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REFINEMENT OF THE KANSAS CITY PLANT SITE CONCEPTUAL MODEL WITH RESPECT TO DENSE NON-AQUEOUS PHASE LIQUIDS (DNAPL)

N. E. Korte
S. C. Hall
J. L. Baker

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FOR THE UNITED STATES
DEPARTMENT OF ENERGY

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ACRONYMS, ABBREVIATIONS, AND INITIALISMS

d	day
D/26	Department 26
1,2-DCE	1,2-dichloroethene
DNAPL	dense non-aqueous phase liquid
DOE	U.S. Department of Energy
EPA	U.S. Environmental Protection Agency
ft	feet
h	hour
KCP	Kansas City Plant
L	liter
μg	microgram
mg	milligram
min	minute
mL	milliliter
ORNL/GJ	Oak Ridge National Laboratory/Grand Junction office
PGDP	Paducah Gaseous Diffusion Plant
RCRA	Resource Conservation and Recovery Act
TCE	trichloroethene
VOCs	volatile organic compounds

ABSTRACT

This document presents a refinement of the site conceptual model with respect to dense non-aqueous phase liquid (DNAPL) at the U.S. Department of Energy Kansas City Plant (KCP). This refinement was prompted by a review of the literature and the results of a limited study that was conducted to evaluate whether pools of DNAPL were present in contaminated locations at the KCP. The field study relied on the micropurge method of sample collection. This method has been demonstrated as a successful approach for obtaining discrete samples within a limited aquifer zone.

Samples were collected at five locations across 5-ft well screens located at the base of the alluvial aquifer at the KCP. The hypothesis was that if pools of DNAPL were present, the dissolved concentration would increase with depth. Four wells with highly contaminated groundwater were selected for the test. Three of the wells were located in areas where DNAPL was suspected, and one where no DNAPL was believed to be present. The results demonstrated no discernible pattern with depth for the four wells tested.

A review of the data in light of the available technical literature suggests that the fine-grained nature of the aquifer materials precludes the formation of pools. Instead, DNAPL is trapped as discontinuous ganglia that are probably widespread throughout the aquifer. The discontinuous nature of the DNAPL distribution prevents the collection of groundwater samples with concentrations approaching saturation. Furthermore, the results indicate that attempts to remediate the aquifer with conventional approaches will not result in restoration to pristine conditions because the tortuous groundwater flow paths will inhibit the efficiency of fluid-flow-based treatments.

1. INTRODUCTION

This report describes a refinement of the site conceptual model with respect to the presence and distribution of dense non-aqueous phase liquids (DNAPL) at the U.S. Department of Energy (DOE) Kansas City Plant (KCP). The refined model is based both on a review of the technical literature and on experimental data acquired from subsurface soil at the KCP. The KCP is operated by AlliedSignal Corporation for DOE Albuquerque Operations. This work was performed by personnel from the Oak Ridge National Laboratory/Grand Junction office (ORNL/GJ) with the assistance and oversight of AlliedSignal personnel in Kansas City.

The KCP has manufactured non-nuclear components of nuclear weapons for more than thirty years. The various manufacturing operations have involved considerable machining of metal parts and subsequent degreasing operations. Formerly used degreasing solvents, primarily trichloroethene (TCE), have been spilled or disposed of on site and have caused contamination of the groundwater (U.S. DOE 1994, 1993a).

Although contaminated groundwater at the KCP is being contained by a pump-and-treat system (U.S. DOE 1992a), it is well known that such treatment is not capable of restoring the contaminated aquifer to the standards required by the Resource Conservation and Recovery Act (RCRA), which are applicable to the KCP (U.S. DOE 1994, 1993b). Predicting the ultimate efficiency of the KCP pump-and-treat system and the time required to achieve a specified level of remediation has not been possible because the nature and actual amounts of the contaminant sources are not known. Because records regarding the size of spills or leaks are insufficient, the quantity of chlorinated solvent potentially available for groundwater contamination is unknown. Moreover, there are no data that permit an evaluation of whether there is a source consisting of DNAPL or whether the observed contamination is primarily in the dissolved phase. As will be described, DNAPL is believed to be present based on several lines of indirect evidence. Consequently, this study was undertaken in order to assess the manner in which DNAPL at the base of the aquifer is distributed.

1.1 Hydrogeologic Setting

The hydrostratigraphy at the KCP can be divided into two major units: the unconsolidated alluvium and the underlying bedrock. The regional and local stratigraphic relationships between the alluvium and the consolidated sequence at the KCP site have been previously documented (Kearl et al. 1984; Korte et al. 1985; Fleischhauer et al. 1986; Madril et al. 1986; Fleischhauer et al. 1987; U.S. DOE 1990, 1992b). For the purposes of this report, only the alluvium will be addressed because studies have shown that the bedrock is an effective barrier to contaminant migration (U.S. DOE 1993c).

Cycles of deposition and erosion have resulted in the alluvial facies distribution shown in Fig. 1, the alluvial fence diagram for the Northeast Area/001 Outfall (U.S. DOE 1993b). This figure exhibits all of the features found in the alluvium at the site. The stratigraphy, however, is not uniform across the KCP because of the presence of fill and the effects of erosional processes.

In general, the alluvium consists of continuous and discontinuous zones of clayey silt, sand, and gravel. Two more-permeable, water-bearing zones are present within the alluvium: an upper sand-clay-silt and a basal gravel with a sand-silt-clay matrix. The two zones are separated in certain areas by a layer of olive to blue-green clayey silt. The two more-permeable zones and the intervening blue-green clayey silt all transmit water and constitute the alluvial aquifer.

The upper zone consists of thin-bedded sequences of clayey silt, with minor amounts of sand. These features, however, do not extend to significant depths within the aquifer. The olive to blue-green clayey silt separates the upper and basal zones in some areas. Generally, this layer appears to have a lower moisture content than the adjacent zones and when encountered during drilling, required a slower drilling rate, indicating a relatively high density. It is important to note that water does flow through this clayey-silt layer, but at a reduced rate (U.S. DOE 1992a).

The basal gravel is continuous throughout the site and ranges in thickness from a few inches to 8 ft. It consists of angular limestone and sandstone gravel with a sand-silt-clay matrix.

Grain-size analyses were conducted on several soil samples collected at various depth intervals from KC84-08, a groundwater monitoring well located in the central portion of the facility. The results indicated only minor differences in grain-size distribution with depth and that the aquifer is composed of grains in the clayey-silt size range (Korte et al. 1985).

1.2 Hydraulic Properties of the Alluvial Aquifer

Five pumping tests, with pumping wells that fully penetrated the alluvial aquifer, have been performed at the KCP to determine the hydraulic properties of the alluvium. These tests indicate that the vertically averaged hydraulic conductivity at the KCP ranges from 1.1 ft/d (3.9×10^{-4} cm/s) to 3.0 ft/d (1.1×10^{-3} cm/s). In addition, numerous slug and bail tests have been conducted at the KCP since 1984. Results and recovery plots of the slug tests are presented in the TCE Still Area RFI report (U.S. DOE 1994, Appendix D). Hydraulic conductivities as calculated from these slug and bail tests are consistent with the pumping test results described above.

In summary, the alluvial system under study consists primarily of a clayey silt in which groundwater flow rates have been estimated at no more than a few 100's of cm/year.

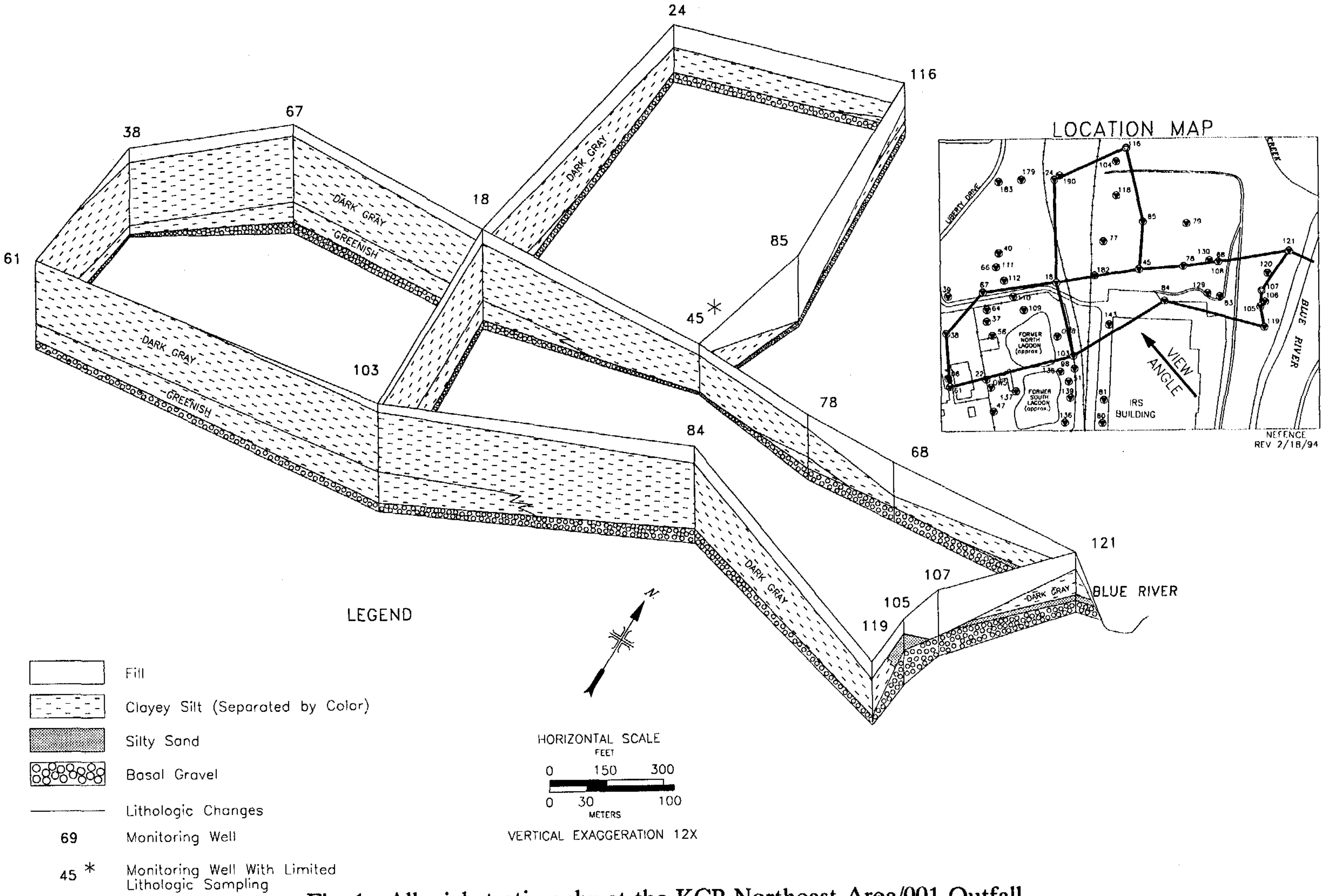


Fig. 1. Alluvial stratigraphy at the KCP Northeast Area/001 Outfall.

1.3 DNAPL Characteristics and their Implication at the KCP

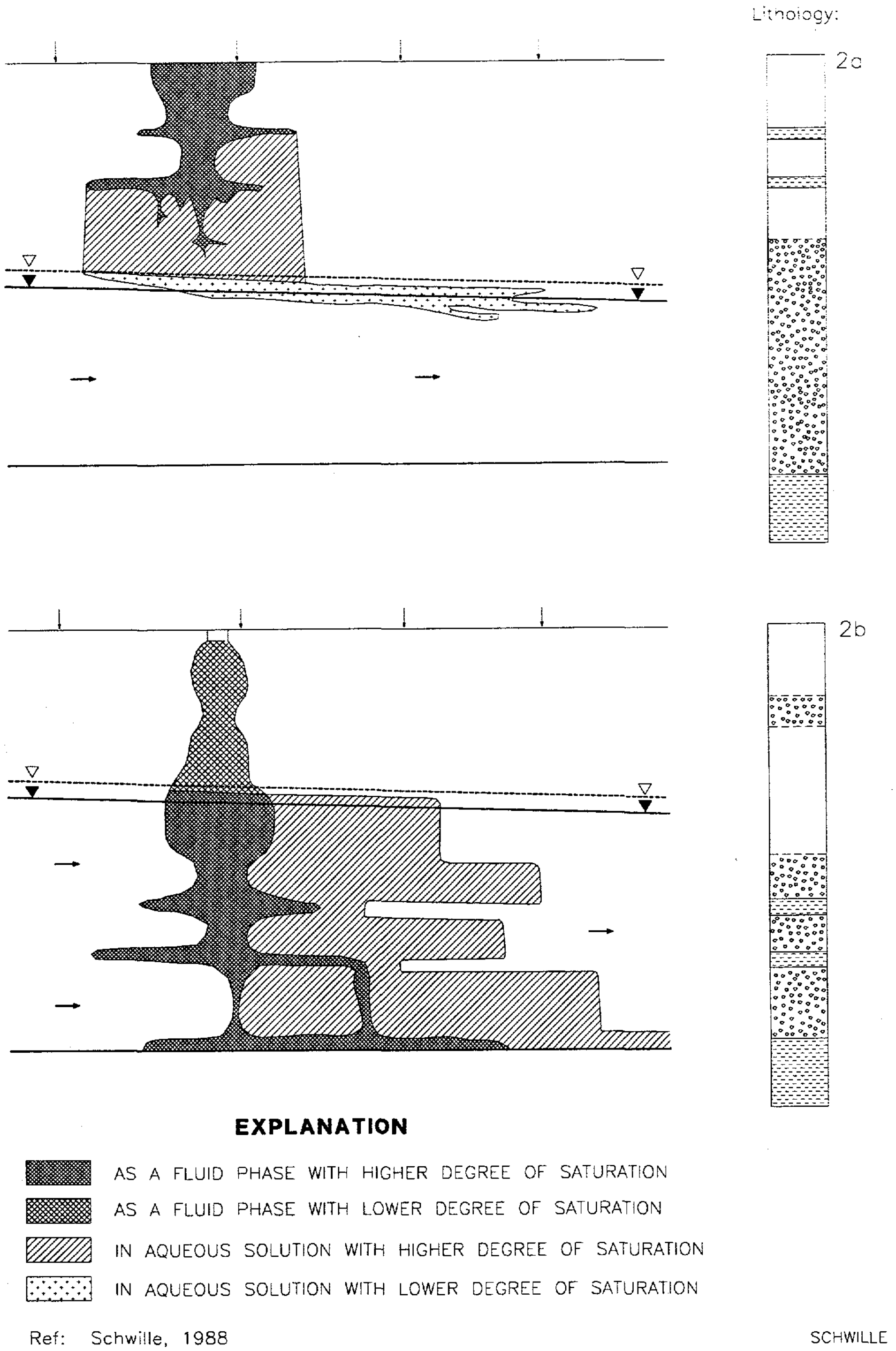
When groundwater contamination with chlorinated solvents was initially investigated, many believed that pump-and-treat would eventually restore an aquifer. Since then, many investigators have demonstrated that chlorinated solvents may form pools of pure DNAPL that can be sources of contamination for decades and possibly centuries (Wilson and Conrad 1984; Schwille 1988). The recognition of this problem has led to a need to develop new strategies that address the fact that treatment of the entire aquifer is not realistic (Korte and Kearl 1990; Wilson 1992; Johnson and Pankow 1992). Some of these strategies are containment by hydraulic means, possibly in conjunction with slurry walls, and the application of passive technology such as reactive gates (Gillham and O'Hannesin 1992). Direct knowledge of DNAPL presence is not essential for applying some of these innovative technologies. However, uncertainties regarding their potential efficiency and placement would be reduced if more precise information were available. Moreover, an enhanced knowledge of how DNAPL is distributed would be useful in evaluating the potential application of source treatment measures or in justifying cessation of pump-and-treat operations that are proving ineffective in reducing contaminant concentrations.

Why DNAPL is Believed Present at the KCP

The general theory of DNAPL movement has been provided by Schwille (1988). DNAPL spilled or leaked to the ground above the water table moves under the force of gravity to the capillary fringe (Fig. 2a). At first, surface tension between the water and the DNAPL is sufficient to prevent penetration of the water table. As more DNAPL is added, eventually enough reaches the water table to overcome the water capillary pressure at the capillary fringe, and the solvent penetrates the water table (Fig. 2b). Under the force of gravity, the solvent migrates rapidly until it encounters a layer of lower permeability. This scenario was suspected at the KCP at some of the sources within a general location known as the TCE Still Area (Fig. 3).

A review of the literature, however, shows that the idealized circumstances presented in Fig. 2 present an oversimplification for a site such as the KCP. Figure 2 is based on models using glass beads, which can only simulate the circumstances for very coarse soil conditions. In contrast, the alluvium at the KCP site is two to four orders of magnitude less-permeable. The actual distribution of DNAPL in such a low-permeable system requires additional consideration.

Figure 4 shows the heterogeneous nature of DNAPL distribution (at the microscale) such as might be encountered in subsurface soils. The system depicted in the figure is coarser than what is present at the KCP but it illustrates how DNAPL is trapped as ganglia in discontinuous phases. Indeed, in a finer-grained system where the capillary entry pressure is significantly higher, a "pool" such as is shown in Fig. 2, cannot form and the overall distribution will look more like that shown in Fig. 5. Figure 5 presents a DNAPL distribution developed for a fine-grained system in the laboratory (Wilson et al. 1989; Conrad et al. 1988; Conrad et al. 1992). A field-scale conceptual drawing of such a distribution is shown in Fig. 6. The figures show that "pools" are not formed and that DNAPL distribution is highly discontinuous. The figure



Ref: Schwille, 1988

Fig. 2. Migration of chlorinated solvents. Grain size at right. Adapted with permission from F. Schwille, *Dense Chlorinated Solvents in Porous and Fractured Media,* Lewis Publishers, Chelsea, Michigan, 1988.

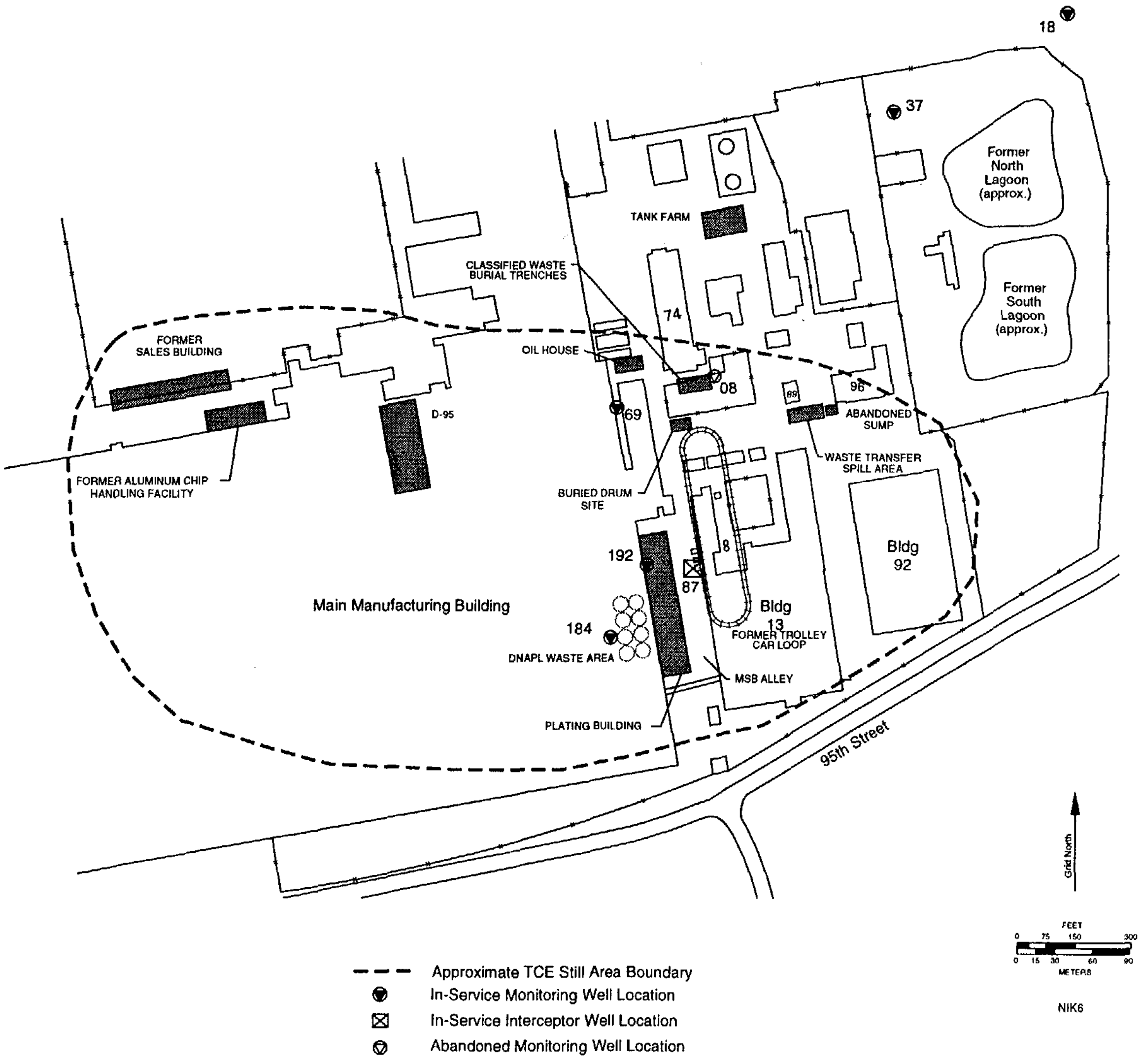


Fig. 3. TCE Still Area location at the KCP.

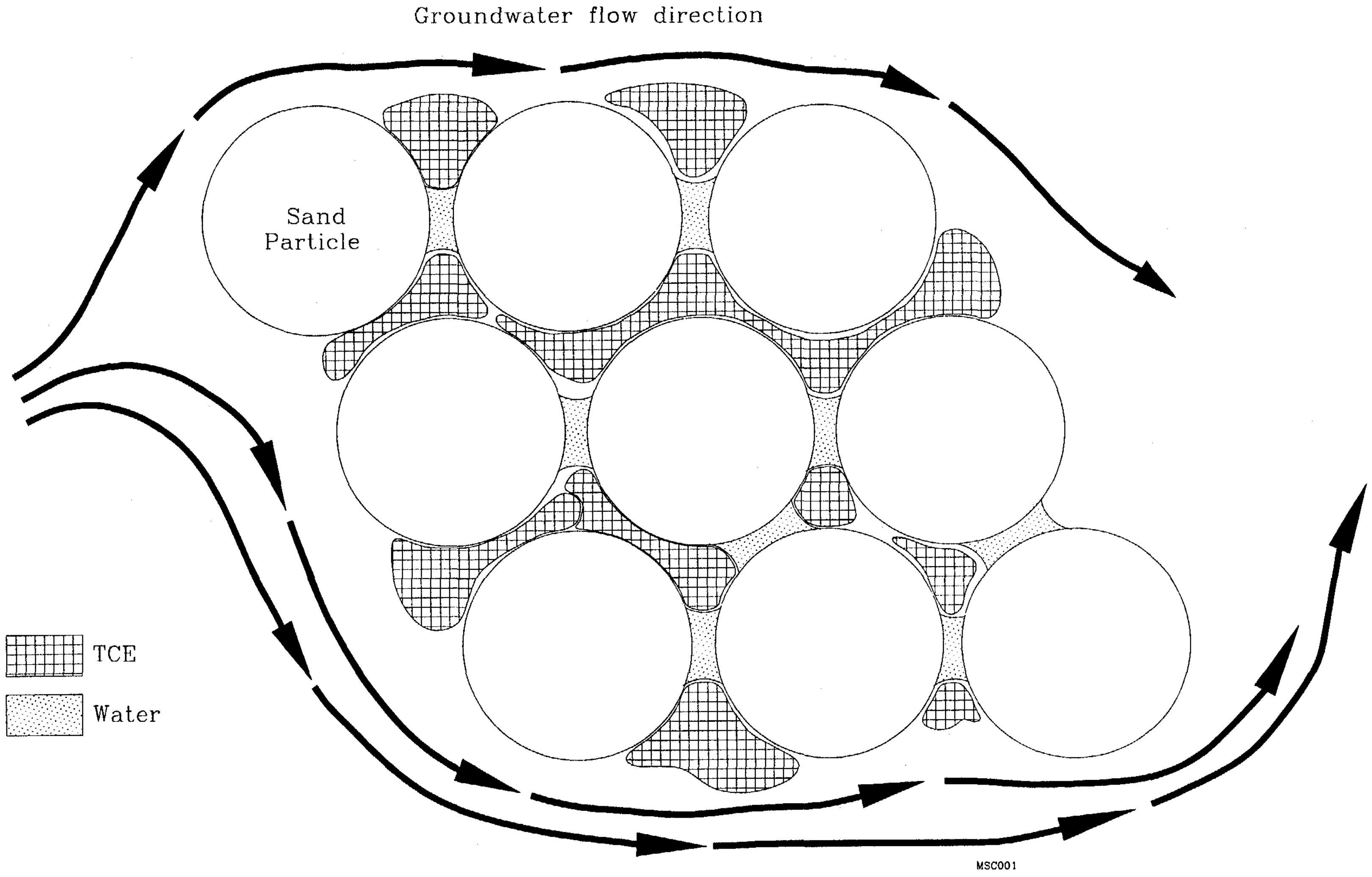


Fig. 4. A DNAPL-contaminated saturated zone has three phases (solid, water, immiscible). The contaminant may be present in any one, or all three phases. *Source: Dense Nonaqueous Phase Liquids: A Workshop Summary.* EPA/600-R-92/030. U.S. Environmental Protection Agency, 1992.

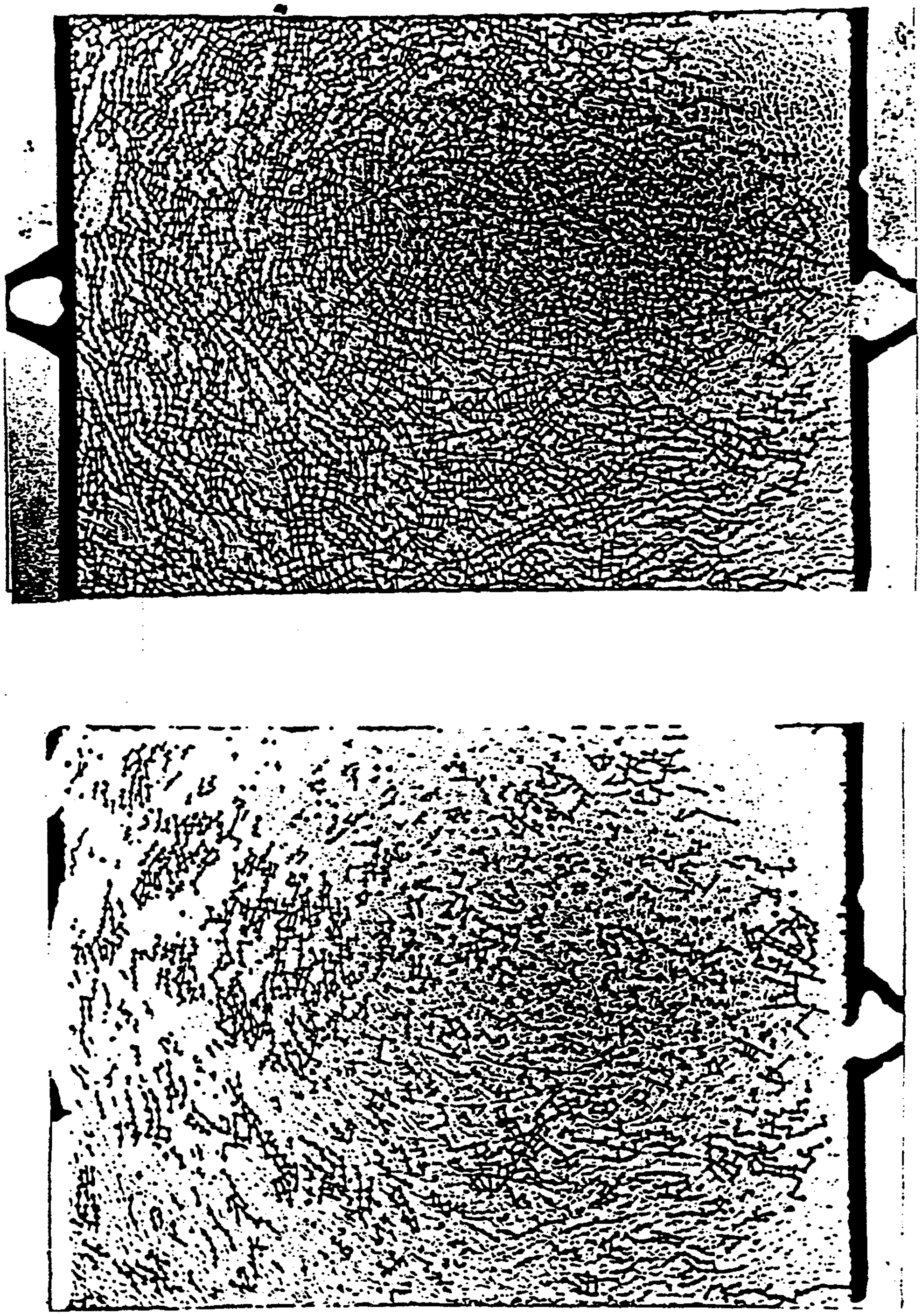


Fig. 5. DNAPL in residual saturation in relatively fine grained systems.
Source: Adapted from Wilson, J. L., S. H. Conrad, W. R. Mason, W. Peplinski, and E. Hagen, *Laboratory Investigation of Residual Liquid Organics from Spills, Leaks, and the Disposal of Hazardous Wastes in Groundwater,* EPA/600/6-90/004, U. S. Environmental Protection Agency.

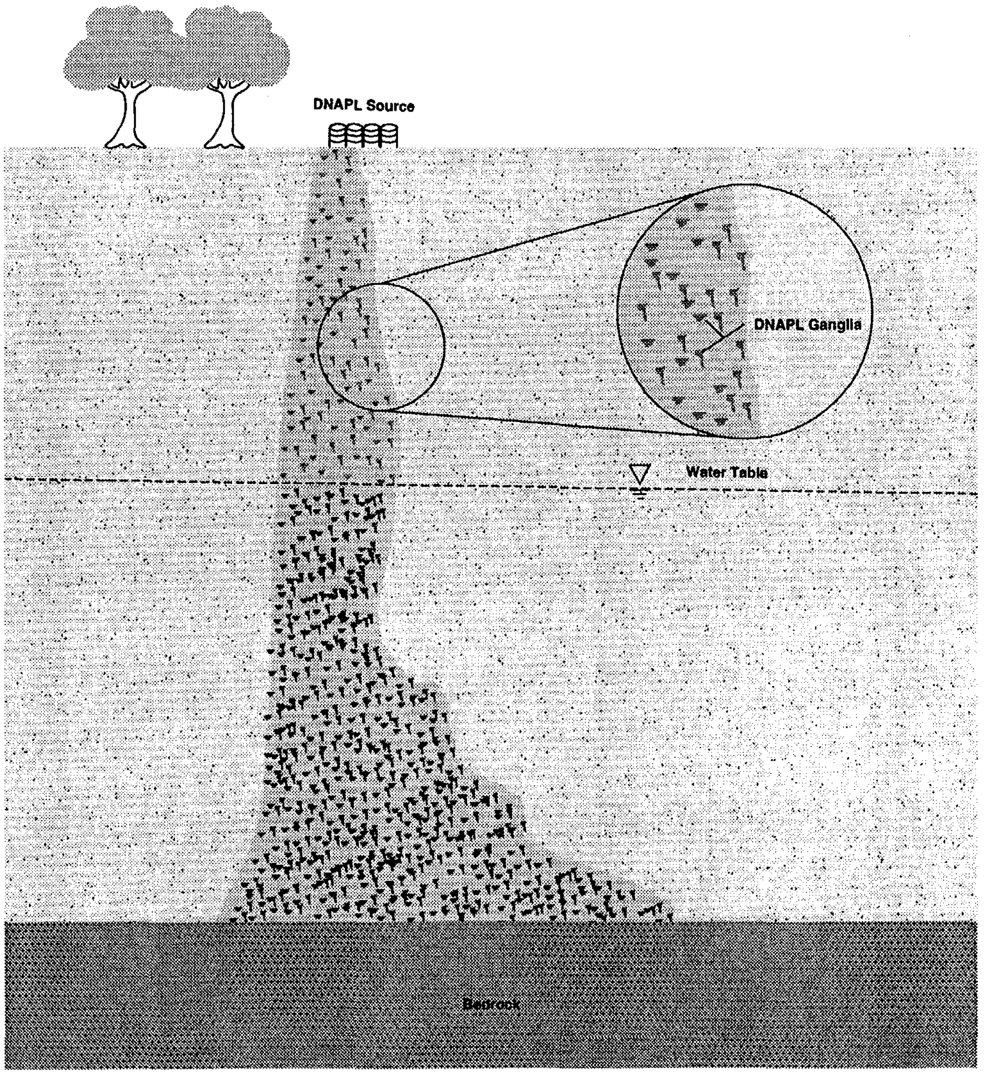


Fig. 6. Conceptual distribution of DNAPL in a homogeneous fine-grained system.

suggests that, especially in heterogeneous field systems, there are dead-end and even closed-off pores where water or DNAPL can accumulate and be virtually impossible to displace. In a sense, the circumstances can be thought of as resulting in many "micropools" of DNAPL interspersed with some water-filled pores as well. In this case, discrete sampling over a 5-ft zone, is unlikely to show large variations in contaminant concentrations. DNAPL ganglia will be dispersed throughout the zone, and even though films of water surrounding the ganglia may contain saturated concentrations of the solvent, bulk samples, even from a very small area, will show significantly lower concentrations. Consequently, the brief field study reported in this document was designed to determine whether the idealized conceptual model for DNAPL in Fig. 2 or the discontinuous distribution shown in Figs. 5 and 6 is more applicable to the KCP.

Site-Specific Data

The alluvial system at the KCP is generally referred to as homogenous in a hydraulic sense. The entire alluvium transmits water, and while the hydraulic conductivity from top to bottom shows some differences, the alluvium can universally be characterized as not very permeable. The basal unit of the alluvium does contain gravel, but the clayey-silt matrix, although there are localized exceptions, dominates the hydraulic characteristics of the unit. However, to describe the alluvium at the KCP as homogenous is not accurate when considering a microscale process such as the movement and distribution of DNAPL. Even the studies with uniform glass beads showed marked fingering and spreading when a uniform fine-grained layer was encountered (Schwille 1988).

Many of the monitoring wells at the KCP were installed as multiple completions in the same borehole. The technique has permitted, in some cases, determination of the location of a spill (Korte and Kearl 1991). For example, in a contaminated area known as the Northeast Area, a well (KC85-37) located within the suspected source area showed high levels of contamination in the upper portion of the aquifer, moderate levels in the middle portion, and much less contamination at depth. Referring again to Fig. 2a, the data at Northeast Area well KC85-37 generally fit this model, suggesting that the DNAPL spill was barely sufficient to overcome the repulsive forces at the capillary fringe. It is clear from the contamination pattern that a spill probably occurred near the well and that a significant DNAPL pool is unlikely to be present at the bedrock in this location.

In contrast, well KC87-69, which is within the TCE Still Area (Fig. 3), shows the opposite pattern to the well described in the preceding paragraph. Contamination in the lower zone of the aquifer is much greater than in the upper zone (this well does not have a middle completion), suggesting that an accumulation of DNAPL may exist at depth at this location. It should be noted that hydrologic data for this location indicate that there is not a significant vertical hydraulic gradient in this portion of the site.

In addition, samples of soil collected below the water table as part of various site investigations have also provided data that suggest the presence of DNAPL. An example is shown in Fig. 7 for samples collected as part of the investigation for a site known as the Plating Building (U.S. DOE 1993d). The maximum results for total VOC concentrations were found at or near the contact of the alluvium with the less-permeable bedrock (samples were collected at 5-ft intervals). Such data are consistent with the scenario for contaminant distribution illustrated in Fig. 2b.

Although contamination patterns suggest the presence of DNAPL, there has been no confirmation because the maximum concentrations found in wells in the area are far less than the concentration at saturation. In other words, if a well were located within a DNAPL pool that formed as shown in Fig. 2b, water at that location should have concentrations of the liquid near saturation (maximum solubility) — circumstances that have been observed at the DOE Paducah Gaseous Diffusion Plant (PGDP), a site where the soil is very coarse grained (J. Douthitt, PGDP, personal communication to Nic Korte, ORNL, March 1993).

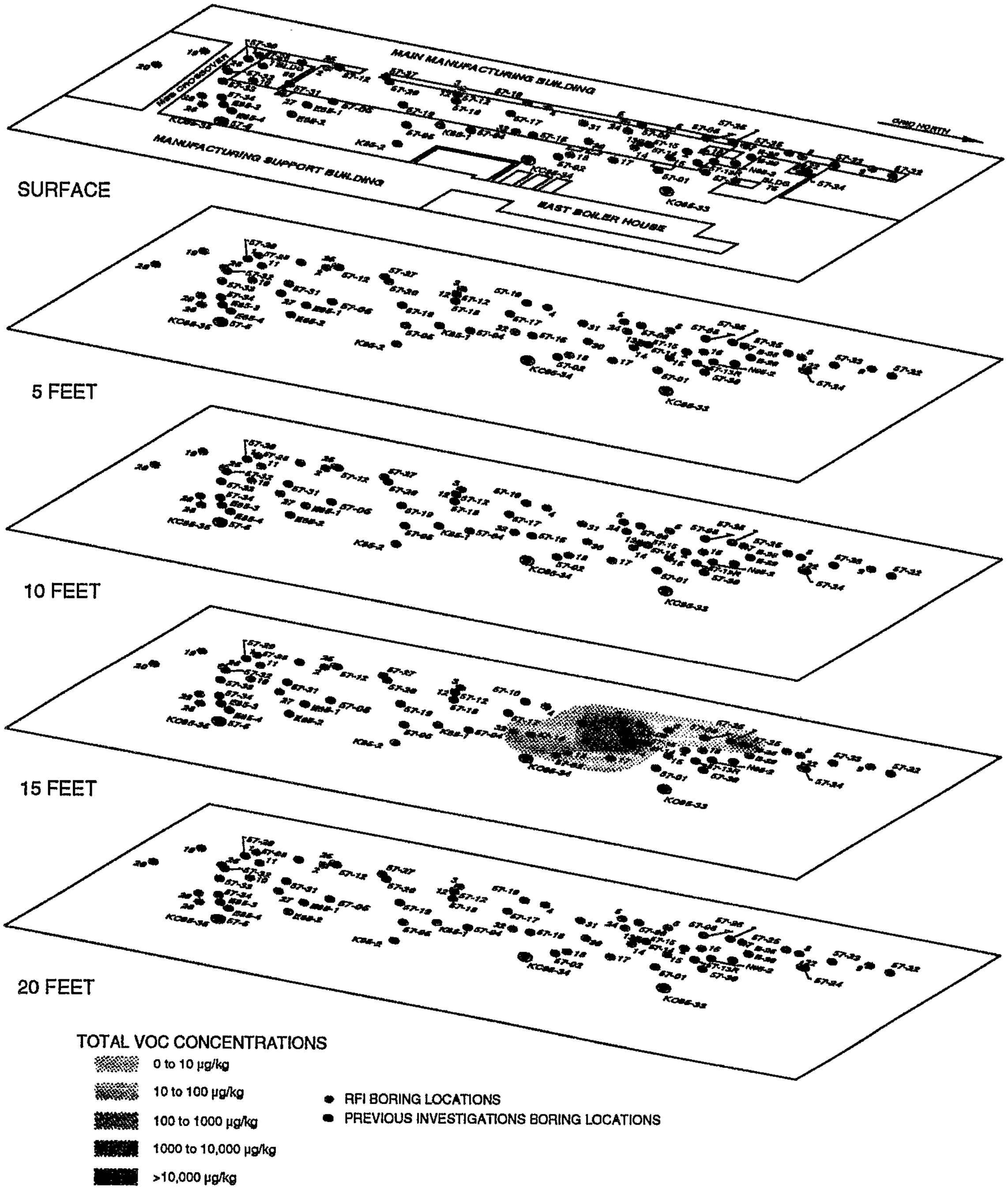


Fig. 7. Soil sample locations and VOC contamination in the Plating Building area.

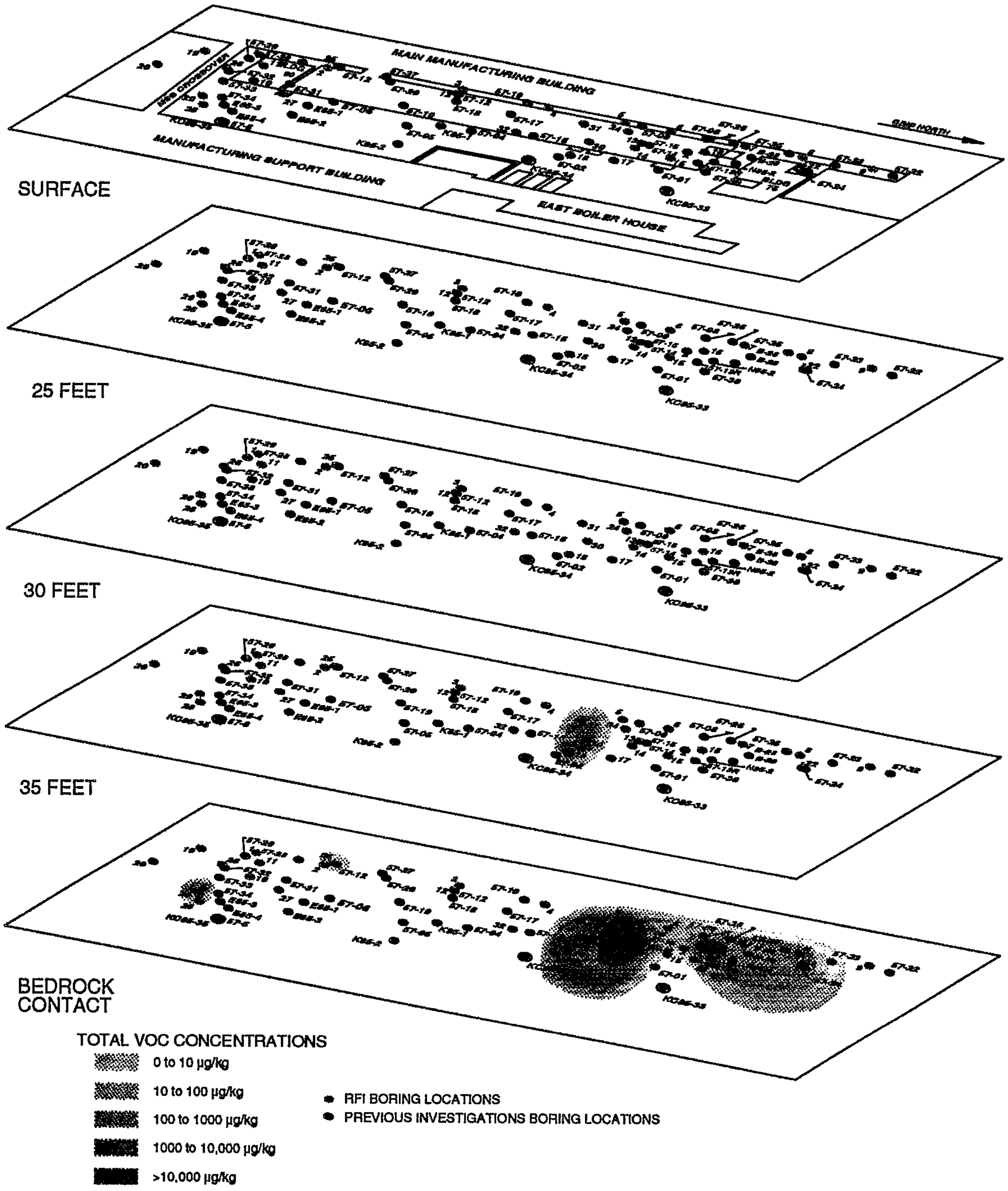


Fig. 7. (continued).

2. U.S. ENVIRONMENTAL PROTECTION AGENCY (EPA) GUIDANCE REGARDING THE INVESTIGATION OF DNAPL

The observation that contaminant concentrations are significantly less than saturation, as at the KCP, is typical according to DNAPL guidance provided by the EPA (U.S. EPA 1992). The EPA guidance includes certain recommendations for inferring the presence of nonaqueous phase liquids. A review of that guidance, with respect to the KCP, indicates that DNAPL is likely to be present. The following are the itemized EPA recommendations and the circumstances at the KCP.

DNAPL may be inferred to be present if:

1. DNAPL concentration in groundwater > 1% of pure phase or the effective solubility limit.

   The solubility of TCE is approximately 1100 mg/L. Concentrations greater than 10 mg/L (> 1% of the solubility limit) are common at the KCP and range to nearly 40% at well KC94-192L.

2. DNAPL concentration in soil > 10,000 mg/kg (1% of soil mass).

   The concentration of TCE in soil samples from the KCP has exceeded 10,000 mg/kg in only one sample so far. The highest concentrations are from two locations: 14,000 mg/kg at the Plating Building (U.S. DOE 1993d) and 2,500 mg/kg within the TCE Still Area (U.S. DOE 1994).

3. DNAPL concentrations in groundwater as calculated from soil-water partitioning relationships and from soil analyses are greater than the effective solubility.

   This condition is not closely approached at the KCP. Site soils have low organic contents and are believed to show little affinity for adsorption of chlorinated solvents.

   Maximum groundwater concentrations are typically 3% or less of the solubility. In a few rare cases, values as high as nearly 40% have been reported.

4. DNAPL chemical concentrations increase with depth in a pattern that is inconsistent with advective transport.

   This condition has been noted as described in the site investigation reports for the Plating Building and Department 26 (D/26) (U.S. DOE 1993c, 1993d) (see previous discussion regarding well KC87-69).

5. Erratic concentrations of DNAPL chemicals are found in groundwater, soil and soil gas.

   Wells in suspected DNAPL areas have shown the most erratic results. An example is well KC87-69. Contaminant trends, as shown in Fig. 8, have often been erratic and may be due to the presence of DNAPL.

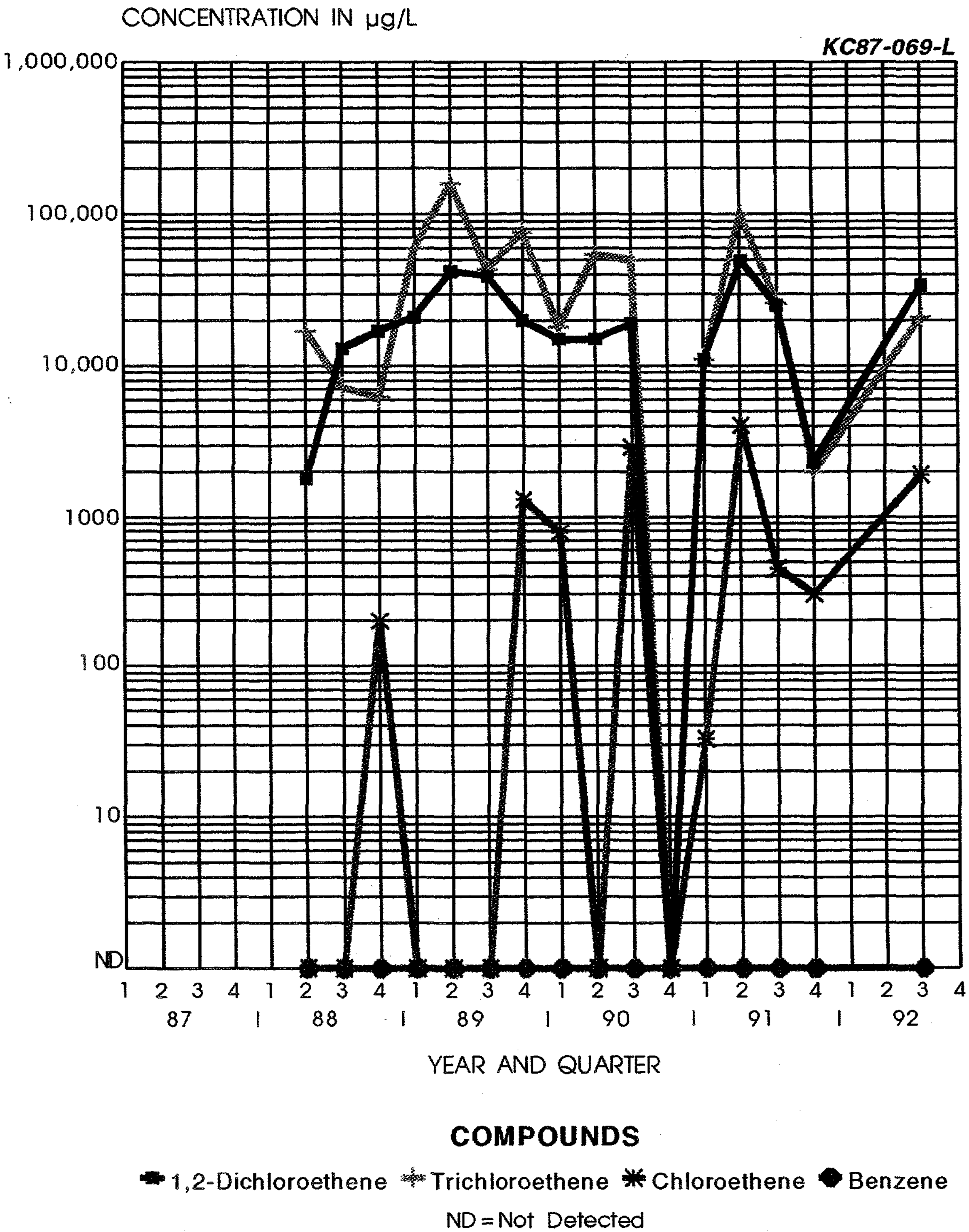


Fig. 8. Trend graph for organic compounds of interest in groundwater.

6. DNAPL chemicals are present in groundwater that is older than potential release dates.

   A limited amount of information regarding groundwater age has been obtained, but no measurements are available from the base of the aquifer. One water sample, collected at 21 ft below land surface, was estimated to be approximately 20 years old (A. D. Laase, ORNL/GJ, letter to J. Baker, AlliedSignal, Inc., June 10, 1994). Considering that the depth to the base of the aquifer is nominally 40 ft, that the spills were 30 to 40 years old when contaminants were first noted in the groundwater, and that the recharge rate typically decreases with depth, it is probable that the DNAPL is present in groundwater older than the potential release dates. The latter statement, however, cannot be considered as confirmed without obtaining additional data.

There are other potential methods for inferring DNAPL presence, but these are believed unlikely to be successful (e.g., transparent bailers) based on previous experience at the site.

3. EXPERIMENTAL DESIGN

The preceding discussion shows that the presence of DNAPL may be inferred based on several lines of evidence at the KCP. The next question was whether the presence of DNAPL could be evaluated in a more direct manner. The method chosen, based both on cost and potential applicability to the site, was depth-discrete water sampling. This technique was among the fluid measurement methods recommended by the EPA for determining the presence of DNAPL (U.S. EPA 1992).

The selected approach was to collect samples at five distinct depth intervals across the 5-ft well screen at the bottom of the aquifer. Four wells were chosen as representing varying conditions and locations at the KCP. If DNAPL pools were present, results would be as shown in Fig. 2b. Maximum concentrations, approaching the solubility limit, would be found in the deepest sample. Concentrations would decrease as the height above the bedrock increased.

3.1 Wells Selected

Four monitoring wells were selected for the study: KC84-18, KC87-69, KC92-184, and KC94-192. The latter three wells were chosen because they are located within or near source areas suspected of containing DNAPL. KC84-18 was included because it contains very high concentrations of contaminants and yet is believed to be downgradient from suspected DNAPL locations. The well locations are shown in Fig. 3.

3.2 Materials and Methods

Two sets of samples were collected from each well with the device shown in Fig. 9. Teflon™ tubing was attached to a rigid pole so that the tubing intake would be positioned at discrete depths. This approach was based on the micropurge sampling technique developed by direct observation of colloid transport in groundwater (Kearl et al. 1992; Kearl et al. 1994). That work showed that insertion of the sampling device causes extreme disturbance within the well bore, but that with dedicated sampling devices and low flow rates (< 100 mL/min), flow to the pump is laminar, with minimal mixing. The device shown in Fig. 9 was lowered into the wells to be sampled and then left for a minimum of 24 h to ensure that the disturbance caused by the insertion had subsided (Kearl et al. 1992). A peristaltic pump was used at the surface because the depth to water was approximately 10 ft or less for each well.

Samples were then collected at a low flow rate. Recent work at the KCP has shown that the low flow rate/micropurge groundwater sampling method provides results for organic contaminants that are not statistically different from the results of traditional sampling methods (Kearl et al. 1994). Except for samples 001 through 0006, samples were collected at a flow rate of 100 mL/min. The other six were collected at flow rates of 150 or 250 mL/min. A review of the results (see next section) does not indicate any unique effects because of the higher flow rates.

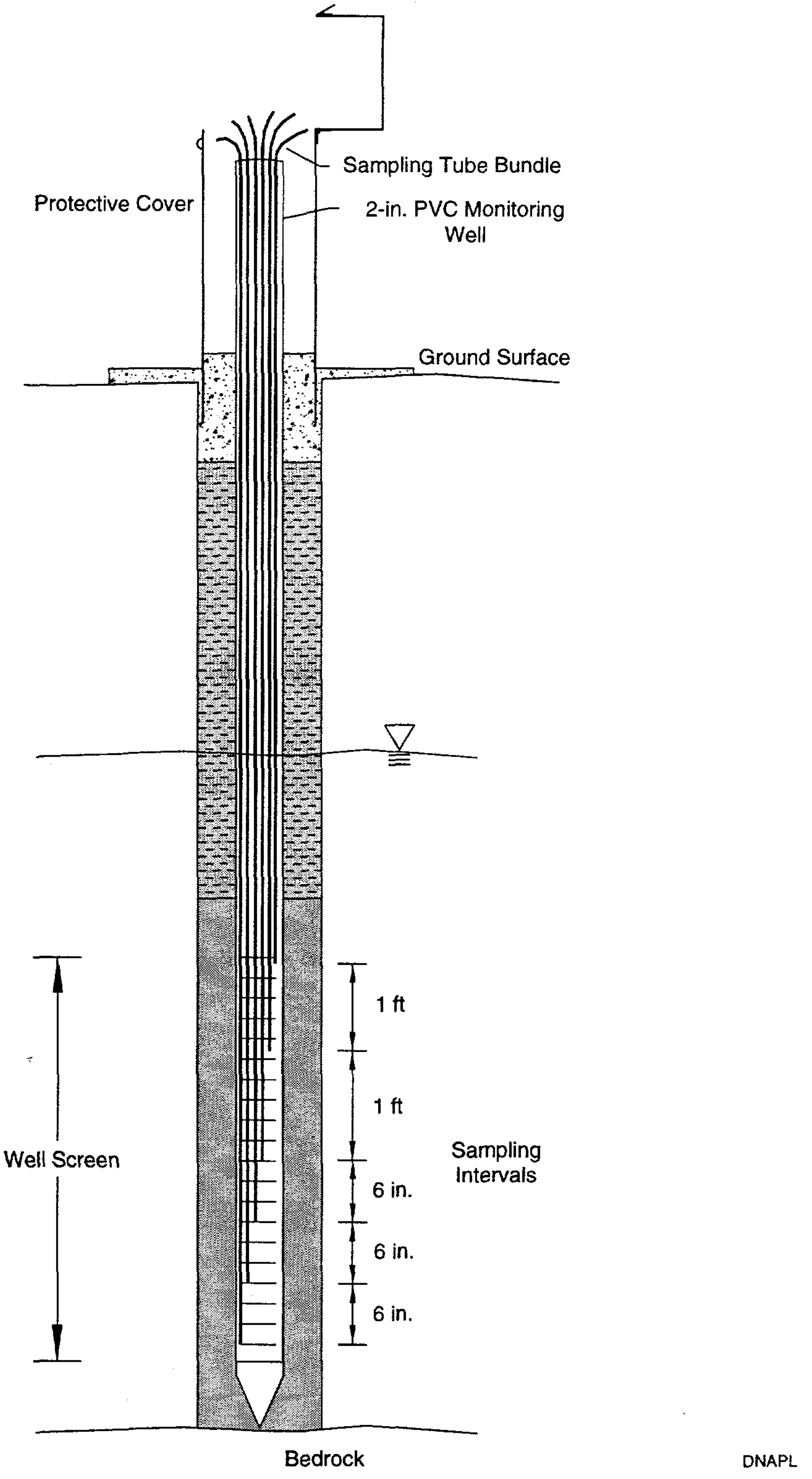


Fig. 9. Sampling device.

Samples from the bottom depth were collected first from each well. After a minimum of one hour, samples were collected from the second depth and so on. In each case, only the volume of tubing was purged (118 to 156 mL depending on the depth of the tubing). Then two 40-mL sample vials were filled. Samples were collected in this manner to minimize disturbance in the wells. Once a complete set of samples was collected from each well, the process was repeated after a 24-h interval. Samples were sent to Pace Laboratories, Inc., in Lenexa, Kansas, for the analysis of volatile organic compounds (VOCs).

4. RESULTS

4.1 KC84-18

This well is located in the Northeast Area downgradient from the location believed to be the primary source of contamination. Contaminant levels are typically high in the lower zone of this well due to the influence of a downward hydraulic vertical gradient. As shown by Fig. 10, the well is screened across 5 ft of clayey gravel and silt above the sandstone bedrock.

Despite the high concentrations of contaminants, DNAPL was not expected in well KC84-18 for several reasons. As noted previously, the source area wells for this contaminant plume did not indicate the presence of DNAPL at depth and the presence of dissolved contamination at depth in well KC84-18 could be explained based on the site's hydrologic conditions and simple advective transport. Another reason that DNAPL was not expected is that well KC84-18 is primarily contaminated with 1,2-dichloroethene (1,2-DCE), which is believed to be present at the KCP only as a biodegradation product of TCE. Because TCE is biodegraded only when in the dissolved phase, it follows that 1,2-DCE must also be in the dissolved phase (Alvarez et al. 1989). The results shown in Table 1 and Fig. 11 (only TCE is graphed because only it would be in a DNAPL phase) demonstrate that there is no significant contaminant pattern with depth for this well. In addition, TCE levels are well below the 1% of solubility limit cited above as representative of DNAPL.

4.2 KC87-69

This well (Fig. 12) is located in the TCE Still Area near the location of a former still that is believed to be a primary source of contamination in the area. This is one of two monitoring wells at the KCP where contaminant levels above 100 mg/L (100,000 μg/L) of total VOCs have been reported. Analytical data are presented in Table 2 and graphed on Fig. 13. The TCE results for the first round of sampling show a maximum at 34.75 ft below ground surface or 1.5 ft above the bedrock contact. A maximum at 1 ft above the bedrock contact is shown in the second round sample. The comparison between the two rounds is not adequate, however, to draw a conclusive interpretation from the data. The prudent approach is to assume that there are no significant differences with depth.

4.3 KC92-184

This well (Fig. 14) is located within the main plant near the former Plating Building, where degreasing operations resulted in significant TCE spills. Contaminant distribution patterns in soil near this location (Fig. 7) were such that DNAPL was suspected in the area. The location of KC92-184 as it relates to the sampling locations on Fig. 7 is shown on Fig. 3. The data obtained in this study are shown in Table 3, and the TCE results are plotted on Fig. 15.

The results do not indicate the idealized pattern shown in Fig. 2, and except for two of the results (first round TCE data at 36.35 and 39.85 ft) are relatively uniform.

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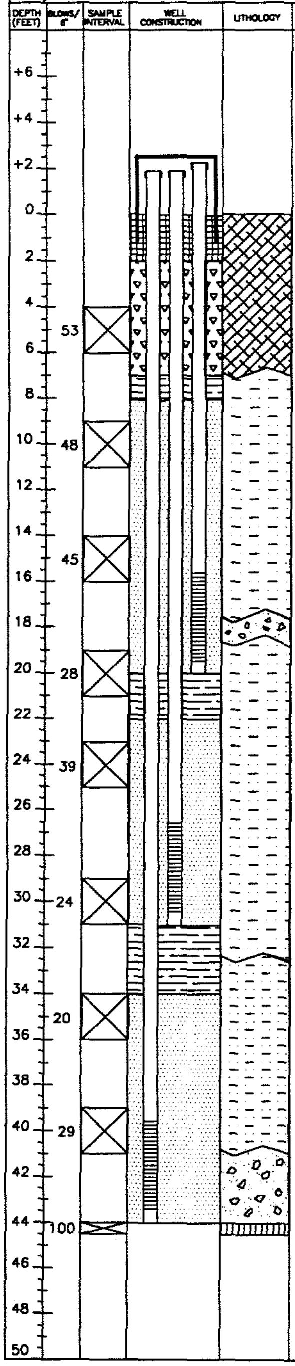
Well Summary Information

Prepared By J. DEXTER (BENDIX) Date 10/15/84 Page 1 of 1
Hole No. KC84-018 CASING ELEVATION: L-798.41', M-798.37', U-798.40' GROUND ELEVATION: 795.60'
Total Depth 44' Number of Completions 3 Rig Type AUGER Location SEE MAP
Auger Size UNKNOWN Sample Type UNKNOWN
Project KANSAS CITY DOE Data Verified By NA Date NA



DESCRIPTION

FILL: clayey silt, organics.

CL CLAYEY SILT: dark gray, organics.

GRAVEL: clay rich matrix, water encountered.

CL CLAYEY SILT: olive gray.

WATER AT 23'

CL CLAYEY SILT: blue gray.

GC GRAVEL: blue gray, clayey silt.

BEDROCK: sandstone, Knobtown (?).

Fig. 10. Lithologic log and completion diagram for well KC84-18.

Table 1. TCE, 1,2-DCE, chloroethene, and total VOC concentrations with depth in KC84-18-L

Well number	Depth, ft	Sample number	Concentration, µg/L			
			TCE	1,2-DCE	Chloroethene	Total VOC
KC84-018L	46.65	0001	ND	13,000	1,000	14,000
		0021	ND	11,000	650	11,650
	46.15	0004	300	9,200	450	9,950
		0024	ND	5,800	500	6,300
	45.65	0007	ND	11,000	510	11,510
		0027	360	13,000	590	13,950
	45.15	0010	2,700	ND	ND	2,700
		0030	300	13,000	600	13,900
	44.15	0013	ND	8,200	ND	8,200
		0033	320	11,000	ND	11,320
	43.15	0016	ND	18,000	ND	18,000
		0036	ND	10,000	ND	10,000

ND = not detected

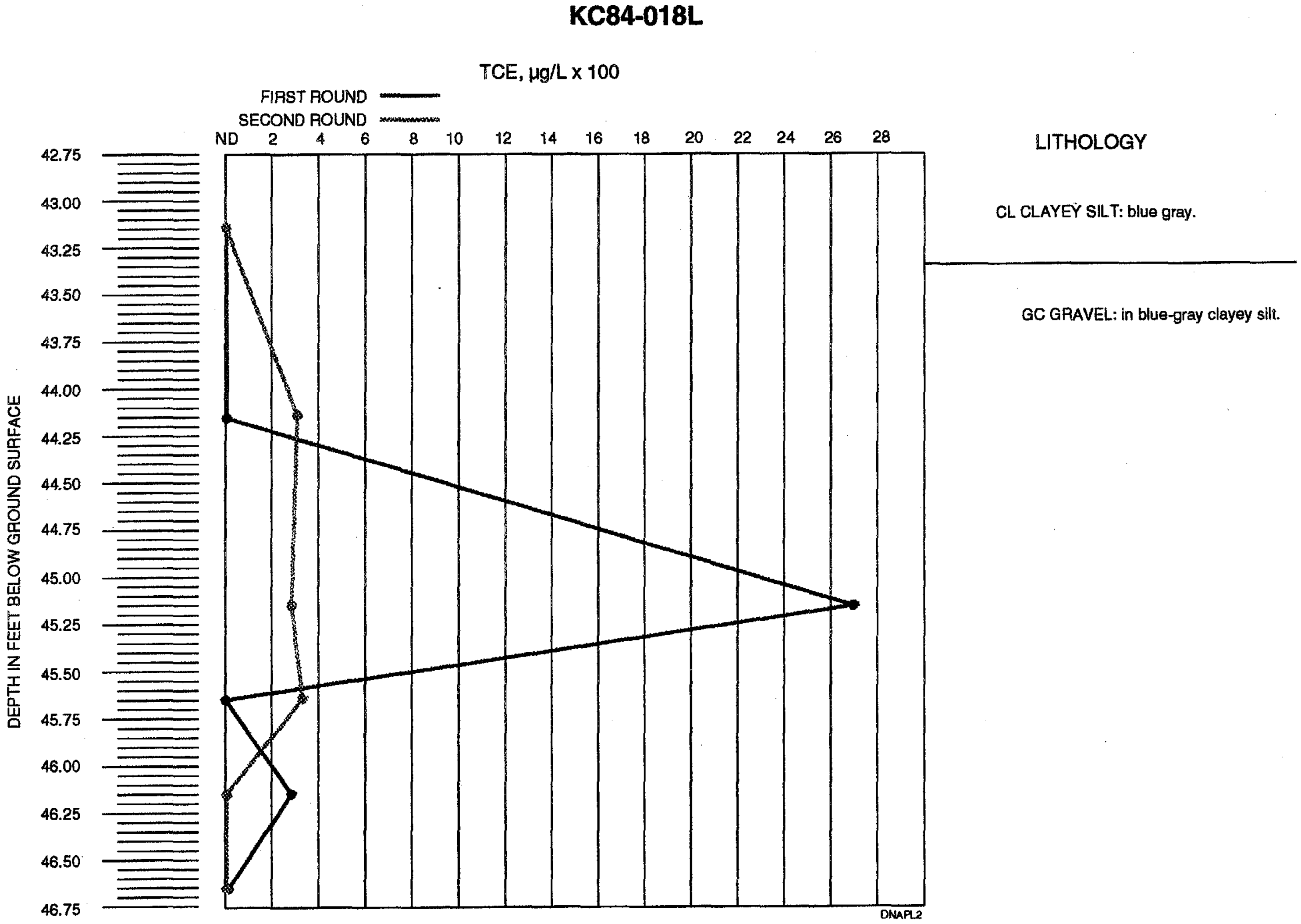


Fig. 11. TCE concentrations in well KC84-18-L.

Well Summary Information

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Prepared By: E. MIGNARDOT (WESTON) Date: 12/10/87 Page: 1 OF 1

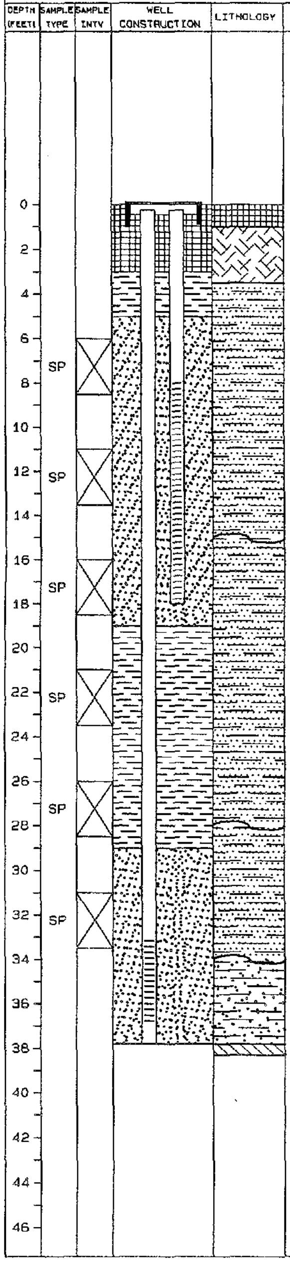
Hole No.: KC87-069 Casing Elevation: L-796.86', U-796.87' Ground Elevation: 796.92'

Total Depth: 37.8' No. of Compl.: 2 Rig Type: AUGER Location: SEE MAP

Auger Size: UNKNOWN Sample Type: 2.5' SPLIT SPOON

Project: KANSAS CITY DOE Data Verified By: NA Date: NA

DESCRIPTION



CONCRETE: 1 ft concrete surface underlain by fill.

FILL: dark-brown clay, dry, soft.

CL SILTY CLAY: grayish-brown (5YR 3/2), moist, soft.

CL SILTY CLAY: as above.

CL CLAYEY SILT: grayish-brown (5YR 3/2), trace of brown sand, wet, soft.

CL CLAYEY SILT: dark yellowish-brown (10YR 2/2), trace brown, moist, soft.

WELL COMPLETION INFORMATION: bentonite and natural fill from 19 to 29 ft.

CL CLAYEY SILT: dark yellowish-brown (10YR 2/2), underlain by greenish-gray, minor and or iron stained, limonite-rich material in green silt, wet, hard.

CL CLAYEY SILT: green-gray (5G 4/1), underlain by brown (10YR 6/2), clayey gravel, minor brown fine sand, wet, saturated, hard.

GC CLAYEY GRAVEL: brown (10YR 6/2), with large (up to 1in) limestone and sandstone pebbles, hard, saturated, trace brown fine sand in gravel.

BEDROCK: weathered Knobtown Sandstone Fm.

Fig. 12. Lithologic log and completion diagram for well KC87-69.

Table 2. TCE, 1,2-DCE, chloroethene, and total VOC concentrations with depth in KC87-69-L

Well number	Depth, ft	Sample number	Concentration, μg/L			
			TCE	1,2-DCE	Chloroethene	Total VOC
KC87-069L	36.25	0002	8,300	53,000	7,900	69,200
		0022	6,800	49,000	ND	55,800
	35.75	0005	5,000	54,000	ND	59,000
		0025	12,000	44,000	6,000	62,000
	35.25	0008	6,100	40,000	3,600	49,700
		0028	14,000	47,000	5,700	66,700
	34.75	0011	18,000	35,000	4,600	57,600
		0031	4,600	44,000	4,400	53,000
	33.75	0014	7,800	29,000	3,700	40,500
		0034	5,200	29,000	3,300	37,500
	32.75	0017	14,000	59,000	7,300	80,300
		0037	4,600	46,000	4,800	55,400

ND = not detected

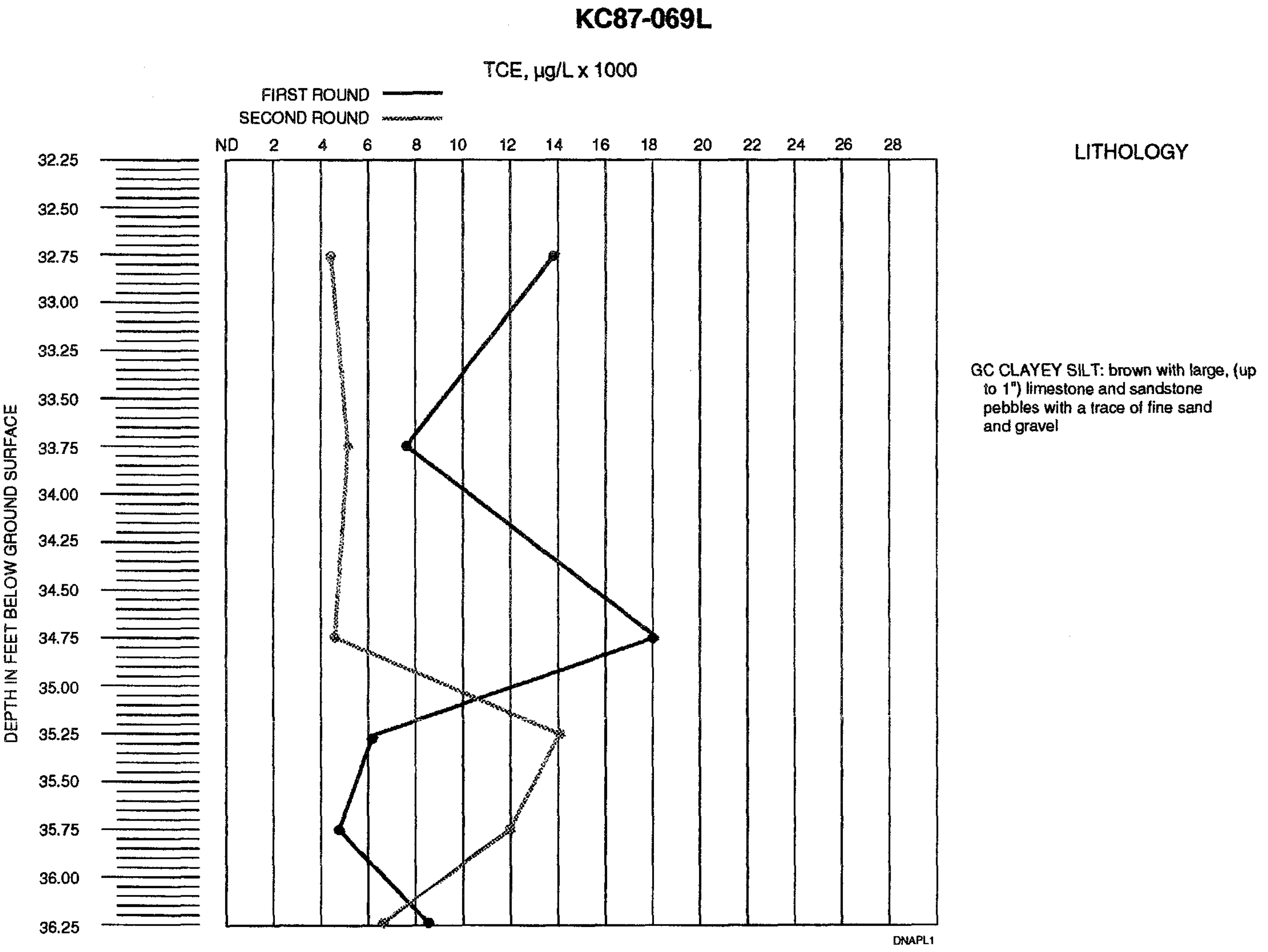


Fig. 13. TCE concentrations in well KC87-69-L.

Well Summary Information

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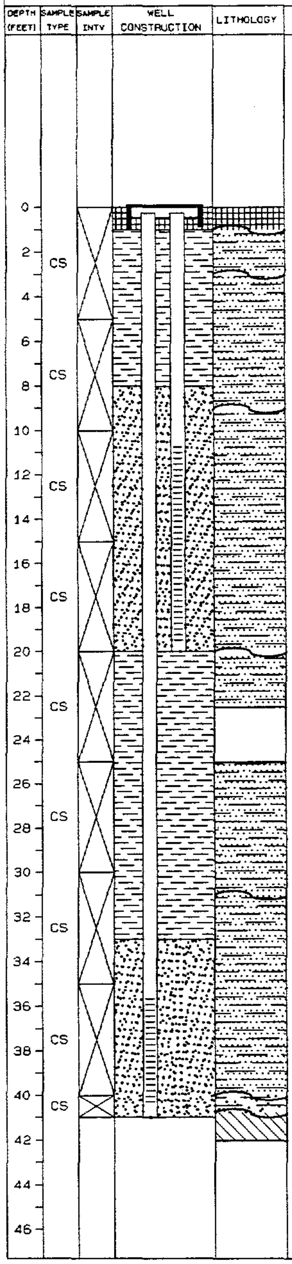
Prepared By: S.R. Sturm/D.B. Ertel Date: 3/29/92 Page: 1 OF 1

Hole No.: KC92-184 Casing Elevation: NOT AVAILABLE Ground Elevation: 800.02'

Total Depth: 41' No. of Compl.: 2 Rig Type: Skid Location: D/95 COLUMN-J-48

Auger Size: 8" O.D. Sample Type: 2" X 5' CONTINUOUS SPLIT SPOON

Project: TCE STILL AREA Data Verified By: A.D. Laase Date: 9/30/92



DESCRIPTION

CONCRETE FLOOR: (1.1').

CL CLAYEY SILT: gray-brown (2.5Y 5/2), mottled very dark gray, occasional Fe nodules, root pores, high plastic fine content, becoming very dark gray (2.5Y 3/0) with increasing depth, mottled by grayish-brown (2.5Y 5/2), wavy bedding, intact roots, high organic content and "swamp odor", slightly moist.

CL CLAYEY SILT: gray-brown (2.5Y 5/2), abundant root pores with black argillans, worm burrows, siltier than previous unit- pores becoming larger to 3 mm with greater argilland thickness, increasing moisture.

CL CLAYEY SILT: dark gray brown (2.5Y 3/2), as above, siltier than previous sample, wet, abundant black, <1 mm Fe oxide at 19'- 20'.

CL CLAYEY SILT: dark gray (2.5Y 4/0), very homogeneous, few roots, few pores, increased clay content from previous sample, wet.

LOST CORE: no sample recovery.

CL CLAYEY SILT: very dark gray (2.5Y 3/0), very homogeneous, scattered blue-gray mudstone inclusions (1 to 3 mm) at 30'-31'.

CL CLAYEY SILT: bluish-gray (5B 5/1), homogeneous, moderately dense, drier than previous unit, scattered Fe oxide.

CL CLAYEY SILT: as above, increasing Fe nodules, limonite staining.

GC CLAYEY GRAVEL: limestone gravel with some chert, angular fragments in a blue-gray clay/ silt matrix.

BEDROCK: sandstone dark blue gray (5B 4/1), very fine grain (lower), subrounded, thin laminar bedding, some Fe oxide, micaceous. Top of the bedrock at 40.8'.

Fig. 14. Lithologic log and completion diagram for well KC92-184.

Table 3. TCE, 1,2-DCE, chloroethene, and total VOC concentrations with depth in KC92-184-L

Well number	Depth, ft	Sample number	Concentrations, µg/L			
			TCE	1,2-DCE	Chloroethene	Total VOC
KC92-184L	39.85	0003	33,000	1,200	ND	34,200
		0023	12,000	650	ND	12,650
	39.35	0006	13,000	660	ND	13,660
		0026	24,000	740	ND	24,740
	38.85	0009	24,000	1,300	ND	25,300
		0029	27,000	920	ND	27,920
	38.35	0012	24,000	1,800	ND	25,800
		0032	24,000	1,000	ND	25,000
	37.35	0015	28,000	1,200	ND	29,200
		0035	22,000	1,000	ND	23,000
	36.35	0018	4,100	250	330	4,680
		0038	26,000	1,000	ND	27,000

ND = not detected

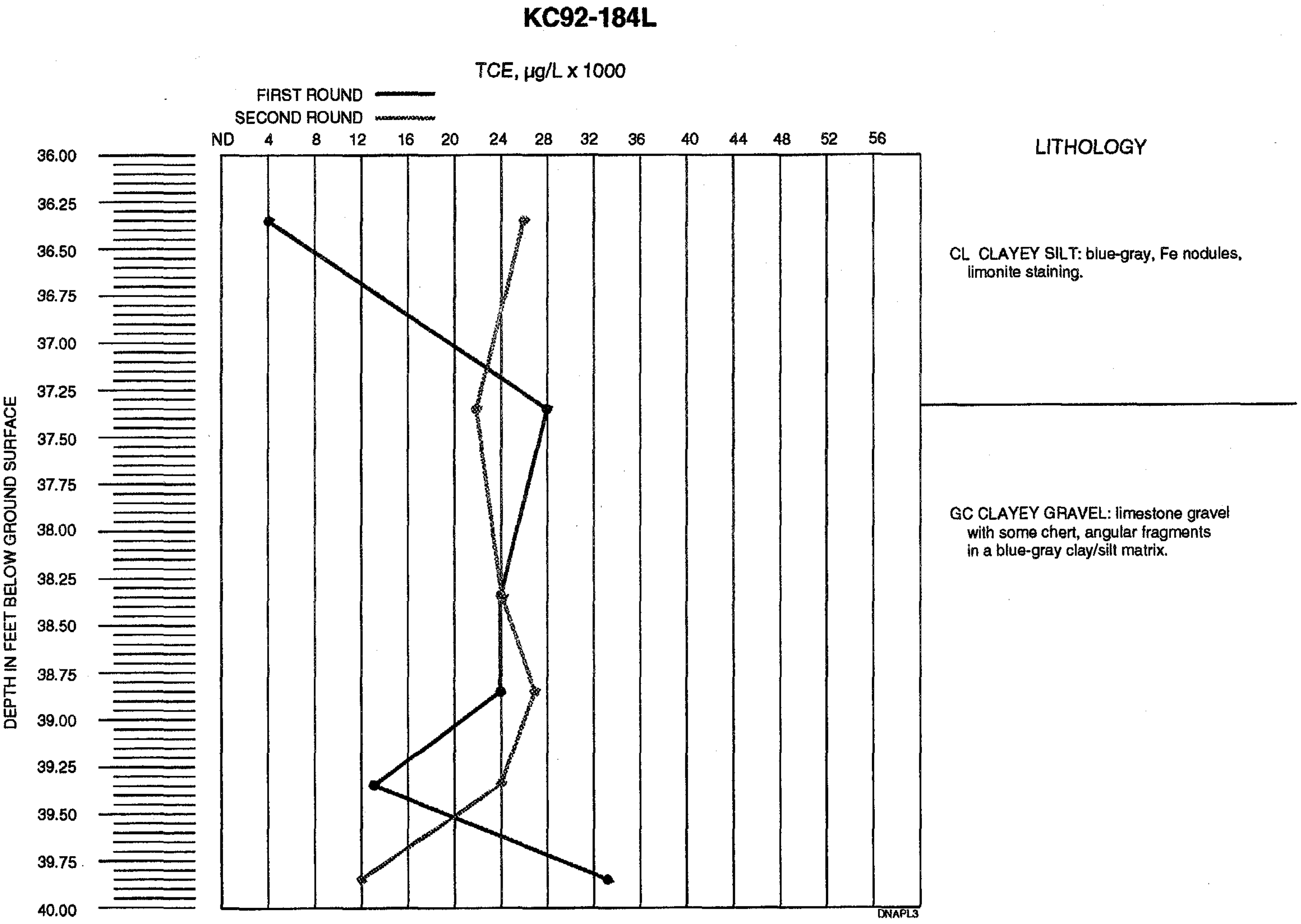


Fig. 15. TCE concentrations in well KC92-184-L.

4.4 KC94-192

This well (Fig. 16) is located in the TCE Still Area between a groundwater interceptor well (KC88-87) and the Main Manufacturing Building. Well KC88-87 consistently shows the highest contaminant concentrations of the interceptor wells. Of the four monitoring wells in this study, KC94-192 has the highest TCE results, with concentrations ranging to nearly 40% of saturation. Those concentrations, as discussed in Sect. 2, are indicative of the presence of DNAPL. The source of contamination is believed to be a degreaser that had been located in the former Plating Building. Consequently, KC94-192 is located in an area where DNAPL is likely. This is one of two monitoring wells on site where contaminant levels above 100,000 μg/L of total VOCs have been reported. Analytical data are presented in Table 4 and graphed in Fig. 17. The TCE results for the first round of sampling indicate a maximum at approximately 42 ft below ground surface or 1 ft above the bedrock contact.

This result is not as apparent in the second round of sampling. It is interesting to note, however, that these zones showed the poorest reproducibility and that the initial concentration, being over 200,000 μg/L, as well as the lack of reproducibility, are indications, of themselves, of the presence of DNAPL (see Sect. 2).

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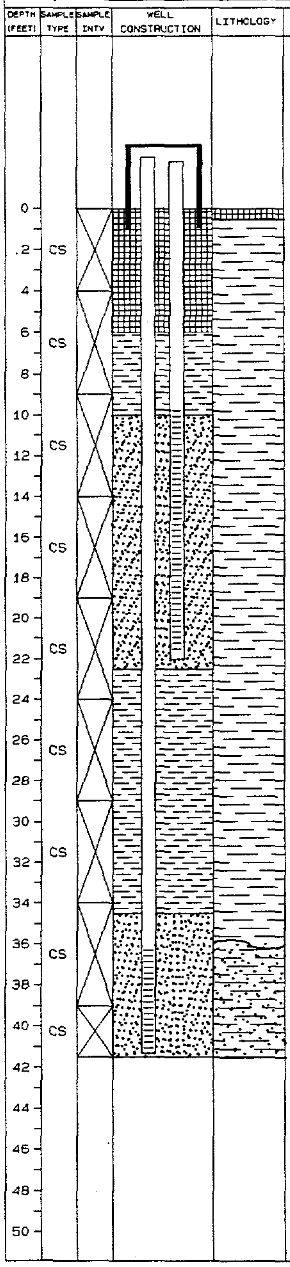
Well Summary Information

Prepared By: Layne Western/KCP Date: 6/6/94 Page: 1 OF 1
Hole No.: KC94-192 Casing Elevation: L 799.59' U 799.51' Ground Elevation: 796.83'
Total Depth: 41.5' No. of Compl.: 2 Rig Type: Unknown Location: Plating Building Area
Auger Size: 7 58" x 4" Sample Type: 5' Continuous Barrel
Project: Data Verified By: Joe Baker Date: 6/7/94



DESCRIPTION

Asphalt: 0.3'.

CL CLAY: brown, damp, common gravel and sand fill.

CL SILTY CLAY: brown, damp, firm.

CL SILTY CLAY: brown, moist, medium.

CL SILTY CLAY: brown, wet, highly plastic, soft.

CL CLAY: brown, wet, very soft, trace silt.

GC CLAYEY GRAVEL: wet, medium.

T.D. auger refusal at shale bedrock.

Fig. 16. Lithologic log and completion diagram for well KC94-192.

Table 4. TCE, 1,2-DCE, chloroethene, and total VOC concentrations with depth in KC94-192

Well number	Depth, ft	Sample number	Concentration, μg/L			
			TCE	1,2-DCE	Chloroethene	Total VOC
KC94-192	42.6	0039	69,000	5,000	ND	74,000
		0045	74,000	6,500	ND	80,500
	42.1	0040	220,000	14,000	ND	234,000
		0046	95,000	11,000	ND	106,000
	41.6	0041	230,000	10,000	ND	240,000
		0047	82,000	6,300	ND	88,300
	41.1	0042	50,000	4,400	ND	54,400
		0048	94,000	7,200	ND	101,200
	40.1	0043	69,000	6,200	ND	75,200
		0049	77,000	5,600	ND	82,600
	39.1	0044	61,000	11,000	ND	72,000
		0050	66,000	15,000	ND	81,000

ND = not detected

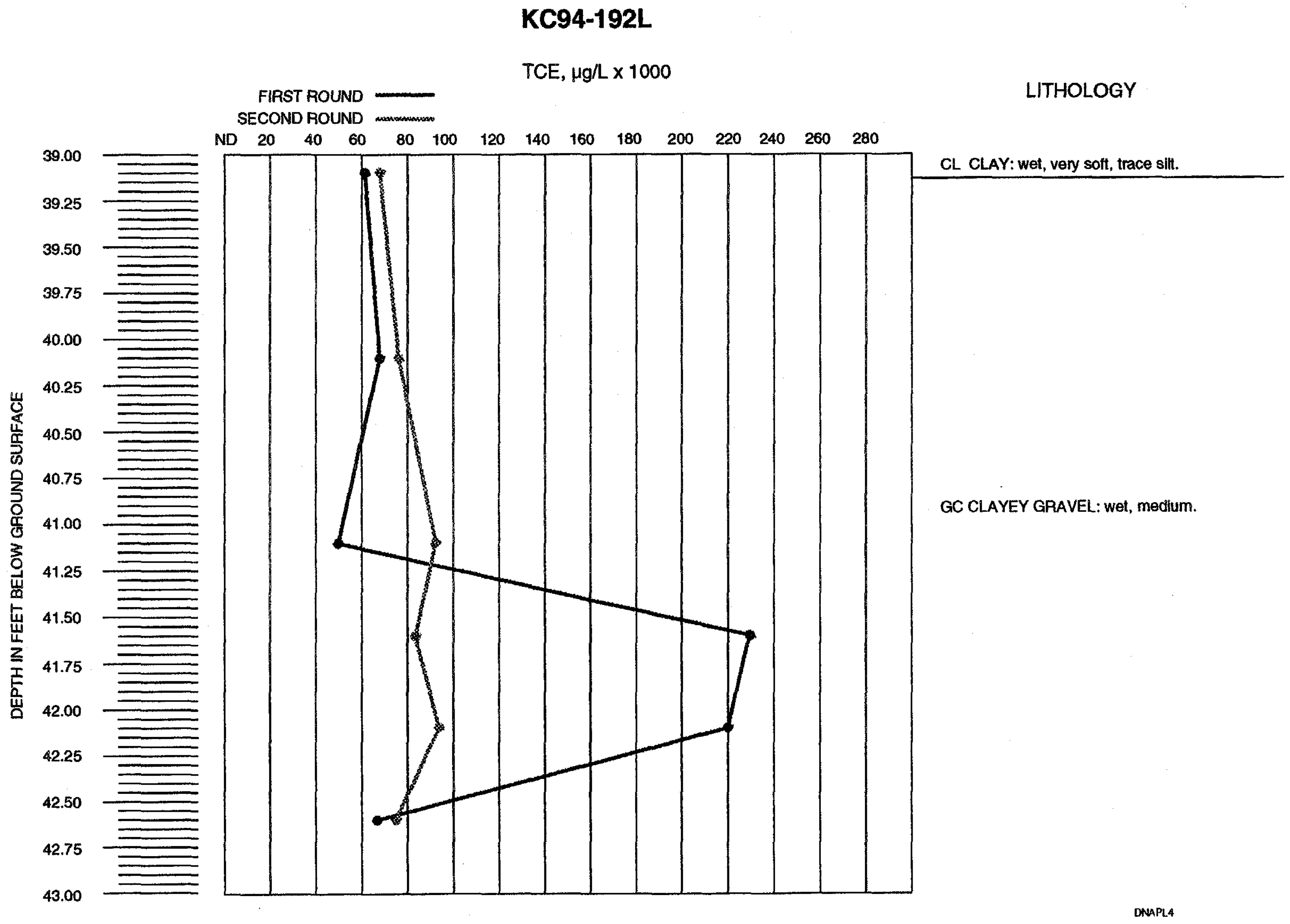


Fig. 17. TCE concentrations in well KC94-192-L.

5. DISCUSSION AND CONCLUSION

The interpretation of these data is not straightforward because of the apparent analytical variability. However, a separate study at the KCP has shown that low-flow sampling provides reproducible results (Kearl et al. 1994). Thus, the primary conclusion to be drawn, as discussed in Sect. 2, is that the variability observed is due to the presence of DNAPL and that the DNAPL is distributed heterogeneously. In other words, the results of this experiment suggest that idealized pools of DNAPL do not exist at the KCP and that DNAPL is not migrating as a separate phase, at least in the vicinity of the wells that were tested.

It must be noted that there are at least three phenomena that could confound the contaminant distribution and subsequent data interpretation. First is that TCE degradation is not uniform in the subsurface. Site-specific data have shown that microbial populations in the KCP subsurface are highly variable (T. J. Phelps and N. E. Korte, ORNL, unpublished data, 1991). Thus, in some locations TCE may be quickly degraded, and in others, it may migrate some distance before degradation occurs. A second potentially confounding factor is the presence of multiple sources or spill events. For example, the former still located near well KC87-69 may have leaked continuously or been subject to spills of different magnitudes several years apart. Spills of different magnitudes would penetrate to different depths in the fine-grained saturated zone. Finally, it is possible that the DNAPL is too dispersed to be detected by the method used in this study.

Nevertheless, while conclusive evidence of DNAPL was not obtained, interpretation of these data in conjunction with historical data is consistent with the hypothesis that DNAPL is trapped as discontinuous ganglia throughout several feet of the soil at the base of the aquifer within the TCE Still Area and within the main building near wells KC92-184 and KC94-192. Consequently, the KCP site conceptual model, with respect to DNAPL, has been refined. The model depicting idealized pools has been replaced to more clearly show the conditions believed to exist, that of discontinuous ganglia that will be sources of contamination to the groundwater for a considerable period of time (Figs. 5 and 6). It is also concluded, because of the likely presence of DNAPL and the tortuous flow path for groundwater at the KCP, that pump-and-treat is unlikely to significantly alter groundwater contaminant concentrations for an extensive period of time.

6. REFERENCES

Alvarez, L. M., P. L. McCarty, and P. V. Roberts. 1989. The effects of sorption on the biotransformation rate of TCE by methanotrophs. Paper presented at the International Symposium *Processes Governing the Movement and Fate of Contaminants in the Subsurface Environment,* Stanford University, Stanford, Calif.

Conrad, S. H., J. L. Wilson, W. Mason, and W. Peplinski. 1988. Observing the transport and fate of petroleum hydrocarbons in soils and in groundwater using flow visualization techniques. In *AAPG Symposium on Environmental Concerns in the Petroleum Industry*, Dec. 22, 1988, Palm Springs, Calif.

Conrad, S. H., J. L. Wilson, W. R. Mason, and W. J. Peplinski. 1992. Visualization of residual organic liquid trapped in aquifers. *Water Resources Research,* 28(2):467-478.

Fleischhauer, H. L., N. Korte, S. Sturm, S. Wagner, and J. M. Sewell. 1986. *Hydrogeologic Site Characterization of the Department of Energy Kansas City Facility: Second Interim Report.* Report No. GJ-40. Bendix Field Engineering Corp., Grand Junction, Colo.

Fleischhauer, H. L., S. Sturm, and M. Sewell. 1987. *Hydrogeologic Site Characterization of Miscellaneous Waste Sites, Contaminant Transport, Modeling Stream Sediment Survey.* Report No. GJ-55. UNC Geotech, Grand Junction, Colo.

Gillham, R. W., and S. F. O'Hannesin. 1992. Metal-catalyzed abiotic degradation of halogenated organic compounds. Paper presented at the 1992 IAH Conference Modern Trends in Hydrogeology, May 10-13, 1992, Hamilton Ontario, Canada.

Johnson, R. L., and J. F. Pankow. 1992. Dissolution of dense chlorinated solvents into groundwater. 2. Source functions for pools of solvent. *Environmental Science and Technology,* 26(5):896.

Kearl, P. M., N. E. Korte, and T. A. Cronk. 1992. Suggested modifications to ground water sampling procedures based on observations from the colloidal borescope. *Ground Water Monitoring Review,* 12(2):155-161.

Kearl, P. M., N. E. Korte, M. E. Stites, and J. L. Baker. 1994. Field comparison of micropurging vs traditional groundwater sampling. *Ground Water Monitoring and Remediation*, 14(4):183.

Kearl, P. M., J. M. Sewell, N. E. Korte, H. L. Fleischhauer, and S. Wagner. 1984. *Preliminary Hydrologic Investigation of the DOE Kansas City Facility.* Rev. 1, Report No. GJ-17. Bendix Field Engineering Corporation, Grand Junction, Colo.

Korte, N. E., P. M. Kearl, H. L. Fleischhauer, and J. M. Sewell. 1985. *Hydrogeologic Characterization of the Department of Energy Kansas City Facility: Interim Report.* Report No. GJ-31. Bendix Field Engineering Corporation, Grand Junction, Colo.

Korte, N. E., and P. M. Kearl. 1990. Plume management: An inexpensive long-term strategy for groundwater contamination at low-risk sites. *Waste Management & Research,* 8:246-248.

Korte, N. E., and P. M. Kearl. 1991. The utility of multiple-completion monitoring wells for describing a solvent plume. *Ground Water Monitoring Review,* 11(2):153.

Madril, M. W., M. R. Meininger, J. M. Sewell, P. R. Engelder, P. M. Kearl, R. J. Zinkl, N. E. Korte, and H. L. Fleischhauer. 1986. *Hydrogeologic Site Characterization of the Department of Energy Kansas City Facility: Hydrogeology and Contaminant Transport Modeling, Tank Farm Engineering, Geophysical Survey.* Report No. GJ-46. Bendix Field Engineering Corporation, Grand Junction, Colo.

Schwille, F. 1988. *Dense Chlorinated Solvents in Porous and Fractured Media.* Lewis Publishers, Chelsea, Mich.

U.S. DOE. 1990. *Groundwater Assessment Plan for the TCE Still Area.* U.S. Department of Energy, Kansas City Plant, Kansas City, Mo.

U.S. DOE. 1992a. *Groundwater Interceptor System Evaluation.* U.S. Department of Energy Albuquerque Operations Office, Environmental Programs Branch, Albuquerque, N.M.

U.S. DOE. 1992b. *Annual Groundwater Monitoring Report for Calendar Year 1991.* U.S. Department of Energy, Kansas City Area Office, Kansas City, Mo.

U.S. DOE. 1993a. *Annual Groundwater Monitoring Report for Calendar Year 1992.* U.S. Department of Energy, Kansas City Plant, Kansas City, Mo.

U.S. DOE. 1993b. *Northeast Area/001 Outfall RCRA Facility Investigation (RFI) Report.* U.S. Department of Energy, Kansas City Plant, Kansas City, Mo.

U.S. DOE. 1993c. *D/26 RCRA Facility Investigation (RFI) Report.* U.S. Department of Energy, Kansas City Plant, Kansas City, Mo.

U.S. DOE. 1993d. *Plating Building RCRA Facility Investigation (RFI) Report.* U.S. Department of Energy, Kansas City Plant, Kansas City, Mo.

U.S. DOE. 1994. *TCE Still Area RCRA Facility Investigation (RFI) Report* (draft). U.S. Department of Energy, Kansas City Plant, Kansas City, Mo.

U.S. EPA. 1992. *Dense Nonaqueous Phase Liquids: A Workshop Summary.* EPA/600/R-92/030. U.S. Environmental Protection Agency, Washington, D.C.

Wilson, J. L. 1992. *Hydraulics of Capture and Plume Manipulation.* National Groundwater Association, Las Vegas Convention Center, Las Vegas, Nev.

Wilson, J. L., and S. H. Conrad. 1984. Is physical displacement of residual hydrocarbons a realistic possibility in aquifer restoration? In *Hydrocarbons and Organic Chemicals in Groundwater,* NWWA/API Conference, Houston, Tex., 274-298.

Wilson, J. L., S. H. Conrad, W. R. Mason, W. Peplinski, and E. Hagen. 1989. *Laboratory Investigation of Residual Liquid Organics from Spills, Leaks, and the Disposal of Hazardous Wastes in Groundwater.* EPA/600/6-90/004. U. S. Environmental Protection Agency.

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