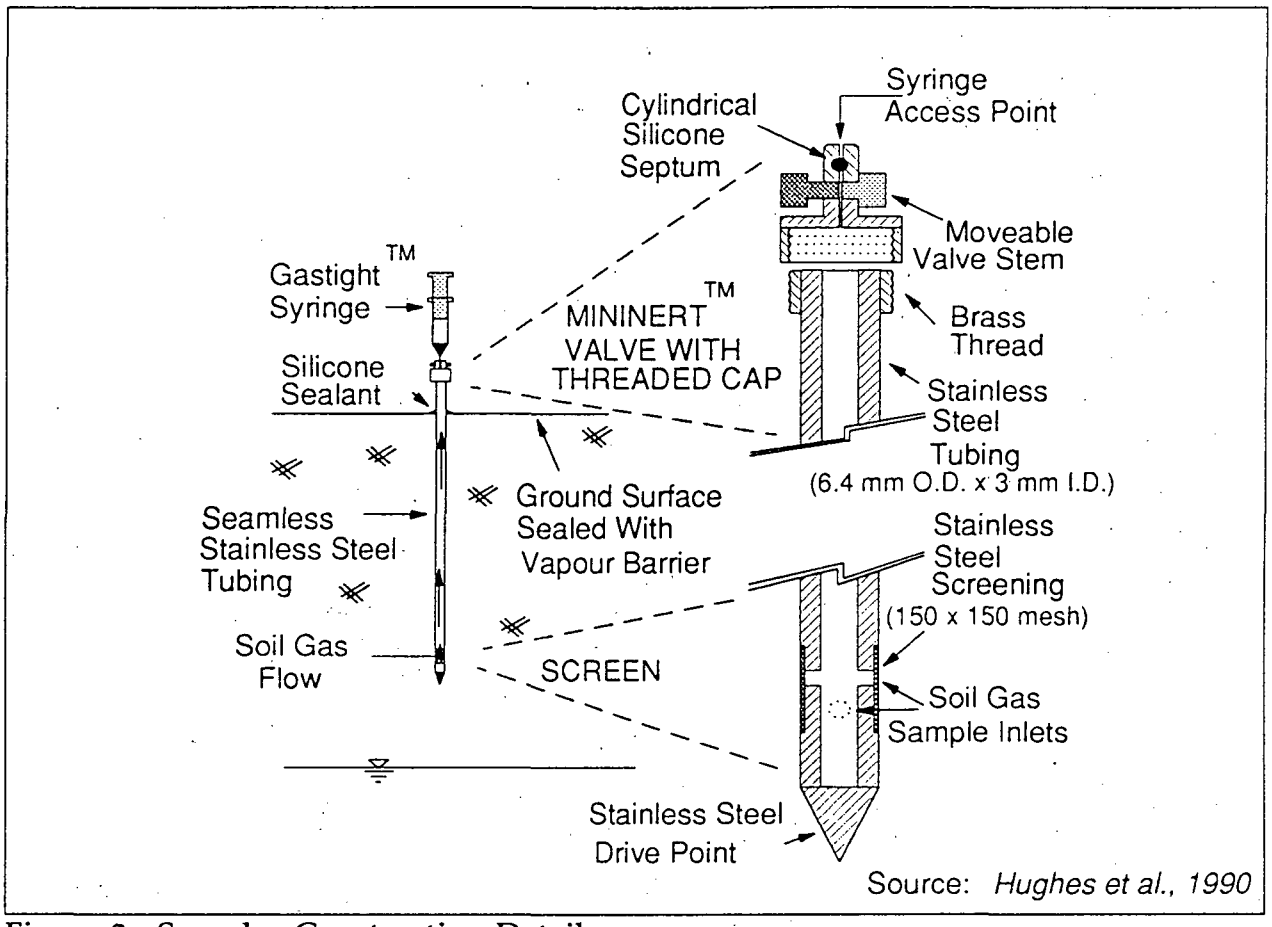

Figure 2: Sampler Construction Detail

In order to monitor the mass removal performance of the SVE system, the volumetric flow rate and the effluent concentration were measured. Along with the gas pressure throughout the piping manifold, these parameters provided an indication of the rate at which mass was being removed from the subsurface.

Vacuum System

The vacuum system consisted of six wells arranged in two rows of three wells along opposite sides of the experimental cell. These were connected to the blower by a piping manifold (see Figure 3 for a the location of wells and pipes). All of the wells and the pipes were constructed of Schedule 40 PVC. The wells were fully screened across the depth of the cell. In order to allow for some flexibility in the operation of the SVE system, each well was equipped with valves that allowed it to be used as either an extraction well or as a passive air inlet well.

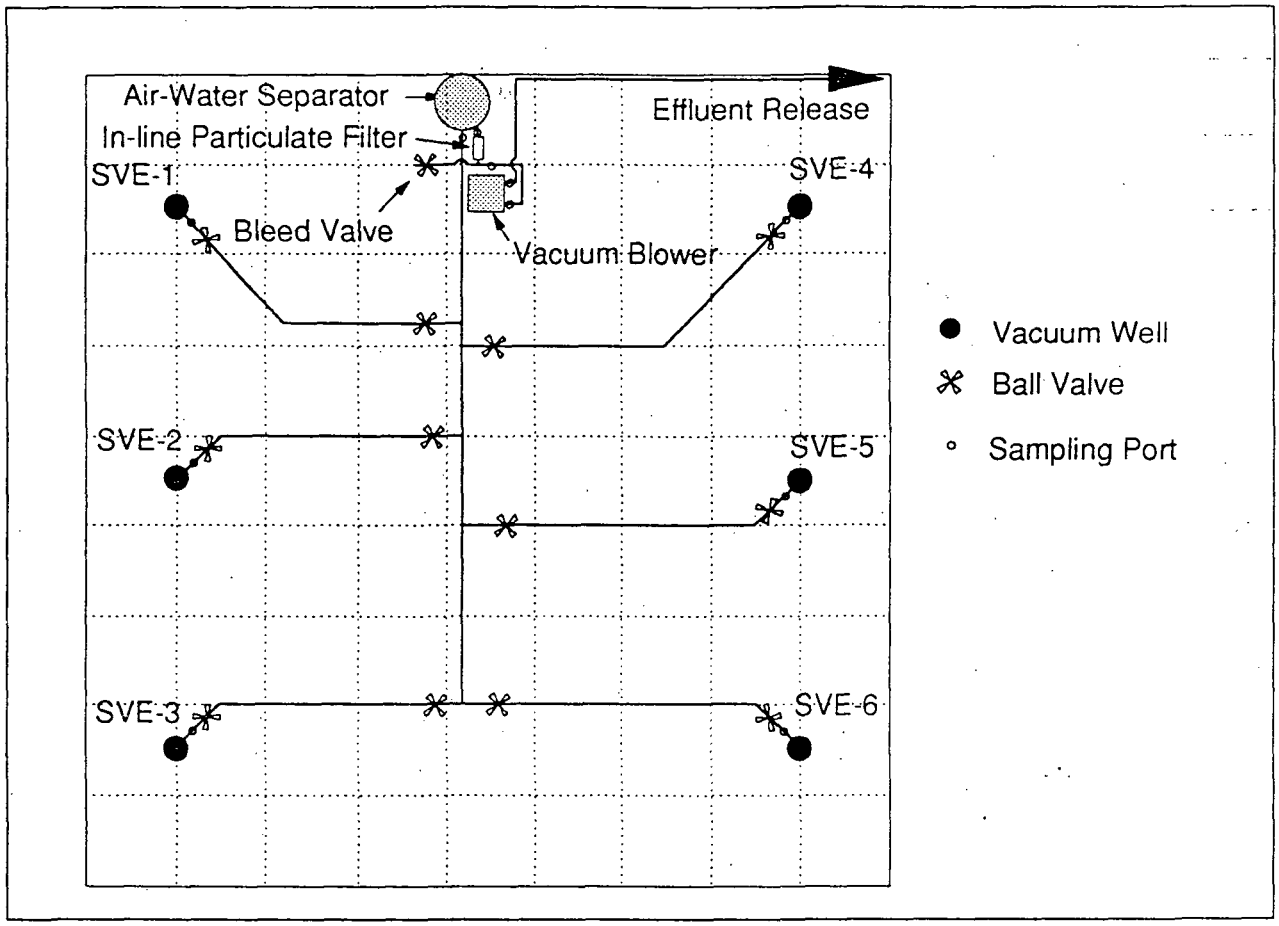

Figure 3: Layout of Vacuum System

Background Conditions

Before the experiment began, it was necessary to establish the distribution of the contamination to provide a reference for comparison with monitoring data collected throughout the course of the experiment. This data was obtained from three principle sources: GPR sections, chemical analysis of soil cores, and soil gas concentration. The first two types of data were combined to produce maps showing the approximate locations of pools of pure phase PCE. Several pools of PCE were located through the cell. As an example, Figure 4 shows the location of a large pool of PCE at 0.8 m b.g.s. *Brewster (1993)* estimated that this pool contained between 33% and 41% of the original mass of PCE injected.

The location of this large pool at 0.8 m b.g.s. can be compared with the soil gas concentrations measured at 1 m b.g.s. as shown in Figure 5. These data confirmed that there was widespread contamination throughout the subsurface at this level. With the exception of the northwest corner of the cell, the soil gas concentration throughout the

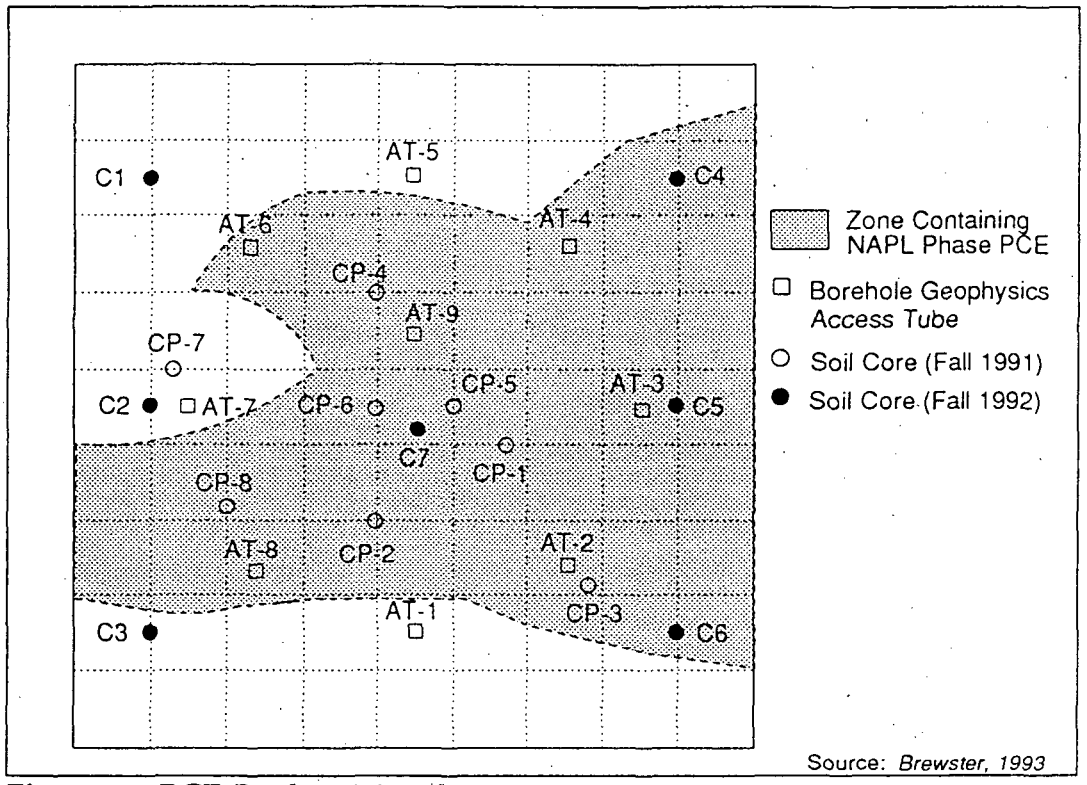

Figure 4: PCE Pool at 0.8 m b.g.s.

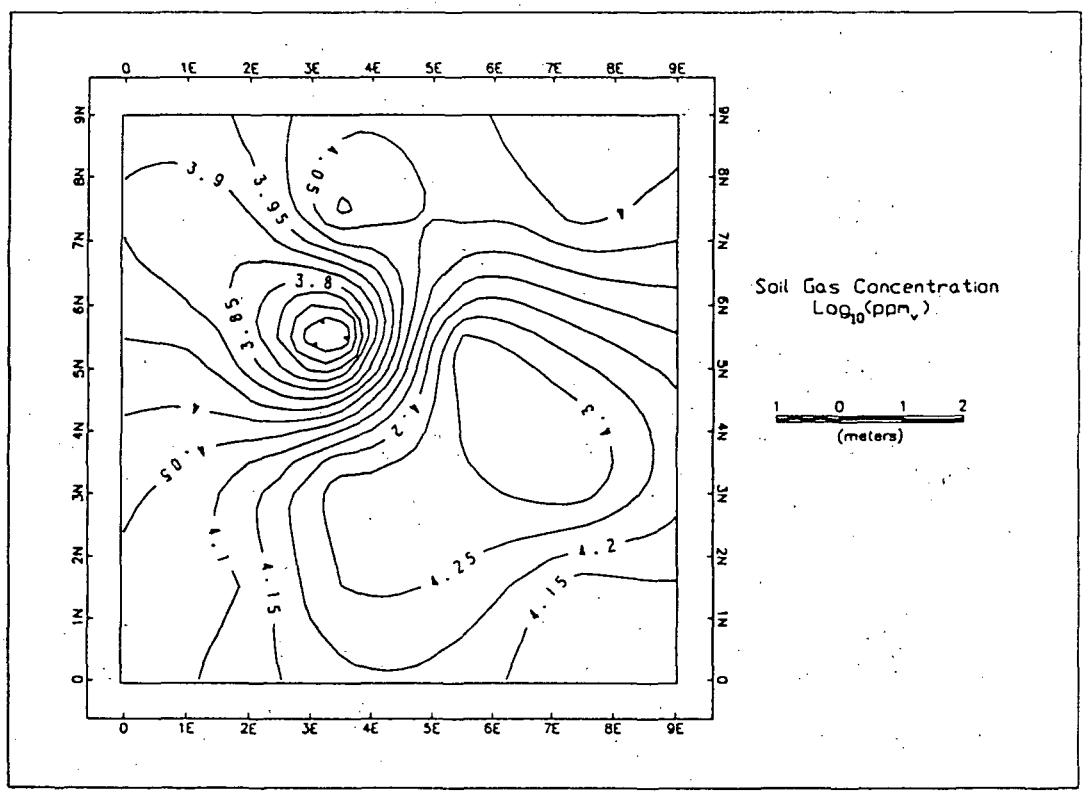

Figure 5: Background Soil Gas Concentration at 1 m b.g.s.

cell was close to the theoretical saturated gas phase concentration of PCE (20000 ppm_v).

Preliminary Experimental Results and Discussion

The SVE experiment began on July 8, 1993. For most of the experiment the system was operated using wells SVE-4, SVE-5, and SVE-6 as extraction wells. The wells on the other side of the cell were opened to the atmosphere to act as passive air inlet wells. The blower ran continuously for most of the experiment, with the exception of equilibration periods before soil gas surveys were performed, and accidental shut-downs due to power interruptions.

The system effluent concentration profile was typical of other SVE remediation efforts reported in the literature in that it had three distinct stages delineated by changes in the slope. Figure 6 shows the effluent concentration profile and the cumulative mass removed after 175 days of operation. Notice that the effluent concentration decreased to very low levels even when there was a significant portion of the original mass remaining in the subsurface. The slope of the effluent concentration curve was approaching zero at approximately 100 days, indicating that a steady state effluent concentration had been reached at this point in the experiment. Using the effluent concentration at 102 days (106 ppm_v) along with an air flow rate of 7.5 scfm (210 L/min), it would take nearly six years to remove the remaining mass contained within the cell at this point in the experiment.

The decrease in effluent concentration reflects a decrease in the mass flux out of the cell; however, the decrease in mass flux was not accompanied by low soil gas concentrations throughout the unsaturated zone in the cell. For example, the mass flux after 58 days of operation was calculated as 0.42 kg/day, even though a soil gas survey performed ten days earlier showed that there were areas within the cell that still contained very high soil gas concentrations (>50% of the saturated gas phase concentration of PCE). This disparity between the mass flux and the degree of contamination is evidence that heterogeneous conditions in the test cell may have been limiting the performance of this vacuum system in terms of both mass removal, and soil clean-up.

One reason for the slow mass removal was that some of the mass of PCE was located within the capillary fringe and the saturated zone; however, this cannot completely explain the slow mass removal rate, since soil gas surveys revealed that there were zones above the capillary fringe exhibiting slow mass removal. A zone at 1 m b.g.s. that had higher soil gas concentrations than other areas of the cell has been highlighted in Figure 7. This zone of higher concentration was observed in all six soil gas surveys performed. As the soil gas concentration around this zone decreased, the concentration in this zone also decreased, but at a much slower rate.

The fact that this porous medium is only weakly heterogeneous would suggest that a SVE system should have easily removed all of the PCE from the unsaturated zone. Since this was not the case, it is interesting to investigate possible causes of this performance.

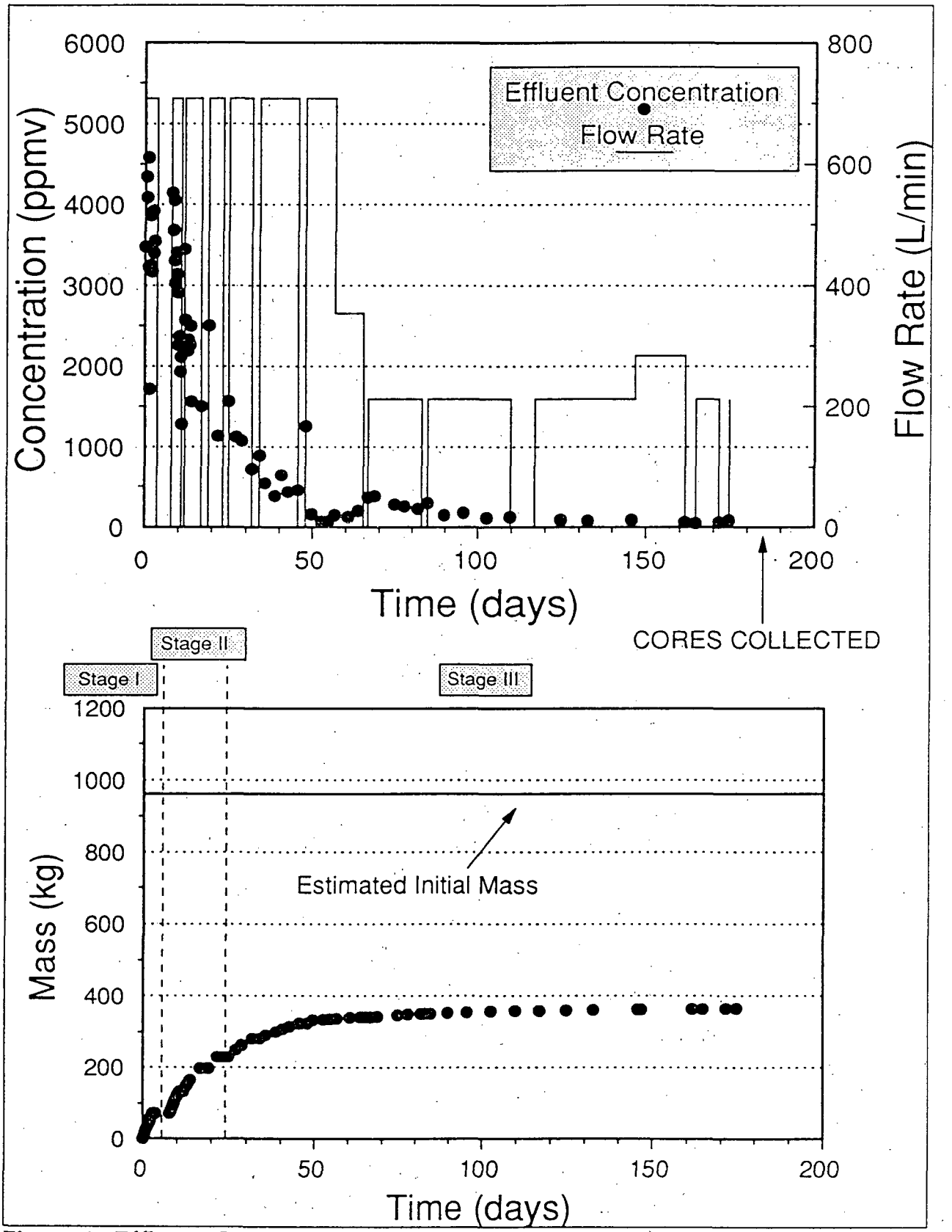

Figure 6: Effluent Concentration and Cumulative Mass Removal

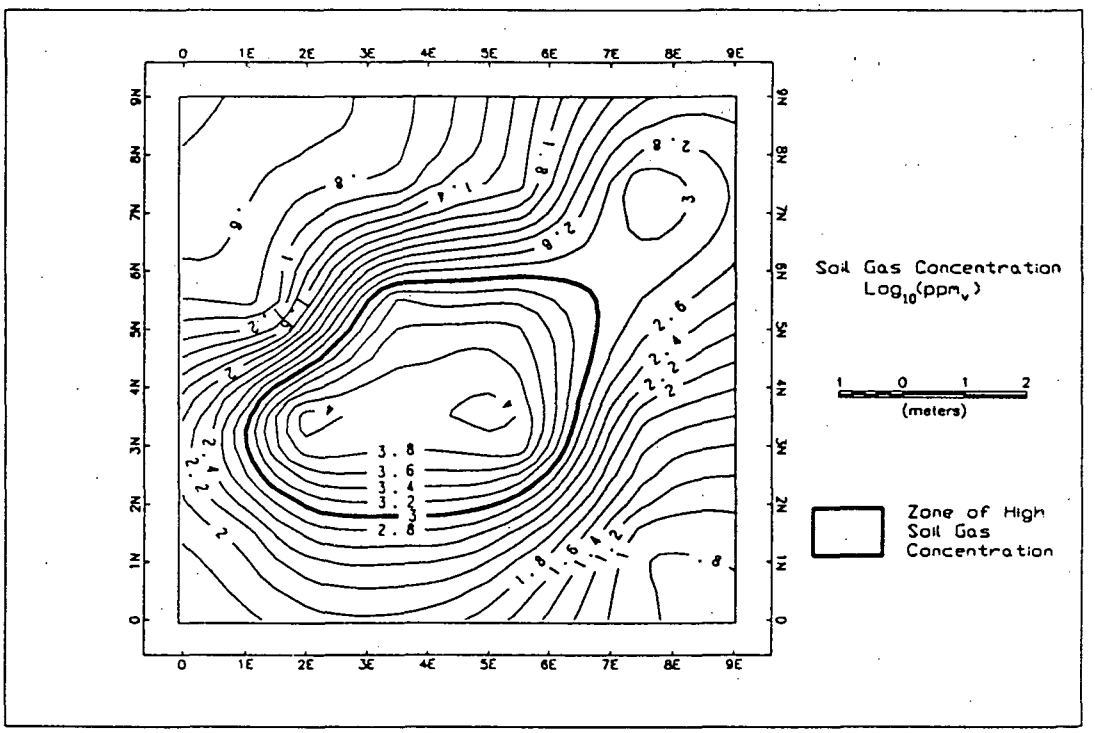

Figure 7: Soil Gas Contour Map 1 m b.g.s. After 47 Days of Operation

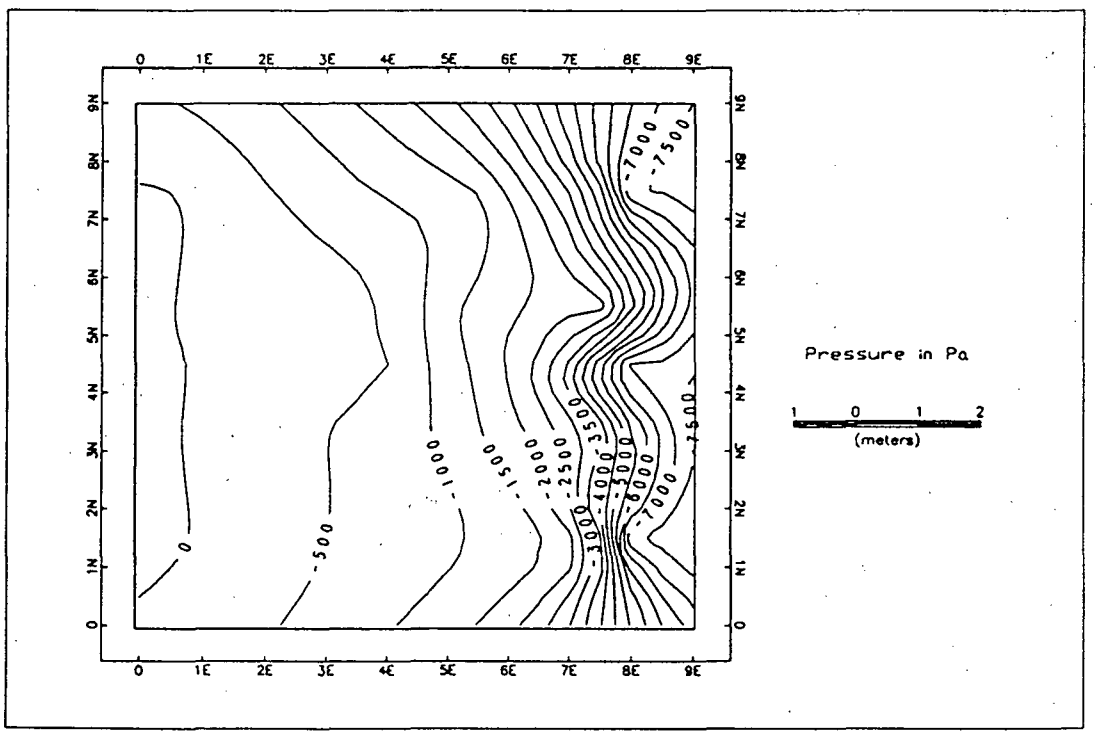

Figure 8: Pressure Field at 1 m b.g.s. - Flow Rate = 710 L/min (25 scfm)

limitation. Since the location of this high soil gas concentration region is asymmetrical relative to the flow direction, the slow clean-up cannot be completely attributed to its distance from the extraction wells. As discussed earlier, soil heterogeneity can affect SVE through flow variations caused by permeability variations, non-uniform NAPL distribution, and non-uniform moisture content. These parameters are discussed below with respect to this high gas concentration zone.

Falling head permeameter measurements made on cores collected in the high gas concentration zone determined that the intrinsic permeability was slightly higher in this zone than in other areas of the cell. This suggests that variations in intrinsic permeability did not have a direct affect on the air flow in this zone.

If the porous medium had been homogeneous, the NAPL should have been uniformly distributed. The initial location of pure phase PCE at 0.8 m b.g.s. (Figure 4) shows that there was a larger NAPL zone in the southwest portion of the cell than in the northwest portion of the cell. *Brewster (1993)* stated that the GPR analysis performed prior to the SVE experiment indicated that there was a vertical NAPL flow conduit in this zone, which may have resulted in higher NAPL saturations within this zone. Since relative air permeability is dependent on the air saturation, a higher NAPL saturation would result in lower air flow through this zone. The analysis of cores collected within this zone prior to the SVE experiment found that these cores had higher NAPL saturation than cores collected elsewhere in the cell. The asymmetrical (*i.e.*, non-uniform) NAPL distribution prior to the experiment would contribute to non-uniform flow in this zone. *In situ* gas pressure data revealed that the southwest quarter of the cell was not as influenced by the subsurface pressure field as the northwest corner was (see Figure 8). A lower pressure drop could be reflected in a lower flow rate in this area.

The moisture content throughout this zone ranged from a high of 20% down to 17.5%, decreasing from west to east. The moisture content on the west side of the cell was the highest measured at this depth. The combination of a relatively high moisture content and a high NAPL saturation would have reduced the air permeability in this region. If pure phase PCE was separated from the moving air by a zone with a high water content, then aqueous phase diffusion limitations would result in slow removal of this mass.

It appears that the degree of heterogeneity in this experimental cell was sufficient to affect clean-up. The high concentration zone persisted even after the mass flux had become very low. Since many contaminated sites will have much more complicated geology than the simple beach deposit at Borden, it can be expected that the performance of a SVE system will be much more limited at these sites than it was in this experiment. The fact that this zone was not strongly influenced by the induced gas pressure field is evidence that the heterogeneous nature of the porous medium was limiting the performance of the SVE system.

Eight soil cores were collected in January, 1994 to further investigate the soil clean-up performance. They are currently being analyzed for PCE concentration and moisture

content. This data will be used to confirm the soil gas data, and to provide more detailed PCE soil concentration profiles.

The results presented here are preliminary, since this SVE system is still operating at this point. More conclusive results will be available once the analysis of the soil cores for PCE concentration is completed.

Conclusions

The field trial of SVE at CFB Borden has provided some insight into the performance of this technology in a heterogeneous soil. The experimental cell contained several elements which added to its complex nature: a heterogeneous porous medium, non-uniform NAPL distribution, and a non-uniform moisture content distribution. The experiment was intensely monitored in order to help quantify the effects of these complexities.

The experiment showed that the mass removal performance of the SVE system decreased significantly even though a significant quantity of PCE remained in the subsurface. If the remaining mass was all trapped within zones with high water saturation, then this decrease in the mass removal performance could be expected. However, soil gas surveys revealed that there was a zone with high soil gas concentrations at 1 m b.g.s. that was not being remediated as quickly as the rest of the cell at this level. It is believed that the heterogeneous nature of the soil played a role in the slow removal of the PCE from the unsaturated zone since this heterogeneous nature gave rise to spatially varying NAPL and moisture content distributions.

Acknowledgements

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ATTACHMENT 2

A New Method for Collecting Core Samples Without a Drilling Rig

by Robert C. Starr and Robert A. Ingleton

Abstract

A new piston sampler allows the collection of high-quality core samples from sand, silt or clay, up to depths of 18 meters. The sampler is operated by a one- or two-person crew without a drilling rig. The sampler and ancillary equipment fit easily into a half-ton truck, making this a highly portable sampling system. Other advantages include minimal mechanical disturbance and precisely known sample depth. Casing is not required to maintain an open corehole below the water table and drilling fluid is not used in the corehole, so the solids and pore water of the sample should not be contaminated by foreign fluids. High-quality samples for physical, geochemical, and microbiological characterization of the subsurface are easily obtained with this new device.

Introduction

Samples of pore water and solid materials from below the ground surface are often required in investigations of subsurface contamination and for physical, geochemical, and microbiological characterization of hydrogeologic regimes. Samples for hydrological investigations should have the following characteristics:

- Known depth of origin
- Good sample recovery
- Limited mechanical disturbance
- Pore water and solid phase uncontaminated by drilling fluids.

Existing sampling techniques and equipment often provide samples that fail to meet one or more of these criteria. For example, the depth of origin of samples collected from drill cuttings is poorly known. Clean, loose sands and gravels form many important aquifers, but sample recovery in these materials is often poor. Split barrel and other thick-walled samplers yield samples that are substantially disturbed mechanically, while samples collected in boreholes drilled with mud, through hollow-stem augers filled with water, or beneath wash-bored casing are contaminated to some degree with drilling fluid.

Drilling rigs are usually required to obtain samples deeper than a few meters below the ground surface. Land access problems, budgetary constraints and scheduling difficulties often make the use of a drilling rig impractical, so manual sampling techniques are sometimes preferable.

Patterson et al. (1978) and Sudicky (1986) describe methods of collecting core samples without using a drilling rig. Both methods rely on wash-bored steel casing to maintain an open borehole below the water table, and both methods are designed to provide minimal disturbance and precisely known sampling depth. One method incorporates a piston and generally yields excellent sample recovery. The major disadvantage with both samplers is that the water used to install the casing contaminates the pore water below the casing, rendering samples immediately below the casing useless for geochemical or microbiological characterization. The zone of penetration of jetting water could vary widely between settings, depending on the hydraulic conductivity of the material, the depth of the water table and the length of time required for advancing the casing. An additional drawback is that large volumes of water are required for wash-boring casing. Providing a water supply can be inconvenient at many sites. Finally, installing and recovering casing is a strenuous, time-consuming task.

A new sampler has been developed that can be used for collecting high-quality soil cores, without using either drilling fluids or a drilling rig. It incorporates a pointed end piece that functions both as a drive point and as a piston, so the device is known as the drive point/piston sampler, or DPPS.

Description of the Drive Point/Piston Sampler

The major components of the drive point/piston sampler are shown in Figure 1. It consists of an aluminum sample tube, a piston inside the sample tube and a rod that controls the piston's motion. Steel casing is connected to the top of the sample tube by an adapter head, and a drive head is attached to the top of the steel casing. Figure 2 shows a short length of sample tube that has been cut to reveal the drive point/piston assembly, the adapter head and inner rod.

The sample tube is a length of 51mm (2.0 inch) outside-diameter aluminum tubing with a wall thickness

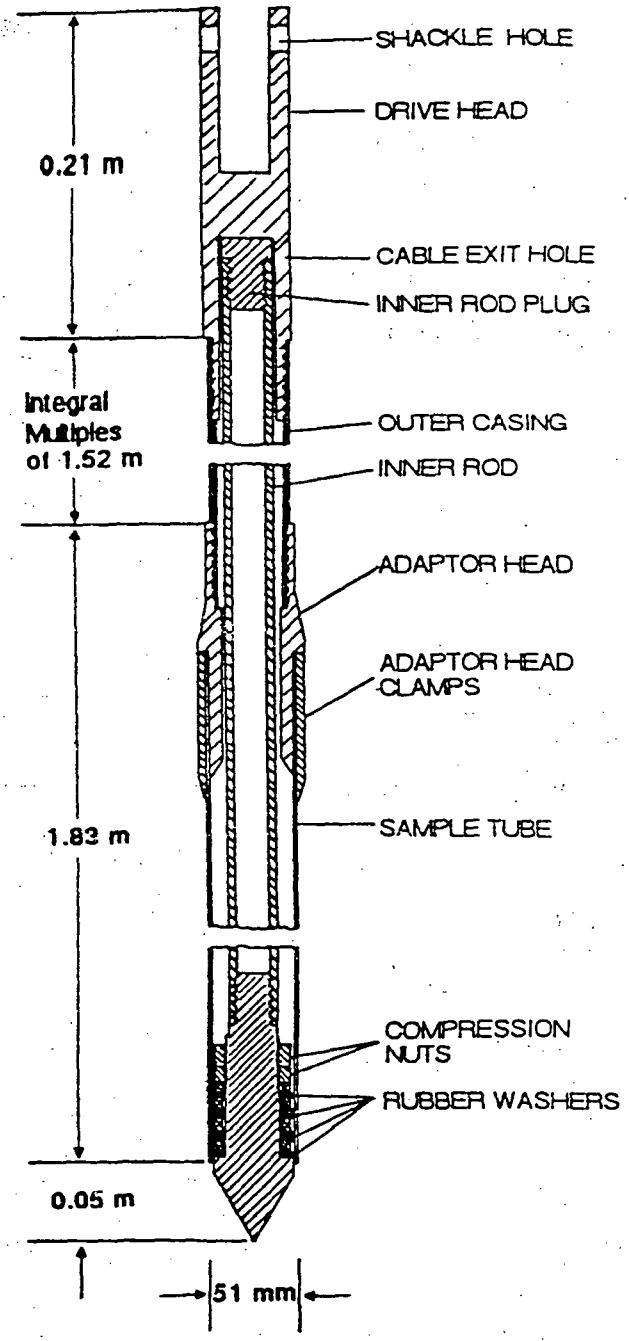

Figure 1. Section through the drive point/piston sampler.

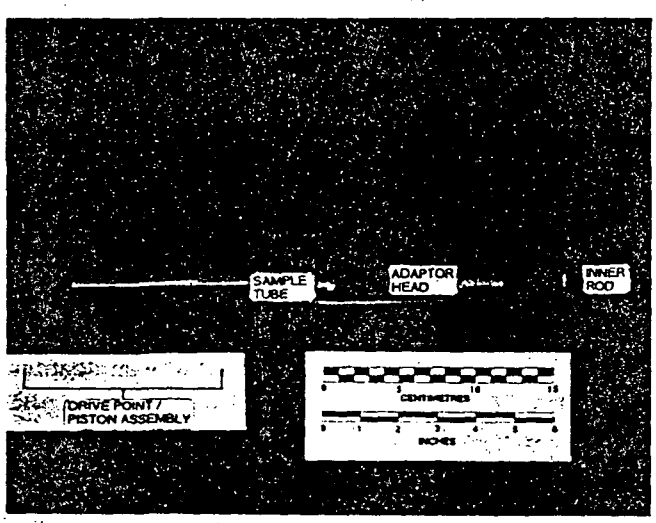

Figure 2. Short length of sample tube, drive point/piston assembly, adapter head, and inner rod.

of 1.3mm (0.050 inch), and allows a 1.5m (5 foot) long sample to be collected. The sample tube contains and protects the sample during transport and storage; a separate tube is used for each sample. The sample tube can be constructed of stainless steel to collect samples for analysis for trace organics, and plastic pipe can be used for sampling soft materials.

The piston prevents material from entering the sample tube before sampling and improves sample recovery by providing a seal above the sample. The upper part of the piston is a mechanical packer, which consists of alternating steel and rubber rings and two threaded steel nuts. One nut compresses the rubber washers so they seal against the inner surface of the sample tube. This adjustment allows slight variation in the diameter of sample tubes and wear of the rubber rings to be easily compensated for in the field. The second nut prevents the first from turning and releasing the compression in the rubber rings. The bottom of the piston extends beyond the sample tube and is pointed so that the sampler can be driven through soil without material entering the sample tube.

The adapter head connects the sample tube to the outer casing (steel EW flush-joint casing [46mm (1.81 inch) O.D., 38mm (1.50 inch I.D.)]) so that samples can be collected from well below ground surface without having to use long, continuous lengths of pipe. The drive head screws into the top of the outer casing. The inner rod (steel RW drill rod [28mm (1.09 inch O.D.), 18mm (0.72 inch I.D.)]) is inside the outer casing and extends from the piston to the drive head. This rod controls the motion of the piston. A plug in the top of the inner rod prevents damage to the threads. Standard EW casing is subject to failure by fracturing near the joints after prolonged use. Casing with a greater wall thickness overcomes this problem.

Operation

Three basic operations are involved in collecting a sample with the DPPS. First, the DPPS is driven into the soil until the sample tube is at the top of the interval to be sampled. Second, the sample tube is advanced through the sample interval. Third, the sampler is withdrawn from the ground and the sample tube, with the sample inside, is removed from the sampler.

The sampler is driven into the soil by pounding on the drive head with a gasoline-powered jackhammer, such as a Cobra (Atlas Copco, Stockholm, Sweden) or a Pionjar (Berema AB, Solna, Sweden). Pneumatically or electrically powered jackhammers or hammer drills are reasonable alternatives to gasoline-powered devices. As the sampler is driven to the top of a sample interval, the threaded plug in the top of the inner rod rests against the inside of the drive head, keeping the drive point/piston assembly at the bottom of the sample tube. Sections of the inner rod and the outer casing are added as the sampler is driven into the soil (Figure 3 a–d).

After the sampler has been advanced to the top of the sample interval, the threaded plug is replaced with a threaded fitting attached to a length of steel cable. The cable is passed through an additional length of

casing and the drive head, and secured to an overhead support (Figure 3e). The sample tube is filled with material from the formation by driving the outer casing and sample tube down with the jackhammer, while the cable and inner rod hold the piston stationary at the top of the sample interval (Figure 3f).

The sample is recovered by withdrawing the entire sampler from the ground using one of several alternatives (Figure 3g). The easiest recovery method is pulling upward on a shackle attached to the drive head with either a winch or chain hoist supported by scaffolding and a beam. Screw jacks can be placed at the ends of the beam to provide extra support. An alternative to an overhead winch or hoist is a slip ring and a high capacity jack, such as a ratchet-lowering jack (Duff-Norton Mfg. Co., Charlotte, North Carolina), a manually operated hydraulic jack, or a manually or electrically powered hydraulic cylinder (Enerpac, Butler, Wisconsin). The latter methods are slower and more laborious than using an overhead winch or hoist, but provide more lifting force and are better suited for use where head room is limited.

The seal provided by the piston at the top of the sample helps to keep the sample from falling out of the sample tube during this operation. Although the friction between the rubber washers and the sample tube is great enough to prevent the piston from sliding down during withdrawal, an internal rod holder can be used to provide extra security against downward movement of the piston.

After the sampler has been removed from the corehole, the sample tube is cut just below the drive point/piston. A new core tube is attached to the adapter head and the sampler is reassembled, placed back into the same corehole and driven to the top of the next sample interval. Boreholes in cohesionless materials usually collapse below the water table as the sampler is withdrawn. This does not present a problem, as the DPPS is merely driven through the collapsed material to the top of the next sample interval. This capability eliminates the requirement for casing or drilling fluid for stabilizing the borehole.

There are several options for processing the sample tube after it is removed from the DPPS. The ends can be sealed with tight-fitting, low-density polyethylene caps, which are available from electrical, plumbing or industrial suppliers. Disks of Teflon® or other material can be placed inside the caps to minimize contact between the polyethylene caps and the core sample, if desired. The ends can be further sealed with duct tape and wax prior to shipment to the laboratory for further analysis. Aseptic subsamples can be collected in the lab or field using an apparatus such as that described by Wilson et al. (1983). In the lab or field, the sample tube can be cut into lengths using ordinary tubing cutters, or split longitudinally to observe the stratigraphy. Core tubes are split using a circular saw equipped with a carbide-tipped blade and a simple plywood jig that holds the sample tube and guides the saw. An experienced operator can split a 1.5m core in approximately five minutes.

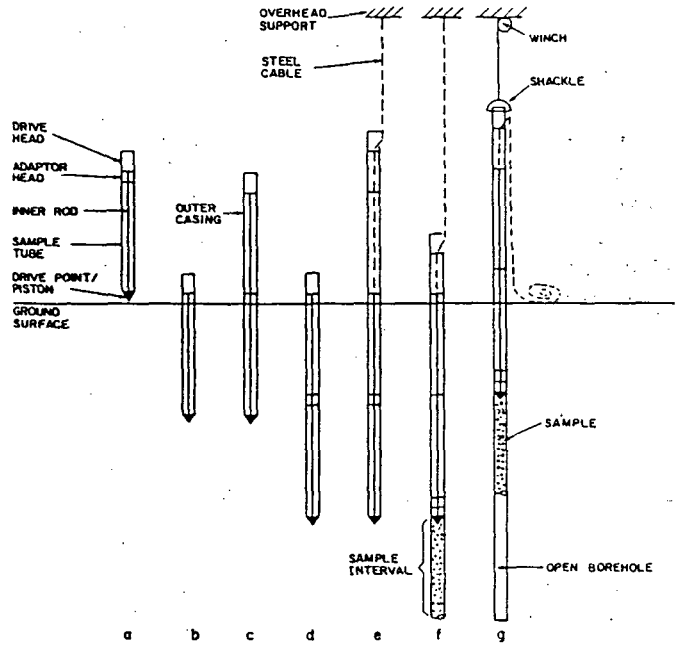

Figure 3. Sampling procedure: (a) Assemble the sampler; (b) Drive it into the ground; (c) Add outer casing and inner rod; (d) Drive the sampler to the top of the sample interval; (e) Attach cable to the inner rod, add outer casing, and secure the cable overhead; (f) Drive the sample tube through the sample interval; (g) Remove the entire sampler from the corehole.

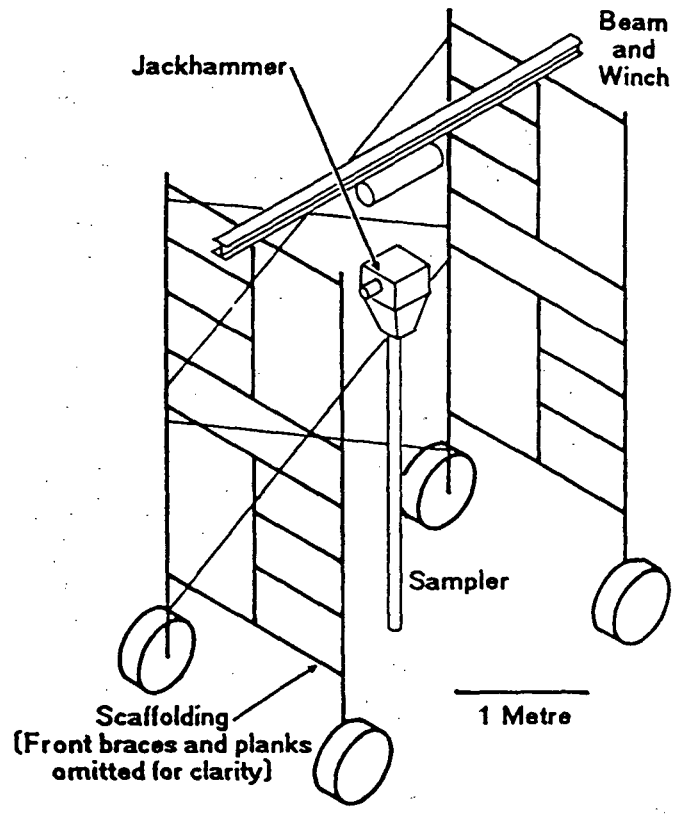

Figure 4. Scaffolding used for coring with the DPPS.

Scaffolding set up around the corehole is an important component of the sampling system (Figure 4). The top of the sampler extends about 2 meters above ground surface before it is driven into the ground, and 3 meters of scaffolding allow the crew to safely work at that height to drive the sampler in. The cable that holds the piston at the top of the sample interval is attached to a beam on top of the scaffolding, which also supports the winch or hoist used to recover the sampler. Scaffolding equip-

ped with wheels can be easily moved about on a site without disassembly.

Applications

The DPPS is routinely used in studies where high-quality samples are required. Starr and Gillham (1989) geochemically characterized the upper 4 meters of the subsurface at two sites using samples collected with an early version of the DPPS. Samples collected using previously available samplers would have been inappropriate for this study because of the likelihood of sample contamination.

Kueper et al. (1991) used samples collected with the DPPS to characterize, on a scale of centimeters, the spatial distribution of hydraulic conductivity in a surficial sandy aquifer. Capillary pressure saturation curves were measured on these samples to define the relationship between hydraulic conductivity and capillary pressure for the aquifer. The DPPS was particularly well suited for this study because it allowed sample interval locations to be accurately determined and because the undisturbed nature of the retrieved core allowed accurate logging in the field. The core of a dipping, thinly bedded fine sand (Figure 5a) illustrates that the DPPS causes little mechanical disturbance of sampled material. Sample recovery in this study ranged from 95 to 100 percent.

In a similar application, Grinnel (1991) modified the DPPS to collect square cross section core samples. A specially designed lab permeameter allowed measurement of both horizontal and vertical hydraulic conductivity on the same undisturbed core samples.

The DPPS and ancillary equipment fit easily into a half-ton truck, which makes it a highly portable sampling tool. It is routinely used for reconnaissance sampling, and when the small number of samples required from relatively shallow depths does not warrant mobilization of a drilling rig to the site. For example, the DPPS was used to collect samples for physical and geochemical characterization of a site near Mexico City where suitable sampling equipment was not readily available (Rudolph et al. 1991). The DPPS, a jackhammer, and a small jig for fabricating sample tubes were shipped by air to the site. Sample tubes were prepared using materials purchased at the site, and scaffolding and a chain hoist were rented locally. Samples were collected from soft lacustrine clay to a depth of 10m (33 feet). One corehole was advanced at an angle of 35 degrees from vertical to an inclined depth of 11m (36 feet) to intersect vertical fractures. This case illustrates that high-quality samples can be collected in remote areas by shipping only a modest amount of equipment, and in particular without having to mobilize a drilling rig.

Pitre (personal communication, University of Waterloo, 1991) used the same inclined coring technique for collecting samples of soft lacustrine clay beneath an inaccessible location. Coreholes were started beside a sewage canal near Mexico City and angled 30 degrees from vertical so that samples were collected from beneath the canal itself. Coreholes were advanced to an inclined depth of 15.2m (50 feet). Vertical coreholes

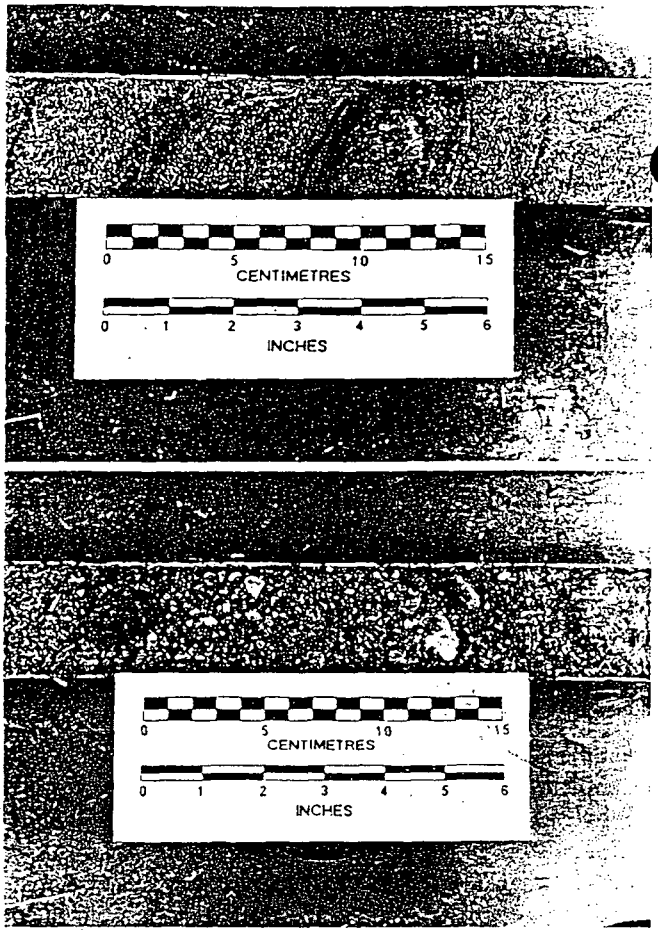

Figure 5. Core collected with the DPPS (longitudinally split for observation) (a) Thinly bedded, dipping fine sand; (b) Gravel interbed in a sand sequence.

would not have been suitable for collecting samples from directly beneath the canal due the practical, aesthetic, and health limitations of drilling from a platform in the middle of a sewage canal, and because coreholes open to the canal could provide conduits for migration of poor-quality water into the underlying water supply aquifer. The same technique could be used for sampling beneath other inaccessible locations.

A version of the DPPS that was modified to facilitate sampling below cased boreholes was used for sampling an aquifer that contained liquid-phase tetrachloroethylene. Core samples were divided into 5-centimeter depth increments, and tetrachloroethylene saturation was determined on aliquoits (Figure 6). Disposable casing was left in each borehole so that coring did not create pathways for migration of tetrachloroethylene, a DNAPL, deeper into the aquifer.

Limitations

The DPPS works well in sands, silts, and soft clays. It is not intended for sampling stony materials that may deform the sample tubes. However, Figure 5b shows that gravelly materials can sometimes be successfully sampled. Sample recovery is poor in very stiff clays, which do not readily enter the core tube.

The amount of time required for sampling varies from site to site, but the sampling rate decreases with increasing depth at all sites. A typical depth limit, based

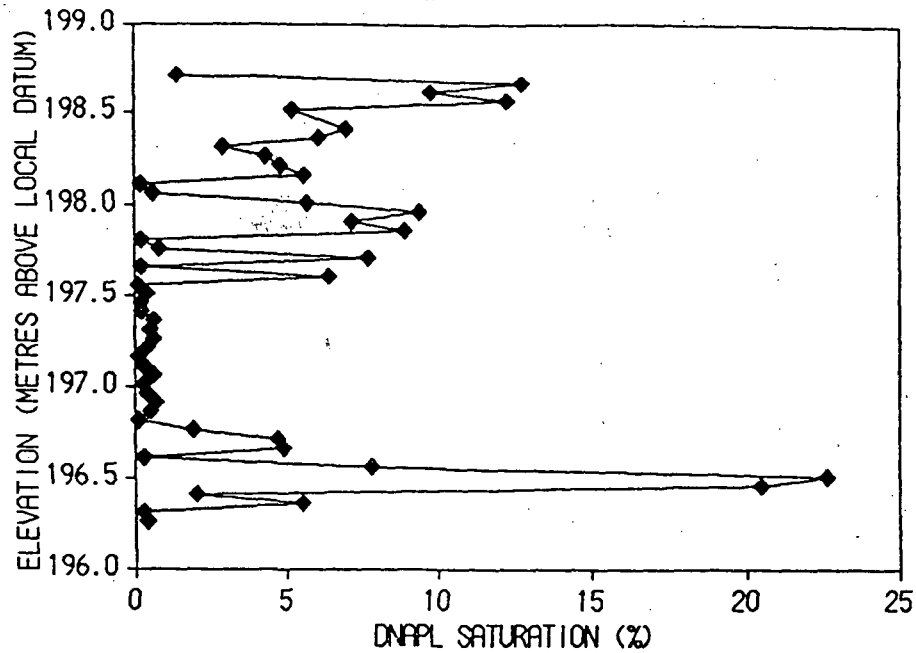

Figure 6. Tetrachloroethylene saturation in core samples from a surficial, sandy aquifer.

on sampling rate, is 6 to 9m (20 to 30 feet). Samples can be collected from greater depths, but sampling becomes more time consuming. The greatest depth sampled to date is 18.3m (60 feet).

Summary

A new method of collecting samples of sands, silts, and soft clays without a drilling rig has been developed. The sampler has been routinely used to a depth of 9 meters (30 feet), and on occasion to 18 meters (60 feet), by a one- or two-person crew. Coreholes can be vertical or inclined. Samples are collected in inexpensive thin-wall aluminum tubing, and a piston provides excellent sample recovery. Casing is not required to maintain an open borehole and drilling fluid is not introduced, minimizing the chances of pore water contamination and making this technique more convenient than traditional sampling methods. Sample disturbance is slight and the sample depth interval is precisely known. The sampler and ancillary equipment fit into a half-ton truck, making it an excellent tool for reconnaissance or working in remote sites. Samples obtained with the DPPS are of better quality than those commonly obtained with other methods because of excellent recovery, minimal mechanical disturbance, lack of contamination by foreign fluids, and the accurately known sample depth interval.

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Biographical Sketches

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Appendix G

Appendix G

Technical Papers

H54

Paper accepted for publication in Ground Water.

Soil-Gas Signatures from Volatile Chlorinated Solvents :Borden Field Experiments

Michael O. Rivett[a]

Abstract

Field experiments have been conducted at the Borden research site to evaluate the widely applied soil-gas survey method. In particular, the ability of surveys to delineate DNAPL chlorinated solvent sources and associated ground-water plumes has been investigated. Field experiments indicated that dissolved-phase plumes from DNAPL pools or residual located about a meter or more below the water table are unlikely to be directly detected by soil-gas surveys. Soil-gas plumes observed at real sites are attributed to volatilization of source material in the vadose zone and consequent formation of very shallow interface zone ground-water contamination that is able to partition to the soil gas as it transports down gradient. The distribution of DNAPL sources and dissolved-phase plumes deeper in the ground-water zone may often bear little resemblance to the shallow interface zone ground-water plume above and hence the location of this deeper contamination will remain highly difficult to identify by soil-gas surveys. Field observations are confirmed with simple analytical 1-D diffusion modeling and the implications of the results to the practice of soil-gas surveys at contaminated sites indicated.

Introduction

Contamination of ground water by volatile organic compounds (VOCs) has been apparent for over a decade (Zoetemann et al., 1981). Due to the expense and time consuming nature of conventional ground-water investigations that use monitoring wells to locate sources of subsurface contamination, indirect reconnaissance methods, such as soil-gas surveys, have evolved (Lapella and Thompson, 1983; Marrin and Thompson, 1984; Spittler et al., 1985). The apparent

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reliability of soil-gas surveys to delineate VOC contamination, coupled with their rapidity and relative low cost, has contributed to their widespread use. Surveys measure VOC concentrations in soil gas that arise from partitioning of contaminated water or non-aqueous phase liquid (NAPL) to the vadose zone air. They are most commonly used to: (a) delineate source zone locations, i.e. spills and leaking tanks or (b) define the approximate extent of ground-water plumes (Devitt et al., 1987). The reconnaissance method aids the initial siting, or further refinement of monitoring well and soil boring networks.

Soil-gas surveys often show good success in locating source areas such as spill zones, leaking tanks and floating petroleum products (Marrin and Thompson, 1984; Marrin and Kerfoot, 1988; Bishop et al., 1990). In the above, it is probable that LNAPL (light non-aqueous phase liquid) residual and/or high vapor concentrations are present in the vadose zone giving high, easily detectable, soil-gas signatures. However, it is apparent that many aquifers have become contaminated by the dissolution of DNAPLs (dense non-aqueous phase liquids) that may reside below the water table (Mackay and Cherry, 1989; Mercer and Cohen, 1990). The viability of using surveys to delineate sub-water table DNAPL sources and associated ground-water plumes is very uncertain. As stated by Marrin (1988), considerable subjective interpretation ultimately goes into approximating ground-water plume boundaries or selecting potential monitoring well locations from soil-gas data. He further indicates that soil-gas data may be prone to misinterpretation and, as emphasised by Reisinger et al. (1987), caution should be exercised when using soil gas to infer the status of contamination below the water table.

In spite of the above reservations, many site investigations suggest that soil-gas surveys may effectively track ground-water plumes (Malley et al., 1985; Marrin and Thompson, 1987; Moseley and Meyer, 1992). Contaminated ground water is generally found at locations showing soil-gas contamination and the spatial extent of soil-gas and ground-water plumes can show reasonable agreement (Devitt et al., 1987). Such effective ground-water plume delineation, would suggest that transfer of VOCs from shallow contaminated ground water to soil gas does occur. However, it is uncertain as to how deep below the water table the soil-gas technique may "see" contamination. Very weak transverse vertical dispersion of plumes observed in tracer tests (Mackay et al., 1986; LeBlanc et al.,1991), suggests that DNAPL zones or dissolved plumes, even relatively short distances below the water table, should give weak, if any, soil-gas signature and remain undetected. It is also possible that soil-gas plumes extending down gradient of sources may be indirectly derived from volatilization of vadose zone sources, rather than dissolution of ground-water zone sources. Vapors from residual NAPL

present in the vadose zone may contaminate the capillary fringe and shallow ground water (Schwille, 1988; Mendoza and McAlary, 1989; Sleep and Sykes, 1989; Conant et al., in prep.). Transport and repartitioning of the so formed "interface zone" ground-water plumes, produced by essentially vadose zone sources, may be responsible for down gradient soil-gas plumes, rather than upward transport of VOCs from dissolved-phase plumes located deeper in the ground-water zone.

It is important to discern the origins of VOCs in soil gas when using surveys to interpret the nature and extent of subsurface contamination. Multiplicity of sources and sparsity of ground-water data at sites usually makes understanding of processes and discernment of soil-gas origins difficult. Because erroneous and unambiguous conclusions may be easily drawn, field experiments have been conducted, using purposely installed DNAPL residual chlorinated solvent sources. The work aimed to address some of the above issues by providing a more simplified representation of scenarios believed common at contaminated sites. Goals of the research are itemized below.

1). Provide detailed field observations of soil-gas plumes (signatures) that develop from various types of subsurface contamination, in particular DNAPL sources.

2). Evaluate contaminant transport processes that influenced soil-gas plume formation in the field experiments.

3). Develop a conceptual model to be used as a basis to assess the effectiveness and limitations of soil-gas surveys as a reconnaissance tool at real contaminated sites.

Although the paper focuses upon soil-gas behavior from DNAPL source zones, some conclusions drawn may equally apply to LNAPL or dissolved-phase contaminant spills. It is acknowledged that some of the above goals, for example goal 2, may be better addressed through more detailed field vertical profile studies (Barber et al., 1990) or laboratory studies (McCarthy and Johnson, 1993), rather than the "field-oriented" approach adopted here. In general, it was hoped that this field demonstration would provide a more tangible appreciation of ground water-soil gas interactions and lead to improved interpretation of soil-gas survey data.

Site Details

Field experiments were conducted at the CFB Borden Research Site (Ontario), that has previously hosted many ground-water contaminant transport studies (Mackay et al., 1986; Sutton and Barker, 1985). Soil-gas studies were

conducted at two separate experimental areas located about 200 m apart. The sites are referred to as the "Emplaced Source Site" (ES Site) and the "Vapor Transport Site" (VT Site) and are shown in Figure 1.

The unconfined sand aquifer has a saturated thickness of about 8 m, the lower 2 m of which contains a leachate plume from a nearby domestic waste landfill. Experiments were performed in the overlying contaminant free ground-water and vadose zones. Vadose zone thickness varies between 2 to 3 m at the ES Site and 3 to 6 m at the VT Site. Annual water table fluctuation is about 80 cm with the majority of recharge occurring in the early spring. Aquifer deposits are comprised of stratified medium-grained to fine-grained sand with occasional, 1 to 5 cm scale, coarse sand and gravel, as well as fine silty clay horizons. The aquifer is relatively homogeneous compared to most, with hydraulic conductivity values generally within a factor of 3 of the mean $6.34_{x10^{-3}}$ cm/s value (ES Site). Ground cover is of a grassed or light forested nature with a thin, 20 cm, soil horizon. The ES Site has a mean ground-water velocity of 8.5 cm/day, a gradient of 0.51% and porosity of 33%. Sorption of hydrophobic organics is expected to be low based on a low fractional organic carbon (f_{oc}) of 0.035% (ES Site). Similar properties are found at the VT Site (Hughes, 1991; Hughes et al., 1992).

Experimental Setup and Monitoring

This study utilized areas of contamination established during research experiments in which immiscible-phase chlorinated solvent sources were placed in the subsurface. Contaminant source zones were artificial in nature and consisted of regular shaped zones of homogeneously distributed DNAPL residual. The purposely installed source zones were located below the water table at the ES Site and above the water table at the VT Site. Sources were used to study various aspects of contaminant transport behavior; the soil-gas survey studies, reported here, represent a small portion of the research conducted at the sites. Other research at the ES Site focused upon ground-water zone contaminant transport and remediation, an overview of this work is given by Rivett et al., (1994 and in prep.). The VT Site was initially used by Hughes et al. (1992) to study migration of vapors from a DNAPL source and subsequently the formation and remediation of an interface zone ground-water plume derived from the source (Conant et al., in prep.). Evaluation of soil-gas surveys was not included in the initial research program for the VT Site, but at a later date pursued as an opportunistic research venture. The chronology of experiments, sampling events and site remedial activities performed at the two sites is indicated in Figure

2 and discussed in the sections below. Properties of the chemicals used at the sites are listed in Table 1. All are volatile DNAPL chlorinated solvents and are among the most commonly encountered ground-water contaminants (Plumb, 1985). Their volatility, low sorptive potential and resistance to degradation suggest that they would be excellent soil-gas tracers (Marrin, 1988).

ES Site

The ES Site contained only one DNAPL source zone. This was installed in October 1989 and remained in place throughout and beyond the study period. This source was emplaced below the water table (Figure 3a) and contained sand mixed with an immiscible-phase blend of chlorinated solvents, fabricated as a block measuring 1 m high, 1.5 m wide and 0.5 m in thickness. The residual solvent saturation of the pore space was 5% and comprised 6% TCM (trichloromethane or chloroform), 39% TCE (trichloroethylene) and 55% PCE (perchloroethylene) for a total of 14.8 L solvent. Solvent dissolution is slow, hence flow of ground water through the ES Source over time produced continuous dissolved-phase plumes in the aquifer down gradient. The saturated aquifer thickness above the source varied between 0.9 and 1.7 m due to seasonal water table fluctuations. Although the natural aquifer, in particular any layering of sands, was perturbed by the source installation process, effects on contaminant transport processes were minimised by return of native sand to the excavated zone. The ES Site scenario, i.e. a DNAPL source zone localised some distance below the water table, would not typically occur at real spill sites where DNAPL would likely start from ground surface and migrate downward. The simplified experiment scenario, however, permits greater potential to examine soil-gas behavior than possible at real sites.

Ground-water and soil-gas monitoring at the ES Site was spatially intensive (Figure 1a). Soil-gas samples were obtained from arrays of 83 probes at 2 m depth below ground, 45 probes at 0.5 m depth, as well as 5 depth profiles (Figure 1a). Dynamic (grab) soil-gas sampling was performed with soil-gas samples being immediately analyzed on site following their collection (Marrin and Thompson, 1987). Probes were manually driven, 6.4 mm diameter, stainless steel pipe fitted with disposable "drive-point" tips. A peristaltic suction pump was used to purge the probes and the gas stream within the probe subsequently sampled by a GC syringe and immediately analyzed using a Varian 3400 GC-ECD. Detection limit for TCE was about 0.001 µg/l (at 10 ^{0}C), which is equivalent to 0.2 ppbv. This detection limit is typical of the more sensitive soil-gas surveys performed at real sites. Four soil gas sampling events were

performed in the period 280 to 550 days after source emplacement (Figure 2). A total of 173 Teflon multilevel piezometers, the majority containing 14 sampling points with 30 cm vertical spacing, permitted three dimensional ground-water monitoring. Although many ground-water monitoring episodes were conducted, only data obtained from the major sampling round at 322 days (Figure 2) are used in this study. Further details of the dissolved plume monitoring is given by Rivett et al. (in prep.). Ground-water samples were collected via a sampling manifold and analyzed by liquid-liquid pentane extraction with GC-ECD to a detection limit of about 1 µg/L.

VT Site

Although the VT site contained a number of temporary sources, those of most relevance to this study are the two residual TCE sources used by Hughes et al. (1992) to evaluate vapor migration in the vadose zone over a region extending up to 10 m from the source. These sources were installed at the same location and were in place for periods of just 28 and 90 days. This source location is hence referred to as the Vapor Transport (VT) Source. The VT Source installation procedure and results of the vapor migration study are presented in detail by Hughes (1991) and overviewed by Hughes et al. (1992). In contrast to the ES Source, the VT Source was located above the water table, as illustrated in Figure 3b. The source contained sand mixed with residual immiscible-phase TCE and was fabricated as a cylinder measuring 0.8 m high and 1.2 m diameter. It contained 40 L of TCE at a pore space residual saturation of about 13% and was located between 2.5 and 3.5 m above the seasonally variable water table. The source zone was covered with a synthetic membrane to prevent direct infiltration of water through the source. After the vapor transport experiments and excavation of the VT source, the area within about a 10 m radius was treated by soil vapor extraction for a period of 4 months (Figure 2). Other temporary DNAPL sources were also created at the VT Site within the area encompassed by the soil-gas survey (Figure 1b). These included two experimental spill releases of 6 L of PCE, that were subsequently excavated from the vadose zone (Poulsen and Kueper, 1992). A pilot soil vapor extraction study area, that used TCE during 1989, may also have resulted in the release of vapors to the vadose zone.

The presented soil-gas survey and ground-water data were collected 400 days after removal of the VT Source. The survey extended over a much greater area (Figure 1b) than the monitoring conducted in the original vapor transport experiment by Hughes et al. (1992). The ground-water data are drawn from Conant

et al. (in prep.), who provide a more detailed evaluation of the ground-water contamination present at the VT Site. Similar monitoring to that performed at the ES Site was used at the VT Site, but at a less detailed scale (Figure 1b). A total of 51 soil-gas probes extending 2 m below ground surface, in addition to one soil-gas depth profile, were sampled. Ground water was sampled at 52 locations using multilevel piezometers, or narrow diameter short screen wells.

Signatures From Ground-Water Sources and Plumes (ES Site)

Investigation of soil-gas signatures from sources and plumes located below the water table is provided by the ES Site data. Unfortunately, during the installation of the ES Site experiment, trace amounts of source mixture, i.e., sand containing immiscible solvents, were inadvertently introduced above the source zone. Early time monitoring of ground water (Rivett et al., in prep.) suggested that initial conditions consisted of a well defined source zone of residual DNAPL below the water table (Figure 3a), with a heterogeneous "sprinkling" of droplets of spilt trace residual DNAPL above, enriched in PCE and TCE relative to TCM. Spilt residual was believed to occupy ground-water and vadose zones and reside predominantly to the east of the source, toward the source mixing location at the ground surface about 6 m away. Monitoring of ground water 1 m down gradient of the source indicated that dissolved-phase contamination was already present between the top of the source zone and the water table at early time, as a result of the spillage during installation. Hence, in this experiment, soil-gas plumes may originate from: (a) transport of the dissolved-phase contamination from the DNAPL source zone upward through the capillary fringe; or (b) vaporisation or dissolution of spilt solvent contaminated sand residing in zones other than the source. Although the experiment was designed to evaluate whether process (a) was occurring, results below suggest that most, if not all, of the soil-gas observed was due to process (b).

Figure 4 shows TCM, TCE and PCE soil-gas and ground-water plumes approximately 300 days after source emplacement. Ground-water plumes represent maximum concentrations in the zone 1-2 m below the water table and soil-gas plumes indicate concentrations about 0.7 m above the water table. Longitudinal profiles along the ground-water plumes are also shown in Figure 5. Very low concentration soil-gas plumes are approximately centred around the source and extend in the direction of ground-water flow. Since advective gas flow in a specific direction, due to say temperature or pressure gradients was unlikely, the down gradient elongation of soil gas plumes implied that shallow ground-

water solutes had partitioned to the soil gas. Indeed, the extent of the soil-gas profiles down gradient show good agreement with the extent of near water table contamination (Figure 5). It is difficult to establish with certainty the origin of the ground-water contamination close to the water table, however the configuration of the plumes suggest that it is predominantly due to the dissolution of spilt residual DNAPL in the 96.5 to 97.0 m elevation zone above the source and not vertical transport of the plume from the defined DNAPL source zone. The impact of residual DNAPL spilt above the water table is indicated by the presence of up gradient soil-gas contamination and the lobes of soil-gas contamination to the east, that centre around the original source mixing area about 6 m away. The magnitude and areal extent of soil-gas signatures declined in the order PCE > TCE > TCM. This order is the reverse of the extent of the ground-water plumes, whose mobility is a reflection of their relative sorption potential to the aquifer (Table 1). As gas phase diffusion coefficients are similar for each chemical, other parameters in Table 1 control the extent of soil-gas plumes such as, sorption to solids (proportional to K_{oc}), Henry's Law water-air partitioning (H_c), or vapor pressures (P_v), if spilt residual in the vadose zone is the source. The observed order of mobility of the soil-gas plumes and relative order of chemical properties suggest that sorption to aquifer solids is of minor importance and that Henry's water-air partitioning and volatilisation from spilt solvent residual (expected to be predominantly PCE, with some TCE and very little TCM) are the controlling factors. The relative order of mobility of the soil-gas plumes combined with its spatial location suggests that the soil-gas plumes are derived from the trace amounts of spilt DNAPL.

Figures 4 and 5 do not indicate that the soil-gas plumes originated from vertical transport of the dissolved-phase plume emanating from the DNAPL source zone. Since the site is located in a recharge area, ground-water streamlines were expected to be horizontal to slightly dipping and thus significant vertical solute dispersion was necessary for dissolved solutes from the DNAPL source to be transported to the soil gas. The combination of advective and dispersive transport should have caused soil-gas plumes to be centred some distance down gradient of the source, rather than at the source as observed. Also, TCM is the most mobile ground-water zone solute and PCE the least mobile, due to their relative sorption and diffusion properties. Hence, if concentrations at the water table interface were due to vertical dispersion of the DNAPL source plume, one would expect the order of contamination to be TCM > TCE > PCE, which is the reverse to that observed (Figure 5). Minimal movement of the 1000 µg/L dissolved plume contours up toward the water table; discontinuity of

concentrations above the source top elevation; the appearance of plumes emanating from above the source zone (particularly at the 96.5 to 97 m elevation); and the inability to trace contours of the most mobile solute, TCM, from the source to the water table suggests that the near water table contamination, and hence soil-gas plumes, do not originate from the DNAPL source zone.

It is concluded that soil-gas plumes developed as a result of the spilt DNAPL; had spillage not occurred, it is probable that no soil-gas plumes would have been detected. Migration of soil-gas plumes down gradient indicated that when ground-water solutes were sufficiently close to the water table, then vertical transport over limited saturated distances may occur to yield soil-gas contamination. It is proposed that solutes dissolved from spilt residual DNAPL located just below the water table, have a sufficient vertical component of flow to reach the water-air interface during their down gradient transport in the ground-water zone. Such vertical dispersive transport arises from mechanical mixing and diffusion processes; the times and distances over which this transport may be effective is considered later. Plume configurations in Figure 5 suggested insufficient time had elapsed for soil-gas plumes to be directly observed from the vertical transport of solutes from a DNAPL source about 1 m below the water table. In fact, temporal monitoring of PCE soil-gas (Figure 6), indicated an approximate order of magnitude concentration decline between 285 and 550 days. Although temporal changes of infiltration may be expected to cause variation in soil-gas concentrations and fluxes (Ong et al., 1992), the observed decrease is probably due to depletion of the spilt DNAPL present in the vadose zone with time. Longer times for vertical transport do not guarantee that soil-gas will eventually be detected, since continual accretion of recharge from above will increase the effective transport distance through ground water to the water-air interface with time.

Signatures From Interface Zone Plumes (VT Site)

Investigation of soil-gas signatures from "interface zone" plumes is provided by the VT Site data. The "interface zone" is defined to include the upper ground-water zone in close proximity to the water table, the fully saturated capillary fringe and the transition zone to residual water saturation. A TCE ground-water plume was formed in the interface zone as a result of the VT Source used by Hughes et al. (1992) in their vapor transport experiments. Hughes (1991) indicates that TCE vapor concentrations emitted from the vadose zone DNAPL source approached saturation (260 mg/L at 10^0C) and that after 40

days, concentrations up to 180 µg/L had migrated almost 10 m radially about the source. Ground water below the vapor plume was believed to have become contaminated by: diffusive transport and partitioning into the water in the capillary fringe; vapor partitioning to infiltration subsequently incorporated into the interface zone and rising ground-water levels into vapor contaminated vadose zone strata (Conant et al., in prep.). Formation of interface zone ground-water plumes by volatilization of vadose zone sources has been described by Schwille (1988) and modeled by Mendoza and McAlary (1989) and Sleep and Sykes (1989). The interface zone plume at the VT Site resulted from the volatilization of temporary TCE sources, present in the vadose zone for periods of just 28 and 90 days. A detailed discussion of the formation and significance of this interface zone ground-water plume is provided by Conant et al. (in prep.).

Soil-gas and ground-water plumes at the VT Site, 400 days after removal of the DNAPL sources, are shown in Figure 7. The ground-water plume was generally within about a meter of the water table (i.e., an interface zone plume) and extended over 100 m down gradient. The peak TCE concentration from the second vapor transport experiment was located 25 to 80 m down gradient of the original VT Source location and approached 10,000 µg/L. The 100 µg/L contour at 100 m is believed to be the tailing edge of the pulse from the first experiment (monitoring further down gradient was prevented by buildings). The much greater width of the interface zone ground-water plume, compared to the original VT Source width (20 to 35 m compared to 1.2 m), is attributed to the radial diffusion of vapors from the DNAPL source forming extensive contamination transverse to the ground-water flow direction (Conant et al., in prep). The lobe and some concentrations on the east side of the interface zone plume, may perhaps be attributed to TCE vapors from the pilot soil vapor extraction experiments, however, this is believed to be a minor TCE source relative to the VT Source used in the vapor transport experiments.

The soil-gas plume showed good spatial correlation with the interface zone ground-water plume. TCE in the soil gas exceeded 0.1 µg/L over much of the site and even extended 100 m down gradient of the original source. This is in contrast to the ES Site where TCE values in excess of 0.1 µg/L were only detected within 5 m of the DNAPL source zone. The plan survey showed a maximum soil-gas value of 5 µg/L close to the previous location of the vapor transport sources, despite removal of residual DNAPL sources by excavation over 400 days previous and soil vapor extraction of the immediate area for 4 months following excavation. A soil-gas maximum also coincided with the location of peak ground-water contamination, about 70 m down gradient. Figure 7 shows concentrations

at this point rising with depth to 22 µg/L at 0.7 m above the water table; similar concentration increases with depth may be anticipated elsewhere. The good spatial correlation between the soil-gas and interface ground-water plumes is shown by the excellent agreement of soil-gas and ground-water boundaries up gradient of the source and along the west plume boundary (Figure 7). Further, the ground-water concentration low at 90 m down gradient is also reflected in the overlying soil-gas plume. Discrepancies along the east plume boundary may perhaps be partly explained by vapors from the pilot soil vapor extraction site.

The development of the soil-gas plume down gradient is unlikely to be due to lateral gas migration from subsurface pressure gradients. There is little reason for such a pronounced directional pressure gradient. In addition, Hughes (1991) indicated that the initial migration of vapors from the DNAPL source was radially symmetric. Instead, the development of high soil-gas concentrations and closely correlated plumes down gradient is attributed to the continued partitioning between the TCE interface zone plume and the soil gas. Initially vapors extending radially from the DNAPL source were incorporated into the capillary fringe water via simple vapor-water contact or perhaps partitioning into infiltration. TCE within the capillary fringe may be incorporated to the more mobile, deeper, ground water via diffusion or accretion of recharge above (Conant et al., in prep.). The development of soil-gas plumes far down gradient indicates that contaminated mobile ground water was sufficiently close to the air-water interface to transfer back across the capillary fringe via diffusion, mechanical mixing and water table fluctuation mechanisms during its down gradient transport. With increasing time and travel distance, accumulation of recharge may cause a freshwater lens to develop over the ground-water plume that may attain sufficient thickness to inhibit partitioning to soil gas. However, repetitive partitioning of interface zone TCE to soil gas and subsequent re-incorporation into infiltration water is expected to hinder development of a fresh water lens and cause interface zone plumes, and hence soil-gas plumes, to persist substantial distances down gradient of sources.

In conclusion, previous work at the VT Site (Hughes, 1991; Hughes et al., 1992; Conant et al., in prep.) has shown that vapor transport from vadose zone DNAPL sources can create significant interface zone ground-water plumes. Such plumes are wide relative to the vadose zone DNAPL source and may extend far down gradient. The plumes are thin, but may have relatively high concentrations. The soil-gas work performed here, in conjunction with the above, indicates that such vadose zone sources and interface zone ground-water plumes, are easily delineated by soil-gas surveys. Their easy detection is attributed to the close proximity of interface plumes to the vadose zone, the extensive lateral nature

of these plumes and the high vapor concentrations initially emitted from the vadose zone DNAPL source material.

Other Important Field Observations

During the research, some other important field observations have been made that are relevant to soil-gas survey techniques and are briefly discussed below.

Infiltration of VOC contaminated water through the vadose zone may produce soil-gas concentrations due to water-air partitioning. Figure 8a shows TCE soil-gas concentrations at the ES Site about 100 days after the accidental spillage of contaminated water associated with operation of the ground-water pump-and-treat system. The spill comprised 300 L of water containing TCE at about 1000 µg/L. A soil-gas plume developed on the west side of the site, down gradient of the pump-and-treat treatment facility where the spill occurred, and was distinct from the soil-gas plume originating from the experimental DNAPL source zone. Soil-gas concentrations from the water spillage are significantly greater than those observed over the highly concentrated sub-water table plume down gradient of the DNAPL source.

Although soil-gas surveys are usually conducted prior to installation of ground-water monitoring wells, this is not always the case. This study has also found that previous well installations may cause confusing or anomalous soil-gas concentrations to result. Smearing of contaminated auger cuttings in the vadose zone, during installation of remediation wells in the concentrated ground-water plume at the ES Site, proved to be a source of localized soil-gas contamination. The small zone of contamination 25 m down gradient of the source zone in Figure 8a resulted from a well installation at that location 5 months previous; shortly after installation concentrations had been over 0.2 µg/L TCE. In addition, extremely high TCE soil-gas contamination at 200 µg/L was initially detected after installation of a well just down gradient of the DNAPL source. Figure 8a, sampled 5 months later, indicates this contamination had since declined to 0.6 µg/L, illustrating that high concentrations were relatively temporary, presumably due to the limited amount of displaced contaminated sand and water involved.

Data indicated that the soil-gas technique was so sensitive that it may still delineate the location of original source zones, even after these zones have been "remediated". This was previously illustrated by Figure 7, in which the TCE soil-gas plume accurately delineated the original location of the VT Source zone in spite of its removal and soil vapor extraction of the area. A

further example is provided by the PCE soil-gas plumes delineated at the VT Site (Figure 8b) that precisely located the position used for the two 6 L releases of PCE used by Poulsen and Kueper (1992) in their vadose zone experiments. This delineation is remarkable as the spill site was completely excavated and all residual DNAPL removed over 450 days previous. The soil-gas contamination is attributed to vapor migration from residual PCE present during the 3 month period over which excavation of the spill proceeded.

Comparison of Soil-Gas Signatures

The relative potential of various sources and associated plumes to be delineated by soil-gas surveys may be illustrated by comparison of the TCE soil-gas plumes in Figures 7 and 8a (note different scales). The interface zone ground-water plume (Figure 7), formed from the presence of a small 0.9 m^3 volume of residual TCE in the vadose zone for a total of about 100 days, had by far the greatest potential to form extensive soil gas plumes. If remediation of the original source zone had not occurred, or the source had been left to volatilize over several years (as at real sites), interface and soil-gas plumes would have been even larger and at higher concentration. At the other extreme, Figure 8a shows that the ES Site continuing DNAPL source, located about 1 m below the water table, had caused negligible soil-gas contamination after 550 days. Soil-gas above 0.01 µg/L covered an area of 80 m^2 (compared to 4,000 m^2 at the VT Site), most of which, if not all, originated from spilt DNAPL, rather than the actual ES Source zone. In all probability, such soil-gas contamination at real sites, if located, would be interpreted to be insignificant. Infiltration of VOC contaminated water (Figure 8a) may cause soil-gas plumes of intermediate character, their extent primarily dependent upon the volume spilt and concentrations present. Even small leakages, from perhaps sewers, may cause greater soil-gas signatures than DNAPL located only short distances below the water table.

The contrast in soil-gas signatures from various sources is also illustrated by TCE depth profiles in Figure 9. Soil-gas concentrations spanned 7 orders of magnitude, decreasing from the very high values of profile (a) taken 5 m from the vadose zone DNAPL source (at day 41 of Hughes' (1991) vapor transport experiment), through profile (b) associated with the 400 day old interface zone plume (i.e. contaminants in the capillary fringe and upper ground-water zone), to the weak signature of profile (c) associated with the deeper ground-water zone DNAPL source plume. Figure 9, and previous figures, suggest that if any residual DNAPL is present in the vadose zone, it may be

expected to produce extensive soil-gas contamination that will easily mask detection of soil-gas signatures from other sources or plumes short distances below the water table, as alluded to by Marrin (1984) and Silka (1988). It is also emphasised that the degree of ground-water contamination may often not be related to the degree of soil-gas contamination above. This is highlighted by Figure 9c, in which ground-water concentrations 2 m below the water table are 7 orders of magnitude greater than soil-gas concentrations observed 2 m above the water table. Data from five vertical profiles, including Figures 9b and 9c, also indicate that field Henry's Law partition coefficients (H_c), calculated from adjacent soil-gas and ground-water data points closest to the interface, give values generally 2 to 3 orders of magnitude lower than accepted H_c values (Table 1), even when the soil-gas plume directly originates from the ground-water plume. Thompson and Marrin (1987) state that field H_c values may, at best, agree to expected values on an order of magnitude basis. Given the often high concentration gradients of vertical profiles and relatively long, 3 m, well screens typically used, agreement of field H_c values with accepted values would likely be circumstantial and that most field H_c values would be meaningless.

Ground Water - Soil Gas Transfer Modeling

Simple analytical one-dimensional diffusion modeling is conducted to further investigate the production of soil-gas signatures from ground-water zone plumes. We aim to confirm the qualitative experimental observations that suggest solutes in the interface zone transfer to the soil gas, whereas solutes even just a metre or so below the water table exhibit little potential to transfer. Steady state diffusion modeling of ground water-soil gas transfer has been conducted by Swallow and Gschwend (1983) and Barber et al. (1990). More rigorous numerical simulation of VOC transfer across the capillary fringe has been conducted by McCarthy and Johnson (1993) and Van Vliet (1993). We adopt Barber et al.'s (1990) simple approach and approximate the saturated and unsaturated zones by a region of two connected domains of differing, but uniform, diffusion coefficients with a constant source concentration at the lower boundary of the ground-water domain. Such representation of the unsaturated zone is simplistic as vapor diffusion and sorption coefficients are a function of water contents, which will vary temporally and spatially (Ong et al., 1992). However, given that diffusion coefficients in water are generally 4 orders of magnitude lower than those in air and because we are primarily interested in transit times through the saturated zone, more rigorous simulation of the vadose zone is unnecessary for the specific objectives of this paper.

Diffusion modeling for vertical transport in the saturated zone is justified below.

Transverse vertical ground-water transport is typically represented by a dispersion coefficient (D_{tv}) which is comprised of a mechanical and diffusive term:

$$D_{tv} = D_d + D' = D_0\tau + \alpha_{tv} v \qquad (1)$$

where D_d is the bulk diffusion coefficient, D' is the mechanical dispersion coefficient, D_0 is the free-solution diffusion coefficient, τ is the tortuosity, α_{tv} is the local scale vertical transverse dispersivity and v is the advective pore water velocity. We may further write:

$$D_{tv} = A_{tv} v = D_0\tau + \alpha_{tv} v \qquad (2)$$

where A_{tv} is the (field scale) transverse vertical macrodispersivity. Reliable estimates of A_{tv} are provided by tracer tests at Borden (Rajaram and Gelhar, 1991) and Cape Cod (Garabedian et al., 1991) that give very low values of 2.2 mm and 1.5 mm respectively. Rajaram and Gelhar give values of D_0=2.00 x 10^{-9} m^2s^{-1}, v=0.09 md^{-1} and τ=0.6 for the Borden bromide data, and calculate α_{tv}=1.1 mm. Substitution of these values into the above gives: D_{tv}=2.35 x 10^{-9} m^2s^{-1}, D_d=1.20 x 10^{-9} m^2s^{-1} and D'=1.15 x 10^{-9} m^2s^{-1}, and would indicate that the contribution of mechanical dispersion to transverse vertical dispersion is on the same order as molecular diffusion. Given the uncertainty in determination of A_{tv}, D_0 and τ, a factor of 2 difference between D_{tv} and D_d above is considered small and hence the coefficient of transverse dispersion may be approximated to the effective diffusion coefficient. Thus for ground-water velocities of at least up to 0.4 m day^{-1} (maximum of the above tracer tests), vertical transport of ground-water solutes may be adequately represented by the diffusion process alone.

Steady State Diffusion Modeling

Steady state 1-D diffusion profiles are used to provide an indication of maximum soil-gas concentrations that may be derived from a specified ground-water zone plume. We use the steady state analytical solution, given by Barber et al. (1990) for a constant concentration source boundary (C_0), located at some depth (X_v) below the gas-air interface. This solution is based on Fick's Law, with equilibrium Henry's Law Constant (H_c [dimensionless]) partitioning at the water-air interface. Equating fluxes across this interface gives:

$$C_{gi} = \frac{\left[C_{go} + \left(\frac{L_g D_w C_0}{X_w D_g}\right)\right]}{\left[1 + \left(\frac{L_g D_w}{X_w D_g H_c}\right)\right]} \tag{3}$$

where C_{gi} is the gas phase concentration immediately adjacent to the water-air interface, L_g is the depth of the unsaturated zone, C_{go} the gas phase concentration near ground surface and D_w and D_g are water and gas phase effective diffusion coefficients respectively. As noted by Barber et al. (1990), for H_c greater than about 0.01, C_{gi} can be approximated to within 10% by:

$$C_{gi} = C_{go} + \left(\frac{L_g D_w C_0}{X_w D_g}\right) \tag{4}$$

Steady state concentration profiles are linear between end members of each medium, and as pointed out by Barber et al.(1990) are almost independent of H_c. Figure 10 (note log scale) shows steady state modeled values compared with field profiles from (a) the VT Site interface zone plume, 70 m down gradient of the original VT source, and (b) 10 m down gradient of the ES Site source. C_0 values were chosen by equating with various field ground-water concentrations and the water-air interface was set at 20 cm above the water table elevation, approximating the location of the saturated capillary fringe surface. In spite of the model simplicity, modeled profiles, particularly Figure 10a, display reasonable agreement with observed soil-gas when C_0 values are located close to the water table. However, steady state profiles from deeper C_0 values (Figure 10b) show very poor agreement with ground-water data and greatly over predict soil-gas concentrations and would indicate that steady state has not developed from such deep source concentrations. It may appear from Figure 10b that some field ground-water concentrations have apparently diffused from the deep high concentration plume toward the water table, these near water table concentrations, although in part may be due to vertical diffusive transport, are mostly attributed to dissolution of spilt residual material at these elevations.

The data suggest that if linear soil-gas profiles indicative of steady state are observed at sites, then application of equations (3) or (4) may provide an estimate of the magnitude of ground-water concentrations in the immediate vicinity of the water table. However, prediction of deeper ground-water quality, even just a meter or so below the air-water interface, is likely to be poor.

Transient Diffusion Modeling

Given infinite time, i.e., steady state, sources at any fixed depth below the water table will eventually cause some level of soil-gas contamination by diffusion. Since steady state may be slow to occur, transient modeling is employed to assess whether soil-gas contamination may be observed from ground-water zone sources over realistic time periods. In practice, accretion of recharge imposes a downward ground-water velocity at the water table, which may continually increase the effective distance over which diffusion has to occur with time. If the upward ground-water diffusion rate does not exceed the downward recharge rate, then solutes will not reach the interface to give soil-gas signatures. Transient analytical modeling is conducted, which although ignoring the continual increase in distance over which diffusion has to occur, is still a valuable indicator of typical times required for VOCs to diffuse through a fixed length of ground water to the interface. We use a transient solution adapted from the diffusion equations of Crank (1975) and Carslaw and Jaeger (1959) for a semi-infinite composite medium. The solution assumes that the water phase is modeled by a region of effective diffusion coefficient D_w extending from $-l < x < 0$ and the gas phase by a semi-infinite region of effective diffusion coefficient D_g for the region $x > 0$. Assuming Fick's Law, governing equations for gas and water phase concentrations, C_g and C_w respectively are:

$$\frac{\partial^2 C_w}{\partial x^2} - \frac{1}{D_w}\frac{\partial C_w}{\partial t} = 0 \qquad -l < x < 0,\ t > 0 \tag{5}$$

$$\frac{\partial^2 C_g}{\partial x^2} - \frac{1}{D_g}\frac{\partial C_g}{\partial t} = 0 \qquad x > 0,\ t > 0 \tag{6}$$

If we assume continuity of flux and validity of Henry's Law coefficients (H_c) at the soil gas-water interface, then:

$$D_g \frac{\partial C_g}{\partial x} = D_w \frac{\partial C_w}{\partial x} \qquad ,\ x = 0,\ t > 0 \tag{7}$$

$$C_g = H_c C_w \qquad ,\ x = 0,\ t > 0 \tag{8}$$

The solution to the problem of zero initial concentration throughout, with the lower surface of the water phase, $x=-l$ maintained at constant concentration C_0 is:

$$C_w = C_0 \sum_{n=0}^{\infty} \alpha^n \left\{ \mathrm{erfc}\left[\frac{(2n+1)l + x}{2\sqrt{D_w t}}\right] - \alpha\,\mathrm{erfc}\left[\frac{(2n+1)l - x}{2\sqrt{D_w t}}\right]\right\} \quad (9)$$

$$C_g = \frac{2kH_c C_0}{k + H_c} \sum_{n=0}^{\infty} \alpha^n \mathrm{erfc}\left[\frac{(2n+1)l + kx}{2\sqrt{D_w t}}\right] \quad (10)$$

$$\textit{where} \quad k = \left(\frac{D_w}{D_g}\right)^{1/2}, \quad \alpha = \frac{H_c - k}{H_c + k} \quad (11)$$

The solutions are only slightly modified from Crank (1975) with the addition of $C_g = H_c C_w$, from $C_g = C_w$, at the interface. The results are strictly only valid for a semi-infinite gas phase. In reality, they may adequately represent real finite bounded soil-gas zones if the gas phase is long relative to the water phase. This is not true for the present site and thus simulated and actual profiles in the gas phase will differ as the model will not maintain a zero concentration at the actual ground surface boundary. However, due to water-air diffusion coefficient ratios being of the order of 10^{-4}, the solutions are expected to reliably predict temporal profiles observed in the ground-water zone and soil-gas concentrations immediately above the interface, which are the primary interests of this work.

Figure 11 shows ground-water zone TCE transient profiles from a source located 1.1 m below the water-air interface. This depth equates to the minimum field observed water thickness between the ES Site DNAPL source top and interface, assuming a tension saturated capillary fringe zone of 20 cm. A time of 3 years is indicated for soil-gas concentrations at 10^{-6} C_0 to be observed, which is equivalent to soil-gas detection limit values of 0.001 µg/L for a C_0 of 1000 µg/L, or 1 µg/L if C_0 is the solubility of TCE. However, the vertical downward velocity at the water table due to recharge of 0.4 m year^{-1} estimated for Borden by Solomon et al., (1992) and the observed water table rise of 0.8 m (Figure 3a), suggest effective water thicknesses to transport through are greater than that used in Figure 11 and might be toward 1.5 to 2 m, by the time monitoring at 300 days was conducted. Similar transient simulations for water thicknesses of 1.5 m and 2 m, indicate times of 5 and 10 years respectively are required for 10^{-6} C_0 soil-gas concentrations to be observed. Thus the transient modeling indicates soil-gas is unlikely to be detected from the ES Site DNAPL source plume over the time-scale of the experiment and would support the interpretation previously made of the field results.

Figure 12 indicates the calculated times required for sources at various

depths below the water-air interface, to give specific soil-gas concentrations immediately above that interface. Although values pertaining to TCE and Borden are used, the figure may approximate many VOCs and porous media aquifers. For sources a few decimeters or less below the interface, times for diffusion across this distance are relatively short and detectable soil-gas is likely observed. However, times significantly increase with greater depth and since accretion of recharge may continually increase the effective thickness over which diffusion has to occur with time, solutes may never reach the interface. In many climates, the downward velocity imposed by recharge will exceed the diffusion rate upwards from sources located at about a meter or more below the water table and hence soil-gas signatures will not be observed. Primary exception to the above behavior may be anticipated in areas where hydraulic gradients have an upward vertical component, i.e. ground-water discharge areas. The potential of VOCs previously at depth in ground-water systems to be transferred to soil gas is then obviously much greater, however, discharge areas at many sites are typically of limited extent.

Conclusions and Relevance to Real Sites

Experimental Conclusions

The field experiments and modeling indicate that ground-water plumes originating from sources, such as DNAPL pools or residual, located much below the water table are unlikely to give soil-gas signatures due to the weakness of vertical transverse transport in the ground-water zone. The downward velocity near the water table due to recharge, may often be sufficient to prevent ground-water zone solutes partitioning to the soil gas, unless they originate from less than about a meter below the air-water interface. These conclusions are in agreement with the results of laboratory studies and rigorous numerical simulations of VOC transfer between ground water and soil gas by McCarthy and Johnson (1993). Strong soil-gas signatures may, however, be derived from DNAPL sources in the vadose zone; either directly by vapor transport or indirectly via formation of interface zone ground-water plumes that are sufficiently close to the air-water interface for vertical transport to cause soil-gas partitioning. The vapor transport mechanism causes radial soil-gas contamination about the vadose zone source extending to tens of meters (Silka, 1988; Mendoza and Frind, 1990; Hughes, 1991), whereas the latter mechanism may cause soil-gas and interface zone ground-water plumes to extend far down gradient. Thus, soil-gas signatures from vadose zone DNAPL sources and their associated interface zone ground-water plumes will predominate and mask any signatures from other ground-water zone plumes; only dissolution of DNAPL in the saturated zone that is

within, or very close to, the interface zone may contribute to the soil-gas contamination.

Application to Real Sites

Multiple sources, aquifer heterogeneity and variable ground cover at real sites may lead to complex soil-gas distributions. However, the general conclusions above are expected to apply. These conclusions are discussed below and are embodied within the conceptual model of soil-gas and ground-water contamination from a typical DNAPL spill in Figure 13. The discussion assumes that diffusion is the predominant gas phase transport mechanism and advective gas flow is negligible. This assumption is often valid, but not always. Pressure and temperature gradients may cause advection near subsurface structures that provide preferential conduits to the atmosphere, for example, basements or high permeability channels (Nazaroff et al., 1987). Density driven advection may be important in high permeability media for high vapor concentrations of dense solvents (Mendoza and Frind, 1990). Diurnal temperature and pressure variations may produce minor vertical piston-type fluctuations in soil-gas advection.

After a DNAPL spill, DNAPL may be fully contained in the vadose zone, or else have penetrated the water table to form DNAPL pools below the water table as well as leaving a trail of residual along its migration pathway in the vadose and ground-water zones (Figure 13; Mercer and Cohen, 1990). Since vadose zone sources are primarily responsible for soil-gas and interface zone plume formation, both spill scenarios, as they each contain such sources, may be anticipated to produce extensive and similar soil-gas and interface zone contamination. Due to this similarity, it is impossible to infer from the presence of a soil-gas plume whether DNAPL is, or is not, present below the water table. For DNAPL spills that penetrate below the water table, dissolved-phase plumes will initially emanate from the entire, continuous, vertical distribution of DNAPL in the ground water (Figure 13). DNAPL present in, or close to, the interface zone may produce dissolved-phase contamination that may easily partition to the soil gas. Soil-gas contamination derived from vadose zone or interface zone DNAPL may be expected to mask any soil-gas signatures that might arise from deeper ground-water zone DNAPL. Complete depletion of the DNAPL present in the vadose zone and interface zone, that produces orders of magnitude stronger signatures, would be required for discernment of any possible soil-gas signature that might arise from any deeper ground-water zone sources and plumes.

Typically, one could reasonably interpret from soil-gas plumes that up

gradient maxima are indicative of source locations and that the soil-gas plume may approximately define the extent of the very shallow, interface zone ground-water contamination (Figure 13). However, further interpretation of ground-water quality at depths greater than a meter or so is highly subjective as direct soil-gas signatures are likely not observed. The spatial distribution of deeper ground-water plumes and sources may differ substantially from the soil-gas distribution or shallow interface zone ground-water contamination. For example, aquifer heterogeneity may cause deeper plumes to migrate substantially greater distances than the interface (and soil-gas) plume if they are located in more conductive horizons. Layered strata may also cause substantial lateral migration of DNAPL from the site of spillage. Soil-gas monitoring would probably indicate the spill point, but fail to detect the extent of the lateral DNAPL migration and any associated dissolved-phase plumes.

The plan views in Figure 13 illustrate that the discrepancy in plume widths may cause a further problem in delineating ground-water contamination at depth from soil-gas plume data. Let us consider a hypothetical spill in which the plan cross sectional area of residual DNAPL source is constant with depth. Soil-gas and interface zone plumes will be tens of meters wider than the source zone, due to vapor transport lateral to the ground-water flow direction; whereas deeper ground-water plumes will be not much wider than the DNAPL source zone, due to the weakness of transverse horizontal dispersion (Anderson et al., 1992). Such soil-gas contamination over wide areas is typical of many sites (Marrin and Thompson, 1987; Devitt et al., 1987 and Bishop et al., 1990) and is predicted by the vapor migration studies of Mendoza and Frind (1990) and Hughes (1991). Although deeper, and probably higher concentration, ground-water plumes may often underlie soil-gas and interface zone plumes, the absence of direct soil-gas signatures and anticipated narrow plume widths that may be derived from the dissolution of discrete "stringers" of DNAPL residual (Anderson et al., 1992), would make location of such plumes highly difficult. Nevertheless, the location of maximum soil-gas and interface zone ground-water contamination that occurs close to the source zone and will migrate directly down hydraulic gradient may assist delineation of deeper plumes. In a relatively homogeneous aquifer, DNAPL sources and narrow dissolved plumes in the ground-water zone may be expected to directly underlie the maxima in the soil-gas and interface zone ground-water plumes, generated from vadose zone and interface zone DNAPL. Thus, although deep ground-water zone DNAPL sources and dissolved plumes do not give soil-gas signatures, their location might possibly be inferred from locations of maxima in detailed soil-gas transects perpendicular to the ground-water flow direction. However, temporal changes in ground-water flow, as well as DNAPL sources being

laterally displaced away from the original spill zone in more heterogeneous aquifers, may prevent the above reasoning from being a useful guide to locate deeper ground-water plumes.

The inability of soil-gas surveys to see far below the water table and practical constraints at most sites, that impose relatively wide spacing of ground-water monitoring wells, would cause deep ground-water zone plumes and sources to easily evade delineation. Conversely, shallow interface zone ground-water plumes, formed from vapors, may be relatively widespread and of significant vertical thickness, if appreciable water table rises into vapor contaminated strata have occurred and easily detected by soil-gas surveys and subsequent ground-water monitoring. In general, observations at real sites of wide and extensive soil-gas plumes; relatively wide, low concentration ground-water plumes and the apparent absence of DNAPL or highly concentrated plumes would lend support to the above conceptualisations.

Although the research focused primarily upon DNAPLs, some conclusions may apply to the delineation of sources and plumes associated with spills of LNAPL or aqueous phase material by soil-gas surveys. The generation of soil-gas and ground-water plumes from such spills is expected to be similar to that produced by a DNAPL spill that fails to penetrate below the water table. A wide soil-gas and interface zone plume may be anticipated similar to the upper two plan sections in Figure 13. Indeed, as LNAPLs have a much greater potential to spread laterally at the water table, plumes that develop may be much wider than those associated with vadose zone DNAPL sources. The physical restriction of LNAPL and aqueous spill source material to the vadose zone and shallow ground-water zone also makes detection of contamination associated with such spills much more amenable to soil-gas techniques. From physical transport considerations one may anticipate relatively good agreement between the spatial extent of LNAPL derived soil-gas and ground-water plumes. However, many LNAPL compounds are degraded aerobically and since the potential for degradation is spatially variable, poor agreement of plumes may occur in practice.

Temporal Effects at Real Sites

With time, depletion of the vadose zone DNAPL occurs and the generation of soil-gas plumes and interface zone ground-water plumes may decline. The rate of decline depends on compound physical properties, in addition to site considerations such as the quantity and spatial distribution of source material, aquifer heterogeneity and thickness of the vadose zone and ground cover permeability. The sensitivity of source longevity and vapor plume extent to some of these factors has been indicated by the numerical modeling studies of

Mendoza and Frind (1990). Often, DNAPL volatilization and desorption from vapor contaminated strata will be sufficiently slow that soil-gas surveys may delineate vadose zone sources and associated interface zone plumes many years after spill incidents. Although contribution to the soil-gas and interface plumes from vadose zone sources may ultimately cease, interface plumes and hence soil-gas plumes may still be generated if DNAPL residual or pools are present in the interface zone. Upon eventual complete dissolution of this DNAPL, the interface plume will cease to generate and will be transported down gradient, partitioning to the soil gas until eventually prevented from so doing by accumulation of recharge from above. If substantial DNAPL originally penetrated below the water table, and dissolution is slow relative to vadose zone volatilisation (as may often be expected), then a site may ultimately evolve to a state with only deep DNAPL being present, similar to the ES Site scenario. Soil-gas signatures are likely absent and hence a long term scenario evolves in which substantial DNAPL is present below the water table, undetectable by soil-gas surveys. The evolution to this state would typically be long, vary from site to site and spill to spill, but has a greater probability of occurring at older spill sites.

Summary

It is concluded that in spite of their limitations, soil-gas surveys may still be a valuable reconnaissance tool to delineate subsurface VOC contamination and facilitate location of monitoring wells and soil borings. However, since the majority of soil-gas contamination originates directly or indirectly from vadose zone sources and very little is expected to arise from DNAPL sources and associated ground-water plumes that develop relatively short distances below the water table, reliable definition of deeper ground-water contamination by soil-gas surveys should not be expected. Soil-gas plumes, in the absence of advective gas flow or complex vadose zone geology, may approximate the extent of the shallow interface zone ground-water contamination, and may indicate ground surface spill locations; however, these may not coincide with the location and extent of ground-water plumes and sources at depth. It is clear that soil-gas data, although of value, should be used with caution and their limitations recognised.

Acknowledgments

The author wishes to thank Doug Morton for assistance with soil-gas

sampling, Bernadette Conant for provision of the VT Site ground-water data, Stan Feenstra for assistance with ES Site ground-water sampling and Masaki Hayashi for modification of the transient diffusion equations. Helpful comments on the manuscript from Stan Feenstra, Bernadette Conant and John Cherry are appreciated. The work was supported by the University Consortium Solvents-in-Groundwater Research Program which is sponsored by Boeing, Ciba Geigy, Eastman Kodak, General Electric, Laidlaw Environmental Services, the Ontario Research Incentive Fund and the Natural Sciences and Engineering Research Council of Canada.

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Tables

Table 1. Physical-chemical properties of experimental solutes (at 10°C unless otherwise noted).

Solute	MW [a]	D_{air} [b]	D_{water} [c]	H_c [d]	P_v [e]	S [f]	K_{oc} [g]	R [h]
	$g\ mol^{-1}$	m^2s^{-1}	m^2s^{-1}		mm Hg	$mg\ L^{-1}$	$mL\ g^{-1}$	
TCM	119.39	8.4×10^{-6}	7.9×10^{-10}	0.0676	98.9	8700	44	1.05
TCE	131.40	7.6×10^{-6}	7.4×10^{-10}	0.172	35.1	1400	126	1.14
PCE	165.85	7.0×10^{-6}	6.8×10^{-10}	0.312	7.8	240	364	1.4

[a] Molecular weight; [b] Free air diffusion coefficient, calculated from measured diffusion volumes (Perry, 1984); [c] Free water diffusion coefficient, calculated from Wilke-Chang equation (Perry, 1984); [d] Henry's constant (dimensionless), [e] calculated from regression data of Gossett (1987); Vapor pressure (Mendoza and Frind, 1990); [f] Solubility at 22°C, (Broholm and Feenstra, in subm.); [g] Organic carbon partition coefficient at 20°C, (Schwille, 1988); [h] Retardation factor, calculated from K_{oc} and Borden F_{oc} and bulk density.

Figure Captions

Fig. 1. Plan view of monitoring instrumentation and source locations for (a) ES Site and (b) VT Site. The scale is in meters with origins located at ES and VT sources.

Fig. 2. Chronology of experiments, sampling events and remediation conducted at ES and VT Sites. Only soil-gas and ground-water sampling events pertaining to this study are indicated.

Fig. 3. Vertical section showing relative location of DNAPL sources for (a) ES Site tracer test and (b) VT Site vapor transport study by Hughes et al., (1992).

Fig. 4. ES Site plan views of TCM, TCE and PCE soil-gas plumes (contoured in µg/L at 2 m below ground surface) 285 days and ground-water plumes 322 days after source installation.

Fig. 5. ES Site longitudinal profiles of TCM, TCE and PCE contamination taken along the line of migration of ground-water plumes in Figure 4.

Fig. 6. ES Site temporal variation of PCE soil-gas contamination (recorded 2 m below ground surface).

Fig. 7. VT Site TCE ground-water and soil-gas plumes approximately 400 days after removal of the VT Source DNAPL used by Hughes et al., (1992). Soil-gas concentrations are in µg/L and are contoured in the plan view (measured 2 m below ground surface) and recorded as point values in the longitudinal profile.

Fig. 8. Other important field observations: (a) ES Site 550 days after source installation showing TCE soil-gas contamination due to a spill of contaminated water, installation of a monitoring well and the DNAPL source; (b) VT Site PCE soil-gas (contoured in µg/L) and ground-water plumes (shaded area) 450 days after excavation of the PCE experimental spill by Poulsen and Kueper (1992) at the location indicated.

Fig. 9. TCE soil-gas and ground-water depth profiles: (a) close to a vadose zone DNAPL source (approximately 5 m from the VT Source of Hughes, (1991) at day 41 of their experiment); (b) above an interface zone plume (70 m down gradient of the VT Source); (c) above a ground-water plume from a DNAPL source (10 m down gradient of the ES Source about 300 days after source installation). Elevations of DNAPL sources are shown and similar concentration scales apply to each plot.

Fig. 10. Comparison of field data with steady state 1-D diffusion profiles: (a) VT Site interface zone plume and (b) ES Site ground-water plume 10 m down gradient of source. Steady state C_0 values were chosen to coincide with various field ground-water concentrations, indicated in µg/L. Similar concentration scales apply to each plot.

Fig. 11. Modeled transient TCE diffusion profiles in the ground-water zone from a source concentration (C_0) located 1.1 m below the water-air interface. Values of D_{air}, D_{water}, and H_c are from table 1. Effective diffusion coefficients were calculated from the product of the free diffusion coefficient and tortuosity divided by a retardation factor. A tortuosity of 0.6 and a TCE retardation factor of 1.14 (Table 1), were used for both zones.

Fig. 12. Plot of source depth below the water-air interface against TCE soil-gas concentration produced immediately above the interface for various times. Concentrations are expressed relative to the source concentration (C_0) and calculated from the transient diffusion equation (10) using similar parameters

to Figure 11.

Fig. 13. Conceptual model showing longitudinal and plan sections of ground-water and soil-gas contamination resulting from a typical DNAPL spill.

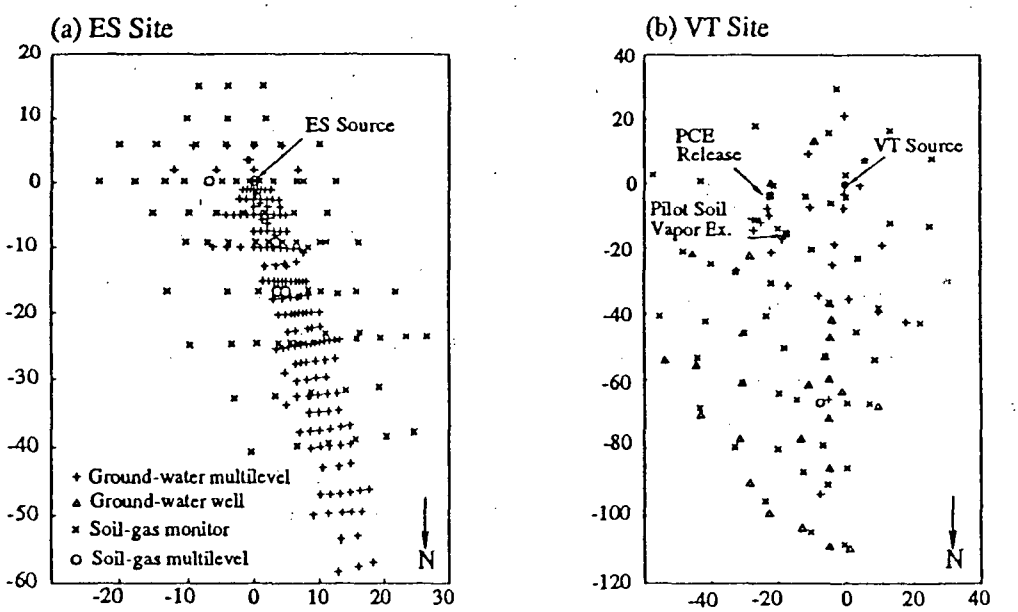

(a) ES Site
ES Source
Ground-water multilevel
Ground-water well
Soil-gas monitor
Soil-gas multilevel
N
(b) VT Site
PCE Release
VT Source
Pilot Soil Vapor Ex.
N

Fig. 1

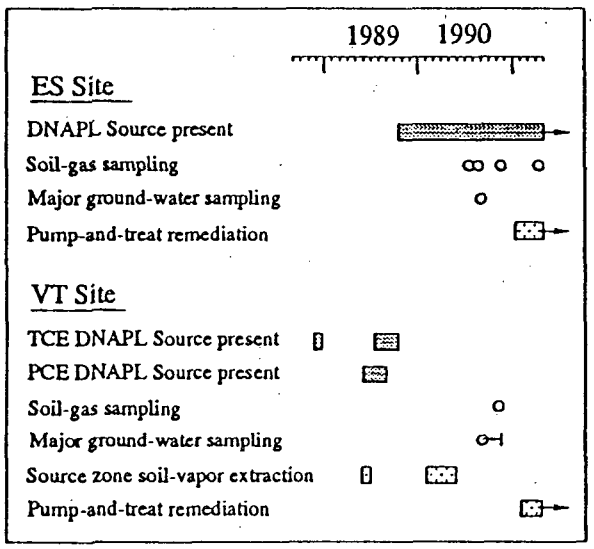
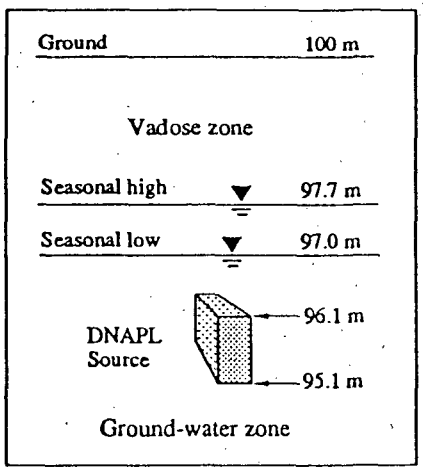

1989
1990
ES Site
DNAPL Source present
Soil-gas sampling
Major ground-water sampling
Pump-and-treat remediation
VT Site
TCE DNAPL Source present
PCE DNAPL Source present
Soil-gas sampling
Major ground-water sampling
Source zone soil-vapor extraction
Pump-and-treat remediation

Fig. 2

(a) ES Site DNAPL Source



(b) VT Site DNAPL Source

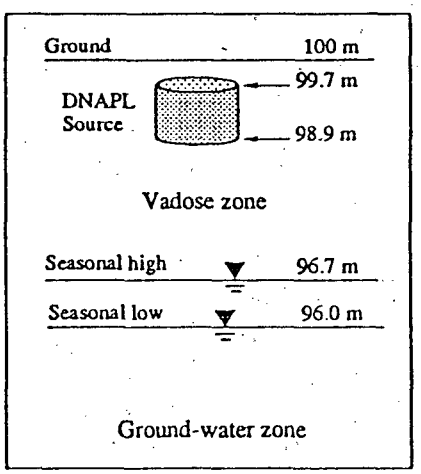


Fig. 3

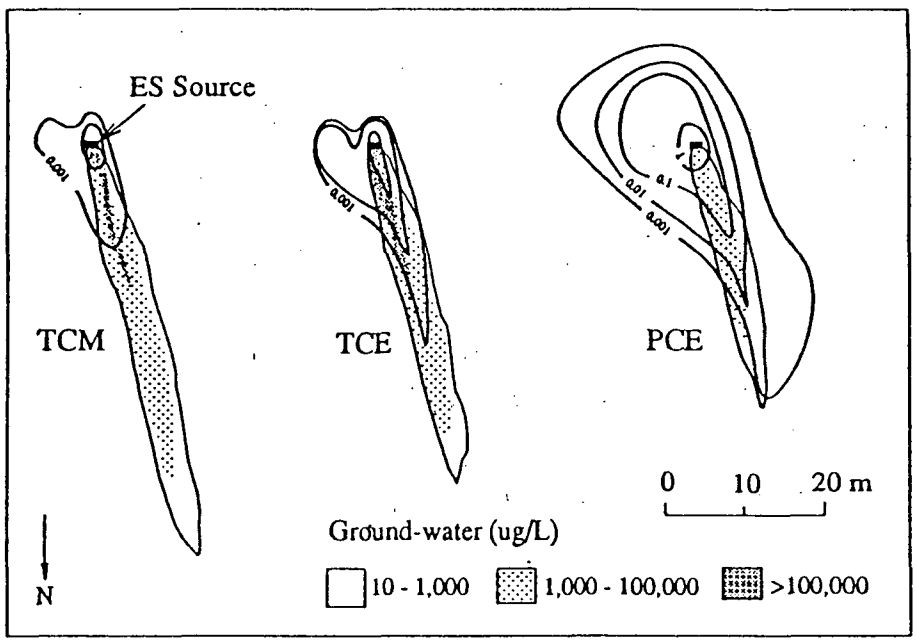

ES Source
0.001
TCM
0.001
TCE
0.1
0.01
0.001
PCE
0 10 20 m
N
Ground-water (ug/L)
10 - 1,000
1,000 - 100,000
>100,000

Fig. 4

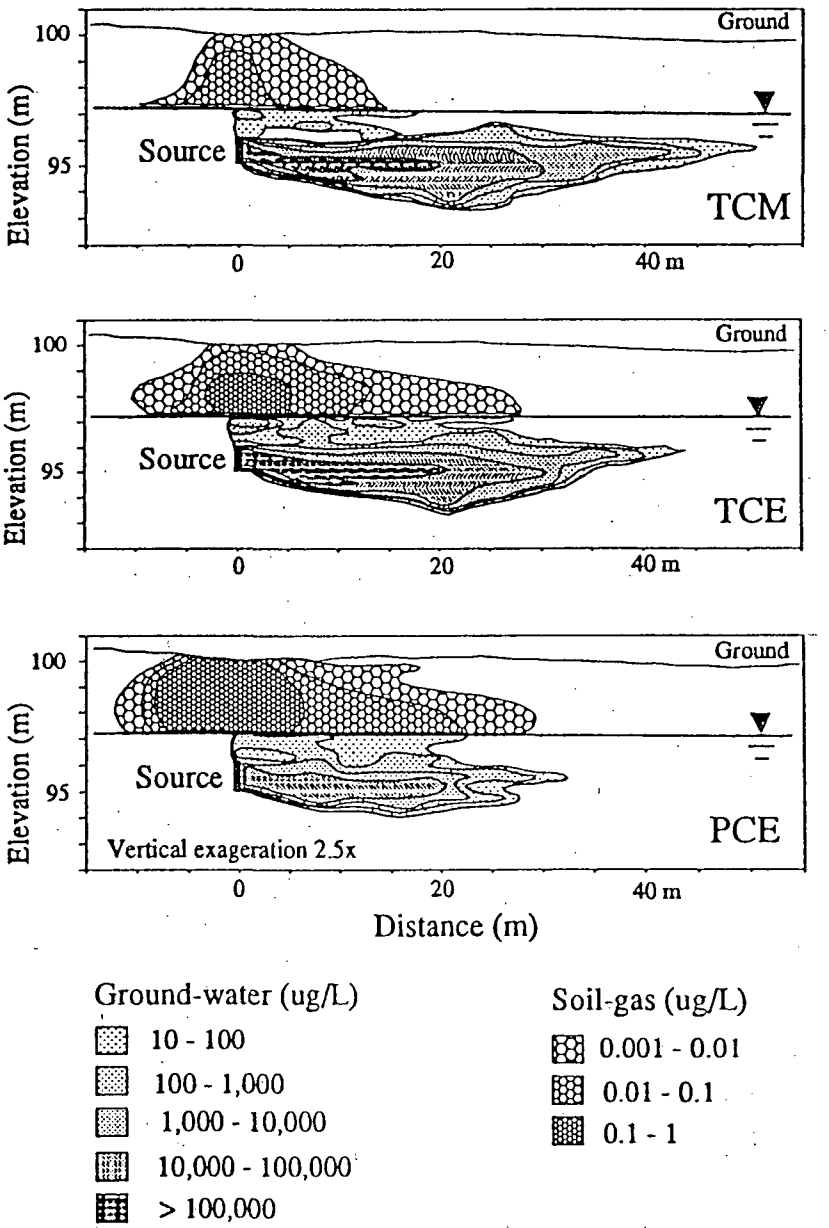

Ground
100
95
Elevation (m)
Source
TCM
0
20
40 m
Ground
100
95
Elevation (m)
Source
TCE
0
20
40 m
Ground
100
95
Elevation (m)
Source
PCE
Vertical exageration 2.5x
0
20
40 m
Distance (m)
Ground-water (ug/L)
10 - 100
100 - 1,000
1,000 - 10,000
10,000 - 100,000
> 100,000
Soil-gas (ug/L)
0.001 - 0.01
0.01 - 0.1
0.1 - 1

Fig. 5

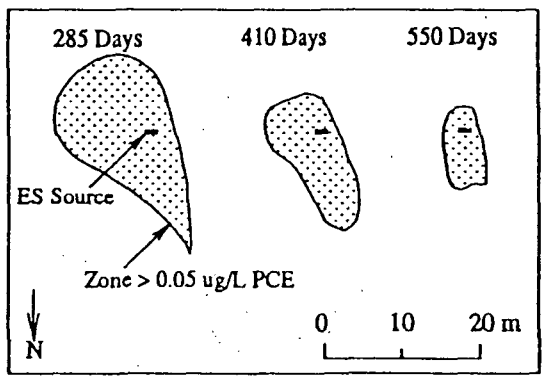


Fig. 6

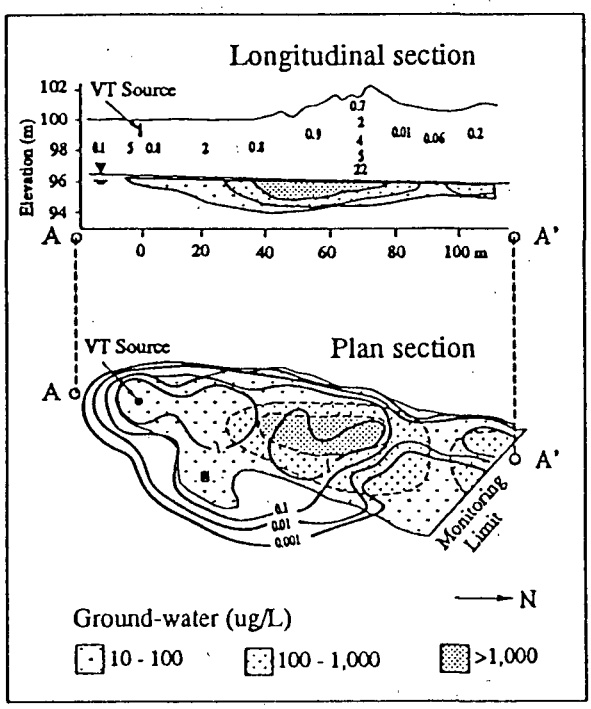
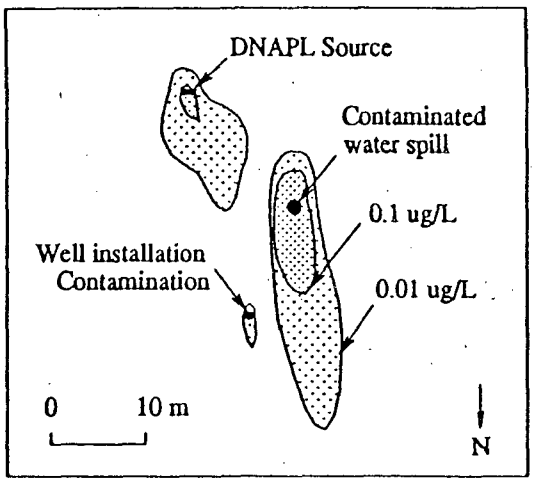

Longitudinal section
VT Source
Elevation (m)
102
100
98
96
94
A
A'
0
20
40
60
80
100 m
Plan section
VT Source
A
A'
0.1
0.01
0.001
Monitoring Limit
N
Ground-water (ug/L)
10 - 100
100 - 1,000
>1,000

Fig. 7

(a) ES Site



(b) VT Site

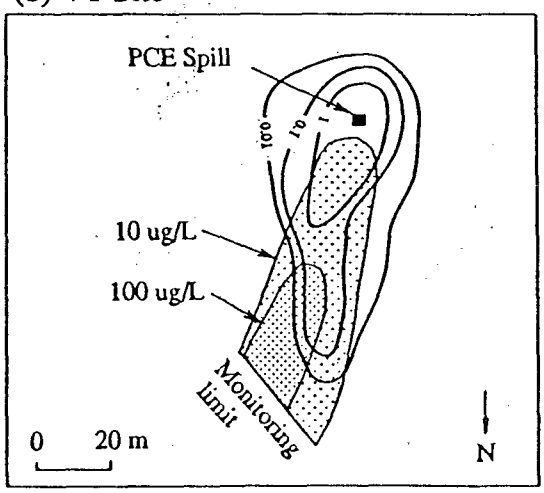


Fig. 8

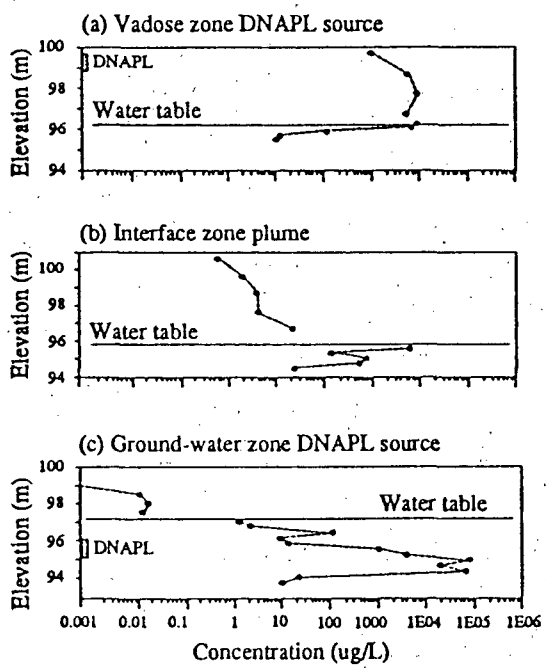

(a) Vadose zone DNAPL source
DNAPL
Water table
Elevation (m)
100
98
96
94
(b) Interface zone plume
Water table
Elevation (m)
100
98
96
94
(c) Ground-water zone DNAPL source
Water table
DNAPL
Elevation (m)
100
98
96
94
0.001
0.01
0.1
1
10
100
1000
1E04
1E05
1E06
Concentration (ug/L)

Fig. 9

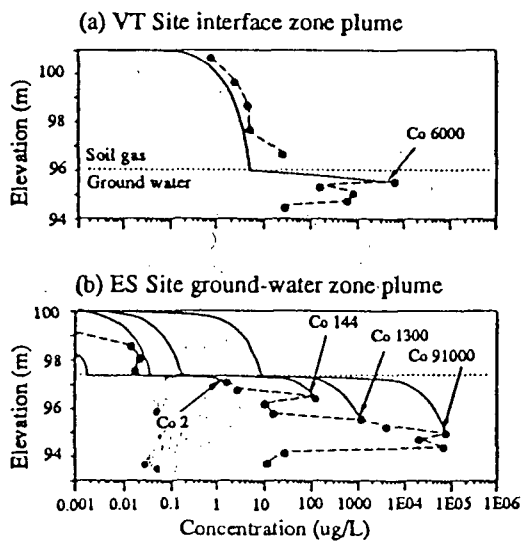

(a) VT Site interface zone plume
Elevation (m)
100
98
96
94
Soil gas
Ground water
Co 6000
(b) ES Site ground-water zone plume
Elevation (m)
100
98
96
94
Co 144
Co 1300
Co 91000
Co 2
0.001
0.01
0.1
1
10
100
1000
1E04
1E05
1E06
Concentration (ug/L)

Fig. 10

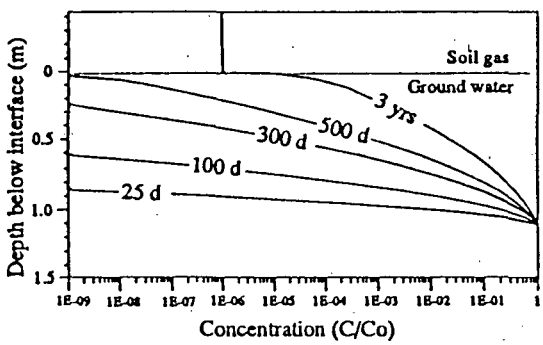

Soil gas
Ground water
3 yrs
500 d
300 d
100 d
25 d
Depth below interface (m)
0
0.5
1.0
1.5
1E-09
1E-08
1E-07
1E-06
1E-05
1E-04
1E-03
1E-02
1E-01
1
Concentration (C/Co)

Fig. 11

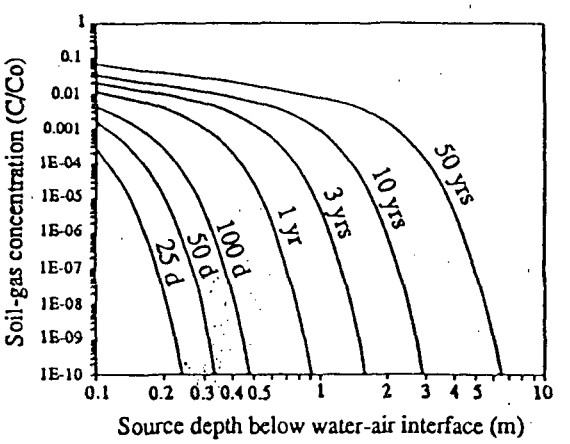

Soil-gas concentration (C/Co)
1
0.1
0.01
0.001
1E-04
1E-05
1E-06
1E-07
1E-08
1E-09
1E-10
0.1
0.2
0.3
0.4
0.5
1
2
3
4
5
10
Source depth below water-air interface (m)
25 d
50 d
100 d
1 yr
3 yrs
10 yrs
50 yrs

Fig. 12

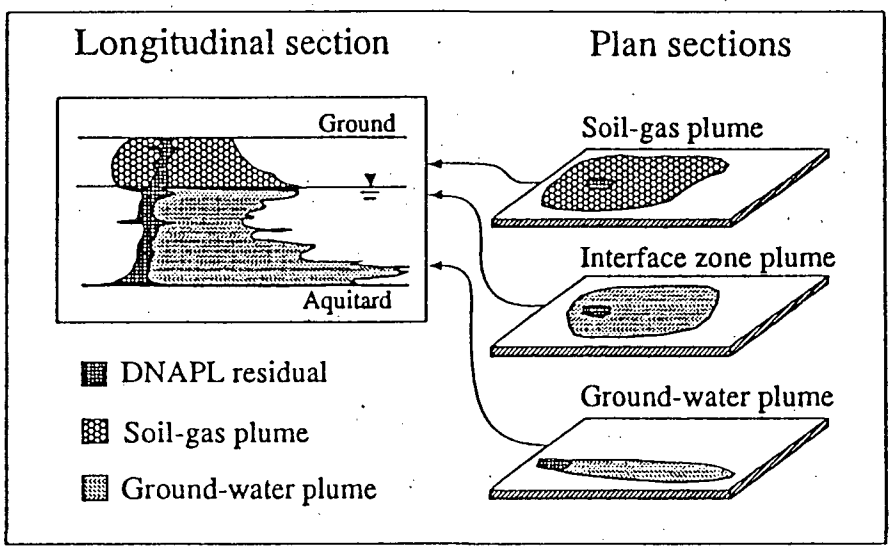

Longitudinal section
Plan sections
Ground
Aquitard
Soil-gas plume
Interface zone plume
Ground-water plume
DNAPL residual
Soil-gas plume
Ground-water plume

Fig. 13

Paper Presented at the 1992 IAH Conference "Modern trends in Hydrogeology", Hamilton Ontario Canada, May 10-13.

An In-Situ Oxidation Technique to destroy residual DNAPL from soil

By

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University of Waterloo, Waterloo, Ontario, Canada

ABSTRACT

Aquifers contaminated with dense non-aqueous phase liquids (DNAPL's) such as chlorinated solvents pose difficult remediation problems due to the formation of a discontinuous residual within the aquifer porosity. A variety of clean-up technologies have emerged to address such problems and most have experienced some success depending on conditions. In-situ treatment would be desirable in many cases by avoiding extraction and/or removal costs provided that additional harm is not done to the aquifer.

Promising results into in-situ oxidation have been obtained from laboratory scale experiments involving potassium permanganate ($KMnO_4$) oxidation of the double bonded solvents TCE and PCE. Laboratory soil columns were contaminated with PCE or TCE and remediated with flushes of $Kmno_4$. Monitoring of the by-products of the reactions allowed the reaction to be followed. Mass balances have shown complete removal of the pure phase product. Aqueous phase PCE concentration are typically near or below drinking water standards.

INTRODUCTION

Aquifers contaminated with dense non-aqueous phase liquids (DNAPL) such as perchloroethylene (PCE) and

trichloroethylene (TCE) have received much attention during the last decade. The heavy industrial use of PCE and TCE since the 1940's combined with the lack of proper environmental regulations for disposal has resulted in the contamination of numerous sites across Canada and the United States. The environmental damage resulting from spills of PCE or TCE will persist because technology available to remove the DNAPL from groundwater is limited.

The physical properties of DNAPL such as PCE and TCE cause many difficulties with respect to remediation. Their high surface tension and immiscibility in water result in the development of a discontinuous residual phase within an aquifer. Because of this discontinuity, DNAPL are difficult to remove from porous media through conventional pumping techniques. The persistence of PCE and TCE and other DNAPL within the environment is well documented (Schaumberg, 1990). Natural degradation of PCE and TCE within both anoxic and aerobic groundwater environments occurs very slowly. The solubility, although several orders of magnitude higher than drinking water standards (DWS), is low enough to ensure that non-equilibrium dissolution of the DNAPL by pumping the aqueous phase is a very long term activity. Contamination at levels below saturation but well above the DWS will continue for a long time (Cherry et al., 1990).

Methods of DNAPL removal that have been researched and field tested include surfactant mobilization and chemically-enhanced solubilization with co-solvents (Cherry et al., 1990). These techniques change the solubility or surface tension of the DNAPL without altering the chemicals themselves.

In-situ oxidation has received limited attention as a remediation technology. However, certain environmentally sensitive chemicals including PCE and TCE possess unsaturated carbon bonds that provide an excellent opportunity for destruction through oxidation. Oxidation of PCE and TCE has the potential to cleave the double bond and release less

hazardous and more mobile chemicals into the groundwater. In-situ oxidation was successfully field tested on double-bonded formalin (CH_2O) spilled near Springfield, Massachusetts (Cowie, et al., 1986). Formalin in the subsurface was oxidized through the injection of a hydrogen peroxide solution directly into the spill area. The project illustrated the feasibility of in-situ chemical treatment in spill remediation technology.

Experiments performed for this research made use of potassium permanganate ($KMnO_4$) as an in-situ oxidant for aquifer remediation. $KMnO_4$ is a powerful oxidant that remains stable in water yet reacts quickly when it contacts organic matter such as PCE and TCE. Oxidation with $KMnO_4$ has been used in drinking water treatment to removed odour causing organic material and the predecessors of halogenated organics (Singer et al., 1980).

CHEMICAL REACTIONS

The oxidation of PCE and TCE by $KMnO_4$ involves cleaving the double bond between the two carbon atoms followed by further oxidation of the two chlorinated carbon atoms. The products of complete destruction include carbon dioxide (CO_2) in solution or gaseous phase, potassium chloride (KCl), chlorine (Cl_2), hydrochloric acid (HCl) and manganese dioxide (MnO_2). The reaction scheme is shown in Equation 1 for TCE and Equation 2 for PCE.

$$C_2Cl_3H(TCE) + 2KMnO_4 \rightarrow 2CO_2 + 2MnO_2(s) + 2KCl + HCl \qquad (1)$$

$$C_2Cl_4(PCE) + 2KMnO_4 \rightarrow 2CO_2 + 2MnO_2(s) + 2KCl + Cl_2 \qquad (2)$$

In the PCE reaction, Cl_2 will combine with water to form hypochlorous acid (HOCl) and the hypochlorite (OCl^-) ion (Equation 3).

The Ontario DWS for Cl^- is 250 mg/l; listed under Maximum

$$Cl_2 + H_2O \rightleftharpoons HOCl + H^+ + Cl^-$$

$$HOCl \rightleftharpoons H^+ + OCl^- \qquad (3)$$

Desirable Concentration (MDC) limits for aesthetic as opposed to health concerns (MOE, 1984).

$MnO_2(s)$ is produced in both reactions as a solid phase by-product of $KMnO_4$ oxidation. Within the porous media, the $MnO_2(s)$ produced will either be deposited directly on the aquifer matrix or be transported as suspended matter. Aqueous phase manganese (Mn^{2+}) will be subsequently leached from the $MnO_2(s)$ produced, however, $MnO_2(s)$ is a common constituent of many soils. It has in fact been investigated as an important oxidant of organic contamination in natural environments (Ulrich, et al., 1989). Fortunately, Mn^{2+} and particulate $MnO_2(s)$ can be readily removed from water by oxidation and sedimentation. The DWS for manganese are also listed under the aforementioned MDC limits at a concentration of 0.05 mg/l. The DWS for PCE are listed under the Maximum Acceptable Concentrations (MAC) for health concerns not aesthetic reasons (MOE, 1984). The current DWS for PCE in Ontario is 0.05 mg/l.

The remediation scheme envisaged in this research would involve pumping a solution of $KMnO_4$ into an aquifer contaminated with PCE or TCE for the purpose of in-situ oxidation. Hydraulic control would be necessary.

An laboratory experimental programme was established to investigation the in-situ oxidation technique. Previous laboratory experiments were conducted by Gonullu and Farquhar (1990) in which TCE was oxidized by $KMnO_4$ application to quartz based soils in glass columns. Nearly complete oxidation was achieved with stoichiometric release of CO_2 and no organic products. The $MnO_2(s)$ formed did not inhibit flow and, for the most part was flushed from the columns. Subsequent treatment with sodium bisulphite ($NaHSO_3$) removed the $MnO_2(s)$ remaining in the soil. The research here focuses on the use of $KMnO_4$ to oxidize PCE in calcareous soils taken

from the site of a proposed field trial.

The objectives of the laboratory experimentation were:

1. to investigate if PCE residual in soil can be completely transformed to less harmful by-products through treatment with solutions of $KMnO_4$,
2. to evaluate the PCE destruction rate in porous media with varying concentrations and flow rates of $KMnO_4$ and
3. to perform mass balances on chloride produced to study the extent of the oxidation and to identify any intermediate organic products.

EXPERIMENTAL PROCEDURE

Extent of PCE Oxidation by $KMnO_4$

Before soil column experiments with PCE and $KMnO_4$ could begin, an investigation into the reaction products and the reaction efficiency was required. Because aqueous phase $KMnO_4$ and PCE are immiscible, acetone was selected as a suitable co-solvent. $KMnO_4$ is more reactive with PCE than acetone and acetone does not contain chloride which may alter the mass balance. The concentrations of Cl^-, OCl^- and HOCl were monitored with an Orion Research Incorporated Combination Chloride Electrode #96-17-00 until the reaction stopped. The electrode does not distinguish between the species; the measurement was therefore referred to as total chloride (Cl_T).

Volumes of gas produced (Cl_2 and CO_2) were measured by bubbling the gas into an inverted graduated cylinder filled with a solution of sodium thiosulphate ($Na_2S_2O_3$). The $Na_2S_2O_3$ was later titrated with $KMnO_4$ to quantify $Na_2S_2O_3$ loss due to Cl_2 production.

The co-solvent experiments involved 1.6 g of PCE and 4.62 g of $KMnO_4$ dissolved in 150 ml of acetone and 100 ml of water. The amount of $KMnO_4$ was twice the total amount needed to completely destroy all the PCE (Equation 2). After fifteen

minutes of reaction, the chloride concentration stabilized at 5400 mg/l. A heavy precipitate of $MnO_2(s)$ formed and no purple $KMnO_4$ colour remained. The gas collected measured 75 ml but there was no loss of $Na_2S_2O_3$. It was concluded therefore that all gas produced was CO_2 with no Cl_2. The Cl_2 produced remained in solution as HOCl and OCl^-.

Complete destruction of 1.6 g of PCE would have produced a Cl_T concentration of 5470 mg/l. Since the actual concentration was 5400 mg/l, it was concluded that PCE can be completely destroyed by $KMnO_4$. Thus the potential for complete destruction in soils exists if conditions of contact are sufficient.

Soil Column Experiments

Five glass columns were filled with a silty fine sand from the University of Waterloo experimental area at CFB Borden. The sand was sieved through a #40 sieve to remove coarse organic material such as twigs and roots. Chemical composition of the sand has been previously researched and the results are shown in Table 1. Another mineralogical investigation concluded that a 5 percent fraction (bulk) is primarily opaque magnetite and ilmenite (Ball, et al., 1990). Porosity of the columns averaged 39% v/v and the organic carbon content of the soil was measured at .06% w/w.

Table I - Mineralogy of a Bulk Sample of Borden Sand

Component	Percent of Total
Quartz	58
Feldspar	19
Carbonates	14
Amphiboles	7
Chlorite	2

(Mackay et al., 1986)

The columns were packed dry in approximately 1 cm layers and flushed with CO_2 for a period of 4 hours to displace air. Water was slowly flushed through the columns using a peristaltic pump. Flushing continued uninterrupted for several days to ensure that all gases were dissolved from the columns. PCE dyed red with Sudan IV was added to each column either by displacing the water in the columns with PCE and allowing it to drain fully, or by injection with a syringe. The PCE was allowed to redistribute over a period of 2 to 5 days to create a more stable residual formation.

Solutions of $KMnO_4$ in various concentrations were pumped through the columns at different flow rates. An experimental schematic is shown in Figure 1. Effluent analysis included measurements of PCE, aqueous Mn^{2+}, Cl_T, $KMnO_4$ residual and gas volumes. The PCE was analyzed with a Shimadzu GC-9A FID gas chromatograph using an SPB-5 column and a Control Data Systems 330 Concentrator. The aqueous Mn^{2+} was analyzed with a ARL DCP Spectrophotometer. Chloride was analyzed with the aforementioned electrode. Residual $KMnO_4$ was analyzed by titration with $Na_2S_2O_3$. Gas volumes were measured in inverted graduated burettes.

DISCUSSION OF RESULTS

Phase 1 Column Experiments

The objectives of the Phase 1 experiments were to determine if PCE oxidation by aqueous solutions of $KMnO_4$ was possible and to examine the influence of $KMnO_4$ concentration on the PCE oxidation rate. Three columns were packed with Borden sand and contaminated with approximately 30 grams of PCE by imbibition and drainage. Solutions of either $KMnO_4$ and/or sodium hexametaphosphate ($Na(PO_3)_6$) were subsequently flushed through the columns. $Na(PO_3)_6$ was used as an anti-flocculant in an attempt to keep the $MnO_2(s)$ from forming floc particles and perhaps shielding PCE from contact with the oxidant. $KMnO_4$ concentrations were varied to assess their

impact on oxidation rate under conditions shown in Table II.

Table II - Initial Column Experiments Flushing Conditions

	Flow (cm/min)	$KMnO_4$	$Na_2S_2O_3$
Column 1	.27	none	5 g/l
Column 2	.26	2 to 10 g/l	5 g/l
Column 3	.26	2 to 10 g/l	none

The experiment continued for a period of more than 2500 hours with over 180 pore volumes being flushed through the column. Four different concentrations of $KMnO_4$ were applied to the columns. The Cl_T concentrations in the effluent versus pore volumes flushed are in Figure 2. The results of the PCE destruction, monitored through Cl_T concentrations, are seen in Figure 3. PCE destruction was calculated using the Cl_T concentrations with each mole of PCE producing four moles of Cl_T.

The small differences in PCE destruction rates between columns #2 and #3 indicated that $Na(PO_3)_6$ did not significantly increase the oxidation rate, although the actual removal of $MnO_2(s)$ from the soil was not recorded. The changing Cl_T production with varying concentrations of $KMnO_4$ added (see Figure 2) showed that increased oxidant concentrations improve the reaction rate significantly. Subsequent experiments showed that $KMnO_4$ concentrations in excess of 10 g/l created gas release rates high enough to disrupt the soil. The 10 g/l concentration was therefore selected as a working maximum.

At a concentration of 2 g/l $KMnO_4$, chlorinated organic compounds indicating incomplete oxidation were present in the effluent. These compounds showed up as peaks on the gas chromatograph. At this point in the work, no attempt was made to identify these compounds. With $KMnO_4$ concentrations of 5 g/l or greater, no such by-products were found.

The results of the Phase 1 experiments suggested that, with the use of $KMnO_4$, the removal of PCE can be achieved at a much faster rate than would be possible with a simple pump and treat method. The average removal rate of PCE by water flushing from these experiments was calculated to be approximately 0.04 g of PCE per pore volume flushed. The average removal rate with 10 g/l of $KMnO_4$ was calculated to be 1.0 g of PCE per pore volume flushed. Figure 3 shows that these experiments resulted in the oxidation of approximately 14 g of the 30 g of PCE added to the soil.

Phase 2 Column Experiments

The objectives of the Phase 2 experiments were to examine the influence of $KMnO_4$ concentration and application rate on the rate of PCE oxidation and the possibility of complete PCE oxidation in soil. Accordingly, a smaller PCE residual source was used. Five columns were packed with Borden sand and subsequently injected with 1.6 grams of PCE. A mass balance based on Cl_T and PCE added was conducted. Flow rates and $KMnO_4$ concentrations were varied in four of the columns while the fifth was maintained as a control involving only a water flush. The pumping rates and $KMnO_4$ concentrations for each column are shown in Table III. The flow rates were chosen to establish a range of pumping conditions similiar to those that could be experienced in a field trial. The experiments continued over a period of over 500 hours although the destruction of the PCE by $KMnO_4$ was completed in approximately 150 hours in column 3 and 300 hours in column 2.

Data from the Phase 2 experiments are presented in Figures 4 through 7. The Cl_T concentrations verses pore volumes flushed are found in Figure 4 and total accumulative destruction of the PCE calculated from the Cl_T is shown in Figure 6.

For each figure, the origin is the point of $KMnO_4$

Table III - Phase 2 Column Experiments Data

	Col 1	Col 2	Col 3	Col 4	Col 5
Flow Rate (m/d)	0.42	0.42	0.63	0.68	0.61
$KMnO_4$ injected (g/l)	10	7.5	10	7.5	0

application. The lag time between the origin and the first Cl_T appearance in the effluent results from $KMnO_4$ oxidizing soil organics matter. It was found that approximately 37.6 g of $KMnO_4$ were consumed per 1 kilogram of Borden soil. This initial loss of $KMnO_4$ will vary with the organic content of the soil but will occur only during the initial treatment stages.

In each column, $KMnO_4$ application was stopped and water flushing begun when the Cl_T concentration measured in the effluent approached zero. This corresponded to approximately 26, 29, 34 and 45 pore volumes for experiments 1, 3, 2 and 4 in Figure 4. The same sequence indicates that the most efficient oxidation of PCE as measured by Cl_T production occurs with high $KMnO_4$ concentrations and low flow rates although a lower range of flow rates should be studied to seek an optimal condition.

In each case when the $KMnO_4$ addition was stopped and the water flush begun, the resultant PCE concentrations in the effluent were less than 50 ug/l and, in most cases, less than 20 ug/l. In contrast, the water flush prior to $KMnO_4$ addition yielded PCE concentrations near 100 mg/l, approaching the equilibrium solubility in water. These results show nearly complete oxidation of the 1.6 kg of PCE added. The PCE concentrations less than 20 ug/l suggest very little PCE residual remaining in the soil.

Concentrations of total manganese (Mn_T) measured in the post-$KMnO_4$ water flush were not-detectable. This indicates

that the $MnO_2(s)$ residual in the soil after oxidation does not represent a significant source of long term groundwater contamination.

The conversion of Cl_T production data to estimates of PCE oxidized identified significant problems in the methods used. In experiments 1, 3 and 4, the calculated mass of PCE oxidized was up to 20% greater than the mass of PCE added. This is shown in Figure 6 where PCE oxidized is plotted against pore volumes. The reasons for this error are not fully understood.

Significant problems were experienced in maintaining constant flow rates. Subsequently, it was found that the actual $KMnO_4$ flow rates exceeded the nominal values shown in Table III by significant amounts. This is thought to have been the major source of the error. The Cl_T measurements and the injection of the initial mass of PCE were found to be very accurate and not considered to yield significant errors. Other sources of errors are still being evaluated.

Since the very low PCE concentrations measured in the post-$KMnO_4$ water flush suggested nearly complete oxidation, the data nave been normalized in Figure 7. The data show PCE oxidized as a fraction of PCE added.

DISCUSSION AND CONCLUSIONS

The experiments have shown that it is possible to achieve nearly complete oxidation of PCE residual in soil with aqueous solutions of $KMnO_4$. The rate of oxidation increased proportional to $KMnO_4$ concentrations up to 10 g/l. No PCE was present in effluent during the addition of $KMnO_4$ and no other chlorinated organics were present with $KMnO_4$ concentrations above 2 g/l. The very low PCE concentrations in the post-$KMnO_4$ water flush suggested that the residual PCE in the soil was small, perhaps negligible.

The variation in oxidation rate with $KMnO_4$ flow rate indicates that the reaction is kinetically controlled. These results and those of related experiments suggest that the

oxidation involves mostly PCE in aqueous solution and not PCE as an immiscible phase. In the presence of $KMnO_4$, PCE going into solution is oxidized and the high concentration gradient enhances further PCE dissolution. Enhanced dissolution followed by rapid oxidation supports the rapid PCE removal observed.

Further support for the kinetic control comes from the work of Gonullu and Farquhar (1990). They performed similiar experiments with TCE. Rates of oxidation were much more rapid than those shown here with PCE. The solubility of TCE is about 7 times higher than that of PCE.

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FIGURES

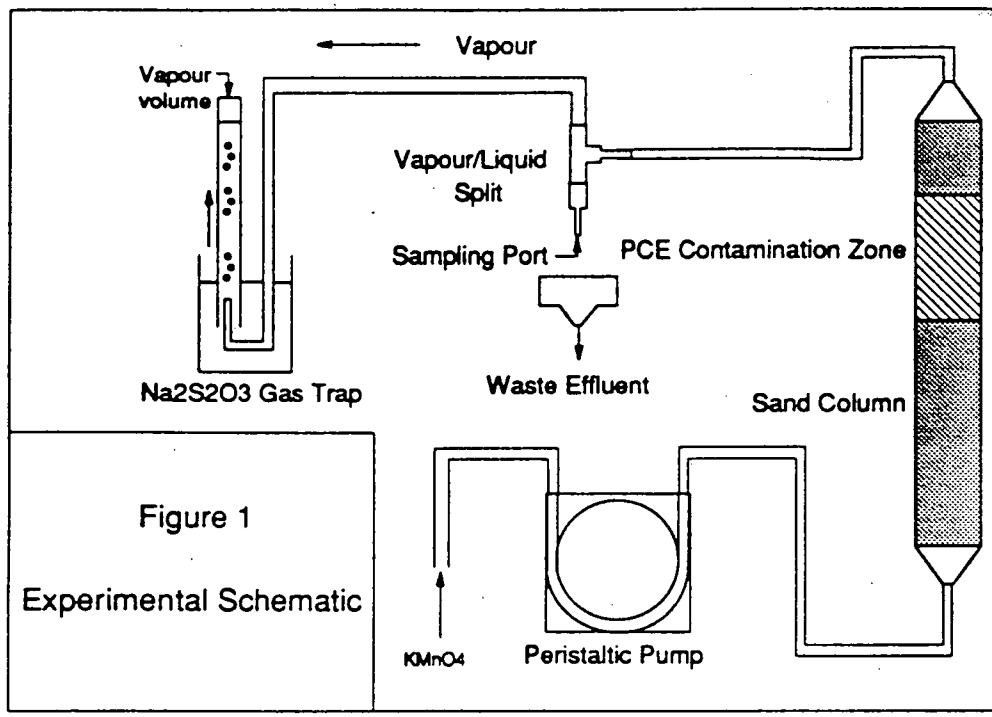


Figure 1

Experimental Schematic

Figure 2 - Chloride Production

from PCE destruction

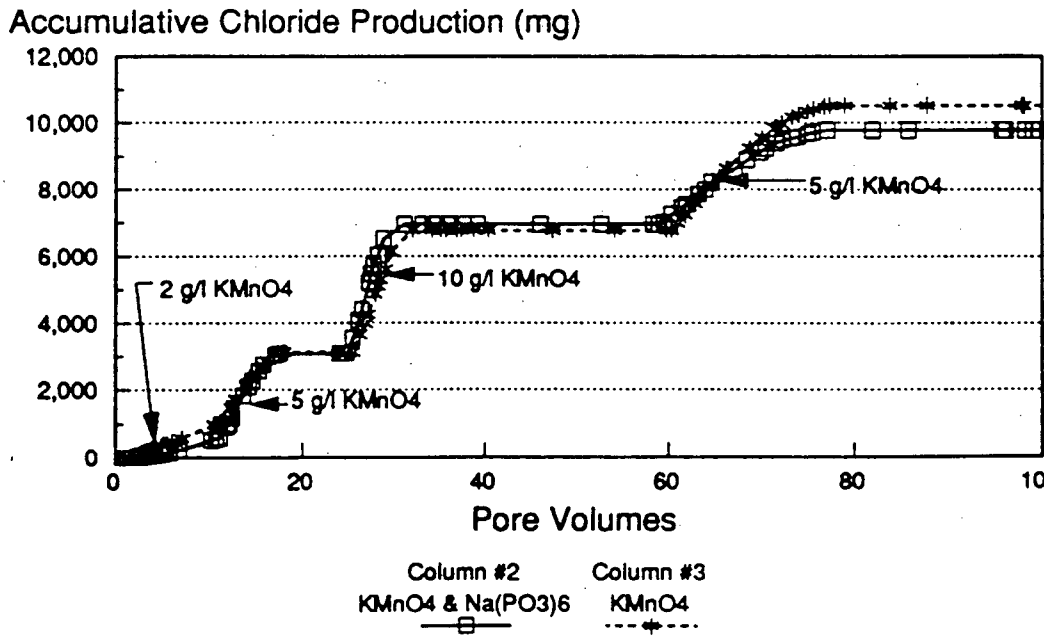


Figure 3 - PCE Removal

by oxidation and dissolution

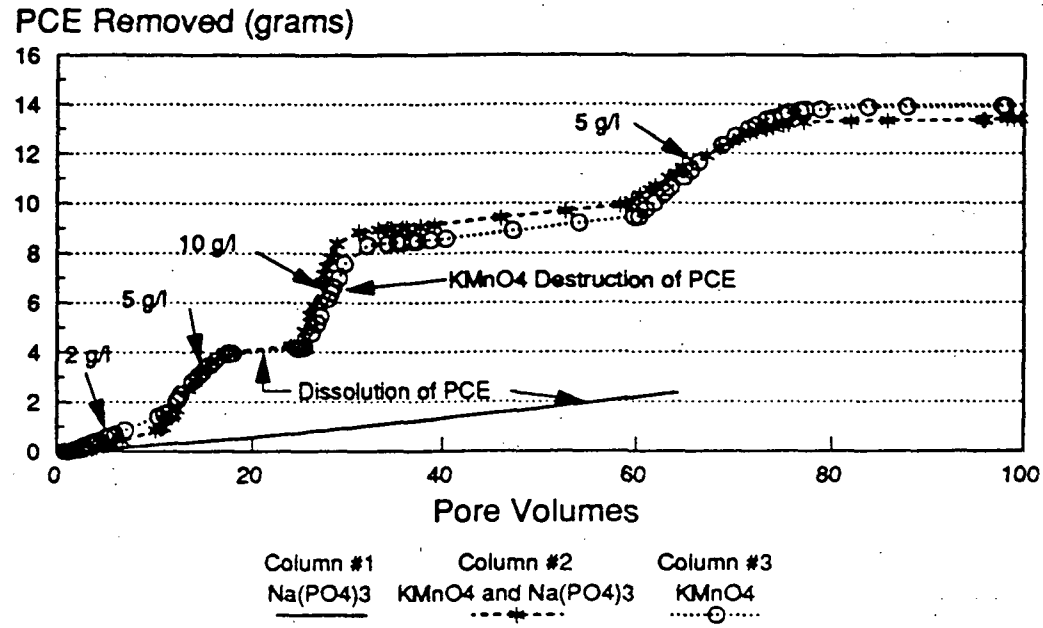


Figure 4 - Chloride Production

from PCE Destruction

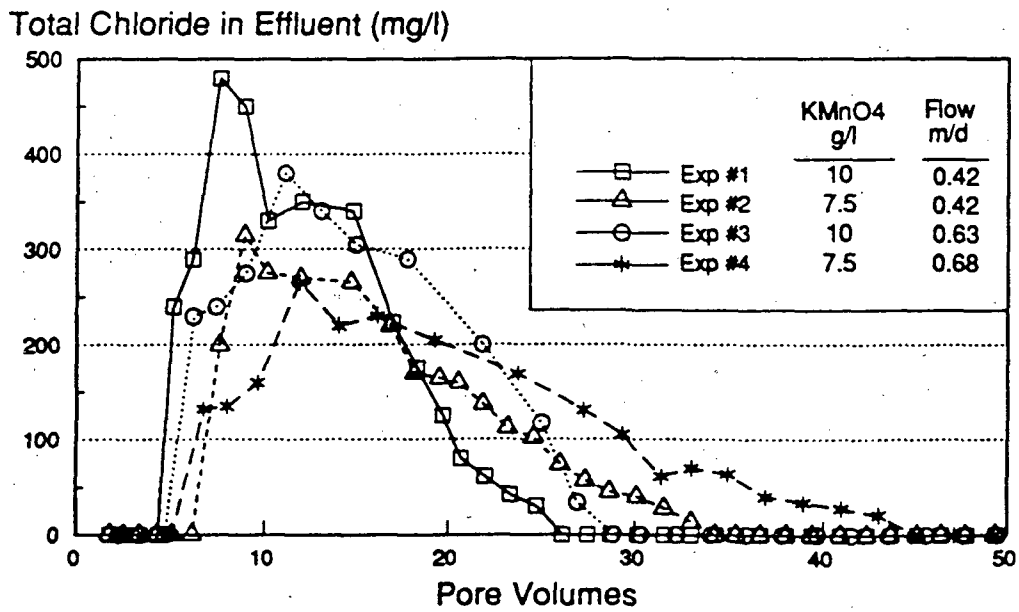
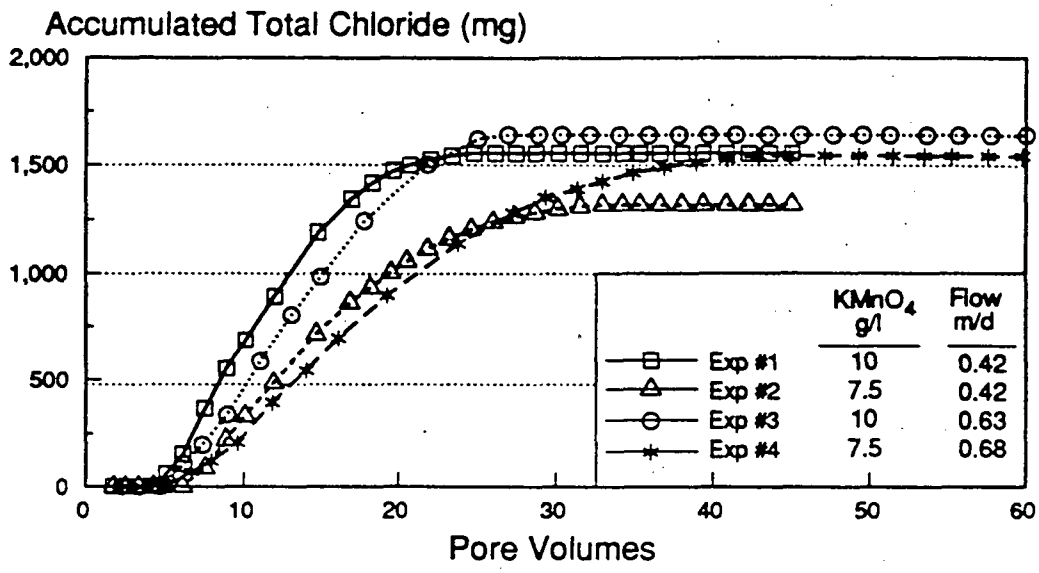


Figure 5 - Chloride Production

from PCE destruction



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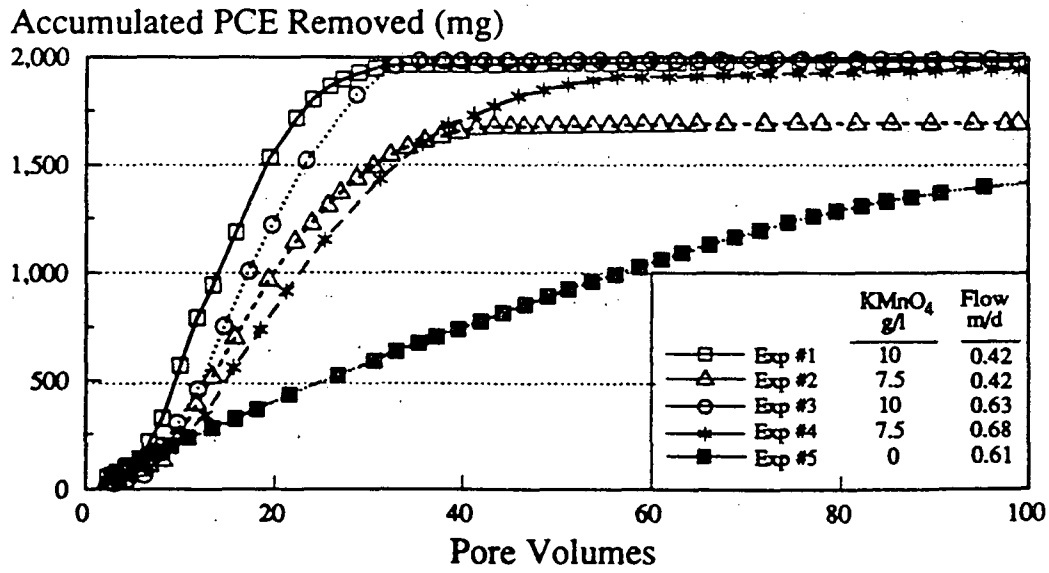
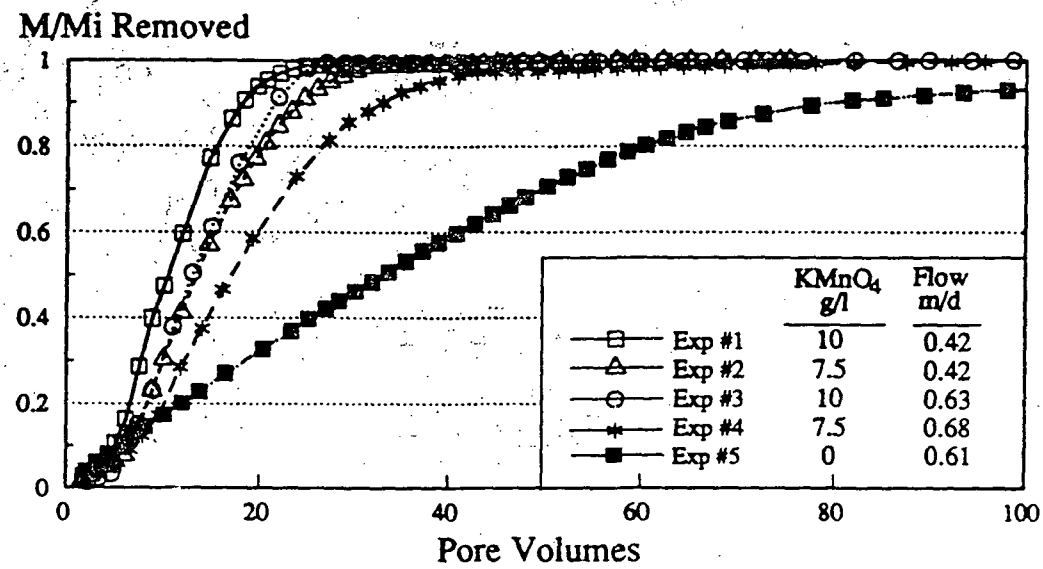


Figure 7 - Normalized PCE Removed

by Destruction and Dissolution