Section 4

Contaminant Fate and Transport

Contaminant distribution data and site physical data can be integrated to create a model of contaminant fate and transport. Numerous physical and chemical factors can influence the transport of contaminants introduced into the environment. Because the vast majority of contaminants appear to have been released in the subsurface at the former disposal basin, and as a result of the soil analyses, migration along airborne pathways is not considered in the site model. The migration routes and influences are limited mainly to fluid flow and chemistry in the vadose zone and saturated zone. Processes and factors that influence the fate and transport can be very different in the two zones. Therefore, this section is divided into a discussion of the fate and transport in the soils (Section 4.1) and the fate and transport in the groundwater (Section 4.2).

Persistence of chemical compounds released to the environment can be a major factor when considering remedial alternatives. Some chemical compounds have a very short half-life and break down into benign components shortly after their release. Other compounds may persist, with very long half-lives. The persistence of chemical compounds in soils and groundwater is discussed in Sections 4.1.1 and 4.1.2. The transport of contaminants is discussed in Sections 4.1.2 and 4.2.2 for vadose and saltwater zones, respectively.

4.1 CONCEPTUAL MODEL OF FATE AND TRANSPORT IN SOIL

Organic compounds introduced into the vadose zone occur in vapor, liquid, and sorbed phases. The concentrations or amounts of each compound in each phase depend on the physical characteristics of the compound and the soil. For example, a compound with a high vapor pressure will tend to have high volatilization rates and high vapor concentrations, and a compound with a low K_{ow} (the log of the octanol/water partition coefficient) will be weakly adsorbed to soil and may be more mobile in the presence of infiltrating water.

Table 4-1 summarizes the chemical and physical properties of the four principal contaminants of concern – 1,2-dibromo-3 chloropropane (DBCP), 1,2-dichloropropane (DCP), 1,2-dibromoethane (EDB), and carbon tetrachloride (CCl_4) at Frontier Fertilizer.

4.1.1 Contaminant Persistence

Contaminant persistence in the environment is an important factor for evaluating remedial alternatives. In some cases, a contaminant (e.g., elemental contaminants such as metals) may not decay at all. Contaminants like the pesticides at Frontier Fertilizer are organic compounds that can decay by various mechanisms in the environment.

The DBCP, DCP, and EDB in the soils at Frontier Fertilizer will decay into base compounds such as chloride, bromine, and other benign compounds by biodegradation, oxidation, and light-enhanced oxidation. Organic compounds can volatilize into soil gas, eventually diffusing into

Table 4-1 Summary of Chemical and Physical Properties of Contaminants of Concern at Frontier Fertilizer

Property	Chemical Name			
	DBCP	DCP	EDB	CCl_4
Molecular Weight	236.36	112.99	187.88	153.8
Boiling Point, °C	196	96.8	131.6	76.7
Melting Point, °C	6	-100	10	-23
Specific Gravity, g/ml (water = 1.0)	2.093	1.16	2.172	1.59
Solubility in Water	1,200 mg/l	2,700 mg/l	3,400 mg/l	800 mg/l
Solubility in Organics	Miscible with oils, isopropyl alcohol, and dichloropropane	Miscible with organic solvents	Miscible with alcohol and ether	Miscible with alcohol, benzene, chloroform, ether, and carbon disulfide
Log K_{ow}	2.43	2.28	4.0	2.64
Vapor Pressure, mm Hg	0.80 (@ 21°C)	42.0 (@ 20°C)	11.0 (@ 25°C)	90.0 (@ 20°C)
Vapor Density	–	3.9	–	5.32
Henry's Law Constant	164	–	43	–

the atmosphere where they are oxidized. Since DBCP and EDB have low vapor pressures, they volatilize very slowly. DCP has a vapor pressure of 42 mm Hg, indicating that it volatilizes more quickly from the soils than DBCP or EDB (see Table 4-1).

Another factor that affects a chemical's persistence is the geologic matrix into which it is released. Open, permeable geologic materials are more conducive to volatilization, whereas the clays and silts in the vadose zone at Frontier Fertilizer can trap the liquid pesticide residues and reduce volatilization rates. The proportion of natural organic material in the vadose zone can also influence the persistence of certain organic compounds, for various reasons. Adsorption occurs when an organic compound is removed from solution and adheres to an organic carbon in the soil matrix. This process, however, can be reversed. Because the infiltrating fluids carry lower concentrations of organic compounds, the previously adsorbed molecules will be desorbed back into solution. In some cases, the pesticide, when it is adsorbed to soil organic carbon, may be consumed by bacteria as a food source.

CCl_4 has a much higher vapor pressure and a lower solubility than DCP, DBCP, and EDB (see Table 4-1) and thus a higher rate of volatilization and a lower degree of dissolution into

infiltrating water. The lack of information regarding a CCl_4 source means that little else can be inferred for the contaminant persistence and migration in the vadose zone.

In summary, the chemicals of concern at the Frontier Fertilizer site are persistent in the environment, especially in the clay and silt in the vadose zone at Frontier Fertilizer. Low volatilization rates and low volumes of recharging water add to the persistence of DBCP, EDB, and DCP in the vadose zone.

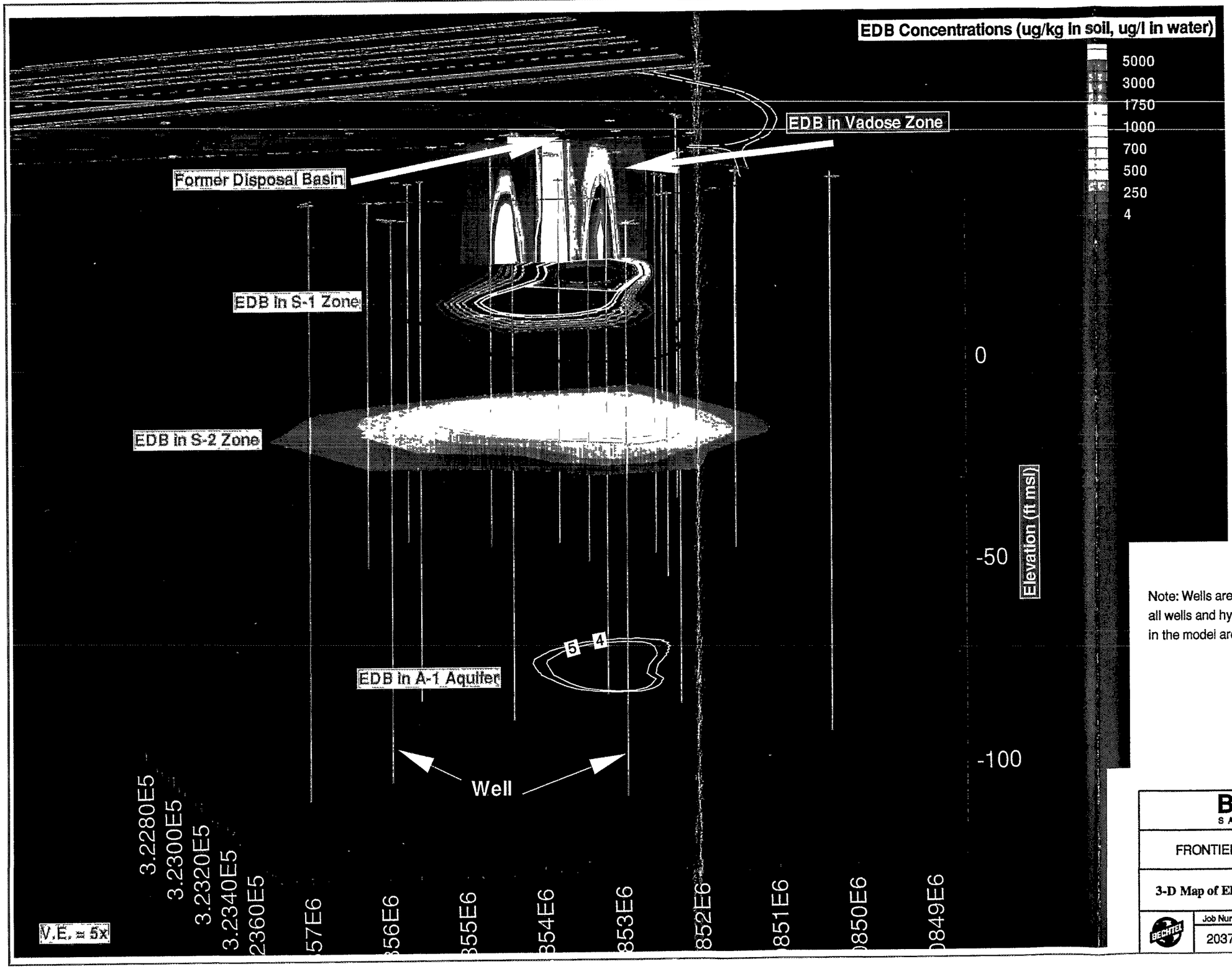
4.1.2 Contaminant Migration

At Frontier Fertilizer, the primary chemicals of concern are strongly adsorbed to organics in soil, they have low vapor pressures (especially DBCP), and they occur as nonpolar liquids, immiscible in water. In general, these properties mean relatively low mobility as a soil gas or as a solute in infiltrating water. However, as discussed in Section 3, the nature of contamination indicates that a dense non-aqueous phase liquid (DNAPL) release may have occurred. A DNAPL can be very mobile in the vadose zone, especially when there is low-volume constant source or a high-volume instantaneous release.

The evidence at the Frontier Fertilizer indicates that the DNAPL release was a low-volume persistent release that accords with site activities of pesticide residue disposal and wastewater disposal in the former disposal basin. These practices have probably led to the frequent release of small volumes of DNAPL over the years, coupled with higher volumes of wastewater containing dissolved pesticides. The migration of low-volume DNAPL releases is characterized by thin, tortuous migration pathways through the vadose zone. Depending on the source, there may be multiple pathways or one single pathway. A pathway may be as thin as a fracture or root hole in a clay bed, or it may be several 10s of feet long horizontally and only several feet downward (Cherry, 1994).

The DNAPL will remain mobile as long as there is a source of DNAPL at the surface or a sufficient driving head to overcome entry pressure (the pressure needed for the DNAPL, as it migrates, to displace air or water from the pores). At the Frontier Fertilizer site, the soil excavation at the former disposal basin removed the primary source of DNAPL, and the remaining DNAPL is most likely a nonmobile residual DNAPL within the deeper vadose zone, beyond the limits of the excavation.

The soil sampling results around the former disposal basin indicated that contaminants migrated vertically along preferential pathways. There appear to be distinct vertical pathways within the vadose zone in the vicinity of the disposal basin, as shown in Figures 4-1, 4-2, and 4-3.



Note: Wells are shown for visual effect only, all wells and hydropunch locations used in the model are not shown in this figure.

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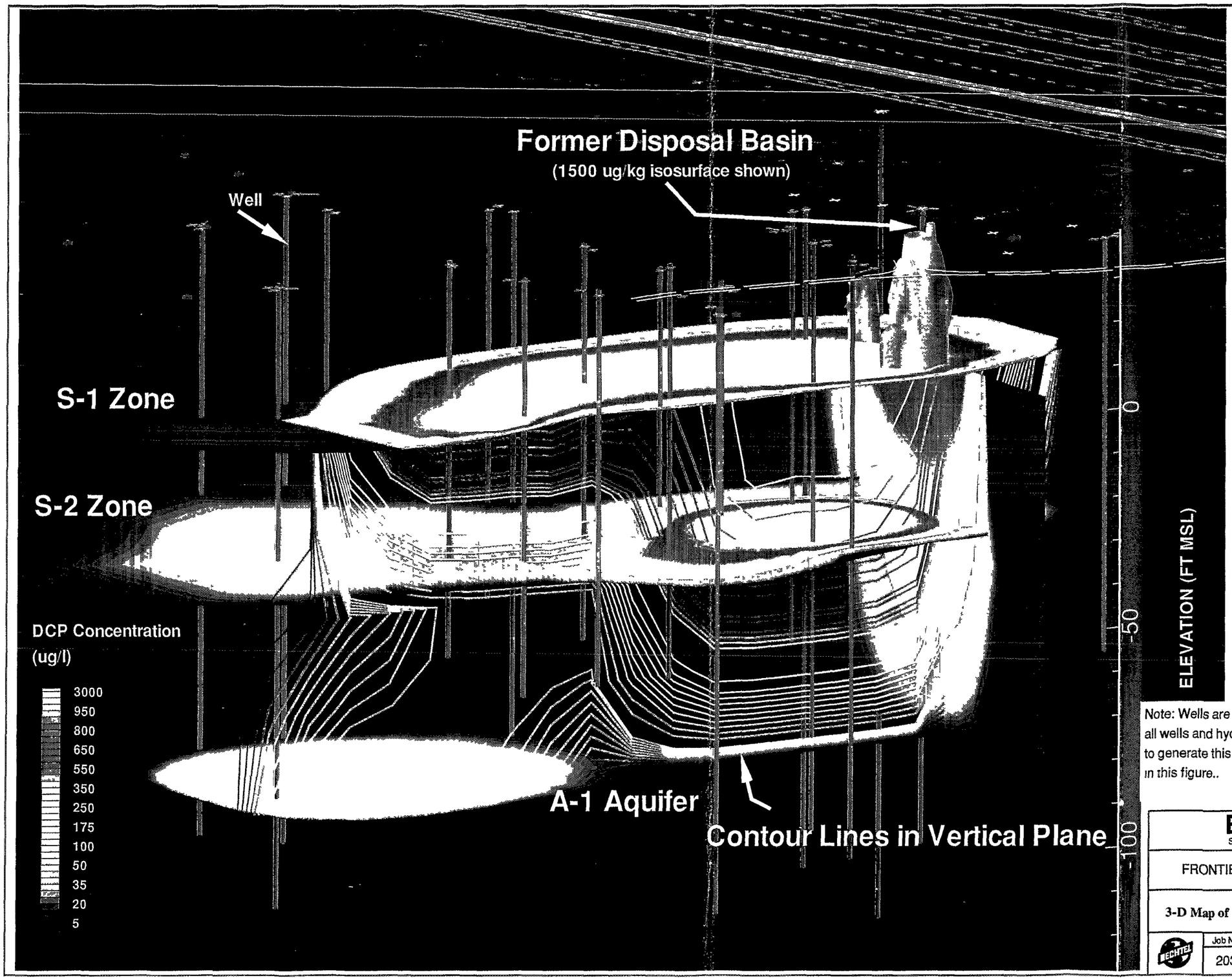
3-D Map of EDB in Groundwater and Soils

Job Number	Drawing No.	Rev.
20376	FIGURE 4-1	A



Note: Wells are shown for visual effect only, all wells and hydropunch locations used to generate this model are not shown in this figure..

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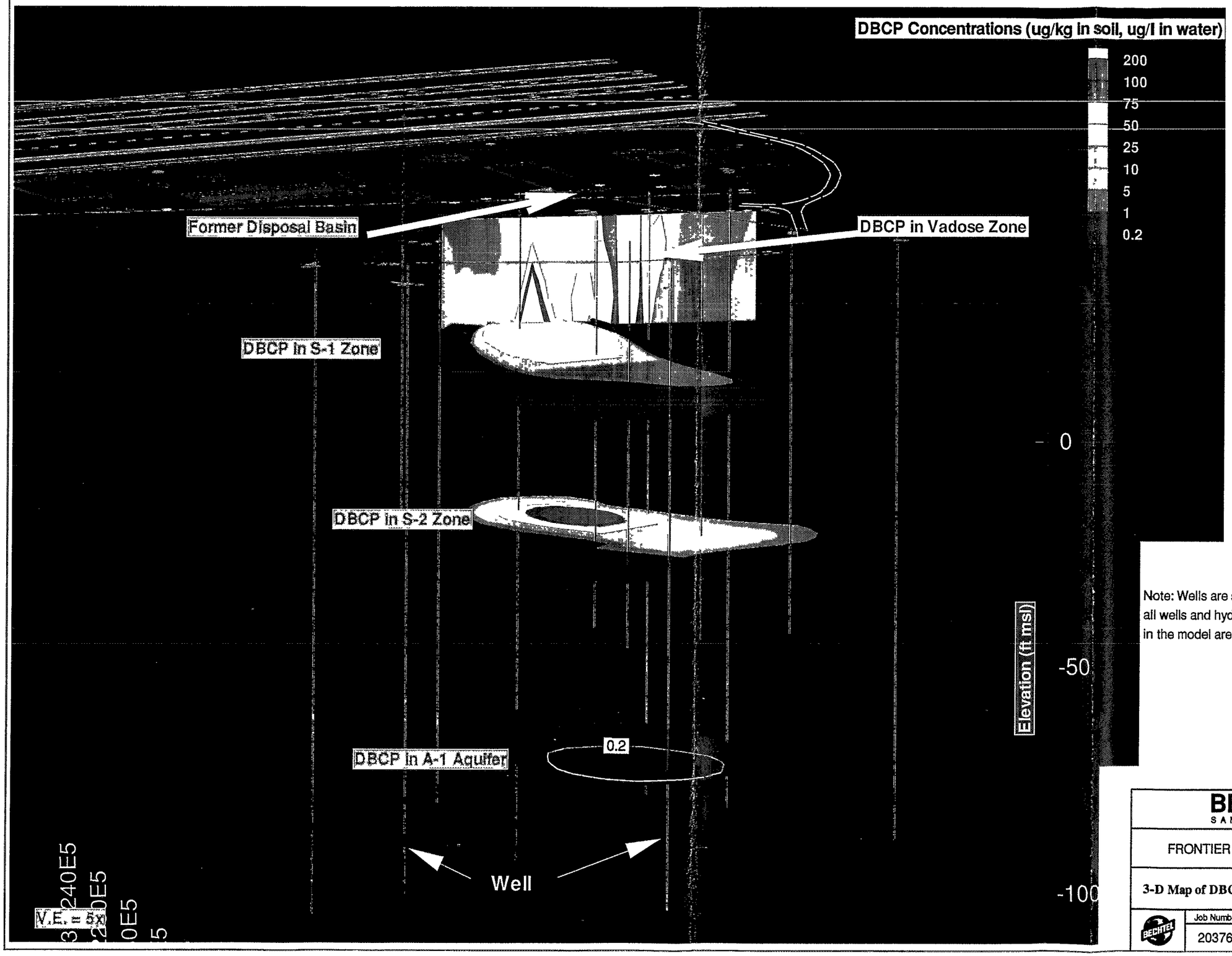
3-D Map of DCP in Groundwater and Soils

Job Number	Drawing No	Rev.
20376	FIGURE 4-2	A



Note: Wells are shown for visual effect only, all wells and hydropunch locations used in the model are not shown in this figure.

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3-D Map of DBCP in Groundwater and Soils

Job Number	Drawing No.	Rev.
20376	FIGURE 4-3	A

There is some indication from groundwater data and deeper soils data that DNAPL migrated downward and north or northwest from the former disposal basin. As illustrated on Figures 3-1 through 3-8, EDB and DCP contamination spreads north from the area of the disposal basin with increasing depth. For example, wells MW-4A and MW-4B contain much lower concentrations of pesticides than wells MW-7A, MW-7B, and MW-7C. The MW-4 wells are located the same horizontal distance from the basin as the MW-7 wells, but the much lower concentrations in the MW-4 wells mean that a DNAPL did not migrate into the saturated zone near these wells (Figures 3-22, 3-24, 3-26, and 3-28).

4.2 CONCEPTUAL MODEL OF FATE AND TRANSPORT IN GROUNDWATER

DBCP, DCP, and EDB are the primary focus of the discussion below. Since the source of carbon tetrachloride is unknown and does not appear to be the former disposal basin, this compound is discussed only where relevant.

Organic compounds are introduced into the groundwater from one or more of the following:

- A non-aqueous phase liquid (NAPL) or DNAPL migrating into the groundwater
- Contaminated water infiltrating through the vadose zone to the groundwater
- As soil gas impinging on the groundwater surface and dissolving into the groundwater

It appears that the S-1 and S-2 zones are affected by a residual non-mobile DNAPL, whereas the source of contamination in the A-1 aquifer is the transport of dissolved phase pesticides from the S-2 zone into the A-1 aquifer. This transport appears to occur in the region north of the disposal basin where the aquitard between the S-2 and A-1 pinches out and the two permeable zones coalesce. Downward gradients induced by seasonal pumping from the A-1 provide additional transport of dissolved pesticides into the A-1 aquifer.

4.2.1 Fate and Transport of DBCP, DCP, and EDB

Of the three mechanisms listed above, the most efficient, in terms of transfer of contaminant mass to the groundwater, is NAPL migration. Mass transfer of dissolved contaminants typically requires large volumes of infiltrating water because of the relatively low solubilities of the organic compounds. Transfer of contaminant mass from soil gas is an inefficient mechanism (Rivett and Cherry, 1991).

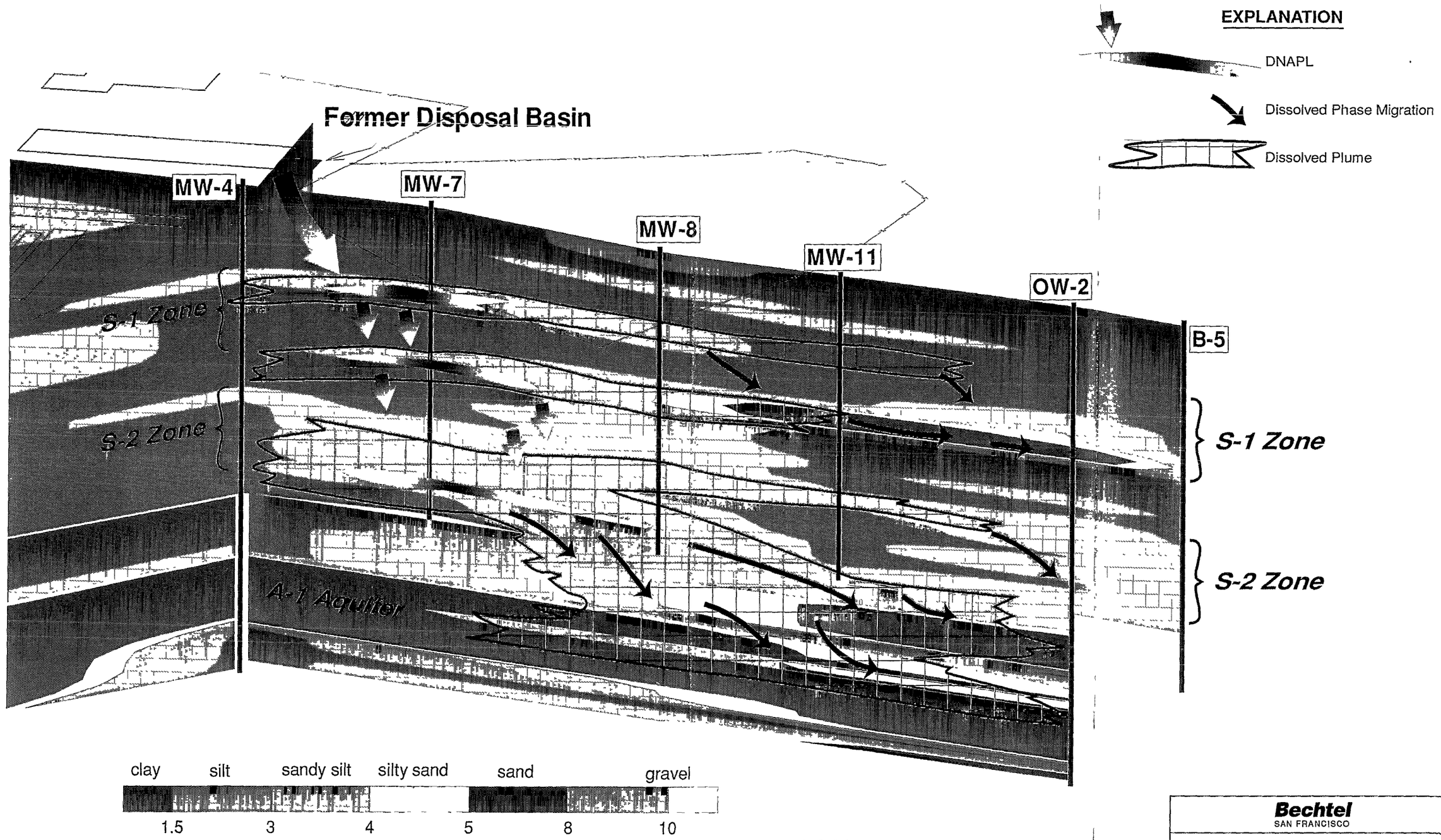
At the Frontier Fertilizer site, the available information indicates that contamination was potentially released as a DNAPL. It is likely that some pesticides were placed in the former disposal pit as a NAPL, or undissolved in the rinsewater. EDB, DBCP, and DCP have a specific

gravity greater than 1.0, making them a DNAPL in pure or mixed liquids. The rinsewater also infiltrated into the vadose zone, transporting dissolved pesticides.

DNAPL appears to have reached the S-2 zone, given the high concentration of EDB and DCP detected in wells MW-7C and MW-13B. The concentrations of these chemicals are at least as high as concentrations detected in the S-1 zone immediately overlying this area (Figures 4-1 and 4-2). Because there is no vertical concentration gradient and because the concentrations in the S-1 and S-2 zones are about 1 percent of the respective saturated concentrations of EDB and DCP (Table 3-31), there is more evidence that the initial release was a DNAPL.

The data indicate that the DNAPL did not enter the A-1 aquifer. DNAPL migration into the A-1 aquifer is not indicated by the groundwater data. DNAPL migration may have halted within the S-2 zone due to closure of the former disposal basin and removal of the DNAPL source in the vadose zone. However, DNAPL in the saturated zone has the potential to remain mobile or to remobilize under certain conditions such as large changes in hydraulic gradients or drilling through a DNAPL pool. It appears that the contaminants are introduced into the A-1 aquifer in the region north of MW-7D, where the aquitard between the S-2 zone and the A-1 aquifer pinches out. The downward gradient between these zones, coupled with a much greater degree of hydraulic interconnection between the S-2 zone and A-1 aquifer in this area, provides the transport pathway for dissolved contaminants to enter the A-1 aquifer (Figure 4-4).

Once the dissolved contaminants have entered the A-1 aquifer, there appears to be significant dilution due to the very high groundwater flux through the A-1 aquifer. This results in concentrations that are much lower in the A-1 aquifer than in the S-2 zone, and dilution also limits the lateral extent of the plume, which is diluted to concentrations slightly above the detection limits within 400 feet of the highest concentrations (Figures 4-1 and 4-2). This is also illustrated in Figures 3-26 and 3-30, where EDB occurs in OW-2C at a concentration of 8.1 µg/l, the highest concentration in an A-1 aquifer well. This concentration is more than 1,000 times lower than the highest concentrations in the S-1 and S-2 zones. In the A-1 aquifer, concentrations of 0.036 µg/l and 0.096 µg/l were detected in wells OW-4C and MW-9C, less than 400 feet downgradient from OW-2C. As shown in Figures 3-18, 3-19, and 3-20, the flow direction in the A-1 aquifer is to the south; however, previous data collected by other investigators have shown seasonal northern flow directions in the A-1 aquifer. Based on this information, wells OW-4C and MW-9C are downgradient from OW-2C prior to beginning operation of the groundwater remediation system.



NOTE:

1) Extent of DNAPL Zone is not well-constrained by data. This figure is a conceptual representation only.

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Conceptual Fate and Transport Model

Job Number	Drawing No.	Rev.
20376	FIGURE 4-4	A

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6/10/96

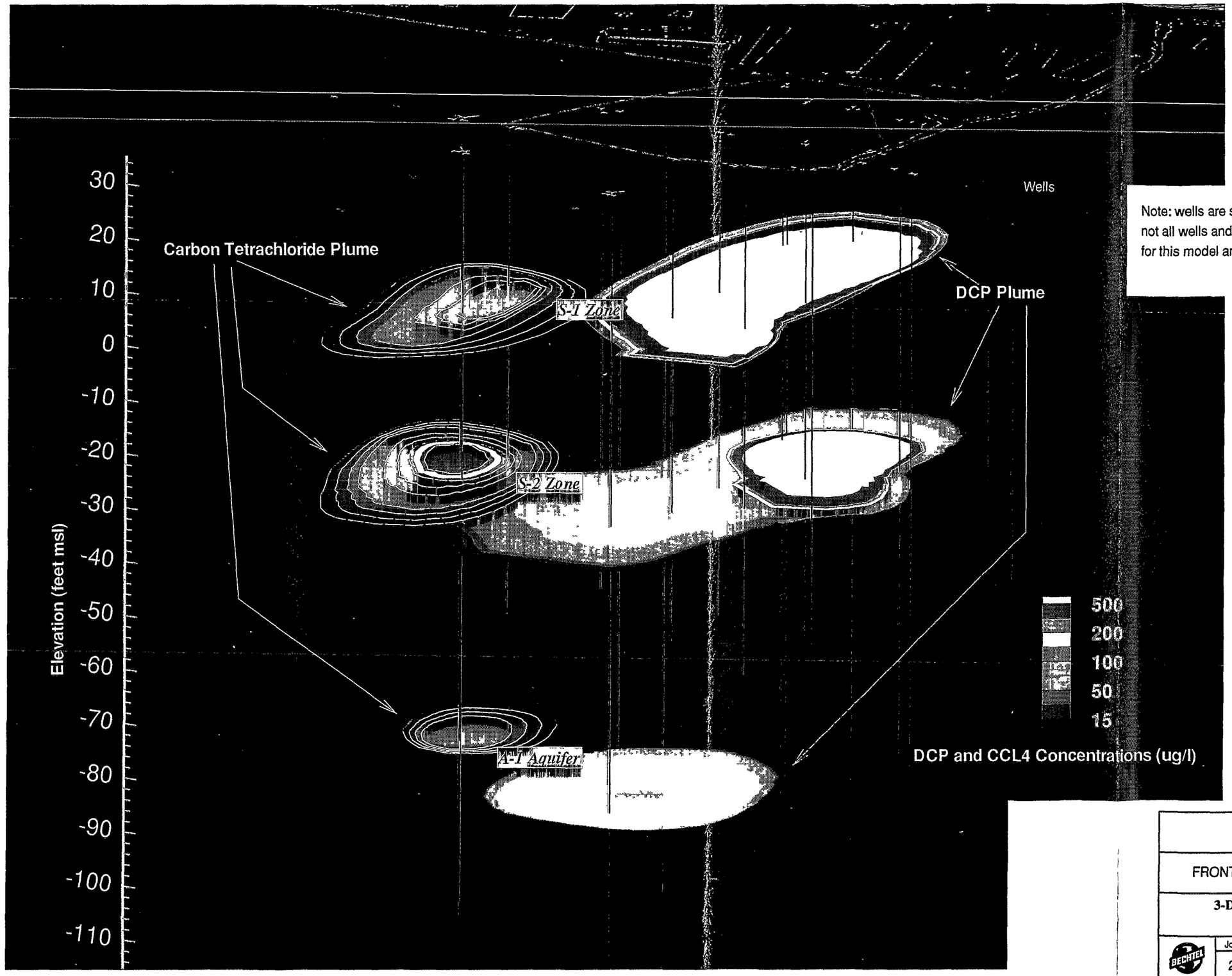
Slightly higher concentrations ranging from 0.28 to 1.6 µg/l were detected in wells MW-13C, X-1C, and MW-7D, located near the former disposal basin. These concentrations may be due to direct downward transport of dissolved EDB between the S-2 zone and the A-1 aquifer near the DNAPL zone, or they may due to southward transport of dissolved phase EDB introduced into the A-1 aquifer to the north, where the S-2 zone and the A-1 aquifer are interconnected. Regardless, these concentrations in the A-1 aquifer indicate marked decreases in EDB and do not indicate DNAPL migration to the A-1 aquifer.

The fate of these contaminants in the environment depends on the complex physicochemical and biochemical interactions within the saturated zones. The DNAPL's fate is primarily dissolution and diffusion into groundwater. Once dissolved into groundwater, the contaminants are degraded biologically, adsorbed onto organic particles in the geologic material, where they may eventually be broken down or desorbed, volatilized into the soil gas (in the S-1 zone), diluted, or discharged from the aquifer system at pumping wells. The most likely ultimate fate of these compounds is biodegradation and discharge to the surface via pumping wells. Once discharged to the surface, these compounds volatilize and/or photodegrade. The majority of local extraction wells screened in the A-1 aquifer are irrigation wells, not domestic and municipal drinking water wells.

In summary, it appears there was a DNAPL release from the former disposal basin that migrated through the vadose zone, into the S-1 zone, through the clay between the S-1 and S-2 zones and then into the S-2 zone. The data do not indicate a DNAPL migration beyond the S-2 zone. Under recent conditions, the transport of DBCP, DCP, and EDB in the groundwater occurs as groundwater flows past the residual, nonmobile DNAPL. These compounds are dissolved into the groundwater and transported by advection laterally to the north. In the S-2 zone, the underlying aquitard pinches out and there is hydraulic interconnection between the S-2 zone and the A-1 aquifer. During summer when irrigation pumping occurs, there is a strong downward gradient and vertical migration of dissolved pesticides occurs. In the S-1 zone, the pesticides are diluted, adsorbed, biodegraded, or volatilized to soil gas and then to the atmosphere. In the S-2 zone, the pesticides are adsorbed, biodegraded, diluted, or migrate vertically into the A-1 aquifer. In the A-1 aquifer, these compounds are attenuated or diluted because of the relatively high fluxes of groundwater in this aquifer.

4.2.2 Fate and Transport of Carbon Tetrachloride

As described in Section 3, the nature and extent of carbon tetrachloride in the groundwater is very different from the nature and extent of EDB, DBCP, and DCP. Carbon tetrachloride seems to have a source that differs from that of the other three pesticides (Figure 4-5). Additional characterization work is planned to delineate the carbon tetrachloride plume and to identify the source. In general, the same factors influencing the fate and transport of DBCP, DCP, and EDB will affect carbon tetrachloride.



Note: wells are shown for visual effect only, not all wells and hydropunch locations used for this model are shown in figure.

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3-D Distribution of DCP and Carbon Tetrachloride

Job Number	Drawing No	Rev.
20376	FIGURE 4-5	A

4.3 EFFECTS OF THE INTERIM REMEDIATION SYSTEM

A groundwater pump-and-treat system has been installed at Frontier Fertilizer to prevent further migration of dissolved contaminants. The system consists of 17 pumping wells, 9 injection wells, and a granular-activated carbon (GAC) for water treatment. The pumping wells are all screened in either the S-1 or S-2 zones. No pumping wells are screened in the A-1 zone. As of April 9, 1996, the system was extracting a combined flow of 50 gallons per minute (gpm) (slightly less than 3 gpm per extraction well). After treatment, 15 gpm was injected and 35 gpm was discharged to the sanitary sewer.

Figures 4-6, 4-7, and 4-8 are contour plots of the hydraulic head in each of the three saturated zones. The data used for these plots were collected from May 6 through May 9, 1996. The system was operating while water levels were measured. The heads in the S-1 zone show a steep horizontal gradient between the pumping wells north of the former disposal basin and the injection wells south of the basin. In the S-2 zone, there is a similar pattern. Because the S-1 and S-2 zones have similar hydraulic properties, the former will have a steeper mound owing to the higher flux of injected water.

The contour plots were prepared using water levels measured in the pumping and extraction wells. No corrections were applied to the levels in these wells to account for head loss due to well inefficiency. Therefore, the low heads in some extraction wells will be exaggerated, and the groundwater mounding associated with injection wells will also be exaggerated. Both the cone of depression from pumping and the mounding from injection are likely to be less pronounced than what is shown in these figures. Nonetheless, the contour patterns will be similar, even if heads are corrected for well efficiency.

Another line of evidence that illustrates the effectiveness of the remediation system is a capture zone calculation using the combined flow rates and transmissivities of the S-1 and S-2 zones. The capture zone is expressed as the following equation:

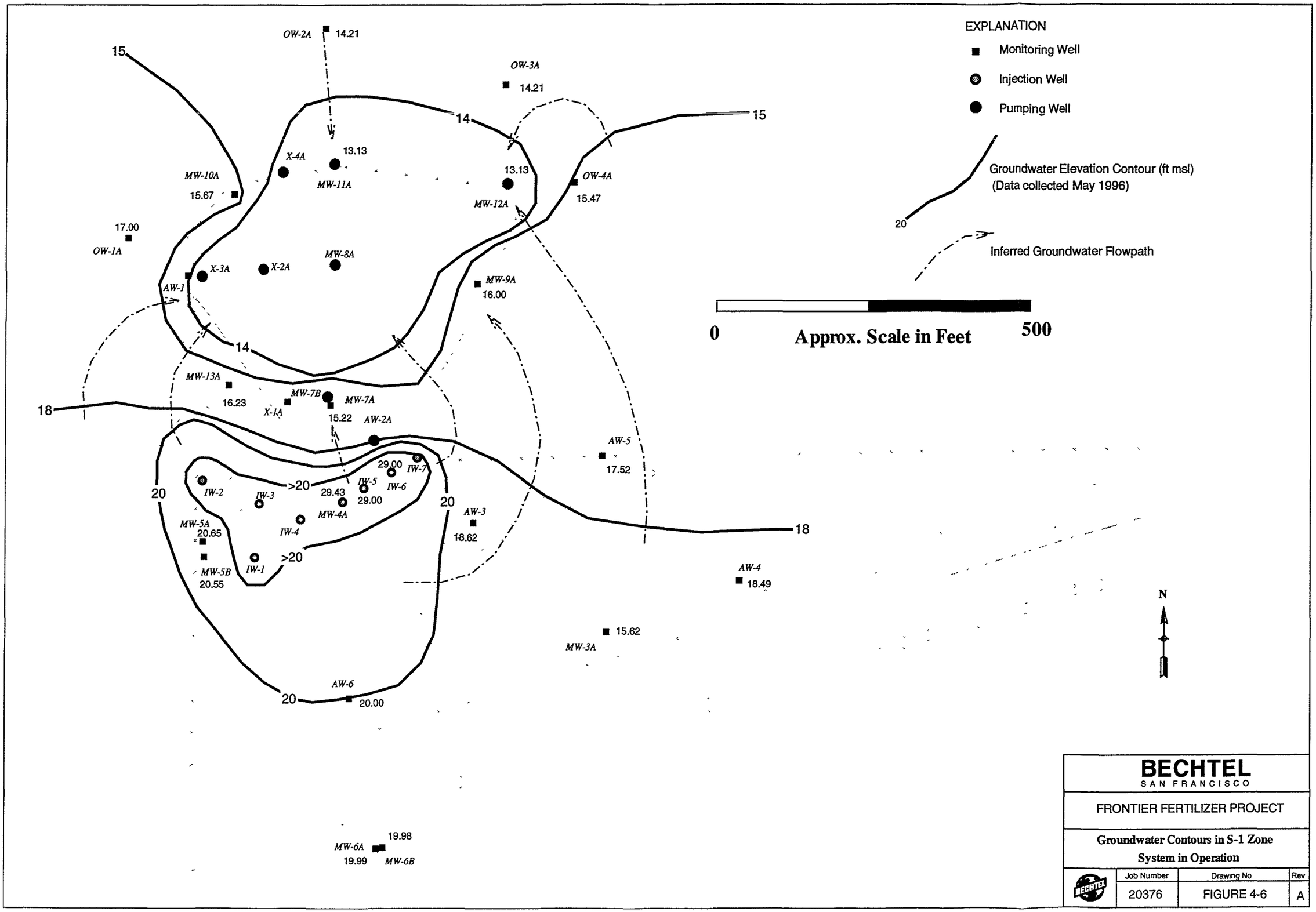
$$CZ = Q/Ti$$

where

Q = flow rate in ft^3/day

T = transmissivity in ft^2/day

i = average horizontal gradient across the site



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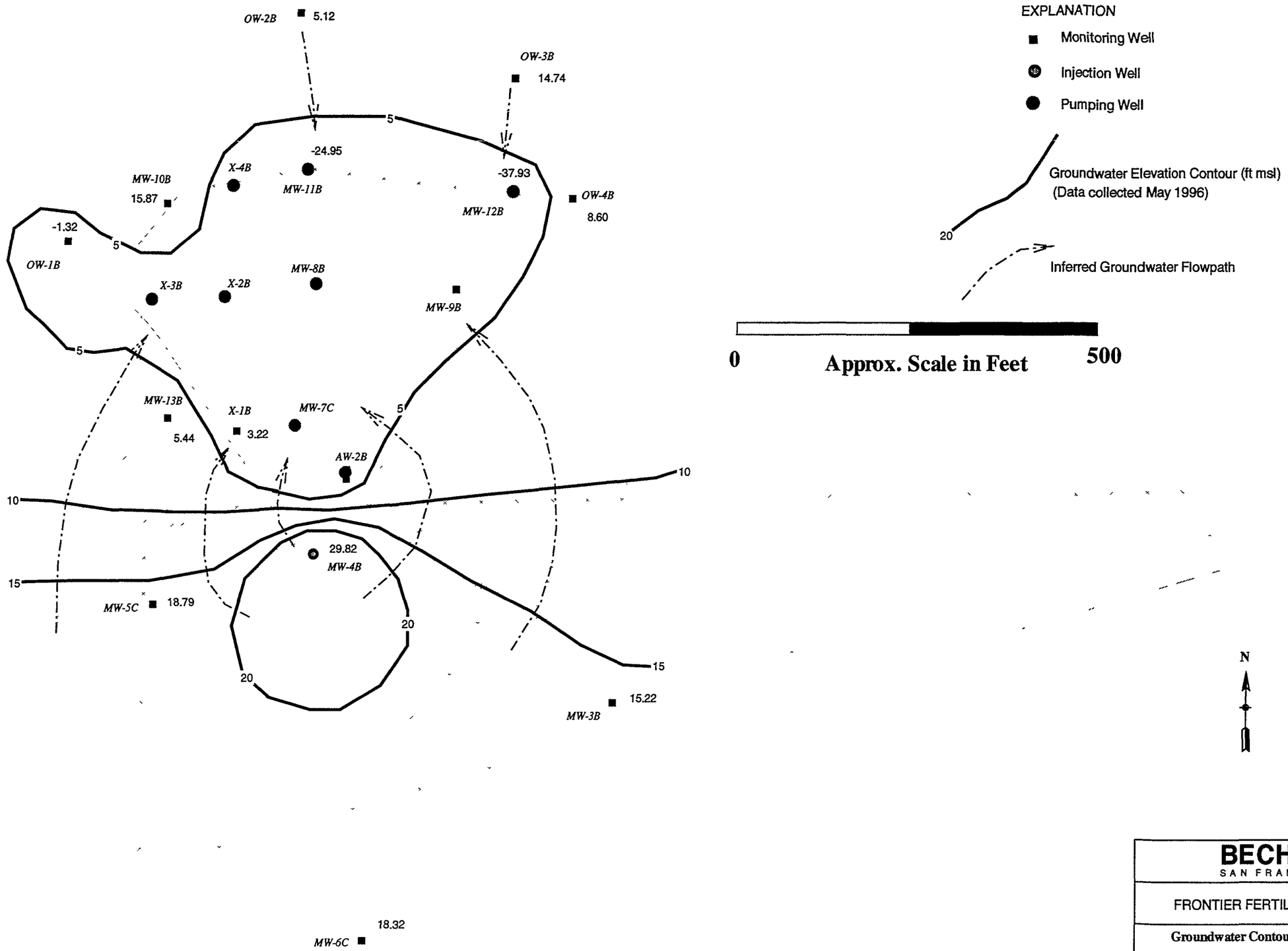
Groundwater Contours in S-1 Zone
System in Operation

Job Number	Drawing No	Rev
20376	FIGURE 4-6	A



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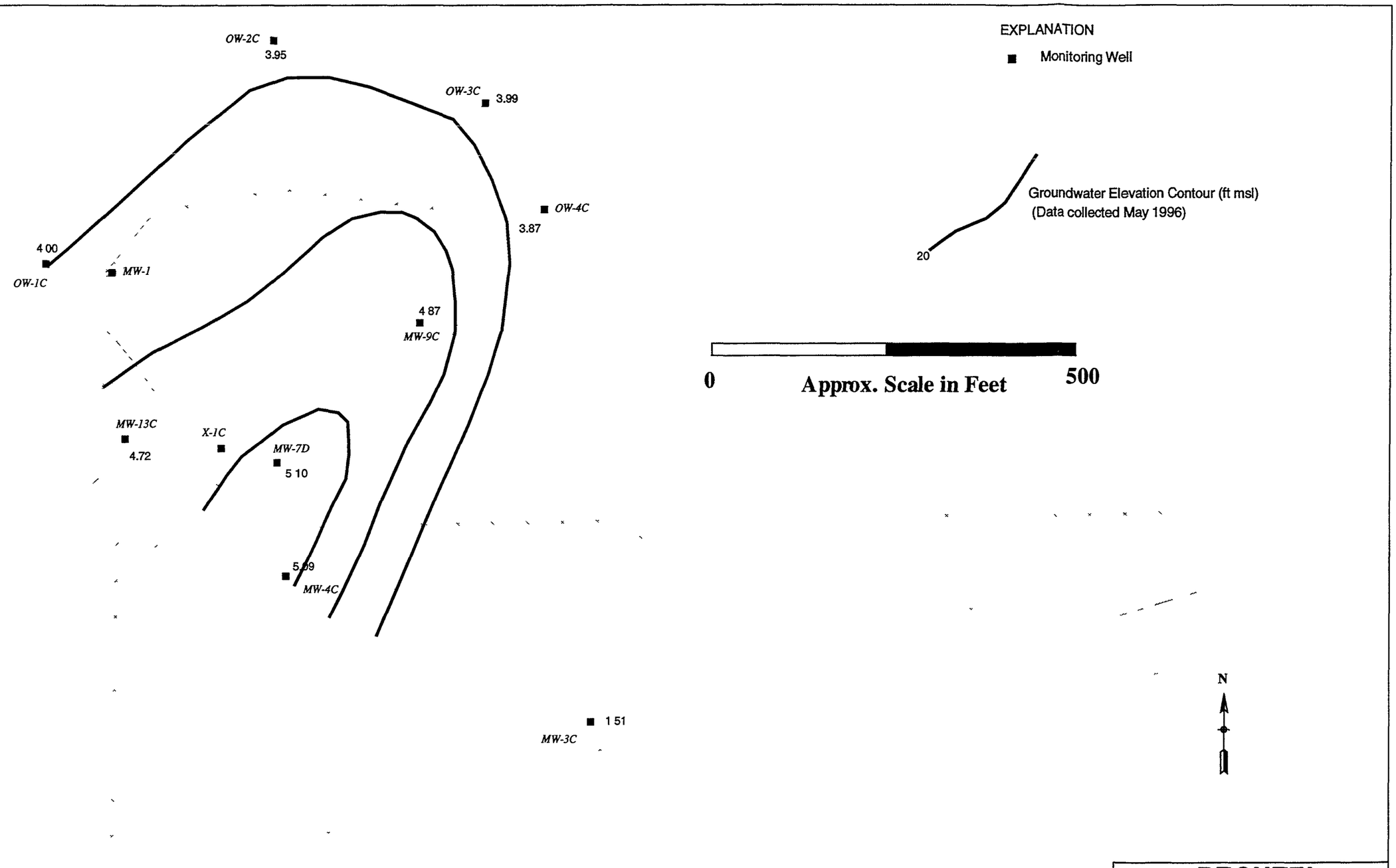
Groundwater Contours in S-2 Zone System in Operation

Job Number	Drawing No	Rev
20376	FIGURE 4-7	A



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Groundwater Contours in A-1 Aquifer System in Operation

Job Number	Drawing No	Rev
20376	FIGURE 4-8	A

Using the flow rates provided by the treatment system operator,

$Q = 9{,}626\ ft^3/day$ (50 gpm)

$T = 413\ ft^2/day$ (combined S-1 and S-2 average transmissivity)

$i = 0.005$

Recall that the groundwater is treated, then 15 gpm is injected and 35 gpm is discharged to the sanitary sewer. This means that the capture zone calculation should be based on the net removal (35 gpm) rather than the total combined flow rate of 50 gpm. A Q of 35 gpm or 6,740 ft^3/day was used in the calculation.

$CZ = 6{,}740/0.005 \times 413 = 3{,}263$ feet

Another way to view a capture zone is by the aquifer discharge equation:

$Q = K \times i \times A$

where Q is the discharge across an aquifer with a cross-sectional area, A, under gradient, i. Area is aquifer thickness, b, times the width of the aquifer section. Thus,

$A = b \times \text{width}$ and,

$Q = K \times i \times (b \times \text{width})$.

If this last equation is solved for width, the result is the capture zone equation:

width (or CZ) = $Q / K \times b \times I$ where

$K \times b$ = Transmissivity (T)

The capture zone is the width of the aquifer that is needed to supply the necessary flow to the wellfield.

In other words, the 17 extraction wells at the Frontier Fertilizer site require a 3,263-foot-wide section of the S-1 and S-2 zones to supply the combined discharge of 35 gpm. The capture zone narrows slightly at the wellfield, but accounting for this in the calculation is not critical.

This capture zone represents average conditions for the S-1 and S-2 zones and could vary considerably in either zone if flow rates in individual wells are highly variable. Another factor that may have a significant influence on the capture zones is the distribution of the transmissivity. Higher transmissivity zones may significantly reduce the capture zones. Another factor that may have a significant impact on the capture zones is the vertical hydraulic conductivity. Although this term is not accounted for in the capture zone equation, the vertical flow components will likely influence the horizontal capture zones estimated by this analysis. Strong downward flow from the

S-2 to the A-1 aquifer will increase the horizontal capture zone estimates while upward flow components will reduce the horizontal capture zones.

However, the calculated capture zone is on the order of the capture zone that can be projected from groundwater flow paths plotted from contours. The plotted capture zone and the calculated capture zone both encompass the region where groundwater is contaminated by DBCP, DCP, EDB, and carbon tetrachloride north of the former disposal basin.

EDB concentrations in the extracted groundwater ranged from 460 µg/l to 2,300 µg/l; DBCP concentrations ranged from 4 to 100 µg/l; DCP concentrations ranged from 2,000 to 6,600 µg/; and carbon tetrachloride was detected only once, at a concentration of 5 µg/l. Reports from the treatment system operator indicate that the system's flow rate was started at about 28 gpm in July 1995, and gradually increased to 50 gpm. Given these flow rates and the influent concentrations of EDB, DBCP, and DCP, a cumulative recovery of over 250 kilograms can be estimated for the period from July 1995 through February 1996, as shown in Figure 4-9.

In summary, under the conditions reported for April and May 1996, the data and analyses indicate that the remediation system has established hydraulic containment of the plumes within the S-1 and S-2 zones. However, there is some uncertainty regarding the degree of hydraulic containment achieved by the remediation system. Some of the uncertainty will be addressed by collecting additional data at the site; however, it will not be possible to dispel all the uncertainty regarding hydraulic containment of the plumes. The steepened horizontal gradient beneath the former disposal basin will probably increase the flux of groundwater through the contaminated portions of the S-1 and S-2 zones.

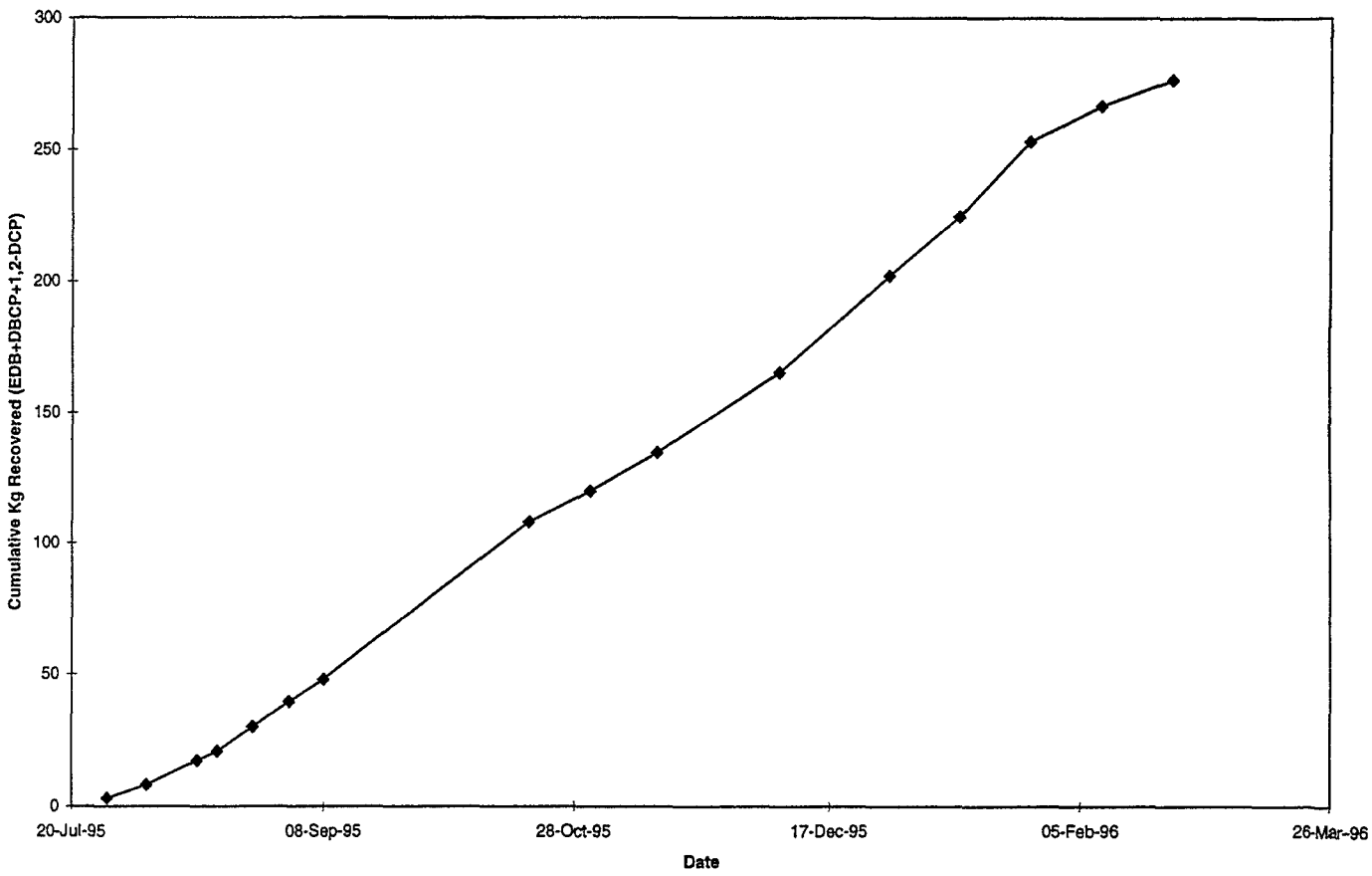

Figure 4-9 Pesticide Recovery Rates

Section 5

Conclusions and Recommendations

5.1 CONCLUSIONS

The Frontier Fertilizer site now has a fairly complete remedial investigation (RI) database to provide a reasonable assessment of the nature and extent of contamination, and the resulting fate and transport of these contaminants. The analyses performed indicate that preliminary remediation goals (PRGs) are exceeded in soils and that maximum contaminant levels (MCLs) are exceeded in groundwater for a variety of organic compounds. The conclusions drawn from the data collection and analyses are given below.

5.1.1 Data Quality

An evaluation of the usability of analytical results obtained during and prior to the remedial investigation was conducted. This evaluation included:

- Usability of non-detect results
- Field quality control (QC) analytical results
- Data validation results

The effect of elevated sample quantitation limits (SQLs) on data quality was evaluated. To perform this assessment the specific affected sample locations were identified. There is no risk of determining a contaminant is not present when in fact it is if a sample location with an elevated SQL has other results that are greater than the applicable PRG or MCL. The results from sample locations with elevated SQLs, but without other results that are greater than the applicable PRG or MCL, were evaluated. In general, non-detect results with elevated SQLs did not affect the usability of the data from impacted sample locations.

Three types of field QC samples were collected and analyzed during the remedial investigation. Field duplicates were evaluated as part of data validation and are discussed below. A review of equipment rinsate blank results indicated that there were no detected results that would require a SQL to be adjusted above the PRG or MCL for an analyte. As expected, the relative percent difference between split samples varied widely; however, in all cases examined, both splits detected the same compounds.

Because a significant portion of all data collected has been validated, the results of the data validation are considered representative of the data usability of the entire data set. Thus, the quality of validated results can be extrapolated to the entire data set. The results of data validation indicate that, with rare exceptions, the data are usable for the purposes for which they were collected.

It was found that all analytical results, other than those rejected and identified with an "R" qualifier flag (less than 1 percent of the data) were usable and would not result in concluding

contamination is not present when it is present. In summary, data are of sufficient quality to address all data quality objectives (DQOs).

5.1.2 Soils

- Contaminated soil has not been transported off site by wind or surface water runoff.
- Soils in the immediate vicinity of the former disposal basin contain levels of contaminants that may not be above RCRA hazardous levels.
- Soils beneath and adjacent to the former disposal basin are contaminated with pesticides to depths corresponding, at a minimum, to the water table at a depth of 32 feet bgs.
- The lateral extent of these contaminated soils has been delineated.
- Other possible sources of contaminants were investigated but none were found.
- Background soils contained detectable concentrations of several pesticides.
- Contaminant levels in soils are indicative of a dense-aqueous phase liquid (DNAPL) release. The highest levels of 1,2-dibromoethane (EDB) and 1,2-dichloropropane (DCP) were detected in soils near the former disposal basin.
- DNAPL migration probably extended beyond the water table, and into the S-2 water-bearing zone.
- Site surface soils are not generally contaminated with pesticides at concentrations above PRGs.

5.1.3 Groundwater

- Groundwater occurs in three water-bearing zones. From shallowest to deepest, they are the S-1 zone, the S-2 zone, and the A-1 aquifer. The S-1 and S-2 zones are silty sand lenses surrounded by a clay and silt material. The A-1 aquifer is a more regionally extensive gravel and sand aquifer with one to two orders of magnitude greater transmissivity than that of the shallower sand zones. The site hydrogeology is a 3-dimensional flow system. The flow system exhibits a horizontal or lateral anisotropy, therefore S-1 and S-2 sands and the A-1 aquifer are valid representations of site conditions. However, there are significant vertical flow components that are recognized and integrated into the conceptual model.
- There is an areally extensive clay aquitard between the S-1 and S-2 zones. Although this clay appears to be extensive, there may be localized regions of interconnection between the S-1 and S-2 zones. The aquitard separating the S-2 zone and the A-1 aquifer pinches out to the north. There is evidence from the seasonal water level

changes and the geologic data that the S-2 zone and A-1 aquifer are hydraulically interconnected in this area.

- Groundwater contamination was detected at high levels locally in the S-1 and S-2 zones and at much lower levels in the A-1 aquifer.
- The highest concentrations of EDB, 1,2-dibromo-3-chloropropane (DBCP), and DCP were detected in the S-1 and S-2 zone wells located immediately downgradient from the former disposal basin.
- Contaminant levels in the S-1 and S-2 zones indicate a localized presence of DNAPL. Although the DNAPL may no longer be mobile, it does appear to have migrated into the S-2 zone around wells MW-7C and MW-13B.
- Dissolved phase contaminants enter the A-1 aquifer where the intervening aquitard pinches out, and the downward gradients between the A-1 aquifer and S-2 zone induce migration of groundwater from the S-2 into the A-1 aquifer. Because of the low concentrations of DCP, EDB, and DBCP and the limited areal extent of these compounds in the A-1 aquifer, there was no indication of a DNAPL in the A-1 aquifer.
- Carbon tetrachloride was detected at concentrations above the MCL in the S-1, S-2, and A-1 zones. The plume configuration is markedly different from the pesticide plume configuration, indicating the carbon tetrachloride source is not the former disposal basin. Soil and groundwater data do not indicate the source for the carbon tetrachloride.
- Background wells, located across I-80 and hydraulically upgradient from the site, contained tetrachloroethene (PCE) and other organic compounds at detectable concentrations. During one sampling event, PCE concentrations were above the MCL (5.0 μg/l) in two upgradient wells.

5.1.4 Treatment System

Field data and a simple analytical model indicate that the extraction system has achieved hydraulic control of the groundwater plumes in the S-1 and S-2 zones. Although there are some data gaps associated with this conclusion, several lines of evidence point out that hydraulic control has been achieved. Future work will address these data gaps and reduce uncertainties associated with the degree of hydraulic containment established by the remediation system with emphasis on field data collection rather than modeling. This conclusion is based on water levels measured while the system was operating, a capture zone estimate that used the aquifer parameters measured by others, and the combined flow rate from the 17 pumping wells. The estimated capture zone in the S-1 and S-2 zones is approximately 3,260 feet wide. This capture zone should be sufficient to control further migration of the dissolved plume and provide control of the source area. Although the capture zone was calculated using simplifying assumptions, it is supported by the observed

heads in the wellfield. Approximately 250 kg of dissolved pesticides were recovered between July 1995 and February 1996.

5.2 RECOMMENDATIONS

The occurrence of a potential DNAPL zone within the S-1 and S-2 zones and the overlying vadose zone indicates that options for cleanup are limited. Alternatively, the strategy may focus on containment rather than cleanup, given the costs of available cleanup alternatives. The following recommendations are made:

- Continue groundwater monitoring at the site using selected wells on a quarterly basis, and monitoring water levels in all wells every quarter.
- Resurvey top-of-casing elevations for the MW-3, MW-8, and MW-11 well clusters and for well MW-7A.
- Establish a detailed system operation database to track and monitor system performance. This database will permit rapid reporting of system data for evaluating performance and will also serve as an operational log for the system, recording maintenance operations, downtime, and other events. The database will ultimately be used to enhance system performance and reliability, reduce the monitoring effort, and lower maintenance costs.
- Delineate CCl_4 in soil and groundwater. This has been requested by EPA, and further work will be conducted.
- Assess the potential for contaminant migration into the A-1 aquifer along monitoring well screens installed in the S-2 zone. Hydrographs indicate some interconnection exists, and downward migration may be enhanced by S-2 well screens. Abandon wells MW-7C, MW-13B, and OW-2B that show potential interconnections with the A-1 aquifer.

Confirming the presence of a DNAPL in the saturated zone poses a challenge and can risk mobilizing the contaminants. There are some methods that can be employed without additional risks associated with drilling through a potential DNAPL zone. First, the bottom sumps of the existing wells may act as collectors for DNAPL, assuming the well is screen across a mobile DNAPL zone. These sumps can be sampled using stainless steel bailers and decanting the liquid and sediment into a clear glass container with dye that turns red in the presence of DNAPLs. If the dye turns color, this will confirm the presence of DNAPL.

Inferential data can be collected by densely spaced discrete level sampling in an existing well located near the presumed DNAPL zone. Discrete level sampling can collect samples on 3-inch intervals along the entire well screen, if needed. A high-resolution vertical profile of contaminant

distribution can be made, and if peak concentrations indicate the groundwater is saturated with respect to a multi-compound DNAPL, then this will confirm the presence of DNAPL.

Alternatively, one to four borings can be drilled into the S-1 zone with continuous cores collected during drilling. The recovered cores can be logged and tested for DNAPLs. Testing can be done visually, with the shaker dye test or using ultra-violet light. Recovery of a DNAPL sample will permit testing to ascertain the composition and properties of the DNAPL.

Although the techniques exist to confirm the presence of DNAPL, the result of an investigation may not be a physical sample of DNAPL. Typically, the result of such an investigation is more data that strongly indicate the presence of a DNAPL. Therefore, the need for DNAPL confirmation and characterization must be weighed against the cost and risk.