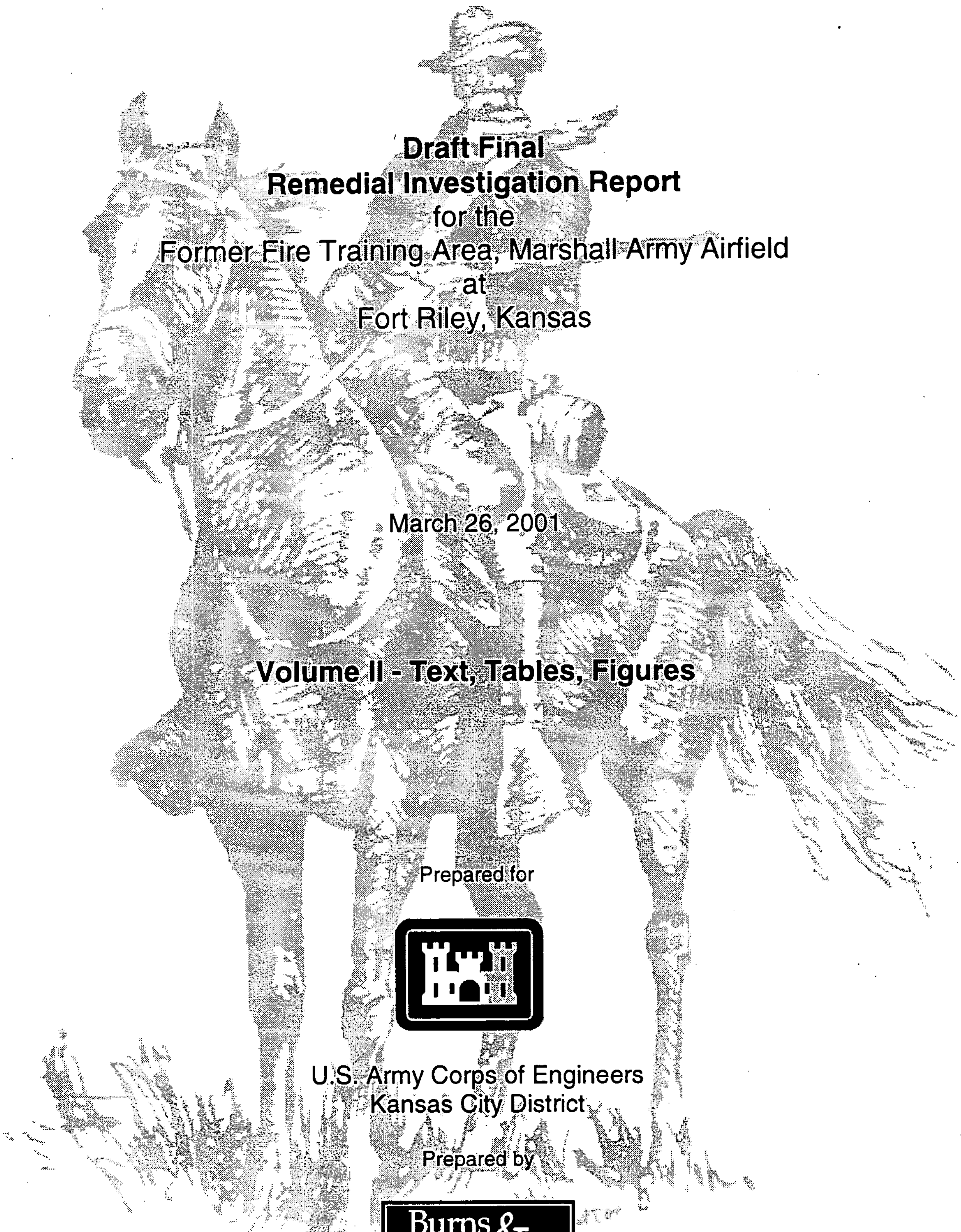

Draft Final
Remedial Investigation Report
for the
Former Fire Training Area, Marshall Army Airfield
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5.0 NATURE AND EXTENT OF CONTAMINATION

5.1 SOURCES

Fire training operations were conducted at the FFTA-MAAF from the mid 1960s through 1984. Flammable liquids used for training purposes were stored at the Site in drums. During fire training area operations, flammable liquids were poured into the pit, ignited, then extinguished. The predominant materials used for the fire training exercises were petroleum hydrocarbons, including JP-4, diesel, motor gasoline with lead alkyls, and gasoline. It is documented that in August 1982, 55 gallons of PCE was inadvertently poured into the pit. The following day, the PCE was pumped from the pit prior to ignition. Hay was spread over the remaining liquid in the pit to absorb any residual PCE, and then removed, drummed, and properly disposed of. A drum storage area was also located approximately 100 feet to the southeast of the burn pit. This area has been investigated and was also found to be a potential source of contamination.

5.2 BACKGROUND VALUES FOR METALS

To properly evaluate the nature and extent of contamination at a site the levels of naturally occurring chemicals must be taken into consideration. Metals are natural constituents of soil and groundwater. As a result of their common occurrence in the environment, statistical methods have been utilized to assess whether past Site activities have contributed to current soil and groundwater metal levels. In determining how to compute background concentrations and statistically compare these concentrations to other results, several sources were consulted. These sources included:

- *Statistical Analysis of Groundwater Monitoring Data at RCRA Facilities - Interim Final Guidance* (USEPA, 1989a) [*Groundwater Statistical Guidance*]

- *Statistical Analysis of Groundwater Monitoring Data at RCRA Facilities - Addendum to Interim Final Guidance* (USEPA, 1992) [*Groundwater Statistical Guidance Addendum*]

- *Determination of Background Concentrations of Inorganics in Soils and Sediments at Hazardous Waste Sites* (USEPA, 1995) [*Background in Soils*]

- *Statistical Methods for Environmental Pollution Monitoring* (Gilbert, 1987) [*Gilbert*]

Statistical methods were used to evaluate and interpret validated data from past investigations at the Site that were determined to constitute background levels, as defined later in this subsection. The process described in the following discussion was applied to a matrix-specific data set. For purposes of this evaluation, a data set was defined as all of the measurements of a metal compound within a single matrix.

The statistical methods used to compute background concentrations are largely dependent on the frequency of detection of a given analyte in a data set. Nondetect values imply some uncertainty of the concentration of the result between the method detection limit (MDL) and zero, and as the proportion of nondetects in a data set increases, so does the uncertainty in the distribution and statistics. In *Groundwater Statistical Guidance Addendum* (USEPA, 1992) USEPA recommends several procedures for dealing with nondetect values in data sets. The background data sets for each analyte associated with the FFTA-MAAF site are divided into five groups, dependent upon the proportion of nondetect values. These are:

Group A	Data sets containing between 0 and 15 percent nondetects
Group B	Data sets containing between 16 and 50 percent nondetects
Group C	Data sets containing between 51 and 89 percent nondetects

Group D	Data sets containing between 90 and 99 percent nondetects
Group E	Data sets containing 100 percent nondetects

Background values for metals in groundwater and soil are statistically determined as described in Appendix 5A using these data groups. All calculations performed and plots constructed for the statistical determination of background levels in soil and groundwater are also provided in Appendix 5A.

5.2.1 Contaminant Comparison to Background for Metals in Groundwater

The first step in establishing background concentrations is to determine which sample locations constitute background conditions. Criteria used to select background wells included the following. A well must have been sampled each of the last ten rounds, must be beyond the contaminant influence of the FFTA-MAAF, and must be free of detections other than metals over the last ten sampling rounds. The last ten rounds of sampling, from December 1996 through August 1999, were chosen for analysis because this data has been validated, the sampling rounds occurred on a regular basis, and the guidance requires that all data used to form an upper tolerance limit (UTL) be collected over the same time period. Several wells were identified as potential background wells, based on an upgradient or side gradient location relative to the FFTA-MAAF, or far enough downgradient from the FFTA-MAAF not to be affected. The only two wells free of contamination and sampled each of the last ten rounds were upgradient Monitoring Well FP-93-07 and side gradient Well N-1 (a private supply well). These wells are considered background for the Site for purposes of this evaluation.

According to the *Groundwater Statistical Guidance* (USEPA, 1989a), plume and background samples must be obtained from comparable zones in the same aquifer and during the same sampling event. Well completion techniques and usage of background wells should be similar to those of the wells under investigation. Sampled wells generally should be screened at similar zones within the same aquifer, because different depths may have different water chemistry. The two wells identified as background wells, FP-93-07 and N-1, are defined as a shallow monitoring well and an unknown supply well, respectively. Unfortunately, wells appropriate to serve as background are not available for each separate zone of the aquifer. Therefore, this background evaluation was only performed for the shallow zone. Metals in intermediate and deep zones were compared to MCLs.

The *Groundwater Statistical Guidance* (USEPA, 1989a) suggests using a tolerance interval to determine whether there is statistically significant evidence of contamination when comparing background concentrations to sample results. A tolerance interval was constructed from the data on the background wells. Table 5-1 illustrates the calculations performed on the background data and provides the calculated background concentrations. These calculations are discussed in detail in the following sections.

This tolerance interval is compared with concentrations from the compliance wells, wells located within the contaminant plume. If a concentration at a compliance well exceeds the tolerance interval it is considered to be potentially statistically significant evidence of contamination. A 95 percent UTL is determined for the background concentrations of the metals. This UTL contains at least 95 percent of the distribution of the results from the background wells. The determination of a UTL requires at least eight samples for an adequate population. The UTL, for normally distributed data, is calculated by the following formula:

$$UTL = \bar{x} + KS_d$$

Where

$\bar{x}$ = mean of background well data
K = one-sided normal tolerance factor
S_d = standard deviation of background well data

A UTL is different from the commonly seen statistical upper confidence limit (UCL). A UCL is constructed on each compliance well to compare to a compliance limit, such as a drinking water MCL, taken from *Drinking Water Regulations and Health Advisories* (USEPA, 1996a). If the entire confidence interval exceeds the compliance limit, there is statistically significant evidence that the mean concentration exceeds the compliance limit. A UCL, for normal data, is calculated by the following formula:

$$UCL = \bar{x} + t\frac{S_d}{n^{1/2}}$$

Where

$\bar{x}$ = mean of compliance well data
t = Student's t-Distribution
S_d = standard deviation of compliance well data
n = degrees of freedom (sample size)

The relationship between K and t in the above equations is expressed by the following formula:

$$K = t_{n-1,1-\beta}\sqrt{(1+\frac{1}{n})}$$

Where

K = one-sided normal tolerance factor
t = Student's t-Distribution
n = degrees of freedom (sample size)
∃ = confidence (0.95)

The discussions provided in Appendix 5A describe the statistical procedures followed for each data group in the determination of the distribution of the data and, ultimately, the background value. It must be made clear that the determinations of distribution are, at best, educated assumptions because of the small sample size. Also, the grouping of all wells and the determination of only one background value, regardless of well construction, screened interval, or use may bias the calculated background values.

Also, according to the *Groundwater Statistical Guidance* (USEPA, 1989a) and *Groundwater Statistical Guidance Addendum* (USEPA, 1992), "All the available tests for Normality do at best is a fair job of rejecting non-Normal data when the sample size is small (say less than 20 to 30 observations)." Thus, the distributional analysis may not be accurate if additional data points are added at a later date, but allows assumptions to be made on current data points for statistical determination of the background concentrations. Most of the distributional analyses require at least 10 samples; the background data sets for groundwater and soil consist of 20 and 22 samples, respectively.

5.2.1.1 Background Concentrations and Comparisons

Table 5-1 provides the calculated background levels for the groundwater at this Site. The calculated background values are all either less than or equal to MCLs.

Metal, Total	Preliminary Calculation of Background (mg/L)	MCL (mg/L)
Antimony	0.006	0.006
Arsenic	0.02	0.05
Beryllium	0.001	0.004
Cadmium	0.001	0.005
Chromium	0.0065	0.1
Copper	0.052	1.3 (Action Level)
Lead	0.012	0.015 (Action Level)
Mercury	0.0002	0.002
Nickel	0.01	-
Selenium	0.005	0.05
Silver	0.008	-
Thallium	0.001	0.002
Zinc	0.388	-

Detections in compliance wells above background from the May and August 1997 sampling rounds are provided in Table 5-2. Metals have not been analyzed for at the Site since August 1997.

Five metals were detected at statistically significant concentrations (exceeding the background level or 95 percent UTL) in the groundwater at the Site in May and August 1997. These metals include: arsenic, chromium, lead, nickel, and selenium. The highest concentrations detected are compared to MCLs in the table below.

Metal, Total	Highest Detection (mg/L)	MCL (mg/L)
Arsenic	0.040	0.05
Chromium	0.207	0.1
Lead	0.013	0.015 (Action Level)
Nickel	0.091	0.1
Selenium	0.024	0.05

Arsenic was detected in shallow Monitoring Wells FP-96-19, FP-96-20, I-1, R-1, and R-2 at detections ranging from 0.022 to 0.040 mg/L. These shallow zone detections are above the background level of 0.02 mg/L and below the MCL of 0.05 mg/L. Arsenic was not detected in the intermediate and deep zones above the MCL of 0.05 mg/L.

Chromium was detected in Piezometer FP-94-12PZ at concentrations ranging from 0.022 to 0.207 mg/L. The shallow zone detection of chromium in May 1997 was above the MCL of 0.1 mg/L. Chromium was not detected in the intermediate and deep zones above the MCL of 0.05 mg/L.

Lead was detected once at Monitoring Wells FP-93-05 above its background level at a concentration of 0.013 mg/L, minimally above the background level of 0.012 mg/L. The Federal Action Limit for lead of 0.015 mg/L was not exceeded. Lead was not detected in the intermediate and deep zones above the MCL of 0.05 mg/L.

The highest detection for nickel of 0.091 mg/L occurred at Piezometer FP-94-12PZ. Nickel was also detected above its background level at shallow Monitoring Wells FP-94-11, FP-96-26, and R-2 at detections ranging from 0.011 to 0.016 mg/L, minimally above the background of 0.01 mg/L. All shallow zone detections of nickel were below the MCL of 0.1 mg/L. Nickel was not detected in the intermediate and deep zones above the MCL of 0.05 mg/L.

Selenium was detected at concentrations above the background level in shallow Monitoring Wells FP-94-10, FP-94-11, FP-96-18, FP-96-21, FP-96-24, and FP-96-26 at concentrations ranging from 0.006 to 0.024 mg/L. All shallow zone detections of selenium were below the MCL of 0.05 mg/L. Selenium was not detected in the intermediate and deep zones above the MCL of 0.05 mg/L.

From the above discussion, it can be concluded that occurrences of high metal concentrations in the groundwater at the Site are minimal. The groundwater samples collected to date have been unfiltered samples that were analyzed for total metals. No data is currently available on dissolved metals. However, the groundwater samples taken at the Site are required to have turbidity readings of 30 nephelometric turbidity units (NTUs) or lower. Historically, the NTUs for groundwater samples at the Site have averaged around 10 NTUs. Thus, it can be assumed that the metals detected in the groundwater are primarily in the dissolved state.

5.2.2 Contaminant Comparison to Background for Metals in Soil

The requirements for selecting soil boring data for calculating Site background soil metal levels are similar to the selection requirements for background groundwater wells. The soil boring must be beyond the influence of the FFTA-MAAF and soil analytical data must be free of detections other than metals. The soil borings included for consideration for background were chosen because of their location outside the areas of activity, the burn pit and the former drum storage area. Eight sample locations including PSB-1, PSB-6, PSB-26, PSB-33, PSB-35, PSB-37, PSB-45, and PSB-46 were free of contamination at the time of the post-pilot sampling (see Tables 3-12 and 3-13 for Post-Pilot Study Results). However, because of the proximity of Soil Borings PSB-1, PSB-6, and PSB-26 to soil borings with detected contaminants, these borings were determined to be potentially within the influence of the FFTA-MAAF. The five soil sampling locations determined to be beyond the influence of the FFTA-MAAF include Soil Borings PSB-33, PSB-35, PSB-37, PSB-45, and PSB-46. Soil analytical data from these soil borings were used in determining background values for metals in soil at the Site.

In *Background in Soils* (USEPA, 1995) the USEPA suggests using the mean of the background data plus three standard deviations as a maximum upper limit for comparison of background concentrations to sample results. Any results above this limit are considered statistically significant evidence of contamination. *Background in Soils* (USEPA, 1995) also suggests procedures for handling nondetect values which assume that the data, including nondetects, is normally distributed. However, this assumption may not always be true of the data sets. To determine if data sets are normally distributed, statistical analysis was performed as described below.

Because several data sets were nonparametric (non-normal), procedures for handling nondetects can not be followed as outlined in *Background in Soils* (USEPA, 1995). However, a UTL can be determined for nonparametric and parametric data alike that approximates the mean plus three standard deviations. Based on the distribution, a parametric, nonparametric, or Poisson UTL with 98 percent confidence was calculated. A 98 percent UTL was chosen because it is slightly more conservative than the 99 percent UTL which closely approximates the mean plus three standard deviations for perfectly normal data. A 98 percent UTL is more conservative than a 99 percent UTL because it includes less of a population in a determined distribution, thus the value of a 98 percent UTL is lower and more conservative than a 99 percent UTL.

Calculations on the soil background data are provided in Table 5-3. The discussions provided in Appendix 5A describe the statistical procedures followed for each data group in the determination of the distribution of the data and, ultimately, the background value.

5.2.2.1 Background Concentrations and Comparisons

Table 5-3 provides the calculated background levels for the soil at the FFTA-MAAF. Detections in post-pilot study soil borings above the background are provided in Table 5-4. Six metals were detected at statistically significant concentrations in soil at the FFTA-MAAF: beryllium, cadmium, copper, lead, selenium, and zinc.

Beryllium was detected above background twice, once at Soil Boring PSB-21 at a level of 1.20 mg/kg and once at Soil Boring PSB-36 at a level of 1.30 mg/kg. Both detections are slightly above the background level of 1.10 mg/kg. Both detections were within the top 7 feet of soil.

Eight detections of cadmium occurred above the background level of 1.00 mg/kg. All of the detections occurred within the top 7.5 feet of soil and ranged from 1.20 mg/kg to 1.60 mg/kg.

Copper was detected once at Soil Boring PSB-22 and once at Soil Boring PSB-36 above the background value of 17.68 mg/kg at concentrations of 32.00 mg/kg and 21.00 mg/kg, respectively.

Lead was detected three times at Soil Boring PSB-4 at concentrations of 36.40, 101.00, and 507.00 mg/kg, above the background value of 32.31 mg/kg. Boring PSB-4 was located in the center of the former burn pit area. The lead detections were most likely due to the release of leaded gasoline in this area.

Selenium was detected above the background only once at Soil Boring PSB-24 at a concentration of 0.70 mg/kg. This detection was slightly above the background value of 0.60 mg/kg.

Six detections of zinc occurred above its background level of 72.86 mg/kg, ranging from 74 to 89 mg/kg.

From this discussion, it can be concluded that occurrences of high metal concentrations in the post-pilot soil at the Site are minimal and localized. Regional values from *Element Concentrations in Soil and Other Surficial Materials of the Conterminous United States* (USGS, 1984) for the Topeka, Kansas area and the natural concentrations from *The Soil Chemistry of Hazardous Materials* (Dragun, 1988) [*Soil Chemistry*] are compared to computed background values for soil at the FFTA-MAAF below:

Metal	**Site Background Value (mg/kg)**	**Regional Concentration (USGS, 1984) (mg/kg)**	**Natural Concentrations (Dragun, 1988) (mg/kg)**
Antimony	6.0	-	0.6-10
Arsenic	5.0	4.1	1.0-40
Beryllium	1.10	<1	0.1-40
Cadmium	1.0	1.5-2.0	0.01-7.0
Chromium	24.06	50	5.0-3000
Copper	17.68	0-10	2.0-100
Lead	32.31	15	2.0-200
Mercury	0.1	-	0.01-0.08
Nickel	24.18	7-10	5.0-1000
Selenium	0.6	0.7-5.0	0.1-2.0
Silver	1.0	-	0.1-5.0

Metal	Site Background Value (mg/kg)	Regional Concentration (USGS, 1984) (mg/kg)	Natural Concentrations (Dragun, 1988) (mg/kg)
Thallium	1.0	-	0.1-12.0
Zinc	72.86	45	10-300

These comparisons are meant to provide a basis for discussion of elevated metals detections. Most Site background values for metals are lower than, or only slightly above, the regional concentrations; all metals are within the natural concentration range provided by Dragun. Several metals above the regional concentrations are copper, lead, nickel, and zinc.

The two detections of beryllium above Site background are above regional concentrations, but well within natural concentrations. The highest detection was only 15 percent above Site background.

The highest cadmium detection of 1.6 mg/kg occurred at Soil Boring PSB-21. This detection was 60 percent above the calculated soil background level of 1.0 mg/kg. The detected concentrations above background were all within the regional concentration range. Also, the raised concentrations are spread throughout the area and are not confined to an area of known activity.

Two detections of copper occurred above Site background. The Site background value for copper exceeds the regional concentration, but is well within the natural concentrations.

Lead was detected above Site background in only one location, PSB-4. Of the five samples taken from this location, the three highest were 507.00 mg/kg in the 1- to 3-foot interval, 101.00 mg/kg in the 4.2 to 6.0 foot interval, and 36.40 mg/kg in the 14.8- to 15.8-foot interval. The high detections greatly exceeded the Site background of 32.31 mg/kg and exceeded the natural range of concentrations. These detections likely occurred as a result of documented releases of leaded gasoline for fire training purposes. The elevated detections in soil are confined to one location in the center of the former fire training pit. The detected concentrations of lead in adjacent sampling locations were well below the Site background value.

To further evaluate analytical data for lead in comparison to background, a 95 percent UCL value was calculated for lead using the equation presented on Table 5-5. The analytical data for lead obtained from within the former fire training pit (sample locations PSB-5, PSB-4, PSB-30, PSB-13, PSB-15, PSB-16, PSB-3, and PSB-14) resulted in a 95 percent UCL value of 20.7 mg/kg. Although three detected concentrations for lead were above background levels, the 95 percent UCL value for lead was below the Site background value.

Selenium was only detected above Site background once. The detection of 0.7 mg/kg only slightly exceeded the Site background of 0.6 mg/kg and was well within the regional concentration range for selenium.

Six detections of zinc occurred above the Site background value of 72.86 mg/kg. The Site background value exceeded the regional concentration of 45 mg/kg, but was under the natural concentration. The detections above Site background ranged from 74 to 89 mg/kg, all of which are well within the natural concentration. The elevated zinc detections occurred throughout the Site and were not confined to an area of known contamination or activity.

5.3 OVERVIEW OF CONTAMINATION IN THE ENVIRONMENT

Metals have been evaluated in this Report by comparing detections to site-specific background levels as discussed in Section 5.2. Metals were detected above background levels in a limited number of soil samples; however, all metals were detected above background in fewer than 5 percent of samples collected. With a large data set such as this one, 5 percent of samples can reasonably be expected to exceed the 95 percent UTL value. Additionally, all metals detected above background levels were still within the range of naturally observed levels, with the exception of lead in soils at PSB-4. Although the maximum detected concentrations of lead were above background levels, the calculated 95 percent UCL values for lead were below background.

During the two rounds of RI groundwater sampling that included analysis of metals, only arsenic, nickel, and selenium were detected in more than 5 percent of the samples. Arsenic, nickel and selenium were all detected at levels below the respective MCLs, in diverse locations, and are not know to be associated with activities conducted at the Site. The evaluation of all metals detections indicates that with the exception of lead at PSB-4, activities at the Site have not contributed to current soil and groundwater metal levels.

Based on the results of the post-pilot study soil borings, RI soil sampling, and the quarterly groundwater sampling, the frequency of detection of SVOC and VOC contaminants are presented on Tables 5-6 and 5-7. Contaminants detected at a frequency greater than or equal to 5 percent in either media, groundwater or soil, are evaluated in this section. These contaminants include: TPH-DRO, TPH-GRO, PCE, TCE, 1,2-DCE (cis and trans isomers), benzene, toluene, ethylbenzene, xylenes (total), dichloromethane, and 2-methylnaphthalene. For the purposes of this discussion, these compounds have been identified as the preliminary chemicals of potential concern (PCOPCs). Although VC and 1,1-DCE did not meet the 5 percent detection criteria, they are considered in this discussion because they are both potential daughter products in the reductive dechlorination pathway of PCE (refer to Section 7.0 for further discussion of selection of chemicals of potential concern (COPCs) using the USEPA *Risk Assessment Guidance for Superfund, Volume I: Human Health Evaluation Manual* (USEPA, 1989) [*RAGS Part A*]). Naphthalene is also considered a PCOPC because it was identified as such in the *RI/FS WP*, and is close to the 5 percent detection criteria.

TPH-DRO, TPH-GRO, and xylenes were detected in the soil at the Site in both the Post-Pilot Study and RI Study sample collection at a frequency of greater than 5 percent. PCE was detected in the soils collected as part of the RI Study at a higher frequency than the Post-Pilot Study. However, it is important to note that this does not indicate increases in contamination, but reflects the lower detection level achieved for chlorinated solvents during the RI Study. A main objective of the RI Study was to ensure masking of the chlorinated solvents was not occurring due to presence of high petroleum products resulting in elevated detection limits. 2-Methylnaphthalene was detected in the Post-Pilot Study at a frequency of greater than 5 percent; however, SVOCs were not analyzed for as part of the RI Study. All other contaminants in soil were detected in less than 5 percent of the samples.

TPH-GRO, 1,2-DCE, PCE, and TCE were detected in the groundwater at the Site in both the SI and RI Study sample collection at a frequency of greater than 5 percent. Ethylbenzene, toluene, and xylenes were detected in greater than 5 percent of the SI samples; however, during the RI groundwater monitoring program, these compounds were detected in less than 5 percent of the samples. Benzene and dichloromethane were detected in almost 5 percent of the samples during the SI sampling and greater than 5 percent of the samples during the RI Study. All other contaminants in groundwater were detected in less than 5 percent of the samples during both the SI and RI groundwater monitoring activities.

5.4 SOILS AND VADOSE ZONE ORGANIC CONTAMINATION

The discussion of the nature and extent of contamination in soil presented in this section is based on the most recent sampling event, the RI Study, for all compounds except naphthalene and 2-methylnaphthalene. SVOCs were not analyzed as part of the RI Study sampling. Therefore, the extent of these compounds in the soil at the Site is discussed based on the Post-Pilot Study results. Results of the June 1999 investigation indicate that soil contamination in the FFTA is similar in nature and extent to the results of the Post-Pilot Study conducted in April 1996. The similarity in nature and extent of the TPH levels encountered during the two investigations indicated that further degradation of TPH had not occurred at the Site. Evaluation of the degradation of PCE, TCE, and cis-1,2-DCE was inconclusive due to the elevated detection levels encountered during the Post-Pilot Study. Therefore, the RI Study is most appropriate for discussion of nature and extent of compounds in soil for all compounds except those not analyzed, the SVOCs.

Upon release to the environment, petroleum product movement through the soil profile would be expected to be primarily vertical as allowed by soil permeability. As the petroleum moves downward through the soil, soil adsorption and retention of fuel in soil pores would be expected. The petroleum product remaining in the soil will age over time, resulting in changes in chemical characteristics of the fuel oil. Lighter constituents of the petroleum fuel (naphthalenes) are most likely to leach into infiltrating groundwater or volatilize into soil gas. The heavier end compounds are most likely to remain adsorbed to soil in the soil profile. The presence of BTEX, naphthalene, and 2-methylnaphthalene in the soil profile years after fire training activities ceased at the FFTA-MAAF likely reflects the common occurrence of these parameters in petroleum fuels and their moderate soil adsorption coefficient.

5.4.1 SVOCs

During the Post-Pilot Study sampling (LBA, 1996a), naphthalene detections in soil occurred either within the boundaries of the burn pit or at nearby borings above an elevation of 1040 feet above msl. Naphthalene was most frequently detected at Soil Boring PSB-4 with concentrations ranging from 1000 to 18,000 µg/kg. Naphthalene was detected in every sample at Soil Boring PSB-4 except the 12.6 to 13.1 feet bgs interval. Two detections of naphthalene occurred at Soil Boring PSB-5 in the sampling intervals of 10 to 12 feet bgs and 12.5 to 13 feet bgs, at concentrations of 6,500 µg/kg and 840 µg/kg, respectively. Naphthalene was detected only once in each of the soil borings PSB-31, PSB-30, PSB-44, and PSB-25. These limited detections of naphthalene all occurred around the elevation of 1040 feet msl in the center of the former fire training pit, at concentrations ranging from 680 to 2,000 µg/kg.

2-Methylnaphthalene likely entered the environment at the MAAF-FFTA from the use of fuels during fire training exercises and was detected in soil samples located near the former burn pit. Detections at Soil Boring PSB-4 ranged from 790 to 46,000 µg/kg. The highest detection also occurred in the sampling interval of 4.2 to 6 feet bgs. 2-Methylnaphthalene was detected at Soil Boring PSB-5. Concentrations ranged from 1,200 to 13,000 µg/kg. Also, limited detections of 2-methylnaphthalene occurred at Soil Borings PSB-7, PSB-15, PSB-29, PSB-30, PSB-31, and PSB-44 at detections ranging from 740 to 3,200 µg/kg. All detections of 2-methylnaphthalene are centered at the former fire training pit.

5.4.2 Chlorinated Solvents

The extent of PCE, TCE, and cis-1,2-DCE contamination is depicted in Figure 5-1. VC was not detected in soil samples at the Site. PCE, TCE, and cis-1,2-DCE were detected at various depths at Location FP-99-SB13, located near the center of the former fire training pit and PSB-4 and PSB-5, the location of the SVOC detections from the Post-Pilot Study. PCE, TCE, or cis-1,2-DCE was detected at depths of 12 to 16 feet bgs (below the water table at the time of sampling) at Locations FP-99-SB01, FP-99-SB02, FP-99-SB12, FP-99-SB14, and FP-99-SB15, all located adjacent to the FFTA. The contamination encountered near the center of the FFTA and at deep locations adjacent to the FFTA can be attributed to a documented solvent release in August 1982 and firefighter training exercises. The locations of the deep chlorinated VOC detections are highlighted in green on Figure 5-2.

PCE was also detected at 8 locations in or near the former drum storage area at depths of less than 4 feet bgs with an additional detection at 8 to 12 feet bgs at Location FP-99-SB09. Shallow detections (less than 4 feet bgs) of PCE are listed below:

FP-99-SB08
FP-99-SB17
FP-99-SB11
FP-99-SB31
FP-99-SB15
FP-99-SB33
FP-99-SB16
FP-99-SB36

The highest concentrations encountered in the former drum storage area were at Locations FP-99-SB16 and FP-99-SB31. The source of this contamination appears to be solvent releases in the former drum storage area and spreading of soils during regrading of the area after operations ceased at the FFTA and the former drum storage area. The locations of the shallow chlorinated solvents are highlighted in yellow on Figure 5-2.

5.4.3 Petroleum Products

The extent of TVPH, TPH as diesel fuel, and TPH in the $C_{19} - C_{40}$ range contamination is depicted on Figures 5-3, 5-4, and 5-5, respectively. TPH $C_{19} - C_{40}$ range is typically referred to as TPH as motor oil, however during this investigation the detections did not match the typical chromatographic pattern for motor oil, but appear to be similar to the pattern expected from a weathered diesel fuel. This method does not allow for product identification without the use of a known standard.

TVPH, TPH as diesel fuel, and TPH in the $C_{19} - C_{40}$ range were detected from the surface to the total depth of the probehole at Location FP-99-SB13, located near the center of the FFTA. TVPH was also encountered at depths of 12 to 16 feet bgs (below the water table at the time of the sampling) at most locations adjacent to the FFTA. The contamination encountered near the center of the FFTA and at deep locations adjacent to the FFTA can be attributed to firefighter training exercises.

TPH in the $C_{19} - C_{40}$ range was also detected in the 0 to 4 feet bgs soil samples at 29 locations and in the 4 to 8 feet bgs soil samples at 8 locations. Locations in which TPH as motor oil was absent above 8 feet bgs are listed below:

FP-99-SB01
FP-99-SB30
FP-99-SB05
FP-99-SB35
FP-99-SB11
FP-99-SB25

The source of the $C_{19} - C_{40}$ contamination appears to be related to the firefighter training exercises and spreading of soils during regrading of the area after operations ceased at the FFTA.

5.4.4 Leaching to Groundwater Potential

The primary objective of this remedial investigation was to determine the extent to which contaminants may be leaching to groundwater from the unsaturated zone in the vicinity of the FFTA and former drum storage area. The results of the soil sampling analyses were compared to the levels in the KDHE *Risk-Based Standards for Kansas* (*RSK Manual*) (KDHE, 1999) and to the *Clean-Up Levels for Total Petroleum Hydrocarbons* (*TPH Addendum*) (KDHE, 2000). The *RSK Manual* supersedes the previous KDHE guidance policy *Interim Remedial Guidelines for Soils (BER-RS-016)*, dated August 1995. The *Clean-Up Levels for Total Petroleum Hydrocarbons* serves as an addendum to Appendix A of the *RSK Manual.*

The *RSK Manual* establishes risk-based cleanup levels for soil and groundwater through a tiered approach without requiring the completion of a baseline risk assessment (see Sections 8.0 and 9.0, respectively, for the human health and ecological risk assessments). For the purpose of this evaluation the Tier 1 step was not considered and the results for the PCOPCs were compared to the KDHE Tier 2 Risk-Based Summary Table in Appendix A of the *RSK Manual* and the *TPH Addendum*. The values for the *Soil to Groundwater Pathway for Residential Scenarios* were selected as the appropriate screening levels to evaluate contaminant leaching to groundwater at the Site. Table 5-8 presents the screening levels along with maximum concentrations from this investigation for the PCOPCs. All other exposures are fully evaluated in the human health and ecological risk assessments found in Sections 7.0 and 8.0 of this Report, respectively. The maximum contaminant concentrations for the all of the PCOPCs detected during the investigation, except TPH, were at or below the screening levels for *Soil to Groundwater Pathway for Residential Scenarios*. The screening levels are set such that soil contaminant levels below these values are not expected to result in groundwater contaminant concentrations above drinking water MCLs.

Benzene and VC were not detected during this investigation. The detection limit for benzene and VC was greater than the *Soil to Groundwater Pathway for Residential Scenarios* levels at 11 locations. However, current and predicted future concentrations of benzene and VC in groundwater are fully evaluated in the human health and ecological risk assessments in Sections 7.0 and 8.0 of this Report, respectively.

TPH is the only PCOPC that exceeded the screening levels for *Soil to Groundwater Pathway for Residential Scenarios*. TPH in soil exceeded the residential screening level presented in the *TPH Addendum* for samples collected at or near the former fire-training pit. TPH in soil is contained on-post and does not present a risk to off-post receptors. TPH detections above the residential groundwater screening level in off-post wells occurred in May and August 1997 in FP-96-09b and in December 1995 in FP-94-11. TPH has not exceeded the residential groundwater screening level presented in the *TPH Addendum* for any off-post wells since August 1997. This data suggests that TPH in groundwater at concentrations above the residential screening levels is not currently migrating off-post. TPH in off-post groundwater is expected to remain below the residential screening levels, since groundwater TPH concentrations have historically decreased in all off-post wells, no new known TPH sources have be introduced to the aquifer, and since the 1995 Pilot Test removed an estimated 1,896 lbs of TPH from the FFTA source area (Section 3.4.3).

5.5 GROUNDWATER ORGANIC CONTAMINATION

DSRs have been prepared for the quarterly groundwater monitoring conducted since July 1994. Analytical results for the ten RI groundwater sampling rounds from July 1996 through August 1999 are evaluated in this section of the Report. Samples were collected during the following dates:

- August 1996
- December 1996
- May 1997
- August 1997
- February 1998
- May 1998
- August 1998
- January 1999
- May 1999
- August 1999

Most samples were analyzed for TPH, VOCs, and some SVOCs. TPH was excluded from selected wells during the August 1999 sampling event. The August 1996 sampling event included total 1,2-DCE, but all of the subsequent sampling events included trans-1,2-DCE and cis-1,2-DCE as separate components. Dichloromethane was not analyzed in August 1996. SVOCs were analyzed for in the first four RI sample rounds, and thereafter, naphthalene was the only SVOC analyzed. Methane was included in the groundwater sampling events, and is discussed as a natural attenuation parameter in Section 6.0. Results of all of the groundwater monitoring activities at the Site are provided in Table 3-7 with comparisons to the MCLs.

Detections of contaminants in groundwater occurred primarily in wells that have been designated as lying along the centerline of the plume. Figures 5-6 and 5-7 (trend charts) show the detections of chlorinated solvents, and TPH and BTEX, respectively, in the centerline wells over time. These wells and the distance they lie from the source on a line drawn through each well are as follows:

WELL	FEET
FP-93-04	0
FP-93-02	300
FP-96-25	700
FP-96-26	1,100
FP-94-09	1,350
FP-96-23	2,100
FP-98-27	2,950
FP-98-29	4,100
FP-98-31	4,850
FP-99-32	6,800

5.5.1 Chlorinated Solvents

There are multiple figures depicting the chlorinated solvents detected at the Site referenced in the following section. Figures 5-6 and 5-8 are trend charts of the chlorinated solvent detections down the centerline of the plume and through a cross-section of the plume, respectively. There are also numerous figures depicting the groundwater plume since April 1995 as follows:

- April 1995
    - Stacked depiction of PCE, TCE, and cis-1,2-DCE in the three aquifer zones (Figures 5-9 to 5-11)
- December 1996
    - Stacked depiction of PCE, TCE, and cis-1,2-DCE in the three aquifer zones (Figures 5-12 to 5-14)
    - Vertical cross-section of PCE, TCE, and cis-1,2-DCE down the centerline of the plume (Figures 5-15 to 5-17)
- May 1998
    - Stacked depiction of PCE, TCE, and cis-1,2-DCE in the three aquifer zones (Figures 5-18 to 5-20)
    - Vertical cross-section of PCE, TCE, and cis-1,2-DCE down the centerline of the plume (Figures 5-21 to 5-23)

- May 1999
    - Stacked depiction of PCE, TCE, and cis-1,2-DCE in the three aquifer zones (Figures 5-24 to 5-26)
    - Vertical cross-section of PCE, TCE, and cis-1,2-DCE down the centerline of the plume (Figures 5-27 to 5-29)
- August 1999
    - Stacked depiction of PCE, TCE, and cis-1,2-DCE in the three aquifer zones (Figures 5-30 to 5-32)
    - Vertical cross-section of PCE, TCE, and cis-1,2-DCE down the centerline of the plume (Figures 5-33 to 5-35)

5.5.1.1 PCE Shallow

PCE has not been detected at the source area in the last ten sampling rounds, and was only detected at the source area once in prior sampling rounds. Levels of PCE directly downgradient of the source have been decreasing (from a high of 320 µg/L in April 1995 to the August 1999 current level of 5.9 µg/L) steadily over time. Further downgradient from the source, Monitoring Well FP-96-23 and beyond, there have been no detections of PCE in the shallow aquifer zone (see Figures 5-9, 5-12, 5-18, 5-24, and 5-30). In Monitoring Well FP-94-09, which is 1,350 ft from the source, there have been no detections of PCE in the last 6 sampling rounds, although it was detected in August of 1997 at 7.4 µg/L which is above the MCL of 5 µg/L, and once in December 1996, at 2.5 µg/L. In 1999, detections of PCE above the MCL of 5 µg/L were limited to Monitoring Wells FP-93-02 and FP-96-26.

5.5.1.2 PCE Intermediate

The highest detection of PCE in the intermediate zone occurred in August of 1998 in Monitoring Well FP-98-27b at 34.8 µg/L. This well is located about 2,950 feet from the source. Detections of PCE have been steadily decreasing in this well since that time (see Figure 5-6). 1999 sample results showed PCE contamination centered on Monitoring Well FP-98-29b, which is 4,100 ft from the source. The highest 1999 detection of PCE is in this well at 20.6 µg/L, and occurred in January. PCE was detected in Monitoring Well FP-99-32b, located next to the Kansas River, in August of 1999 at 8 µg/L. These1999 detections of PCE in the downgradient portion of the plume are above the PCE MCL of 5 µg/L.

5.5.1.3 PCE Deep

PCE has not been detected in the deep aquifer zone above a level of 17.7 µg/L, which occurred in January of 1999 at FP-98-29c. Further downgradient, PCE levels were steadily dropping until the August 1999 sampling round which had detections in both FP-98-31c and FP-99-32c around 14 µg/L. During the 1999 sampling events, PCE was consistently detected above the MCL of 5 µg/L in Monitoring Wells FP-98-29c and FP-98-31c (see Figure 5-6). PCE was also detected above its MCL in Monitoring Well FP-99-32c, located next to the Kansas River, when it was sampled for the first time in August 1999.

5.5.1.4 TCE Shallow

TCE levels in the shallow zone have been steadily dropping since May 1997 (see Figure 5-6). TCE peaked in May 1995 in Monitoring Well FP-96-25 at 190 µg/L, about 700 feet from the source. There have been no detections of TCE in the shallow zone in Monitoring Well FP-96-23 or wells further from the source (see Figures 5-10, 5-13, 5-19, 5-25, and 5-31).

5.5.1.5 TCE Intermediate

TCE levels in the intermediate zone have never exceeded 27.7 µg/L which occurred in August 1999 in Monitoring Well FP-93-02b, 300 feet from the source (see Figure 5-6). TCE is also present 2,950 feet from the source in Monitoring Well FP-98-27b, although levels in this well have been decreasing since August 1998. Further from the source, TCE levels have been steady at about 6 µg/L (see Figures 5-10, 5-13, 5-19, 5-25, and 5-31). Monitoring Well FP-99-32b, the well furthest from the source, had a TCE concentration of 7.7 µg/L, above the TCE MCL of 5 µg/L, when first sampled in August 1999. During the 1999 sampling events TCE was detected above its MCL in the intermediate zone in Monitoring Wells FP-96-02b, FP-98-27b, FP-98-29b, FP-98-31b, and FP-99-32b.

5.5.1.6 TCE Deep

The highest detected concentration of TCE in the deep aquifer zone occurred in Monitoring Well FP-98-29c in January 1999, at 10.3 µg/L. The highest TCE detection in the deep aquifer zone has occurred in this well for the five sampling rounds preceding the August 1999 round. In August 1999, the peak appears to have moved a bit further from the source and occurred in Monitoring Well FP-98-31c, at 8.1 µg/L, above the MCL of 5 µg/L. During the 1999 sampling events, TCE was detected above its MCL of 5 µg/L in the deep zone in Monitoring Wells FP-98-29c and FP-98-31c.

5.5.1.7 1,2-DCE Shallow

Cis-1,2-DCE has not been detected in the shallow aquifer zone in Monitoring Wells FP-98-29, FP-98-31, and FP-99-32, which are furthest from the source (see Figures 5-11, 5-14, 5-20, 5-26, and 5-32). The highest concentration of cis-1,2-DCE has occurred at Monitoring Well FP-94-09, 1,350 feet from the source, during all of the sampling rounds, and reached its highest point to date of 685 µg/L in May 1999. The August 1999 sampling round indicated a lower level of cis-1,2-DCE in Monitoring Well FP-94-09 (496 µg/L). Levels of cis-1,2-DCE in all of the wells in the shallow zone also decreased in August 1999. During the 1999 sampling events, cis-1,2-DCE was consistently detected above its MCL of 70 µg/L in Monitoring Wells FP-94-09 and FP-94-11.

Trans-1,2-DCE has been detected at various shallow wells throughout the groundwater plume including: FP-94-09, FP-94-11, FP-96-23, FP-96-25, and FP-96-26. The highest detection occurred at Monitoring Well FP-94-09 in August 1999 at 4 µg/L. These detections are all well below the MCL for trans-1,2-DCE of 100 µg/L.

5.5.1.8 1,2-DCE Intermediate

Cis-1,2-DCE has been detected in every well in the centerline of the plume in the intermediate zone (see Figure 5-6). The cis-1,2-DCE high occurs in the intermediate zone at the same location (Monitoring Well FP-94-09b) as in the shallow zone. The maximum concentration occurred in August 1997 at 1,100µg/L. After that date, the levels of cis-1,2-DCE have remained somewhat steady at about 300 µg/L (see Figures 5-11, 5-14, 5-20, 5-26, and 5-32). As this early high close to the source area (1,350 feet) has been falling, a later high 2,950 feet from the source seems to be emerging in Monitoring Well FP-98-27b. Detections in this well have steadily increased since May 1998 when it was first sampled. The August 1999 concentration in this well was 257 µg/L. Currently, Monitoring Well Clusters FP-94-09 through FP-98-27 along the centerline of the plume have cis-1,2-DCE concentrations above the MCL.

Cis-1,2-DCE has been detected further out in the plume in the intermediate zone, but these detections have not been above 52 µg/L and in the last three sampling rounds have not been above 30 µg/L. The concentration in Monitoring Well FP-98-32b (the well furthest from the source) was 24.5 µg/L, below the MCL of 70 µg/L, in August 1999, the first time this well was sampled.

Trans-1,2-DCE has been detected at various intermediate wells throughout the groundwater plume including: FP-96-02b, FP-96-23b, and FP-98-27b. The highest detections occurred at Monitoring Well FP-96-23b in August of 1999 at 1.2 µg/L and at Monitoring Well FP-96-02 in January of 1999 at 1.2 µg/L. These detections are all well below the MCL for trans-1,2-DCE of 100 µg/L.

5.5.1.9 1,2-DCE Deep

Cis-1,2-DCE has not been detected in the deep aquifer zone close to the source. The first detection of cis-1,2-DCE in the deep zone occurred in Monitoring Well FP-96-26c at 0.5 µg/L in May 1998. This is the only detection of cis-1,2-DCE in that well which is 1,100 feet from the source. The next closest downgradient well, FP-96-09c, located 1,350 feet from the source has had detections of cis-1,2-DCE in five sampling rounds since December 1996. However none of the detections exceeded 1.9 µg/L. A high of cis-1,2-DCE is centered around Monitoring Well FP-96-23c and moving outward to Monitoring Well FP-98-27c located 2,100 and 2,950 feet from the source, respectively. All detections of cis-1,2-DCE in August 1999 were below 90 µg/L. During the 1999 sampling events, cis-1,2-DCE was detected above the MCL in Monitoring Wells FP-96-23c and FP-98-27c. The highest cis-1,2-DCE detection in 1999 occurred at Monitoring Well FP-96-23c in May 1999 at 198 µg/L.

Further out in the plume, cis-1,2-DCE levels are around 40 µg/L, and have been so for the last three sampling rounds. The August 1999 sampling round for Monitoring Well FP-98-32c showed a cis-1,2-DCE concentration of 39.1 µg/L.

Trans-1,2-DCE was detected in only one well in the deep zone of the aquifer, Monitoring Well FP-96-23c. The highest detection occurred in January 1999 at 0.7 µg/L, well below the MCL for trans-1,2-DCE of 100 µg/L.

5.5.1.10 Other PCE, TCE, and 1,2-DCE Detections

Several wells not identified as center-line wells, or not clearly screened in either the shallow, intermediate, or deep aquifer zones also had detections of PCE, TCE and/or 1,2-DCE. Wells R-1 and R-2 have both had detections of PCE, TCE, and 1,2-DCE.

In the August sampling round, cis-1,2-DCE was detected in Well R-1 at 110 µg/L, and the highest detection in this well occurred in January 1999, at 264 µg/L. Previous detections of 1,2-DCE in this well have been at or below 129 µg/L with the exception of the October 1994 sample which was 290 µg/L. Well R-1 is located in the same area as Monitoring Well Cluster FP-96-26. PCE and TCE have been detected in Well R-1 in every sampling round, and with the exception of the two most recent samples in May and August 1999, every detection has been above 5 µg/L, which is the MCL for PCE and for TCE. The highest detection of PCE and TCE in Well R-1 both occurred in October 1994 with PCE at 330 µg/L, and TCE at 76 µg/L.

Well R-2, also a private well like R-1, had detections of cis-1,2-DCE in all of the sampling rounds, although the most recent detection above the MCL of 70 µg/L occurred in May 1998 at 120 µg/L. Well R-2 is located in the same area as Monitoring Well Cluster FP-96-25. TCE has been detected in Well R-2 in all sampling rounds with the exception of the May 1999 sample. All of the detections with the exception of the August 1999 detection, have exceeded 5 µg/L, with the highest detections of TCE occurring in April, 1995 at 96 µg/L. Detections of PCE have not occurred in the last three sampling rounds. Prior to that, PCE was detected in every sampling round with all but one detection above 5 µg/L.

5.5.1.11 1,1-DCE

1,1-DCE was detected in 5 of 474 samples (1.05 percent). Three of these detections occurred in the main part of the plume, two in Well FP-94-09, and one in Well FP-96-23. One detection occurred in Well FP-94-11, which has had historically high (above 100 µg/L) detections of cis-1,2-DCE, and the remaining detection of 1,1-DCE occurred in Well R-1. All of the detections of 1,1-DCE were at or below 1.2 µg/L. The MCL for 1,1-DCE is 7 µg/L.

5.5.1.12 VC

VC has only been detected in two wells, three times in Monitoring Well FP-94-09, and two times in Monitoring Well FP-94-11. Both wells are screened in the shallow aquifer zone. Monitoring Well FP-94-09 is on the centerline of the plume, about 1,350 feet from the source area, and Monitoring Well FP-94-11, although not designated as a well lying on the centerline of the plume, is located 150 feet west of Monitoring Well FP-96-25, and lies on a line between Monitoring Well FP-93-04 at the source area, and Monitoring Well FP-94-09, where VC was also detected. The three detections of VC in Monitoring Well FP-94-09 have all been below the MCL of 2 µg/L, with the highest detection of 1.7 µg/L occurring in August 1997, and the other detections occurring in January and May 1999.

The two detections of VC in Monitoring Well FP-94-11 were both above the MCL of 2 µg/L. The January 1999 detection was 2.1 µg/L, and the August 1999 detection was 2.8 µg/L. VC was not detected in this well in May 1999.

5.5.1.13 Dichloromethane

Dichloromethane was detected in three of 41 samples (7.3 percent), but only one of these detections occurred in the main portion of the plume. This detection occurred in May/June 1998 in Monitoring Well FP-96-26c at 1 µg/L. The MCL for dichloromethane is 5 µg/L. Dichloromethane was also detected in Monitoring Well FP-96-21b at 1.4 µg/L and R-1 at 1 µg/L. It is important to note that dichloromethane, or methylene chloride, is a common laboratory contaminant. The blanks reported with the samples from Wells FP-96-26c and R-1 were contaminated with low levels of dichloromethane indicating a high probability of sample contamination at the laboratory.

5.5.2 Petroleum Compounds

Detections of BTEX and TPH compounds in wells down the centerline of the plume from August 1996 to the present are graphed in Figure 5-7.

Benzene was detected in 13.7 percent of the groundwater samples taken at the Site. Benzene is highly mobile in soil and has leached to the groundwater. Benzene will degrade in groundwater under aerobic conditions and where benzene serves as an electron donor for ferric iron, nitrate, sulfate, manganese, chlorinated solvents, and carbon dioxide.

5.5.2.1 Benzene Shallow

In the shallow aquifer zone, benzene has only been detected in two wells in the last ten sampling rounds. The highest detection in Monitoring Well FP-93-04 occurred in May 1999 at 1.1 µg/L. This well is located at the source. Benzene was not detected at this well during the most recent sampling round. Monitoring Well FP-94-09 had seven detections of benzene, the highest at 2.1 µg/L occurring in May 1999. These detections were all below the MCL for benzene of 5 µg/L.

5.5.2.2 Benzene Intermediate

Benzene has been detected in all of the wells 1,350 feet (FP-94-09b) and further from the source. The highest detections occurred prior to 1998 in Monitoring Well FP-94-09b, at up to 12 µg/L. Recent samples in this well have been approximately 2 to 3 µg/L. Monitoring Well FP-96-23b, located 2,100 feet from the source, had its highest detection of benzene in December 1996 at 7.6 µg/L. The detections in this well have been decreasing steadily to the August 1999 low of 2.1 µg/L. Further downgradient from this well, there have been only five detections of benzene with none of them exceeding 0.6 µg/L. Currently, benzene is below the MCL of 5 µg/L in all intermediate wells.

5.5.2.3 Benzene Deep

Benzene has not been detected in the deep aquifer zone close to the source. The first benzene detection downgradient of the source area occurred in Monitoring Well FP-96-23c, which is 2,100 feet from the source. Benzene was detected in this well in all sampling rounds, with the highest detection in January 1999 at 2.7 µg/L. The most recent detection of benzene in this well was 0.6 µg/L in August 1999. Further downgradient, the highest detection of benzene occurred in Monitoring Well FP-98-27c, 2,950 feet from the source, at 2.7 µg/L in May 1999. In the three wells furthest from the source, benzene was not detected higher than 0.7 µg/L. The benzene level in Monitoring Well FP-99-32c, the well furthest from the source, in August 1999 was 0.5 µg/L. This was the first time this well was sampled. Currently, benzene is below the MCL of 5 µg/L in the deep wells.

5.5.2.4 BTEX

In the October 1993 sampling round, which was not a part of the RI, the combined BTEX concentration was 4,100 µg/L at the source area, the highest concentration to date. The only MCL exceedence by BTEX compounds excluding benzene also occurred in October 1993 in Well FP-93-04, with toluene at 3,200 µg/L. During the subsequent RI sampling rounds, BTEX compounds, excluding benzene, were not detected in more than 5 percent of the samples (see Table 5-7), and the detections have all been below the respective MCLs and/or KSWQS (see Table 3-7). The August 1999 BTEX level in Well FP-93-04 was 370 µg/L.

5.5.2.5 TPH Shallow

The highest detections of total TPH at the Site have all occurred in the shallow aquifer zone, in Monitoring Well FP-93-04, which is located at the FFTA. Detections here have varied over time, with the lowest at 880 µg/L in August 1995, and the highest in October 1993 at 14,200 µg/L. Detections in the last four sampling rounds have been in the range of 3,000 to 7,000 µg/L.

Further downgradient from the source of the plume in the shallow aquifer zone, TPH detections have been significantly lower, with the highest detection of 420 µg/L occurring in May 1999 at Monitoring Well FP-94-09 which is about 1,350 feet from the former fire training pit. The most recent sample in this well had a concentration of 360 µg/L.

5.5.2.6 TPH Intermediate

TPH in the intermediate aquifer zone is the highest in Monitoring Well FP-94-09b, with the highest detection occurring in May 1997 at 732 µg/L. Total TPH concentrations in this well, 1,350 feet from the source, have been around 300 µg/L in the last two sampling rounds. Further downgradient, TPH has been detected in Monitoring Wells FP-96-23b and FP-98-27b, and has been around 200 µg/L. TPH has not been detected further than 3,000 feet from the FFTA.

5.5.2.7 TPH Deep

In the deep aquifer zone, the first detection of TPH occurred in Monitoring Well FP-96-23c in August 1998, at a concentration of 220 µg/L. TPH was also detected in May of 1999 in this well at 250 µg/L, and in Monitoring Well FP-98-27c at 200 µg/L. These are the only three detections of TPH in the deep aquifer zone. These wells are 2,100 and 2,950 feet, respectively, from the source area. TPH has not been detected further downgradient from these wells.

5.5.3 SVOCs

4-Methylphenol (140 µg/L) and phenol (17 µg/L) were each detected one time in Monitoring Well R-3 in August of 1997. Neither of these compounds have an MCL available.

Naphthalene, a component of petroleum products, entered the environment at the FFTA-MAAF from the use of fuels in the fire training exercises. Naphthalene was detected in ten of 474 samples (2.1 percent) with detections ranging from 7.7 to 60.3 µg/L.

5.5.4 Overall Trends

Examination of Figures 5-6 and 5-7 reveals that chlorinated solvents, TPH, and BTEX are found in the same areas in the plume and follow similar concentration trends. Detections of these compounds are first encountered in the shallow zone in the four wells closest to the source. These detections were generally quite high in the very early sampling rounds, but have since come down and leveled off, with the exception of TPH in Monitoring Well FP-93-04. The intermediate and deep aquifer zones show very little or no detections of all of these compounds up to 1,200 feet from the source. At Monitoring Wells FP-94-09 and FP-96-09b, 1,350 feet from the source, cis-1,2-DCE detections are at their highest levels in the shallow and intermediate aquifer, as are BTEX and TPH with the exception of early high concentrations in the source area. At this distance from the source, there are no detections of volatiles in the deep aquifer zone, with the exception of cis-1,2-DCE, which was detected five times in Monitoring Well FP-96-09c at levels that did not exceed 2 µg/L.

In the shallow aquifer zone, PCE and TCE concentrations have been decreasing over time in the five wells closest to the FFTA. This decrease in PCE and TCE has been accompanied by an increase in cis-1,2-DCE concentrations, especially evident in Wells FP-94-09 and FP-94-11. VC has been detected five times in the shallow aquifer zone, with four of those detections occurring in 1999. Wells FP-94-09 and FP-94-11 are the only wells with VC detections. Both of these wells have also had high detections of TPH and detections of BTEX in the most recent sampling rounds (see Table 3-7, and Figures 5-6, 5-7, and 5-8). The detections of VC in these two wells during recent sampling rounds, indicates that cis-1,2-DCE is being degraded near these wells. The increasing cis-1,2-DCE, and TPH trends in these wells indicate the possibility for further VC detections in these locations and other areas which may exhibit the same cis-1,2-DCE and TPH trends in the future.

In the intermediate depth aquifer zone, significant detections of volatiles are present at Monitoring Well FP-96-09b, located about 1,350 feet from the source area. In this well, the graphs of cis-1,2-DCE, TPH, and BTEX detections over time follow the same trend. All exhibit a spike on or before August 1997, after which levels drop off significantly, climb in January 1999, and then fall again. At this point the contaminants are migrating downward with groundwater flow and downgradient from these locations. Detections of volatiles are more common in the intermediate and deep aquifer zones than in the shallow zone.

Monitoring wells located further from the source than Monitoring Well FP-96-09b in the intermediate zone show detections of contaminants, but the overall trend in the intermediate zone shows that concentrations have generally been decreasing with time and distance from the source. An exception to this is cis-1,2-DCE in Monitoring Well FP-98-27b, which has increased from a low value of 111 μg/L in May 1998, to the current high of 257 μg/L in the August 1999 sampling round.

In the deep aquifer zone, 2,100 feet from the source, cis-1,2-DCE, TPH, and BTEX have recently been at higher levels than in earlier sampling rounds. This may be due to the vertical and horizontal migration of the peaks of these compounds previously observed in the upgradient intermediate zone Monitoring Well FP-96-09b. The last three wells in the deep aquifer zone, Monitoring Wells FP-98-29c, FP-98-31c, and FP-99-32c, have all had detections of PCE, TCE, and cis-1,2-DCE. The concentrations of these contaminants tend to be somewhat higher than those in the same wells screened in the intermediate zone, but within the same order of magnitude. BTEX follows the same trend in the last three wells, and TPH has not been detected in these wells in the intermediate or deep aquifer zone.

Figure 5-8 presents a transverse cross-section through the monitoring wells located approximately 700 feet downgradient from the former fire training pit. This cross-section includes Monitoring Wells FP-94-11, FP-96-19, and Monitoring Well Cluster FP-96-25. This cross-section suggests that the lateral extent of the chlorinated solvent plume is bounded by Monitoring Wells FP-96-18 and FP-96-19 (i.e. no detections of PCE, TCE, cis-1,2-DCE, or VC in these wells). This figure also illustrates the differences in concentration trends between Monitoring Wells FP-94-11 and FP-96-25. Monitoring Well FP-94-11 has never had significant (greater than MCL) detections of PCE and TCE, but has had detections of increasing cis-1,2-DCE concentrations since December of 1996. Conversely, Monitoring Well FP-96-25 has historically had detections of PCE and TCE as well as cis-1,2-DCE. This well displays a downward concentration trend of PCE and TCE, but an increasing then decreasing cis-1,2-DCE trend. Since TCE was not released at the Site, and cis-1,2-DCE is the predominant DCE daughter product of TCE reductive dechlorination, the concentration trend at these wells suggests that varying reducing environments (i.e. biodegradation environments) may be present between these two wells.

Production of cis-1,2-DCE and degradation of PCE and TCE appears to be occurring more rapidly at Monitoring Well FP-94-11 than at Monitoring Well FP-96-25. This increased degradation may be related to the proximity of these monitoring wells to the location of the former fire training pit and the former drum storage area. Monitoring Well FP-94-11 is located directly downgradient of the former fire training pit, whereas Monitoring Well FP-96-25 is located directly downgradient of the former drum storage area. It is possible that releases of chlorinated solvents at the former fire training pit co-mingled with petroleum product releases and resulted in a greater reducing environment, increased degradation of chlorinated compounds, and increased production of cis-1,2-DCE (evidenced at Well FP-94-11). Site data does not indicate that petroleum products were released from the former drum storage area. This supports the higher concentrations of PCE and TCE at Monitoring Well FP-96-25 and suggests a different degradation environment. A detailed discussion of reductive environments is presented in greater detail in Section 6.0 of this Report.

5.6 SUMMARY

In evaluating the nature and extent of contamination at the FFTA-MAAF Site, the levels of naturally occurring metals in soil and groundwater were taken into consideration. Metals have been evaluated in this Report by comparing detections to site-specific background levels as discussed in Section 5.2. Metals were detected above background levels in a limited number of soil samples; however, all metals were detected above background in fewer than 5 percent of samples collected. During the two rounds of RI groundwater sampling that included analysis of metals, only arsenic, nickel, and selenium were detected in more than 5 percent of the samples. Arsenic, nickel and selenium were all detected at levels below the respective MCLs, in diverse locations, and are not known to be associated with activities conducted at the

Site. The evaluation of all metals detections indicates that with the exception of lead at PSB-4, activities at the Site have not contributed to current soil and groundwater metal levels.

PCOPCs for the Site were identified based upon the frequency of detection in soil and groundwater samples. Contaminants detected at a frequency greater than or equal to 5 percent in either media, groundwater or soil, were identified as PCOPCs, including: TPH-DRO, TPH-GRO, PCE, TCE, 1,2-DCE (cis and trans isomers), benzene, toluene, ethylbenzene, xylenes (total), dichloromethane, and 2-methylnaphthalene. Additional contaminants identified as PCOPCs include VC, 1,1-DCE, and naphthalene.

Contamination in soils is concentrated at the former fire training pit. Limited detections of naphthalene and 2-methylnaphthalene in soil occurred around the elevation of 1,040 feet msl in the center of the former fire training pit. PCE, TCE, cis-1,2-DCE, TVPH, TPH as diesel, and TPH as motor oil were detected at various depths at Location FP-99-SB13, located near the center of the former fire training pit as well as several other locations adjacent to the FFTA. The contamination encountered near the center of the FFTA and at deep locations adjacent to the FFTA can be attributed to the documented solvent release in August 1982 and firefighter training exercises.

PCE and TPH were also detected near the former drum storage area, primarily at depths of less than 4 feet bgs. The source of this contamination appears to be solvent releases in the former drum storage area and spreading of soils during regrading of the area after operations ceased at the FFTA and the former drum storage area.

In the groundwater at the Site chlorinated solvents, TPH, and BTEX are found in the same areas in the plume and follow similar concentration trends. Detections of these compounds are first encountered in the shallow zone in the four wells closest to the source. VC has only been detected five times at the Site, twice above the MCL in Well FP-94-11, and three times below the MCL in Well FP-94-09. All but one VC detection occurred in 1999, and all detections occurred in the shallow zone. The intermediate and deep zones show very little or no detections chlorinated solvents, TPH, and BTEX up to 1,200 feet from the source. In the intermediate zone, significant detections of volatiles are present at Monitoring Well FP-96-09b, located about 1,350 feet from the source area. Monitoring wells located further from the source than Monitoring Well FP-96-09b in the intermediate zone show detections of contaminants, but the overall trend in the intermediate zone shows that concentrations have generally been decreasing with time and distance from the source. In the deep aquifer zone, 2,100 feet from the source, cis-1,2-DCE, TPH, and BTEX have recently been at higher levels than in earlier sampling rounds. This may be due to the vertical and horizontal migration of the peaks of these compounds previously observed in the upgradient intermediate zone Monitoring Well FP-94-09b. The last three wells in the deep aquifer zone, Monitoring Wells FP-98-29c, FP-98-31c, and FP-99-32c, have all had detections of PCE, TCE, and cis-1,2-DCE. The concentrations of these contaminants tend to be somewhat higher than those in the same wells screened in the intermediate zone, but within the same order of magnitude. BTEX follows the same trend in the last three wells, and TPH has not been detected in these wells in the intermediate or deep aquifer zone.

* * * * *

Table 5-1
Groundwater Background Calculations
FFTA-MAAF Remedial Investigation Report

Analyte	Number of Samples	Number of Non-Detects	Minimum (a)	Maximum (b)	Frequency of Detection	Proportion of Non-Detects	Data Group	Mean (c)	Standard Deviation (c)	Median (d)	Skewness (e)	Kurtosis (e)
Antimony	20	20	0.003	0.006	0%	100%	E	N/A	N/A	0.006	N/A	N/A
Arsenic	20	10	0.005	0.02	50%	50%	B	0.012	0.004	0.01	1.821	2.759
Beryllium	20	20	0.001	0.004	0%	100%	E	N/A	N/A	0.001	N/A	N/A
Cadmium	20	20	0.001	0.005	0%	100%	E	N/A	N/A	0.001	N/A	N/A
Chromium	20	19	0.002	0.002	5%	95%	D	N/A	N/A	N/A	N/A	N/A
Copper	20	15	0.01	0.052	25%	75%	C	N/A	N/A	N/A	N/A	N/A
Lead	20	15	0.003	0.012	25%	75%	C	N/A	N/A	N/A	N/A	N/A
Mercury	20	20	0.0002	0.0002	0%	100%	E	N/A	N/A	0.0002	N/A	N/A
Nickel	20	20	0.01	0.04	0%	100%	E	N/A	N/A	0.01	N/A	N/A
Selenium	20	20	0.005	0.005	0%	100%	E	N/A	N/A	0.005	N/A	N/A
Silver	20	19	0.005	0.01	5%	95%	D	N/A	N/A	N/A	N/A	N/A
Thallium	20	20	0.001	0.002	0%	100%	E	N/A	N/A	0.001	N/A	N/A
Zinc	20	8	0.01	0.629	60%	40%	B	0.099	0.168	0.055	3.382	11.593

Table 5-1 (continued)
Groundwater Background Calculations
FFTA-MAAF Remedial Investigation Report

Analyte	Shapiro-Wilk P-Value Original Data	Shapiro-Wilk P-Value Logged Data	Censored Plot r Value Original Data	Detects Only Plot r Value Original Data	Censored Plot r Value Logged Data	Detects Only Plot r Value Logged Data	Critical r Value (95%)	Distribution Type
Antimony	N/A	N/A	N/A	N/A	N/A	N/A	N/A	Unknown
Arsenic	N/A	N/A	0.9009	0.5863	0.9143	0.6114	0.95	Unknown
Beryllium	N/A	N/A	N/A	N/A	N/A	N/A	N/A	Unknown
Cadmium	N/A	N/A	N/A	N/A	N/A	N/A	N/A	Unknown
Chromium	N/A	N/A	N/A	N/A	N/A	N/A	N/A	Poisson
Copper	N/A	N/A	N/A	N/A	N/A	N/A	N/A	Nonparametric
Lead	N/A	N/A	N/A	N/A	N/A	N/A	N/A	Nonparametric
Mercury	N/A	N/A	N/A	N/A	N/A	N/A	N/A	Unknown
Nickel	N/A	N/A	N/A	N/A	N/A	N/A	N/A	Unknown
Selenium	N/A	N/A	N/A	N/A	N/A	N/A	N/A	Unknown
Silver	N/A	N/A	N/A	N/A	N/A	N/A	N/A	Poisson
Thallium	N/A	N/A	N/A	N/A	N/A	N/A	N/A	Unknown
Zinc	N/A	N/A	0.5911	1.4988	0.9359	1.1034	0.95	Normal

Table 5-1 (continued)
Groundwater Background Calculations
FFTA-MAAF Remedial Investigation Report

Analyte	UTL Type	UTL Coverage (f)	Adjustment Type	Adjusted Mean	Adjusted Standard Deviation	UTL (g)	UTL Log (h)	Background Type	Background Value	Background Units
Antimony	N/A	N/A	N/A	N/A	N/A	N/A	N/A	Median DL	0.006	mg/L
Arsenic	Nonparametric	95%	N/A	N/A	N/A	0.02	N/A	Nonparametric UTL	0.02	mg/L
Beryllium	N/A	N/A	N/A	N/A	N/A	N/A	N/A	Median DL	0.001	mg/L
Cadmium	N/A	N/A	N/A	N/A	N/A	N/A	N/A	Median DL	0.001	mg/L
Chromium	Poisson	95%	N/A	N/A	N/A	0.0065	N/A	Poisson UTL	0.0065	mg/L
Copper	Nonparametric	95%	N/A	N/A	N/A	0.052	N/A	Nonparametric UTL	0.052	mg/L
Lead	Nonparametric	95%	N/A	N/A	N/A	0.012	N/A	Nonparametric UTL	0.012	mg/L
Mercury	N/A	N/A	N/A	N/A	N/A	N/A	N/A	Median DL	0.0002	mg/L
Nickel	N/A	N/A	N/A	N/A	N/A	N/A	N/A	Median DL	0.01	mg/L
Selenium	N/A	N/A	N/A	N/A	N/A	N/A	N/A	Median DL	0.005	mg/L
Silver	Poisson	95%	N/A	N/A	N/A	0.008	N/A	Poisson UTL	0.008	mg/L
Thallium	N/A	N/A	N/A	N/A	N/A	N/A	N/A	Median DL	0.001	mg/L
Zinc	Normal	95%	N/A	N/A	N/A	0.388	N/A	Normal UTL	0.388	mg/L

Notes :

N/A - Not Applicable
DL - Detection Limit
UTL - Upper Tolerance Limit
a - For data set groups A-D, this corresponds to the minimum detected value; for data set E this is the minimum DL
b - For data set groups A-D, this corresponds to the maximum detected value; for data set E this is the maximum DL
c - Calculated for data set group A using 1/2 DL; calculated for data set group B using detected values; not calculated for data set groups C, D, and E
d - For data set groups A and B, this is the median of all detected values; for data set group E this is the median DL; not calculated for data set groups C and D
e - For data set groups A and B, this is based on all detected values; not calculated for data set groups C, D, and E

Table 5-2

Metals Detections Above Background in Groundwater

FFTA-MAAF Remedial Investigation Report

Metal	Background Value (mg/L)	Detection Above Background (mg/L)	Sample Point	Sample Date
Arsenic	**0.02**	0.038 0.04	FP-96-19	May-97 August-97
		0.024	FP-96-20	August-97
		0.026 0.031	I-1	May-97 August-97
		0.024 0.023	R-1	May-97 August-97
		0.031 0.022	R-2	May-97 August-97
Chromium	**0.0065**	0.207 0.022	FP-94-12PZ	May-97 August-97
Lead	**0.012**	0.013	FP-93-05	August-97
Nickel	**0.01**	0.012 0.011	FP-94-11	May-97 August-97
		0.091 0.012	FP-94-12PZ	May-97 August-97
		0.016	FP-96-26	August-97
		0.011	R-2	May-97
Selenium	**0.005**	0.006 0.008	FP-94-10	May-97 August-97
		0.007	FP-94-11	May-97
		0.008	FP-96-18	May-97
		0.006 0.008	FP-96-21	May-97 August-97
		0.019 0.024	FP-96-24	May-97 August-97
		0.008 0.01	FP-96-26	May-97 August-97

Notes:

mg/L = milligrams per liter

Data from *May 1997 DSR* (BMcD, 1998a) and *August 1997 DSR* (BMcD, 1998b)

Table 5-3
Soil Background Calculations
FFTA-MAAF Remedial Investigation Report

Analyte	Number of Samples	Number of Non-Detects	Minimum (a)	Maximum (b)	Frequency of Detection	Proportion of Non-Detects	Data Group	Mean (c)	Standard Deviation (c)	Median (d)	Skewness (e)	Kurtosis (e)
Antimony	22	22	5	7	0%	100%	E	N/A	N/A	6.00	N/A	N/A
Arsenic	22	9	1	5	59%	41%	B	2.66	0.94	2.20	1.62	2.25
Beryllium	22	17	0.5	1.1	23%	77%	C	N/A	N/A	N/A	N/A	N/A
Cadmium	22	18	0.5	1	18%	82%	C	N/A	N/A	N/A	N/A	N/A
Chromium	22	1	1	21	95%	5%	A	8.14	6.20	9.00	0.26	-1.05
Copper	22	9	2	16	59%	41%	B	8.39	3.40	8.00	0.99	0.66
Lead	22	0	1.4	16.3	100%	0%	A	5.69	4.19	5.55	1.15	1.07
Mercury	22	22	0.1	0.1	0%	100%	E	N/A	N/A	0.10	N/A	N/A
Nickel	22	9	4	20	59%	41%	B	11.69	4.27	11.00	0.79	-0.26
Selenium	22	22	0.5	0.6	0%	100%	E	N/A	N/A	0.60	N/A	N/A
Silver	22	22	1	1	0%	100%	E	N/A	N/A	1.00	N/A	N/A
Thallium	22	22	1	1	0%	100%	E	N/A	N/A	1.00	N/A	N/A
Zinc	22	0	2	74	100%	0%	A	23.27	19.27	21.50	0.87	0.54

Table 5-3 (continued)
Soil Background Calculations
FFTA-MAAF Remedial Investigation Report

Analyte	Shapiro-Wilk W-Value Original Data	Shapiro-Wilk W-Value Logged Data	Critical W Value 98%	Censored Plot r Value Original Data	Detects Only Plot r Value Original Data	Censored Plot r Value Logged Data	Detects Only Plot r Value Logged Data	Critical r Value 97.50%	Distribution Type
Antimony	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	Unknown
Arsenic	N/A	N/A	N/A	0.91	0.867	0.575	0.065	0.944	Nonparametric
Beryllium	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	Nonparametric
Cadmium	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	Nonparametric
Chromium	0.906	0.883	0.892	N/A	N/A	N/A	N/A	N/A	Normal
Copper	N/A	N/A	N/A	0.931	0.963	0.932	0.994	0.944	Normal
Lead	0.863	0.906	0.892	N/A	N/A	N/A	N/A	N/A	Lognormal
Mercury	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	Unknown
Nickel	N/A	N/A	N/A	0.93	0.960	0.932	0.983	0.944	Normal
Selenium	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	Unknown
Silver	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	Unknown
Thallium	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	Unknown
Zinc	0.895	0.906	0.892	N/A	N/A	N/A	N/A	N/A	Normal

Table 5-3 (continued)
Soil Background Calculations
FFTA-MAAF Remedial Investigation Report

Analyte	UTL Type	UTL Coverage (f)	Adjustment Type	Adjusted Mean	Adjusted Standard Deviation	UTL (g)	UTL Log (h)	Background Type	Background Value	Background Units
Antimony	N/A	N/A	N/A	N/A	N/A	N/A	N/A	Median DL	6.00	mg/kg
Arsenic	Nonparametric	96%	N/A	N/A	N/A	5.00	N/A	Nonparametric UTL	5.00	mg/kg
Beryllium	Nonparametric	96%	N/A	N/A	N/A	1.10	N/A	Nonparametric UTL	1.10	mg/kg
Cadmium	Nonparametric	96%	N/A	N/A	N/A	1.00	N/A	Nonparametric UTL	1.00	mg/kg
Chromium	Parametric	98%	N/A	N/A	N/A	24.06	N/A	Parametric UTL	24.06	mg/kg
Copper	Parametric	98%	Aitchison's	4.955	4.942	17.68	N/A	Parametric UTL	17.68	mg/kg
Lead	Parametric	98%	N/A	N/A	N/A	32.31	N/A	Parametric UTL	32.31	mg/kg
Mercury	N/A	N/A	N/A	N/A	N/A	N/A	N/A	Median DL	0.10	mg/kg
Nickel	Parametric	98%	Aitchison's	6.909	6.711	24.18	N/A	Parametric UTL	24.18	mg/kg
Selenium	N/A	N/A	N/A	N/A	N/A	N/A	N/A	Median DL	0.60	mg/kg
Silver	N/A	N/A	N/A	N/A	N/A	N/A	N/A	Median DL	1.00	mg/kg
Thallium	N/A	N/A	N/A	N/A	N/A	N/A	N/A	Median DL	1.00	mg/kg
Zinc	Parametric	98%	N/A	N/A	N/A	72.86	N/A	Parametric UTL	72.86	mg/kg

Notes:

N/A - Not Applicable
DL - Detection Limit
a - For data set groups A-D, this corresponds to the minimum detected value; for data set E this is the minimum DL
b - For data set groups A-D, this corresponds to the maximum detected value; for data set E this is the maximum DL
c - Calculated for data set group A using 1/2 DL; calculated for data set group B using detected values; not calculated for data set groups C, D, and E
d - For data set groups A and B, this is the median of all detected values; for data set group E this is the median DL; not calculated for data set groups C and D
e - For data set groups A and B, this is based on all detected values; not calculated for data set groups C, D, and E

Table 5-4
Metals Detections Above Background in Post-Pilot Study Soil Borings
FFTA-MAAF Remedial Investigation Report

Metal	Background Value (mg/kg)	Detection Above Background (mg/kg)	Sample Point	Sample Depth
Beryllium	**1.10**	1.20	PSB-21	0.5-1.0
		1.30	PSB-36	4-7
Cadmium	**1.00**	1.20	PSB-4	1-3
		1.30	PSB-8	3.9-6.1
		1.30	PSB-10	1-3
		1.40	PSB-12	1-3
		1.20	PSB-17	0.5-1.0
		1.60	PSB-21	0.5-1.0
		1.30	PSB-34	4-7
		1.50	PSB-36	4-7
Copper	**17.68**	32.00	PSB-22	0.5-1.0
		21.00	PSB-36	4-7
Lead	**32.31**	507.00	PSB-4	1-3
		101.00	PSB-4	4.2-6
		36.40	PSB-4	14.8-15.8
Selenium	**0.60**	0.70	PSB-24	0.5-1.0
Zinc	**72.86**	89.00	PSB-4	1-3
		78.00	PSB-8	3.9-6.1
		84.00	PSB-21	0.5-1.0
		74.00	PSB-24	4.2-7
		86.00	PSB-36	4-7
		74.00	PSB-46	0.5-1.0

Notes:

mg/L = milligrams per kilogram

Data from *Pilot Study Report* (LBA, 1999)

Table 5-5
95 Percent Upper Confidence Limit Calculation for Lead in Soil
FFTA-MAAF Remedial Investigation Report

Equation for lognormally distributed data:

$$UCL = e^{(\bar{x} + 0.5s^2 + sH/\sqrt{n-1})}$$

Where:

UCL = 95 percent upper confidence limit
e = Constant (base of the natural log, equal to 2.718)
$\bar{x}$ = Mean of the transformed data
s = Standard deviation of the transformed data
H = H-statistic (Gilbert, 1987)
n = Number of samples

Variable Values:

	n	$\bar{x}$	s	H	95 UCL (mg/kg)
Former Fire Training Pit Data for Lead in Soils					
Lead	39	1.94	1.12	2.51	20.7

Notes:
Former fire training pit data set includes analytical results from sample locations PSB-5, PSB-4, PSB-30, PSB-13, PSB-15, PSB-16, PSB-3, and PSB-14.
Values for mean and standard deviation represent natural log transformed data.
H values were obtained via Lagrangian 4-point interpolation from the values presented in Gilbert (1987).

Table 5-6
Frequency of Detections in Post-Pilot Study Soil Samples and RI Study Soil Samples
FFTA-MAAF Remedial Investigation Report

Chemical	Post-Pilot Study Soil Number of Dections/ Number of Samples	 Frequency of Positive Detections	RI Study Soil Number of Dections/ Number of Samples	 Frequency of Positive Detections
TPH-DRO				
TPH-DRO *	50 / 232	21.60%	15/145	10.34%
TPH-GRO				
TPH-GRO	22 / 232	9.50%	14/145	9.66%
Volatile Organic Compounds				
Benzene	0 / 232	0.00%	0/145	0.00%
Dichloromethane	0 / 232	0.00%	0/145	0.00%
1,2-Dichloroethene	0 / 232	0.00%	4/145	2.76%
Ethylbenzene	3 / 232	1.30%	4/145	2.76%
Tetrachloroethene	8 / 232	3.40%	16/145	11.03%
Trichloroethene	3 / 232	1.30%	3/145	2.07%
Trichloromethane	0 / 232	0.00%	0/145	0.00%
1,1,1-Trichloroethane	0 / 232	0.00%	0/145	0.00%
Toluene	3 / 232	1.30%	3/145	2.07%
Xylenes, Total	15 / 232	6.50%	10/145	6.90%
Semivolatile Organic Compounds				
Acenaphthene	1 / 232	0.40%	NA	NA
Bis(2-ethylhexyl)phthalate	1 / 232	0.40%	NA	NA
Fluorene	1 / 232	0.40%	NA	NA
2-Methyl Naphthalene	15 / 232	6.50%	NA	NA
4-Methylphenol	0 / 232	0.00%	NA	NA
Naphthalene	10 / 232	4.30%	NA	NA
Phenanthrene	5 / 232	2.20%	NA	NA
Pyrene	4 / 232	1.70%	NA	NA

Notes:

TPH-DRO - Total Petroleum Hydrocarbons - Diesel Range Organics

TPH-GRO - Total Petroleum Hydrocarbons - Gasoline Range Organics

NA = Not Analyzed

* = TPH-DRO frequency of positive detections for the RI soil results includes TPH-motor oil, which according to the laboratory appeared to be weathered diesel fuel.

Compounds detected at a frequency greater than 5% are highlighted

References:

Data from *Pilot Study Report* (LBA, 1999) and *RI Soil QCSR (BMcD, 1999d)*

Table 5-7
Frequency of Detections in Groundwater August 1996 to August 1999
FFTA-MAAF Remedial Investigation Report

Chemical	Groundwater 10/93-6/96		Groundwater 7/96-9/99	
	Number of Dections/ Number of Samples	Frequency of Positive Detections	Number of Dections/ Number of Samples	Frequency of Positive Detections
TPH-DRO				
TPH-DRO	6 / 123	4.90%	18 / 383	4.70%
TPH-GRO				
TPH-GRO	18 / 123	14.60%	55 / 458	12.01%
Volatile Organic Compounds				
Acetone	0 / 123	0.00%	2 / 474	0.42%
Benzene	6 / 123	4.90%	65 / 474	13.71%
Dichloromethane	5 / 123	4.07%	3 / 41	7.32%
1,2-Dichloroethene	38 / 123	30.90%	8 / 32	25.00%
cis-1,2-Dichloroethene	NA	NA	191 / 442	43.21%
trans-1,2-Dichloroethene	NA	NA	58 / 442	13.12%
1,1-Dichloroethene	0 / 123	0.00%	5 / 474	1.05%
Ethylbenzene	7 / 123	5.70%	15 / 474	3.16%
Tetrachloroethene	22 / 123	17.90%	90 / 474	18.99%
Trichloroethene	31 / 123	25.20%	143 / 474	30.17%
Trichloromethane	1 / 123	0.80%	1 / 474	0.21%
1,1,1-Trichloroethane	1 / 123	0.80%	NA	NA
Toluene	14 / 123	11.40%	22 / 474	4.64%
Vinyl Chloride	0 / 123	0.00%	5 / 474	1.05%
o-Xylene	NA	NA	10 / 474	2.11%
m-&/or-p-Xylene	NA	NA	12 / 474	2.53%
Xylenes, Total	9 / 123	7.30%	NA	NA
Semivolatile Organic Compounds				
Acenaphthene	0 / 123	0.00%	NA	NA
Bis(2-ethylhexyl)phthalate	2 / 123	1.60%	NA	NA
Fluorene	0 / 123	0.00%	NA	NA
2-Methyl Naphthalene	1 / 123	0.80%	NA	NA
4-Methylphenol	1 / 123	0.80%	1 / 164	0.61%
Naphthalene	6 / 123	4.90%	10 / 474	2.11%
Phenanthrene	0 / 123	0.00%	NA	NA
Phenol	0 / 123	0.00%	1 / 474	0.21%
Pyrene	0 / 123	0.00%	NA	NA

Notes:

TPH-DRO - Total Petroleum Hydrocarbons - Diesel Range Organics

TPH-GRO - Total Petroleum Hydrocarbons - Gasoline Range Organics

NA = Not Analyzed

Compounds detected at a frequency greater than 5% are highlighted

References:

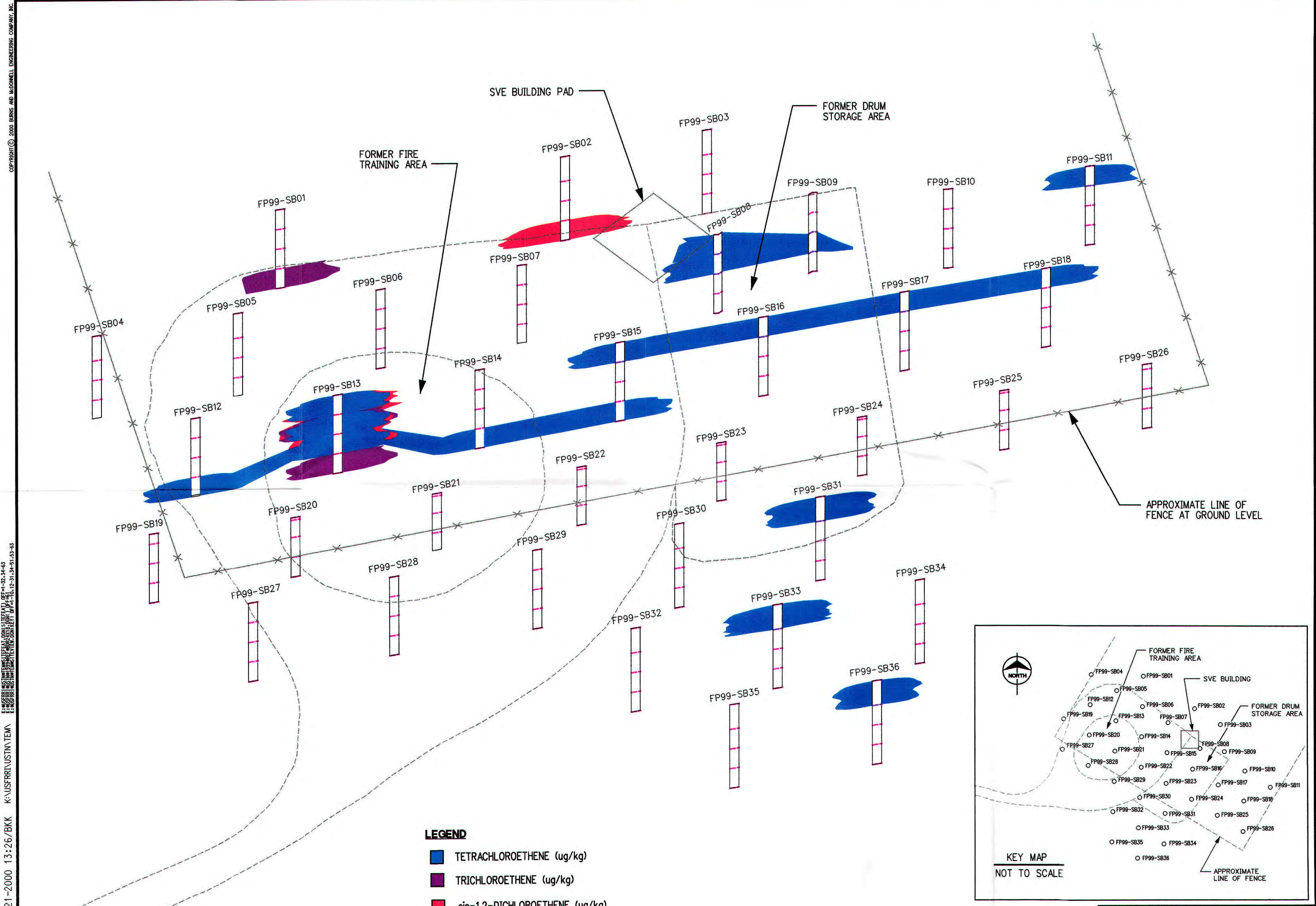
Groundwater data taken from *Data Summary Reports*

TABLE 5-8
Soil To Groundwater Protection Pathway Comparison for PCOPCs
FFTA-MAAF Remedial Investigation Report

Chemical Name	Soil to Groundwater Protection Pathway (μg/kg)	Maximum Contaminant Concentration (μg/kg)	Location of Maximum Contaminant Concentration
Benzene	80	320 U**	FP99-SB13b
Ethylbenzene	55,000	14,000	FP99-SB13b
Toluene	40,000	39,000	FP99-SB13b
Xylenes	700,000	77,000	FP99-SB13b
Tetrachloroethene	180	170	FP99-SB16a
Trichloroethene	200	19 J	FP99-SB01d-r
cis-1,2-Dichloroethene	800	800 J	FP99-SB13b
trans-1,2-Dichloroethene	1,500	320 U**	FP99-SB13b
Vinyl Chloride	20	39 U**	FP99-SB14d-r
TPH-GRO	39,000	1,800,000	FP99-SB13c
TPH-DRO	3,000,000	11,700,000	FP99-SB13c
TPH*	Sum of Ratios = 1	50	NA

Notes:

U	Qualified as undetected by laboratory
J	Qualified as estimated by laboratory
r	Results from resampling DMD analysis
*	Residential TPH is calculated as [(TPH-GRO/39,000 μg/L) + (TPH-DRO/3,000,000 μg/L)] = N. N must be less than or equal to 1.
**	Nondetects were used for comparing benzene, trans-1,2-dichloroethene, and vinyl chloride because this nondetect value represents the most conservative concentration possible.

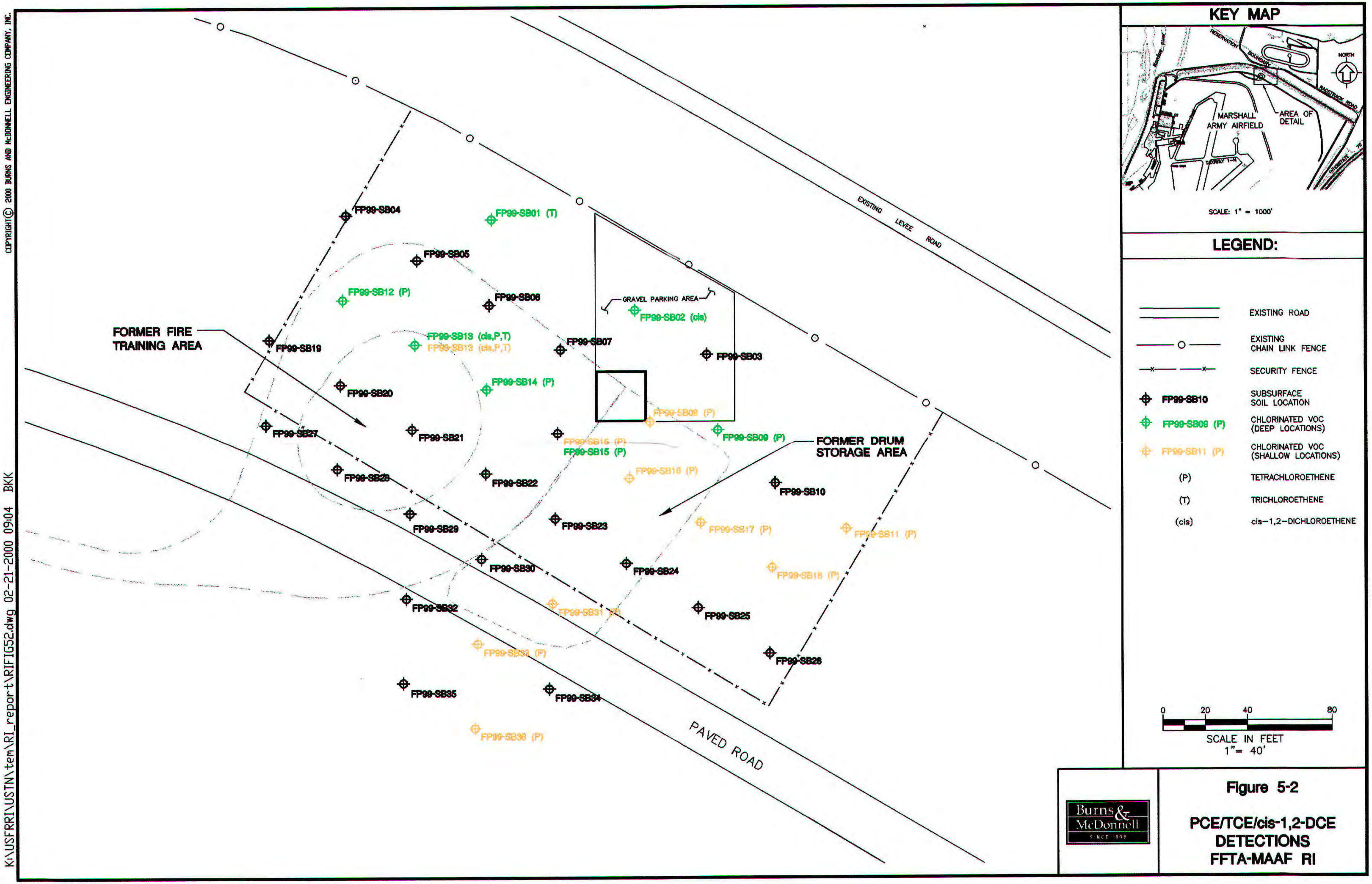


Burns & McDonnell
SINCE 1898

Figure 5-1

PCE, TCE AND
cis-1,2-DCE IN SOIL
JUNE, 1999

FFTA-MAAF RI

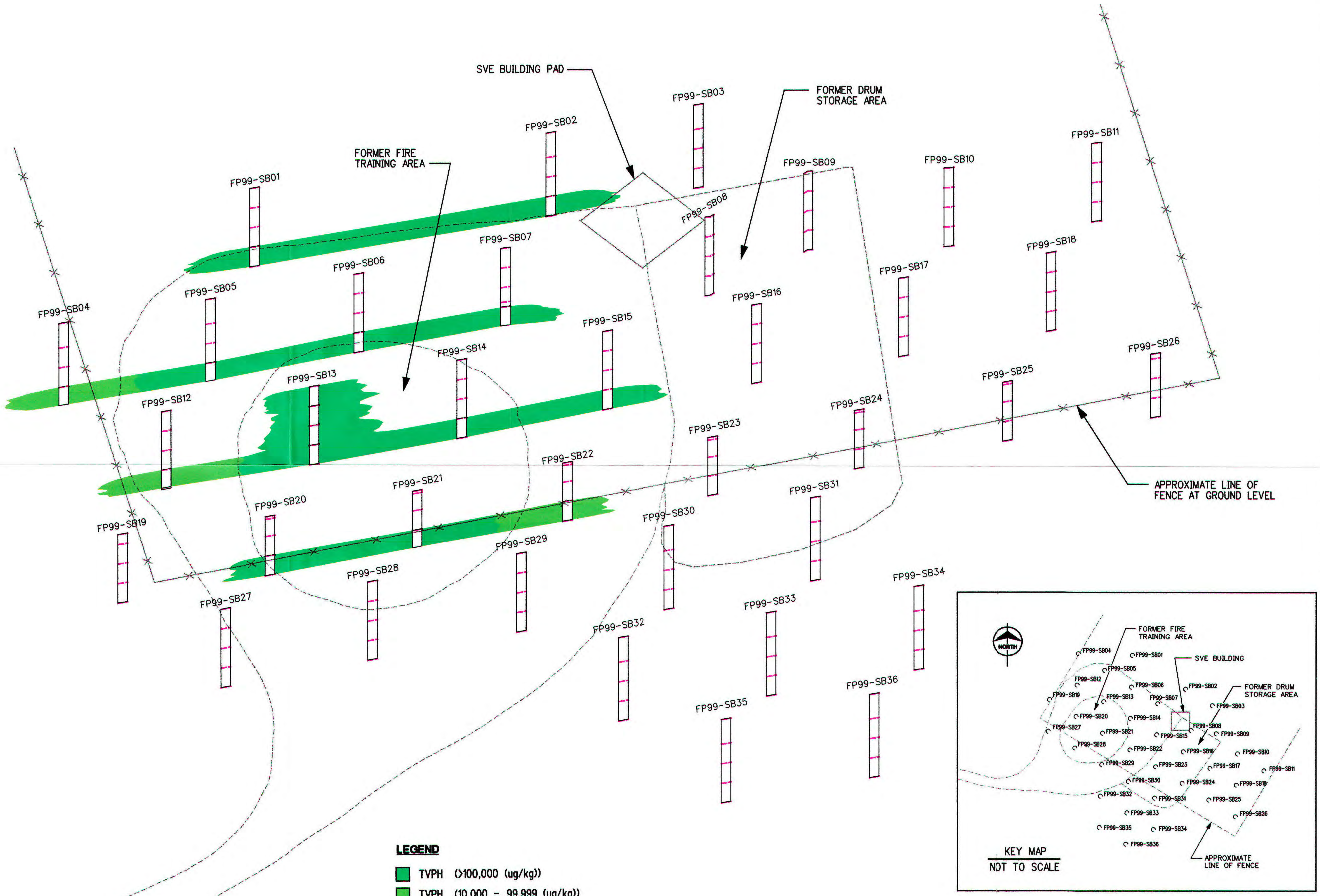


Burns & McDonnell
SINCE 1898

Figure 5-2

PCE/TCE/cis-1,2-DCE DETECTIONS FFTA-MAAF RI

K:\USFRRI\USTN\tem\RI_report\RIFIG52.dwg 02-21-2000 09:04 BKK



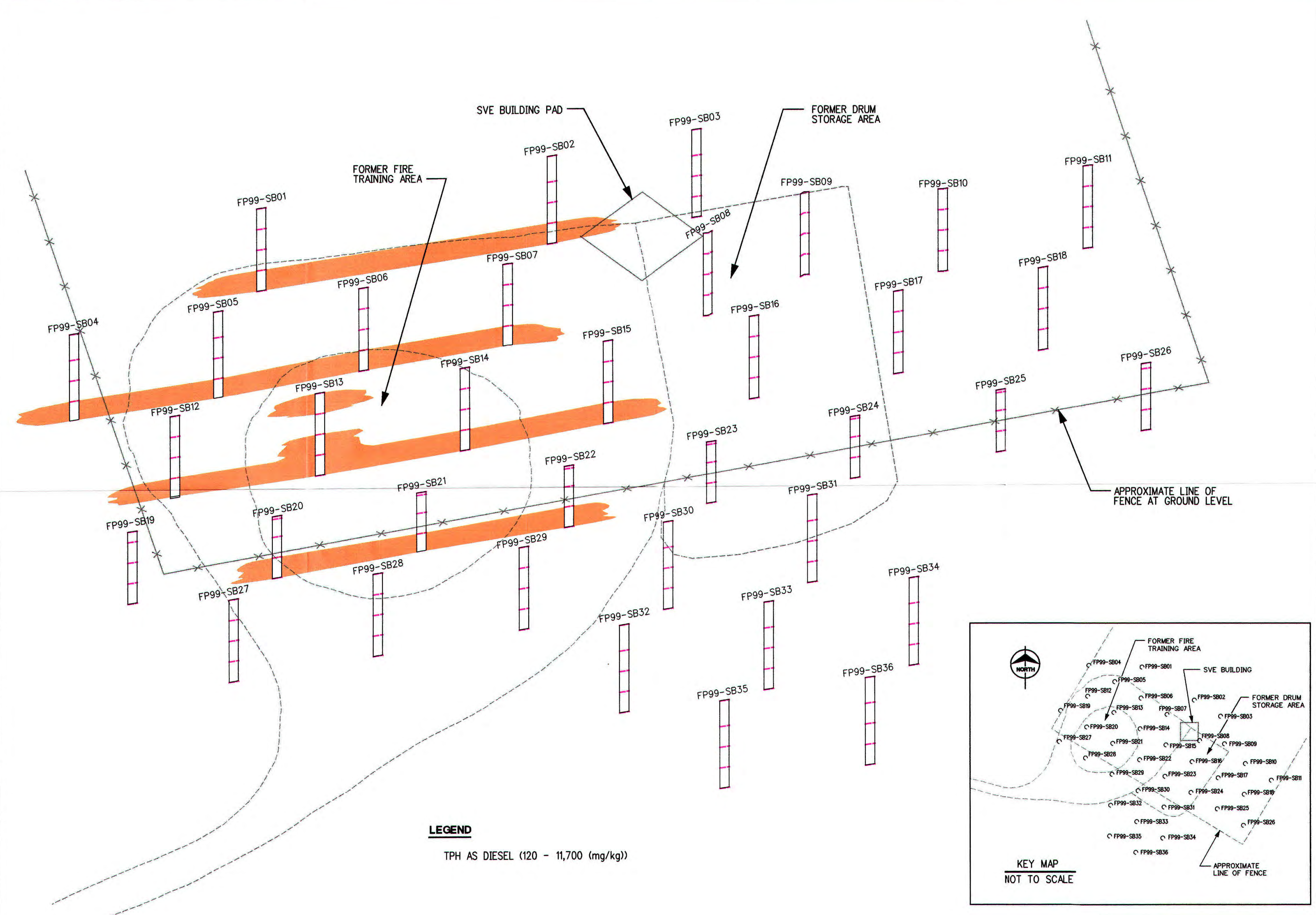
LEGEND

🟩 TVPH (>100,000 (ug/kg))
🟩 TVPH (10,000 - 99,999 (ug/kg))
🟩 TVPH (1,000 - 9,999 (ug/kg))

Burns & McDonnell
SINCE 1898

Figure 5-3
TOTAL VOLATILE PETROLEUM HYDROCARBONS IN SOIL
JUNE, 1999
FFTA-MAAF RI

RITVPH.DGN/ 9-21-2000 10:59/TFG
K:\RES\GLOBAL\STDBDR\ARCH\ 2D\
K:\USFRRI\USTN\TEM\RI_report
K:#USFRRI#USTN#TEM#SITEFEAT.DGN(SITEFEAT) OFF=1-32,34-63
K:#USFRRI#USTN#TEM#PCE.DGN(PCE) OFF=5,10-12,22,24,27-34,36,38,45-46,54-56
K:#USFRRI#USTN#TEM#STEVIEW.DGN(KEY) OFF=1-10,12-31,34-51,53-63
K:#USFRRI#USTN#TEM#RI_REPORT#RI182480.DGN(RIBDR) OFF=10-11,25,51-56,61
K:#USFRRI#USTN#1999#REF#BDR24X18.DGN(BORDER) OFF=61

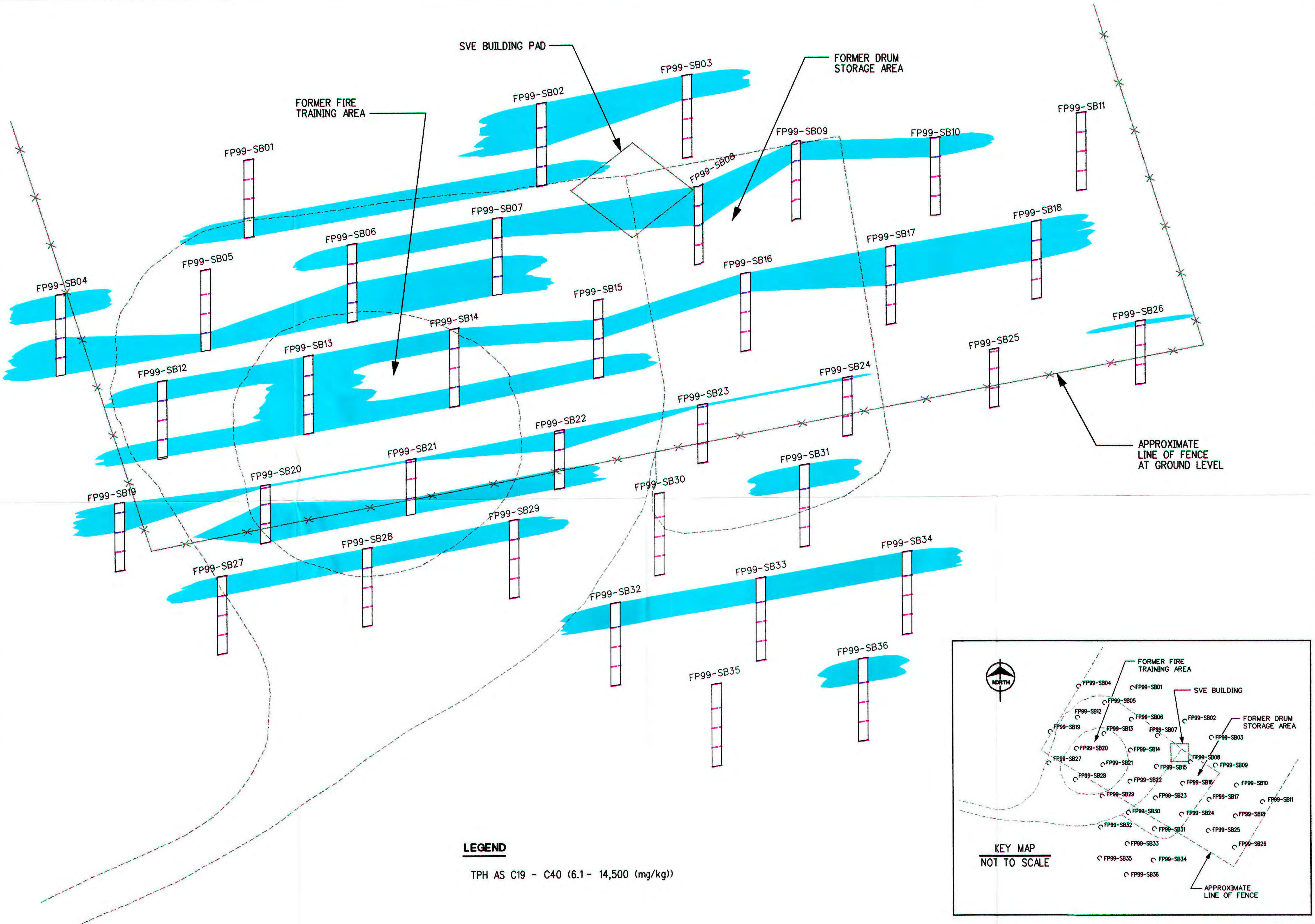


Burns & McDonnell
SINCE 1898

Figure 5-4

TPH REPORTED
AS DIESEL IN SOIL
JUNE, 1999
FFTA-MAAF RI

K:\RES\GLOBAL\STDBDR\ARCH. 20\
RITPHDSL.DGN/ 9-21-2000 11:06/TFG K:\USFRRI\USTN\TEMA\RL_report\



LEGEND

TPH AS C19 - C40 (6.1 - 14,500 (mg/kg))

Burns & McDonnell SINCE 1898

Figure 5-5

TPH REPORTED
AS C19-C40 IN SOIL
JUNE, 1999

FFTA-MAAF RI

TPHMOIL2.DGN/ 9-29-2000 10:33/TFG

K:\USFRRI\USTN\TEM\

Notes:
750 ft =Distance Between Wells Down Centerline of the Plume.

Zero entries on the data table indicate non-detects, see Table 3-7 for analytical reporting limits.

Burns & McDonnell
SINCE 1898

Figure 5-6
Groundwater
PCOPC Trend Chart
FFTA-MAAF RI

Notes:
750 ft = Distance Between Wells Down Centerline of the Plume Data from Data Summary Reports

Zero entries on the data table indicate non-detects, see Table 3-7 for analytical reporting limits.

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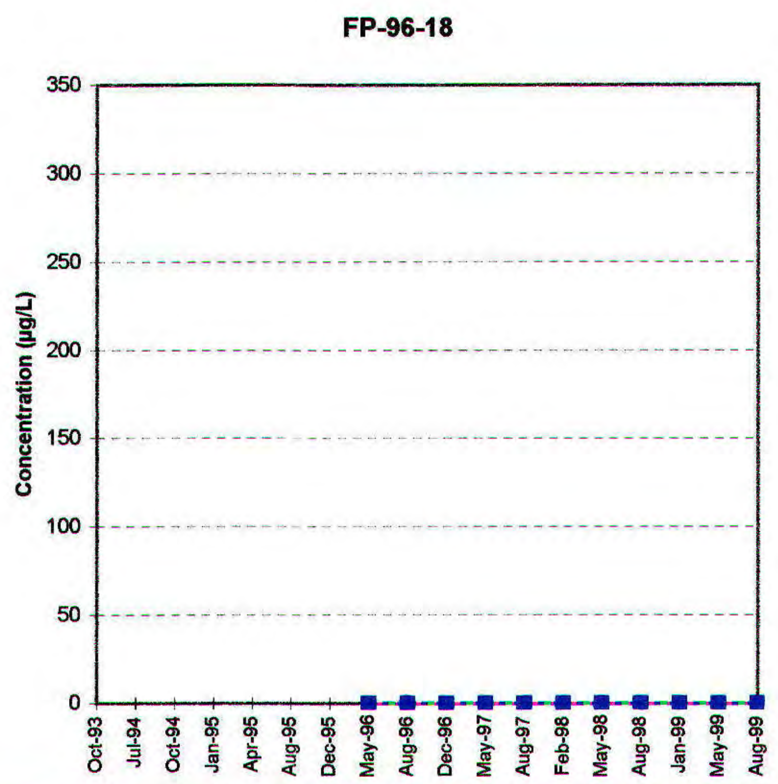
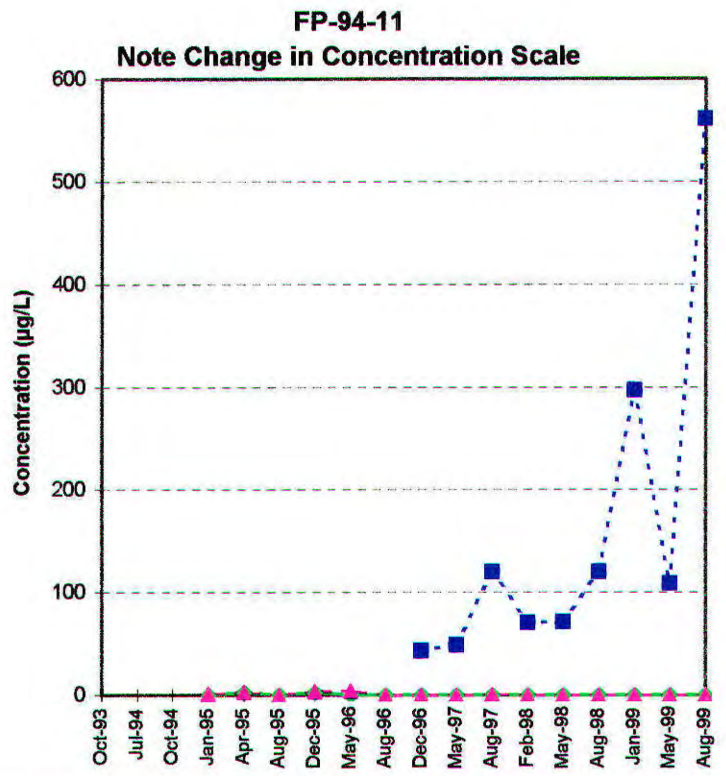
SINCE 1898

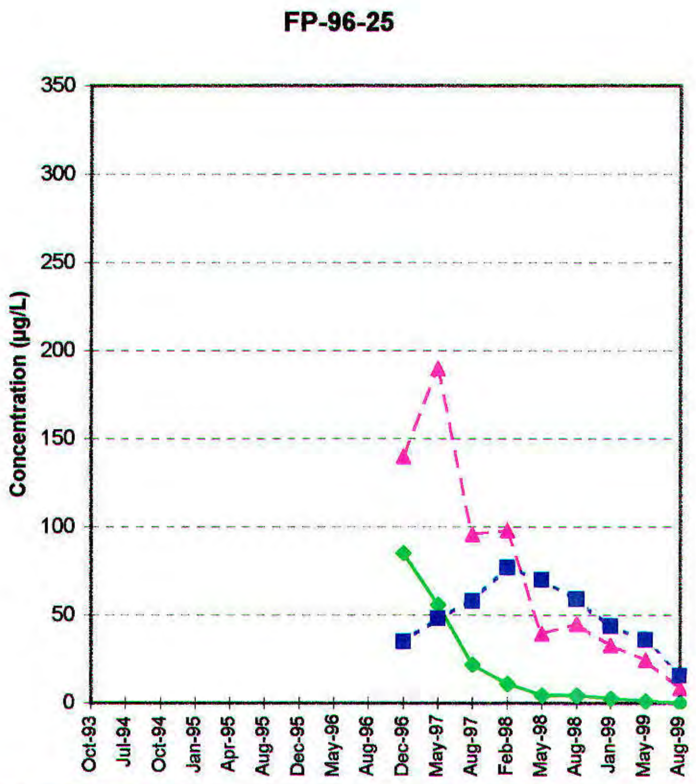
Figure 5-7
BTEX and TPH Trend Chart
FFTA-MAAF RI



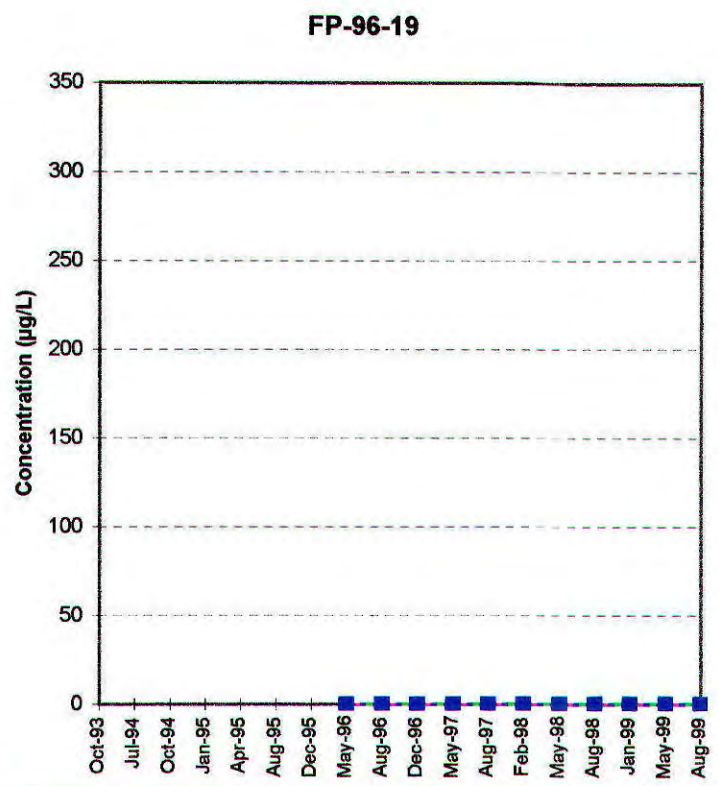
	Oct-93	Jul-94	Oct-94	Jan-95	Apr-95	Aug-95	Dec-95	May-96	Aug-96	Dec-96	May-97	Aug-97	Feb-98	May-98	Aug-98	Jan-99	May-99	Aug-99
PCE								0	0	0	0	0	0	0	0	0	0	0
TCE								0	0	0	0	0	0	0	0	0	0	0
cis,-1,2-DCE								0	0	0	0	0	0	0	0	0	0	0



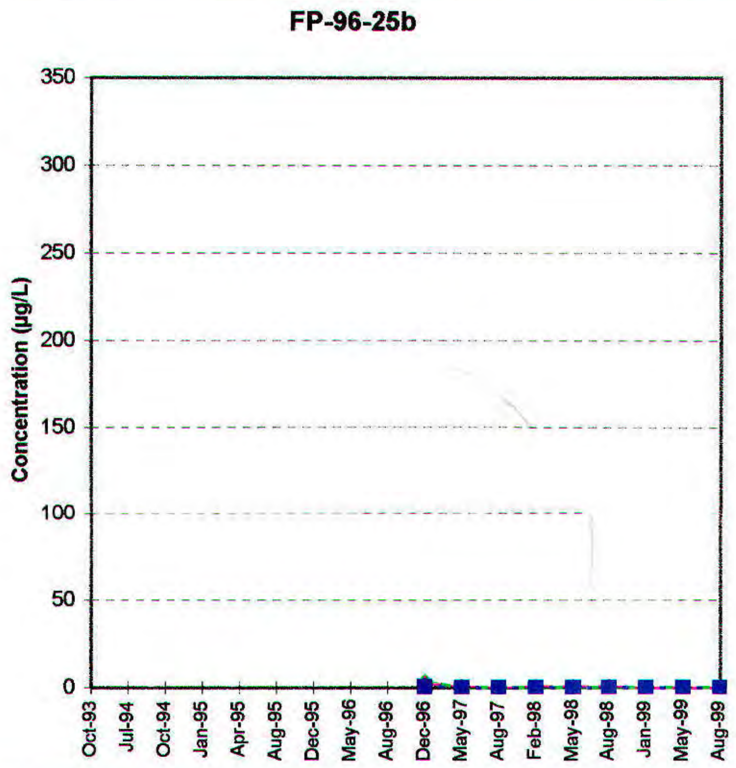
	Oct-93	Jul-94	Oct-94	Jan-95	Apr-95	Aug-95	Dec-95	May-96	Aug-96	Dec-96	May-97	Aug-97	Feb-98	May-98	Aug-98	Jan-99	May-99	Aug-99
PCE				0	2.5	0	2.2	0	0	0	0	0	0	0	0	0	0	0
TCE				1	3.1	0	3.9	4.6	0	0	0	0.7	0	0	0	0	0	0
cis,-1,2-DCE										43	49	120	71	71.2	120	297	109	561



	Oct-93	Jul-94	Oct-94	Jan-95	Apr-95	Aug-95	Dec-95	May-96	Aug-96	Dec-96	May-97	Aug-97	Feb-98	May-98	Aug-98	Jan-99	May-99	Aug-99
PCE										85	56	22	11	4.5	4.3	2.4	1.2	0
TCE										140	190	96	98	39.7	45.2	33.2	24.9	8.9
cis,-1,2-DCE										35	48	58	77	70	59.3	43.9	36.2	15.7



	Oct-93	Jul-94	Oct-94	Jan-95	Apr-95	Aug-95	Dec-95	May-96	Aug-96	Dec-96	May-97	Aug-97	Feb-98	May-98	Aug-98	Jan-99	May-99	Aug-99
PCE								0	0	0	0	0	0	0	0	0	0	0
TCE								0	0	0	0	0	0	0	0	0	0	0
cis,-1,2-DCE								0	0	0	0	0	0	0	0	0	0	0

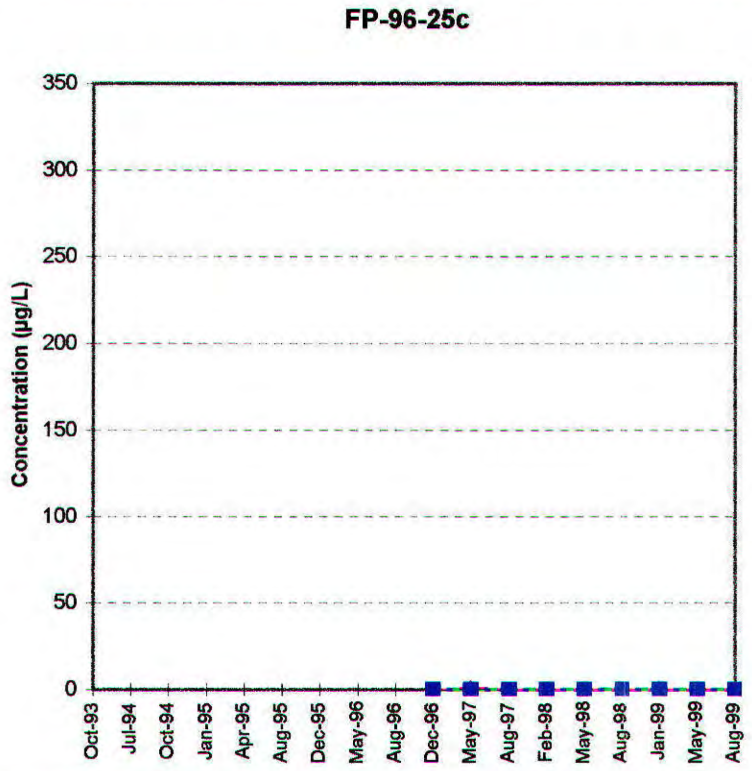


	Oct-93	Jul-94	Oct-94	Jan-95	Apr-95	Aug-95	Dec-95	May-96	Aug-96	Dec-96	May-97	Aug-97	Feb-98	May-98	Aug-98	Jan-99	May-99	Aug-99
PCE										3.4	0	0	0	0	0	0	0	0
TCE										2.4	0.8	0	0.7	0.8	0.8	0	0	0
cis,-1,2-DCE										0.6	0	0	0	0	0	0	0	0

—◆— PCE

– ▲ – TCE

· · ■ · · cis-1,2-DCE



	Oct-93	Jul-94	Oct-94	Jan-95	Apr-95	Aug-95	Dec-95	May-96	Aug-96	Dec-96	May-97	Aug-97	Feb-98	May-98	Aug-98	Jan-99	May-99	Aug-99
PCE										0	0	0	0	0	0	0	0	0
TCE										0	1	0	0	0	0	0	0	0
cis,-1,2-DCE										0	0	0	0	0	0	0	0	0

Notes:
Zero entries on the data table indicate non-detects, see Table 3-7 for analytical reporting limits.

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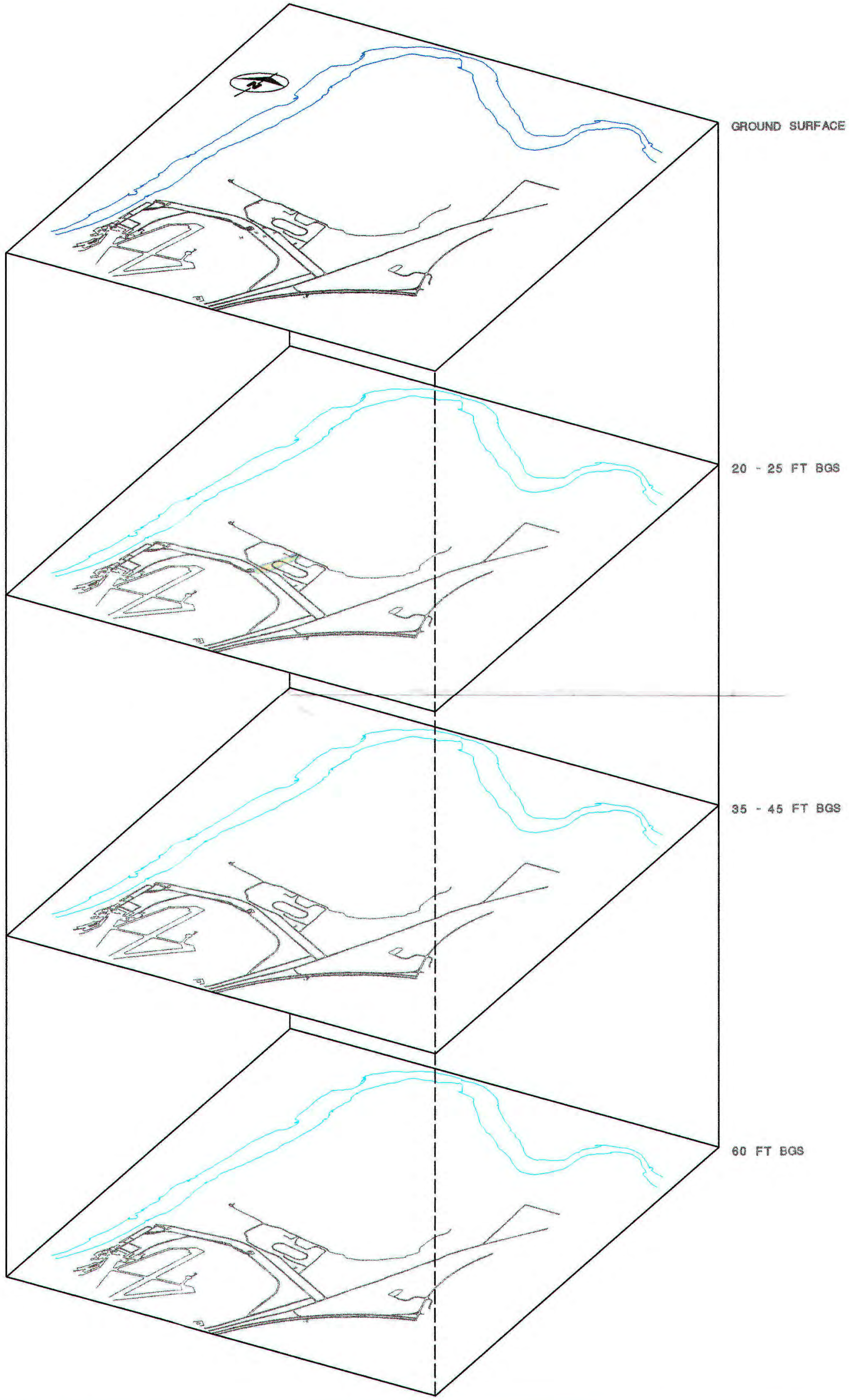
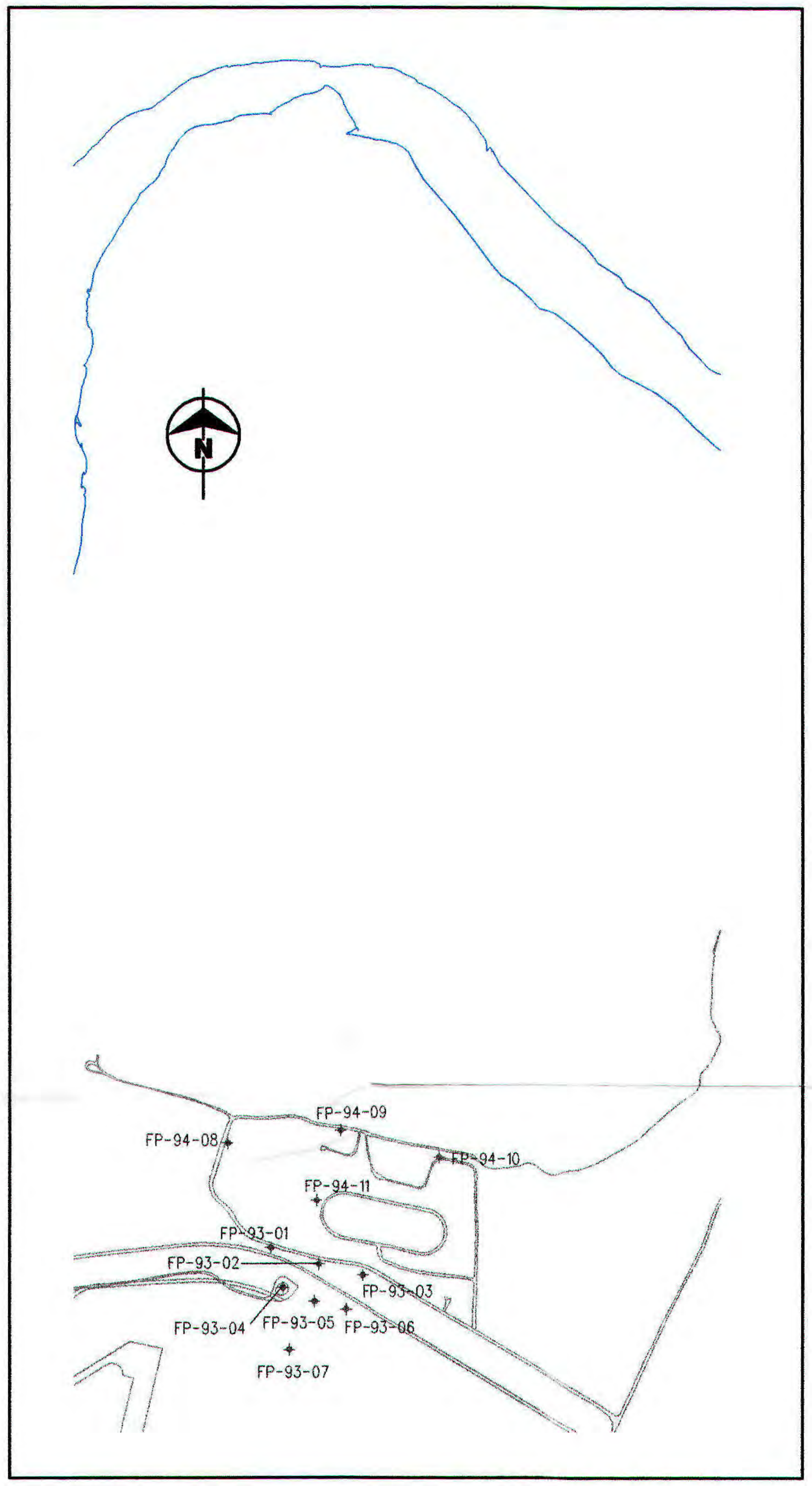
SINCE 1898

Figure 5-8
COPC Cross-Section Trend Chart
FFTA-MAAF RI





LEGEND

- ✦ MONITORING WELL OR CLUSTER
- 🟪 2 ug/L
- 🟦 5 ug/L
- 🟦 10 ug/L
- 🟦 25 ug/L
- 🟩 50 ug/L
- 🟩 100 ug/L
- 🟨 150 ug/L
- 🟨 200 ug/L
- 🟧 300 ug/L
- 🟧 400 ug/L
- 🟥 500 ug/L
- 🟥 700 ug/L

NOTE:

PLUME NOT FULLY DEFINED IN APRIL 1995

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SINCE 1898

Figure 5-9
PCE IN GROUNDWATER
APRIL 1995

FFTA-MAAF RI

0495PCESTACK.DGN/ 2-21-2000 9:51/BKK

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K:#USFRRI#USTN#999#FIG#SP27WELLSZ.DGN( ) OFF=5-10,12-32,34-56,59-60,62-63
K:#USFRRI#USTN#999#FIG#DR24X18.DGN( ) OFF=NONE
K:#USFRRI#USTN#999#FIG#05BASESTACK.DGN(BASE) OFF=5-6,8-10,12-40,42-57,60,63
K:\USFRRI\USTN\1999\FIG\

0495TCESTACK.DGN/ 2-21-2000 10:40/BKK

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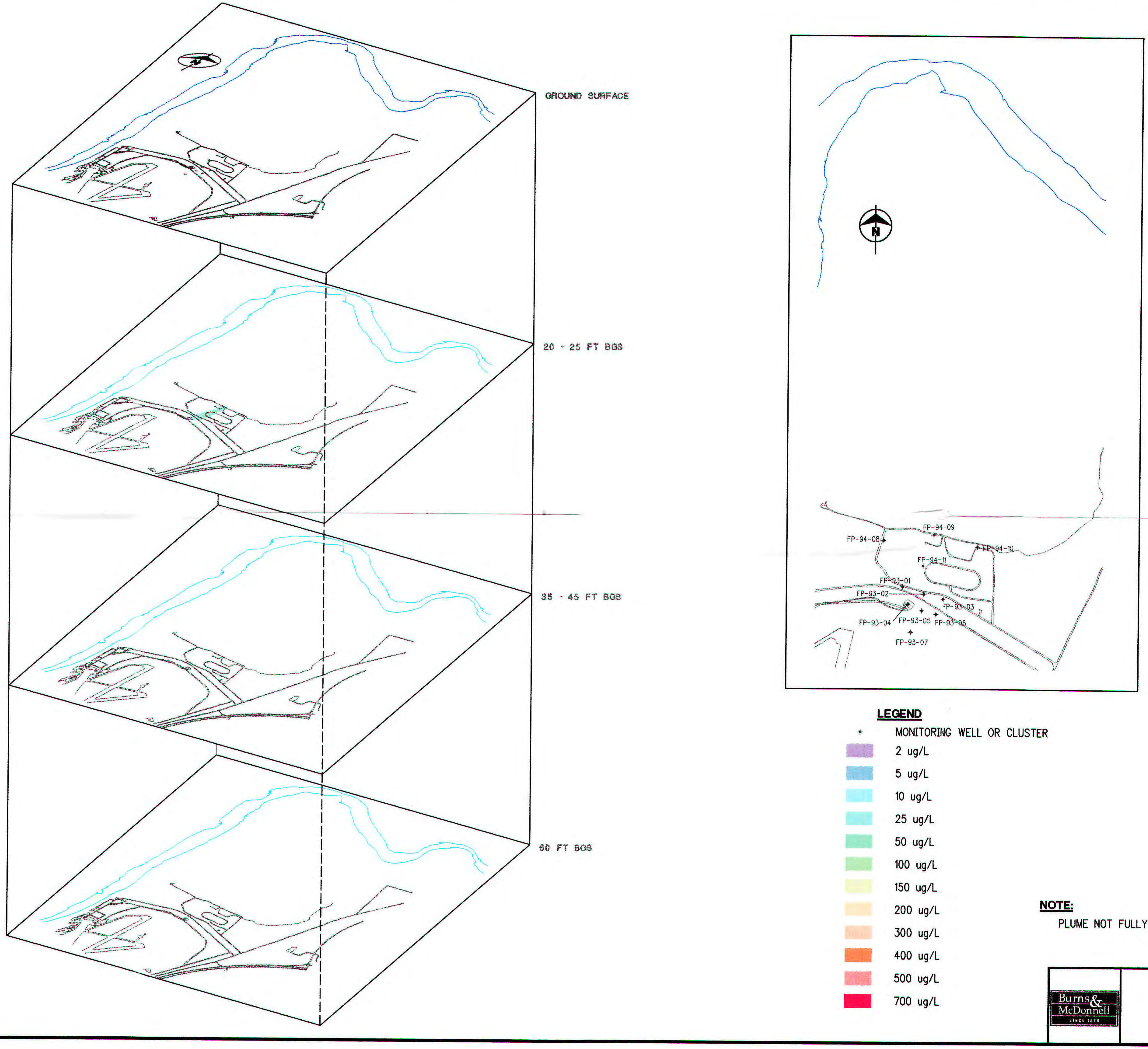
K:#USFRRI#USTN#1999#FIG#05INSET.DGN() OFF=7,21,23,25,27,31-33,35,37,39,41,43,45,47,58
K:#USFRRI#USTN#1999#FIG#SP27WELLSZ.DGN() OFF=5-10,12-32,34-56,59-60,62-63
K:#USFRRI#USTN#1999#FIG#BDR24X18.DGN() OFF=NONE
K:#USFRRI#USTN#1999#FIG#05BASESTACK.DGN(BASE) OFF=5-6,8-10,12-40,42-57,60,63
K:\USFRRI\USTN\1999 \FIG\
```



LEGEND

✦ MONITORING WELL OR CLUSTER
🟪 2 ug/L
🟦 5 ug/L
🟦 10 ug/L
🟦 25 ug/L
🟩 50 ug/L
🟩 100 ug/L
🟨 150 ug/L
🟨 200 ug/L
🟧 300 ug/L
🟧 400 ug/L
🟥 500 ug/L
🟥 700 ug/L

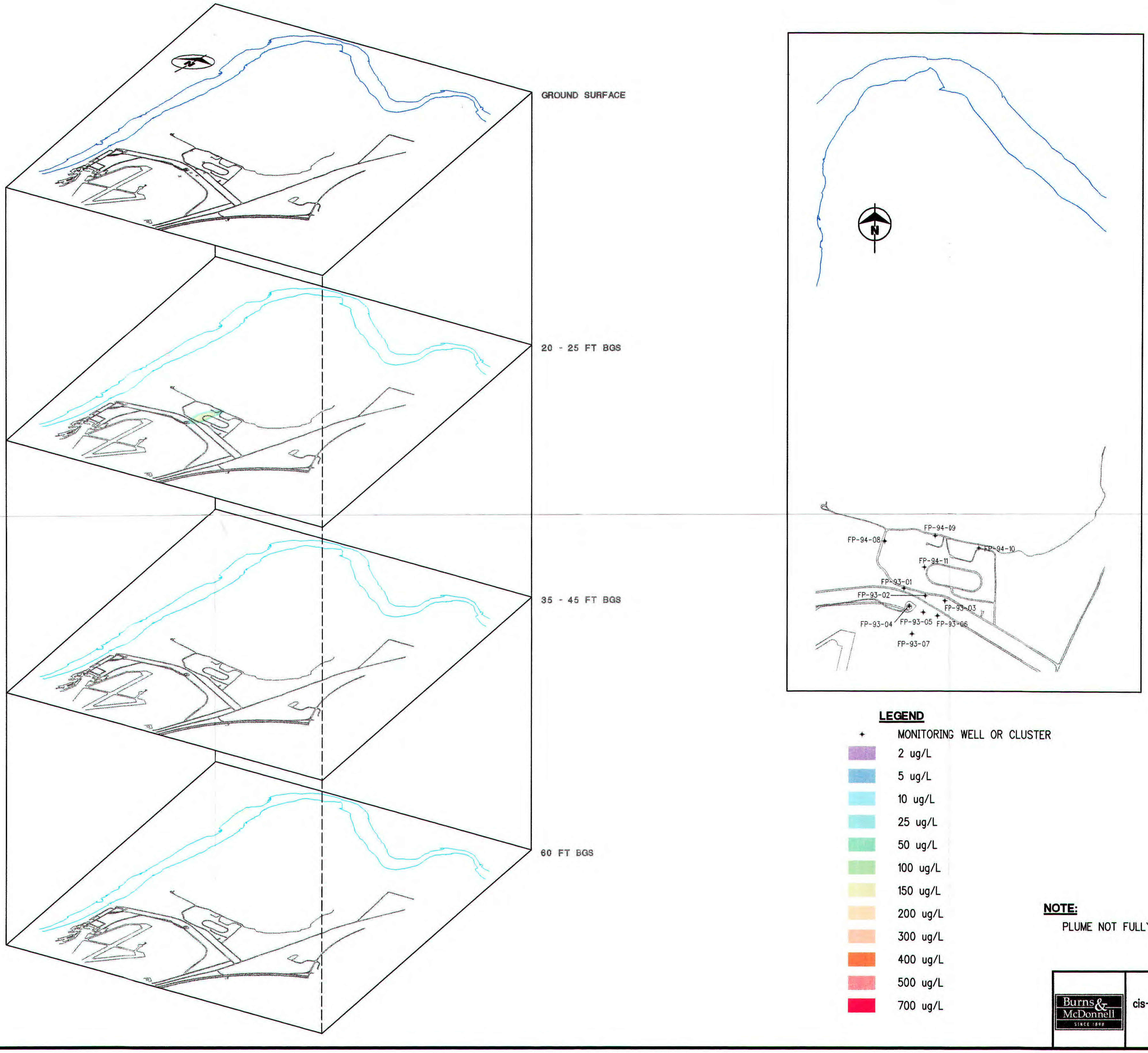
NOTE:
PLUME NOT FULLY DEFINED IN APRIL 1995

Burns & McDonnell
SINCE 1898

Figure 5-10
TCE IN GROUNDWATER
APRIL 1995

FFTA-MAAF RI

K:#USFRRI#USTN#1999#FIG#05INSET.DGN( ) OFF=7,21,23,25,27,31-33,35,37,39,41,43,45,47,58
K:#USFRRI#USTN#1999#FIG#SP27WELLS7.DGN( ) OFF=5-10,12-32,34-56,59-60,62-63
K:#USFRRI#USTN#1999#FIG#DR24X18.DGN( ) OFF=NONE
K:#USFRRI#USTN#1999#FIG#05BASESTACK.DGN(BASE) OFF=5-6,8-10,12-40,42-57,60,63
K:\USFRRI\USTN\1999\FIG\
0495DCESTACK.DGN/ 2-21-2000 10:21/BKK



NOTE:

PLUME NOT FULLY DEFINED IN APRIL 1995

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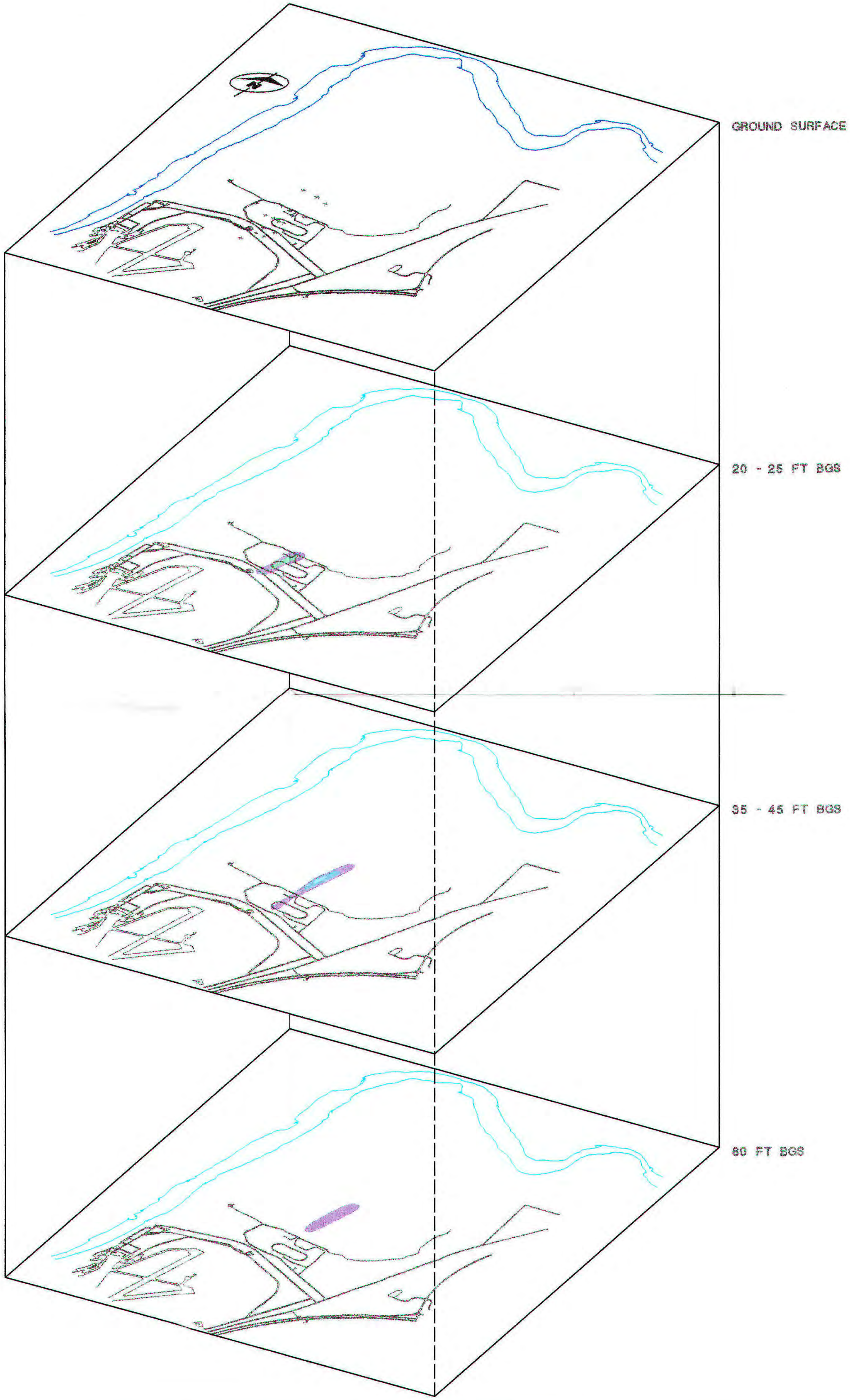
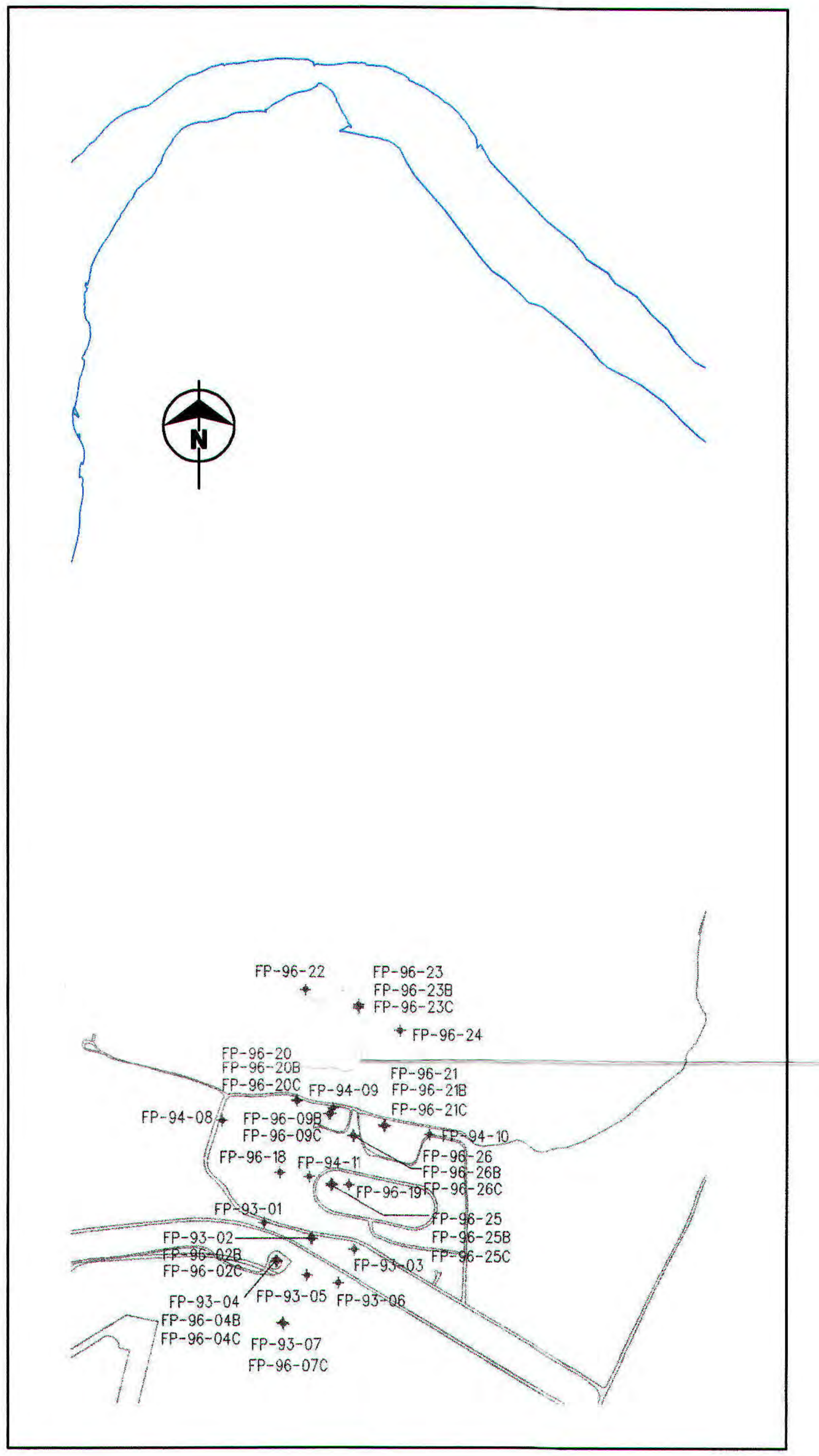
Figure 5-11
cis-1,2-DCE IN GROUNDWATER
APRIL 1995

FFTA-MAAF RI





LEGEND

✦	MONITORING WELL OR CLUSTER
🟪	2 ug/L
🟦	5 ug/L
🟦	10 ug/L
🟦	25 ug/L
🟩	50 ug/L
🟩	100 ug/L
🟨	150 ug/L
🟧	200 ug/L
🟧	300 ug/L
🟧	400 ug/L
🟥	500 ug/L
🟥	700 ug/L

NOTE:

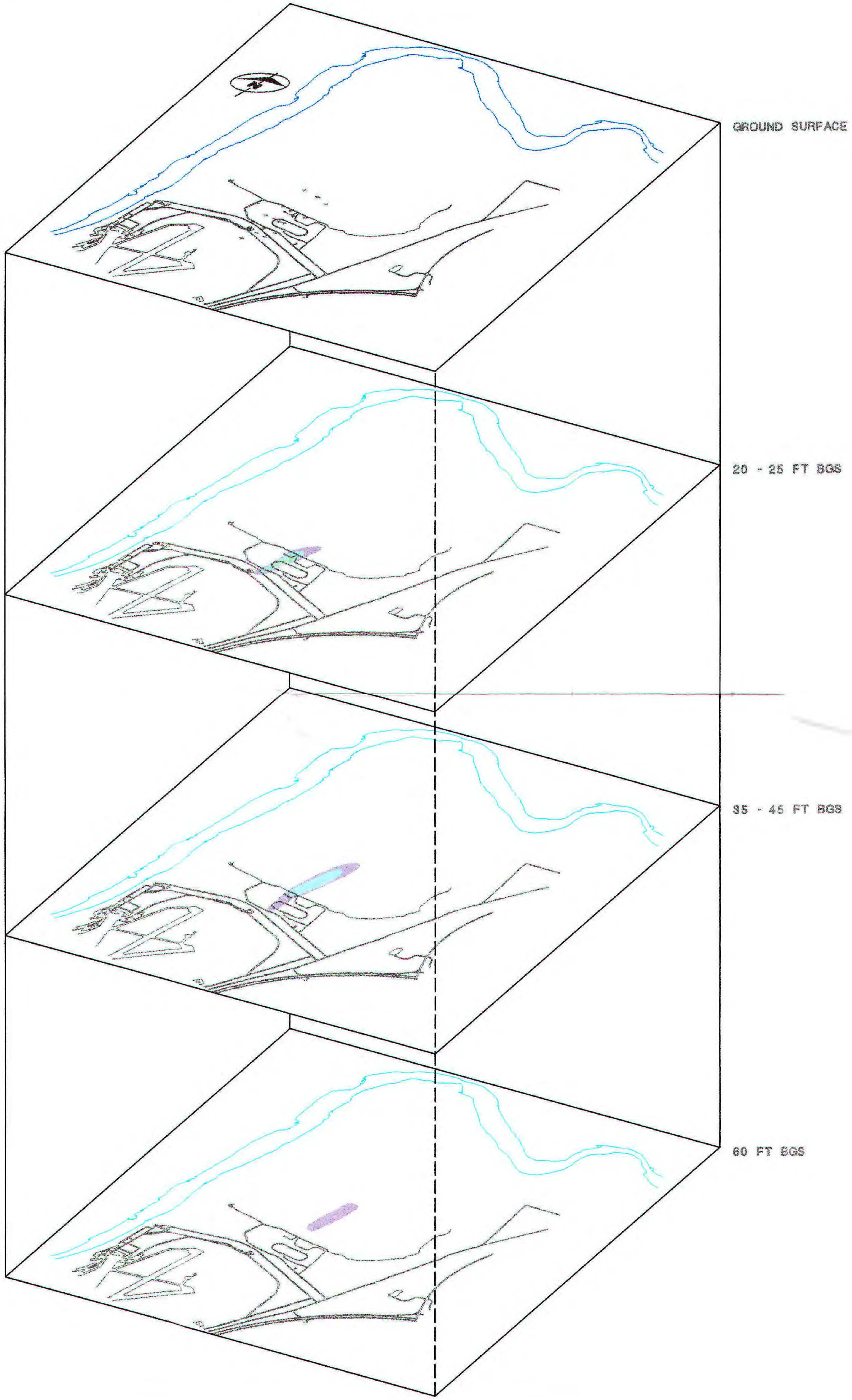
PLUME NOT FULLY DEFINED IN DECEMBER 1996

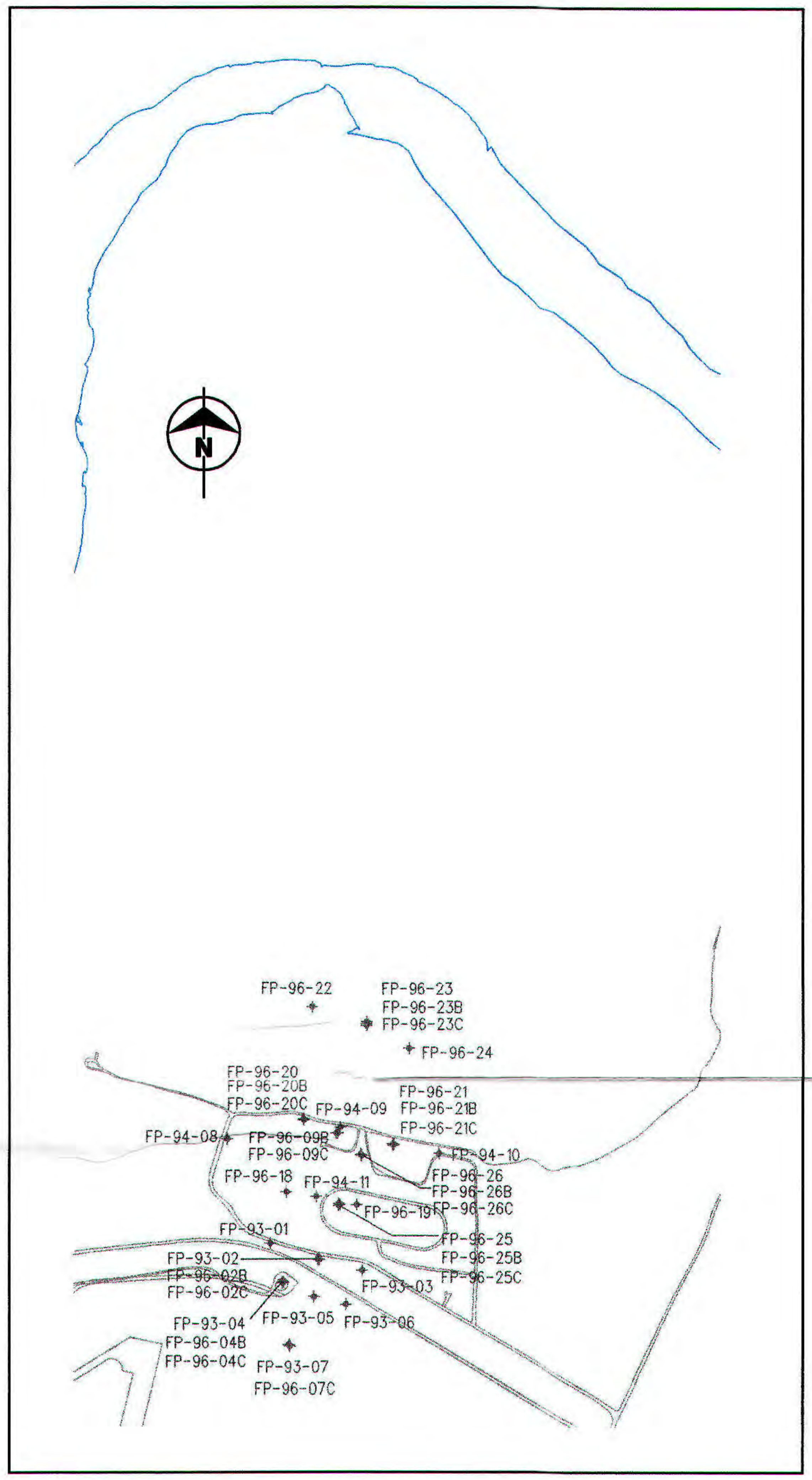
Burns & McDonnell
SINCE 1898

Figure 5-12
PCE IN GROUNDWATER
DECEMBER 1996

FFTA-MAAF RI

K:#USFRRI#USTN#1999#FIG#05INSET.DGN( ) OFF=7,21,23,27,30-33,35,37,39,41,43,45,47,58
K:#USFRRI#USTN#1999#FIG#SP27WELLSZ.DGN( ) OFF=5-10,12-32,34-56,59-60,62-63
K:#USFRRI#USTN#1999#FIG#BDR24X18.DGN( ) OFF=NONE
K:#USFRRI#USTN#1999#FIG#05BASESTACK.DGN(BASE) OFF=5-6,8-10,12-40,42-57,60,63
1296PCESTACK.DGN/ 2-21-2000 13:53/BKK K:\USFRRI\USTN\1999\FIG\





LEGEND

+	MONITORING WELL OR CLUSTER
🟪	2 ug/L
🟦	5 ug/L
🟦	10 ug/L
🟦	25 ug/L
🟩	50 ug/L
🟩	100 ug/L
🟨	150 ug/L
🟧	200 ug/L
🟧	300 ug/L
🟧	400 ug/L
🟥	500 ug/L
🟥	700 ug/L

NOTE:

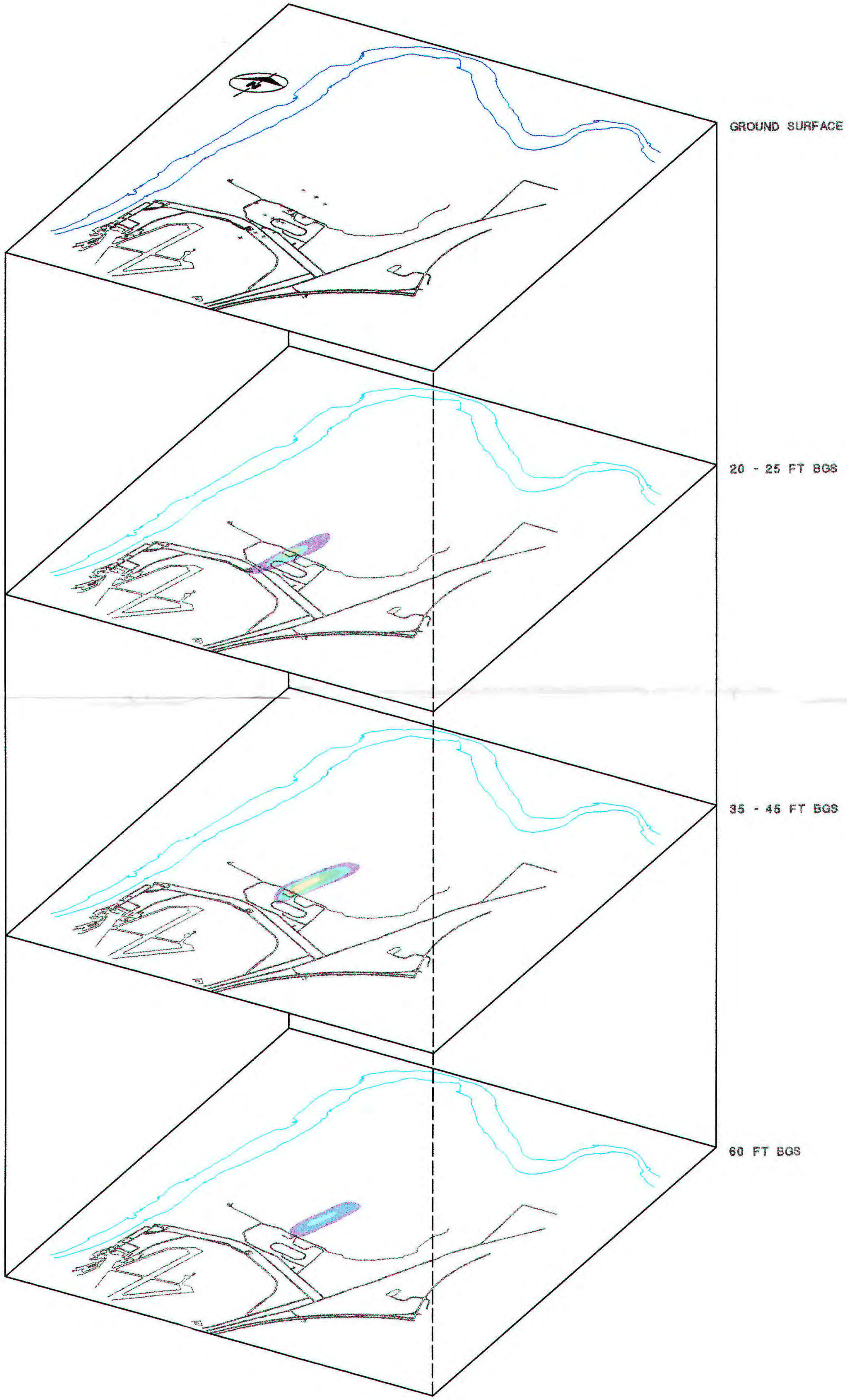
PLUME NOT FULLY DEFINED IN
DECEMBER 1996

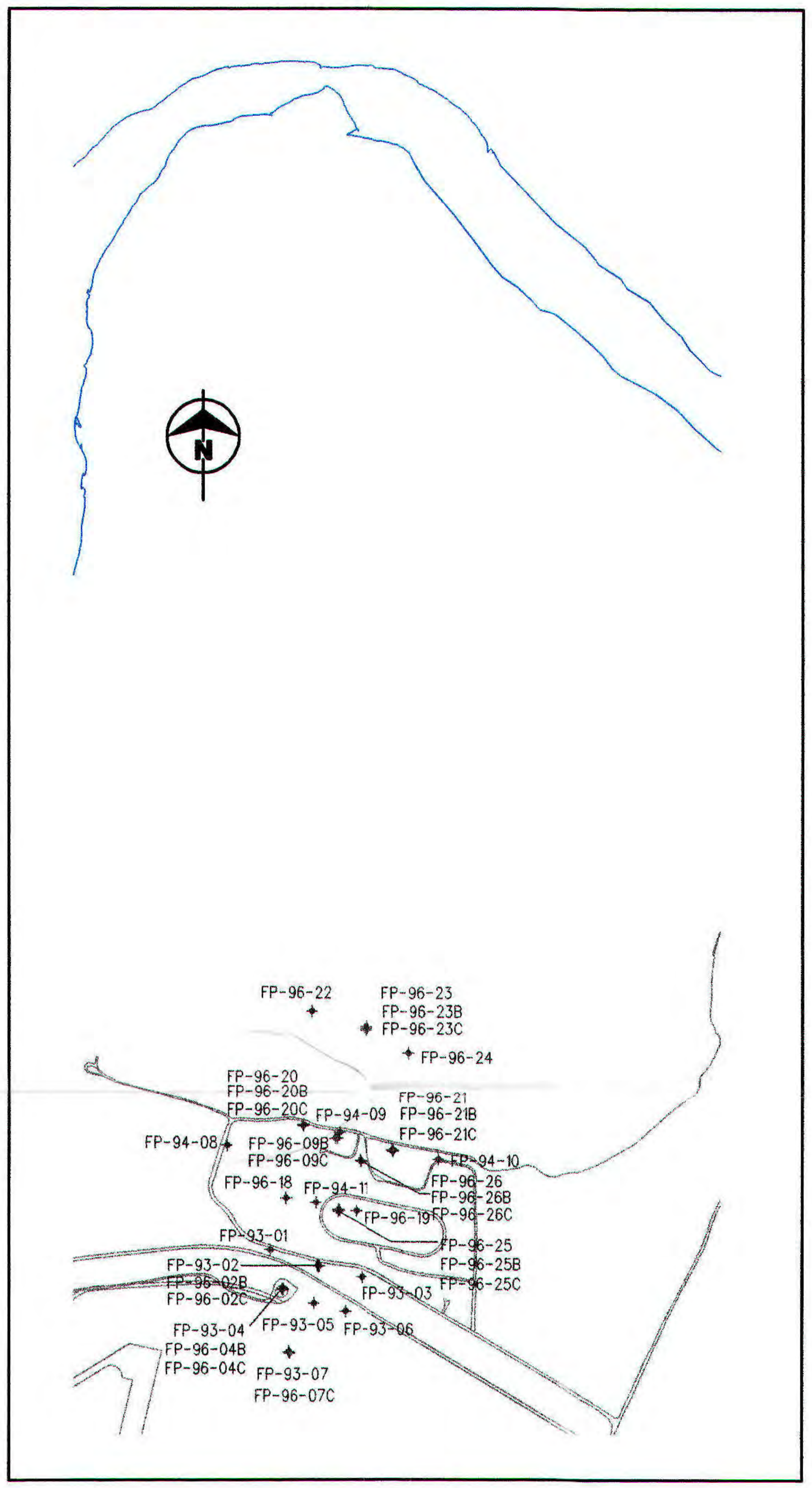
Burns & McDonnell
SINCE 1898

Figure 5-13
TCE IN GROUNDWATER
DECEMBER 1996

FFTA-MAAF RI

K:\USFRRI\USTN\1999\FIG\05INSET.DGN( ) OFF=7,21,23,25,27,31-33,35,37,39,41,43,45,47,58
K:\USFRRI\USTN\1999\FIG\SP27WELLSZ.DGN( ) OFF=5-10,12-32,34-56,59-60,62-63
K:\USFRRI\USTN\1999\FIG\BDR24X18.DGN( ) OFF=NONE
K:\USFRRI\USTN\1999\FIG\05BASESTACK.DGN(BASE) OFF=5-6,8-10,12-40,42-57,60,63
K:\USFRRI\USTN\1999\FIG\
1296TCESTACK.DGN/ 2-21-2000 10:14/BKK





LEGEND

✦	MONITORING WELL OR CLUSTER
🟪	2 ug/L
🟦	5 ug/L
🟦	10 ug/L
🟦	25 ug/L
🟩	50 ug/L
🟩	100 ug/L
🟨	150 ug/L
🟨	200 ug/L
🟧	300 ug/L
🟧	400 ug/L
🟥	500 ug/L
🟥	700 ug/L

NOTE:

PLUME NOT FULLY DEFINED IN DECEMBER 1996

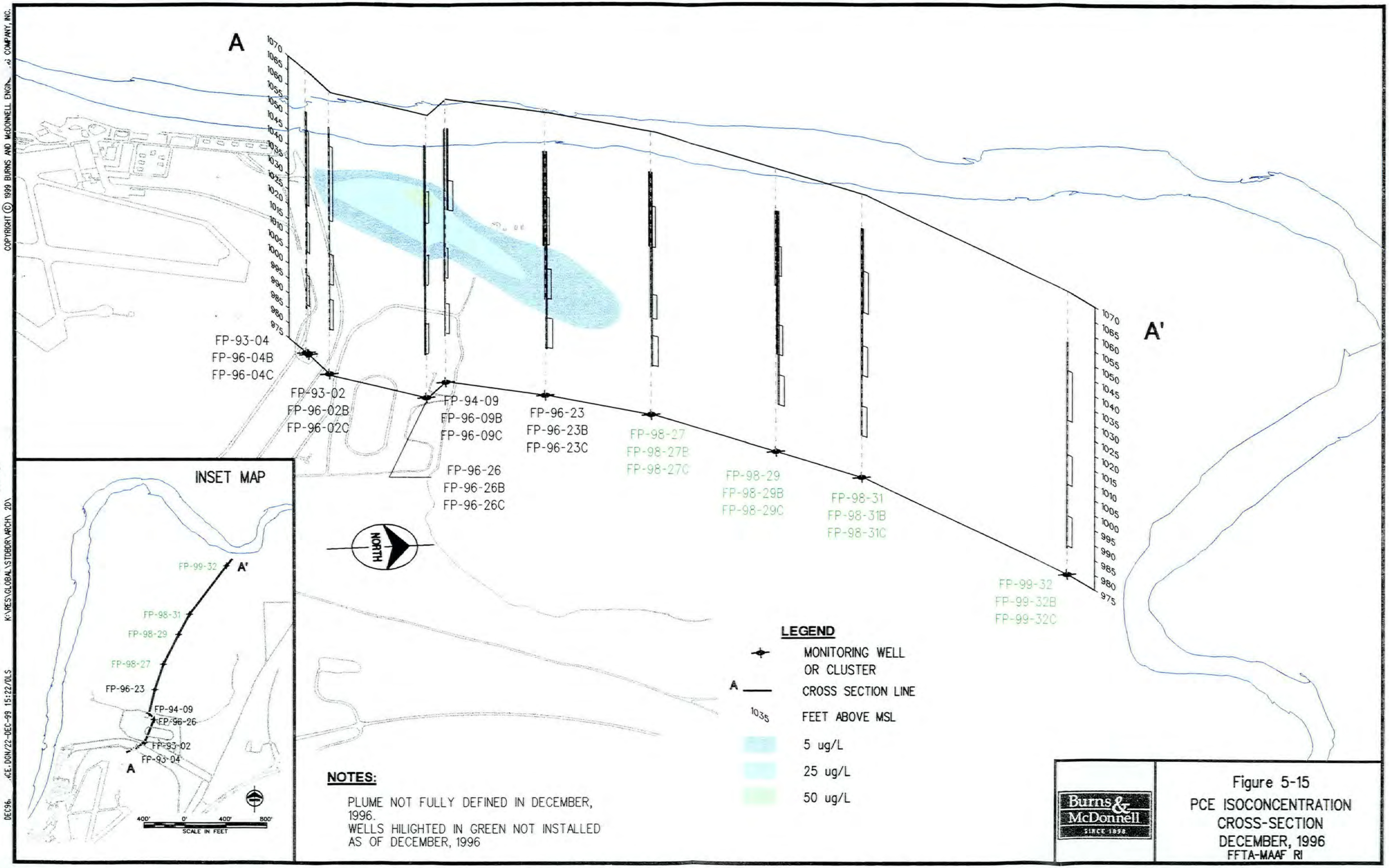
Burns & McDonnell
SINCE 1898

Figure 5-14
cis-1,2-DCE IN GROUNDWATER
DECEMBER 1996

FFTA-MAAF RI

K:*USFRRI*USTN*1999*FIG*05INSET.DGN() OFF=7,21,23,25,27,31-33,35,37,39,41,43,45,47,58
K:*USFRRI*USTN*1999*FIG*SP27WELLSZ.DGN() OFF=5-10,12-32,34-56,59-60,62-63
K:*USFRRI*USTN*1999*FIG*BDR24X18.DGN() OFF=NONE
K:*USFRRI*USTN*1999*FIG*05BASESTACK.DGN(BASE) OFF=5-6,8-10,12-40,42-57,60,63
K:\USFRRI\USTN\1999 \FIG\

1296DCESTACK.DGN/ 2-21-2000 10:04/BKK

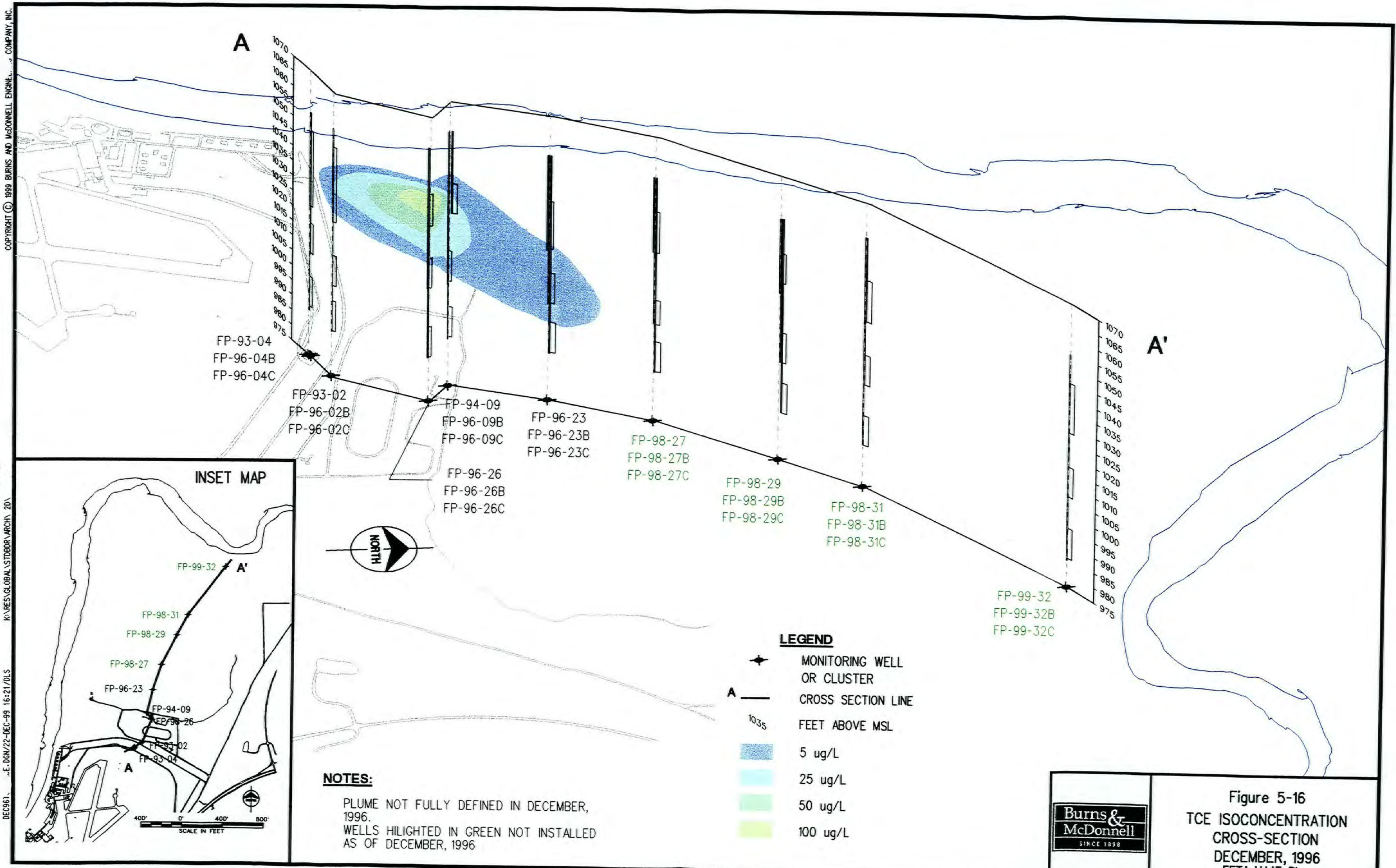


NOTES:

PLUME NOT FULLY DEFINED IN DECEMBER, 1996.
WELLS HILIGHTED IN GREEN NOT INSTALLED AS OF DECEMBER, 1996

Burns & McDonnell
SINCE 1898

Figure 5-15
PCE ISOCONCENTRATION
CROSS-SECTION
DECEMBER, 1996
FFTA-MAAF RI



LEGEND

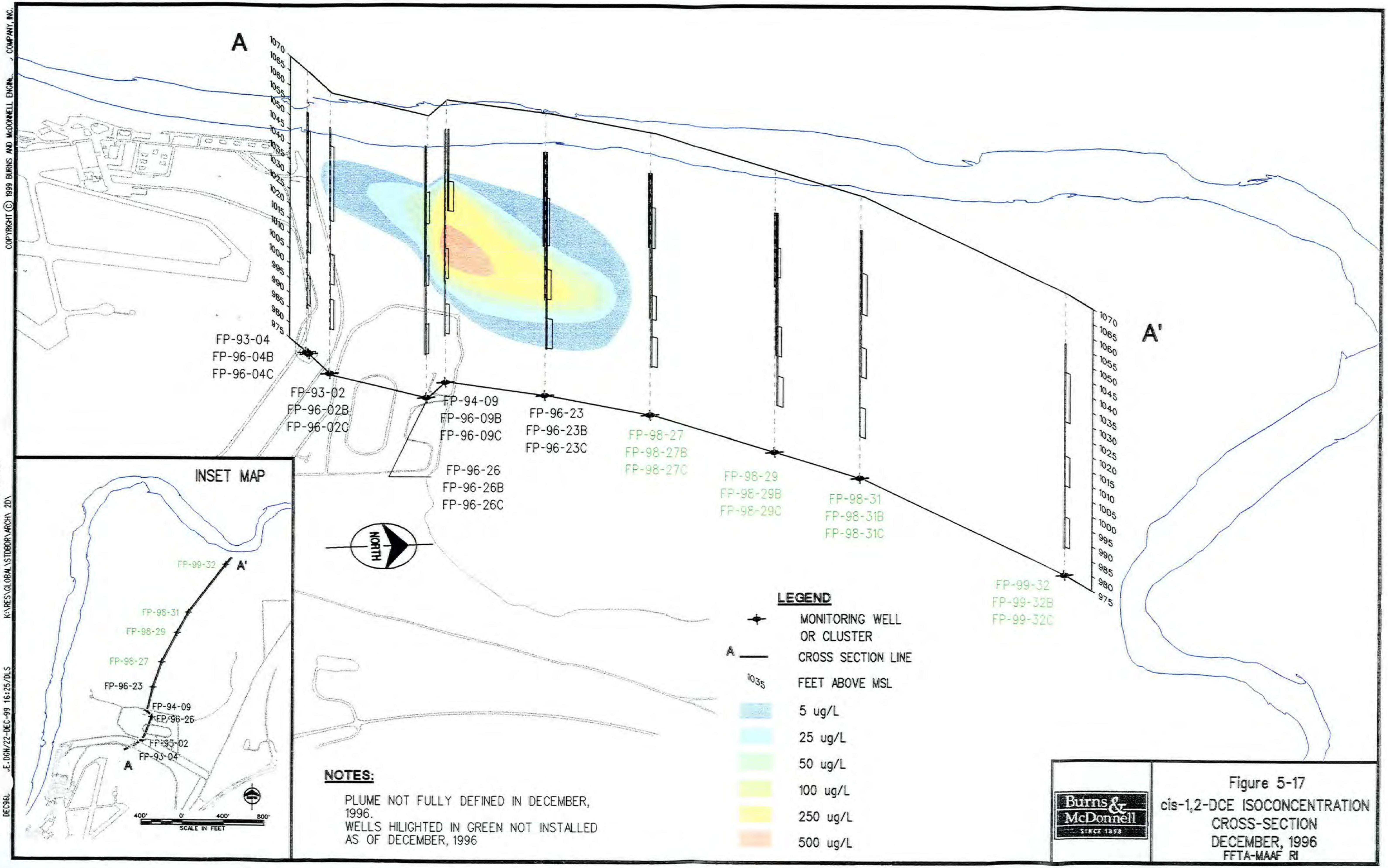
✛	MONITORING WELL OR CLUSTER
A ―	CROSS SECTION LINE
1035	FEET ABOVE MSL
▨	5 ug/L
▨	25 ug/L
▨	50 ug/L
▨	100 ug/L

NOTES:

PLUME NOT FULLY DEFINED IN DECEMBER, 1996.
WELLS HILIGHTED IN GREEN NOT INSTALLED AS OF DECEMBER, 1996

Burns & McDonnell
SINCE 1898

Figure 5-16
TCE ISOCONCENTRATION
CROSS-SECTION
DECEMBER, 1996
FFTA-MAAF RI



LEGEND

✦	MONITORING WELL OR CLUSTER
A ──	CROSS SECTION LINE
1035	FEET ABOVE MSL
🟦	5 ug/L
▨	25 ug/L
🟩	50 ug/L
▨	100 ug/L
🟨	250 ug/L
🟧	500 ug/L

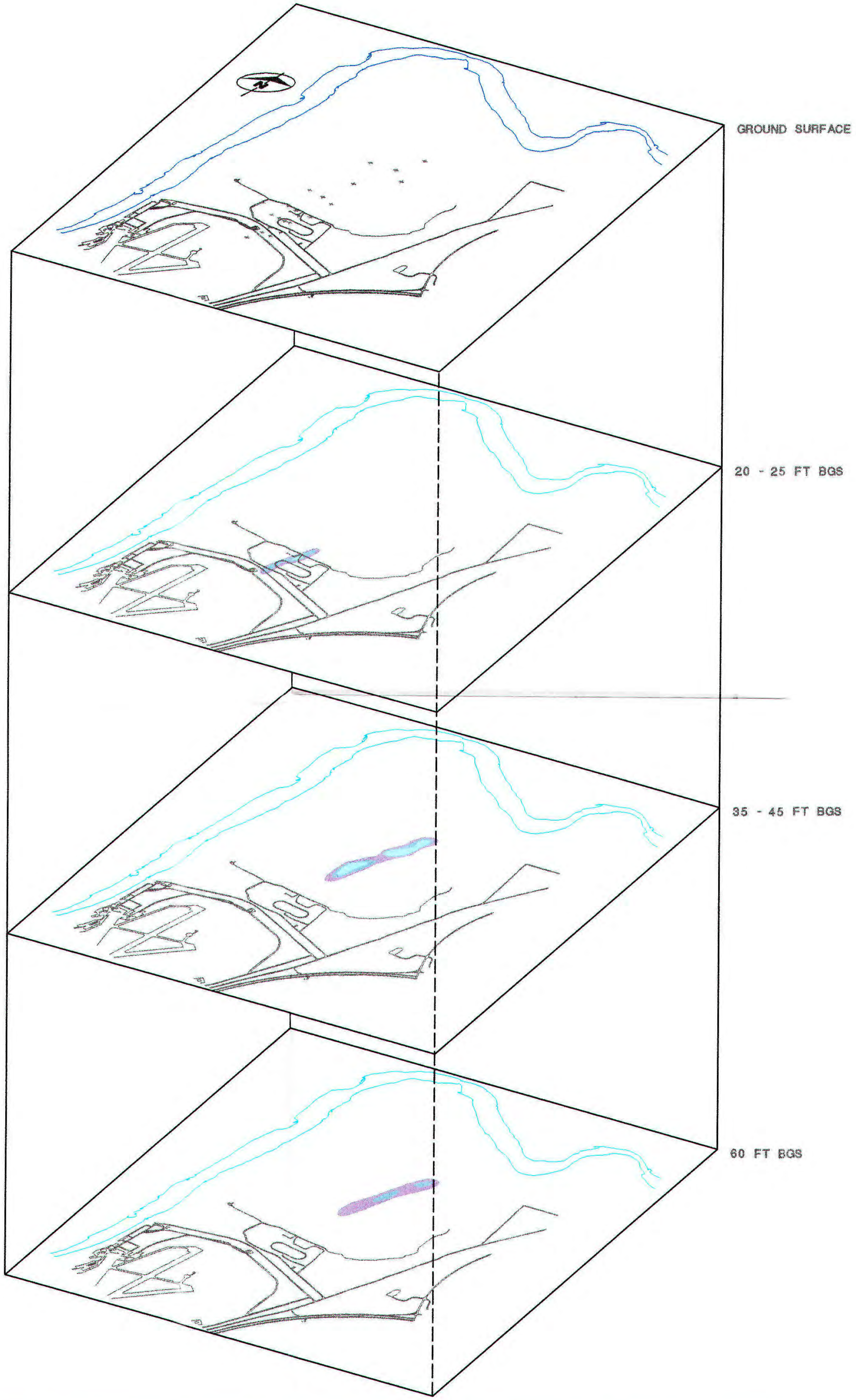
NOTES:

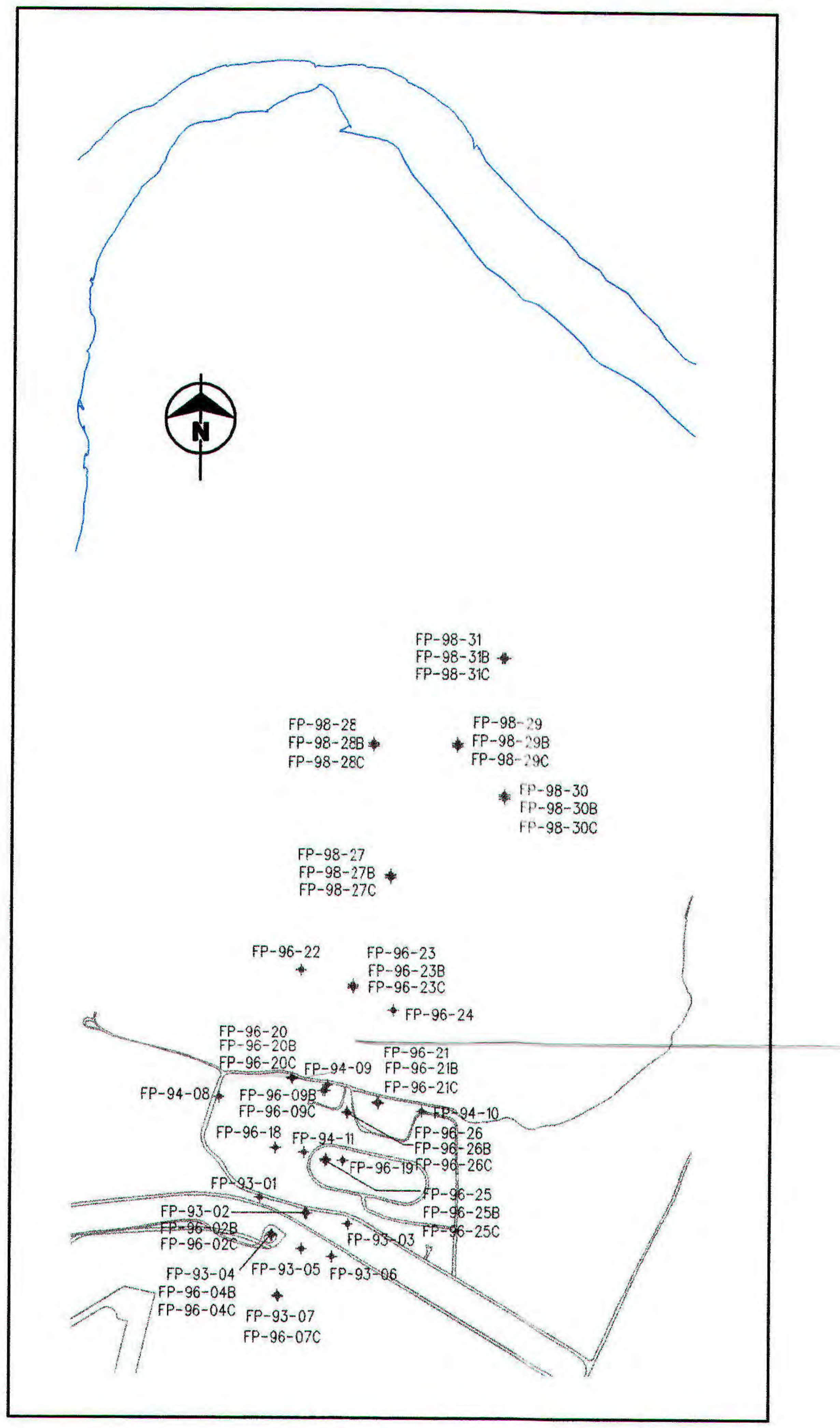
PLUME NOT FULLY DEFINED IN DECEMBER, 1996.
WELLS HILIGHTED IN GREEN NOT INSTALLED AS OF DECEMBER, 1996

Burns & McDonnell
SINCE 1898

Figure 5-17
cis-1,2-DCE ISOCONCENTRATION
CROSS-SECTION
DECEMBER, 1996
FFTA-MAAF RI

u:#frilley#dgn#sec#x3d#dpth#1296dce.dgn
K:\RES\GLOBAL\STDBDR\ARCH 2D\
DEC96L...E.DGN/22-DEC-99 16:25/DLS





LEGEND

- ✦ MONITORING WELL OR CLUSTER
- ■ 2 ug/L
- ■ 5 ug/L
- ■ 10 ug/L
- ■ 25 ug/L
- ■ 50 ug/L
- ■ 100 ug/L
- ■ 150 ug/L
- ■ 200 ug/L
- ■ 300 ug/L
- ■ 400 ug/L
- ■ 500 ug/L
- ■ 700 ug/L

NOTE:

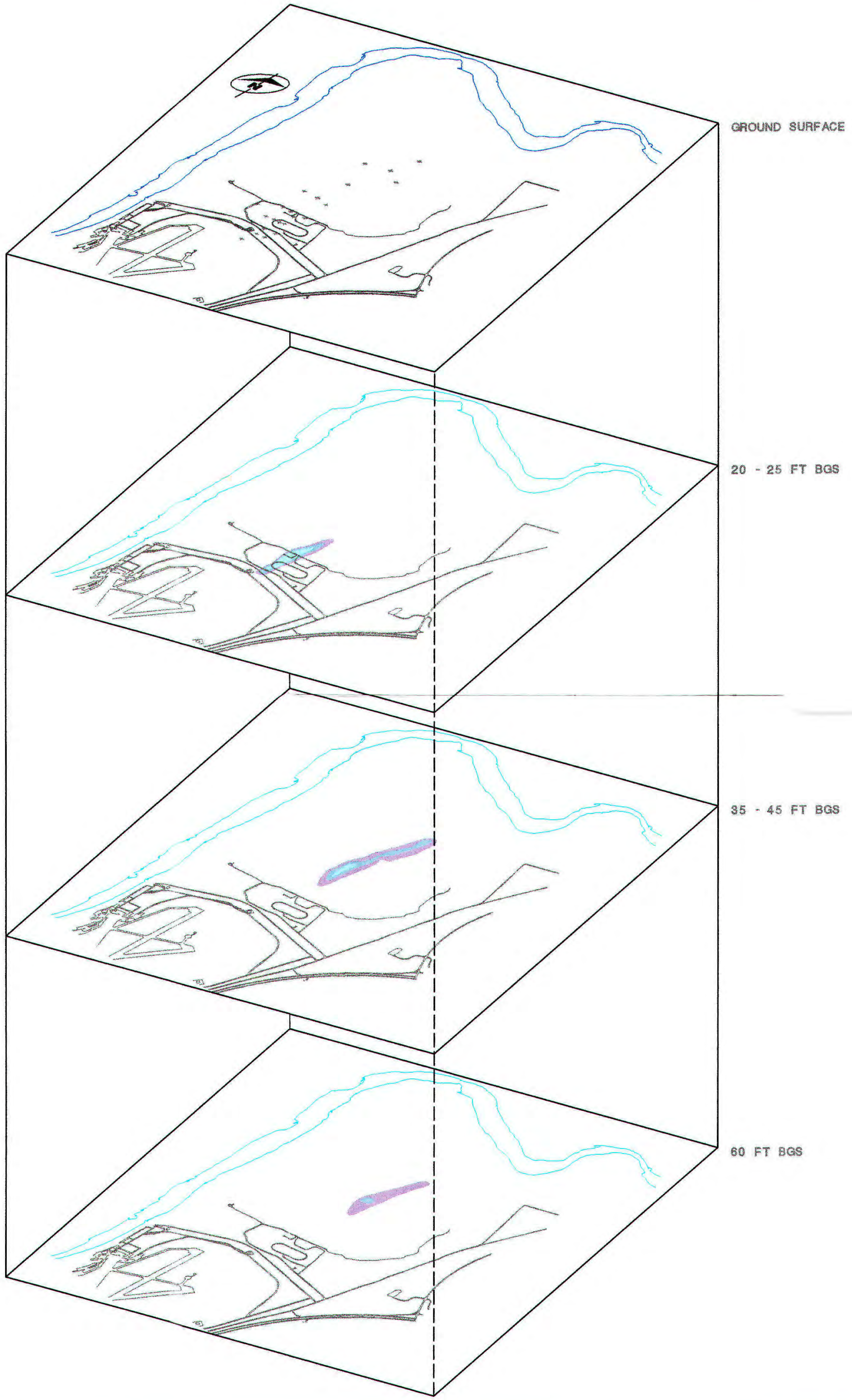
PLUME NOT FULLY DEFINED IN MAY 1998

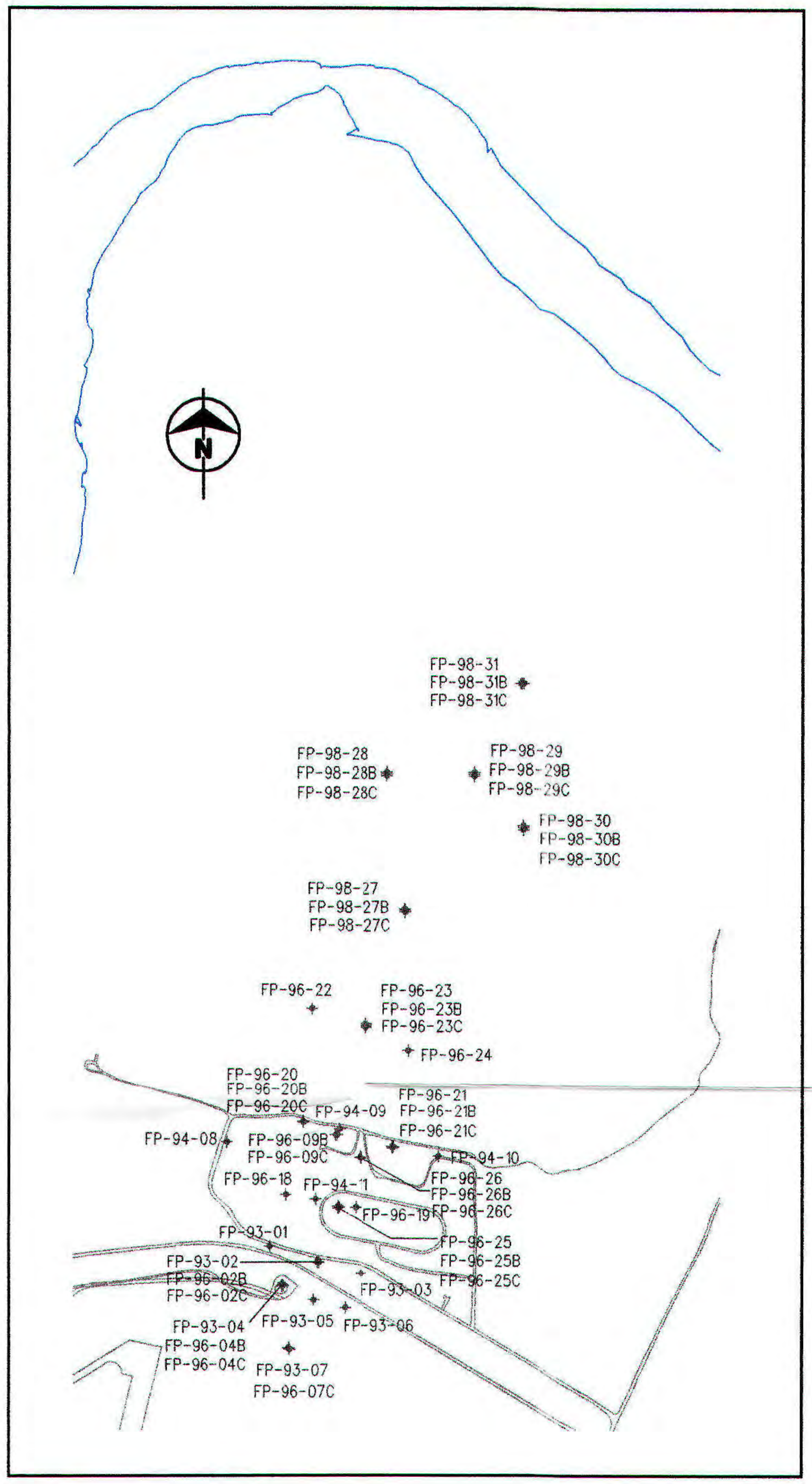
Burns & McDonnell
SINCE 1898

Figure 5-18
PCE IN GROUNDWATER
MAY 1998

FFTA-MAAF RI

0598PCESTACK.DGN/ 2-29-2000 13:29/BKK
05INSET.DGN() Off=7,21,23,25,27,31-33,35,37,39,41,43,45,47,58
SP27WELLS7.DGN() Off=5-10,12-32,34-56,59-60,62-63
BDR24X18.DGN() Off=none
05BASESTACK.DGN(base) Off=5-6,8-10,12-40,42-57,60,63
U:\FTRILEY\DGN\





LEGEND

- ✦ MONITORING WELL OR CLUSTER
- 🟪 2 ug/L
- 🟦 5 ug/L
- 🟦 10 ug/L
- 🟦 25 ug/L
- 🟩 50 ug/L
- 🟩 100 ug/L
- 🟨 150 ug/L
- 🟨 200 ug/L
- 🟧 300 ug/L
- 🟧 400 ug/L
- 🟥 500 ug/L
- 🟥 700 ug/L

NOTE:

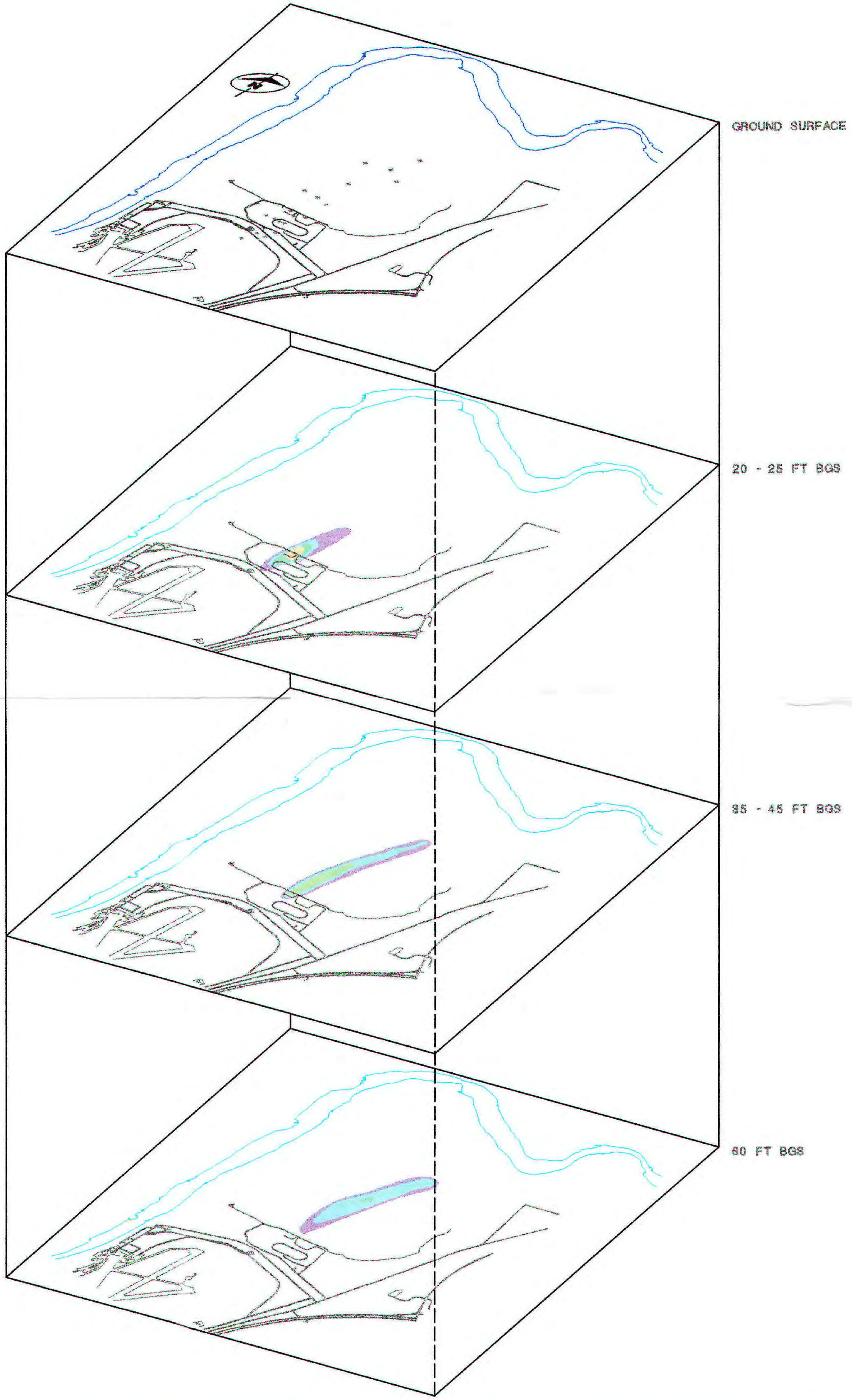
PLUME NOT FULLY DEFINED IN MAY 1998

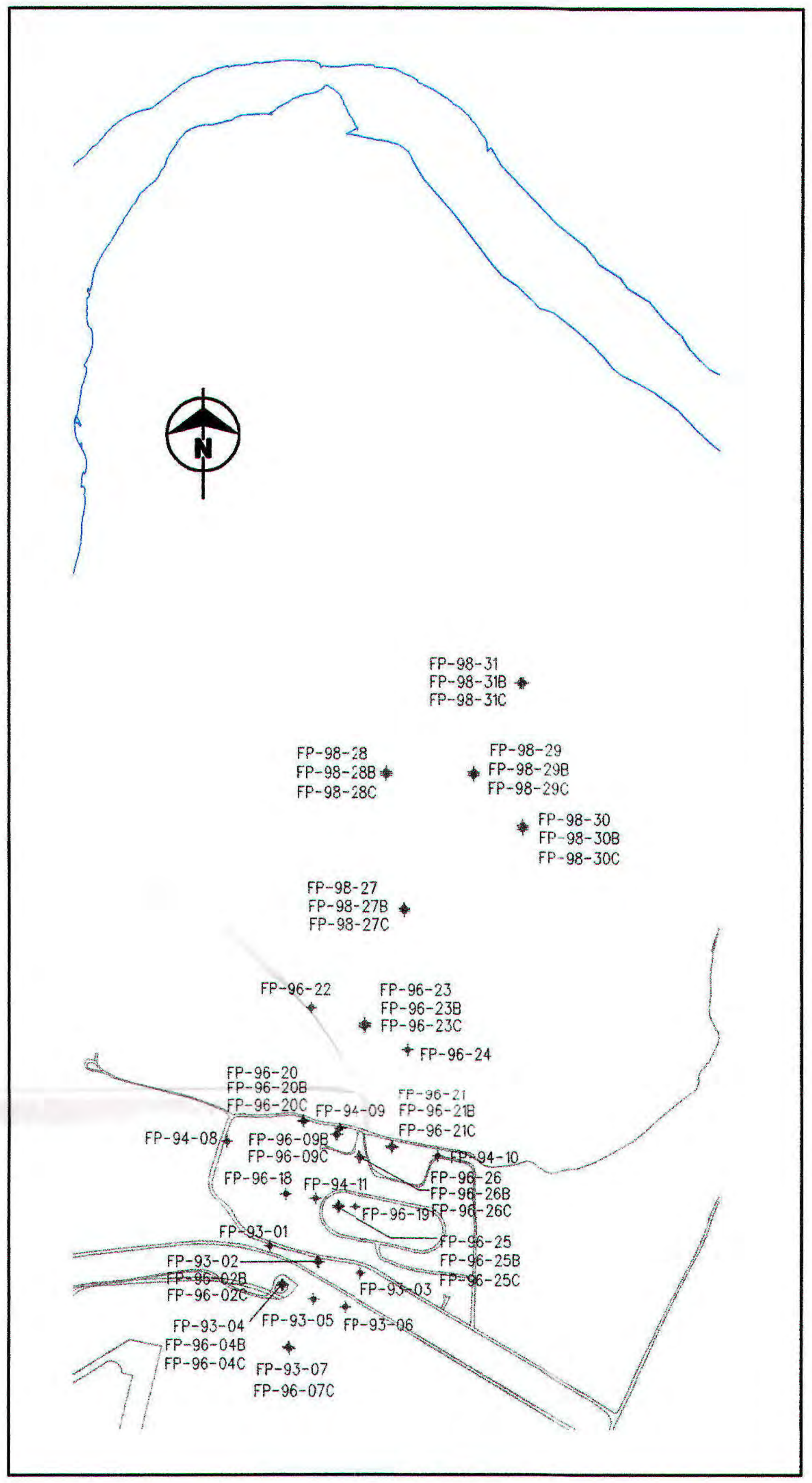
Burns & McDonnell
SINCE 1898

Figure 5-19
TCE IN GROUNDWATER
MAY 1998

FFTA-MAAF RI

u:#ftriley#dgn#05inset.dgn
u:#ftriley#dgn#sp27wellsz.dgn
u:#ftriley#dgn#bdr24x18.dgn
u:#ftriley#dgn#05basestack.dgn
U:\FTRILEY\DGN\
0598TCESTACK.DGN/ 2-29-2000 14:04/BKK





LEGEND

+	MONITORING WELL OR CLUSTER
🟪	2 ug/L
🟦	5 ug/L
🟦	10 ug/L
🟦	25 ug/L
🟩	50 ug/L
🟩	100 ug/L
🟨	150 ug/L
🟨	200 ug/L
🟧	300 ug/L
🟧	400 ug/L
🟥	500 ug/L
🟥	700 ug/L

NOTE:

PLUME NOT FULLY DEFINED IN MAY 1998

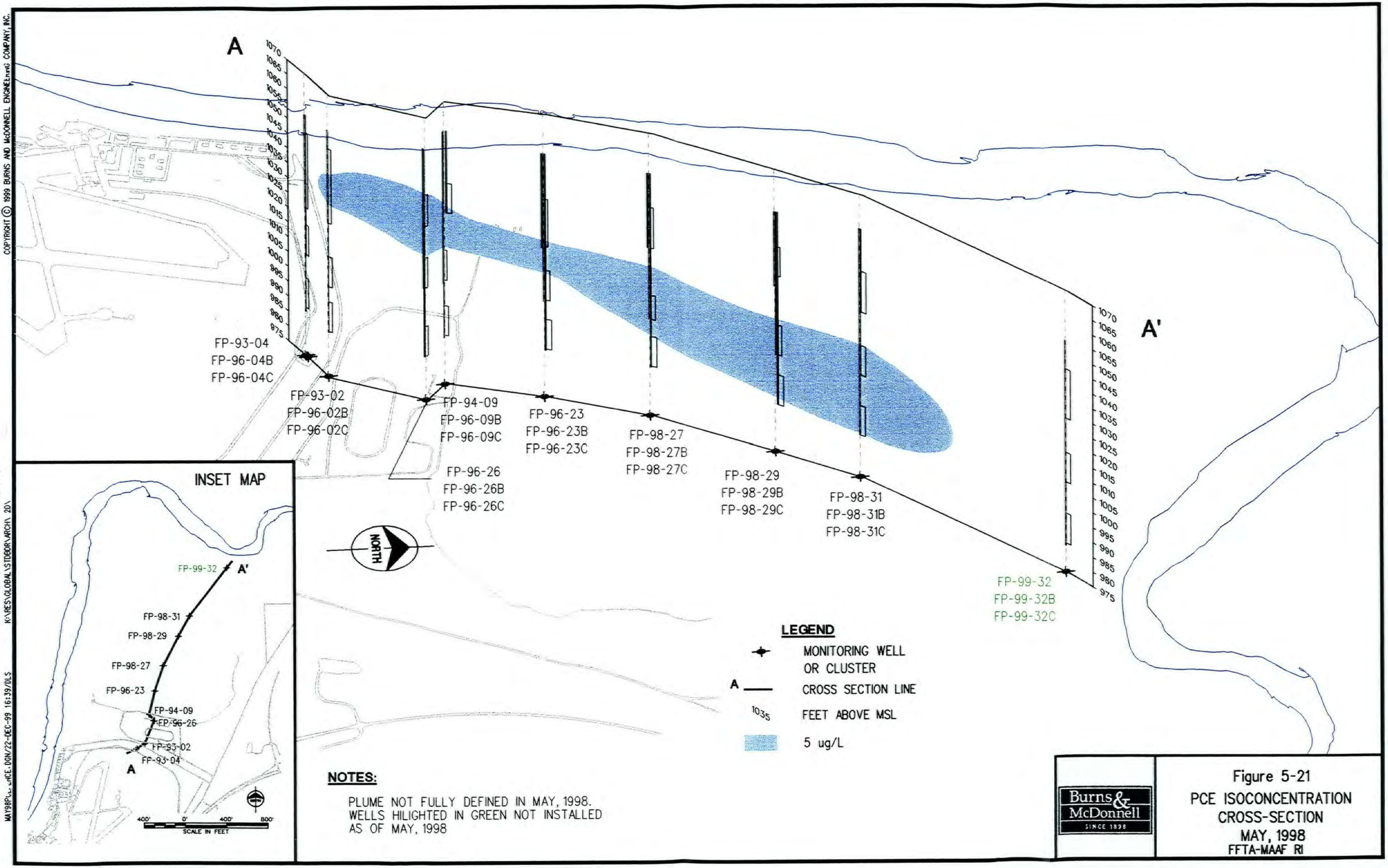
Burns & McDonnell
SINCE 1898

Figure 5-20
cis-1,1-DCE IN GROUNDWATER
MAY 1998

FFTA-MAAF RI

0598DCESTACK.DGN/16-DEC-99 11:38/SOS

u:#ftrilley#dgn#05inset.dgn
u:#ftrilley#dgn#sp27wellsz.dgn
u:#ftrilley#dgn#br24x18.dgn
u:#ftrilley#dgn#05basestack.dgn
U:\FTRILEY\DGN\



LEGEND

✦	MONITORING WELL OR CLUSTER
A ───	CROSS SECTION LINE
1035	FEET ABOVE MSL
▨	5 ug/L

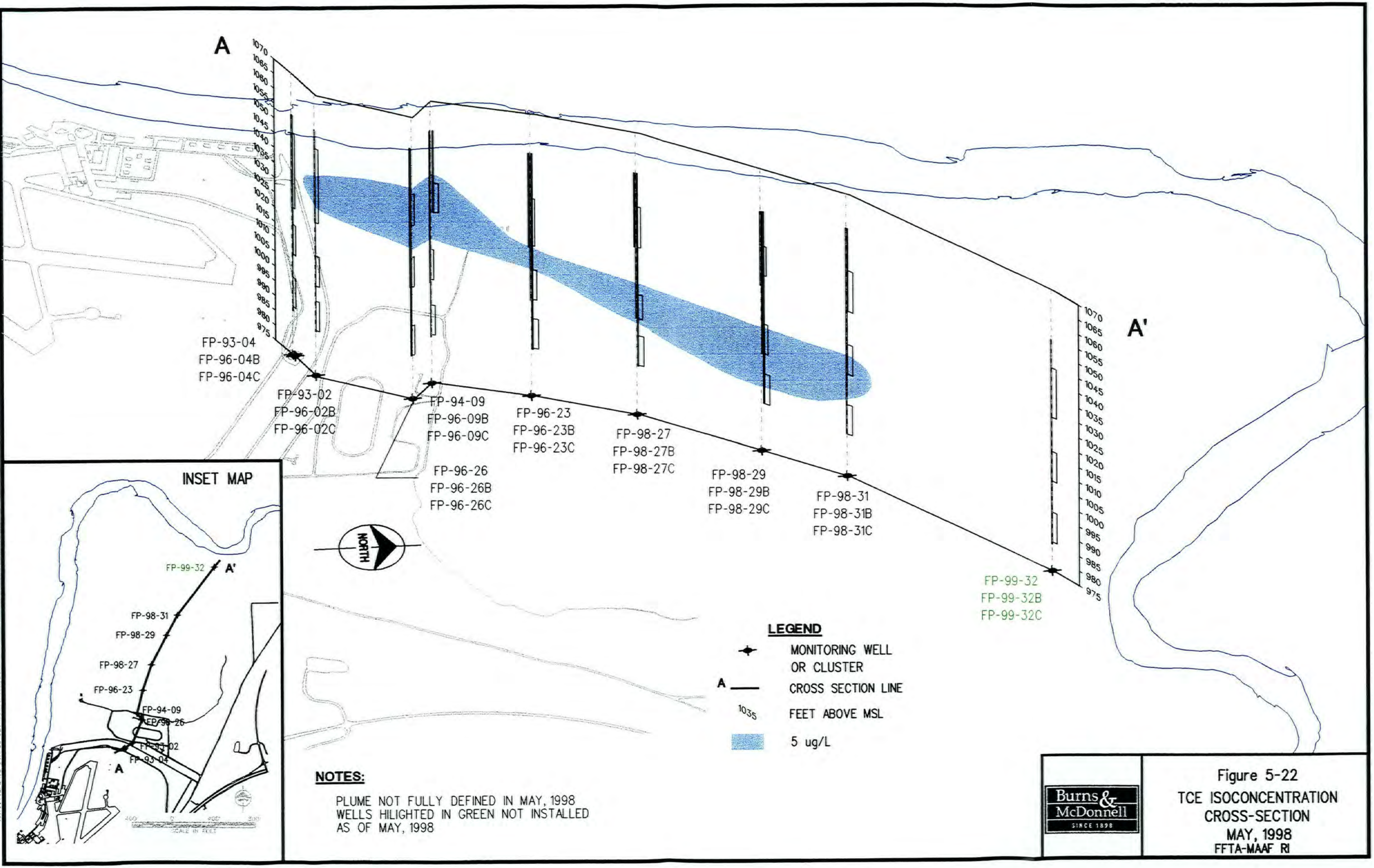
NOTES:

PLUME NOT FULLY DEFINED IN MAY, 1998.
WELLS HILIGHTED IN GREEN NOT INSTALLED
AS OF MAY, 1998

Burns & McDonnell
SINCE 1898

Figure 5-21
PCE ISOCONCENTRATION
CROSS-SECTION
MAY, 1998
FFTA-MAAF RI

MAY98PCE.DGN/22-DEC-99 16:39/DLS
u:#ftrilley#dgn#seclinez.dgn
u:#ftrilley#dgn#sec#x3d#dpth#0598pce.dgn
K:\RES\GLOBAL\STDBDR\ARCH\ 2D\



LEGEND

✦	MONITORING WELL OR CLUSTER
A ——	CROSS SECTION LINE
1035	FEET ABOVE MSL
▨	5 ug/L

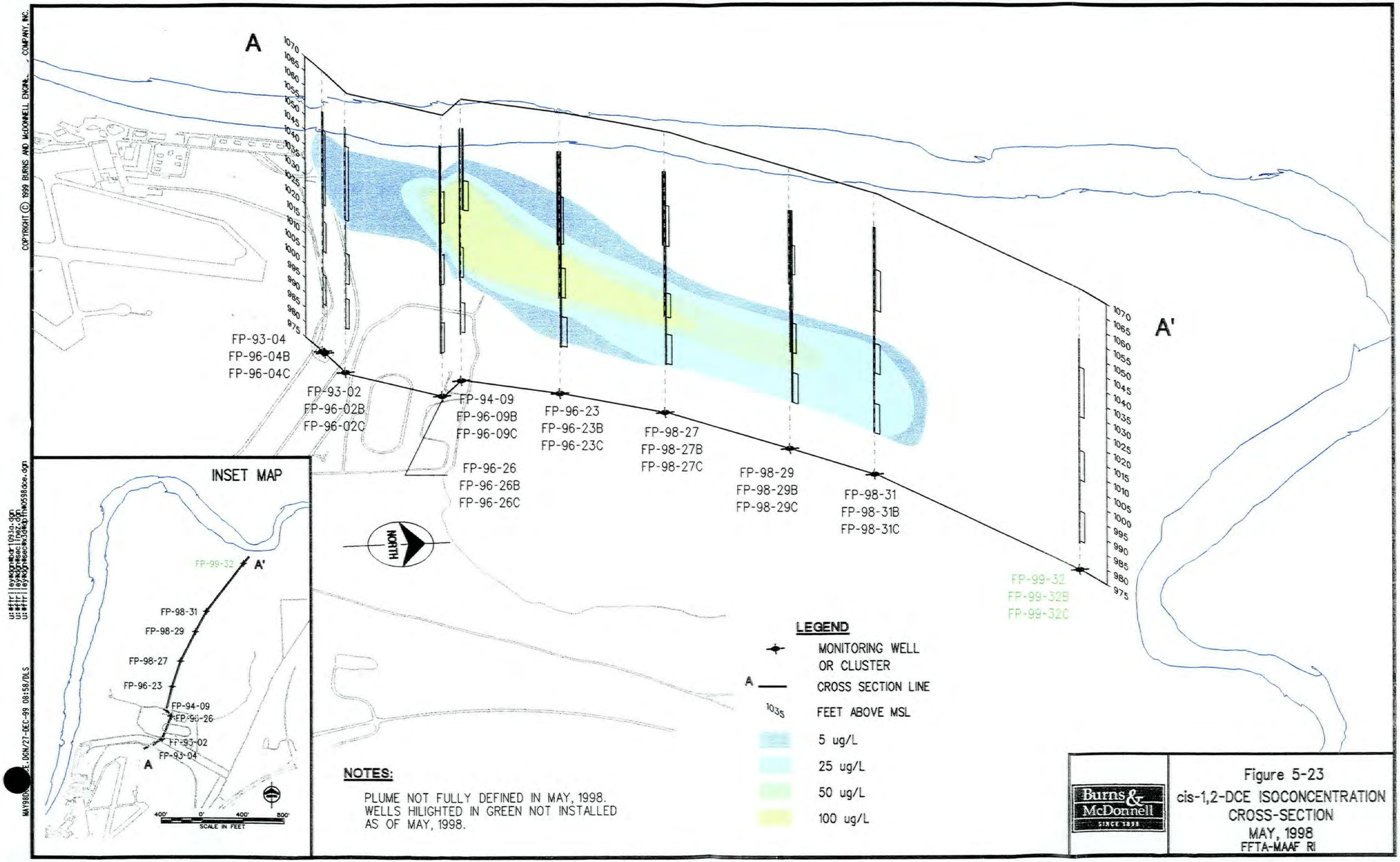
NOTES:

PLUME NOT FULLY DEFINED IN MAY, 1998
WELLS HILIGHTED IN GREEN NOT INSTALLED
AS OF MAY, 1998

Burns & McDonnell
SINCE 1898

Figure 5-22
TCE ISOCONCENTRATION
CROSS-SECTION
MAY, 1998
FFTA-MAAF RI

MAY98DC[illegible]E.DGN/27-DEC-99 08:58/DLS
u:\ftr\leyk\dgn\bdr1093a.dgn
u:\ftr\leyk\dgn\sec\linez.dgn
u:\ftr\leyk\dgn\sec\x3d\dpth\0598dce.dgn



LEGEND

✦	MONITORING WELL OR CLUSTER
A ──	CROSS SECTION LINE
1035	FEET ABOVE MSL
▨	5 ug/L
▨	25 ug/L
▨	50 ug/L
▨	100 ug/L

NOTES:

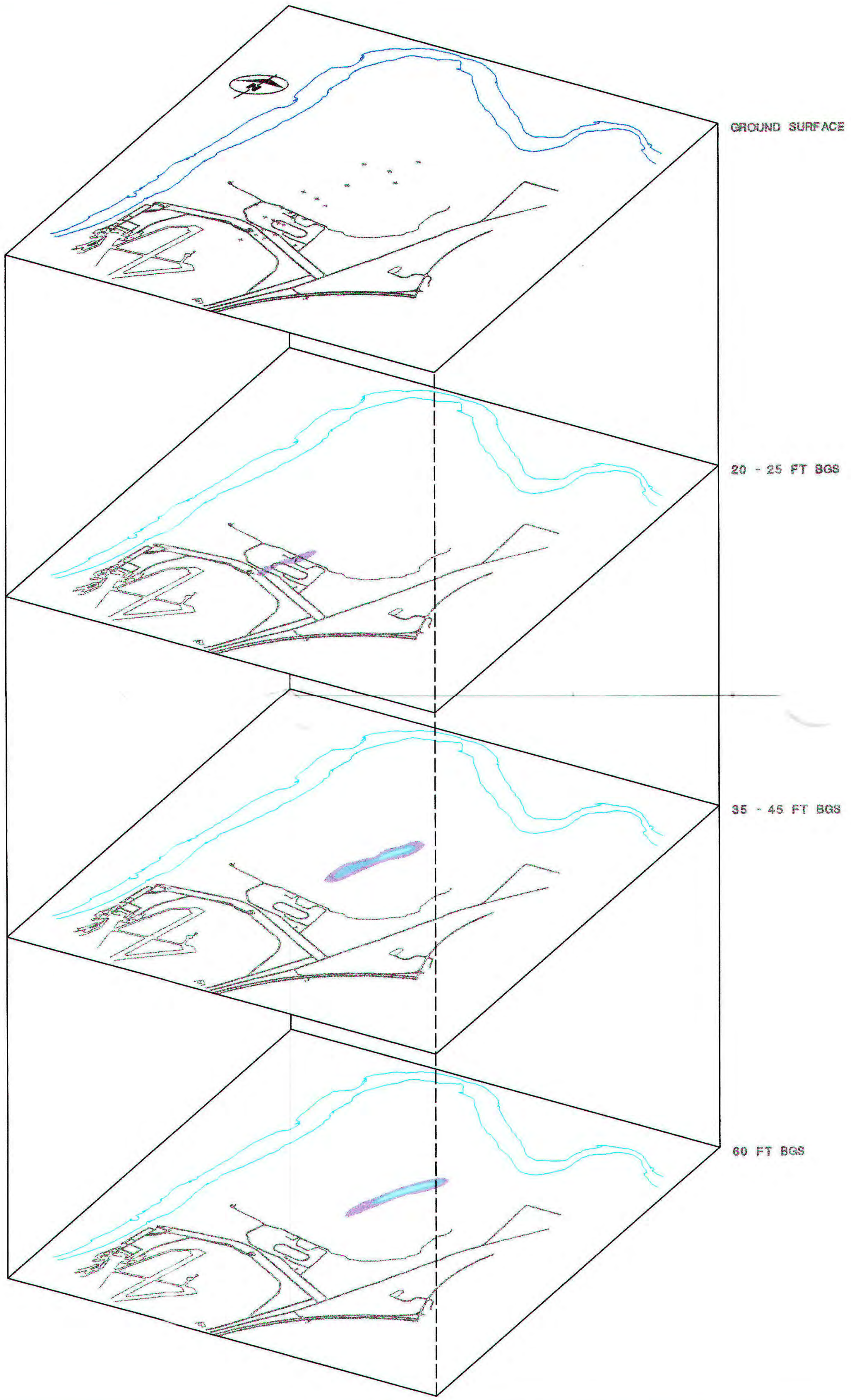
PLUME NOT FULLY DEFINED IN MAY, 1998.
WELLS HILIGHTED IN GREEN NOT INSTALLED AS OF MAY, 1998.

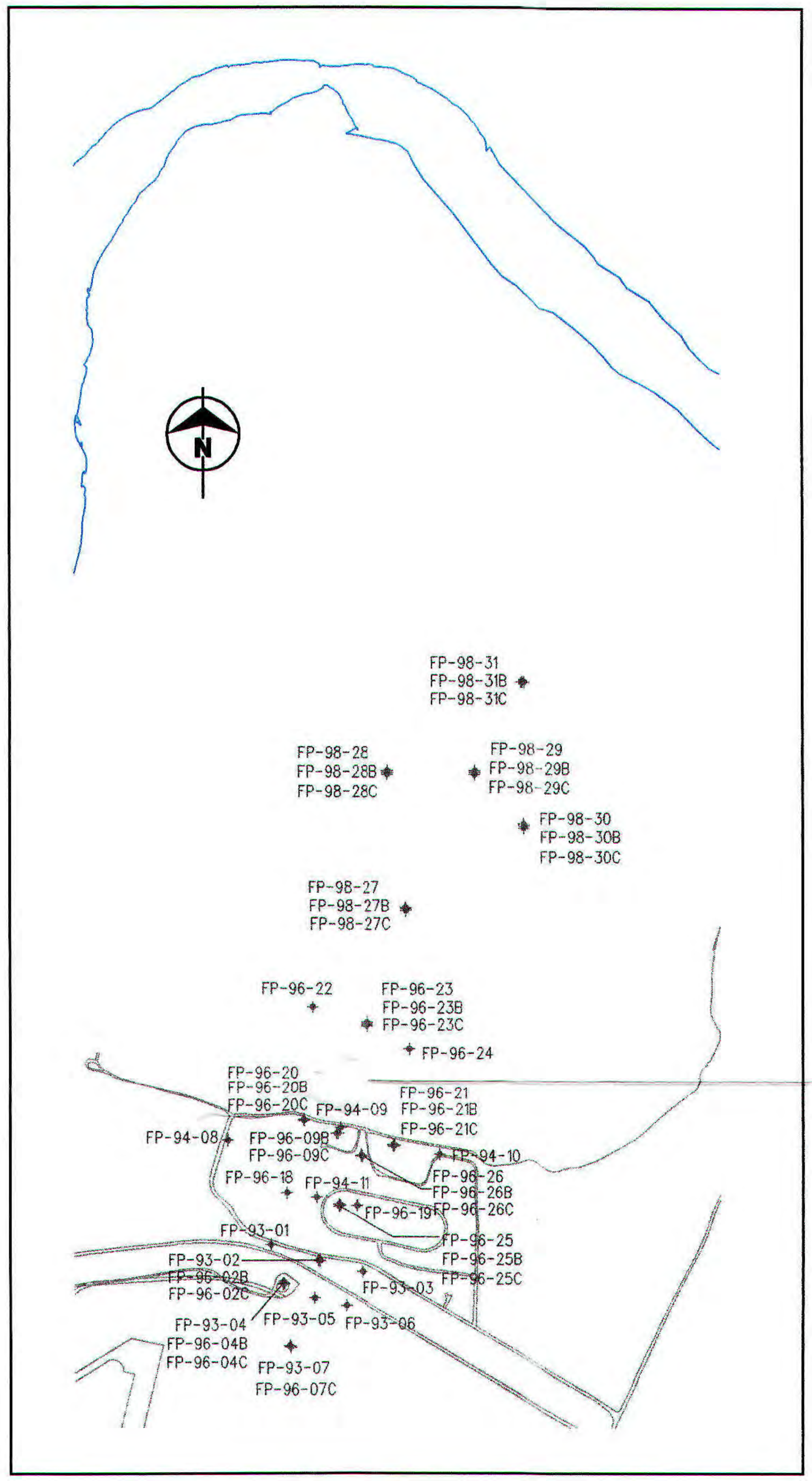
Burns & McDonnell
SINCE 1898

Figure 5-23
cis-1,2-DCE ISOCONCENTRATION CROSS-SECTION
MAY, 1998
FFTA-MAAF RI

0599PCESTACK.DGN/ 2-29-2000 10:36/BKK

05INSET.DGN( ) Off=7,21,23,25,27,31-33,35,37,39,41,43,45,47,58
SP27WELLSZ.DGN( ) Off=5-10,12-32,34-56,59-60,62-63
BDR24X18.DGN( ) Off=none
05BASESTACK.DGN(base) Off=5-6,8-10,12-40,42-57,60,63
K:\USFRR\USTN\1999\FIG\





LEGEND

✦ MONITORING WELL OR CLUSTER
🟪 2 ug/L
🟦 5 ug/L
🟦 10 ug/L
🟦 25 ug/L
🟩 50 ug/L
🟩 100 ug/L
🟨 150 ug/L
🟨 200 ug/L
🟧 300 ug/L
🟧 400 ug/L
🟥 500 ug/L
🟥 700 ug/L

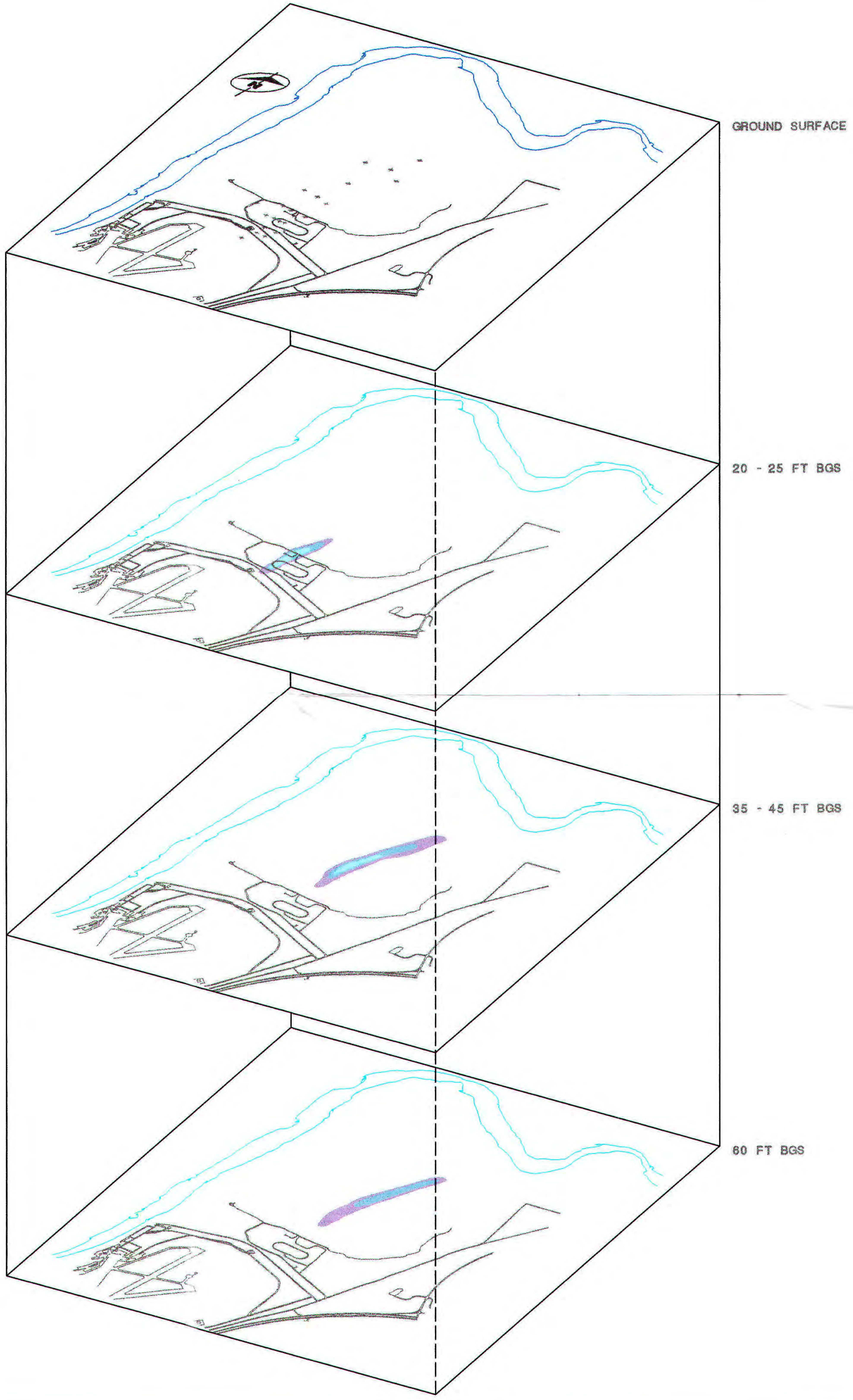
NOTE:

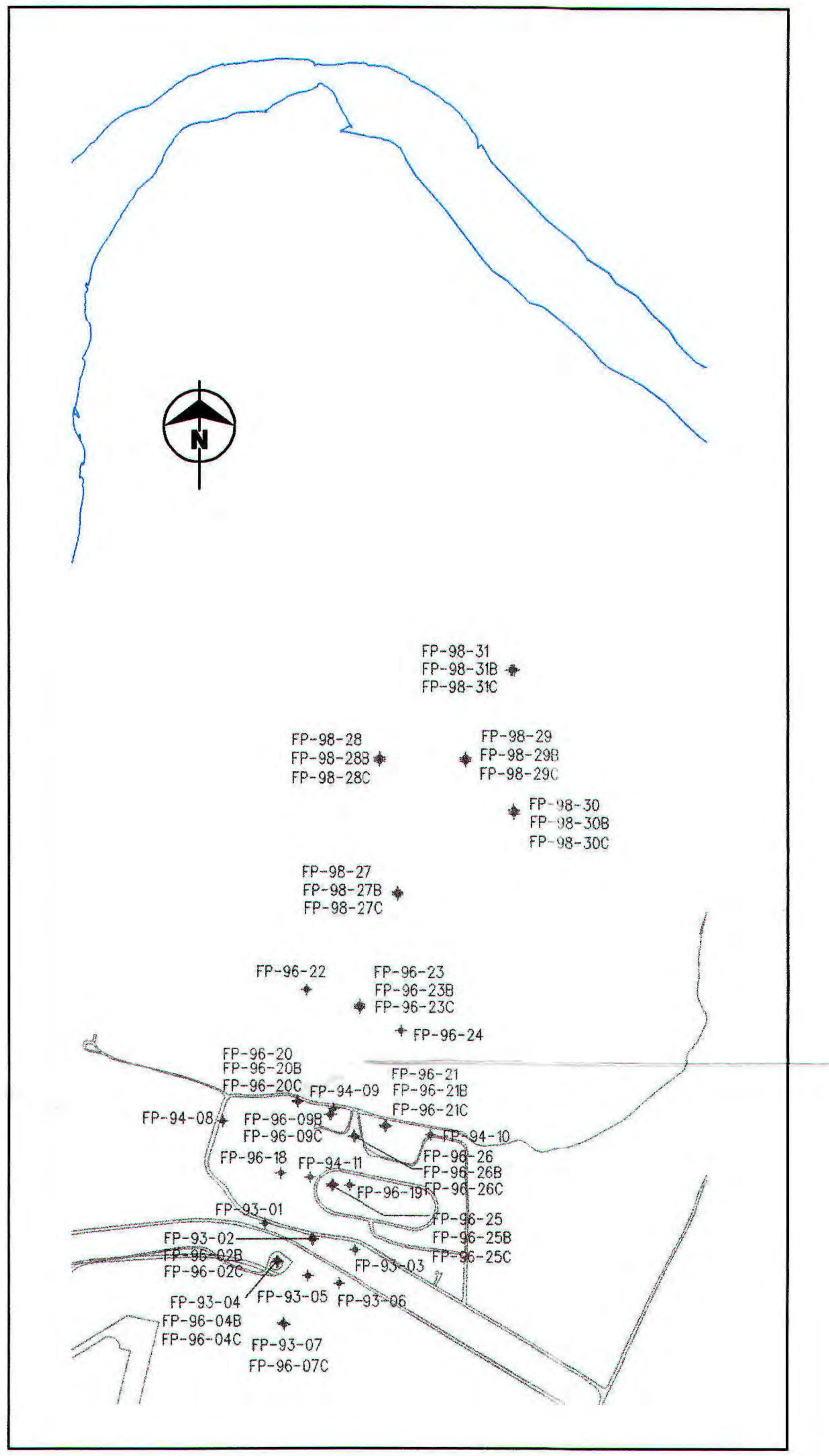
PLUME NOT FULLY DEFINED IN MAY 1999

Burns & McDonnell
SINCE 1898

Figure 5-24
PCE IN GROUNDWATER
MAY 1999

FFTA-MAAF RI





LEGEND

+	MONITORING WELL OR CLUSTER
🟪	2 ug/L
🟦	5 ug/L
🟦	10 ug/L
🟦	25 ug/L
🟩	50 ug/L
🟩	100 ug/L
🟨	150 ug/L
🟨	200 ug/L
🟧	300 ug/L
🟧	400 ug/L
🟥	500 ug/L
🟥	700 ug/L

NOTE:

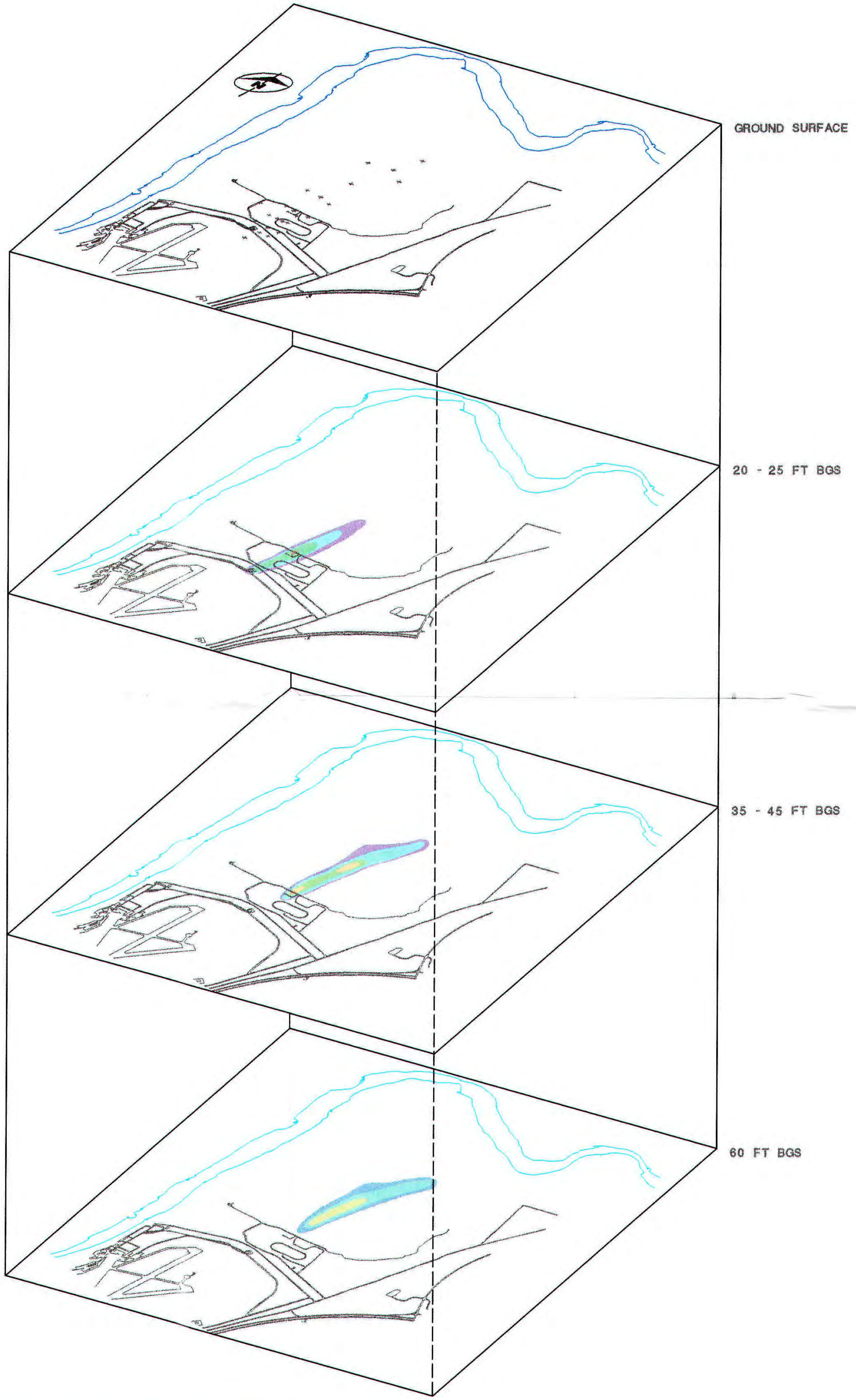
PLUME NOT FULLY DEFINED IN MAY 1999

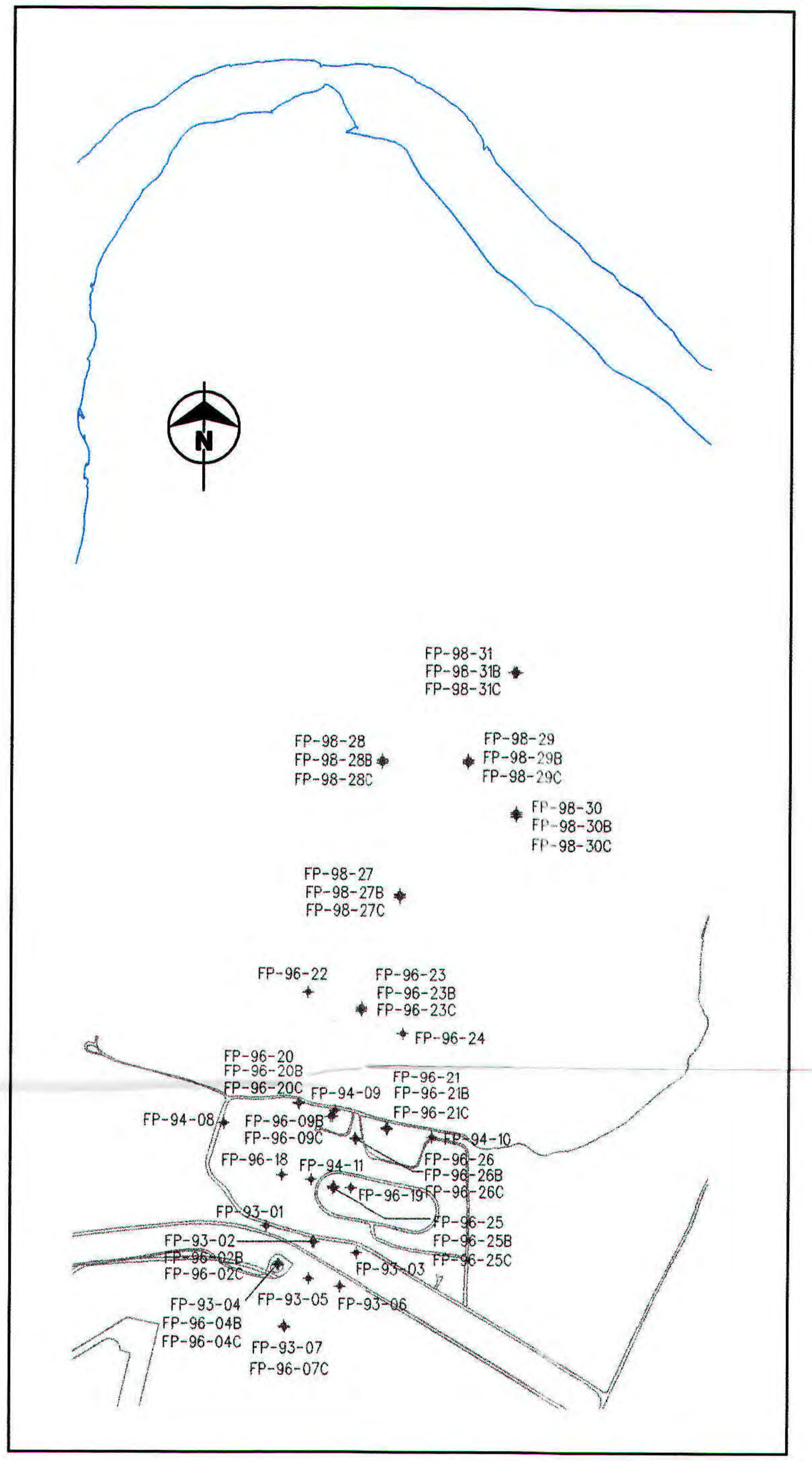
Burns & McDonnell
SINCE 1898

Figure 5-25
TCE IN GROUNDWATER
MAY 1999

FFTA-MAAF RI

0599TCESTACK.DGN/ 2-28-2000 17:19/BKK
05INSET.DGN() Off=7,21,23,25,27,31-33,35,37,39,41,43,45,47,58
SP27WELLSZ.DGN() Off=5-10,12-32,34-56,59-60,62-63
BDR24X18.DGN() Off=none
05BASESTACK.DGN(base) Off=5-6,8-10,12-40,42-57,60,63
K:\USFRRI\USTN\1999 \FIG\





LEGEND

- ✦ MONITORING WELL OR CLUSTER
- 🟪 2 ug/L
- 🟦 5 ug/L
- 🟦 10 ug/L
- 🟦 25 ug/L
- 🟩 50 ug/L
- 🟩 100 ug/L
- 🟨 150 ug/L
- 🟧 200 ug/L
- 🟧 300 ug/L
- 🟧 400 ug/L
- 🟥 500 ug/L
- 🟥 700 ug/L

NOTE:

PLUME NOT FULLY DEFINED IN MAY 1999

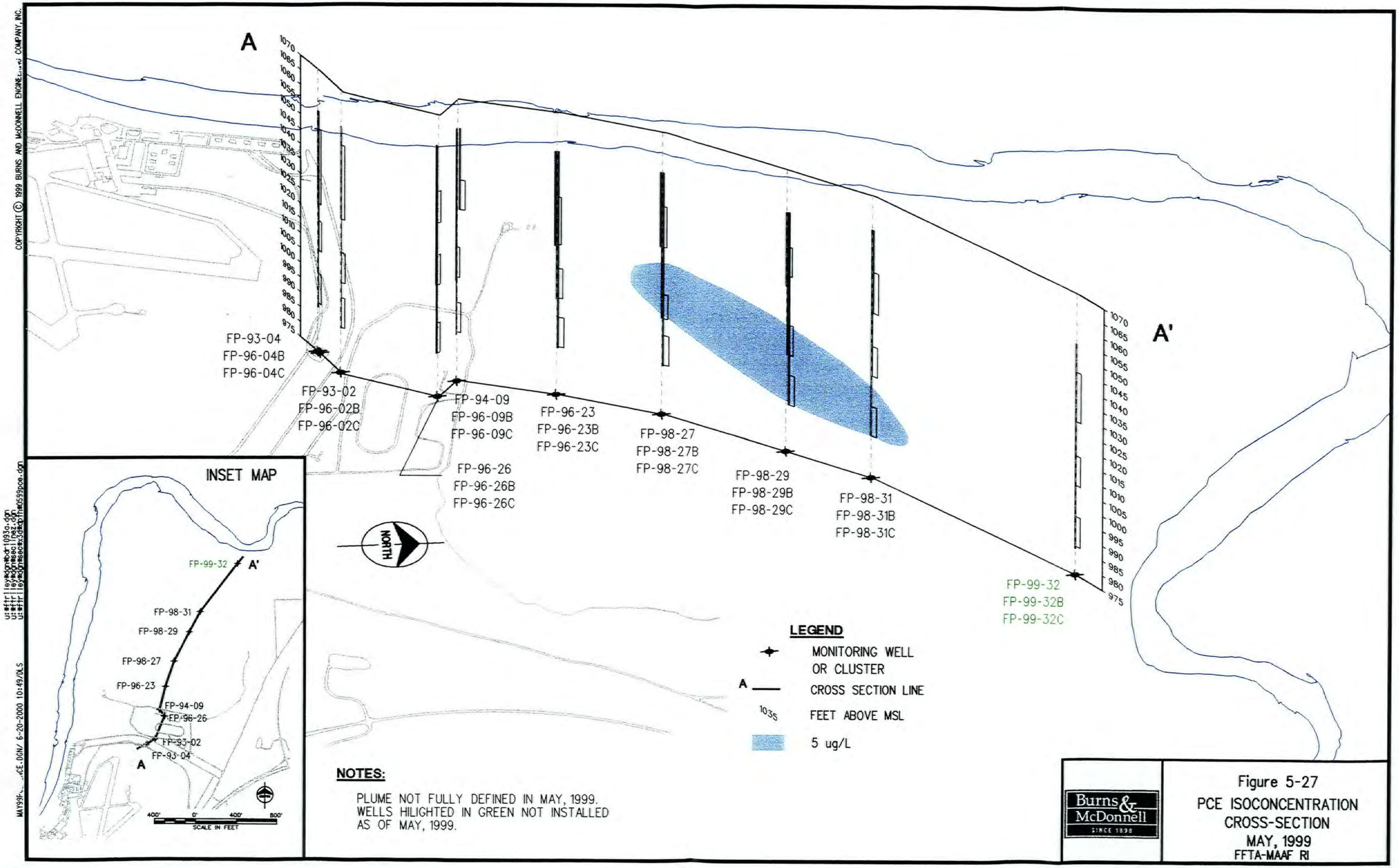
Burns & McDonnell
SINCE 1898

Figure 5-26
cis-1,2-DCE IN GROUNDWATER
MAY 1999

FFTA-MAAF RI

0599DCESTACK.DGN/ 2-29-2000 10:06/BKK

05INSET.DGN( ) Off=7,21,23,25,27,31-33,35,37,39,41,43,45,47,58
SP27WELLS7.DGN( ) Off=5-10,12-32,34-56,59-60,62-63
BDR24X18.DGN( ) Off=none
05BASESTACK.DGN(BASE) Off=5-6,8-10,12-40,42-57,60-63
K:\USFRRI\USTN\1999\FIG\



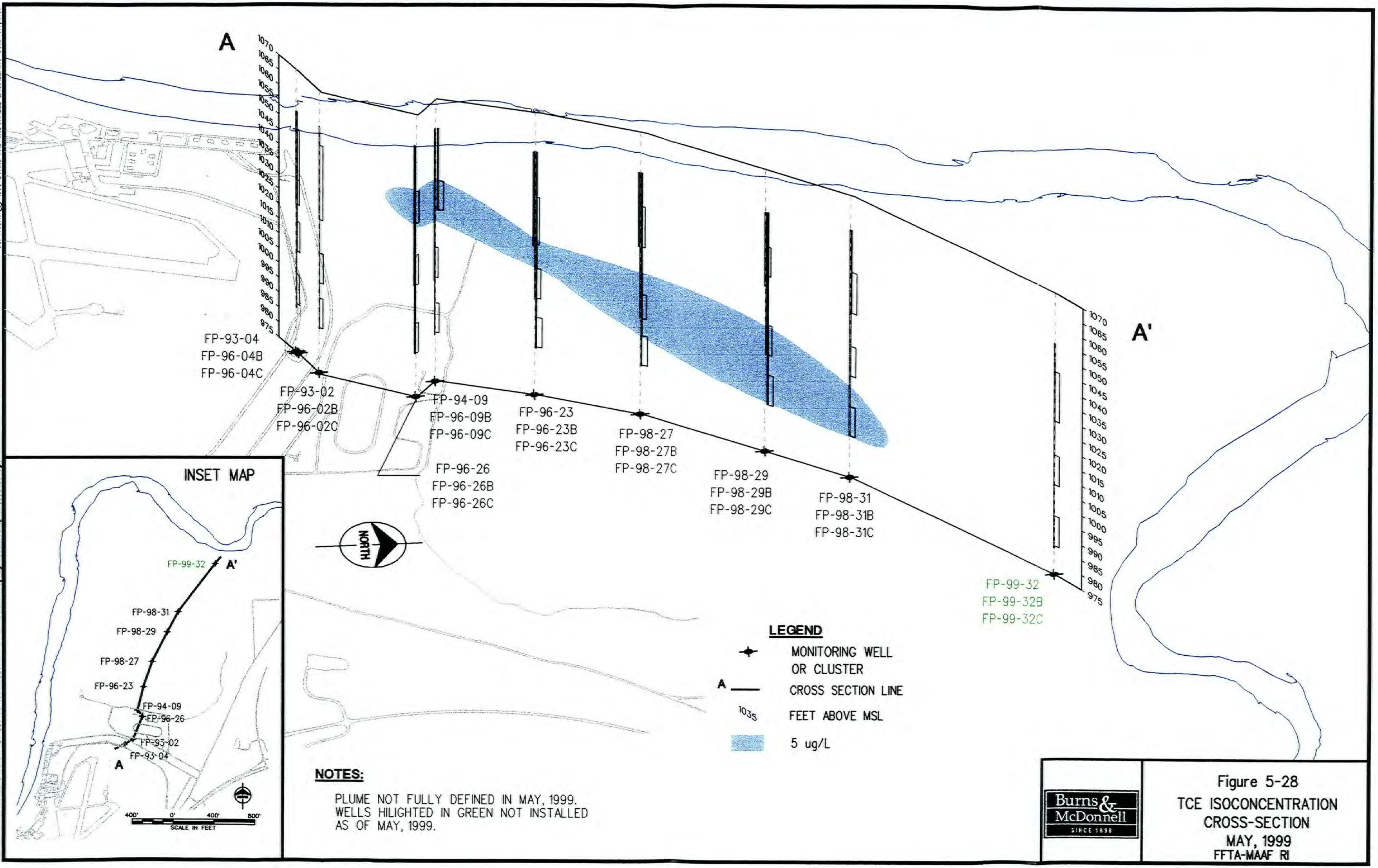
NOTES:

PLUME NOT FULLY DEFINED IN MAY, 1999.
WELLS HILIGHTED IN GREEN NOT INSTALLED AS OF MAY, 1999.

Burns & McDonnell
SINCE 1898

Figure 5-27
PCE ISOCONCENTRATION CROSS-SECTION
MAY, 1999
FFTA-MAAF RI

MAY99F...CE.DGN/ 6-20-2000 10:49/OLS

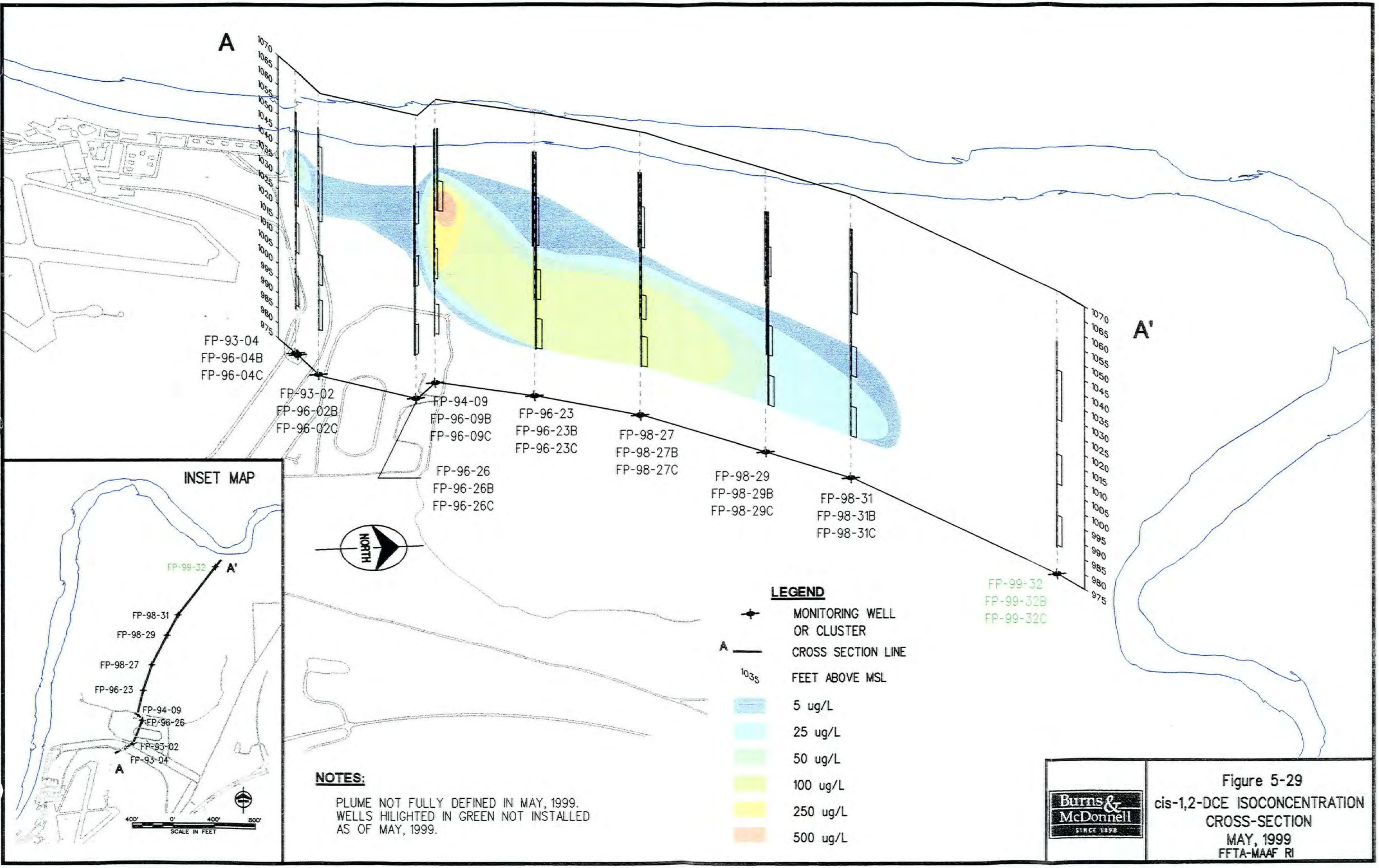


NOTES:

PLUME NOT FULLY DEFINED IN MAY, 1999.
WELLS HILIGHTED IN GREEN NOT INSTALLED
AS OF MAY, 1999.

Burns & McDonnell
SINCE 1898

Figure 5-28
TCE ISOCONCENTRATION
CROSS-SECTION
MAY, 1999
FFTA-MAAF RI

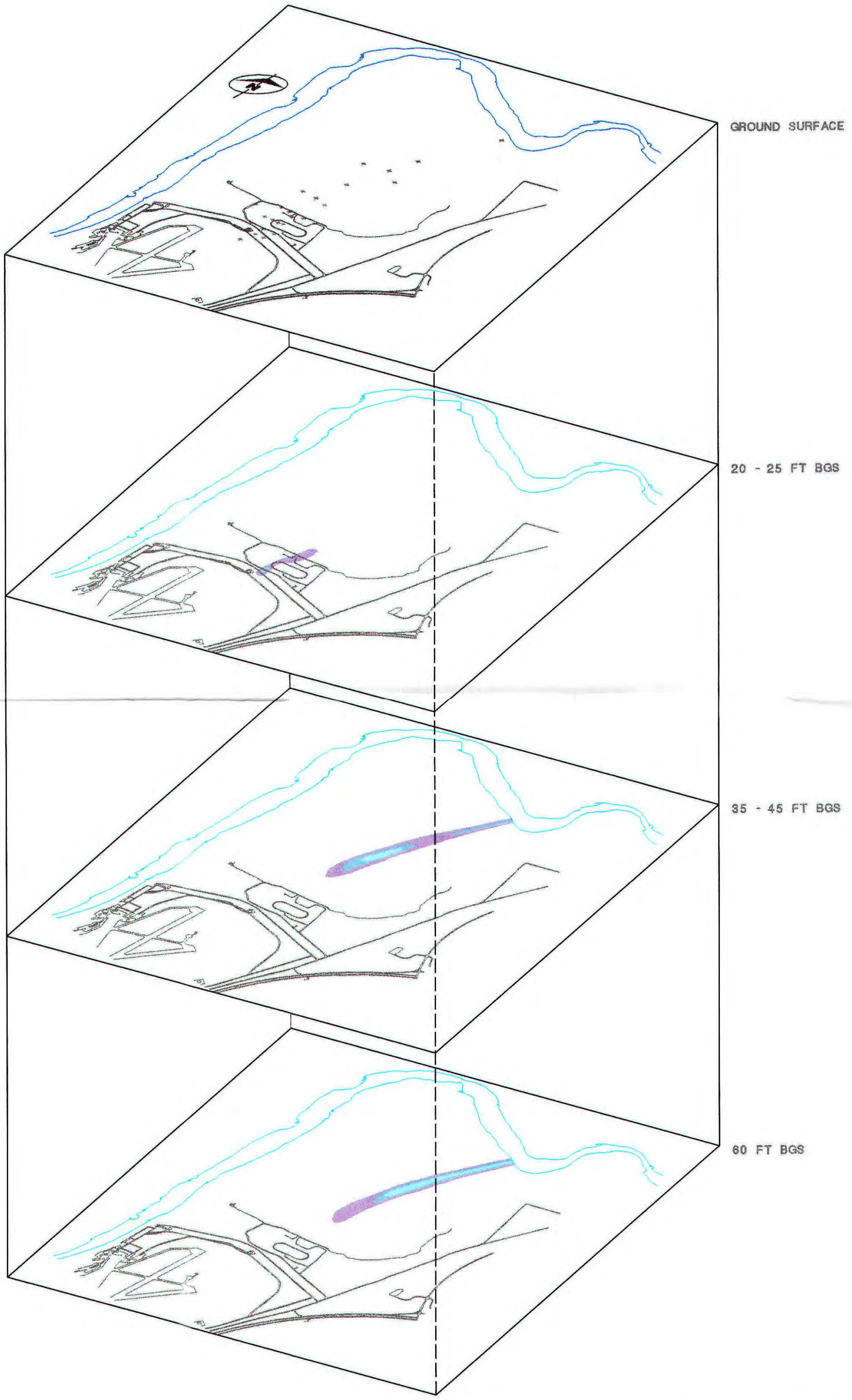


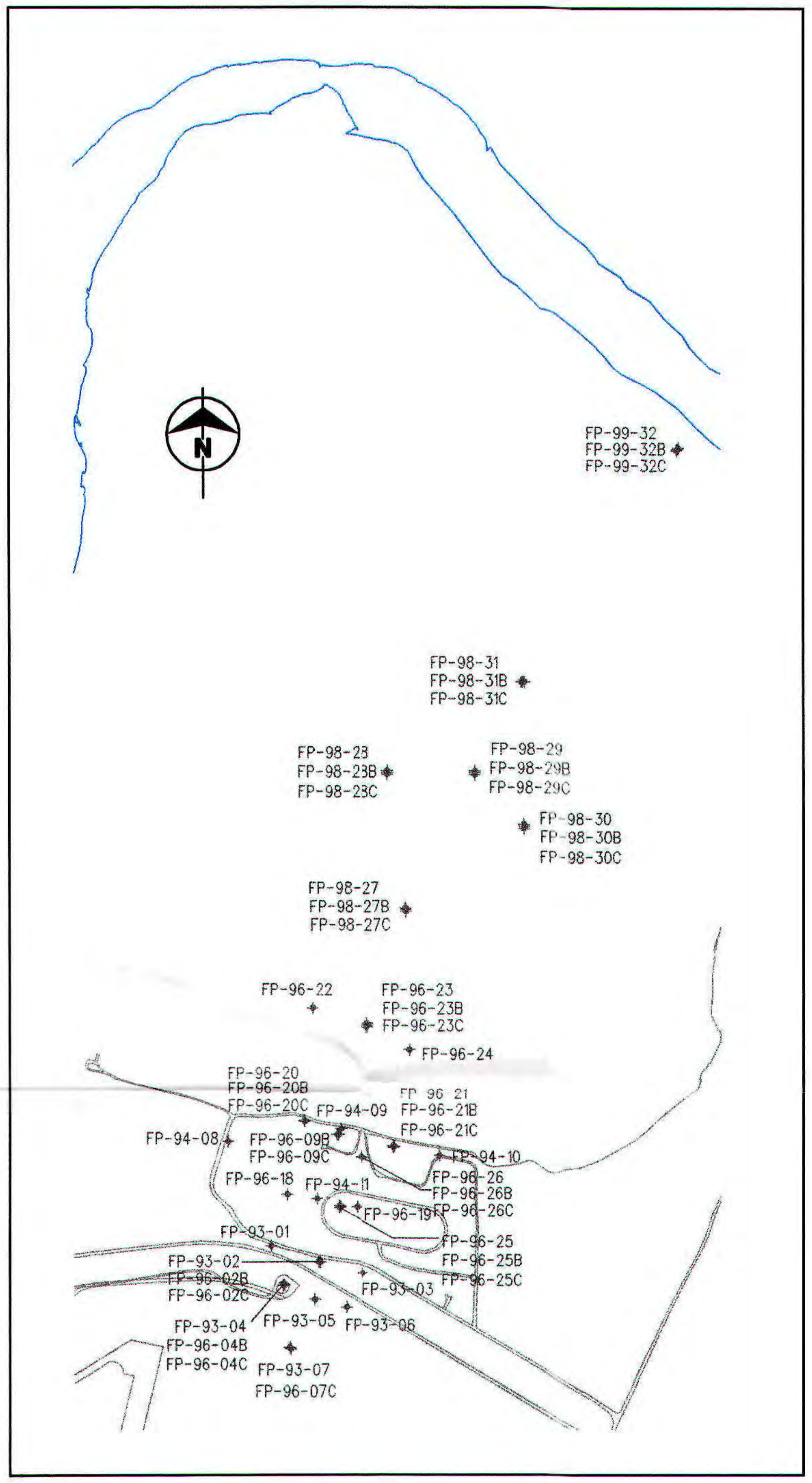
NOTES:

PLUME NOT FULLY DEFINED IN MAY, 1999.
WELLS HILIGHTED IN GREEN NOT INSTALLED AS OF MAY, 1999.

Burns & McDonnell
SINCE 1898

Figure 5-29
cis-1,2-DCE ISOCONCENTRATION CROSS-SECTION
MAY, 1999
FFTA-MAAF RI





LEGEND

✦	MONITORING WELL OR CLUSTER
🟪	2 ug/L
🟦	5 ug/L
🟦	10 ug/L
🟦	25 ug/L
🟩	50 ug/L
🟩	100 ug/L
🟨	150 ug/L
🟨	200 ug/L
🟧	300 ug/L
🟧	400 ug/L
🟥	500 ug/L
🟥	700 ug/L

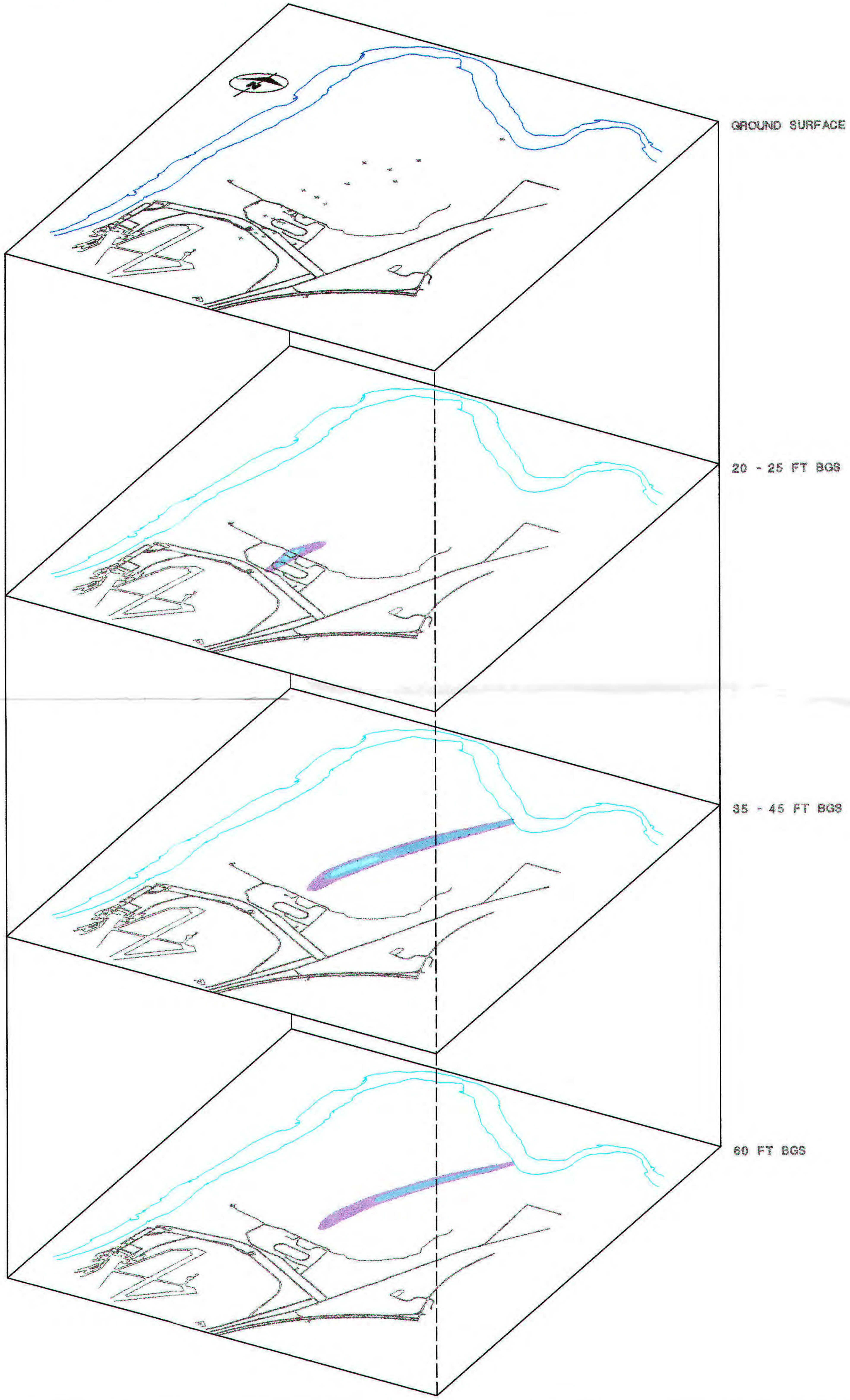
Figure 5-30
PCE IN GROUNDWATER
AUGUST 1999

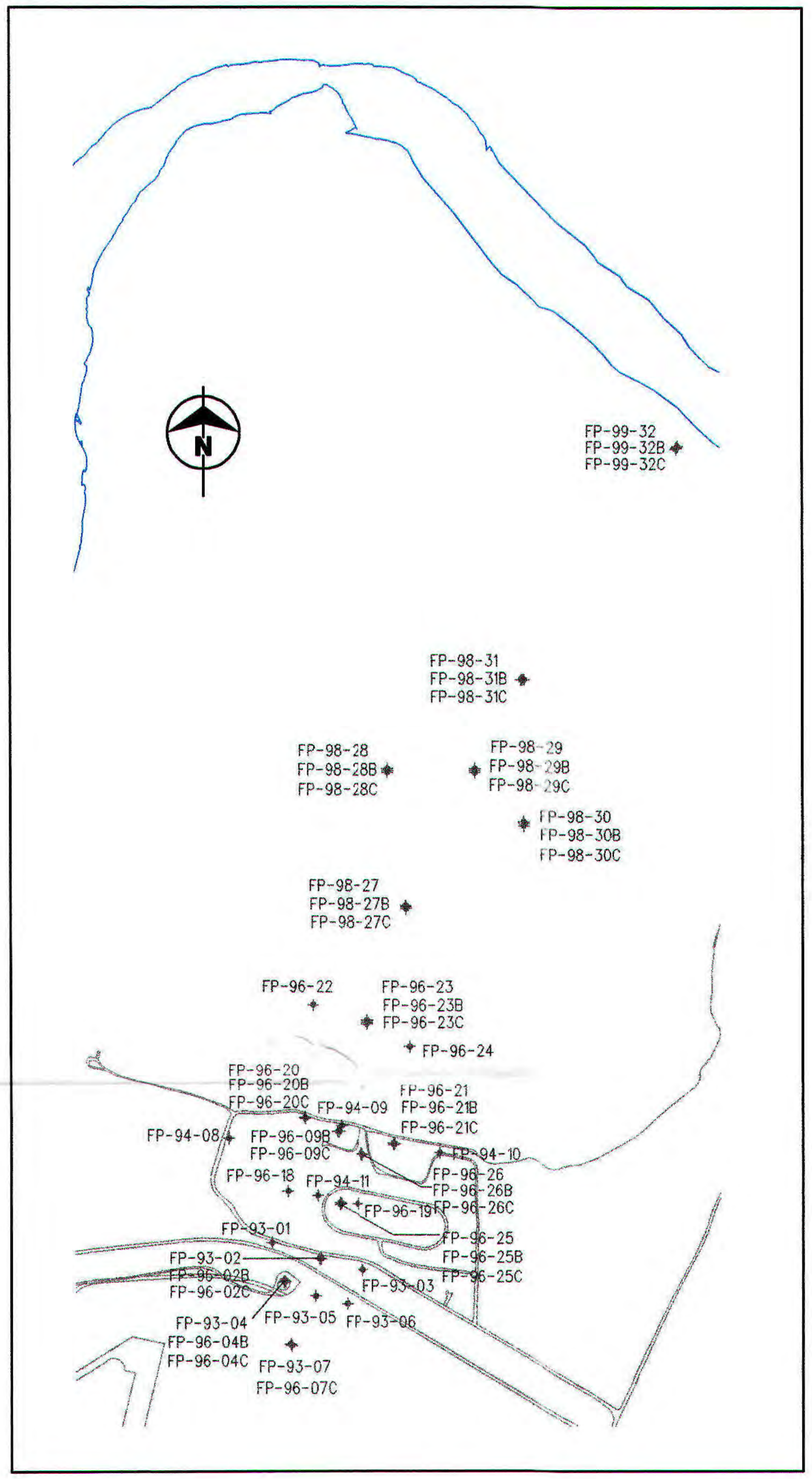
FFTA-MAAF RI

K:#USFRRI#USTN#1999#FIG#05INSET.DGN( ) OFF=7,21,23,25,27,31-33,35,37,39,41,43,45,47,58
K:#USFRRI#USTN#1999#FIG#SP27WELLSZ.DGN( ) OFF=5-10,12-32,34-56,59-60,62-63
K:#USFRRI#USTN#1999#FIG#BDR24X18.DGN( ) OFF=NONE
K:#USFRRI#USTN#1999#FIG#05BASESTACK.DGN(BASE) OFF=5-6,8-10,12-40,42-57,60,63
0899PCESTACK.DGN/ 2-21-2000 11:18/BKK K:\USFRRI\USTN\1999 \FIG\

0899TCESTACK.DGN/ 2-21-2000 11:14/BKK

K:¥USFRRI¥USTN¥1999¥FIG¥05INSET.DGN( ) OFF=7,21,23,25,27,31-33,35,37,39,41,43,45,47,58
K:¥USFRRI¥USTN¥1999¥FIG¥SP27WELLSZ.DGN( ) OFF=5-10,12-32,34-56,59-60,62-63
K:¥USFRRI¥USTN¥1999¥FIG¥BDR24X18.DGN( ) OFF=NONE
K:¥USFRRI¥USTN¥1999¥FIG¥05BASESTACK.DGN(BASE) OFF=5-6,8-10,12-40,42-57,60,63
K:\USFRRI\USTN\1999\FIG\





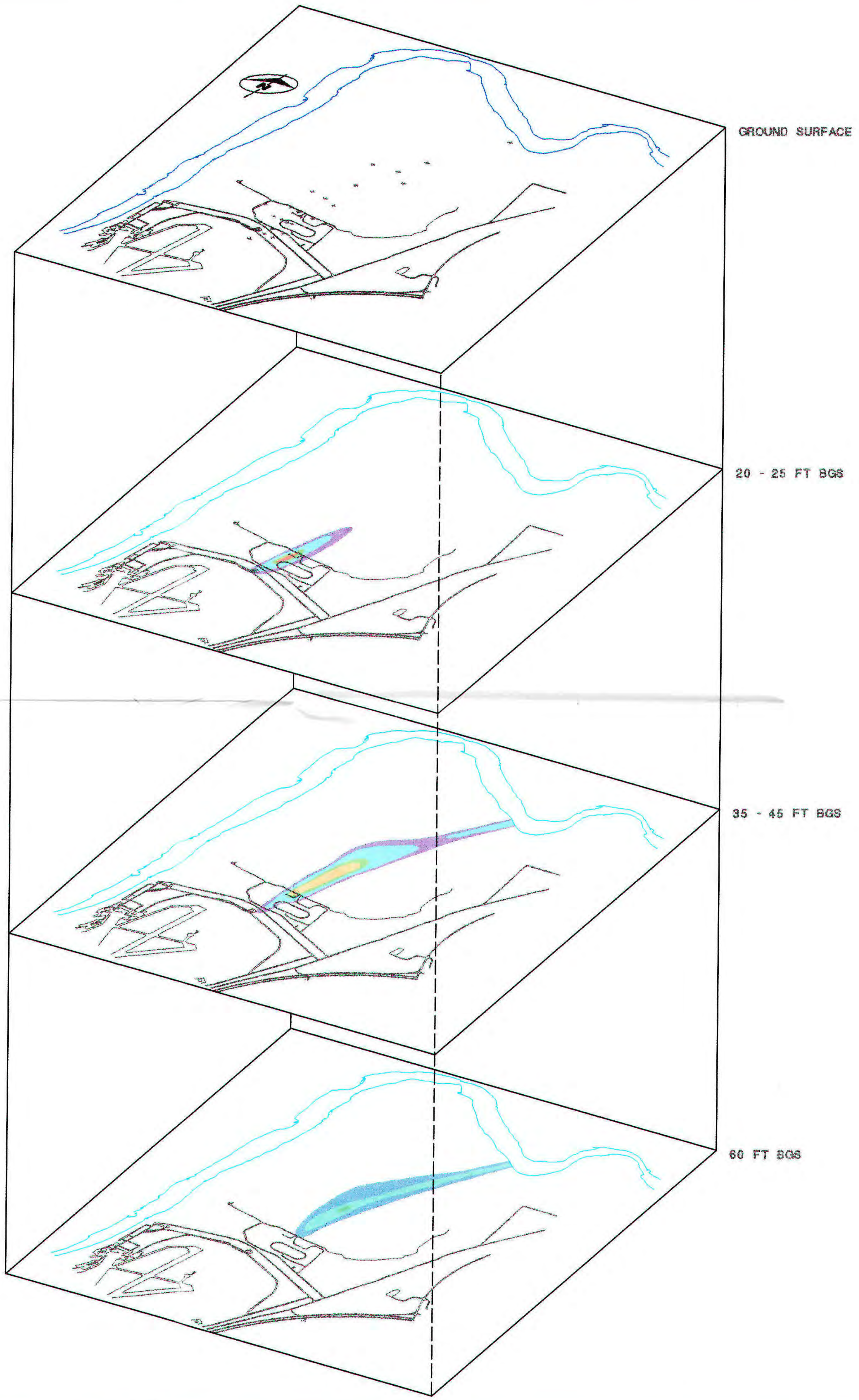
LEGEND

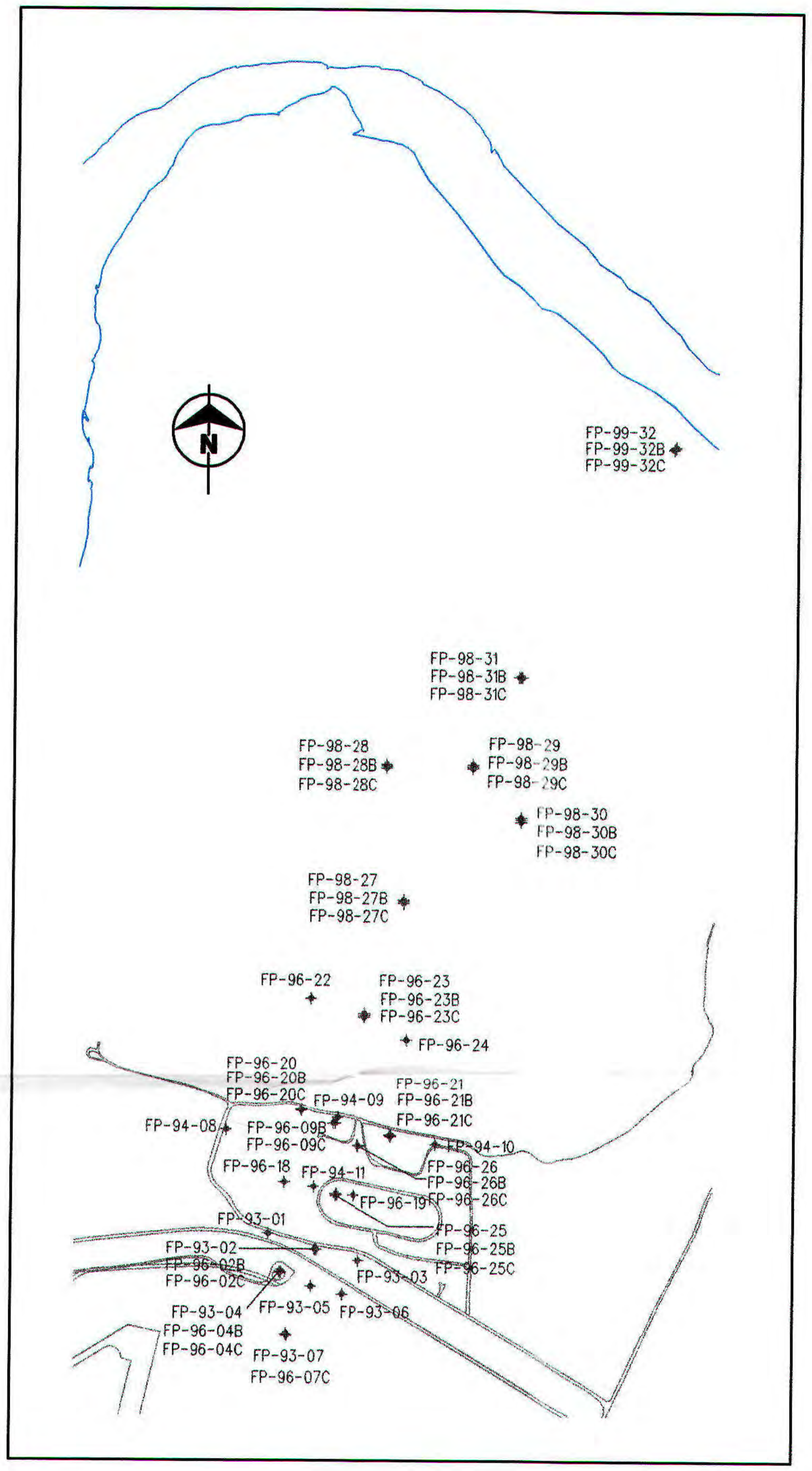
✦ MONITORING WELL OR CLUSTER
🟪 2 ug/L
🟦 5 ug/L
🟦 10 ug/L
🟦 25 ug/L
🟩 50 ug/L
🟩 100 ug/L
🟨 150 ug/L
🟧 200 ug/L
🟧 300 ug/L
🟧 400 ug/L
🟥 500 ug/L
🟥 700 ug/L

Burns & McDonnell
SINCE 1898

Figure 5-31
TCE IN GROUNDWATER
AUGUST 1999

FFTA-MAAF RI





LEGEND

✦	MONITORING WELL OR CLUSTER
▨	2 ug/L
▨	5 ug/L
▨	10 ug/L
▨	25 ug/L
▨	50 ug/L
▨	100 ug/L
▨	150 ug/L
▨	200 ug/L
▨	300 ug/L
▨	400 ug/L
▨	500 ug/L
▨	700 ug/L

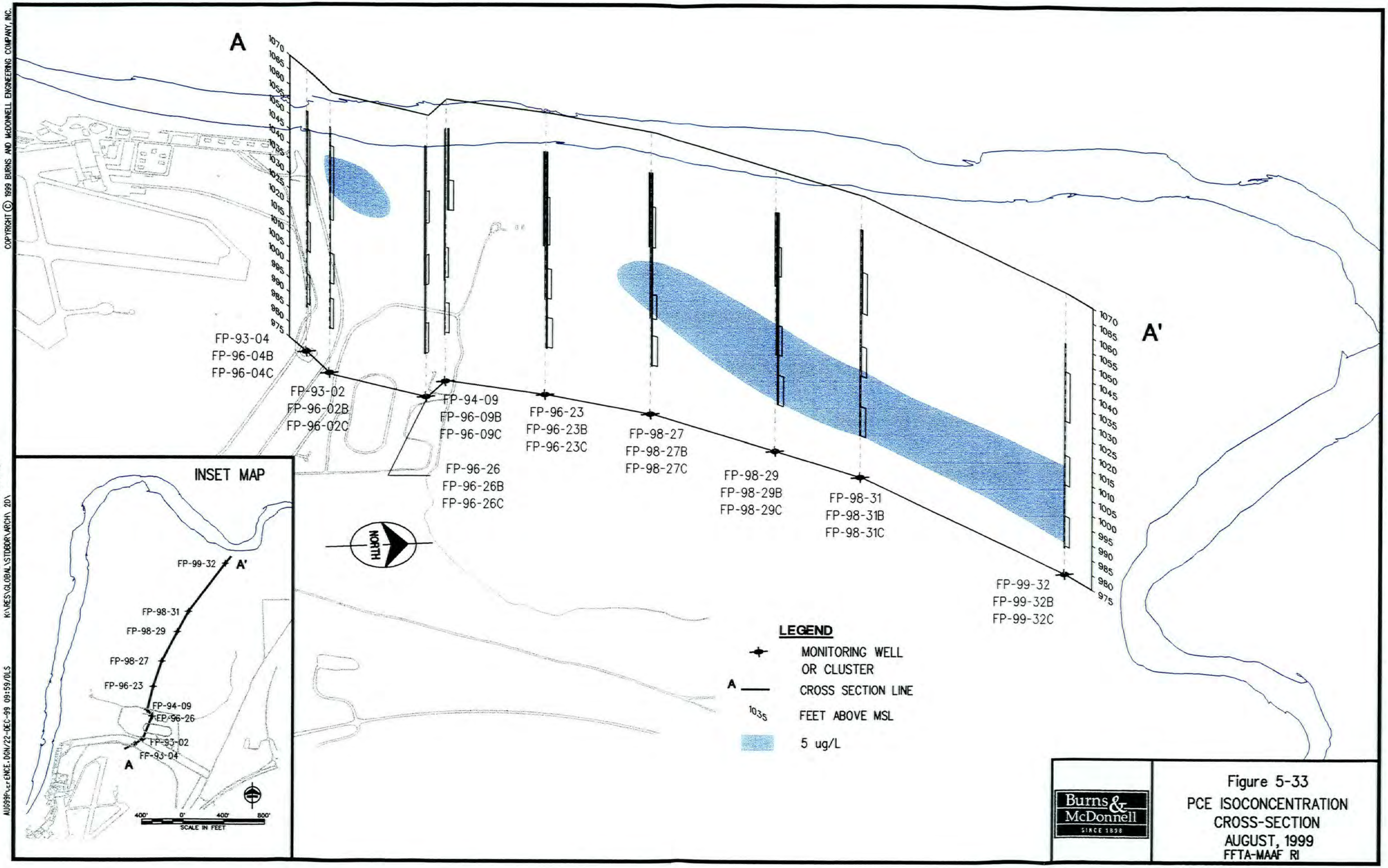
Burns & McDonnell
SINCE 1898

Figure 5-32
cis-1,2-DCE IN GROUNDWATER
AUGUST 1999

FFTA-MAAF RI

0899DCESTACK.DGN/ 2-21-2000 11:06/BKK

K:#USFRRI#USTN#1999#FIG#05INSET.DGN( ) OFF=7,21,23,25,27,31-33,35,37,39,41,43,45,47,58
K:#USFRRI#USTN#1999#FIG#SP27WELLS7.DGN( ) OFF=5-10,12-32,34-56,59-60,62-63
K:#USFRRI#USTN#1999#FIG#BDR24X18.DGN( ) OFF=NONE
K:#USFRRI#USTN#1999#FIG#05BASESTACK.DGN(BASE) OFF=5-6,8-10,12-40,42-57,60,63
K:\USFRRI\USTN\1999\FIG\



Burns & McDonnell
SINCE 1898

Figure 5-33
PCE ISOCONCENTRATION
CROSS-SECTION
AUGUST, 1999
FFTA-MAAF RI

u:#ftrilley#dgn#seclinez.dgn
u:#ftrilley#dgn#sec#x3d#dpth#0899tce.dgn
K:\RES\GLOBAL\STDBDR\ARCH\ 2D\
AUG991... cNCE.DGN/22-DEC-99 10:00/DLS

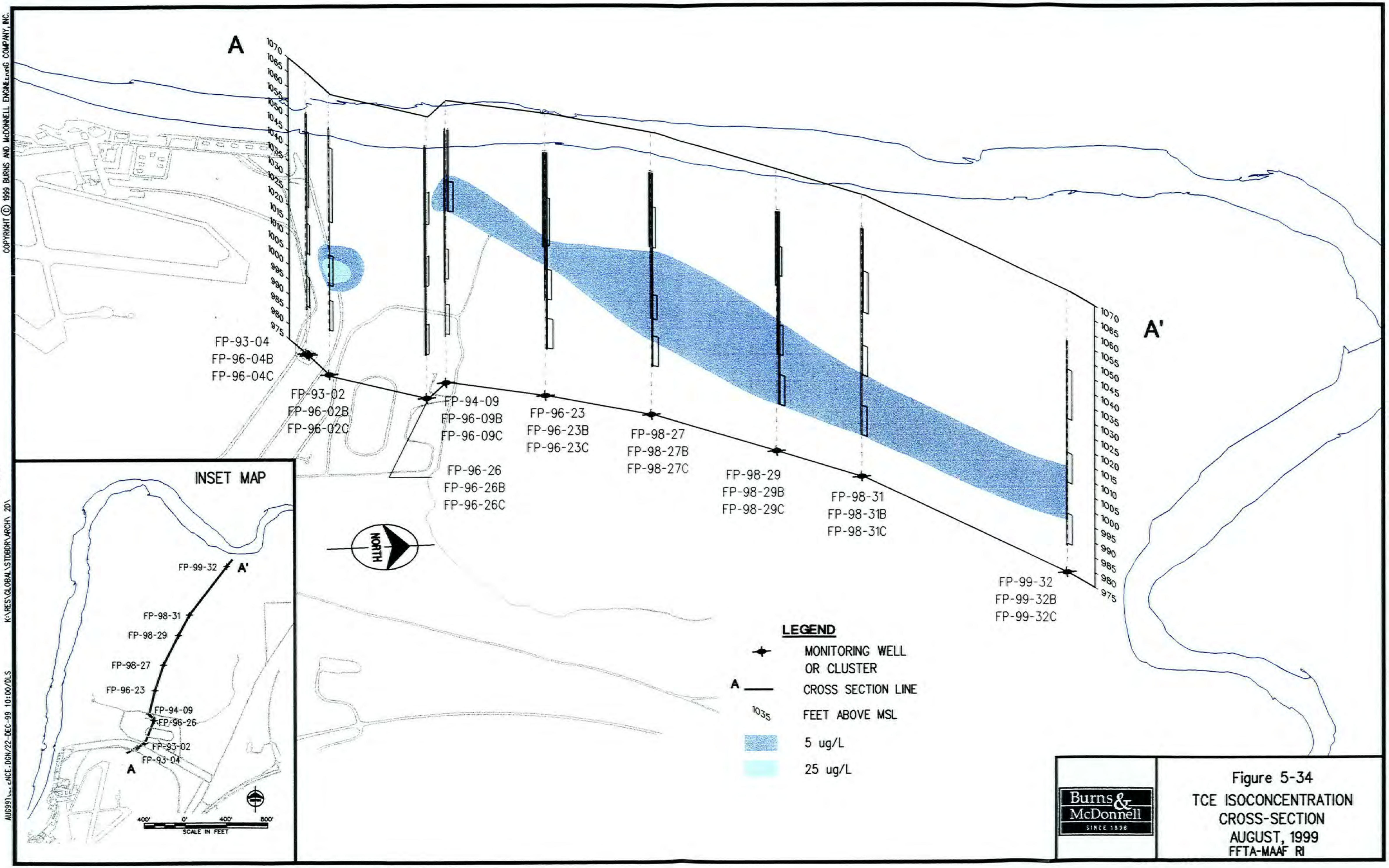


Figure 5-34
TCE ISOCONCENTRATION
CROSS-SECTION
AUGUST, 1999
FFTA-MAAF RI

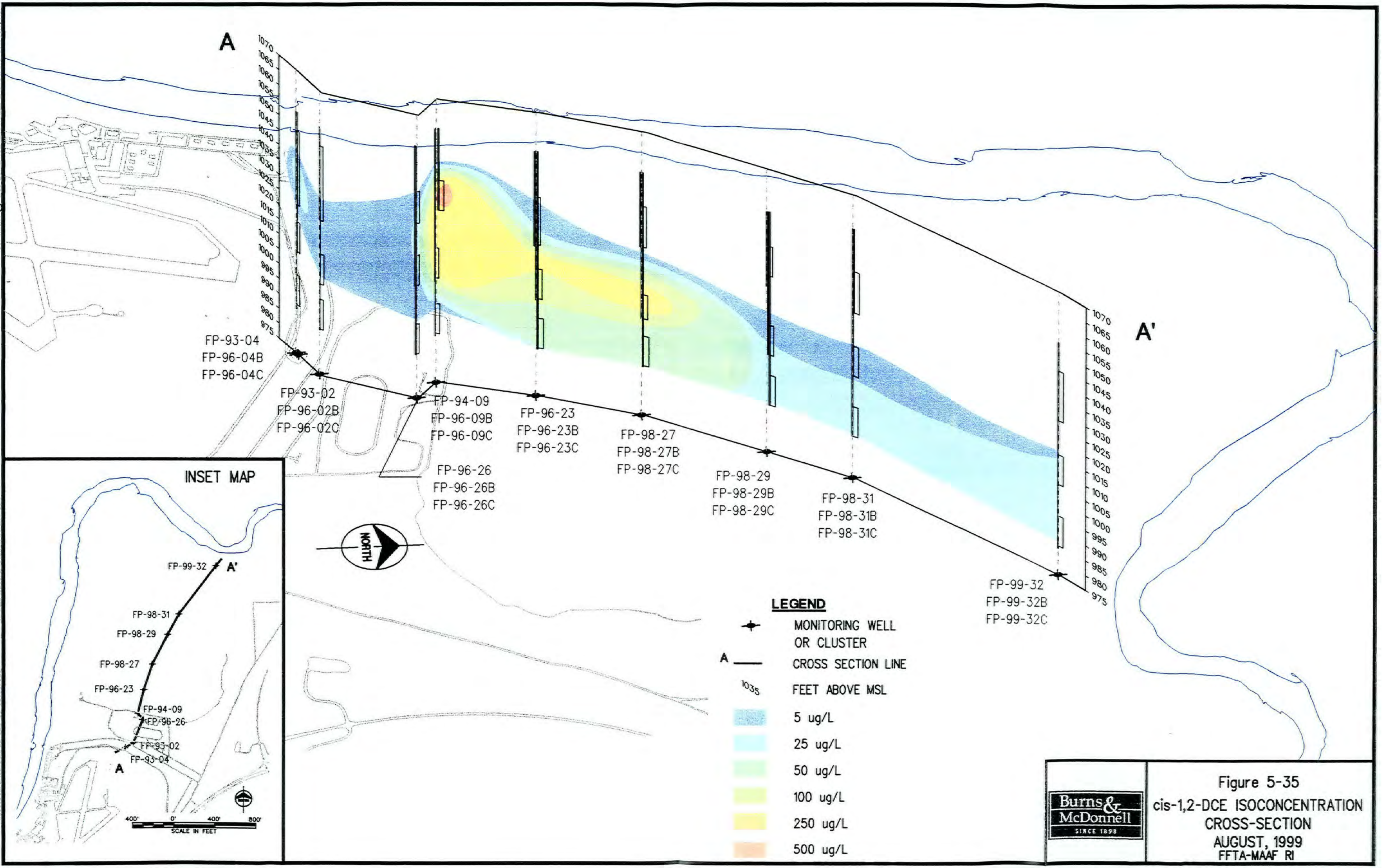


Figure 5-35
cis-1,2-DCE ISOCONCENTRATION
CROSS-SECTION
AUGUST, 1999
FFTA-MAAF RI

u:*ffrilley*dgn*sec*x3d*dpfh*0899dce.dgn
K:\RES\GLOBAL\STDBDR\ARCH\ 2D\
AUG99D…ENCE.DGN/22-DEC-99 09:59/DLS

6.0 FATE AND TRANSPORT EVALUATION

6.1 INTRODUCTION

6.1.1 Purpose

This evaluation was performed to investigate the fate of PCOPCs in the subsurface and the transport mechanisms in action at the FFTA-MAAF Site. This was accomplished through modeling and careful assessment of current and past Site conditions. Site conditions were assessed by conducting a microcosm study, a tracer test, and by analyzing and interpreting data from the groundwater monitoring program.

The purpose of the contaminant fate and transport modeling was to simulate the transport of PCOPCs in the subsurface, to provide a tool to aid in prediction of future concentrations at potential receptor locations, and to further evaluate natural attenuation processes occurring at the Site. The PCOPCs identified in Section 5.0 for fate and transport evaluation are: PCE, TCE, DCE (cis and trans isomers), VC, naphthalene, and BTEX (benzene, toluene, ethylbenzene, and xylenes).

Because naphthalene and BTEX fate and transport can serve as a suitable surrogate for TPH-DRO and TPH-GRO fate and transport, TPH was not evaluated independently in this Section. 1,1-DCE was only detected in a small percentage of total samples, and is not the primary daughter product of TCE degradation, and is therefore not evaluated in this Section. 2-Methylnaphthalene was not considered in this evaluation because it was detected only in a small number of post pilot study soil samples.

6.1.2 Objectives

The primary objective of this evaluation was to determine the fate and transport mechanisms in action at the Site and the impact of these mechanisms on contaminant concentrations and distribution. The secondary objective of the evaluation was to determine the degree to which natural attenuation processes are occurring at the Site. Natural attenuation processes include abiotic and biotic degradation, dispersion, sorption, and volatilization.

Contaminant transport modeling used to simulate the fate of the PCOPCs was based upon field evidence of fate and transport mechanisms operating at the Site. The model simulates the groundwater flow direction and gradient observed at the Site, evaluates the potential for contaminants to be captured by a nearby irrigation well, simulates the fate and transport of PCOPCs, and provides future concentration data for the ensuing risk assessment.

6.1.3 Approach/Organization

This fate and transport evaluation includes several elements. The first element discusses the possible destructive and non-destructive mechanisms that may be affecting the contaminants at the Site. These mechanisms were evaluated for their potential to occur at the Site based upon field data and observations. Changes in contaminant and indicator parameter concentrations with time and distance were evaluated for evidence of degradation mechanisms potentially occurring in the aquifer. The second element presents a conceptual Site model used to develop a contaminant transport model to predict future concentrations.

The third element presents the contaminant modeling methods and results. A groundwater flow conceptual model of the Site was developed and calibrated to observed water levels at the Site. A sensitivity analysis was performed using the groundwater flow model to assess the variability of model output based on changes in input parameters. A reactive transport model was constructed to predict the fate of chlorinated solvents and calibrated to concentrations observed at the Site. The reactive transport model was run long-term to predict potential receptor point concentrations over time and maximum aquifer concentrations, as well as to evaluate natural attenuation processes. A second contaminant transport model was developed to predict the fate of naphthalene and BTEX.

6.2 FATE AND TRANSPORT MECHANISMS

This section presents an overview of fate and transport mechanisms affecting the PCOPCs at the Site.

6.2.1 Non-Destructive Mechanisms

Mechanisms that result in a reduction of contaminant concentrations but not contaminant mass are referred to as nondestructive fate and transport mechanisms. These processes include advection, dispersion, sorption, dilution, and volatilization.

Contaminant behavior in the environment is an important determinant of exposure pathways and concentrations. The behavior of contaminants is a function of the physical and chemical properties specific to the contaminant, as well as characteristics of the matrix in which the contaminant exists or moves. Important contaminant-specific physical and chemical properties include molecular weight, water solubility, vapor pressure, volatility (Henry's Law constant), octanol-water partitioning coefficient (K_{ow}), organic carbon-water partitioning coefficient (K_{oc}), air diffusion coefficient, and half-life. These chemical and physical properties affect the rate and degree of completion of certain chemical reactions, thereby determining the fate of a contaminant in the subsurface. Table 6-1 summarizes the chemical and physical properties of the PCOPCs at the Site and the values chosen to represent these parameters. The rationale for the chosen values is introduced in the following sections.

6.2.1.1 Advection

Advection, or seepage velocity, is the movement of the dissolved contaminant along with the bulk groundwater. This transport mechanism depends only on the properties of the aquifer, and is independent of chemical properties. Hydraulic conductivity, hydraulic gradient, and effective porosity are all components of advective transport. Refer to Section 4.1.5.3 for further discussion of seepage velocity.

6.2.1.1.1 Hydraulic Conductivity

Hydraulic conductivity is a measure of the aquifer's ability to transmit water. Hydraulic conductivity is commonly measured in the field by means of aquifer pumping tests or slug tests, with pumping tests being the most reliable. Hydraulic conductivity is dependent upon the arrangement of the pores in the aquifer, the viscous properties of the fluid flowing in the aquifer (water), and is typically determined for the horizontal flow in the aquifer using standard pumping and/or slug tests, or can be estimated from the grain sizes of aquifer materials.

A pumping test performed approximately 7,000 feet southwest of the FFTA yielded average horizontal hydraulic conductivities of 664 ft/day (Section 2.5.2). Values for horizontal hydraulic conductivity calculated from slug tests at the Site ranged from 16 to 30 ft/day (Section 2.5.2). Values for horizontal hydraulic conductivity calculated from grain size data ranged from 47 to 697 ft/day (Section 2.5.2).

6.2.1.1.2 Hydraulic Gradient

Hydraulic gradient is the driving force for groundwater flow and is expressed as the change in head over the distance the change occurs (either vertically or horizontally). This determines the magnitude and direction of groundwater flow.

The horizontal component of the hydraulic gradient at the Site has typically been in the range of 0.0006 to 0.0009 ft/ft (Section 2.5.2). The measured values for the vertical component of the hydraulic gradient at the Site range from a negative 0.0031 ft/ft to positive 0.0034 ft/ft (Section 2.5.2).

6.2.1.1.3 Effective Porosity

Effective porosity is defined as the porosity through which flow can occur (Fetter, 1993). Therefore, non-interconnected and dead-end pores are not included in the effective porosity. Effective porosity has been estimated from the tracer study based upon arrival times of the tracer at a well (Section 4.1.5). The effective porosity values estimated from this study are as follows: 0.22 for the shallow zone, 0.42 for the intermediate zone, and 0.53 for the deep zone.

Effective porosity has been measured using SSSA Part 1 Method 36-2231 for three shallow well borings completed at the Site: FP-96-18, FP-96-19, and FP-96-21 (Table 2-4). Of the nine samples collected from these borings, three samples represent a clay soil. Since aquifer materials at the Site are predominately fine to coarse sand, the samples representing a clay soil were excluded from the calculations of average effective porosity. This allowed for an average effective porosity that more closely represented aquifer conditions at the Site. The measured effective porosity (excluding clay samples) ranges from 0.31 to 0.40, with a mean of 0.35.

6.2.1.2 Hydrodynamic Dispersion

Hydrodynamic dispersion is defined as the mixing of contaminated water with uncontaminated water and is a function of mechanical dispersion and molecular diffusion. Overall, dispersive processes cause some contaminant molecules to move faster than the seepage velocity and others to move slower, thus causing the contaminant plume to spread out over time. This spreading allows the contaminant plume to move forward more quickly than would be predicted by advection alone. Because the leading edge of the plume is made up of those molecules that have traveled more quickly than the seepage velocity, the leading edge becomes more diffuse, but arrives more quickly than advective processes would predict.

6.2.1.2.1 Mechanical Dispersivity

Mechanical dispersivity is the mixing of contaminant molecules due to local variations in contaminant velocity. There are three dominant processes which cause velocity variations. Contaminants traveling through pores of various sizes results in a slower rate through large pores, and a quicker rate through smaller pores. The pore length (or tortuosity) allows contaminants taking more tortuous paths to take longer to traverse than straighter paths, thus affecting the contaminant velocity. Within an individual pore, the fluid may flow at different rates due to the throat size of the pore or boundary effects. This allows contaminant molecules close to the edge of the pore to move more slowly than those in the middle of the pore.

Mechanical dispersion has three components: longitudinal, transverse, and vertical dispersion. These components are represented by the parameter dispersivity. Dispersivity (α), multiplied by the groundwater velocity, is a measure of mechanical dispersion. Longitudinal dispersivity was estimated from the tracer study by using the average arrival time of the tracer at an observation well (Section 4.1.5). The transverse and vertical dispersivities were then determined from the longitudinal dispersivity through commonly used conversion factors (Section 4.1.5.3). The dispersivity results of the tracer study are as follows:

Longitudinal dispersivity, $\alpha_x = 71$ cm
Transverse dispersivity, $\alpha_y = 7.1$ cm
Vertical dispersivity, $\alpha_z = 1.78$ to 7.1 cm

Since dispersivity is scale dependent, methods presented by Xu and Eckstein (1994) were used to estimate longitudinal dispersivity at the Site. The equation used to make this estimate is given as $\alpha_x = 0.83(\mathrm{Log}_{10}L)^{2.414}$, where L is the field scale. The field scale is generally assumed to be the distance from the center of mass to a down-gradient receptor. The field scale for this Site was taken as the distance from the center of the plume (Well FP-94-09 from May 1999) to the Kansas River. The center of the plume was determined from the May 1999 sampling event as the highest concentration of cis-1,2-DCE at the Site. Since cis-1,2-DCE is present in much higher concentrations than PCE or TCE, it was used to define the plume's center. The field scale at the Site was determined to be approximately 5,400 feet. Longitudinal dispersivity was then computed to be approximately 20 feet. This value is proportional to the longitudinal dispersivity determined from the tracer test performed at the Site (Section 4.1.5). Longitudinal dispersivity computed from the tracer test was determined to be 2.33 feet (71 cm), using a 50-foot field scale. Using the Xu and Eckstein (1994) approach, a similar α_x was calculated to be 2.98 feet, using a 50-foot field scale. This correlation suggests that the Xu and Eckstein equation is a valid estimate of dispersivity at the Site.

Transverse dispersivity is generally estimated as 1/ 10th of the longitudinal dispersivity, and vertical dispersivity is taken as 1/10th of the transverse dispersivity (Gelhar et al., 1992). Therefore, the following values were used as dispersivity estimates for the Site: $\alpha_x = 20$ feet, $\alpha_y = 2$ feet, and $\alpha_z = 0.2$ feet.

6.2.1.2.2. Molecular Diffusion

Molecular diffusion is the mixing of contaminated water with uncontaminated water due to concentration gradients. Usually molecular diffusion is only a significant factor in the case of very low velocities, such as in a tight soil or clay liner or in the case of mass transport involving very long time periods (Bedient, 1994). Since aquifer materials at the Site are relatively coarse and have high hydraulic conductivities, molecular diffusion is assumed to have a negligible effect on contaminant transport at this Site.

6.2.1.3 Sorption

The process by which contaminants become temporarily attached to the aquifer matrix is termed sorption. Effects from sorption result in contaminant movement that is slower than that predicted by only advective effects, and leads to a reduction in dissolved contaminant concentration. Sorption is a reversible process in which an equilibrium between adsorption and desorption is usually reached, although it may take some time based on individual contaminant properties. Because sorption is reversible, it does not permanently remove a contaminant from solution, but acts to slow the migration rate of the contaminant (Wiedemeier et al., 1999).

6.2.1.3.1 Distribution Coefficient, K_d

The Distribution Coefficient is the ratio of the sorbed contaminant concentration to the dissolved contaminant concentration. The higher the K_d, the greater the potential for sorption to the aquifer matrix. The K_d is controlled by the hydrophobicity of the contaminant and the total surface area of the aquifer matrix available for sorption. The partitioning of a contaminant onto mineral surfaces or the organic carbon content in the soil is almost exclusively onto the organic carbon fraction (f_{oc}) if it constitutes at least 0.1% (i.e. f_{oc}=0.001) of the aquifer on a weight basis (Pankow and Cherry, 1996). Under these circumstances, K_d can be estimated as $K_d = K_{oc}(f_{oc})$ where K_{oc} is the organic carbon partitioning coefficient (Fetter, 1993).

TOC has been measured for six well borings collected at the Site: FP-96-18, FP-96-19, FP-96-21, FP-96-20c, FP-96-23c, and FP-96-26c. Of the 45 samples collected from these borings, six samples represent a clay soil. Since aquifer materials at the Site are predominately fine to coarse sand, the samples representing a clay soil were excluded from TOC estimates. This allowed for an average TOC that more closely represented aquifer conditions at the Site. TOC values measured at the Site are summarized on Table 2-5. To convert TOC to f_{oc}, a dimensionless parameter, TOC is divided by 10^6. The mean f_{oc} for samples collected at the Site was determined to be 0.0053. For the purposes of this RI Report, K_d values were estimated by multiplying literature K_{oc} values by field f_{oc} values and are presented in Table 6-1. f_{oc} was calculated from field TOC data.

6.2.1.3.2 Octanol-Water Partition Coefficient, K_{ow}

The Octanol-Water Partition Coefficient is the ratio of the equilibrium concentration of an organic chemical in octanol divided by the concentration of the chemical in water. The K_{ow} expresses the extent of chemical affinity for octanol versus water. This value gives an indication of how hydrophobic the chemical is and its potential to adsorb to soil or to bioaccumulate in organisms. The greater the K_{ow}, the more likely the chemical will accumulate in soil, sediment, and biota. Chemicals with low K_{ow} values tend to partition mostly to air or water. In general, as K_{ow} increases, bioaccumulation, persistence, and adsorption increase while water solubility, mobility, and biodegradation decrease. Chemicals with log K_{ow} values greater than 3 are expected to adsorb to soil and to bioaccumulate. Chemicals with log K_{ow} values less than 2.7 are not expected to significantly adsorb to soil or to bioaccumulate (Ney, 1990). Literature K_{ow} values for the Site contaminants are provided on Table 6-1. This table illustrates that the log K_{ow} values for PCE, ethylbenzene, xylenes, and naphthalene are greater than 3 and are therefore expected to adsorb to soil and bioaccumulate. The log K_{ow} value for all other contaminants is less than 2.7. Therefore, they are not expected to significantly adsorb.

6.2.1.3.3 Organic Carbon Partition Coefficient, K_{oc}

The Organic Carbon Partition Coefficient is a measure of the propensity for organic compounds to be adsorbed by organic carbon in soil and sediment. A high K_{oc} (>10,000 cubic centimeters per gram [cm^3/g]) indicates a chemical is expected to be sorbed tightly to carbon-containing soil and to be less available for migration to water. Chemicals with K_{oc} values between 100 cm^3/g to 10,000 cm^3/g are expected to be moderately sorbed. A low K_{oc} value (< 100 cm^3/g) indicates a chemical is expected to be weakly sorbed and available for migration (Ney, 1990).

K_{oc} is generally estimated from the octanol-water partition coefficient (K_{ow}) of the contaminant of interest, or is measured from laboratory studies. Literature K_{oc} values for the Site contaminants are provided on Table 6-1. K_{oc} values for PCE and TCE were selected from USEPA, 1996. These values were computed as the geometric mean from 15 and 21 studies respectively. This document, however, does not provide K_{oc} values for cis-1,2-DCE or VC. Values for these chemicals were selected from KDHE, 1999. Values provided in this reference, however, are estimated from K_{ow} values and may not be as reliable as measured values. K_{oc} values for the petroleum hydrocarbon contaminants at the Site were taken from (Wiedemeier, 1999).

6.2.1.4 Dilution

Dilution occurs when a given mass of contaminant is dissolved in an increasing amount of solvent (water in this case). Dilution affects are related to advection and dispersion, but are also influenced by infiltration and contaminant solubility. Water solubility, often referred to as just solubility, refers to the maximum concentration of a chemical that will dissolve in a given amount of pure water. The solubility of a contaminant is important to understanding its ability to migrate in the environment. The solubility of a chemical is a major determinant of how a contaminant will be affected by infiltrating and flowing water and, therefore, how quickly the contaminant will migrate through the subsurface. Compounds with water solubilities greater than 1000 mg/L are generally expected to migrate significantly, and compounds with water solubilities less than 10 mg/L are not expected to migrate. Highly water-soluble chemicals are less strongly adsorbed to soil and can be readily leached to groundwater. Additionally, highly water-soluble chemicals tend to volatilize less from water and be more biodegradable. Water solubility affects hydrolysis, photolysis, and biodegradation rates. In general, as solubility increases, mobility and biodegradation increase while adsorption, persistence, and bioaccumulation decrease (Ney, 1990). TCE, cis-1,2-DCE, VC, and benzene all have solubilities greater than 1,000 mg/L, therefore, significant migration of these contaminants is expected. VC has the greatest solubility of Site PCOPCs, at 8,800 mg/L. The solubility of naphthalene is the lowest of Site PCOPCs, at 31 mg/L.

6.2.1.5 Volatilization

Volatilization is the transfer of a compound from the liquid to the gaseous phase. Vapor pressure is a measure of the volatility of a chemical in its pure state and is an important determinant of the rate of volatilization from contaminated soils and waters. As vapor pressure increases, volatilization increases, and water solubility and adsorption decrease. Compounds with vapor pressures greater than 0.01 torr have high volatilities, and compounds with vapor pressures less than 1 x 10^{-6} torr have low volatilities (Ney, 1990). In general, chemicals with low vapor pressures and high affinity for soils or water are less apt to vaporize. All of the PCOPCs for the Site have high volatilities.

The degree to which a chemical will volatilize is expressed as the Henry's law constant. Henry's law states that the concentration of a contaminant in the gaseous phase is directly proportional to the compound's concentration in the liquid phase and is a constant characteristic of the compound (Wiedemeier, 1999). Henry's Law constant incorporates molecular weight, solubility, and vapor pressures to indicate the degree of volatility of a chemical in solution. Chemicals with a Henry's law constant greater than 1 x 10^{-3} atmospheres-cubic meters/mole (or atm-m^3/mol) are considered highly volatile, and chemicals with a Henry's Law constant less than 3 x 10^{-7} atm-m^3/mol are considered nonvolatile. Henry's law constant is conventionally expressed as a ratio of partial pressures in the vapor to the concentration in the liquid. It is therefore, a coefficient that reflects the air-water partitioning.

Several conditions make it possible to assume negligible effect from volatilization on the natural attenuation of contaminants. First, the surface area of groundwater exposed to the soil gas is quite low, therefore limiting the interface where volatilization might occur. Second, for portions of contaminant plumes more than one meter below the water table, little, if anything, of solvent concentrations will be detectable in soil gas, due to the downward groundwater gradient in the vicinity of the water table (Wiedemeier, 1999).

6.2.2 Destructive Mechanisms

The non-destructive fate and transport mechanisms discussed above affect the PCOPCs at the Site by lowering the observed concentrations but not the overall mass of the contaminant in the environment. On the other hand, destructive fate and transport mechanisms decrease the observed concentration and the mass of a chemical.

Chlorinated solvents and petroleum hydrocarbons are organic compounds that can be degraded by both biotic and abiotic destructive mechanisms. Biotic degradation, or biodegradation, is the process by which chemicals are decomposed by direct or indirect reactions with microorganisms, whereas abiotic degradation occurs without microorganisms. Organics often undergo both biotic and abiotic degradation. Figure 6-1 depicts these degradative pathways and the resulting daughter products for the chlorinated solvents at the Site.

6.2.2.1 Abiotic Mechanisms

Abiotic degradation occurs without microorganisms. Several examples of reactions which may be abiotic include hydrolysis, dehydrohalogenation, and oxidation-reduction reactions. Hydrolysis is a substitution reaction in which an organic molecule reacts with water or a component ion of water and a halogen is replaced with a hydroxyl group. Dehydrohalogenation is an elimination reaction involving halogenated alkanes in which a halogen is removed from one carbon atom, followed by the subsequent removal of a hydrogen atom from an adjacent carbon atom. Anaerobic abiotic oxidation-reduction reactions commonly occur in the presence of microbial activity that precedes and produces the reducing conditions required.

6.2.2.1.1 Abiotic Fe(II) Reduction

The abiotic process of reduction of chlorinated solvents by Fe(II) present in the aquifer is currently being researched as a potential degradation process for chlorinated solvents not previously considered. Natural sources of ferrous iron are present in many aquifer sediments in the form of pyrite ($Fe S_2$) and siderite ($FeCO_3$). Iron oxides from the Dakota Sandstone Formation may also wash into this Site, especially through inflow from the Republican River. If the iron in these sources is made bioavailable in the form of Fe(II), it can reduce TCE to ethene.

This process is fundamental in the innovative In Situ Redox Manipulation (ISRM) technology. In the ISRM process, a strong reductant is introduced into the aquifer to reduce the Fe(III) (ferric iron) oxides naturally present in the aquifer to Fe(II). The Fe(II) is then available for the reduction of TCE to ethene. This process has not been utilized on other chlorinated solvents and has not been proven to occur naturally in the environment. However, Batelle Northwest Laboratories (Pers. Comm., 1998) indicates the potential of the abiotic Fe(II) reduction reaction occurring at the Site because of the naturally occurring Fe(II) (iron pyrite and iron siderite) mineral deposits.

6.2.2.2 Biotic Mechanisms

Biodegradation can occur in aerobic or anaerobic environments. Aerobic degradation requires the presence of dissolved oxygen. In the aerobic process, some organics may be partially degraded and converted to intermediate products, or the compound may be completely degraded to carbon dioxide, water, and minerals (e.g., chloride ions). Anaerobic degradation by oxidation utilizes alternate electron acceptors instead of dissolved oxygen in the degradation process.

Chlorinated solvents may undergo biodegradation through three different pathways: as an electron acceptor (reductive dechlorination), as an electron donor (direct mineralization or oxidation), or through cometabolism (Figure 6-1). Microorganisms are capable of carrying out all of these reactions, but they will facilitate only those reactions that have a net yield of energy (*Technical Protocol for Evaluation Natural Attenuation of Chlorinated Solvents in Ground Water* (USEPA and AFCEE, 1998) [*Natural Attenuation Protocol for Chlorinated Solvents*]). These processes are discussed in greater detail below.

6.2.2.2.1 Reductive Dechlorination

The best documented biodegradation process for chlorinated hydrocarbons under anaerobic conditions is reductive dechlorination. The term reductive dechlorination is used in this Report to refer to the biotic oxidation-reduction process only. Reductive dechlorination utilizes the chlorinated hydrocarbon as an electron acceptor by removing a chlorine atom and replacing it with a hydrogen atom. During biodegradation, microorganisms transform available nutrients into forms useful for energy by facilitating the transfer of electrons from donors to acceptors. This results in oxidation of electron donors and reduction of electron acceptors. Possible electron donors utilized during reductive dechlorination include natural organic material and anthropogenic sources such as fuel hydrocarbons. Typically, fuel hydrocarbons are completely degraded when used as electron donors. Competitive electron acceptors include dissolved oxygen, nitrate, manganese, iron, sulfate, carbon dioxide, and chlorinated hydrocarbons. Microorganisms use these electron acceptors in the sequence of the energy they provide. Aerobic respiration, the use of oxygen as an electron acceptor, provides a microorganism the most energy. Nitrate reduction, iron reduction, manganese reduction, chlorinated solvent reduction, and sulfate reduction provide decreasing amounts of energy for the microorganism. ORP of groundwater is a measure of electron activity and is an indicator of the relative tendency of a solution to accept or transfer electrons.

Reductive dechlorination in groundwater is biologically mediated, and therefore, the ORP of groundwater depends upon, and influences, the rates of biodegradation. Figure 6-2 shows the typical ORP conditions for groundwater when different electron acceptors are used.

Chlorinated hydrocarbons may serve as alternate electron acceptors when sufficient organic material is available. The presence of elevated concentrations of organic substrate in the aquifer, as is present in certain portions of the aquifer at FFTA-MAAF as a result of fuel spills, results in a surplus of electron donors. This surplus of electron donors increases the reducing potential of the groundwater. If the appropriate microorganisms are available to facilitate oxidation-reduction reactions between surplus electron donors and electron acceptors, more common inorganic electron acceptors such as dissolved oxygen, nitrate, and ferric iron will be reduced. The microorganisms may facilitate equal thermodynamically favorable reduction-oxidation reactions between the remaining surplus electron donors and alternate electron acceptors, such as chlorinated hydrocarbons. The fuel hydrocarbons will be completely oxidized to water and carbon dioxide and the chlorinated hydrocarbons will be sequentially dechlorinated. However, this process may be interrupted and is dependent upon environmental factors. As a direct result of the reductive dechlorination process, and without considering other potential reactions of degradation compounds, daughter products will accumulate and the concentration of the chloride ions will increase.

The rate at which reductive dechlorination occurs decreases as the ratio of chlorine to carbon decreases. In other words, PCE is the most vulnerable to reductive dechlorination and VC is the least vulnerable. Reductive dechlorination can occur over the range of nitrate to methanogenic reducing conditions. However, the most rapid biodegradation rates and the most complete conversions of PCE to ethene occur under sulfate-reducing and methanogenic conditions.

In general, reductive dechlorination of chlorinated ethenes occurs by sequential dechlorination from PCE to TCE to cis-1,2-DCE to VC to ethene. This sequence may be interrupted depending on environmental conditions. In general, the rate of reductive dechlorination of chlorinated ethenes decreases with the number of chlorine substituents. Studies have shown that TCE can be anaerobically reduced to either 1,1-DCE, cis-1,2-DCE, or trans-1,2-DCE. However, studies have also shown that during reductive dechlorination cis-1,2-DCE is the most common 1,2-DCE isomer formed, followed by trans-1,2-DCE and then 1,1-DCE. All of these compounds can be further reduced to VC. VC may be further reduced to end products such as ethene and ethane.

6.2.2.2.2 Direct Mineralization

Reductive dechlorination of the less chlorinated organics, such as 1,2-DCE and VC, is usually slow and under some conditions incomplete. However, under aerobic and some anaerobic conditions, these less oxidized chlorinated ethenes can be used as the primary substrate (electron donor) in biologically mediated oxidation-reduction reactions. In this type of reaction, the facilitating microorganism obtains energy and organic carbon from the degraded chlorinated hydrocarbon. Metabolism of less oxidized compounds would be indicated by a loss of mass and decreasing molar ratio of these compounds to other chlorinated aliphatics. In addition, the resulting end products of direct mineralization are water and carbon dioxide.

On the other hand, the highly chlorinated ethenes are not likely to serve as electron donors or substrates for microbial degradation reactions. This is because the highly chlorinated compounds tend to be much more oxidized than many compounds present in a natural groundwater system (USEPA and AFCEE, 1998). Therefore, attenuation of TCE and PCE through direct aerobic mineralization is expected to be small.

Aerobic Mineralization by O_2

Aerobic oxidation occurs when aerobic bacteria use the chlorinated solvents as electron donors by utilizing oxygen as an electron acceptor. McCarty and Semprini (1994) have shown that VC can be used as a primary substrate under aerobic conditions, with VC being directly mineralized to carbon dioxide and water. Although direct DCE oxidation has not been verified, a recent study (Bradley, et al., 1998a) has suggested that DCE isomers may be used as primary substrates. The authors indicated that the mechanism of oxidation could have been direct or cometabolic oxidation. Aerobic oxidation is rapid relative to reductive dechlorination of VC and cis-1,2-DCE.

Aerobic oxidation of VC and DCE has been reported by a number of investigators. Thus, it has been suggested that anaerobic/aerobic sequential biodegradation by indigenous microorganisms may be an effective means of bioremediating aquifer contaminated with chlorinated ethenes.

Anaerobic Mineralization by Fe(III) or Mn(IV)

Anaerobic oxidation occurs when anaerobic bacteria use the chlorinated solvents as electron donors by utilizing an available electron acceptor such as ferric iron (Fe(III)) or Mn(IV). Bradley and Chapelle (1996) have shown the addition of chelated Fe(III) to anaerobic aquifer microcosms resulted in mineralization of up to 34 percent of VC within 84 hours. These results indicated that VC can be mineralized under anaerobic, Fe(III)-reducing conditions to carbon dioxide and water. The rate of this reaction depends on the bioavailability of Fe(III). A field and laboratory study to assess the potential of VC biodegradation in a Fe(III)-reducing aquifer, concluded that VC degradation can be significant under Fe(III)-reducing conditions (Bradley, et al., 1998). First-order VC degradation rates from their study ranged from 0.03 to 1.3 percent per day.

Fe(III) oxides are common and naturally occurring in many groundwater systems. Therefore, oxidation of VC under Fe(III)-reducing conditions may be a significant mechanism for bioremediation in groundwater. It is important to note that the availability of Fe(III) will affect the rate of mineralization. EPA currently has a method under development to measure biologically available Fe(III) in soil (USEPA and AFCEE, 1998).

Studies indicate that Fe(III) reduction is not sufficient to directly mineralize 1,2-DCE. Low but significant mineralization of 1,2-DCE under anaerobic conditions has been reported; however, this mineralization involved significant accumulation of VC. This VC accumulation was not decreased by the addition of Fe(III), indicating that the initial step was a reduction and that Fe(III) reduction was not sufficient to mineralize 1,2-DCE directly. These observations suggest that anaerobic mineralization of 1,2-DCE requires a terminal-electron-accepting process that is more energetically favorable than Fe(III) reduction (Bradley, et al., 1998a).

Bradley (Bradley, et al., 1998a) studied the anaerobic oxidation of cis-1,2-DCE under manganese (Mn(IV)) reducing conditions. The natural abundance of Mn(IV), the greater availability for microbial reduction of Mn(IV) oxides, and the more favorable energetics of Mn(IV) reduction suggest that Mn(IV) reduction may support oxidation of DCE to carbon dioxide under anaerobic conditions without the accumulation of VC. Mn(IV) oxides are powerful oxidants and are common in aquifer sediments and groundwater. This research provided the first evidence of anaerobic oxidation of DCE in Mn(IV) reducing conditions and the first report of anaerobic mineralization of DCE without the accumulation of intermediates.

Locally high concentrations of manganese hydroxide have been found in the Kansas River Valley alluvial aquifer sediments which are prevalent at the Site. This manganese hydroxide can become solubilized in the presence of reducing conditions, resulting in high levels of Mn(IV), which then may be available for participation in anaerobic mineralization reactions at the Site. This type of manganese hydroxide solubilization has been shown to occur at other sites in the area contaminated with petroleum products in a reducing environment such as that present at the FFTA-MAAF Site (Pers. Comm., 2000).

6.2.2.2.3 Cometabolism

When a chlorinated hydrocarbon is biodegraded by cometabolism, the degradation is catalyzed by an enzyme or cofactor that is produced by the organism for other purposes. The organism receives no known benefit from the degradation of the chlorinated hydrocarbon. Cometabolism is best documented in aerobic environments, although it potentially could occur under anaerobic conditions. The rate of cometabolism generally decreases as the degree of dechlorination increases. During cometabolism, the chlorinated hydrocarbon is indirectly transformed by bacteria as they use petroleum hydrocarbons or another substrate to meet their energy requirements. Cometabolism requires the presence of a primary substrate such as toluene or methane at concentrations higher than the chlorinated solvent.

Cometabolism is usually not nearly as important a degradation mechanism as reductive dechlorination for chlorinated solvents. Due to the need for a substrate that may be present in limited concentrations, rates of cometabolism are often slow enough that this process may not be detectable unless the system is stimulated with additional substrate mass (USEPA and AFCEE, 1998).

6.3 EVALUATING FATE AND TRANSPORT MECHANISMS

The fate and transport mechanisms discussed above are likely occurring at the Site. The following sections evaluate field data and utilize known Site characteristics to model PCOPCs and to determine which fate and transport mechanisms are impacting contaminants at the Site. Model results were used to evaluate both destructive and non-destructive fate and transport mechanisms (Section 6.6). Destructive mechanisms were also evaluated by examining changes in field contaminant concentrations and geochemical parameters.

In this section, trends in geochemical parameters are evaluated and compared with contaminant trends previously identified for the plume. Figures 6-3 to 6-8 show geochemical parameters plotted against the distance from the source for the last three sampling rounds. These figures include a plot of ORP, methane, chloride, TOC, DO, nitrate, ferrous iron, and sulfate in the shallow, intermediate, and deep aquifer zones. Figure 6-9 depicts the level of nitrate, sulfate, DO, and ferrous iron in each centerline well for each sampling date. Also shown on these figures is the AFCEE screening level for each geochemical parameter (EPA, 1998).

6.3.1 Shallow Wells

The shallow wells within 1,400 feet of the source area have historically had the highest detections of contaminants in the shallow zone. The wells located in this area are: FP-93-04, FP-93-02, FP-96-25, FP-96-26, and FP-94-09. As depicted on Figure 5-6, PCE is the predominant chlorinated solvent close to the former fire training pit at Monitoring Well FP-93-02. Several hundred feet downgradient, TCE is the predominant chlorinated solvent. Finally, in Monitoring Well FP-96-26, located 1,100 feet from the FFTA, cis-1,2-DCE is the predominant chlorinated solvent. Further downgradient at Monitoring Well FP-96-23, low levels of chlorinated solvents are present. By Monitoring Well FP-98-27, located 2,950 feet from the FFTA, chlorinated solvents are no longer present in the shallow zone. This change in the predominant contaminant indicates that reductive dechlorination has occurred in this area of the aquifer. Additional evidence of reductive dechlorination will be further discussed later in this section.

Trends in BTEX and TPH concentrations can be observed in Figure 5-7 in the shallow portion of the plume. BTEX and TPH concentrations decrease significantly from Monitoring Well FP-93-04 to

FP-96-23. By Monitoring Well FP-98-27, BTEX and TPH are no longer present in the shallow portion of the plume.

There also are evident changes in the geochemistry of the shallow aquifer both with time and distance downgradient. DO is the most thermodynamically favored electron acceptor used by microbes for the biodegradation of contaminants. As oxygen is utilized by microbes during biodegradation, DO levels decrease significantly. DO levels below 1 mg/L indicate anaerobic conditions, and above 1 mg/L indicate aerobic conditions. Figures 6-3 and 6-9, show that DO levels in the shallow zone close to the source are at or below 2 mg/L and in most cases are less than 1 mg/L, suggesting anaerobic conditions. In the same area close to the former fire training pit (i.e., Monitoring Wells FP-93-04, FP-93-02, and FP-96-25) BTEX, TPH, and chlorinated solvent concentrations have decreased significantly since monitoring began. Therefore, it appears that the DO has been utilized in the biodegradation of Site contaminants close to the source area. Beyond 1,500 feet from the source area (Monitoring Well FP-96-27) in the shallow zone, DO levels have tended to be at or above 1 mg/L, and contaminant levels have been at or near zero. This evidence indicates a potential area where aerobic oxidation of contaminants, specifically 1,2-DCE and VC, may be occurring.

Nitrate is the second most thermodynamically favored electron acceptor used by microbes for the biodegradation of contaminants. Nitrate concentrations decrease as it is utilized during biodegradation. Nitrate levels in the shallow wells have remained quite low. In the shallow aquifer, Monitoring Well FP-96-26 has had nitrate levels up to 2.5 mg/L; however, this is the only monitoring well in the impacted area of the shallow zone of the aquifer with detectable nitrate levels. Nitrate is present in the shallow zone of the aquifer at Monitoring Well FP-98-27 and further downgradient. This is the same area of the plume where little to no chlorinated solvents have been detected and DO levels are elevated. Therefore, it appears that nitrate has been utilized in the biodegradation of Site contaminants close to the source area.

Iron is the third most thermodynamically favored electron acceptor used by microbes for the biodegradation of contaminants. Fe(III) is reduced to Fe(II) during biodegradation of organics, thus Fe(II) concentrations can be used as an indicator of anaerobic degradation of fuel compounds and chlorinated solvents. In the shallow zone, Fe(II) levels have been highest in the most contaminated wells, Monitoring Wells FP-96-25 and FP-94-09, suggesting that the conditions in these wells have been iron reducing, resulting in elevated ferrous iron levels. Monitoring Well FP-96-26, which is located within the most contaminated area in the shallow zone, has had very low levels of reduced iron, although the contaminant levels in this well have been somewhat lower than in other wells within this area of the plume. This suggests that a lack of high levels of contamination in this well in comparison to the two neighboring wells have led to less reducing conditions. Further from the source area in the shallow zone, ferrous iron levels quickly fall to zero, indicating a lack of iron reductive activity. It is important to note that the area of the shallow aquifer with low Fe(II) levels is the same area with elevated DO, nitrate, and a lack of contamination. Again, this evidence indicates the potential for aerobic oxidation to be occurring in this portion of the aquifer.

As sulfate is reduced through use as an electron acceptor during anaerobic biodegradation of organics, the sulfide level rises. Therefore, low sulfate and high sulfide levels may indicate a sulfate reducing environment. Sulfate levels at all depths have been above 20 mg/L, and sulfide levels have been 0 mg/L. Therefore, there is no direct evidence of sulfate reduction occurring in the aquifer.

In the shallow aquifer zone (see Figure 6-4), the six wells closest to the source area have lower ORP values than those wells further out in the plume. AFCEE screening protocol suggests that ORP values below 50 mV indicate that the reductive dechlorination pathway is possible. Monitoring Well FP-93-02 has historically shown ORP below 50 mV, but has been increasing over time, indicating a less reducing environment. Prior to the August 1999 sampling round, the wells between FP-93-02 and FP-98-27 had remained below 50 mV, with the exception of Well FP-96-26, although the August 1999 sampling rounds detected ORP values above 100 for all of these wells except Well FP-98-27. Wells further out in the plume have had ORP values consistently above 50mV. This indicates that Well FP-93-02 may be shifting from historically anaerobic to aerobic, wells between FP-93-02 and FP-98-27 have historically been anaerobic and remain so, and that wells further downgradient than Well FP-98-27 are aerobic.

During biodegradation of chlorinated hydrocarbons, chloride is released to the environment causing chloride concentrations in the plume to be elevated compared to background concentrations. In the shallow aquifer, chloride levels have been in the range of 15 to 35 mg/L in wells within 1,500 feet of the source area, and taper off to about 5 mg/L in wells further from the source area. Those areas of highest chloride ion concentration correspond with areas of high chlorinated solvent, TPH, and BTEX contamination. Beyond about 1,500 feet from the source (past Well FP-94-09), contaminant levels and chloride ion levels are quite low in the shallow aquifer. This is an indication that chlorinated solvents have been reductively dechlorinated in areas of the aquifer with higher chloride ion levels.

Other parameters which have been measured and show noticeable trends in the most contaminated area of the shallow aquifer zone include methane and TOC. Both of these parameters are at significantly higher levels close to the source area than downgradient. Methane concentrations near the source recently have ranged from 20 up to 160 µg/L, decreasing downgradient in the plume to 0 to 5 µg/L. With the exception of the 1996 detection of 4,800 µg/L in Well FP-93-04, these methane values are well below 500 µg/L above which methanogenic conditions may be expected. TOC values near the source are approximately 5 to 20 mg/L, decreasing downgradient in the plume to 0 to 5 mg/L. TOC values and trends are discussed further in Section 6.4. These natural attenuation parameter trends also suggest that biodegradation has occurred in the shallow zone of the aquifer from the former fire training pit through Monitoring Well FP-96-23.

To obtain a better understanding of the overall trends of the natural attenuation parameters, average values were calculated for the following three periods: January 99 – August 99, August 96 – August 99, and August 98 – August 00. The first two periods were chosen since these were the periods evaluated and presented in the Draft RI. The last period was selected to evaluate natural attenuation parameters over the last two years using the most updated data. The February and August 2000 natural attenuation data are included in Appendix 6B. The table presented below provides natural attenuation parameters averaged over three periods for the shallow zone. Upgradient centerline wells are as follows: FP-93-04, FP-93-02, FP-96-25, FP-96-26, FP-94-09, and FP-96-23. Downgradient centerline wells are as follows: FP-98-27, FP-98-29, FP-98-31, and FP-98-32.

SHALLOW WELLS	Upgradient Centerline Wells			Downgradient Centerline Wells			AFCEE
	1/99 – 8/99	8/96 – 8/99	8/98 – 8/00	1/99 – 8/99	8/96 – 8/99	8/98 – 8/00	
Oxidation/Reduction Potential (units in mV)	-3.21	-16.60	-26.80	78.88	86.71	65.13	< 50 mV
Sulfide (units in mg/L)	0.02	0.01	0.02	0.00	0.00	0.00	> 1 mg/L
Nitrate, as N (units in mg/L)	0.71	0.53	0.80	11.28	10.69	9.74	< 1 mg/L
Sulfate (units in mg/L)	105.73	117.62	107.20	57.63	57.93	61.13	< 20 mg/L
Chloride (units in mg/L)	19.20	17.73	19.33	3.14	3.62	3.40	> 2x background
TOC (units in mg/L)	4.41	7.82	5.26	1.63	2.76	2.81	> 20 mg/L

SHALLOW WELLS	Upgradient Centerline Wells			Downgradient Centerline Wells			AFCEE
	1/99 – 8/99	8/96 – 8/99	8/98 – 8/00	1/99 – 8/99	8/96 – 8/99	8/98 – 8/00	
DO (units in mg/L)	0.55	1.01	0.52	2.27	2.27	1.92	< 0.5 mg/L
Methane (units in µg/L)	54.08	134.29	40.05	0.44	0.24	0.24	> 0.5 mg/L
Iron (II), Ferrous (units in mg/L)	4.58	4.49	3.83	0.08	0.08	0.11	> 1 mg/L

Evaluation of the results from the above table indicate that there is evidence for reductive dechlorination in the shallow zone upgradient of Well FP-98-27. The average values for the natural attenuation parameters Iron (II), Nitrate, and ORP are within the suggested AFCEE range. Average dissolved oxygen concentrations are very close to the 0.5 mg/L criteria, and suggest that conditions are marginally anaerobic in this zone of the aquifer. Sulfate and Sulfide are not within the range suggested by AFCEE and indicate that sulfate reduction is limited or not occurring in this aquifer zone.

The natural attenuation parameters TOC, chloride, and methane are proportional to the amount of contaminants present at a site. Since the AFCEE protocol was developed from data collected at highly contaminated sites (i.e. low mg/L range), the ideal levels suggested in this protocol are applicable to highly contaminated sites. At this Site, since contaminant concentrations are relatively low, the mass of contaminants is not great enough to produce the ideal AFCEE concentrations for TOC, chloride, and methane.

Instead, a more beneficial way to evaluate TOC and chloride levels is to compare levels within the plume to background levels. Since the wells labeled as downgradient wells have not had significant detections of contaminants, these wells should provide an adequate representation of background TOC and chloride levels. From the table presented above, notice that TOC levels in contaminated wells (upgradient) are roughly twice that of uncontaminated (downgradient) wells. The same is true for chloride, except upgradient concentrations are roughly five time the downgradient levels. This provides evidence that chloride production is occurring via reductive dechlorination, but that the initial contaminant concentrations are not elevated enough to produce the levels typically observed at highly contaminated sites. The same conclusion can be drawn from the TOC data. TOC is available for reductive dechlorination, but since the contaminant concentrations are so low, the TOC observed at this Site is less than typically observed at highly contaminated sites.

To determine if the variation displayed by natural attenuation parameters is statistically significant, a nonparametric method (Friedman Test) was applied to the data. The Friedman Test (Gilbert, 1987) was applied to the parameters DO, Iron (II), ORP, chloride, nitrate, methane, sulfate, and TOC collected from upgradient shallow centerline wells. Sulfide was not evaluated due to limited detections. Upgradient centerline wells are as follows: FP-93-04, FP-93-02, FP-96-25, FP-96-26, FP-94-09, and FP-96-23. The Friedman Test was performed using the StatView 5 software (SAS Institute. Gary, North Carolina). Results indicate that the variation displayed by all parameters except ORP is statistically insignificant. Friedman test results are presented in Appendix 6B. P-values <0.05 indicate a significant difference, and P-values >0.05 indicate an insignificant difference.

Variation in ORP values is commonly observed in field conditions. The primary reason for this variation is because ORP displays a high degree of imbalance (dis-equilibrium) compared to other natural attenuation parameters. This imbalance is a result of many simultaneously occurring processes such as reduction, oxidation, precipitation, and complexation. All of these processes affect the electrical potential between cells, and can create a large fluctuation in ORP values. Another reason for the variation in ORP values is because this concept was originally applied to single species systems. Extending this concept to multi-species groundwater systems greatly increases the electrical imbalance, and causes variations in the ORP readings [(USEPA, 1999b; Snoeyink and Jenkins, 1980; and Deutsch, 1997).

In addition to these geochemical parameters and decreases in chemical concentrations indicating evidence of biodegradation occurring in portions of the shallow aquifer, other trends in the PCOPC concentration data provide evidence of biodegradation in the shallow portion of the aquifer. Figure 5-8 shows a transverse cross-section through the monitoring wells located approximately 700 feet downgradient from the former fire training pit. This cross-section includes Monitoring Wells FP-96-18, FP-94-11, FP-96-19, and Monitoring Well Cluster FP-96-25. The lateral extent of the chlorinated solvent plume at this location is bounded by Monitoring Wells FP-96-18 and FP-96-19 (i.e. no detections of PCE, TCE, cis-1,2-DCE, or VC in these wells). This figure illustrates the differences in concentration trends between Monitoring Wells FP-94-11 and FP-96-25. Monitoring Well FP-94-11 has never had significant detections of PCE and TCE, but has had increasing cis-1,2-DCE concentrations since December of 1996. Conversely, Monitoring Well FP-96-25 has historically had detections of PCE and TCE as well as cis-1,2-DCE. This well displays a downward concentration trend of PCE and TCE, but an increasing then decreasing cis-1,2-DCE trend. Since TCE was not released at the Site and cis-1,2-DCE is the predominant DCE daughter product of TCE reductive dechlorination, the concentration trend at these wells suggests that varying reducing environments (i.e. biodegradation environments) may be present between these two wells. Production of cis-1,2-DCE and degradation of PCE and TCE appears to be occurring more rapidly at Monitoring Well FP-94-11 than at Monitoring Well FP-96-25. This increased degradation may be related to the proximity of these monitoring wells to the location of the former fire training pit and the former drum storage area. Monitoring Well FP-94-11 is located directly downgradient of the former fire training pit, whereas Monitoring Well FP-96-25 is located directly downgradient of the former drum storage area. It is possible that releases of chlorinated solvents at the former fire training pit co-mingled with petroleum product releases and resulted in a greater reducing environment and increased production of cis-1,2-DCE (evidenced at Well FP-94-11) in the monitoring wells directly downgradient of the former fire training pit. On the other hand, it appears that a spill of PCE may have occurred at the former drum storage area without similar releases of petroleum products to drive the reduction. This supports the higher concentrations of PCE and TCE at Monitoring Well FP-96-25 and suggests a different biodegradation environment.

In summary, the shallow portion of the aquifer having the highest levels of contamination exhibits characteristics of an iron reducing environment. DO and nitrate levels have been low while ferrous iron levels have been high. In addition, TOC levels have decreased appreciably with time in this area, coinciding with considerable reductive dechlorination of PCE and TCE. On the other hand, the shallow zone of the aquifer past Monitoring Well FP-96-23 exhibits evidence of an aerobic zone. In this area, DO levels are above 1 mg/L, nitrate and ORP levels are elevated, and Fe(II), sulfate, and methane levels are low. Also, in this same area there is an evident lack of contamination. These observations support the fact that aerobic oxidation is occurring in the shallow zone of the aquifer downgradient of Well FP-96-23.

6.3.2 Intermediate Wells

In the intermediate aquifer zone, significant detections of volatiles are present at Monitoring Well FP-94-09b, located about 1,350 feet from the source area. In this well, the graphs of cis-1,2-DCE, TPH, and BTEX detections over time follow the same trend (Figures 5-6 and 5-7 respectively). All exhibit a spike on or before August 1997, after which levels drop off significantly, climb in January 1999, and then fall again.

Monitoring wells located further from the source than Monitoring Well FP-96-09b in the intermediate zone show detections of contaminants, but the overall trend in the intermediate zone shows that concentrations have generally been decreasing with time and distance from the source. An exception to this is cis-1,2-

DCE in Monitoring Well FP-98-27b, which has climbed from a low value of 111 µg/L in May 1998, to the current high of 257 µg/L in the August 1999 sampling round.

In the intermediate depth, the main area of contamination occurs from 1,300 to 3,000 feet from the source area. This includes Monitoring Wells FP-94-09b, FP-96-23b, and FP-98-27b. These three wells have all had high levels of cis-1,2-DCE detected, with most recent levels in the range of 200 to 300 µg/L. This area also has very low levels of PCE and TCE.

DO levels have been somewhat lower in the three most contaminated wells (Monitoring Wells FP-96-09b, FP-96-23b, and FP-98-27b), with only four samples having levels above 0.5 mg/L. As shown on Figure 6-5, DO levels in the intermediate portion of the aquifer during 1999 have all been below 1 mg/L. These low DO levels indicate an anaerobic environment throughout the intermediate portion of the aquifer.

Nitrate levels in the intermediate aquifer zone have been non-detect. This is evidence of nitrate reduction having occurred in the aquifer.

Ferrous iron levels have been somewhat higher, in the range of 4 to 12 mg/L in the most contaminated wells as compared to 0 to 9 mg/L close to the source. In the wells furthest from the source area, (Monitoring Wells FP-98-29b, FP-98-31b, and FP-98-32b) the range has historically been between 4 and 6 mg/L, although in the August 1999 sampling round, a value of 16.64 mg/L was recorded for Monitoring Well FP-98-29b. In the intermediate aquifer, Fe(II) levels have followed a predictable trend, with higher levels occurring in wells that show higher levels of chlorinated solvents, further downgradient from the source area.

The ORP values in the intermediate aquifer zone follow a different trend, with wells close to the source area generally having higher ORP values then those further downgradient (Figure 6-6). In general, ORP close to the source area has varied from –175 to 150 mV in the intermediate screened wells. In the wells further from the source area, the ORP has been steadier, ranging from –150 to -50 mV. ORP levels are generally lowest in areas of the aquifer that show the highest levels of chlorinated solvents, indicating increasingly reductive environments.

Other parameters which have been measured include chloride, methane, and TOC. In the intermediate zone, chloride is around 18 mg/L at all distances from the source area. There is no evident increase in chloride concentrations in the intermediate zone in the areas of contamination. Methane detections follow the same trend as cis-1,2-DCE detection, with a peak in Monitoring Well FP-94-09b at 250 to 450 µg/L, and a smaller peak in Monitoring Well FP-98-27b of approximately 100 µg/L. Methane values above 500µg/L are generally expected for methanogenic conditions. In downgradient areas of the plume, methane levels are much lower, but still detected. During the 1999 sampling events, the TOC levels were in the range of 0 to 9 mg/L, with the January 1999 and May 1999 levels averaging 2.5 mg/L, and the August 1999 levels averaging 5 mg/L. TOC values and trends are discussed further in Section 6.4.

To obtain a better understanding of the overall trends of the natural attenuation parameters, average values were calculated for the following three periods: January 99 – August 99, August 96 – August 99, and August 98 – August 00. The first two periods were chosen since these were the periods evaluated and presented in the Draft RI. The last period was selected to evaluate natural attenuation parameters over the last two years using the most updated data. The February and August 2000 natural attenuation data are included in Appendix 6B. Results from average calculations for the intermediate zone are presented below. All of the centerline wells are evaluated together in this zone since anaerobic conditions are present throughout the entire zone.

INTERMEDIATE WELLS	Centerline Wells			All Wells			AFCEE
	1/99 – 8/99	8/96 – 8/99	8/98 – 8/00	1/99 – 8/99	8/96 – 8/99	8/98 – 8/00	
Oxidation/Reduction Potential (units in mV)	-72.85	-80.31	-82.83	-68.19	-74.98	-79.14	< 50 mV
Sulfide (units in mg/L)	0.00	0.00	0.00	0.00	0.00	0.00	> 1 mg/L
Nitrate, as N (units in mg/L)	0.00	0.00	0.00	0.00	0.00	0.00	< 1 mg/L
Sulfate (units in mg/L)	71.16	67.26	71.96	68.76	65.19	69.74	< 20 mg/L
Chloride (units in mg/L)	17.71	17.61	17.52	17.65	17.69	17.65	> 2x background
TOC (units in mg/L)	3.31	6.00	4.25	2.98	5.59	4.02	> 20 mg/L
DO (units in mg/L)	0.26	0.36	0.30	0.28	0.37	0.31	< 0.5 mg/L
Methane (units in µg/L)	64.95	54.25	85.37	47.85	41.65	63.98	> 0.5 mg/L
Iron (II), Ferrous (units in mg/L)	6.47	6.53	5.81	6.42	6.30	5.70	> 1 mg/L

Evaluation of the results from the above table indicate that there is evidence for reductive dechlorination in the intermediate zone. The average values for the natural attenuation parameters DO, Iron (II), Nitrate, and ORP are within the suggested AFCEE range. The natural attenuation parameters TOC, chloride, and methane are proportional to the amount of contaminants present at a site. Since the AFCEE protocol was developed from data collected at highly contaminated sites (i.e. low mg/L range), the ideal levels suggested in this protocol are applicable to highly contaminated sites. At this Site, since contaminant concentrations are relatively low, the mass of contaminants is not great enough to produce the ideal AFCEE concentrations for TOC, chloride, and methane.

To determine if the variation displayed by natural attenuation parameters is statistically significant, a nonparametric method (Friedman Test) was applied to the data. The Friedman Test (Gilbert, 1987) was applied to the parameters DO, Iron (II), ORP, chloride, methane, sulfate, and TOC collected from intermediate centerline wells. Sulfide and nitrate were not evaluated due to limited detections. The Friedman Test was performed using the StatView 5 software (SAS Institute. Gary, North Carolina). Results indicate that the variation displayed by all parameters except ORP is statistically insignificant. Friedman test results are presented in Appendix 6B. P-values <0.05 indicate a significant difference, and P-values >0.05 indicate an insignificant difference.

Variation in ORP values is commonly observed in field conditions. The primary reason for this variation is because ORP displays a high degree of imbalance (dis-equilibrium) compared to other natural attenuation parameters. This imbalance is a result of many simultaneously occurring processes such as reduction, oxidation, precipitation, and complexation. All of these processes affect the electrical potential between cells, and can create a large fluctuation in ORP values. Another reason for the variation in ORP values is because this concept was originally applied to single species systems. Extending this concept to multi-species groundwater systems greatly increases the electrical imbalance, and causes variations in the ORP readings [(USEPA, 1999b; Snoeyink and Jenkins, 1980; and Deutsch, 1997).

In conclusion, the portion of the intermediate aquifer surrounding Monitoring Wells FP-96-09b, FP-96-23b, and FP-98-27b exhibits evidence of biodegradation. This area of the intermediate zone of the aquifer has had decreases in cis-1,2-DCE levels and has very low levels of PCE and TCE. Low DO and nondetect nitrate along with elevated ferrous iron levels indicate an iron-reducing environment.

6.3.3 Deep Wells

In the deep aquifer zone, 2,100 feet from the source, cis-1,2-DCE, TPH, and BTEX have recently been at higher levels than in earlier sampling rounds. This may be due to the vertical and horizontal migration of the peaks of these compounds previously observed in the upgradient intermediate zone Monitoring Well FP-96-09b. The last three wells in the deep aquifer zone, Monitoring Wells FP-98-29c, FP-98-31c, and FP-99-32c, have all had comparatively low detections of PCE, TCE, and cis-1,2-DCE. BTEX is also found in the deep portion of the aquifer, but TPH has not been detected in the last three wells in the deep aquifer zone.

In the deep zone of the aquifer, the locations with the highest levels of contamination are Monitoring Wells FP-96-23c and FP-98-27c. These wells are located from 2,000 to 3,000 feet from the source area.

DO levels in the deep wells have been consistently below 1 mg/L. There were two detections of DO above 1 mg/L close to the source area, where there is a lack of contamination in the deep portion of the aquifer. Nitrate has also been detected at very low concentrations or not detected in the deep portion of the aquifer. The only detections of nitrate in the deep wells have occurred in Monitoring Well FP-96-02c, and all detections have been below 0.3 mg/L.

On the other hand, Fe(II) levels are higher in the deep wells that also have contamination present, specifically Monitoring Wells FP-96-23c, FP-98-27c, and FP-98-29c. Fe(II) levels are much lower in the portions of the plume without contamination present. This evidence indicates iron reducing activity in the portion of the plume with contamination.

The ORP levels close to the source area in the deep portion of the aquifer exhibit fluctuations closest to the source area. After approximately 2,000 feet downgradient of the source area, the readings are less erratic and have all been at or below –50 mV, indicative of a reducing environment.

In the deep aquifer zone, methane peaks around 2,100 feet from the source area in Monitoring Well FP-96-23c, at 110 to 150 μg/L. Wells closer to the source have had very few detections of methane, and none of them above 5 μg/L. Monitoring Well FP-98-27c, which is 2,950 feet from the source area has had detections around 70 μg/L, while wells further downgradient have been around 15 μg/L. These methane levels do not indicate the presence of methanogenic conditions.

During the 1999 sampling events, the TOC levels were in the range of 0 to 9 mg/L, with the January 1999 and May 1999 levels averaging 2.5 mg/L, and the August 1999 levels averaging 5 mg/L. This was the trend in all depths of the aquifer, excluding the shallow zone beyond Well FP-96-23, where TOC levels are somewhat lower. TOC levels and trends are discussed further in Section 6.4.

To obtain a better understanding of the overall trends of the natural attenuation parameters, average values were calculated for the following three periods: January 99 – August 99, August 96 – August 99, and August 98 – August 00. The first two periods were chosen since these were the periods evaluated and presented in the Draft RI. The last period was selected to evaluate natural attenuation parameters over the last two years using the most updated data. The February and August 2000 natural attenuation data are included in Appendix 6B. Results from average calculations for the deep zone are presented below. All of the centerline wells are evaluated together in this zone since anaerobic conditions are present throughout the entire zone.

DEEP WELLS	Centerline Wells			All Wells			AFCEE
	1/99 – 8/99	8/96 – 8/99	8/98 – 8/00	1/99 – 8/99	8/-96 – 8/99	8/98 – 8/00	
Oxidation/Reduction Potential (units in mV)	-63.88	-57.32	-61.40	-38.42	-31.08	-46.28	< 50 mV
Sulfide (units in mg/L)	0.00	0.00	0.00	0.00	0.00	0.00	> 1 mg/L
Nitrate, as N (units in mg/L)	0.03	0.01	0.04	0.14	0.18	0.15	< 1 mg/L
Sulfate (units in mg/L)	53.96	53.22	54.22	53.88	53.50	54.88	< 20 mg/L
Chloride (units in mg/L)	28.65	28.52	29.04	29.91	29.45	30.12	> 2x background
TOC (units in mg/L)	2.87	6.72	3.77	2.75	5.99	3.78	> 20 mg/L
DO (units in mg/L)	0.18	0.38	0.33	0.21	0.53	0.37	< 0.5 mg/L
Methane (units in µg/L)	31.05	15.39	25.72	23.04	11.44	18.98	> 0.5 mg/L
Iron (II), Ferrous (units in mg/L)	4.35	3.91	3.84	4.22	3.64	3.69	> 1 mg/L

Evaluation of the results from the above table indicate that there is evidence for reductive dechlorination in the deep zone. The average values for the natural attenuation parameters DO, Iron (II), Nitrate, and ORP are within the suggested AFCEE range. The natural attenuation parameters TOC, chloride, and methane are proportional to the amount of contaminants present at a site. Since the AFCEE protocol was developed from data collected at highly contaminated sites (i.e. low mg/L range), the ideal levels suggested in this protocol are applicable to highly contaminated sites. At this Site, since contaminant concentrations are relatively low, the mass of contaminants is not great enough to produce the ideal AFCEE concentrations for TOC, chloride, and methane.

To determine if the variation displayed by natural attenuation parameters is statistically significant, a nonparametric method (Friedman Test) was applied to the data. The Friedman Test (Gilbert, 1987) was applied to the parameters DO, Iron (II), ORP, chloride, methane, sulfate, and TOC collected from deep centerline wells. Sulfide and nitrate were not evaluated due to limited detections. The Friedman Test was performed using the StatView 5 software (SAS Institute. Gary, North Carolina). Results indicate that the variation displayed by all parameters except DO, Iron (II), and ORP is statistically insignificant. Friedman test results are presented in Appendix 6B. P-values <0.05 indicate a significant difference, and P-values >0.05 indicate an insignificant difference.

Variation in ORP values is commonly observed in field conditions. The primary reason for this variation is because ORP displays a high degree of imbalance (dis-equilibrium) compared to other natural attenuation parameters. This imbalance is a result of many simultaneously occurring processes such as reduction, oxidation, precipitation, and complexation. All of these processes affect the electrical potential between cells, and can create a large fluctuation in ORP values. Another reason for the variation in ORP values is because this concept was originally applied to single species systems. Extending this concept to multi-species groundwater systems greatly increases the electrical imbalance, and causes variations in the ORP readings [(USEPA, 1999b; Snoeyink and Jenkins, 1980; and Deutsch, 1997).

In summary, in the deep zone of the aquifer surrounding the monitoring wells with the highest levels of contamination reductive dechlorination has been evident. Low DO, nondetect nitrate, and elevated ferrous iron indicate an iron reducing environment in the contaminated portion of the deep aquifer.

6.3.4 Destructive Mechanism Trends

The next step in this evaluation was to determine if the data trends discussed above provide evidence of the type of destructive mechanisms occurring in the aquifer. The following sections summarize the results of this evaluation.

6.3.4.1 Abiotic Fe(II) Reduction

The abiotic process of reduction of chlorinated solvents by Fe(II) present in the aquifer is currently being researched as a potential degradation process for chlorinated solvents not previously considered. Natural sources of ferrous iron are present in many aquifer sediments in the form of pyrite (FeS_2) and siderite ($FeCO_3$). If the Fe(II) is available, it can reduce TCE to ethene. This process has not been utilized on other chlorinated solvents and has not been proven to occur naturally in the environment. Personal communication between USACE, KCD, and Battelle Northwest Laboratories (Pers. Comm., 1998b) indicates the possibility of this reaction occurring at the Site. Further research into the applicability of this reaction at FFTA-MAAF would be necessary to determine its impact on the chlorinated solvent concentrations.

6.3.4.2 Reductive Dechlorination

There are several guidance documents available to aid in the evaluation of reductive dechlorination's impact on the contamination in an aquifer. The most widely used reference is the USEPA and AFCEE *Technical Protocol for Evaluating Natural Attenuation of Chlorinated Solvents in Ground Water* (USEPA and AFCEE, 1998). This reference includes a screening methodology for evaluating reductive dechlorination in groundwater.

6.3.4.2.1 AFCEE Screening

The *Natural Attenuation Protocol for Chlorinated Solvents Dissolved in Groundwater* (USEPA and AFCEE, 1998) contains a methodology for assessing the efficacy of reductive dechlorination in a groundwater system. This screening is designed to recognize the geochemical environments in which reductive dechlorination is plausible. The screening does not consider other degradation pathways. Table 6-2 describes the geochemical parameters used in scoring.

Table 6-3 contains the scoring values that USEPA/AFCEE has established to assess the likelihood that biodegradation via reductive dechlorination is occurring. Table 6-3 also summarizes the interpretation of the points awarded. Table 6-4 summarizes the scoring for the Site and provides an interpretation. This screening assumes that reductive dechlorination will cause predictable changes in the groundwater chemistry of a site. The only documented chlorinated solvent released at this Site was PCE; therefore barring any other unknown releases, the presence of TCE, cis-1,2-DCE, and VC is the result of reductive dechlorination of the PCE. Groundwater within the contaminant plume has low dissolved oxygen and nitrate concentrations, but high Fe(II), methane, and chloride concentrations. The geochemical conditions at the Site resulted in a score of 22 points, indicative of strong evidence for reductive dechlorination.

Temperature

Elevated groundwater temperature (above 20°C), will tend to increase the metabolic activity of microorganisms, therefore creating a more favorable environment for reductive dehalogenation. The temperature in the most contaminated area of the aquifer has been below 20°C, and therefore does not increase the Site score.

pH

Neutral pH values (between 5 and 9 pH units), provide suitable conditions for reductive dehalogenation. The Site pH has varied from 7.1 to 7.3 in the most contaminated zone, indicating that pH is not an inhibitory factor in reductive dehalogenation. This pH range neither increases nor decreases the Site score.

Methane

High levels of methane in a chlorinated solvent plume can be indicative of strongly reducing conditions, which are favorable for reductive dechlorination. Since levels of methane above 0.5 mg/L have been found at the Site, the Site score is 3, which indicates that the environment is favorable for reductive dechlorination.

Ethene/Ethane

Ethene is the daughter product of reductive dechlorination of VC. Ethane is a potential breakdown product of cis-1,2-DCE (see Figure 6-1). Presence of either one of these compounds may indicate the occurrence of reductive dehalogenation. At the Site, neither one of these compounds has been detected, therefore the Site score is not increased.

Alkalinity

Increased alkalinity correlates to increased microbial activity. Therefore, values of alkalinity greater than twice the background value may indicate a favorable environment for reductive dechlorination. Increases in alkalinity are caused by the microbial generation of carbon dioxide which in turn increases the dissolution of rock in the aquifer. Background levels for alkalinity were determined by Fader (1974) for groundwater from the Kansas River alluvial deposits to average 340 mg/L and range from 170 to 470 mg/L. Alkalinity values at the Site have been in the range from 412 to 510 mg/. This range of values is at the upper end of alkalinity values determined for the area, and therefore does not increase the Site score for the USEPA/AFCEE screening.

Nitrate

High nitrate levels may compete with the reductive pathway, therefore levels below 1.0 mg/L are more indicative of an environment amenable to natural attenuation of chlorinated solvents according to USEPA/AFCEE. Nitrate levels at the Site in the most contaminated zone have been lower than 1 mg/L, therefore the Site receives a favorable score of 2 for nitrate levels.

Sulfate/Sulfide

Concentrations of sulfate greater than 20 mg/L may cause competitive exclusion of dechlorination. Sulfate levels at the Site have been between 52 and 130 mg/L. With few exceptions, sulfide levels have been below detection. There is no evidence of sulfate reduction occurring in the aquifer. Therefore, the Site receives a score of 0 for sulfate levels according to the USEPA/AFCEE screening.

Chloride

Chloride may be found in the groundwater as a result of dechlorination of chlorinated solvents. The USEPA/AFCEE screening level for chloride is two times the background value. The background value of chloride ion for groundwater from the Kansas River alluvial deposits has been reported as 28 mg/L with a range of 3.0 to 84 mg/L by Fader (1974). A score of 2 is given for chloride values greater than twice the background level, which in this case would be 56 mg/L. Chloride values at the Site in the areas with the most contamination have ranged from 15 to 35 mg/L. This suggests the chloride may be present as a product of the reductive dechlorination pathway, and may still be indicative of reductive dechlorination processes occurring.

TOC

According to USEPA/AFCEE screening criteria, TOC levels greater than 20 mg/L can contribute to optimizing conditions for the occurrence of reductive dechlorination. For reductive dechlorination to occur in groundwater at optimal conditions, the TOC values should be greater than 20 mg/L. TOC levels at the Site have recently been quite low, therefore not indicative of favorable conditions for reductive dechlorination according to the USEPA/AFCEE screening criteria. TOC is discussed in greater detail later in this section.

DO

USEPA/AFCEE screening levels of DO below 0.5 mg/L indicates an anaerobic environment suitable for reductive dechlorination. The majority of the DO levels in the aquifer where contamination is also present, have been at or below 0.5 mg/L, therefore, the Site score for DO level is a 3. In general, there is evidence that oxygen reduction has occurred in the Site aquifer.

ORP

The *Natural Attenuation Protocol for Chlorinated Solvents* indicates that an ORP below –100 mV provides an environment where the reductive pathway is likely, and that ORP below 50 mV indicates the reductive pathway is possible. In the case of chlorinated solvents, each sequential use of electron acceptors drives the ORP down into a range within which reductive dechlorination can occur. Because reductive dechlorination is most effective in the sulfate-reduction and methanogenesis ORP range, competitive exclusion between sulfate reducers, methanogens, and reductive dechlorination can occur. The presence of fuel hydrocarbons can also reduce the ORP of groundwater to the extent that reductive dechlorination is favorable. Areas in the aquifer with the highest levels of contamination have generally had the lowest levels for ORP. These levels indicate a score of 2 is appropriate according to the USEPA/AFCEE screening for ORP levels at this Site.

Iron

According to USEPA/AFCEE, Fe(II) levels above 1.0 mg/L indicate reducing conditions, and are favorable for the reductive pathway. Fe(II) levels at the Site in the areas with contamination have all been above 4 mg/L. Therefore, there is evidence of iron reduction occurring in the portions of the aquifer with higher chlorinated solvent detections. These elevated iron levels result in a score of 3 for the Site.

Assessment of all the USEPA/AFCEE screening parameters results in a total Site score of 22. This indicates strong evidence for anaerobic biodegradation of chlorinated organics.

6.3.4.2.2 Field Evidence

The main evidence of reductive dechlorination is the presence of daughter products from the degradation of PCE. When reductive dechlorination occurs, PCE degrades to TCE, which in turn degrades to 1,2-DCE. This evidence of reductive dechlorination can be further examined by creating concentrations ratios between parent and daughter compounds.

Chlorinated solvent concentration ratios were determined by dividing the concentration of parent compound by the concentration of daughter product. This was done for all sampling dates, and each monitoring well down the centerline. Ratios were determined for PCE to TCE, PCE to cis-1,2-DCE, and TCE to cis-1,2-DCE. Ratios were not determined for VC because it has only been detected five times in two wells. Table 6-5 shows the results of these calculations. In the shallow aquifer zone, PCE and TCE were not detected downgradient of Monitoring Well FP-94-09, and cis-1,2-DCE was not detected downgradient of Monitoring Well FP-98-27. Similarly, in the deep aquifer zone, PCE was not detected upgradient of Monitoring Well FP-96-23c, TCE was not detected in Monitoring Wells FP-93-04c, FP-93-02c, FP-96-26c, and FP-96-09c, and cis-1,2-DCE was not detected upgradient of Monitoring Well FP-96-26c. Therefore, several of these wells are not presented on Table 6-5.

Highlighted values in the table indicate a sample where the concentration of parent compound exceeded that of the daughter product. Examination of trends in highlighted cells assists in giving an overall picture of when and where reductive dechlorination processes have been most active in the plume. In the shallow zone, the highest ratios occur close to the source area, particularly in Monitoring Well FP-93-02, and in the 1997 and early 1998 sampling rounds. Further from the source area, and in the most recent sampling rounds, the ratios drop below one indicating that daughter products are the prevalent chlorinated compounds, and that reductive dechlorination has been active in the degradation of parent compounds. This trend is most evident in the TCE to cis-1,2-DCE ratios.

In the intermediate aquifer zone, PCE to TCE ratios in the past have been higher closer to the source area. Recently, the high ratios have appeared further out in the plume (i.e. Wells FP-98-27b, FP-98-29b, and FP-98-31b), indicating that the concentration of TCE in this area is decreasing more quickly than the concentration of PCE. Also evident is that there are relatively high concentrations of cis-1,2-DCE occurring in the area of the plume beyond 2,500 feet from the source, as is evidenced by the very low PCE to cis-1,2-DCE and TCE to cis-1,2-DCE ratios. This is an indication that either PCE and TCE have not reached these portions of the plume in appreciable amounts, or that cis-1,2-DCE may be accumulating in this area. The deep aquifer zone shows similar trends to those found in the intermediate aquifer zone.

It is also important to note the difference in detections of the trans- and cis-1,2-DCE isomers. When DCE is released from a chemical spill, the chemical is found in approximately equal concentrations of the trans- and cis-1,2-DCE isomer. However, when 1,2-DCE is the daughter product from the reductive dechlorination of TCE the majority of the detections of 1,2-DCE will be the cis- isomer. This is true at the FFTA-MAAF Site. The trans- isomer has been detected at very low levels at the Site in 11 monitoring wells. These detections have ranged 0.6 to 4 µg/L. The highest detections occurred at Monitoring Wells FP-94-09 and FP-94-11. These monitoring wells have also had the highest levels of cis-1,2-DCE.

Shallow Monitoring Wells FP-94-09 and FP-94-11 are the only two monitoring wells at the Site to have detections of VC. The first detection of VC occurred in August 1997 at Monitoring Well FP-94-09 at a concentration of 1.7 µg/L. Two other detections of VC occurred at this well in January and May 1999 at concentrations below the initial detection. VC was also detected at Monitoring Well FP-94-11 in January and August 1999 at concentrations of 2.1 and 2.8 µg/L, respectively. This is very strong evidence of reductive dechlorination continuing past cis-1,2-DCE, but at rates low enough to maintain acceptable levels of VC in the aquifer. VC levels are expected to remain low because the iron reducing environment of the aquifer (as opposed to sulfate reducing) does not present conditions where rapid dechlorination of cis-1,2-DCE to VC is expected. VC is also subject to aerobic oxidation, and Fe(III)/Mn(IV) anaerobic oxidation.

6.3.4.3 Mineralization

In the shallow zone of the aquifer past Monitoring Well FP-96-23, DO levels are above 1 mg/L, nitrate and sulfate levels are extremely low, and Fe(II) levels are elevated. This is direct evidence of an aerobic zone in the shallow aquifer past Monitoring Well FP-96-23 (Figure 6-10). Therefore, there is the potential for aerobic oxidation to occur in this zone of the aquifer. In addition, the sudden decrease in contaminant levels at this location may indicate rapid aerobic mineralization of cis-1,2-DCE. However, there is no direct evidence of aerobic mineralization in this area, such as a microcosm study or increases in chloride levels in the groundwater aquifer. However, increases in chloride levels would be difficult to detect from the degradation of the low levels of chlorinated solvents present in this area of the aquifer. The possibility of aerobic mineralization will be further explored in the modeling (Section 6.5.3.5.1) by determining the aerobic degradation rates for 1,2-DCE and VC necessary to match field data (i.e. no contamination in this zone).

Anaerobic mineralization of VC under iron reducing conditions also has the potential to occur in certain portions of the aquifer. Figure 6-9 shows elevated levels of Fe(II), depressed levels of nitrate, and low levels of DO, all of which suggest an environment suitable for reductive dechlorination of chlorinated solvents and anaerobic mineralization of VC. However, direct evidence of anaerobic mineralization, such as a microcosm study, has not been obtained for this Site.

6.3.4.4 Cometabolism

Cometabolism is best documented in aerobic environments, although it potentially could occur under anaerobic conditions. The rate of cometabolism generally decreases as the degree of chemical chlorination increases. During cometabolism, the chlorinated hydrocarbon is indirectly transformed by bacteria as they use petroleum hydrocarbons or another substrate to meet their energy requirements. Cometabolism requires the presence of a primary substrate such as toluene or methane at concentrations higher than the chlorinated solvent. Currently, BTEX concentrations in the plume are considerably less than the chlorinated solvent concentrations in the plume. Cometabolism is usually not nearly as important a degradation mechanism as reductive dechlorination for chlorinated solvents. Due to the need for a substrate that may be present in limited concentrations, rates of cometabolism are often slow enough that this process may not be detectable unless the system is stimulated with additional substrate mass (USEPA and AFCEE, 1998). However, it is likely that cometabolism occurred in the past, when BTEX concentrations at the source area were measured in October 1993 at approximately 4,000 µg/L.

6.4 CONCEPTUAL SITE MODEL

This section summarizes the conclusions that may be drawn from Site data regarding the contamination present and the type of degradation expected to have occurred and predicted to continue at the Site.

The only documented release of a chlorinated solvent at the Site was PCE. Therefore, TCE and cis-1,2-DCE in groundwater at the Site are assumed to be daughter products from the breakdown of PCE. Figure 5-6 shows the highest PCE concentrations are approximately 400 feet from the source, the highest TCE levels are approximately 800 feet from the source, and the highest 1,2-DCE levels are approximately 1,500 feet from the source in the shallow depth. DCE has lingered at the Site and migrated laterally and vertically with the groundwater to the intermediate and deep depths. Advection and dispersion seem to be spreading the cis-1,2-DCE center of mass over time as it moves further downgradient from the source area.

Within 2,000 feet of the source in the shallow zone, the plume appears to be in an anaerobic zone that had active degradation of chlorinated solvents occurring in the past. Figure 6-9 shows elevated levels of Fe(II), depressed levels of nitrate, and low levels of DO, all of which suggest an environment suitable for reductive dechlorination of chlorinated solvents and anaerobic mineralization of VC.
The last zone, which begins about 3,000 feet from the source area in the shallow depth, appears to be aerobic with elevated levels of DO and nitrate, and very low levels of Fe(II) (see Figure 6-10). This is a favorable environment for aerobic oxidation of 1,2-DCE and VC. This part of the shallow zone is essentially free of chlorinated solvent detections.

In the intermediate and deep zones, Fe(II) levels are elevated and DO and nitrate levels are low. This suggests an iron-reducing anaerobic environment. However, the level of 1,2-DCE degradation occurring is unknown. Furthermore, about 3,000 feet and greater distances downgradient from the source in the intermediate and deep zones, some detections (at or below 25 µg/L) of PCE and TCE have occurred, indicating limited reductive dechlorination.

Cis-1,2-DCE is less amenable to dechlorination in an anaerobic reducing environment, as compared to PCE and TCE. In this system, it appears that once the degradation pathway reaches cis-1,2-DCE, the reductive dechlorination process slows. VC has been detected in two locations in the plume, at Monitoring Wells FP-94-09 and FP-94-11, indicating the potential for further reductive dechlorination in the plume if appropriate reducing conditions are present. However, detections of VC are limited indicating relative stalling of the reductive dechlorination process at cis-1,2-DCE. Another factor influencing reductive dechlorination is the availability of primary carbon sources to act as electron donors. Close to the source area, BTEX and TPH concentrations are much higher than further downgradient. These organics, especially BTEX compounds can serve as primary substrate for microorganisms facilitating reductive dechlorination.

Figure 6-11 shows the concentrations of TOC detected in wells down the center line of the plume for sampling periods from 1996 to the most recent in August 1999. The August 1997 value for TOC in groundwater of 96 mg/L in Well FP-96-26c was excluded from the graph because of differences in scale, but is considered in this evaluation of Site TOC in groundwater conditions. When evaluating TOC levels, it is important to note that the measure of organic carbon in groundwater from laboratory testing is not necessarily a measure of biologically available carbon. The USEPA/AFCEE protocol suggests TOC levels greater than 20 mg/L in groundwater are necessary to drive reductive dechlorination. However, this value was taken as an average value from many highly contaminated sites. Since the TOC concentration reported by a laboratory is greatly influenced by the carbon that is contributed from the contaminant, sites with higher levels of contamination will have higher concentrations of TOC in groundwater. Therefore, TOC in groundwater should only be used as an estimation to determine if organic carbon is a limiting factor in biodegradation.

Examination of Figure 6-11 shows historically high values of TOC in groundwater in the areas closest to the FFTA in all depths of the aquifer. Note that TOC values were not measured in Well Cluster FP-93-04 at the source area. In the shallow portion of the aquifer in areas greater than 2,000 feet from the source, TOC in groundwater has recently been quite low, but also in this area very little contamination has been detected. In the intermediate and deep portions of the aquifer, the most recent sampling round shows an increasing trend in TOC levels. This increasing trend is partially due to the migration of contamination horizontally downgradient and vertically downward as the plume moves from the source area. These recent increases in groundwater TOC indicate that there is a greater potential for further reductive dechlorination to occur as the contaminants move downgradient, if TOC was a limiting factor in the biological pathway.

The contaminant modeling presented in the following section simulates the transport of the PCOPCs for the Site using the information known about Site characteristics and the degradation of contaminants at the Site. The model is a reactive transport model which simulates the reductive dechlorination pathway. The initial model and calibration were based upon the entire Site undergoing anaerobic reductive dechlorination. However, the model was also run simulating an aerobic portion of the aquifer in the shallow zone.

6.5 CONTAMINANT MODELING

6.5.1 INTRODUCTION

6.5.1.1 Purpose

The purpose of the contaminant fate and transport modeling is to simulate the transport of PCOPCs in the subsurface, to predict future concentrations at potential receptor locations, and to further evaluate natural attenuation processes occurring at the Site.

During the *RI/FS WP* development, contaminant migration in the saturated zone was modeled using SESOIL/AT123D computer codes (BMcD, 1998k). The results of this modeling are limited because AT123D could not simulate the sequential chlorinated solvent degradation and the intermediate and deep plumes had not been defined at the time of the modeling. Therefore, the former modeling underestimated the total contaminant mass and extent of contaminant migration. Since that time, the contaminant plume has been fully delineated. In addition, a contaminant fate and transport computer code capable of simulating sequential degradation, RT3D, is now available. This code, RT3D, is used in combination with MODFLOW in this RI evaluation to model the chlorinated solvent concentrations as described in the following sections.

The PCOPCs identified in Section 5.0 for fate and transport modeling are: PCE, TCE, DCE, VC, naphthalene, and BTEX (benzene, toluene, ethylbenzene, and xylenes). However, the reactive transport model allows only one isomer of DCE. Therefore, DCE was modeled as cis-1,2-DCE since Site data indicates this is the dominant isomer.

6.5.1.2 Objectives

The objectives of the contaminant transport modeling are described below.

- Simulate the groundwater flow direction and gradient observed at the Site.
- Construct a groundwater flow model that will generate the appropriate files to be used during ensuing contaminant transport modeling.
- Evaluate the potential for contaminants to be captured by a nearby irrigation well.
- Construct a contaminant transport model that will simulate the fate and transport of PCOPCs.
- Provide future concentration data for ensuing risk assessment.

6.5.1.3 Approach

The general approach taken for performing the contaminant fate and transport modeling is described below.

- Develop a groundwater flow conceptual model of the Site and gather data to be used as input parameters.

- Construct the groundwater flow model and calibrate to observed water levels at the Site.

- Perform a sensitivity analysis on the groundwater flow model to access the variability of model output based on changes in input parameters.

- Develop a contaminant transport conceptual model of the Site and gather data to be used as input parameters.
- Construct a reactive transport model that predicts the fate of PCE and its daughter products, and calibrate to concentrations observed at the Site.

- Enter initial concentration data, and run the reactive transport model long-term to predict potential receptor point concentrations over time, as well as to evaluate natural attenuation processes.

- Construct a contaminant transport model that predicts the fate of naphthalene and BTEX.

- Enter initial concentration data, and run the contaminant transport model long-term to predict potential receptor point concentrations over time, as well as to evaluate natural attenuation processes.

6.5.1.4 Modeling Organization

This contaminant fate and transport modeling discussion is organized in the sequence of steps used to address the objectives outlined in Section 6.5.1.2 and consists of the following sections:

- Introduction (Section 6.5.1) – States the purpose of the fate and transport modeling, identifies the PCOPCs, outlines the objectives, and discusses the approach used to model PCOPCs.
- Groundwater Flow Modeling (Section 6.5.2) – Provides a detailed description of the methodology and procedures used to construct the groundwater flow model at the Site. Also provides a particle tracking evaluation, sensitivity analysis, and results from the flow modeling.
- Chlorinated Solvent Transport Modeling (Section 6.5.3) – Provides a detailed description of the methodology and procedures used to model the fate and transport of chlorinated solvents (PCE, TCE, cis-1,2-DCE, and VC) at the Site. Also provides a sensitivity analysis and results from the transport modeling.
- Petroleum Hydrocarbon Transport Modeling (Section 6.5.4) – Provides a detailed description of the methodology and procedures used to model the fate and transport of petroleum hydrocarbons (naphthalene and BTEX) at the Site.

6.5.2 Groundwater Flow Modeling

6.5.2.1 Introduction

To simulate groundwater flow at the Site, BMcD used the USGS modular flow model MODFLOW (McDonald and Harbaugh, 1988). MODFLOW is a three-dimensional finite-difference groundwater flow model and is currently the most widely used numerical model for groundwater flow studies.

To evaluate groundwater flow paths and advective transport at the Site, BMcD used the USGS MODPATH computer code. MODPATH is a particle tracking package used to compute three-dimensional flow paths from MODFLOW groundwater flow simulations (Pollock, 1994).

To develop the appropriate data files for MODFLOW and MODPATH, BMcD utilized the U.S. DoD Groundwater Modeling System (GMS). GMS is a widely used graphical user interface package designed for the pre-processing and post-processing of data files for numerical models including MODFLOW and MODPATH. GMS allows the user to develop a conceptual flow model of the Site, which is then converted to an appropriate format and executed by the MODFLOW package. Results from MODFLOW simulations are then imported back into GMS for interpretation and analysis.

The purpose of this section is to present the procedures, assumptions, and input parameters used with groundwater flow modeling performed at the Site. The primary objectives of the groundwater flow modeling are to:

- Formulate a conceptual representation of the hydrogeologic system at the Site including the hydrostratigraphic units, initial conditions, and boundary conditions.
- Simulate the groundwater flow direction and gradient observed at the Site.
- Develop a flow model that will generate the appropriate files to be used during ensuing contaminant transport modeling.

- Perform a sensitivity analysis to evaluate the variability of model output based on changes in input parameters.
- Evaluate the potential for contaminants to be captured by a nearby irrigation well.

6.5.2.2 Conceptual Model

To develop a groundwater flow model at the Site, BMcD employed an existing regional MODFLOW model constructed by the USGS. The USGS is currently in the process of publishing a complete summary of this model. Existing boundary and initial conditions were utilized from the regional model to develop a localized flow model for the Site. This conversion from the regional model to the localized model was performed in GMS through a regional to local refining procedure (EMRL, 1999).

Results from the USGS regional model indicate groundwater flow at the Site is predominately north/northeast and parallels the Kansas River Valley. The model suggests this flow pattern is the prevalent direction the majority of the time. Exceptions to this pattern are intermittent changes in groundwater direction due to peak river flows during periods of flood. Although the USGS model is transient (time dependent), particle tracking performed using this model indicates that intermittent groundwater fluctuations have minimal impact on the long-term flow direction. This conclusion is also consistent with the narrow contaminant plume observed at the Site and the observations noted in Section 2.5.2. In this section (Section 6.5.2), the term contaminant refers generally to the chlorinated solvents: PCE, TCE, cis-1,2-DCE, and VC.

To simulate the predominant groundwater flow observed at the Site, BMcD has used a steady-state modeling approach. This approach was selected because it simulates long-term flow conditions and can be used to assess future contaminant migration.

6.5.2.3 Boundary Conditions

Where possible, model boundaries used in the USGS regional model were retained for the local model. Natural boundaries for the FFTA-MAAF model include the eastern bedrock valley wall and the Kansas River. The boundary of the eastern valley wall was retained from the regional model as a no-flow boundary (Figure 6-12). The Kansas River bounds the north and west side of the model area and was simulated using the River Package in MODFLOW (Figure 6-12). A value of 60 ft/day was retained from the regional model as the hydraulic conductivity of riverbed sediments. Riverbed sediments are defined as the sediments directly below the bottom of the river. The conductivity of these sediments is used to compute the flow between the river and the alluvial aquifer. MODFLOW uses this relationship to determine when water is flowing from the aquifer to the river, and when water is flowing from the river to the aquifer. To calculate the appropriate values of conductance (C) required by MODFLOW, the following equation is used:

$$C = {}^{K_r}\!/_{t} \cdot w \cdot l \qquad \text{(Equation 6.1)}$$

Where:

K_r = Hydraulic conductivity of riverbed sediments
t = Thickness of riverbed sediments
w = Width of river
l = Length of the river boundary crossing each cell

For modeling purposes, the thickness of riverbed sediments is generally assumed to be one unit (this assumption is also consistent with the USGS model). To determine the width term used in the equation, an average river width was measured along three segments of the model. These segments and the rational used to define them is fully described in Section 6.5.2.8.2. The average width measured for each segment was determined to be 413 feet, 460 feet, and 348 feet for segments 1, 2, and 3 respectively (Figure 6-12). Since the length of the river boundary within each cell varies from cell to cell, an automated feature is included in GMS which calculates this length and incorporates it into Equation 6.1 for each cell.

A General Head Boundary (GHB) was selected to represent the southern boundary of the local model (Figure 6-12). This boundary condition was chosen as part of the regional to local conversion procedure outlined in the GMS Manual (EMRL, 1999). The GHB was created by digitizing an equipotential contour line from the regional flow model. This contour was located at a sufficient distance from the FFTA to minimize boundary effects. The GHB was assigned a conductance value of $(K_r/t)\cdot w\cdot l = 6000\cdot l$ to allow unrestricted flow through this boundary. As with the river boundary, GMS computes the (l) term in this equation. The purpose of the GHB at this Site was to define the initial groundwater heads (elevations) without restricting flow into the model. Preliminary simulations indicated the conductance value of $6000\cdot l$ was large enough to allow unrestricted flow to enter the model through the GHB.

6.5.2.4 Model Grid

Before converting the conceptual model to a MODFLOW format, a numerical grid was constructed to represent the area of interest. This task was performed in GMS by selecting a grid frame and then assigning cells within this frame. Cells were assigned by placing a refining point near the centerline of the plume at Well FP-94-09. From this point, variable grid spacing along the x-axis was determined necessary for the ensuing contaminant transport modeling. Grid spacing was initially set at 20 feet and increased five percent per cell from the refining point until a maximum grid size of 100 feet along the x-axis was reached. The grid spacing along the y-axis was uniformly set at 20 feet for every cell, since fine spacing was required along the length of the plume. The grid frame was then rotated –19 degrees to orient the principal axes parallel and perpendicular to the flow direction observed at the Site.

Model layers selected for the local model were retained from the regional flow model (Figure 6-12). During construction of the regional flow model, BMcD coordinated with the USGS so that model layers were constructed to correspond with screened intervals of monitoring wells located at the Site. Model layers 1, 2, and 3 in Figure 6-12 correspond to the shallow, intermediate, and deep screened intervals respectively. All three layers dip slightly in the down gradient direction of the Kansas River Valley and correspond to the U-shaped bedrock topography. Model layers from the regional model were interpolated to the local model using the geostatistical package included in GMS.

6.5.2.5 Recharge

Average annual precipitation at the Site was used as a basis for the direct recharge rate. The nearest recorded precipitation data is reported for Manhattan, Kansas as the average annual precipitation for a fifty-year period and is listed as 33.14 inches per year (NCDC, 1999). Using the assumption that twenty-percent of precipitation reaches the water table (Pers. Comm., 1999), results in a daily recharge rate of 0.0015 ft/day. This value was used as an initial condition in the conceptual model to approximate annual recharge to the aquifer.

The geometry of the river valley and upland area east of the bedrock valley wall suggests an increased volume of recharge enters the valley at the bedrock wall. To simulate this condition, increased recharge was added to layer 1 model cells adjacent to the eastern no-flow boundary. These cells were assigned a value of ten times the recharge applied to the valley (0.015 ft/day). This value is consistent with USGS regional model and was determined by approximating the ratio between the area draining toward the valley wall and the area of the model cells at the no-flow boundary (Pers. Comm., 1999).

6.5.2.6 Sources/Sinks

A pumping well (I-1) used for irrigation is located approximately 2,400 feet down gradient from the FFTA (Figure 6-12). Effects from this well were simulated in the model by computing the average daily flow based on the total volume of water removed from the well over a five-year period. Between 1994 and 1998, 96,167,400 gallons were removed from the irrigation well (Kansas Department of Agriculture). This equates to an average flow rate of 7,044 ft^3/day which was incorporated into the flow model. A particle tracking evaluation of transient flow conditions from the irrigation well confirmed that steady-state pumping from this well is an appropriate approximation to transient flow. The results from this evaluation are presented in Section 6.5.2.9.

6.5.2.7 Aquifer Properties

Aquifer properties used in the local FFTA-MAAF model were retained from the USGS regional model. These properties were used as initial assumptions and later verified during calibration. Hydraulic conductivity values increase with depth to be consistent with the stratigraphy observed at the Site, which consists of a fining upward alluvial sequence (Section 2.5). Vertical hydraulic conductivity is generally assumed to be 1/10th of the horizontal hydraulic conductivity (Fetter, 1994). This assumption is consistent with the vertical hydraulic conductivity used in the USGS regional model. Limited data was available to determine an appropriate value for the riverbed conductivity. Therefore, the vertical riverbed conductivity is assumed to be similar to the vertical hydraulic conductivity of model layer one. This assumption is also consistent with the USGS regional model. A summary of the various sources used to estimate aquifer properties at this Site are provided in Section 2.5. Aquifer properties are summarized below.

Properties	Layer 1 (Shallow)	Layer 2 (Int.)	Layer 3 (Deep)
Horizontal Hydraulic Conductivity (ft /day)	600	800	900
Vertical Hydraulic Conductivity (ft/day)	60	80	90
Riverbed Conductivity (ft/day)	60	Not Applicable	Not Applicable

6.5.2.8 Calibration

6.5.2.8.1 Data Set Selection

To calibrate the flow model, it was necessary to identify a water level measurement data set or sets that represented relatively steady flow conditions consistent with long-term average conditions. To identify the possible data sets, water levels in Monitoring Well FP-93-01 were graphed along with daily stage (elevation) measurements of the Kansas River, over a 7-year monitoring period (Figure 6-13). This well was selected because of its close proximity to the Kansas River relative to the other 1993 existing wells. Monitoring Well FP-93-03 was also initially graphed to determine if Well FP-93-01 is more directly influenced by the Kansas River. The trend of water levels in both wells was nearly identical, and Well FP-93-03 was removed from the graph for simplicity.

The selection of a calibration data set was initially restricted to the dates included in the USGS regional calibration model from November 10, 1997 to April 2, 1998. This allowed a data set to be chosen based on steady flow conditions displayed by the regional model. From this evaluation, the November 25, 1997 data set was determined to best represent stable flow conditions at the Site during the regional model calibration period. Furthermore, Figure 6-13 shows a steady downward trend of water levels from monitoring dates immediately preceding November 25, 1997.

Although the November 25, 1997 data represented the most steady flow period between November 10, 1997 and April 2, 1998, the groundwater elevation at Well FP-93-01 (1037.58 feet above msl) is approximately 2 feet below the 7-year average (1039.52 feet above msl) at Well FP-93-01. Therefore, a second measurement date was chosen to better represent average conditions.

April 15, 1997 was chosen as a second calibration date since the groundwater elevation at Well FP-93-01 (1038.81 feet above msl) is closer to the 7-year average and relatively stable flow conditions appear to exist (Figure 6-13). This date is also during a period when water level measurements were available from the 1996 monitoring wells. By including the 1996 monitoring wells, a better calibration to the gradient observed at the Site is possible.

To further calibrate to the groundwater gradient observed at the Site, a measurement round which included the monitoring wells installed in May/June 1998 was selected. July 28, 1998 was chosen as a third calibration date since the groundwater elevation in Well FP-93-01 (1039.74 feet above msl) approximates the 7-year average and relatively stable flow conditions appear to exist (Figure 6-13).

The groundwater flow model was calibrated separately to all three identified data sets. Results from these calibrations are discussed in the following sections. For simplicity, only results from the final calibration are presented as figures.

6.5.2.8.2 November 25, 1997, Calibration

Calibration to the November 25, 1997 data set was achieved using the input parameters given in Section 6.5.2.7. A recharge of 0.0015 ft/day was assigned to the model interior, and a recharge of 0.015 ft/day was assigned along the bedrock valley wall.

Preliminary simulations indicated that the greatest influence on groundwater flow and gradient was the stage of the Kansas River. To achieve the proper gradient in the aquifer, the river was divided into three segments. Selection of these segments was based upon the observed groundwater flow direction with respect to river flow direction. Along the first segment (Segment 1), the river and aquifer gradient are approximately parallel. Therefore, river nodes 1 and 2 (Figure 6-12) were assigned values of 1040.5 feet above msl and 1034.1 feet above msl respectively to match the observed gradient in the aquifer. Along the second segment (Segment 2), the river turns east and flows perpendicular to groundwater flow. As a result, the river gradient is predicted to flatten as increased groundwater enters the river along this reach. This segment was assigned the values of 1034.1 feet above msl and 1033.1 feet above msl to river nodes 2 and 3 respectively (Figure 6-12). Along the third segment (Segment 3), the river gradient is predicted to continue to flatten, as increasing groundwater flow enters the river. River nodes 3 and 4 (Figure 6-12) were assigned 1033.1 feet above msl and 1031.1 feet above msl respectively along this segment. Adjustments made to the river gradient by dividing the river into three segments, greatly improved the calibration to the aquifer gradient while preserving the predicted behavior of the river along this reach.

When calibrating the flow model to the November 25, 1997 data set, trial and error methods were used by adjusting the model input parameters to achieve a calibration that visually appeared to match the gradient and water levels observed at the Site. The computed gradient between Well FP-96-04 and Well FP-96-23 was approximately 6.32 x 10^{-4}. This compares closely with an observed gradient (from November 25, 1997) between these wells of 6.00 x 10^{-4}.

Another method used to develop an understanding of the overall calibration at the Site is to compare the error at each observation well. This is generally accomplished by averaging the residual values (residuals) computed for each well. Residuals represent the difference between the model-calculated water level at a well and the observed water level at the same well. The average of residuals is generally referred to as the mean error. The mean error calculated for the November 25, 1997 calibration was 0.04 feet (0.48 inches).

This suggests a slight overestimation of the water levels at the Site, although some of this can be attributed to poor calibration at wells near the Kansas River.

Calibration results indicate that wells located near the Kansas River do not have as close a match to observed water levels as the other wells at the Site. This occurs because these wells are more affected by stage fluctuations in the Kansas River than wells near the center of the plume. Water levels observed in these wells display time dependent conditions rather than the relatively steady conditions observed near the contaminant plume.

An additional statistical technique for interpreting calibration results is to average the absolute value of the residuals, referred to as the mean absolute error. The mean absolute error for the November 25, 1997 calibration was 0.09 feet (1.08 inches). This indicates the average residual at the Site is ±1.08 inches. A calibration of this accuracy is considered excellent for groundwater flow modeling.

6.5.2.8.3 April 15, 1997, Calibration

Calibration to the April 15, 1997 data set was achieved using the input parameters given in Section 6.5.2.7. Recharge was assigned 0.0015 ft/day to the model interior, and 0.015 ft/day along the bedrock valley wall. River nodes were assigned the values 1041.8, 1035.1, 1034.1, and 1032.1 feet above msl to nodes 1, 2, 3, and, 4 respectively. The computed gradient between Well FP-96-04 and Well FP-96-23 was determined to be approximately 6.84×10^{-4}. This matches identically with an observed gradient (from April 15, 1997) between these wells of 6.84×10^{-4}.

The mean error calculated for the April 15, 1997 calibration was 0.00 feet. This improved match to the data is a result of the better calibration to wells near the Kansas River. The mean absolute error for the April 15, 1997 calibration was 0.08 feet (0.96 inches). A calibration of this accuracy is also considered excellent for groundwater flow modeling.

Calibration to this data set appears to be a better match than the November 25, 1997 data set. This can be attributed to the relatively steady flow conditions displayed by the April 15, 1997 data set. Prior to water level measurements collected on April 15, 1997, the stage in the Kansas River had been relatively stable for approximately four months (Figure 6-13). This allowed groundwater flow conditions in the aquifer to approach steady-state with minimal influence from stage changes in the Kansas River.

6.5.2.8.4 July 28, 1998, Calibration

Calibration to the July 28, 1998 data set was also achieved using the input parameters given in Section 6.5.2.7. Recharge was assigned 0.0015 ft/day to the model interior, and 0.015 ft/day along the bedrock valley wall. River nodes were assigned the values 1042.7, 1036.1, 1035.1, and 1033.1 feet above msl to nodes 1, 2, 3, and, 4 respectively. The computed gradient between Well FP-96-04 and Well FP-98-31 was determined to be approximately 6.92×10^{-4}. This compares closely with an observed gradient (from July 28, 1998) between these wells of 7.10×10^{-4}. Results from this calibration are presented in Figures 6-14 and 6-15. Figure 6-15 is an enlarged view of the calibration area.

Error bars indicated on these figures were assigned a calibration target of ±0.5 feet from observed water levels. Green error bars represent a calibration within ±0.5 feet of the observed water level, yellow error bars represent a calibration that exceeds ±0.5 feet but is within ±1.0 feet of the observed water level, and red error bars represent a calibration that exceeds ±1.0 feet of the observed water level. The length of the error bars represent the residual value on a scale from 0.0 feet to ±0.5 feet. For example, a well which displays a positive (upward) green error bar extending halfway up the error scale, represents a calculated water level which is 0.25 feet above the observed water level (a residual of 0.25 feet). At some of the wells indicated on Figures 6-14 and 6-15, the calculated water level is so close to the observed water level that green error bars are not visible.

The mean error calculated for the July 28, 1998 calibration was 0.04 feet (0.48 inches), and the mean absolute error was 0.16 feet (1.92 inches). Although this calibration does not appear to be as accurate as the previous calibrated data sets, it is still considered excellent for groundwater flow modeling. Calibration results are displayed graphically in Figure 6-16. This figure represents the observed water level at each well verses the computed water level at each well.

The diminished calibration to the July 28, 1998 data set is likely the result of two limitations. First, the July 28, 1998 data set does not display groundwater flow conditions that are as steady as the previous data sets. This data set was chosen because it displayed the most steady flow conditions of the available data sets which include water level measurements from the 1998 wells. Therefore, since the effect of transient flow conditions near the river is present in this data set, the steady-state model is not expected to calibrate as well. However, calibration to the observed gradient along the centerline of the plume is still assumed possible. The second limitation of this data set is the apparent use of the irrigation well immediately preceding and/or during the July 28, 1998 measurement date. This use is suspected since observed water levels in Wells I-1 and FP-96-22 are considerably lower than expected. It is possible to better calibrate the model to these wells by increasing the flow rate from the pumping well, however this would contradict the long-term steady flow paths observed at the Site.

6.5.2.8.5 Selected Calibration for Ensuing Contaminant Transport Modeling

Calibration to three separate data sets collected at the Site required minimal variation in model input parameters. Simulations performed with these data sets show that steady flow conditions are present at the Site and are successfully simulated using the steady-state groundwater flow model described in this section.

From the three calibrated models available, the July 28, 1998 calibrated model was chosen to represent long-term groundwater flow conditions at the Site. This determination was based on the availability of the May/June 1998 well data, which provided a more confident calibration to the observed gradient. Although the July 28, 1998 model does not calibrate to the observed data as well as the April 15, 1997 model, the similar gradients suggest that both calibrated models are a valid approximation of groundwater flow at the Site. The gradient reported for the July 28, 1998 model of 6.92×10^{-4} is comparable to the gradient of 6.84×10^{-4} reported for the April 15, 1997 model. A summary of the final input parameters used in the MODFLOW model is provided in Table 6-6.

6.5.2.9 Particle Tracking Evaluation

Particle tracking with MODPATH was performed using all three calibrated flow models to compare the flow path of particles originating at the FFTA to the path displayed by the observed contaminant plume. Results from these simulations were nearly identical and showed particle pathlines matching very closely with the centerline of the contaminant plume (Figure 6-15). The contaminant plume displayed in Figure 6-15 is May 1999 cis-1,2-DCE, from the intermediate zone. This plume is displayed because it appears to be the most extensive at the Site. Results from this evaluation indicate the groundwater flow direction computed by the MODFLOW model approximates the steady flow direction observed at the Site.

To evaluate components of vertical groundwater flow at the Site, the MODPATH simulations performed using the July 28, 1998 calibrated model were observed in profile view (Figure 6-17). Particle tracks in this view clearly indicate a vertical component of flow is present at the Site. Particles tracked in this study assume advective transport only. Effects due to vertical dispersivity and density differences are not represented. To confirm the assumption that vertical flow is directly related to recharge, particles were tracked from the FFTA using the July 28, 1998 model with recharge removed from the simulation. Particle tracks from this study showed no vertical component of flow, thus confirming the assumption. These results help to provide further understanding of the advective transport of contaminants at the Site.

To evaluate groundwater flow near Irrigation Well I-1 at the Site, BMcD performed a transient particle tracking study. The purpose of this evaluation was to access the impact on the contaminant plume from periodic pumping of Well I-1, as well as to determine the validity of assuming steady-state pumping as an approximation to long-term flow at the Site.

To evaluate seasonal pumping effects on the contaminant plume, a transient simulation, hereinafter referred to as Model 1, was performed. This model was constructed by creating a 120-day pumping period, followed by a 240-day idle period. To investigate particle tracking beyond one year, these stress periods were repeated several times and added to the total length of the simulation. Stress period lengths were determined by assuming the irrigation well is only operated during a four-month irrigation season. The well is assumed idle during the remaining eight months. To determine an appropriate pumping rate for the irrigation well, the largest volume of water removed from the well in one season (25,149,300 gal. in 1997) was divided into 120 days. This resulted in a constant flow rate of 146 gallons per min (gpm) (28,105 ft^3/day) applied over this 120-day period.

A capture zone analysis was performed using a backward particle tracking approach. This method allows particles captured by a well to move in reverse to their original positions in a given amount of time. This method identifies the capture zone of the well for a given time interval. Simulations performed using this technique were conducted for up to 1,200 days. Results from these simulations indicate that it is unlikely for contaminant concentrations above MCL to enter the irrigation well (Figure 6-18). This conclusion is based on plume maps from the May 1999 sampling date. The plume displayed in Figure 6-18 is May 1999 cis-1,2-DCE, from the intermediate zone. This plume was selected because it is appears to be the most extensive at the Site and has the highest concentrations near the irrigation well.

It is important to realize that conclusions drawn from these simulations are based on particle transport by advection only. Actual contaminant transport may be affected by processes of dispersion, sorption, and biodegradation. These processes tend to decrease contaminant concentrations in groundwater. Therefore, these particle-tracking simulations present a conservative view of contaminant transport near the irrigation well.

To further investigate seasonal pumping effects, a second transient model, hereinafter referred to as Model 2, was constructed to refine the pumping period. The purpose of this model was to investigate the assumption that steady pumping at a low flow rate over 120 days approximates periodic pumping at a high flow rate. This model was constructed by pumping the irrigation well at 900 gpm (173,250 ft^3/day) for 72 hours, followed by a 17-day idle period. The flow rate of 900 gpm is the rate typically reported in water use reports by the well owner, and 72 hours is the average length of the pumping period. Applying these periods over the 120-day irrigation season translates to seven pumping periods and six idle periods equaling 27,216,000 gallons of water.

Using the backward particle tracking approach for Model 2 produced a capture zone almost identical to the Model 1 capture zone (Figure 6-19). This suggests that assuming a steady flow rate over an irrigation season is a valid assumption. The major difference between these two models is the flow paths of the particles. Although particles from both models appear to move the same linear distance per time, particles from Model 2 travel further than particles from Model 1. This occurs because particle tracks from Model 2 display a "zigzag" pattern resulting from the increased velocities during the 72-hour pumping periods, followed by very low velocities during the idle period.

An additional evaluation was performed using Model 1 to compare particle tracking along the centerline of the plume with the previous steady-state particle tracking performed using the calibrated models. Using Model 1, particles were placed along the centerline of the plume and tracked forward past the irrigation well. The particle paths produced from this evaluation closely approximate the paths observed in the calibrated models. This conclusion confirms the validity of the steady-state pumping approximation used in the calibrated models to simulate long-term groundwater flow at the Site.

6.5.2.10 Sensitivity Analysis

A sensitivity analysis was performed using the July 28, 1998 calibrated model to assess the variability of model output based on changes in input parameters. This analysis was performed by varying each parameter ±10, ±20, ±30, and ±50-percent from the calibrated value. Parameters evaluated were horizontal hydraulic conductivity (K_x), vertical hydraulic conductivity (K_z), and recharge. Results from this analysis are presented in Figure 6-20.

This analysis confirms the assumption that parameters used in this model adequately characterize the Site. All three parameters evaluated show that changes up to ±50-percent can occur without altering the calibration more than 0.29 feet (3.48 inches). The parameter with the largest affect on calibration is recharge. Increasing recharge up to 50-percent alters the calibration to 0.29 feet, however decreasing recharge 50-percent only alters the calibration to 0.21 feet. Recharge is the most sensitive parameter relative to the parameters evaluated in this analysis, however a change in calibration of 0.13 feet (1.56 inches) is generally not a large enough difference to deem a parameter as "sensitive".

A more important result of varying recharge that is not revealed by Figure 6-20, is its affect on groundwater flow direction. Observations using MODPATH revealed that increasing recharge results in a slight shift of path lines. MODPATH simulations indicate that increasing recharge 50-percent, causes particles to intersect the Kansas River approximately 400 feet west of the particle track shown on Figure 6-15. Conversely, decreasing recharge results in a shift of path lines with a eastward magnitude of approximately 250 feet. This result occurs because the groundwater elevations assigned to each river node are fixed values. Increasing recharge allows more water into the flow model, thus "pushing" the equipotential contours in a counterclockwise rotation about the fixed river nodes. The reverse is true when decreasing recharge.

Recharge effects were further evaluated by adjusting the recharge at the valley wall independently of the regional recharge. Results indicate recharge at the valley wall can be varied ±50-percent without changing the calibration at the Site. The effect from this recharge is only noticeable near the wall and has no noticeable influence on groundwater flow near the contaminant plume.

The second most sensitive parameter is horizontal hydraulic conductivity. Increasing K_x up to 50-percent alters the calibration to 0.18 feet, and decreasing K_x by 50-percent alters the calibration to 0.20 feet. This change is also not significant enough to deem this parameter "sensitive." These results indicate that horizontal flow in the model is not appreciable limited even when decreasing K_x 50-percent.

Vertical conductivity has the smallest affect on calibration. K_z was varied ±50-percent without changing the calibration at the Site. This result is likely due to the magnitude of the vertical conductivity values. The values 60 ft/day, 80 ft/day, and 90 ft/day corresponding to layers 1, 2, and 3 respectively are considered very large. Thus, vertical flow in the model is not limited even when decreasing these values 50 percent.

Although not included in the formal sensitivity analysis, evaluation of River and General Head Boundary conductance was also performed. Simulations indicate that conductance values for both boundaries can be adjusted ±80-percent without noticeable change in residual water levels. This is because the conductance values used for these boundaries are very large values. Therefore, unrestricted groundwater flow is allowed through these boundaries.

6.5.2.11 Summary of Groundwater Flow Modeling

6.5.2.11.1 Assumptions

The following provides a summary of fundamental assumptions made during construction of the groundwater flow model at FFTA-MAAF:

- A steady-state model is appropriate to simulate groundwater flow at the Site, since long-term flow conditions appears to approximate steady-state groundwater flow. This steady-state model can also be used in the contaminant transport and natural attenuation evaluations to assess future contaminant migration.

- The western and northern model boundary is the Kansas River, and is simulated using the River Package in MODFLOW.

- The eastern model boundary is the bedrock valley wall and is modeled as a no-flow boundary.

- The southern model boundary is represented by a General Head Boundary. This boundary was constructed to allow unrestricted groundwater flow to enter the model.

- The model grid was constructed using a 20 feet x 20 feet grid spacing along the centerline of the plume which increased along the x-axis by five percent per cell. The model consists of three layers which dip slightly in the down gradient direction of the Kansas River Valley, and correspond to the U-shaped bedrock topography. All layers correspond to the screened intervals of FFTA-MAAF wells.

- Average annual recharge to the aquifer is assumed to be twenty percent of the average annual precipitation. This was calculated to be 0.0015 ft/day. Increased recharge is predicted to enter the river valley at the bedrock valley wall. This was determined to be ten times the amount of recharge applied to the valley (0.015 ft/day).

- Horizontal hydraulic conductivity was determined to be 600 ft/day, 800 ft/day, and 900 ft/day for model layers one, two, and three respectively. Vertical hydraulic conductivity is assumed to be 1/10 of the horizontal hydraulic conductivity. These values were verified through calibration (Section 6.5.2.8).

- Removal of water from the irrigation well is simulated as a constant flow rate in the steady-state model. This assumption was verified through particle tracking (Section 6.5.2.9).

6.5.2.11.2 Summary

The following provides a summary of the steps taken during construction, calibration, and execution of the groundwater flow model used to simulate flow conditions at the Site.

- A localized groundwater flow model was constructed from the USGS regional groundwater model. Aquifer properties were retained from the regional USGS model (Section 6.5.2.7).

- The initial calibration date was determined to be November 25, 1997. The groundwater model was calibrated to this data set and particle tracking was compared to the current plume location.
- A second calibration date which more resembled steady flow and average groundwater conditions was determined to be April 15, 1997. The model was calibrated to this data set and particle tracking was compared to the current plume location.
- A third calibration date which included the monitoring wells installed in May/June 1998 was determined to be July 28, 1998. This data set was selected to improve the gradient calibration observed at the Site. Particle tracking was also performed on this data set and compared to the current plume location. Additional particle tracking was performed to evaluate the vertical flow component at the Site. Vertical flow was determined to be directly related to recharge.
- The July 28, 1998 calibrated model was chosen to represent long-term groundwater flow conditions at the Site. This determination was based on the availability of June 1998 well data, which provided a more confident calibration to the observed gradient at the Site.
- Particle tracking performed at Irrigation Well I-1 confirmed the validity of assuming steady state pumping as an approximation to long-term flow at the Site. Results from this evaluation also indicated that it is unlikely for contaminant concentrations above their MCLs to enter the irrigation well.
- A sensitivity analysis was performed using the July 28, 1998 calibrated model. The input parameters of horizontal hydraulic conductivity, vertical hydraulic conductivity, and recharge were adjusted during the analysis. Results indicate values used for these parameters are adequate estimates of aquifer properties at the Site.

6.5.2.12 Conclusions

Groundwater flow modeling at the Site has successfully simulated the observed groundwater flow direction and gradient at the Site. Model calibration was achieved for three separate data sets collected at the Site. These calibrations produced mean absolute errors ranging from 0.08 feet (0.96 inches) to 0.16 feet (1.92 inches).

Input parameters used for each calibration were consistent, only stage elevations in the Kansas River were varied. The ability of the model to calibrate successfully to three data sets strengthens the assumption that input parameters adequately characterize aquifer properties at this Site, and the gradient observed in the aquifer under steady flow conditions occurs frequently. The sensitivity analysis performed on the July 28, 1998 calibrated model provides an additional understanding of the effects of parameter uncertainty on model output.

Groundwater modeling at the Site has successfully generated a flow field appropriate for use in the ensuing contaminant transport modeling. MODPATH simulations performed on each calibrated model consistently approximate the contaminant plume observed at the Site. This indicates the flow field established by the model approximates the dominant flow direction at the Site.

Particle-tracking simulations performed to evaluate the capture zone of Irrigation Well I-1, indicate that it is unlikely for contaminant concentrations above MCL to enter the this well.

6.5.3 Chlorinated Solvent Modeling

6.5.3.1 Introduction

To simulate contaminant transport of chlorinated solvents at the Site, BMcD used the U.S. Department of Energy modular transport model: Reactive Multi-species Transport in 3-Dimensional Groundwater Aquifers (RT3D), (Clement, 1998). RT3D is a finite-difference reactive transport model designed for use in conjunction with MODFLOW. RT3D is a valuable tool for natural attenuation modeling because it includes sequential reductive dechlorination of PCE and its daughter products, as well as the other natural attenuation processes sorption and dispersion.

The purpose of this section is to present procedures, assumptions, input parameters, and limitations of the reactive transport modeling performed at the Site. The primary objectives of the reactive transport modeling are to:

- Construct a reactive transport model that predicts the fate of PCE and its daughter products.
- Provide future concentration data for the ensuing risk assessment.
- Provide data to aid in the evaluation of natural attenuation processes at the Site.

6.5.3.2 RT3D Model Parameters

This section identifies the input parameters used in the reactive transport model. The four major transport processes, advection, dispersion, chemical reactions, and sources/sinks are separated into individual packages and accessed by the RT3D code. A description of each package and the appropriate input parameters is provided in the following sections. These parameters were selected as initial conditions, and were adjusted as needed during calibration.

6.5.3.2.1 Advection Package

The advection package is used to simulate the movement of contaminants along with the flowing groundwater. This package utilizes the groundwater flow field computed by MODFLOW to determine the direction and velocity of the advective transport. Since the appropriate files are read in from the MODFLOW solution, no additional parameters are input into the advection package. To solve the transport equations, the appropriate numerical solver is specified in the advection package. For the reactive transport model constructed here, the Modified Method of Characteristics (MMOC) solver was determined to be the best suited. This determination was based upon numerous simulations using the five available solvers. The MMOC solver produced a solution nearly identical to the Method of Characteristics (MOC) solver, however was much faster and more stable at long run times.

Average Linear Velocity (v)

Average linear velocity is used to simulate flowing groundwater in three dimensions. Average linear velocity is the rate at which the flux of the groundwater across the unit cross-sectional area of pore space occurs (Fetter, 1993). Average linear velocity along the x-axis (v_x) is expressed as: $v_x = K_x I/\eta_e$, where K_x is the hydraulic conductivity along the x-axis, I is the hydraulic gradient along the x-axis, and 0_e is the effective porosity of the aquifer. Average linear velocity is expressed similarly for the y- and z-axes. Values for $K_{(x,y,z)}$ and $I_{(x,y,z)}$ are read from the MODFLOW groundwater flow model described in Section 6.5.2. A value for effective porosity is provided in the following section.

Effective Porosity (η_e)

Although effective porosity has been measured for the shallow zone at the Site and estimated through a tracer study (Section 6.2.1.1.3), published data suggests a lower value for aquifer materials represented at the Site. The measured effective porosity (excluding clay samples) ranges from 0.31 to 0.40, with a mean of 0.35. The estimated effective porosity from the tracer study ranged from 0.22 to 0.53, with a mean of

0.39. Average effective porosity values reported in GRI, 1988 are 0.30, 0.32, and 0.29 for fine, medium, and coarse sands respectively. Wiedemeier et al., 1999 report effective porosities ranging from 0.10 – 0.30, 0.15 – 0.30, and 0.20 – 0.35 for fine, medium, and coarse sand respectively. Furthermore, the USGS regional flow model uses a value of 0.25 for specific yield that was determined through calibration and particle tracking studies. Specific yield is generally considered an approximation of effective porosity (Fetter, 1994).

Since effective porosities measured at the Site only represent the shallow zone, BMcD chose to use an effective porosity of 0.3 as an average value for this Site. This value is the average of the USGS value (0.25) and the average measured effective porosity (0.35). Furthermore, this effective porosity agrees with published values for aquifer materials similar to those at the Site (GRI, 1988; Wiedemeier et al., 1999).

6.5.3.2.2 Dispersion Package

The dispersion package is used to simulate mechanical and/or molecular mixing of the contaminants with groundwater.

Mechanical Dispersion

Mechanical mixing, referred to as mechanical dispersion, is represented in RT3D by three terms: longitudinal dispersivity (α_x), transverse dispersivity (α_y), and vertical dispersivity (α_z). Since dispersivity is scale dependent, methods presented by Xu and Eckstein (1994) were used to estimate longitudinal dispersivity at the Site. The equation used to make this estimate is given as $\alpha_x = 0.83(\mathrm{Log}_{10}L)^{2.414}$, where L is the field scale. The field scale is generally assumed to be the distance from the center of mass to a down-gradient receptor. The field scale for this Site was taken as the distance from the center of the plume (Well FP-94-09 from May 1999) to the Kansas River. The center of the plume was determined from the May 1999 sampling event as the highest concentration of cis-1,2-DCE at the Site. Since cis-1,2-DCE is present in much higher concentrations than PCE or TCE, it was used to define the plume's center. The field scale at the Site was determined to be approximately 5,400 feet. Longitudinal dispersivity was then computed to be approximately 20 feet. This value is proportional to the longitudinal dispersivity determined from the tracer test performed at the Site (Section 4.1.5). Longitudinal dispersivity computed from the tracer test was determined to be 2.33 feet (71 cm), using a 50-foot field scale. Using the Xu and Eckstein (1994) approach, a similar α_x was calculated to be 2.98 feet, using a 50-foot field scale.

Transverse dispersivity is generally estimated as 1/ 10th of the longitudinal dispersivity, and vertical dispersivity is taken as 1/10th of the transverse dispersivity (Gelhar et al., 1992). Therefore, the following values were used as initial dispersivity estimates: $\alpha_x = 20$ feet, $\alpha_y = 2$ feet, and $\alpha_z = 0.2$ feet. These values were later changed during calibration (Section 6.5.3.3.2).

Molecular Diffusion

Molecular mixing of contaminants, referred to as molecular diffusion, is simulated in RT3D through the effective molecular diffusion coefficient (D*). Usually molecular diffusion is only a significant factor in the case of very low velocities, such as in a tight soil or clay liner or in the case of mass transport involving very long time periods (Bedient, 1994). Since aquifer materials at the Site are relatively coarse and have large hydraulic conductivities, molecular diffusion is assumed to have a negligible effect on contaminant transport and was excluded from the model.

6.5.3.2.3 Chemical Reaction Package

The chemical reaction package is used to simulate retardation and degradation of the contaminants. The effect by which dissolved constituents move at a slower rate through the aquifer than the groundwater transporting them is referred to as retardation. Retardation is due to sorption of contaminants to aquifer materials and is generally expressed in terms of the retardation coefficient (R): $R = 1 + K_d(\rho_b/\eta_e)$, where K_d is the soil-water distribution coefficient, ρ_b is the bulk density, and η_e is the effective porosity of the aquifer (Olsen, 1990). Due to the relatively low contaminant concentrations at this Site, sorption effects are assumed linear (Wiedemeier, 1999). The retardation coefficient is computed for each model cell from the input parameters K_d, ρ_b, and η_e. Values for ρ_b and K_d are discussed in the following sections.

Bulk Density (ρ_b)

Bulk density at the Site has been measured using USBR Method 5372-89 for samples collected from three well borings at the Site: FP-96-18, FP-96-19, and FP-96-21. Of the nine samples collected from these borings, three samples represent a clay soil. Since aquifer materials at the Site are predominately fine to coarse sand, the samples representing a clay soil were excluded from bulk density estimates. This allowed for an average bulk density that more closely represented aquifer conditions at the Site. Bulk density estimates from samples collected at the Site are presented in Table 2-4. The mean bulk density for samples collected at the Site was 1.6 g/cm^3.

Soil-Water Distribution Coefficient (K_d)

The following K_{oc} values were used to calculate K_d (Section 6.2.1.3.2).

	PCE	TCE	cis-1,2-DCE	VC
K_{oc} (cm^3/g)	265	94	35.5	18.6

From the relationship $K_d = K_{oc}(f_{oc})$, with $f_{oc} = 0.0053$, model input parameters for K_d were estimated to be (Section 6.3.1.3.3):

	PCE	TCE	cis-1,2-DCE	VC
K_d (cm^3/g)	1.41	0.50	0.19	0.01

Degradation

Included in RT3D are reaction packages used to simulate the degradation of organic compounds. To simulate the degradation of PCE and its daughter products via anaerobic pathways, Module #6 (anaerobic decay module) was chosen based on conditions observed at the Site. As input parameters into this module, RT3D requires first-order degradation rates to be defined. Degradation rates (k) are computed from the relationship k = ln(2)/8, where 8 is the half-life of the chemical. The following degradation rates were obtained from published sources and used as initial input parameters into the model:

Chemical	Rate (1/day)
PCE	0.0029
TCE	0.0025
cis-1,2-DCE	0.0017
VC	0.0079

Anaerobic degradation rates for PCE, TCE, and VC were selected from Aronson and Howard, 1997. These rates are mean values from 16, 47, and 19 studies respectively. This document however, does not provide an anaerobic rate for cis-1,2-DCE. Therefore, this degradation rate was obtained from Howard, 1991. Values provided in this reference however, are given as high and low values. Therefore, the initial cis-1,2-DCE degradation rate input into the model was assumed to be the mean of this range.

6.5.3.2.4 Source/Sink Mixing Package

The source/sink mixing package is used to add (source) or remove (sink) a specified amount of contaminant mass to/from the transport model. Sources and sinks available to this package are imported from the MODFLOW model created for the Site (Section 6.5.2), and include the following: Kansas River Boundary, General Head Boundary, Irrigation Well (I-1), and recharge. For the purpose of predicting future contaminant migration at the Site, it is assumed that no ongoing chlorinated solvent source is present at the FFTA. A soil sampling investigation performed in August, 1999 verified that chlorinated solvent concentrations above MCLs are unlikely to source to groundwater (Section 4.2). Therefore, no contaminant sources are added in the source/sink mixing package. Initial contaminant concentrations for the model are discussed in Section 6.5.3.4.

Possible contaminant sinks at the Site include volatilization and/or evapotranspiration of aqueous phase chlorinated solvents. However, it is assumed that these processes are negligible. Therefore, no contaminant sinks are included in this package. Although contaminant particles are allowed to exit the model at the River Boundary and/or Irrigation Well I-1, a specified amount of contaminant mass removed (a contaminant sink) at these locations does not need to be input into this package since removal at these locations is already included in the model.

6.5.3.3 Model Calibration

6.5.3.3.1 Introduction

Calibrating a transport model to site-specific data is commonly a difficult task. Usually, limited and/or sparse site data make calibration with any degree of confidence difficult. Potential calibration methods often sited in the literature include:

- Simulating a spill at the source area and attempting to project forward to match the current plume concentrations and extent.
- Entering an early plume and attempting to match the current plume concentrations and extent.
- Calibrating to changes in total contaminant mass in the plume over time.
- Calibrating to concentration trends observed in individual monitoring wells.

Before attempting to calibrate the reactive transport model, BMcD evaluated the potential of each method to provide a valid calibration. These findings are summarized in the following paragraphs.

Simulating a spill at the source area and attempting to project forward to match the current plume location and extent. Although one known spill has been documented at the FFTA (Section 1.2.2), additional spills may have occurred for which no information is available. Therefore, this method was determined to be impractical since detailed spill history is required to project forward to the current plume position. Preliminary simulations also suggested that calibration using this method was highly unlikely due to the unknown volume of contaminant spilled.

Entering an early plume and attempting to match the current plume location and extent. This method was also determined to be impractical since the contaminant plume at the Site has only been fully defined for less than two years. Therefore, entering an early plume would significantly underestimate the downgradient mass currently observed. BMcD also considered entering the May 1998 plume (the first fully defined date) and calibrating to either the May 1999 or August 1999 plume. However, this method was not possible due to variability of the data and the relatively short interval between data collection rounds.

Calibrating to changes in total contaminant mass in the plume over time. This is one of the few methods that has been reported with reasonable success. However, mass calculations using Site data show an increase in PCE equivalent mass over five years of data, rather than the decreasing PCE equivalent mass required for this calibration method. PCE equivalent mass is determined by converting the mass of TCE, cis-1,2-DCE, and VC to an equivalent mass of PCE. This trend is partially expected since the plume has only been fully defined since 1998. Dates previous to 1998 show a smaller PCE equivalent mass only because concentrations from down gradient wells are not included in the calculation. That is, the total mass is not increasing, rather the data set used to compute the PCE equivalent mass has been extended. Since this calibration method requires data from a fully defined plume, the model is not capable of accounting for mass differences that are dependent on incomplete data. Furthermore, modeled simulations only show a decreasing PCE equivalent mass with time, therefore calibration to changes in mass is not possible at this Site.

Calibrating to concentration trends observed in individual monitoring wells. Based on concentration trends at the Site, this method provides the best opportunity for calibrating the reactive transport model. The criteria for calibrating to an individual well was that the well must display several years of data and must display decreasing concentrations. By comparing the concentration data at each monitoring well, BMcD determined that Well FP-96-25 provided the best opportunity for calibration. This well shows concentrations steadily decreasing for PCE and TCE, but increasing then decreasing for cis-1,2-DCE. This trend is displayed over four years and is typical of chlorinated solvent trends discussed in the literature.

Initially, calibration was attempted using Well FP-93-02. However, calibration to this well presented several problems. The rapid decrease in PCE required using unreasonably high PCE degradation rates and created a very large production of TCE and cis-1,2-DCE. Upon further review, it was determined that since this well was fairly close to the FFTA, the potential existed for this well to be influenced by the effects from the pilot test performed in 1995. This may explain the rapid decrease in PCE concentrations following the pilot test.

6.5.3.3.2 Dispersion Evaluation

Before the reactive transport model was calibrated to Well FP-96-25, a preliminary parameter evaluation was performed to access the initial values defined for dispersivity. The purpose of this evaluation was to confirm that initial values chosen for these parameters did not result in an unexpected behavior of the modeled plume. For example, if the modeled plume became exceptionally wide this would suggest a discrepancy with the value used for transverse dispersivity.

To perform this evaluation, a constant contaminant concentration was assigned to model cells (layer 1) within the FFTA. This was intended to simulate a spill from the assumed source area. To evaluate the vertical dispersivity values, the RT3D model was executed with only the advection and dispersion packages active. Results from this evaluation were analyzed in a qualitative manner. Preliminary simulations using the initial values (Section 6.5.3.2.2) indicated that longitudinal and horizontal values appear to adequately match the shape of the observed plume at the Site. However, the value chosen for vertical dispersivity (0.2) allowed the contaminant plume to travel almost entirely in the shallow layer without allowing appreciable mass into layers two and three. Additional simulations indicated that using a value of 0.02, allowed the contaminant plume to follow the pattern observed at the Site of contamination moving from the shallow zone to the intermediate and deep zones respectively.

To confirm the results of this evaluation, a second series of simulations were performed using the May 1999 cis-1,2-DCE plume (Figures 5-26 and 5-29). These simulations were intended to provide a more valid evaluation by using Site-specific data. Numerous simulations were performed using varying combinations of longitudinal, horizontal, and vertical dispersivities. Results from this evaluation also suggest the initial value for vertical dispersivity (0.2) does not represent the plume behavior observed at the Site. More representative results were obtained by using a vertical dispersivity of (0.02). Therefore this value was used for all subsequent simulations.

6.5.3.3.3 Sorption Evaluation

A second preliminary parameter evaluation was performed to access the initial values defined for sorption. This evaluation was performed by using the May 1999 cis-1,2-DCE plume with the advection, dispersion, and linear sorption packages active. Results from this evaluation were also analyzed in a qualitative manner. Using the initial values proposed for K_d (PCE = 1.41, TCE = 0.5, DCE = 0.19, and VC = 0.1) and a constant bulk density of 1.6 g/cm^3, resulted in a modeled plume that did not display any abnormal or unanticipated effects. In other words, the plume appeared to move in a predictable fashion, did not decrease or persist abnormally, and displayed a downward trend of contaminants moving from layer 1 to layers 2 and 3. As expected, the center of mass of the plume remained more condensed and did not move down-gradient as fast with sorption activated. The initial values chosen to represent sorption at the Site appear to be sufficient to simulate contaminant transport and were used for all subsequent simulations.

6.5.3.3.4 Calibration to Well FP-96-25

The next step in calibration of the reactive transport model was to add degradation to the numerical simulations and calibrate to the concentration trend displayed in Well FP-96-25. Since degradation rates are believed to be the greatest uncertainty in the transport model, much of the effort in the calibration process was applied to adjusting these rates.

To perform the calibration at Well FP-96-25, the December 1996 plume was entered into the model. This sampling date was chosen because this was the first time concentration data was reported for Well FP-96-25. The initial degradation rates used in the model were obtained from published sources (Section 6.5.3.2.3). However, after the model was executed and compared to Well FP-96-25, it appeared these initial degradation rates were too low for PCE and TCE, but too high for cis-1,2-DCE and VC. Therefore, numerous simulations were performed by adjusting the degradation rates until a match to the concentration trend displayed in Well FP-96-25 was reached. These rates were adjusted by using very high rates, very low rates, and various combinations to obtain a better understanding of the range of possible values. The final calibrated rates were determined to be: PCE = 0.018 days^{-1}, TCE = 0.007 days^{-1}, cis-1,2-DCE = 0.00001 days^{-1}, and VC = 0.00001 days^{-1}.

An additional concern in the initial modeling attempts was the accumulation of VC in the model. This contaminant is only occasionally observed in the field data (four positive detections in seven years) at concentrations below or slightly above MCL. Therefore to match the Site data, the degradation rate for VC was set at 0.00001 days^{-1}. Although this rate is equivalent to the cis-1,2-DCE rate, published results support this situation (Wilson et al., 1996). Furthermore, the low degradation rates of cis-1.2-DCE and VC are consistent with the iron-reducing conditions at the Site and strongly support the assumption that cis-1,2-DCE and VC degrade very slowly at the Site (Section 6.4).

The final calibration to Well FP-96-25 is shown in Figure 6-21. Modeled VC concentrations are not indicated because they are very small relative to the other contaminants. The maximum modeled VC concentration reached during calibration was 0.08 µg/L, which is below the laboratory detection limit of 0.1 µg/L. Therefore, the model suggests that VC may be present at Well-96-25, but at concentrations below the detection limit. This conclusion agrees with Site data, since VC has never been detected at this Well FP-96-25. The final input parameter values used to calibrate the model are presented in Table 6-7.

6.5.3.4 Initial Concentration

To predict the fate and transport of the contaminant plume at the Site, initial concentrations were selected to represent current conditions at the Site. These concentrations were chosen by performing a regression analysis on the concentration data reported for each well. This regression approach limits the variability displayed by the concentration data and reduces errors associated with overestimating or underestimating concentrations at a well. For example, the cis-1,2-DCE concentration reported for Well FP-98-23c was 48.3 µg/L in August 1999. However, in May 1999 a concentration of 198 µg/L was reported for this well. Using the most recent sampling round (August , 1999) for initial conditions would have considerably underestimated a significant amount of cis-1,2-DCE mass in the plume. However, by using a regression approach, the complete data set is used to determine the current concentration trends at each well (Table 6-8). The regressed concentrations at each well were then contoured for input into the RT3D model. A total of nine isoconcentration maps representing PCE, TCE, and cis-1,2-DCE for the shallow, intermediate, and deep zones were created for input into the model (Figures 6-22 to 6-30).

To enter the initial concentration data into the RT3D model, the isoconcentration maps displayed in Figures 6-22 to 6-30 were digitized into GMS. To avoid the "stair-step" effect of having a high concentration cell adjacent to a low concentration cell, the digitized contours were interpolated using the geostatistics package (using linear interpolation) included in GMS. This interpolation procedure smoothes the initial concentrations and limits numerical errors introduced by the RT3D solvers. VC concentrations were entered in the appropriate cells where detected. VC concentrations of 2.8 µg/L (August, 1999) and 1.6 µg/L (May, 1999) were entered into the model cells (and adjacent cells) representing Wells FP-94-11 and FP-94-09 respectively. A total of nine cells (cell containing the well and adjacent cells) represent each VC detection.

6.5.3.5 Model Results

Model results are provided for a 30-year simulation. This duration was selected because the ensuing risk assessment requires results in the form of 30-year average concentrations. Model results are presented as the maximum concentration (center of mass) observed in each layer with time (Figure 6-31), and as the maximum concentration observed at the Kansas River in the shallow and intermediate layers with time (Figure 6-32). Since the deep layer does not directly border the Kansas River, it is irrelevant to present concentrations at the river for this layer in Figure 6-32. Contaminants in the deep layer exit the model through the intermediate layer at the river because of the upward flow from the deep to the intermediate layer. Therefore, contaminant concentrations in the deep layer at the river are included in the contaminant concentrations given for the intermediate layer at the river. Also indicated on Figures 6-31 and 6-32 is the predicted time (in years) for maximum concentrations of each contaminant to decrease below MCL.

The maximum concentrations for each contaminant (Table 6-9) were averaged for the 30-year simulation and are presented below:

	PCE (µg/L)	TCE (µg/L)	cis-1,2-DCE (µg/L)	VC (µg/L)
Shallow Zone	0.331	1.365	87.174	0.627
Intermediate Zone	0.673	1.822	61.355	0.360
Deep Zone	0.849	1.851	45.252	0.357
Three-Layer Average	0.618	1.679	64.593	0.448

Although the 30-year average maximum concentrations are provided for risk assessment, these represent a very conservative (in terms of risk) estimate of the concentrations a potential receptor would be exposed to. Conservatism in terms of risk is defined here as the use of assumptions in the model that result in concentrations of the more toxic contaminants being potentially overestimated. Used hereafter, the term

conservatism refers to risk conservatism. Since the maximum concentrations represent a concentration that varies with time and location, a potential receptor would only be exposed to these concentrations if it was possible to obtain groundwater from a location that varies with time. Furthermore, since the center of mass (maximum concentration) for each contaminant occurs at a different location, this also adds to the conservatism of the results provide for risk. It is estimated that the maximum concentration approach provides average values four to five times larger that a worst case stationary location.
Conservatism was also incorporated into the model by selecting degradation rate constants that potentially overestimated the concentrations of the more toxic chlorinated solvents, 1,2-DCE and VC (Section 7.0) at the Site. The degradation rates determined for PCE and TCE are in the upper range of published values (Aronson and Howard, 1997; Howard, 1991), thus resulting in an rapid increase in the more toxic cis-1,2-DCE in the model. Additionally, using very low degradation rates for cis-1,2-DCE and VC, a class A carcinogen, also increase the amounts of cis-1,2-DCE and VC that accumulate in the model. An additional layer of conservatism with respect to VC is added by using a VC degradation rate equal to the cis-1,2-DCE degradation rate. Since recent publications suggest that VC rates are higher than cis-1,2-DCE rates (ITRC, 2000), this potentially results in overestimates of the VC concentrations. The generally low degradation rates for cis-1,2-DCE and VC are supported by the field data, which indicates that the aquifer is generally in the anaerobic, iron-reducing region where slow 1,2-DCE and VC degradation rates are expected. (Section 6.3.1).

Results from the 30-year simulation are also presented as plume maps in Figures 6-33 to 6-51. These figures illustrate the transport of the center of mass for each contaminant in each layer. Due to the variable time steps at which positive detections occur in the model, the plume maps presented in Figures 6-33 to 6-51 are organized as follows:

	1 Year	3 Years	6 Years	9 Years	12 Years	16 Years	20 Years
PCE	Figure 6-33	Figure 6-34					
TCE	Figure 6-35	Figure 6-36	Figure 6-37				
cis-1,2-DCE	Figure 6-38	Figure 6-39	Figure 6-40	Figure 6-41	Figure 6-42	Figure 6-43	Figure 6-44
VC	Figure 6-45	Figure 6-46	Figure 6-47	Figure 6-48	Figure 6-49	Figure 6-50	Figure 6-51

For years left blank, PCE and TCE concentrations are below 1 μg/L and are not visible in the model.

6.5.3.5.1 Additional Model Simulations

Zero Degradation

To further evaluate natural attenuation processes at the Site, the model was executed with the degradation package inactive (i.e. zero degradation). The purpose of this simulation was to evaluate the natural attenuation processes of advection, dispersion, and sorption without the effects of degradation. The results from this simulation are presented in Figure 6-52. Since VC has been detected only in the shallow zone, and the results from the intermediate and deep zones are similar to the shallow zone, only the shallow zone is presented in Figure 6-52.

The degradation chain for chlorinated solvents moves from PCE, to TCE, to cis-1,2-DCE, then VC. Therefore, if there is less of a contaminant degraded, there will be less of the daughter products produced. By excluding contaminant degradation, PCE and TCE are reduced to approximately 2 μg/L after 30 years, whereas by including degradation, they are both below this level within 4 years (Figure 6-52). This lingering of PCE and TCE is to be expected, because the main routes of attenuation for these contaminants have historically been through destructive mechanisms, and are expected to continue into the future.

The model that includes degradation (i.e. the calibrated model) results in more cis-1,2-DCE present at the Site. This is to be expected, because the degradation of TCE will result in the formation of cis-1,2-DCE.

The increased cis-1,2-DCE concentrations are most apparent early in the model simulation, when the influx of new cis-1,2-DCE from TCE degradation is the most pronounced (Figure 6-52). In the second year of the simulation, the different models are at the furthest point apart, with the zero degradation run indicating 267.9 µg/L of cis-1,2-DCE, and the calibrated run having a cis-1,2-DCE concentration 12.1 µg/L higher.

With increasing time, less and less PCE and TCE are available for degradation, resulting in less production of cis-1,2-DCE. The cis-1,2-DCE levels for the two model runs (zero degradation, and calibrated) become closer over time, as the degradation of cis-1,2-DCE results in somewhat quicker removal of the contaminant than nondestructive mechanisms alone. Due to the extremely low degradation rate of cis-1,2-DCE in the model calibrated to the Site data, the attenuation of cis-1,2-DCE over time is not significantly impacted by degradation, as is shown in Figure 6-52. This suggests that for cis-1,2-DCE, non-destructive mechanisms dominate the fate and transport of this contaminant.

Figure 6-52 shows the predicted levels for VC at the Site according to the calibrated model, and the model run without degradation. Because VC has been detected in very few locations at the Site, and at very low concentrations, the initial input for VC was small, and limited to a very small area. As the model runs forward through the first year, this small initial amount of VC is very susceptible to dispersion effects. Therefore, the immediate sharp drop in VC concentration in the first year may be attributed to these effects.

As shown in Figure 6-52, there are significant differences in VC levels between the two models. The calibrated model, with degradation occurring, results in much greater concentrations of VC in the first 25 years. This is due to the degradation of cis-1,2-DCE to VC. The VC degradation rate is very low which allows VC produced at the Site to accumulate somewhat before it is degraded. This suggests that the calibrated model is more conservative for VC than the zero degradation model.

To summarize, destructive processes do play a significant role in the attenuation of PCE, TCE, and VC (Figure 6-52). Low degradation rates for cis-1,2-DCE make the difference between nondestructive only and destructive coupled with nondestructive mechanisms very slight. In this system, the model suggests that attenuation of cis-1,2-DCE is controlled primarily by nondestructive processes.

Aerobic Degradation

An additional model simulation was performed to evaluate the fate and transport of chlorinated solvents through an aerobic zone. Results of this simulation are presented in Figures 6-53 through 6-60, and may be contrasted with results of the calibrated model simulation shown in Figures 6-38 through 6-51. Site data (Section 6.3.1) indicates that an aerobic degradation zone is located in the shallow zone starting between Monitoring Well FP-96-23 and Monitoring Well FP-98-27 and extending to the Kansas River. The purpose of this model simulation is to evaluate the fate and transport of the chlorinated solvents and is not intended to provide results for the human health risk assessment. Although aerobic degradation of cis-1,2-DCE and VC is believed to be occurring in the aerobic zone, this situation was not included in the initial modeling (Section 6.5.3.5) because obtaining calibrated degradation rates for this zone was not possible due to the limited concentration data in this zone and because ignoring the aerobic degradation represents a more conservative approach in terms of risk, i.e. overprediction of VC concentrations. The occurrence of aerobic oxidation of cis-1,2-DCE and/or VC beyond Well FP-98-27 is supported by the absence of cis-1,2-DCE and VC detections at and beyond Well FP-98-27, the portion of the shallow zone with aerobic conditions.

The aerobic degradation model was constructed by dividing the shallow zone along a line perpendicular to the flow direction and located halfway between Monitoring Well FP-96-23 and Monitoring Well

FP-98-27. This location was chosen since Site data indicates that the cis-1,2-DCE plume does not extend past Monitoring Well FP-98-27, and the geochemical data suggests that the aerobic zone starts somewhere between Monitoring Well FP-96-23 and Monitoring Well FP-98-27 (Section 6.5.3.5). Since historic Site concentration data suggests the cis-1,2-DCE plume will not reach the Kansas River in the shallow zone, several degradation rates were tried until this situation was successfully simulated. Positive detections of cis-1,2-DCE and VC have never been reported in shallow monitoring wells downgradient from Monitoring Well FP-98-27, and detections reported in Monitoring Well FP-98-27 have been below 5 µg/L.

After numerous simulations, aerobic degradation rates of cis-1,2-DCE = 0.01 day $^{-1}$ and VC = 1.0 day $^{-1}$ were determined sufficient to match the behavior of the cis-1,2-DCE plume. Using these rates prevented the cis-1,2-DCE plume from extending past Monitoring Well FP-98-27 in concentrations above 5 µg/L and prevented an accumulation of VC in the aerobic zone. The results of this model are presented in Figures 6-53 to 6-60.

Due to the reductive dechlorination method used in RT3D (Module 6), the model is incapable of simulating direct aerobic mineralization of cis-1,2-DCE. Degradation of cis-1,2-DCE as simulated by the model must progress through VC which is then degraded to ethene or ethane. Research (Bradley, et at., 1998a) suggests that aerobic degradation of cis-1,2-DCE leads to complete mineralization without VC as an intermediate. Therefore, to simulate direct mineralization of cis-1,2-DCE, a VC rate of 1.0 day $^{-1}$ was required to prevent VC from artificially accumulating in the aerobic zone. Although the degradation rate chosen for VC is high, it is still a reasonable estimation of Site conditions, within the limitations of the model.

Because aerobic mineralization of cis-1,2-DCE will not lead to VC as an intermediate, the amount of VC potentially occurring in the aerobic shallow zone can only come from the anaerobic degradation of cis-1,2-DCE further upgradient, and the subsequent migration of VC into the aerobic zone. From the aerobic model, the amount of VC appearing in the aerobic zone over time can be estimated. These estimates were then compared to the concentration of VC determined from the calibrated (no aerobic zone) model run.

The only difference in the two models is the addition of the shallow aerobic zone beyond Well FP-98-27, therefore only the concentrations of VC and cis-1,2-DCE in the shallow aerobic zone are different. Since PCE and TCE never reach the area of the aerobic shallow zone in either model, they are not discussed further.

Cis-1,2-DCE levels for each simulation are the same in the shallow anaerobic zone and intermediate and deep zones, but in the shallow aerobic zone simulation, cis-1,2-DCE is degraded much more rapidly. In the aerobic simulation, the leading edge of the cis-1,2-DCE plume is very well defined, and only extends to Well FP-98-27 after six years, but by nine years, the plume is almost gone. In contrast, cis-1,2-DCE in the calibrated model reaches Well FP-98-27 after only one year, is still present after 20 years, and the leading edge of the shallow plume has migrated to the Kansas River after nine years.

In the calibrated model, VC starts to appear at the river at six years, and is still present after twenty years at the river, although at concentrations below 0.2 µg/L. VC in the calibrated model does reach concentrations as high as 1.4 µg/L in the area close to and upgradient of Well FP-98-29, which is designated to be in the aerobic zone in the aerobic model. In the portions of the plume closer to the river, the VC concentrations are significantly lower in the calibrated model.

In contrast, VC in the aerobic model is no longer present above 0.1 µg/L after only nine years, and never reaches the river. The highest concentrations of VC, up to 0.5 µg/L, in the area designated as aerobic occur just downgradient of the line separating the two zones (anaerobic and aerobic), between Wells FP-98-23 and FP-98-27. These concentrations occur after six years in the model.

The purpose of performing this simulation with estimated aerobic degradation rates for cis-1,2-DCE and VC was to more closely represent conditions as they are actually occurring at the Site. It appears that chlorinated solvents may not migrate all the way to the river in the shallow zone, and may be degrading rapidly in the aerobic shallow zone. This is supported by the historical data that shows no 1,2-DCE or VC detections at or beyond Well FP-98-27.

6.5.3.5.2 Sensitivity Analysis

A sensitivity analysis was performed using the RT3D model. The purpose of this analysis was to assess the variability of model output based on changes in input parameters. The sensitivity analysis was performed by varying each selected parameter relative to the calibrated value and evaluating changes in model output. Parameters selected (and the associated process they represent) were: K_d (sorption), η_e (advection), and PCE, TCE degradation rates (chemical reaction). These parameters were selected based on their potential to have a significant impact on model output.

Sorption effects were evaluated by adjusting the K_d values ± 50-percent. This was determined to be within the range of typical published values for aquifer materials similar to those at the Site (Wiedemeier et al., 1999). Advection effects were evaluated by adjusting the effective porosity (η_e) within the range of published values for aquifer materials similar to those at the Site (GRI, 1988; Wiedemeier et al., 1999). Degradation was evaluated by decreasing only the PCE and TCE rates one order of magnitude. Increasing degradation rates would only result in further attenuation of the plume and therefore provide a less conservative analysis. Because of the large range of published degradation rates, adjusted values selected for PCE and TCE were decreased a full order of magnitude to provide a conservative analysis. Since the calibrated cis-1,2-DCE and VC rates are already very low, these rates were not further decreased. The adjusted values used in the sensitivity analysis are presented below:

	Degradation	**K_d (+50%)**	**K_d (-50%)**	**Porosity (+)**	**Porosity (-)**
PCE	0.0018	2.82	0.75	0.35	0.25
TCE	0.0007	1.0	0.25	0.35	0.25
cis-1,2-DCE	no change	0.38	0.1	0.35	0.25
VC	no change	0.2	0.05	0.35	0.25

Results from the sensitivity analysis were interpreted by plotting contaminant concentrations versus time at the Kansas River. Comparing the results from each simulation at a point (the River) provides a general understanding of the contaminant plume behavior to changes in input parameters. The results from the calibrated model recorded at the Kansas River are shown on Figure 6-32 in the RI Report. The modeled maximum concentrations at the river provide an indication of the relative degradation and dispersion of the center of mass as it passes through this location. The time to decrease below the indicated concentrations was used to compare the rates at which contaminants in each simulation decrease and the relative duration for which they occur over the indicated concentration. Since some of the contaminants (cis-1,2-DCE and VC) do not reach the river at concentrations above MCL, lower levels were used for comparison of each sensitivity run. The following concentrations were used for relative comparison purposes only: PCE (0.5 µg/L), TCE (0.5 µg/L), cis-1,2 DCE (5.0 µg/L), VC (0.1 µg/L).

Results from the sensitivity analysis are presented only for comparisons made using the intermediate zone. The results from the shallow zone were nearly identical and were removed for simplicity. These results are displayed below:

	Analyte	**Calibrated Model**	**Decreased Degradation**	**K_d (+50%)**	**K_d (-50%)**	**Effective Porosity (+)**	**Effective Porosity (-)**
Maximum Concentration at the River (μg/L)	**PCE**	8	9.7	8	8	8	8
	TCE	8	7	8.25	7	8.2	7.9
	Cis-1,2-DCE	54	48	57	52	53	55
	VC	0.61	0.55	0.64	0.59	0.71	0.52
Time to decrease below indicated concentration (years)	**PCE < 0.5**	3	29	6.5	2	2.1	4
	TCE < 0.5	6.1	30	11.1	3.8	5.6	5
	Cis-1,2-DCE < 5.0	19.6	21.4	30	15	21.4	19.2
	VC <0.1	18	18	26	14	20.5	16

Observations from the sensitivity analysis are summarized below:

- Decreasing the PCE and TCE degradation rates resulted in only minor changes in maximum concentrations at the river (with the PCE maximum increasing slightly and TCE, cis-1,2-DCE, and VC decreasing slightly). However decreasing the PCE and TCE degradation rates significantly increased the duration required for PCE and TCE concentrations to attenuate to concentrations below the indicated values but only slightly increased the duration required for cis-1,2-DCE and VC to attenuate.

- Increasing K_d resulted in the maximum concentrations for all contaminants to equal or exceed the calibrated values by a relatively small amount. Increasing K_d also increased the duration required for all contaminants to attenuate to concentrations below the indicated values. Increasing K_d retards the movement of the contaminant plume thus allowing the center of mass to remain more concentrated and limit the effects from dispersion.

- Decreasing K_d resulted in the maximum concentrations for contaminants to decline below calibrated values by a relatively small amount. Decreasing K_d also decreased the duration required for all contaminants to attenuate to concentrations below the indicated values. Decreasing K_d allows for greater movement of the contaminant plume and increases effects from dispersion.

- Increasing effective porosity resulted in relatively little change in the maximum concentrations for all contaminants. Increasing effective porosity also slightly decreased the duration required for PCE and TCE to attenuate to concentrations below the indicated values and slightly increased the duration required for cis-1,2-DCE and VC to attenuate. Increasing effective porosity generally decreases the advective rate at which contaminants are removed at the river.

- Similarly, decreasing effective porosity also resulted in relatively little change in the maximum concentrations for all contaminants. Decreasing effective porosity also slightly increased the duration required for PCE to attenuate to concentrations below the indicated values and slightly decreased the duration required for TCE, cis-1,2-DCE, and VC to attenuate. Decreasing effective porosity generally increases the advective rate at which contaminants move through the aquifer.

The following conclusions are drawn from the sensitivity analysis results:

- The model is sensitive to changes in PCE and TCE degradation rates. These rates can have a significant effect on the duration required for PCE and TCE concentrations to decrease. The maximum concentrations for all contaminants do not change significantly with changes in PCE and TCE degradation rates. The maximum concentrations for PCE and TCE usually occurred at or near time step zero.

- The model is slightly sensitive to changes in K_d. Maximum contaminant concentrations at the Kansas River only slightly varied with changes in K_d. Changes in K_d also resulted in relatively moderate changes in the duration required for contaminants to attenuate to concentrations below the indicated values. Results indicate that larger K_d values are more conservative than smaller values.

- The model is generally insensitive to changes in effective porosity within the published range of values for aquifer materials similar to those at the Site.

6.5.3.6 Summary of Chlorinated Solvent Modeling

6.5.3.6.1 Assumptions

The following provides a summary of fundamental assumptions made during construction of the reactive transport model for FFTA-MAAF:

- There is no ongoing vadose zone chlorinated source (above MCL) at the FFTA.
- Molecular diffusion effects are negligible and can be ignored in the model.
- Volatilization is minimal and can be ignored in the model.
- Contaminant sorption to solid particles is linear.
- First order degradation is a valid approximation at the Site.
- Calibrated degradation rates are applicable throughout the Site.
- Scale dependent dispersivity values computed from Xu and Eckstein (1994) are valid.
- Regressed concentrations are a valid approximation of overall current conditions.

6.5.3.6.2 Summary

The following provides a summary of the steps taken during construction, calibration, and execution of the reactive transport model used to predict future concentrations at the Site.

- The groundwater flow model constructed for the Site (Section 6.5.2) was used as a basis from which the reactive transport model was constructed.

- Initial input parameters were estimated based on Site-specific data and published values.

- The reactive transport model was calibrated to concentrations observed in Monitoring Well FP-96-25.

- Initial concentrations were input into the model by using a regression procedure for concentration data reported for each well.

- The reactive transport model was run for 30 years, and predicted maximum contaminant concentrations in the plume and at the Kansas River that were provided for the risk assessment.

6.5.3.6.3 Uncertainties

As with any modeling effort, uncertainties exist surrounding the modeling results. Conservative assumptions were made throughout this modeling effort to compensate for uncertainties. The net results of these uncertainties are expected to yield conservatively high results in terms of predicted contaminant concentrations and migration pathways. Described below are the uncertainties and conservative assumptions associated with the modeling process.

- The greatest uncertainty in the reactive transport model is the contaminant degradation rates. Although the rates used in the model were calibrated to Site-specific conditions, it is assumed these calibrated rates are applicable throughout the Site. Consequently, degradation rates at the Site may change over time or vary from source areas to down-gradient areas. Furthermore, published data indicates these rates may range over several orders of magnitude (Wiedemeier et al., 1999). Despite these uncertainties, degradation rates used in the transport model were selected to provide a conservative estimate (Section 6.5.3.5)

- Other uncertainties include the input parameters: K_d (f_{oc}, K_{oc}), ρ_b, η_e, α_x, α_y, and α_z. Values for these parameters were determined from published sources or averaged from Site-specific data and may not reflect actual Site conditions. Furthermore, values for parameters used in the transport model were kept constant throughout the model. Although this simplification is generally due to limited Site-specific data, actual conditions may vary with location at the Site.

Despite these uncertainties, the values selected for these parameters appear to provide a valid and conservative representation of aquifer conditions at the Site. The following paragraphs further discuss the specific parameters:

- Although K_{oc} values were determined from published sources, the range of reported values is relatively small and K_{oc} is not expected to vary with location at the same site. Therefore, K_{oc}'s used to represent aquifer conditions at the Site appear reasonable.

- The relatively large values of K_d appear to be mainly due to the relatively large f_{oc} values reported for aquifer materials at the Site. Data used to calculate an average f_{oc} value (0.0053) was reported from 45 samples collected at the Site. This value is also within the range of published values for aquifer materials similar to those at the Site (Wiedemeier et al., 1999) and appears to be a reliable approximation of aquifer conditions at the Site.

- Data used to calculate an average ρ_b (1.6 g/cm^3) was reported from six samples collected at the Site. This average ρ_b is identical to the average ρ_b reported for aquifer materials similar to those at the Site (Wiedemeier et al., 1999). Therefore, the value used for this parameter is believed to be a reliable approximation of aquifer conditions at the Site.

- Data used to calculate an average 0_e (0.35) was also reported from six samples collected at the Site. Although the final value used in the transport model was slightly smaller (0.30), published data suggests this is a more appropriate value for aquifer materials at the Site. Therefore, the value used for this parameter is also believed to be a reliable approximation of aquifer conditions at the Site.

- Values for α_x, α_y, and α_z used in the model were determined from Xu and Eckstein, 1994, which is considered to be a reliable source for estimating dispersivity. Furthermore, preliminary simulations to evaluate these parameters indicated that the final values used in the transport model sufficiently represent observed plume conditions at the Site (Section 6.5.3.3.2).

- Additional uncertainties associated with all contaminant transport modeling are the accuracy of the model when predicting small concentrations near zero. The RT3D model used to predict future concentrations is generally considered to be a reliable and stable model. However, this model may also be susceptible to numerical instabilities at very small concentrations. For contaminants at this Site, this uncertainty is more applicable to the small concentrations associated with VC rather than larger concentrations representing cis-1,2-DCE.

- As with all finite difference models, the accuracy of the solution usually improves as the number of cells increases. The transport model constructed for this Site uses a dense grid with a relatively small grid spacing along the x and y-axes. However, there is some uncertainty associated with vertical contaminant transport between layers. It is expected that increasing the number of model layers could significantly improve the accuracy of the model output. However, due to limitations in computer resources this is not a practical option.

6.5.3.6.4 Conclusions

Reactive contaminant transport modeling was performed to simulate the transport of chlorinated solvents in the subsurface, predict future concentrations at potential receptor locations, and to further evaluate natural attenuation processes occurring at the Site. Results of the transport modeling, presented in Figures 6-31 and 6-32, indicated that:

- Maximum concentrations for PCE in the plume have already been reached in all three zones at the Site. The 30-year average maximum concentrations were 0.331 µg/L, 0.673 µg/L, and 0.849 µg/L for the shallow, intermediate, and deep zones respectively. These values are considered very conservative when used for 30-year exposure assessments, since locations of the maximum values are not stationary over time.

- Maximum concentrations for TCE in the plume have already been reached in all three zones at the Site. The 30-year average maximum concentrations were 1.365 µg/L, 1.822 µg/L, and 1.851 µg/L for the shallow, intermediate, and deep zones respectively. Again, these values are considered very conservative for exposure assessment purposes.

- Maximum concentrations for cis-1,2-DCE in the plume have already been reached in the shallow and intermediate zones, but is predicted to peak at 144 µg/L in approximately one year for the deep zone. The 30-year average maximum concentrations were 87.174 µg/L, 61.355 µg/L, and 45.252 µg/L for the shallow, intermediate, and deep zones respectively. Again, these values are considered very conservative for exposure assessment purposes.

- Maximum concentrations for VC in the plume have already been reached in the shallow zone, but is predicted to peak at 0.9 µg/L in approximately six years for both the intermediate and deep zones. The 30-year average maximum concentrations were 0.627 µg/L, 0.360 µg/L, and 0.357 µg/L for the shallow, intermediate, and deep zones respectively. Again, these values are considered very conservative for exposure assessment purposes.

- PCE concentrations at the Kansas River are predicted to peak at 2.4 µg/L in approximately one year for the shallow zone. This does not imply that the PCE plume is moving through the shallow zone to reach the river. Rather, contamination is entering the shallow zone from the intermediate zone due to the upward groundwater flow near the river. The maximum PCE concentrations at the river have already been reached in the intermediate zone. The concentrations from the deep zone are included within the concentrations reported for the intermediate zone at the river, and are a result of the upward groundwater flow near the river.

- TCE concentrations at the Kansas River are predicted to peak at 4.4 µg/L in approximately one year for the shallow zone and at 8.0 µg/L in approximately one year for the intermediate zone.

This does not imply that the TCE plume is moving through the shallow zone to reach the river. Rather, contamination is entering the shallow zone from the intermediate due to the upward groundwater flow near the river. Again, the concentrations from the deep zone are included within the concentrations reported for the intermediate zone at the river, and are a result of the upward groundwater flow near the river.

- cis-1,2-DCE concentrations at the Kansas River are predicted to peak at 54 µg/L in approximately nine years for the shallow zone and at 44 µg/L in approximately nine years for the intermediate zone. Again, the concentrations from the deep zone are included within the concentrations reported for the intermediate zone at the river, and are a result of the upward groundwater flow near the river.

- VC concentrations at the Kansas River are predicted to peak at 0.51 µg/L in approximately eight years for the shallow zone and at 0.61 µg/L in approximately nine years for the intermediate zone. Again, the concentrations from the deep zone are included within the concentrations reported for the intermediate zone at the river, and are a result of the upward groundwater flow near the river.

- Although the model results suggest that contaminants are reaching the Kansas River, there is some question to whether this is actually occurring. Bradley, 1998b suggests that the increased capacity for microbial transformation in streambed sediments (relative to aquifer sediments) may serve to reduce the levels of chlorinated ethenes just before they reach the Kansas River. Therefore, by not accounting for this increased capacity for reductive dechlorination in the streambed sediments, builds an added degree of conservatism into the model.

- Note that the model predicted concentrations at the river are concentrations in groundwater not concentrations in the river. Once groundwater comes in contact with surface water, contaminant concentrations are expected to become diluted below detectable levels in the river. This assumption has been confirmed by surface water sampling performed by the USGS (Section 4.3).

- The transport model was constructed to be as conservative as possible and still accurately simulate conditions at the Site.

- Results of the contaminant fate and transport modeling with respect to the risk assessment are discussed in Sections 7.0 and 8.0.

6.5.4 Petroleum Hydrocarbon Modeling

6.5.4.1 Introduction

Several of the PCOPCs identified for this Site are petroleum products, such as benzene, toluene, ethylbenzene, xylenes (together referred to as BTEX), and naphthalene. BIOSCREEN was chosen to model petroleum hydrocarbons, rather than RT3D, because BIOSCREEN was likely to produce more conservative results for the human health risk assessment. Due to the scattered and limited detections, and relatively low concentrations of petroleum hydrocarbons, using RT3D would likely show concentrations decreasing to zero almost immediately. Since BIOSCREEN is a fairly simple model, more parameters are designated by the model as compared to a more complex model like RT3D where the Site specific parameters are input into the model. Assumptions such as using a continuous source and only one model layer, provide more conservative results for the human health risk assessment.

Overall, BTEX concentrations at the Site have been decreasing with time. Figure 6-61 depicts the total BTEX concentrations in groundwater as a function of distance from the former fire training pit. This figure indicates that BTEX concentrations in the groundwater beyond the former fire training pit are considerably lower than at the former fire training pit. This is especially evident in the shallow aquifer zone. In the intermediate zone, BTEX concentrations have been decreasing with time to a current concentration of less than 4 µg/L. In the deep zone, BTEX has always been below 3 µg/L.

Benzene was detected in August of 1999 a total of eight times in five wells across the Site at a maximum concentration of 2.5 µg/L. Five of these eight detections were equal to or less than 1 µg/L. Figure 6-62 indicates that benzene concentrations in the groundwater have decreased from a high of 64 µg/L at Monitoring Well FP-93-04 (located in the center of the former fire-training pit) to nondetect at the same location in six years. In the intermediate zone, benzene concentrations have decreased from a high of 12 µg/L to its current high of 2.4 µg/L in two years. In the deep zone, benzene concentrations have always been less than 3 µg/L.

Many of the PCOPCs identified, other than the chlorinated solvents, are similar to benzene in either their concentration or limited number of detections. For example, toluene, ethylbenzene, naphthalene, and xylenes were only detected at Monitoring Well FP-93-04 in August 1999. These limited detections are predicted to decrease substantially in the future due to dispersion, sorption, and degradation; and therefore reduce any potential threat to a receptor.
BIOSCREEN, developed by AFCEE, is a screening model which simulates natural attenuation of dissolved hydrocarbons. BIOSCREEN determines the duration a plume will persist until natural attenuation processes cause it to dissipate. The model uses a simple mass balance approach to estimate the concentration versus time. The model has the ability to simulate advection, dispersion, adsorption, and aerobic and anaerobic decay. BIOSCREEN includes three different model types:

- Solute transport without decay
- Solute transport with biodegradation modeled as a first-order decay process
- Solute transport with biodegradation modeled as an "instantaneous" biodegradation reaction

Petroleum hydrocarbon modeling was performed with BIOSCREEN using the solute transport with first-order decay. The purpose of this modeling exercise was to demonstrate that contaminant concentrations will decrease with time (current conditions depict the highest expected concentrations for these compounds), and to determine appropriate exposure concentrations for the human health risk assessment.

Due to limited detections of petroleum hydrocarbons, especially in recent years, calibrating the model with reasonable accuracy is unlikely. Instead, conservative assumptions for the model were used where appropriate.

6.5.4.2 BIOSCREEN Model Parameters

This section identifies the input parameters used in the BIOSCREEN model. The basic data required by the BIOSCREEN model includes information on hydrogeologic conditions, adsorption, dispersivity, biodegradation, and plume definition. The basic input parameters for this modeling exercise were based on the calibrated MODFLOW and RT3D models for the Site and are summarized in Table 6-10.

The model also requires contaminant-specific information such as K_{oc} and half-life. The K_{oc} values used for this modeling exercise are from Wiedemeier (1999). BIOSCREEN has recommended values for half-lives as indicated below. The BIOSCREEN modeling effort utilized the higher recommended half-life values to provide a more conservative estimate. Since naphthalene half-lives are not available in BIOSCREEN, the largest half-life reported in Howard, 1991 was used as a conservative estimate.

Parameter	K_{oc}	BIOSCREEN Recommended Half-Life	Half-Life Used in Modeling
Benzene	38 L/kg	0.02-2 yrs	2 yrs
Toluene	135 L/kg	0.02-0.17 yrs	0.17 yrs
Ethylbenzene	95 L/kg	0.016-0.62 yrs	0.62 yrs
Xylenes	240 L/kg	0.038-1yr	1 yr
Naphthalene	1288 L/kg	Not Available	0.707 yrs

6.5.4.3 Initial Concentrations

The initial concentrations used in the BIOSCREEN model are the highest observed off-post concentrations (on-post for naphthalene and xylene), based on the August 1997 through August 1999 groundwater sampling data. Off-post concentrations were used as exposure concentrations for residential risk assessment. The reasoning behind this off-post scenario is described in greater detail in Section 7.0.

The highest observed benzene in the groundwater over the last two years was 12 µg/L at Monitoring Well FP-96-09b in August 1997. The MCL for benzene is 5 µg/L. The initial concentrations for the benzene modeling were based upon this detection. In August 1997, benzene was not detected in any of the other monitoring wells surrounding Well FP-96-09b. Therefore, the initial plume was assumed to be a maximum of 70 feet in width. The central part of this plume, assumed to be 50 feet in width, was assigned a concentration of 12 µg/L (the maximum observed). Since benzene was not detected in the deep well at this location in August 1997 and the detection in the shallow well was a much lower concentration, the thickness of this plume was assumed to be 20 feet (the thickness of the intermediate zone in the RT3D model for consistency). Finally, the soluble mass in the area of the highest detection is known to be extremely low. The observed benzene detection occurred in an area that is not a source of contamination and the original source of contamination, the former fire training pit, has since been remediated through SVE and bioventing. However, BIOSCREEN requires designation of a source. This mass was set low enough such that the source half-life, the rate of dissolution occurring in the source zone, was calculated to be one year. Since there is no source at the Site, this is an extremely conservative assumption.

The highest observed toluene detection in the groundwater over the last two years was 0.5 µg/L at Monitoring Well FP-96-31 in August 1998, well below its MCL of 1,000 µg/L. The initial conditions for the toluene modeling were based upon this detection. In August 1998, toluene was not detected in any of the other monitoring wells surrounding Well FP-96-31 and was not detected in any other zone of the aquifer at that location. Therefore, the initial plume was assumed to have a maximum width of 50 feet and thickness of 15 feet, the thickness of the shallow zone in the RT3D model. The entire plume was assigned a concentration of 0.5 µg/L (the maximum observed). Finally, the soluble mass in the source area was known to be extremely low since the observed toluene detections occurred in an area that is not a source of contamination. This mass was set low enough such that the source half-life, the rate of dissolution occurring in the source zone, was calculated to be one year. Again, this is a highly conservative assumption.

The highest observed detection of ethylbenzene in the groundwater over the last two years was 2.4 µg/L at Monitoring Well FP-96-23b in August 1997, well below its MCL of 700 µg/L. The initial conditions for the ethylbenzene modeling were based upon this detection. In August 1997, ethylbenzene was not detected in any of the other monitoring wells surrounding FP-96-23b and was not detected in any other zone of the aquifer at this location. Therefore, the initial plume was assumed to be a maximum of 50 feet in width and 20 feet in thickness, the thickness of the intermediate zone in the RT3D model. The entire plume was assigned a concentration of 2.4 µg/L (the maximum observed). Again, the soluble mass in the source area was known to be extremely low since the observed ethylbenzene detection occurred in an area that is not a source of contamination. This mass was set to be low enough such that the source half-life, the rate of dissolution occurring in the source zone, was calculated to be one year. Again, this is a highly conservative assumption.

Naphthalene has not been detected at the Site in off-post wells since 1994. The only detections in the past two years have occurred on-post at Monitoring Well FP-93-04. The highest observed detection of naphthalene in the groundwater over the last two years was 70.8 µg/L at Monitoring Well FP-93-04 in August 1998. The initial conditions for the naphthalene modeling were based upon this detection. In August 1998, naphthalene was not detected in any of the other monitoring wells surrounding FP-93-04 and was not detected in any other zone of the aquifer at this location. Therefore, the initial plume was assumed to be a maximum of 50 feet in width and 15 feet in thickness, the thickness of the shallow zone in the RT3D model. The entire plume was assigned a concentration of 70.8 µg/L (the maximum observed). Again, the soluble mass in the source area was known to be extremely low since there is no ongoing source of naphthalene at the Site. This mass was set to be low enough such that the source half-life, the rate of dissolution occurring in the source zone, was calculated to be one year. Again, this is a highly conservative assumption.

Xylene has not been detected at the Site in off-post wells since 1996. The only detections in the past two years have occurred on-post at Monitoring Wells FP-93-04 and FP-96-02c. The highest observed detection of xylene (total) in the groundwater over the last two years was 418 µg/L at Monitoring Well FP-93-04 in August 1998 [meta- and/or para-xylenes (290 µg/L) + ortho-xylenes (128 µg/L) = 418 µg/L]. The initial conditions for the xylene modeling were based upon this detection. In August 1998, xylene was not detected in any of the other monitoring wells surrounding FP-93-04 and was not detected in any other zone of the aquifer at this location. Therefore, the initial plume was assumed to be a maximum of 50 feet in width and 15 feet in thickness, the thickness of the shallow zone in the RT3D model. The entire plume was assigned a concentration of 418 µg/L (the maximum observed). Again, the soluble mass in the source area was known to be extremely low since there is no ongoing source of xylene at the Site. This mass was set to be low enough such that the source half-life, the rate of dissolution occurring in the source zone, was calculated to be one year. Again, this is a highly conservative assumption.

6.5.4.4 Model Results

BIOSCREEN model results are provided for a 30-year simulation. This duration was selected because the ensuing risk assessment requires results in the form of 30-year average concentrations. Model results are presented as the maximum concentration observed off-post with time on Figures 6-63 to 6-67 for benzene, toluene, ethylbenzene, xylene, and naphthalene respectively and summarized on Table 6-11. Using these results for the risk characterization is conservative in that maximum concentrations will migrate with the groundwater while potential receptors will remain stationary. The BIOSCREEN modeling output for these simulations is provided in Appendix 6A.

Benzene, the only compound that initially exceeded its MCL of 5 µg/L, is predicted to have a concentration of less than 5 µg/L in 12 years. Two years after the high detection of 12 µg/L in August 1997 at Monitoring Well FP-96-09b, benzene was not detected at this well. Also, the highest detection of benzene throughout the plume was 2.4 µg/L, well below the MCL of 5 µg/L, as predicted with BIOSCREEN.

6.5.4.5 Uncertainties

As with any modeling effort, uncertainties exist surrounding the modeling results. Conservative assumptions were made throughout this modeling effort to compensate for uncertainties. These assumptions are expected to yield conservatively high results in terms of predicted contaminant concentrations and migration pathways. Described below are the uncertainties and conservative assumptions associated with the modeling process.

- The greatest uncertainty in the model is the establishment of a representative plume to simulate site-specific conditions. Since the observed contaminant concentrations over the last two years were point detections, the plume geometry was constructed to provide a conservative estimate of reality.

- Another uncertainty in the model is the contaminant degradation rates. For the petroleum hydrocarbon modeling these degradation rates were specifically chosen as conservative estimates.

- As described previously for the RT3D modeling effort, uncertainty also surrounds the input parameters: K_d (f_{oc}, K_{oc}), ρ_b, η_e, α_x, α_y, and α_z. Values for these parameters were determined from published sources or averaged from Site-specific data and may not reflect actual Site conditions. Furthermore, values for parameters used in the transport model were kept constant throughout the model. Although this simplification is generally due to limited site-specific data, actual conditions may vary with location at the Site. Despite these uncertainties, the values selected for these parameters appear to provide a valid and conservative representation of aquifer conditions at the Site.

- Additional uncertainties associated with all contaminant transport modeling is the accuracy of the model when predicting small concentrations near zero.

6.6. FATE AND TRANSPORT EVALUATION SUMMARY AND CONCLUSIONS

6.6.1 Summary

The following summarizes the methods and procedures used to evaluate the fate of PCOPCs in the subsurface, and the transport mechanisms in action at the Site.

Potential destructive and non-destructive mechanisms at the Site were presented to evaluate their influence on PCOPCs at the Site. Non-destructive mechanisms included advection, hydrodynamic dispersion, sorption, dilution, and volatilization. Destructive mechanisms included abiotic Fe(II) reduction, reductive dechlorination, direct mineralization, and cometabolism.

Site-specific geochemical and concentration data was evaluated for each aquifer zone to investigate the various fate and transport mechanisms affecting PCOPCs at the Site. The results from this evaluation are summarized below.

- <u>Shallow Zone</u>
  Alteration from PCE to TCE to cis-1,2-DCE to VC suggests reductive dechlorination is active at the Site.

  Limited and low level detections of VC suggest that the reductive dechlorination sequence may be stalling at the cis-1,2-DCE degradation product.

  Low DO concentrations, absence of nitrate, and high Fe(II) concentrations near the source area suggest anaerobic reducing conditions.

  Higher DO concentrations, presence of nitrate, and lower Fe(II) concentrations at monitoring wells downgradient of Monitoring Well FP-98-23 suggest aerobic conditions persist.

- <u>Intermediate Zone</u>
  Beyond Well FP-96-26b, PCOPC concentrations have generally been decreasing with time and distance from the source area. There have been no significant detections of PCOPCs upgradient of Well FP-96-26b.

  Low DO concentrations, absence of nitrate, and high Fe(II) concentrations suggest the entire intermediate zone is in anaerobic reducing conditions.

  The area surrounding Wells FP-96-09b, FP-96-23b, and FP-98-27b exhibits evidence of biodegradation in conjunction with iron-reducing conditions.

- <u>Deep Zone</u>
  There have been no significant detections of PCOPCs upgradient of Well FP-96-09c.

  The chlorinated solvent plume is currently centered around Monitoring Wells FP-98-23c and FP-98-27c, where signs of reductive dechlorination in an iron-reducing environment are evident.

  Low DO concentrations, absence of nitrate, and high Fe(II) concentrations suggest the entire deep zone is in anaerobic reducing conditions.

USEPA/AFCEE screening procedure was performed to evaluate the possibility of reductive dechlorination at the Site. This procedure resulted in a score of 22 points, indicative of strong evidence for reductive dechlorination.

Ratios determined for PCE:TCE, PCE:cis-1,2-DCE, and TCE:cis-1,2-DCE provide evidence that reductive dechlorination has occurred, and that cis-1,2-DCE may be accumulating at the Site.

A conceptual Site model was developed to describe the location and extent of significant fate and transport mechanisms occurring at the Site.

- The conceptual Site model outlines three different reducing zones that may be present in the shallow aquifer. These zones consist of an anaerobic zone extending from the FFTA 2,000 feet. downgradient, a transition zone extending from 2,000 feet to 3,000 feet. downgradient, and an aerobic zone extending from 3,000 feet downgradient of the FFTA to the Kansas River.

- The conceptual Site model concludes that in the intermediate and deep aquifer zones, there is evidence of an iron-reducing anaerobic environment. The degree of cis-1,2-DCE degradation is unknown, and the recent detections of PCE and TCE at distances greater than 3,000 feet from the FFTA indicate limited reductive dechlorination may be occurring.

- The conceptual Site model also concludes that aquifer conditions at the Site are a mix between Type I, Type II, and Type III environments. Evidence for a Type I environment is present near the source area, evidence for a Type II environment is present downgradient from the source area, and the possibility of a Type III environment exists in the shallow zone downgradient from Monitoring Well FP-98-27.

- The conceptual Site model identifies dilution, dispersion, and sorption as potentially significant nondestructive mechanisms occurring at the Site.

Contaminant fate and transport modeling was performed to simulate the transport of PCOPCs in the subsurface, to provide a tool to aid in prediction of future concentrations at potential receptor locations, and to further evaluate natural attenuation processes occurring at the Site.

- The modeling effort successfully simulated groundwater flow and direction, provides future concentration data for the human health risk assessment, and assisted in evaluating mechanisms affecting the fate and transport of PCOPCs at the Site.

- Particle-tracking simulations performed to evaluate the capture zone of Irrigation Well I-1, indicate that it is unlikely for contaminant concentrations above MCL to enter this well.

- The contaminant transport models were constructed to be conservative while still accurately simulating conditions at the Site.

- The modeling results predict that the maximum concentrations of PCE and TCE have already been reached in all three aquifer zones. The maximum concentrations of cis-1,2-DCE have already been reached in the shallow and intermediate zones, but are predicted to peak at 144 µg/L in approximately one year for the deep zone. Maximum concentrations for VC have already been reached in the shallow zone, but are predicted to peak at 0.9 µg/L in approximately six years for both the intermediate and deep zones.

- The petroleum hydrocarbon modeling results predict that the maximum concentrations of benzene, toluene, and ethylbenzene will continue to decrease with time. Benzene, the only compound which initially exceeded its MCL of 5 µg/L, is predicted to have a concentration of less than 5 µg/L in 12 years.

- To further evaluate nondestructive mechanisms at the Site, the reactive transport model was executed using a zero degradation rate for all the chlorinated solvents at the Site. The most significant result from the zero degradation simulation was that cis-1,2-DCE concentrations do not differ significantly in the future with and without degradation occurring. Therefore, even without biological degradation of cis-1,2-DCE in the future, this contaminant will continue to attenuate through non-destructive mechanisms. Additionally, it was observed that biological processes do play a significant role in reducing the concentrations of PCE and TCE at the Site since these contaminants have much larger degradation rates than cis-1,2-DCE. The effects from biodegradation of VC are not as obvious and differences between the calibrated model and the zero degradation model are likely due to effects from dispersion.

- An additional model simulation was performed to evaluate the fate and transport of chlorinated solvents through an aerobic zone. The model was constructed to simulate aerobic degradation in the shallow zone downgradient of Monitoring Well FP-98-23. Aerobic degradation rates of cis-1,2-DCE = 0.01 day^{-1} and VC = 1.0 day^{-1} were determined sufficient to match the behavior of the cis-1,2-DCE plume at the Site. The aerobic model indicates that the calibrated model was constructed in a risk conservative manner by showing migration of contaminants through the likely aerobic zone to the Kansas River even though Site conditions do not indicate that this migration of contaminants would actually occur through this aerobic zone.

6.6.2 Conclusions

Continued attenuation of all PCOPCs is expected to occur at the Site, and maximum concentrations are expected to continue to decrease. Strong evidence suggests that reductive dechlorination is occurring at the Site and is expected to continue into the future. The presence of cis-1,2-DCE and VC, as well as the USEPA/AFCEE screening results confirm this.

There is also strong evidence for aerobic degradation of chlorinated solvents in the shallow zone downgradient of Monitoring Well FP-98-23. Modeling results confirm that including this degradation zone will significantly reduce contaminant concentration in the shallow zone and prevent migration to the Kansas River in the shallow zone. However, for risk conservatism, this zone was not included in the model results provided for the human health risk assessment.

VC concentrations at the Site are expected to remain quite low since geochemical data indicates that the aquifer is not in a sufficient reducing environment to promote increased degradation of cis-1,2-DCE.

Since the reactive transport model only permits sequential reductive dechlorination of chlorinated solvents, the effects from abiotic Fe(II) reduction and direct mineralization are not included in model results. If these processes are active at the Site, future PCOPC concentrations will be lower than predicted by the reactive transport model.

* * * * *

Table 6-1
Physical and Chemical Characteristics of PCOPCs
FFTA-MAAF Remedial Investigation Report

Parameter		Value	Source
Solubility (mg/L)	PCE	200	HRI, 1995
	TCE	1100	HRI, 1995
	1,2-DCE	3500	HRI, 1995
	VC	8800	HRI, 1995
	Benzene	1790	HRI, 1995
	Toluene	526	HRI, 1995
	Ethylbenzene	206	HRI, 1995
	Xylenes	175	HRI, 1995
	Naphthalene	31	HRI, 1995
Vapor Pressure (torr)	PCE	18.6	HRI, 1995
	TCE	58	HRI, 1995
	1,2-DCE	201	HRI, 1995
	VC	2980	HRI, 1995
	Benzene	95.2	HRI, 1995
	Toluene	28.4	HRI, 1995
	Ethylbenzene	9.6	HRI, 1995
	Xylenes	10	HRI, 1995
	Naphthalene	0.085	HRI, 1995
Henry's Law Constant	PCE	0.754	HRI, 1995
	TCE	0.422	HRI, 1995
	1,2-DCE	0.167	HRI, 1995
	VC	1.11	HRI, 1995
	Benzene	0.226	HRI, 1995
	Toluene	0.272	HRI, 1995
	Ethylbenzene	346	HRI, 1995
	Xylenes	0.289	HRI, 1995
	Naphthalene	0.0198	HRI, 1995
Octonal-Water Partition Coefficient (log K_{ow})	PCE	3.40	HRI, 1995
	TCE	2.42	HRI, 1995
	1,2-DCE	1.86	HRI, 1995
	VC	1.36	HRI, 1995
	Benzene	2.13	HRI, 1995
	Toluene	2.73	HRI, 1995
	Ethylbenzene	3.15	HRI, 1995
	Xylenes	3.26	HRI, 1995
	Naphthalene	3.30	HRI, 1995
Organic Carbon-Water Partition Coefficient (K_{oc}) (cm^3/g)	PCE	265	USEPA, 1996
	TCE	94	USEPA, 1996
	1,2-DCE	35.5	KDHE, 1999
	VC	18.6	KDHE, 1999
	Benzene	38	Wiedemeier, 1999
	Toluene	135	Wiedemeier, 1999
	Ethylbenzene	95	Wiedemeier, 1999
	Xylenes	240	Wiedemeier, 1999
	Naphthalene	1288	Wiedemeier, 1999

Table 6-1 (Continued)
Physical and Chemical Characteristics of PCOPCs
FFTA-MAAF Remedial Investigation Report

Parameter		Value	Source
Soil-Water Distribution Coefficient (K_d) (cm^3/g)	PCE	1.40	$K_d = f_{oc} * K_{oc}$ $f_{oc} = 0.0053$
	TCE	0.50	
	1,2-DCE	0.19	
	VC	0.10	
	Benzene	0.20	
	Toluene	0.72	
	Ethylbenzene	0.50	
	Xylenes	1.27	
	Naphthalene	6.83	

Notes:

cm^3/g = cubic centimeters per grams

PCE = Tetrachloroethene

TCE = Trichloroethene

1,2-DCE = 1,2-Dichloroethene

VC = Vinyl Chloride

Hampshire Research Institute. Risk Assistant for Windows, Version 3. [Risk Assistant] (HRI, 1995)

Kansas Dept. of Health and Environment. Risk-Based Standards for Kansas (RSK Manual). March 24. [RSK Manual] (KDHE, 1999)

USEPA Soil Screening Guidance: Technical Background Document. EPA/540/R-95/128. (USEPA, 1996)

Naural Attenuation of Fuels and Chlorinated Solvents. (Wiedemeier, 1999)

Table 6-2
Geochemical Parameters
FFTA-MAAF Remedial Investigation Report

Parameter	Use for Natural Attenuation Purposes
Temperature	Used to determine if the reductive dehalogenation will be accelerated (T>20°C).
pH	Used to determine if pH is in optimum range for reductive dehalogenation (5<pH<9)
Methane	Used to determine the levels of methane, the product of methanogenisis, where carbon dioxide acts as an electron acceptor and methane is formed. The formation and degradation of VC is most likely under methanogenic conditions. Methane levels above 500 µg/L are indicative of methanogenic conditions.
Ethene/ethane	Used to determine levels of ethene/ethane, which are daughter products of VC/ethene.
Alkalinity	Used to determine if alkalinity increased from carbon dioxide formation from mineralization of VC/DCE is occurring. Positive indications if alkalinity in plume is greater than twice the background alkalinity.
Nitrate	Used to determine the concentrations of nitrate, an electron acceptor generally acting in the ORP range above which reductive dechlorination occurs. Nitrate concentrations less than 1 mg/L imply reductive dechlorination is possible.
Sulfate	Used to determine the amount of sulfate, which potentially competes with the chlorinated solvents for the electrons available from the aquifer carbon. Levels above 20 mg/L indicate possible competition, particularly with the more reduced chlorinated solvents, 1,2-DCE and VC.
Sulfide	Used to determine the amount of sulfide, one of the reduction products of sulfate. Levels above 1 mg/L indicate that significant amounts of sulfate reduction are occurring and increase the potential of reductive dehalogenation.
Chloride	Used to determine the levels of chloride, a daughter product of chlorinated solvent degradation. Generally, chloride levels in the chlorinated solvent plume greater than two times the levels outside the plume indicate degradation. If background chloride concentrations are relatively high compared to the chlorinated solvent concentrations, difference in chloride concentrations will be difficult to see.
Total Organic Carbon (TOC)	Used to determine if adequate amounts of anthropogenic or natural carbon exist to act as electron donors for reduction of chlorinated solvents and other electron acceptors in the aquifer. Generally, if TOC is greater than 20 mg/L, reductive dechlorination is not inhibited. Lower concentrations may still allow reductive dechlorination depending on the concentrations of other electron acceptors i.e., oxygen, nitrate, Fe III, sulfate.
Dissolved Oxygen (DO)	Used to determine the aerobic/anaerobic nature of the aquifer. Generally, DO levels less than 0.5 mg/L allow for chlorinated solvent reduction reactions. DO levels above 1 mg/L allow for direct oxidation of VC and 1,2-DCE.
Oxidation Reduction Potential (ORP)	Used to determine the relative tendency of a solution to accept or transfer electrons as measured by the ORP range. Reductive dechlorination (chlorinated solvents acting as an electron acceptor for electrons donated by native or anthropogenic carbon) is most likely to occur in the ORP ranges where ferric iron, sulfate, and carbon dioxide are also used as electron acceptors. This range is approximately +50mV to -300mV. Reductive dechlorination of 1,2-DCE and VC is expected to occur at lower ORP (-150mV to -300mV) than PCE and TCE (+50mV to -150mV).
Ferrous Iron (Fe II)	Used to determine the amount of ferric iron (Fe III) that has acted as an electron acceptor, resulting in the formation of ferrous iron (Fe II). Fe II concentrations above 1 mg/L indicate use of Fe(III) as an electron acceptor. VC may be directly mineralized under Fe(III) reducing conditions.

Notes:

mg/L = Milligrams per Liter

µg/L = Micrograms per Liter

mV = Millivolts

VC = Vinyl Chloride

1,2-DCE - 1,2-Dichloroethene

TCE = Trichloroethene

PCE = Tetrachloroethene

Sources:

Technical Protocol for Evaluating Natural Attenuation of Chlorinated Solvents in Ground Water (USEPA/AFCEE, 1998)

Natural Attenuation Data Evaluation for FFTA-MAAF (Dona, 1998)

Table 6-3
USEPA/AFCEE Reductive Dechlorination Screening Protocol
FFTA-MAAF Remedial Investigation Report

Analysis	Screening Level in Most Contaminated Zone	Interpretation	Score
Temperature	> 20 °C	At T > 20 °C, biochemical processes are accelerated	1
pH	5 < pH < 9	Optimal range for reductive dechlorination	0
	pH<5 or pH > 9	Outside optimal range for reductive pathway	-2
Methane	< 0.5 mg/L	VC oxidizes	0
	> 0.5 mg/L	Ultimate reductive daughter product, VC, accumulates	3
Ethane/Ethene	> 0.01 mg/L	Daughter product of VC	2
	> 0.1 mg/L	Daughter product of VC	3
Alkalinity	> 2x background	Results from interaction of carbon dioxide with aquifer minerals	1
Nitrate	< 1 mg/L	May compete with reductive pathway at higher concentrations	2
Sulfate	< 20 mg/L	At higher concentrations may compete with reductive pathway	2
Sulfide	> 1 mg/L	Reductive pathway possible	3
Chloride	> 2x background	Daughter product of organic chlorine	2
TOC	> 20 mg/L	Carbon and energy source; drives dechlorination; can be natural or anthropogenic	2
DO	< 0.5 mg/L	Suppresses reductive pathway at higher concentrations	3
	>1 mg/L	VC may be oxidized aerobically	-3
ORP	< 50 mV	Reductive pathway possible	1
	< -100 mV	Reductive pathway likely	2
Fe(II)	> 1 mg/L	Reductive pathway possible; VC may be oxidized under Fe(III)-reducing conditions	3
BTEX	> 0.1 mg/L	Carbon and energy source; drives dechlorination	2
PCE	-	Material released	0
TCE	-	Daughter product of PCE	2
1,2-DCE	-	Daughter prodcut of TCE; If cis is greater than 80% of total DCE, it is probably a daughter product of TCE	2
VC	-	Daughter product of DCE	2

Interpretation of Points Awarded

Total Score	Interpretation
0-5	Inadequate evidence for anaerobic biodegradation of chlorinated organics
6-14	Limited evidence for anaerobic biodegradation of chlorinated organics
15-20	Adequate evidence for anaerobic biodegradation of chlorinated organics
>20	Strong evidence for anaerobic biodegradation of chlorinated organics

Notes:

TOC = Total organic carbon
DO = Dissolved Oxygen
ORP = Oxidation Reduction Potential
Fe(II) = Ferrous Iron
BTEX = Benzene, Toluene, Ethylbenzene, and Xylenes

PCE = Tetrachloroethene
TCE = Trichloroethene
DCE = Dichloroethene
VC = Vinyl Chloride

Source:

Screening process adapted from *Technical Protocol for Evaluating the Natural Attenuation of Chlorinated Solvents Dissolved in Groundwater* (USEPA/AFCEE, 1998)

Table 6-4
Results of USEPA/AFCEE Reductive Dechlorination Screening
FFTA-MAAF Remedial Investigation Report

Analysis	Screening Level in Most Contaminated Zone	Level in Most Contaminated Zone	Site Score
Temperature	> 20°C	< 20 °C	0
pH	5 < pH < 9	7.1 to 7.3	0
Methane	< 0.5 mg/L	ND to 273 mg/L	3
Ethane/Ethene	> 0.01 mg/L	ND	0
Alkalinity	> 2x background	412-510	0
Nitrate	< 1 mg/L	< 0.7 mg/L	2
Sulfate	< 20 mg/L	52 mg/L to 130 mg/L	0
Sulfide	> 1 mg/L	ND	0
Chloride	> 2x background	13-24	1
TOC	> 20 mg/L	< 2.6 mg/L	0
DO	< 0.5 mg/L	< 0.43 mg/L	3
ORP	< -100 mV	-173 to -78	2
Fe(II)	> 1 mg/L	> 4.04 mg/L	3
BTEX	> 0.1 mg/L	ND to 2.5 mg/L	2
PCE	-	ND	0
TCE	-	ND to 9.7 mg/L	2
1,2-DCE	-	0.7 mg/L to 685 mg/L	2
VC	-	ND to 1.6 mg/L	2
		Total Points	**22**

Result: Strong evidence for reductive dechlorination according to USEPA/AFCEE screening procedure

Notes:

Most contaminated zone of aquifer includes Monitoring Well Clusters FP-96-09 and FP-96-23
Considers most recent data, May and August 1999
TOC = Total organic carbon
DO = Dissolved Oxygen
ORP = Oxidation Reduction Potential
Fe(II) = Ferrous Iron
BTEX = Benzene, Toluene, Ethylbenzene, and Xylenes
PCE = Tetrachloroethene
TCE = Trichloroethene
DCE = Dichloroethene
VC = Vinyl Chloride

Table 6-5
Chlorinated Solvent Concentration Ratios Down the Centerline of the Plume
FFTA-MAAF Remedial Investigation Report

Shallow Monitoring Wells

	Well	Oct-93	Jul-94	Oct-94	Jan-95	Apr-95	Aug-95	Dec-95	May-96	Aug-96	Dec-96	May-97	Aug-97	Feb-98	May-98	Aug-98	Jan-99	May-99	Aug-99
	PCE : TCE																		
Increasing Distance Downgradient	FP-93-04					0.85													
	FP-93-02	10	2.5	2.3	3.6	3.4	2.3	0.93	0.80	0.96	1.0	1.2	1.3	1.1	0.83	2.8	3.9	1.5	3.5
	FP-96-25	--	--	--	--	--	--	--	--	--	0.61	0.29	0.23	0.11	0.11	0.10	0.072	0.048	
	FP-96-26	--	--	--	--	--	--	--	--	--	0.71	1.0	1.3	0.68	1.1	0.85	0.56	0.81	0.95
	FP-94-09	--	--	--							0.13		0.23						
	PCE : cis-1,2-DCE																		
Increasing Distance Downgradient	FP-93-04																		
	FP-93-02	2.8	4.8	4.8	2.9	2.3	1.0	3.7	5.5	4.2	2.9	3.1	2.4	2.0	1.5	3.2	4.6	1.2	2.5
	FP-96-25	--	--	--	--	--	--	--	--	--	2.4	1.2	0.38	0.14	0.064	0.073	0.055	0.033	
	FP-96-26	--	--	--	--	--	--	--	--	--	1.0	2.9	4.9	0.38	0.05	0.15	0.36	0.28	0.49
	FP-94-09	--	--	--							0.0095		0.025						
	FP-96-23	--	--	--	--	--	--	--											
	FP-98-27	--	--	--	--	--	--	--	--	--	--	--	--	--					
	TCE : cis-1,2-DCE																		
Increasing Distance Downgradient	FP-93-04																	0.0083	
	FP-93-02	0.28	1.9	2.0	0.80	0.66	0.43	4.0	6.9	4.4	2.7	2.7	1.9	1.9	1.8	1.2	1.2	0.79	0.71
	FP-96-25	--	--	--	--	--	--	--	--	--	4.0	4.0	1.7	1.3	0.57	0.76	0.76	0.69	0.54
	FP-96-26	--	--	--	--	--	--	--	--	--	1.4	2.8	3.8	0.56	0.048	0.18	0.64	0.34	0.52
	FP-94-09	--	--	--	0.020			0.068	0.064	0.067	0.073	0.12	0.11	0.14	0.073	0.10	0.019	0.014	0.034
	FP-96-23	--	--	--	--	--	--	--											
	FP-98-27	--	--	--	--	--	--	--	--	--	--	--	--	--					

Table 6-5 (continued)
Chlorinated Solvent Concentration Ratios Down the Centerline of the Plume
FFTA-MAAF Remedial Investigation Report

Intermediate Monitoring Wells

	Well	Aug-96	Dec-96	May-97	Aug-97	Feb-98	May-98	Aug-98	Jan-99	May-99	Aug-99
	PCE : TCE										
Increasing Distance Downgradient	FP-96-04b										
	FP-96-02b				0.38						
	FP-96-25b	--	1.4								
	FP-96-26b	--	1.4	0.89		0.69			0.38		
	FP-96-09b	--									
	FP-96-23b	--	1.3	1.0	0.65	0.35					
	FP-98-27b	--	--	--	--	--	1.4	1.5	0.67	0.47	0.47
	FP-98-29b	--	--	--	--	--	3.2	3.2	2.4	1.8	1.8
	FP-98-31b	--	--	--	--	--	2.6	2.9	1.7	1.1	0.93
	FP-99-32b	--	--	--	--	--	--	--	--	--	1.0
	PCE : cis-1,2-DCE										
Increasing Distance Downgradient	FP-96-04b										
	FP-96-02b				1.8						
	FP-96-25b	--	5.7								
	FP-96-26b	--	3.0	2.2		0.29			0.026		
	FP-96-09b	--									
	FP-96-23b	--	0.06296	0.049	0.018	0.00667					
	FP-98-27b	--	--	--	--	--	0.19	0.15	0.061	0.031	0.032
	FP-98-29b	--	--	--	--	--	0.35	0.52	0.72	0.42	0.74
	FP-98-31b	--	--	--	--	--	0.47	0.56	0.68	0.34	0.53
	FP-99-32b	--	--	--	--	--	--	--	--	--	0.33
	TCE : cis-1,2-DCE										
Increasing Distance Downgradient	FP-96-04b										
	FP-96-02b				4.6					2.2	3.3
	FP-96-25b	--	4.0								
	FP-96-26b	--	2.2	2.5		0.42		1.1	0.069		0.038
	FP-96-09b	--	0.034	0.018	0.013	0.00472				0.0023	
	FP-96-23b	--	0.048	0.049	0.028	0.019	0.011	0.016	0.013	0.011	0.013
	FP-98-27b	--	--	--	--	--	0.14	0.11	0.091	0.066	0.067
	FP-98-29b	--	--	--	--	--	0.11	0.16	0.30	0.23	0.40
	FP-98-31b	--	--	--	--	--	0.18	0.19	0.40	0.30	0.57
	FP-99-32b	--	--	--	--	--	--	--	--	--	0.31

Table 6-5 (continued)
Chlorinated Solvent Concentration Ratios Down the Centerline of the Plume
FFTA-MAAF Remedial Investigation Report

Deep Monitoring Wells

	Well	Dec-96	May-97	Aug-97	Feb-98	May-98	Aug-98	Jan-99	May-99	Aug-99
	PCE : TCE									
Increasing Distance Downgradient	FP-96-25c									
	FP-96-26c									
	FP-96-09c									
	FP-96-23c	1.5		0.42						
	FP-98-27c	--	--	--	--	1.5	1.2	0.53		0.48
	FP-98-29c	--	--	--	--	1.5	1.7	1.7	1.6	1.7
	FP-98-31c	--	--	--	--	1.9	2.7	2.0	1.6	1.8
	FP-99-32c	--	--	--	--	--	--	--	--	2.9
	PCE : cis-1,2-DCE									
Increasing Distance Downgradient	FP-96-26c									
	FP-96-09c									
	FP-96-23c	0.094		0.018						
	FP-98-27c	--	--	--	--	0.080	0.076	0.026		0.016
	FP-98-29c	--	--	--	--	0.19	0.32	0.49	0.42	0.40
	FP-98-31c	--	--	--	--	0.15	0.25	0.34	0.28	0.38
	FP-99-32c	--	--	--	--	--	--	--	--	0.35
	TCE : cis-1,2-DCE									
Increasing Distance Downgradient	FP-96-26c									
	FP-96-09c									
	FP-96-23c	0.061	0.041	0.043				0.012	0.0051	0.019
	FP-98-27c	--	--	--	--	0.052	0.064	0.049	0.026	0.033
	FP-98-29c	--	--	--	--	0.13	0.18	0.28	0.27	0.23
	FP-98-31c	--	--	--	--	0.081	0.091	0.17	0.18	0.21
	FP-99-32c	--	--	--	--	--	--	--	--	0.12

Notes:

Highlighted cells are those where the concentration of daughter product exceeds that of the parent compound

-- These wells were not yet installed on these dates

The shallow screened wells closest to the river, and the deep screened wells closest to the source had no contamination, therefore ratios aren't reported for them

Table 6-6
MODFLOW Calibrated Input Parameters
FFTA-MAAF Remedial Investigation Report

Parameters		Value
Regional Recharge (ft/day)		0.0015
Recharge Along Valley Wall (ft/day)		0.015
I-1 Pumping Rate (ft^3/day)		7,044
River Node 1 (ft above MSL)		1042.7
River Node 2 (ft above MSL)		1036.1
River Node 3 (ft above MSL)		1035.1
River Node 4 (ft above MSL)		1033.1
Horizontal Hydraulic Conductivity (ft/day)	Shallow	600
	Intermediate	800
	Deep	900
Vertical Hydraulic Conductivity (ft/day)	Shallow	60
	Intermediate	80
	Deep	90
Riverbed Conductivity (ft/day)	Shallow	60
	Intermediate	NA
	Deep	NA

MSL: Mean Sea Level

Table 6-7
RT3D Calibrated Input Parameters
FFTA-MAAF Remedial Investigation Report

Parameters		Value
Effective Porosity, η_e		0.3
Field Scale of Site, L (feet)		5,400
Longitudinal Dispersivity, α_x (feet)		20
Horizontal Transverse Dispersivity, α_y(feet)		2
Vertical Transverse Dispersivity, α_z (feet)		0.02
Bulk Density, ρ_b (g/cm^3)		1.6
Fraction of Organic Carbon, f_{oc}		0.0053
Octanol-Water Partition Coefficient K_{oc} (cm^3/g)	PCE	265
	TCE	94
	cis-1,2 DCE	35.5
	VC	18.6
Soil-Water Distribution Coefficient K_d (cm^3/g)	PCE	1.40
	TCE	0.50
	cis-1,2 DCE	0.19
	VC	0.10
Degradation Rates, k (1/day)	PCE	0.018
	TCE	0.007
	cis-1,2 DCE	0.00001
	VC	0.00001

Notes:

DCE = Dichloroethene

PCE = Tetrachloroethene

TCE = Trichloroethene

VC = Vinyl Chloride

g/cm^3 = grams per cubic centimeter

cm^3/g = cubic centimeter per gram

Table 6-8
Initial Concentrations for RT3D Model
FFTA-MAAF Remedial Investigation Report

Well	Contaminant	S	I	D	Comments
FP-93-04	PCE	ND	ND	ND	
	TCE	0.8	ND	ND	S: Value from 5/99 = 0.8 (Most recent positive value)
	cis-1,2 DCE	56	ND	ND	S: Exp. Fit (.72) = 56
FP-93-02	PCE	6	ND	ND	S: Exp. Fit (.68) = 6
	TCE	2	11.2	ND	S: Exp. Fit (.97) = 2; I: Linear Fit (.21) = 11.2
	cis-1,2 DCE	3	3.7	ND	S: Exp. Fit (.60) = 3; I: Linear Fit (.29) = 3.7
FP-96-25	PCE	1.2	ND	ND	S: Value from 5/99 = 1.2 (Most recent positive value)
	TCE	16	ND	ND	S: Exp. Fit (.88) = 16
	cis-1,2 DCE	21	ND	ND	S: Linear Fit (.62) = 21
FP-94-11	PCE	ND			
	TCE	ND			
	cis-1,2 DCE	285			S: Exp. Fit (.64) = 285
FP-96-26	PCE	4	ND	ND	S: Exp. Fit (.91) = 4
	TCE	5	0.7	ND	S: Exp. Fit (.77) = 5; I: Value from 8/99 = 0.7 (Most recent positive value)
	cis-1,2 DCE	7.5	17	ND	S: Value from 8/99 = 7.5; I: Linear (.23) = 17
FP-94-09	PCE	ND	ND	ND	
	TCE	19	0.8	ND	S: Linear Fit (.31) = 19; I: Value from 5/99 = 0.8 (Most recent positive value)
	cis-1,2 DCE	442	240	0.7	S: Linear Fit (.64) = 442; I: Exp. Fit (.34) = 240; D: Value from 5/99 = 0.7 (M.R.P.V)
FP-96-23	PCE	ND	ND	ND	
	TCE	ND	1.5	0.9	I: Exp. Fit (.73) = 1.5; D: Linear Fit (.04) = 0.9
	cis-1,2 DCE	17	135	118	S: Exp. Fit (.56) = 17; I: Exp. Fit (.26) = 135; D: Linear Fit (.25) = 118
FP-96-24	PCE	ND			
	TCE	1.1			S: Linear Fit (.27) = 1.1
	cis-1,2 DCE	2.8			S: Exp. Fit (.12) = 2.8
FP-98-27	PCE	ND	8	1.4	I: Exp. Fit (.76) = 8; D: Value from 8/99 = 1.4 (Most recent positive value)
	TCE	ND	18	2.9	I: Exp. Fit (.04) = 18; D: Value from 8/99 = 2.9 (Most recent value in downward trend)
	cis-1,2 DCE	2.7	260	142	S: Exp. Fit (.73) = 2.7; I: Linear Fit (.65) = 260; D: Exp. Fit (.67) = 142
FP-98-28	PCE	ND	ND	ND	
	TCE	ND	ND	ND	
	cis-1,2 DCE	ND	5.8	9.6	I: Linear Fit (.54) = 5.8; D: Linear Fit (.97) = 9.6
FP-98-29	PCE	ND	12	14	I: Exp. Fit (.66) = 12; D: Exp. Fit (.27) = 14
	TCE	ND	5.7	8	I: Value from 8/99 = 5.7 (Most recent value in downward trend); D: Exp. Fit (.26) = 8
	cis-1,2 DCE	ND	17.8	29	I: Exp. Fit (.86) = 17.8; D: Exp. Fit (.70) = 29
FP-98-31	PCE	ND	4	14	I: Exp. Fit (.83) = 4; D: Exp. Fit (.37) = 14
	TCE	ND	4	8	I: Linear Fit (.54) = 4; D: Exp. Fit (.88) = 8
	cis-1,2 DCE	ND	8	37	I: Exp. Fit (.96) = 8; D: Exp. Fit (.50) = 37
FP-98-32	PCE	ND	8	13.6	S, I, D: Values from 8/99 (Most recent positive values)
	TCE	ND	7.7	4.7	S, I, D: Values from 8/99 (Most recent positive values)
	cis-1,2 DCE	ND	24.5	39.1	S, I, D: Values from 8/99 (Most recent positive values)

Table 6-8 (continued)
Initial Concentrations for RT3D Model
FFTA-MAAF Remedial Investigation Report

Procedure for determining initial concentrations used in the RT3D model

1. Regression analysis was performed for each well to determine trends in the field data. Exponential (Exp.) regression generally provided the best f
2. Concentration values were recorded where the regression curve intersected the August 1999 sampling date.
3. In some cases the regression analysis suggested zero or negative values. In these situations, if the field data indicated a recent (last 1 or 2 rounds) nonzero value, this number was selected.
4. In some wells, the field data displays increasing then decreasing concentrations. In these situations, the last value of the downward trend was selected.

Notes:

- All concentrations are expressed in µg/L.
- Only wells which display positive dectections were used in this analysis.
- S, I, and D correspond to Shallow, Intermediate, and Deep Zones.
- Comments provide the following: zone, regression type, R2 value, and selected value.
- M.R.P.V: Most Recent Positve Value

DCE = Dichloroethene
PCE = Tetrachloroethene
TCE = Trichloroethene
ND = NonDetect
Exp. = Exponential

Table 6-9
Maximum Modeled (RT3D) Concentrations
FFTA-MAAF Remedial Investigation Report

	Maximum Concentration in Shallow (μg/L)				Maximum Concentration in Intermediate (μg/L)				Maximum Concentration in Deep (μg/L)			
YEAR	PCE	TCE	cis-1,2-DCE	VC	PCE	TCE	cis-1,2-DCE	VC	PCE	TCE	cis-1,2-DCE	VC
0	6	19	442	2.8	12	18	260	0.0	14	18	142	0.00
1	2.6	10.6	338	0.6	4.8	14.6	238	0.3	6.8	13.5	144	0.30
2	0.9	6	280	0.8	2.2	9.9	204	0.6	3.0	10.1	141	0.60
3	0.4	3.2	235	1	1.0	6.1	176	0.7	1.4	6.9	135	0.70
4	0.2	1.7	199	1.1	0.5	3.5	153	0.8	0.6	4.1	127	0.80
5	0.1	0.9	171.0	1.2	0.20	2.0	134	0.8	0.3	2.3	117	0.80
6	0.04	0.5	149.0	1.2	0.10	1.1	119	0.9	0.1	1.2	106	0.90
7	0.02	0.2	130.0	1.2	0.040	0.6	102	0.9	0.06	0.6	94	0.90
8	0.008	0.1	113.0	1.1	0.020	0.3	89	0.8	0.03	0.3	82	0.80
9	0.004	0.06	98	1.1	0.010	0.2	75	0.8	0.01	0.2	69	0.80
10	0.002	0.03	86	1	0.0040	0.08	65	0.80	0.005	0.08	56	0.80
11	0.00115	0.0185	75.5	0.95	0.0024	0.05	57	0.75	0.003	0.05	45	0.75
12	0.00030	0.0070	65	0.9	0.0008	0.020	49	0.70	0.001	0.02	34	0.70
13	0.00018	0.0045	57	0.8	0.0005	0.012	42	0.60	0.0006	0.012	27.5	0.60
14	0.000060	0.0020	49	0.7	0.0002	0.004	35	0.50	0.0002	0.004	21.0	0.50
15	0.000035	0.0013	43	0.65	0.0001	0.002	28.5	0.40	0.0001	0.002	16.5	0.400
16	0.000010	0.0006	37	0.6	0.0000	0.000	22.0	0.30	0.0000	0.000	12.0	0.300
17	0.000005	0.0003	32	0.5	0.0000	0.000	17.0	0.20	0.0000	0.000	9.5	0.190
18	0.000000	0.0000	27	0.4	0.0000	0.000	12.0	0.10	0.0000	0.000	7.0	0.080
19	0.000000	0.0000	22.5	0.3	0.0000	0.000	9.0	0.075	0.0000	0.000	5.5	0.060
20	0.000000	0.0000	18.0	0.2	0.0000	0.000	6.0	0.050	0.0000	0.000	4.0	0.040
21	0.000000	0.0000	13.5	0.14	0.0000	0.000	4.0	0.035	0.0000	0.000	3.0	0.025
22	0.000000	0.0000	9.0	0.08	0.0000	0.000	2.0	0.020	0.0000	0.000	2.0	0.010
23	0.000000	0.0000	6.0	0.05	0.0000	0.000	1.3	0.012	0.0000	0.000	1.25	0.0065
24	0.000000	0.0000	3.0	0.02	0.0000	0.000	0.6	0.004	0.0000	0.000	0.50	0.0030
25	0.000000	0.0000	2.0	0.015	0.0000	0.000	0.5	0.0035	0.0000	0.000	0.40	0.0020
26	0.000000	0.0000	1.0	0.01	0.0000	0.000	0.4	0.0030	0.0000	0.000	0.30	0.0010
27	0.000000	0.0000	0.5	0.008	0.0000	0.000	0.3	0.0025	0.0000	0.000	0.20	0.0005
28	0.000000	0.0000	0.25	0.006	0.0000	0.000	0.2	0.0025	0.0000	0.000	0.10	0.00010
29	0.000000	0.0000	0.10	0.005	0.0000	0.000	0.1	0.0020	0.0000	0.000	0.05	0.00005
30	0.000000	0.0000	0.03	0.003	0.0000	0.000	0.1	0.0020	0.0000	0.000	0.00	0.00000

Table 6-10
BIOSCREEN Input Parameters
FFTA-MAAF Remedial Investigation Report

Parameters		Value
Hydraulic Conductivity (ft/day)		600
Effective Porosity, η_e		0.3
Longitudinal Dispersivity, α_x (feet)		20
Horizontal Transverse Dispersivity, α_y(feet)		2
Vertical Transverse Dispersivity, α_z (feet)		0.02
Bulk Density, ρ_b (kg/L)		1.6
Fraction of Organic Carbon, f_{oc}		0.0053
Octanol-Water Partition Coefficient K_{oc} (cm^3/g)	Benzene	38
	Toluene	135
	Ethylbenzene	95
	Xylene	240
	Naphthalene	1288
Half-Life, λ (year) $k = \ln(2)/\lambda$	Benzene	2.00
	Toluene	0.17
	Ethylbenzene	0.62
	Xylene	1.00
	Naphthalene	0.71

Notes:

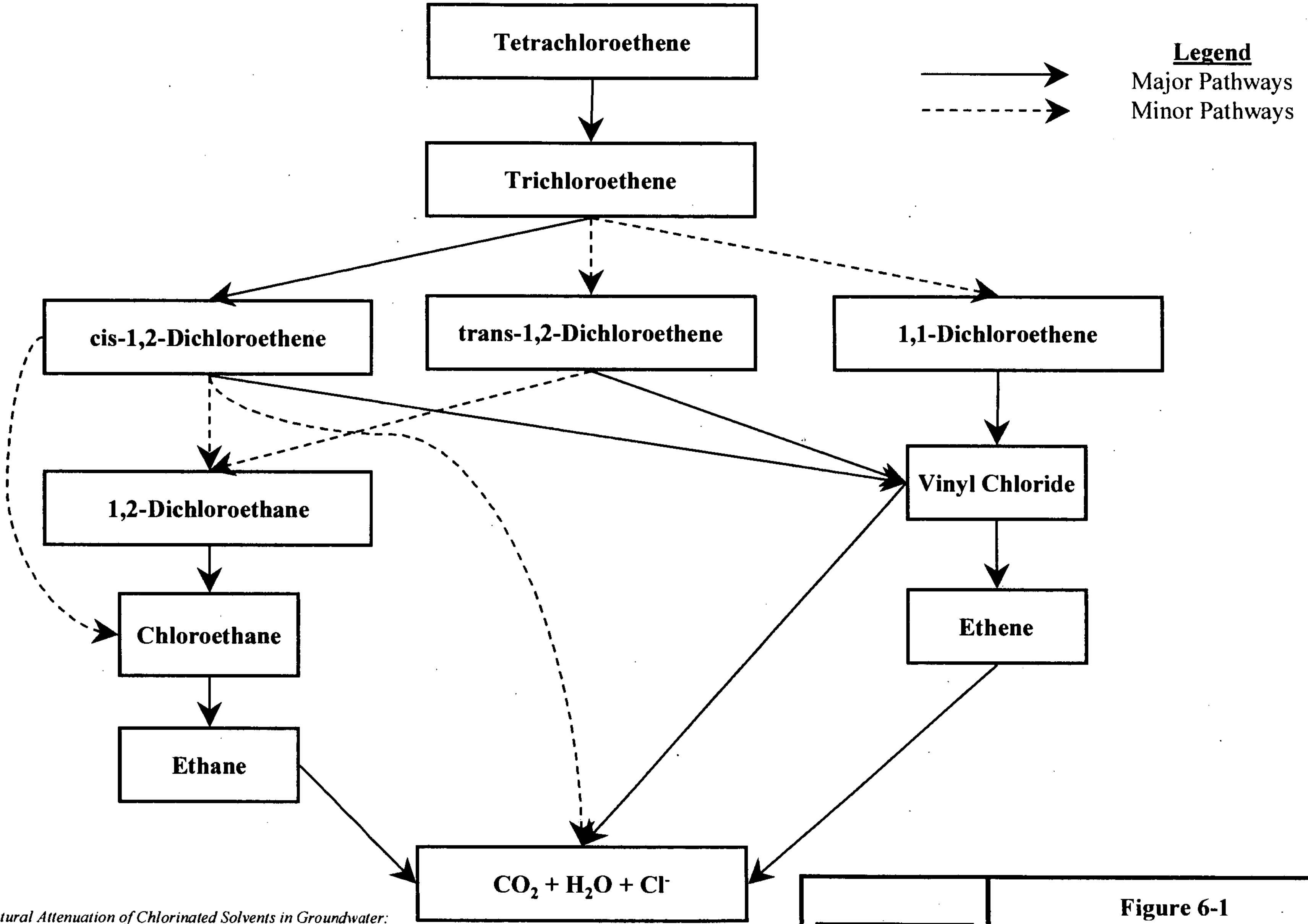
g/cm^3 = grams per cubic centimeter

cm^3/g = cubic centimeter per gram

k = Degradation Rate (1/year)

Table 6-11
Maximum Modeled (BIOSCREEN) Concentrations
FFTA-MAAF Remedial Investigation Report

Year	Benzene (µg/L)	Toluene (µg/L)	Ethylbenzene (µg/L)	Xylene (µg/L)	Naphthalene (µg/L)
0	1.20E+01	5.00E-01	2.40E+00	0.00E+00	0.00E+00
1	7.02E+00	3.14E-01	1.32E+00	0.00E+00	0.00E+00
2	4.11E+00	1.97E-01	7.29E-01	1.00E-03	0.00E+00
3	2.40E+00	1.24E-01	4.02E-01	8.10E-02	0.00E+00
4	1.40E+00	7.77E-02	2.21E-01	6.34E-01	0.00E+00
5	8.21E-01	4.88E-02	1.22E-01	1.61E+00	0.00E+00
6	4.80E-01	3.06E-02	6.72E-02	2.45E+00	0.00E+00
7	2.81E-01	1.92E-02	3.70E-02	2.94E+00	0.00E+00
8	1.64E-01	1.21E-02	2.04E-02	1.87E+00	0.00E+00
9	1.10E-01	7.57E-03	1.12E-02	1.07E+00	0.00E+00
10	7.13E-02	4.75E-03	6.19E-03	6.02E-01	0.00E+00
11	3.82E-02	2.98E-03	2.41E-03	3.37E-01	0.00E+00
12	3.40E-02	1.87E-03	1.88E-03	1.88E-01	0.00E+00
13	2.04E-02	1.18E-03	1.04E-03	1.05E-01	0.00E+00
14	1.66E-02	7.38E-04	5.71E-04	5.90E-02	0.00E+00
15	1.09E-02	4.64E-04	3.15E-04	3.30E-02	0.00E+00
16	6.61E-03	2.91E-04	1.74E-04	1.80E-02	0.00E+00
17	5.31E-03	1.83E-04	9.56E-05	1.00E-02	0.00E+00
18	3.56E-03	1.15E-04	5.27E-05	6.00E-03	0.00E+00
19	2.21E-03	7.20E-05	2.90E-05	3.00E-03	0.00E+00
20	1.74E-03	4.52E-05	1.60E-05	2.00E-03	0.00E+00
21	1.18E-03	2.84E-05	8.82E-06	1.00E-03	0.00E+00
22	7.43E-04	1.78E-05	4.86E-06	0.00E+00	0.00E+00
23	5.27E-04	1.12E-05	2.68E-06	0.00E+00	0.00E+00
24	5.27E-04	7.02E-06	1.48E-06	0.00E+00	0.00E+00
25	3.99E-04	4.41E-06	8.13E-07	0.00E+00	0.00E+00
26	2.54E-04	2.77E-06	4.48E-07	0.00E+00	0.00E+00
27	1.36E-04	1.74E-06	2.47E-07	0.00E+00	0.00E+00
28	8.76E-05	1.09E-06	1.36E-07	0.00E+00	0.00E+00
29	5.37E-05	6.85E-07	7.50E-08	0.00E+00	0.00E+00
30	4.67E-05	4.30E-07	4.13E-08	0.00E+00	0.00E+00



Source: *Natural Attenuation of Chlorinated Solvents in Groundwater: Principles and Practices* (ITRC, 1999) & *In Situ Bioremediation,* (Rittmann, Seagren, & Wrenn, 1994).

Note: This figure depicts the biotic reductive dechlorination and abiotic and biotic direct mineralization pathways. Other pathways may be occurring at the site and are discussed in the text.

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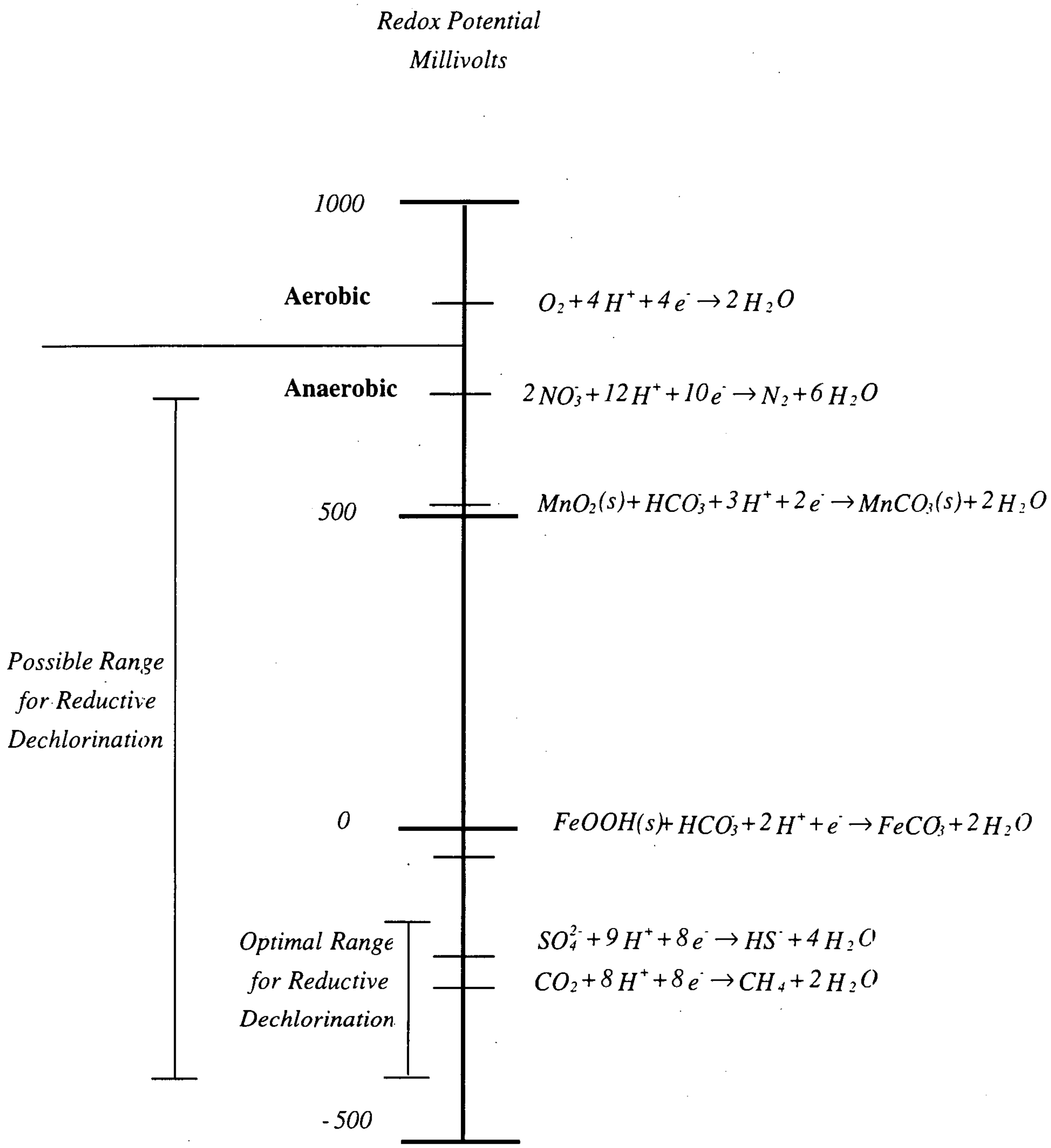
Figure 6-1

Degradation Pathways of Chlorinated Solvents

FFTA-MAAF RI



Source: *Technical Protocol for Evaluating Natural Attenuation of Chlorinated Solvents in Groundwater* (USEPA/AFCEE, 1998)

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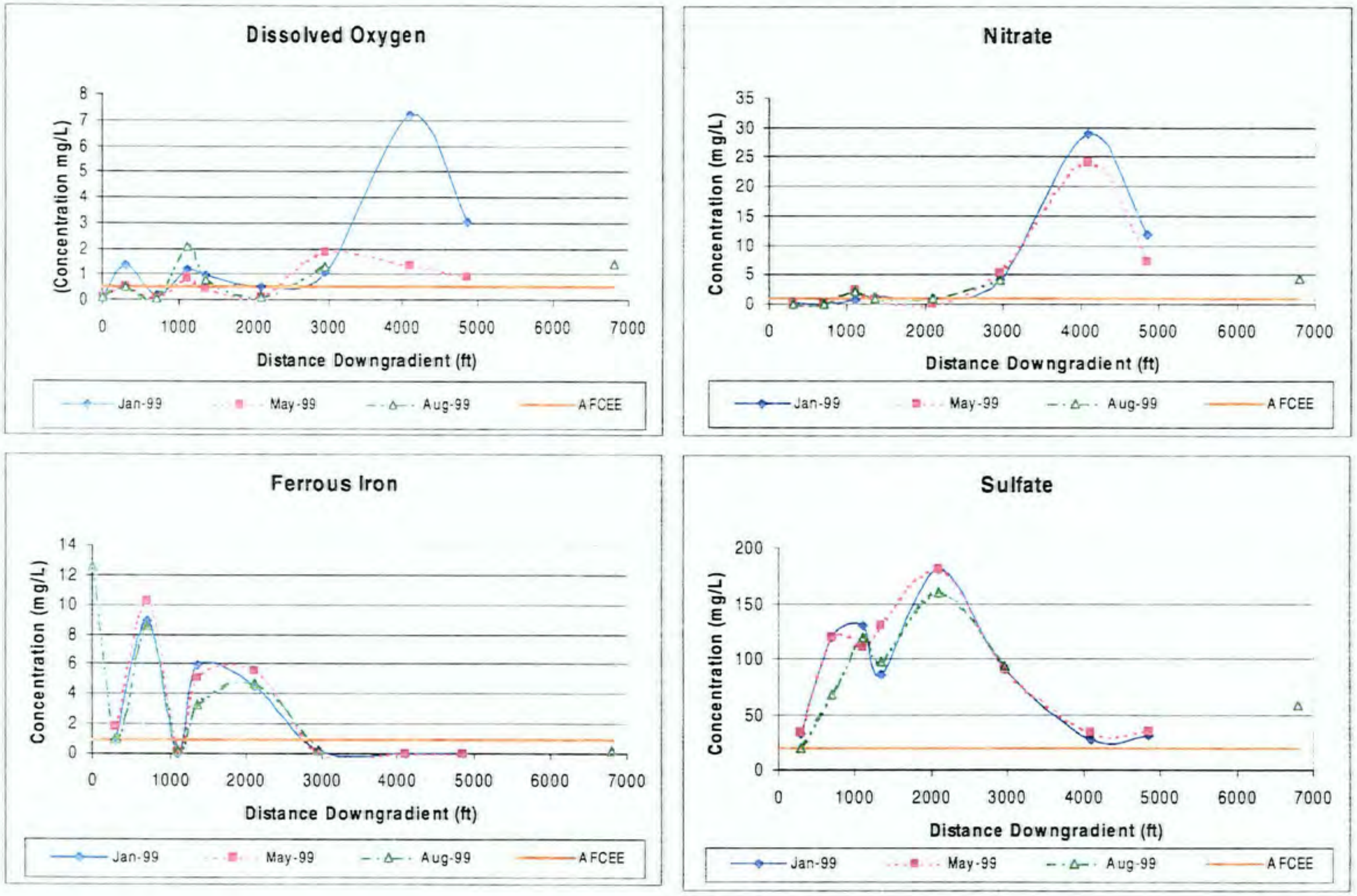
Figure 6-2

Oxidation Reduction Potential

FFTA-MAAF RI



Parameter	Favorable Geochemical Conditions
Dissolved Oxygen	<0.5 mg/L
Nitrate	<1 mg/L
Ferrous Iron	>1 mg/L
Sulfate	<20 mg/L

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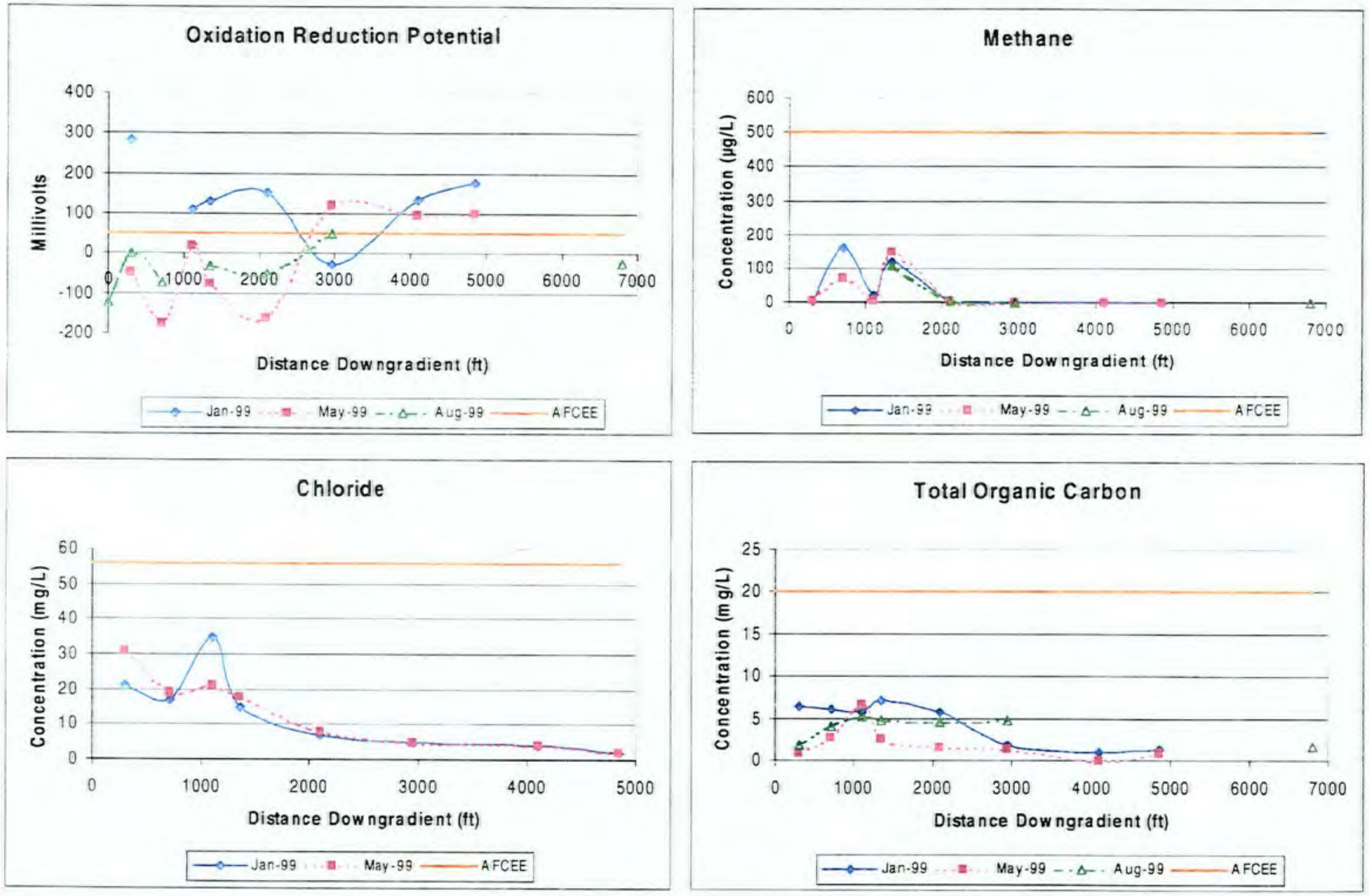
SINCE 1898

Figure 6-3

Electron Acceptors/Donors in Shallow Groundwater

FFTA-MAAF RI



Parameter	Favorable Geochemical Conditions
Oxidation Reduction Potential	<50 mV
Methane	>500 µg/L
Chloride	>56 mg/L
Total Organic Carbon	>20 mg/L

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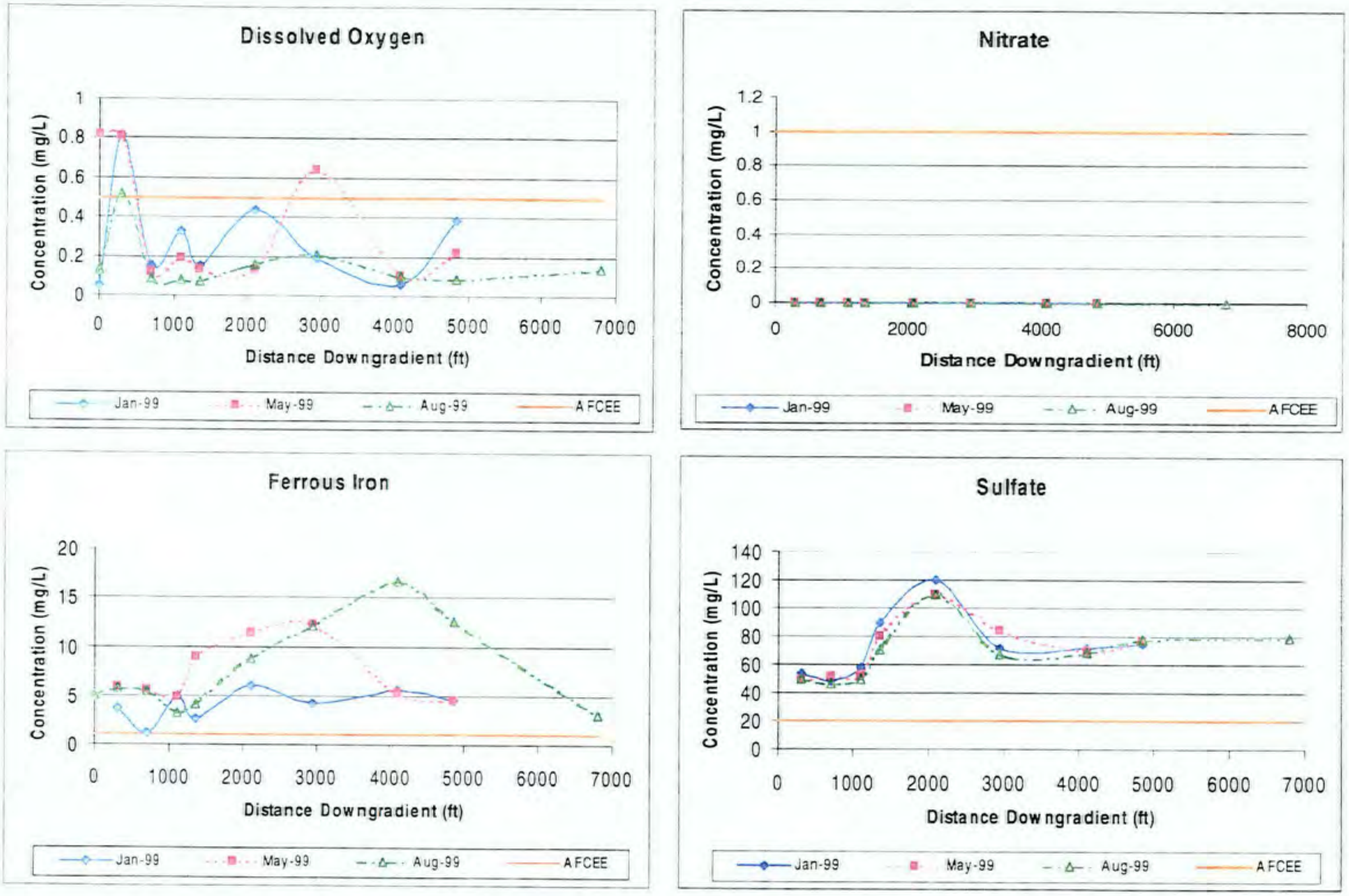
Figure 6-4

Geochemical Parameters in Shallow Groundwater

FFTA-MAAF RI



Parameter	Favorable Geochemical Conditions
Dissolved Oxygen	<0.5 mg/L
Nitrate	<1 mg/L
Ferrous Iron	>1 mg/L
Sulfate	<20 mg/L

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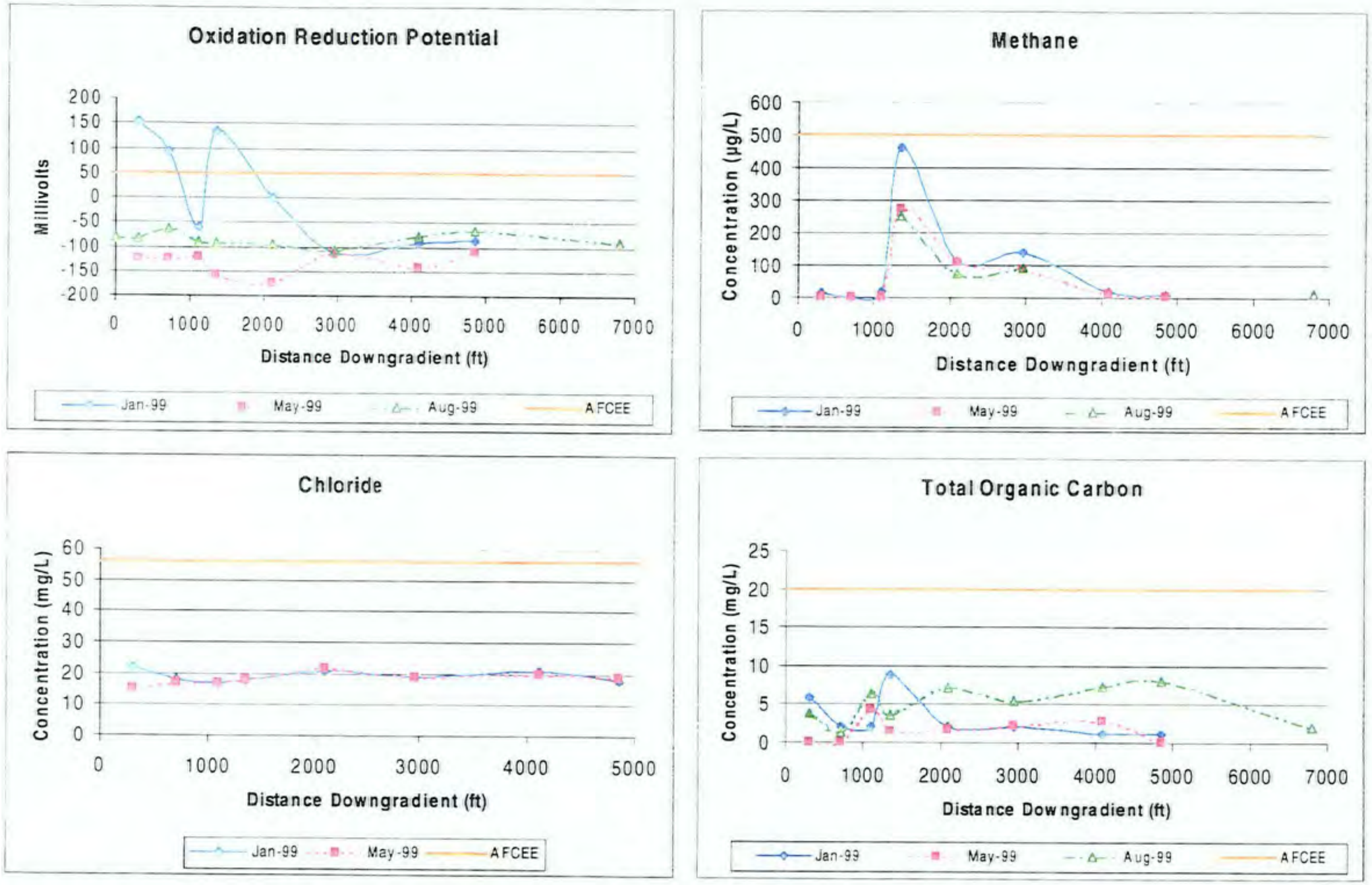
Figure 6-5

Electron Acceptors/Donors in Intermediate Groundwater

FFTA-MAAF RI



Parameter	Favorable Geochemical Conditions
Oxidation Reduction Potential	<50 mV
Methane	>500 µg/L
Chloride	>56 mg/L
Total Organic Carbon	>20 mg/L

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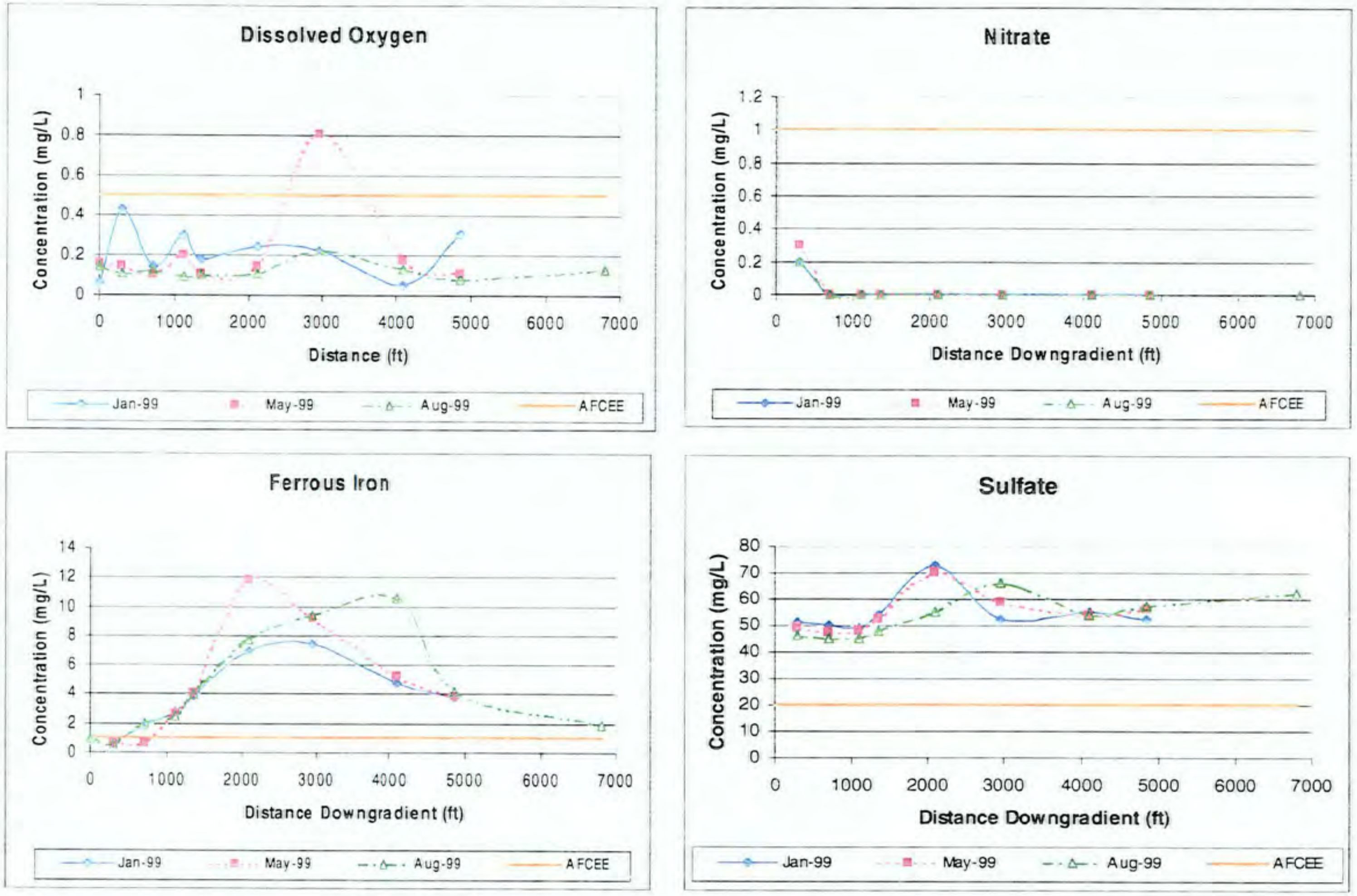
SINCE 1898

Figure 6-6

Geochemical Parameters in Intermediate Groundwater

FFTA-MAAF RI



Parameter	Favorable Geochemical Conditions
Dissolved Oxygen	<0.5 mg/L
Nitrate	<1 mg/L
Ferrous Iron	>1 mg/L
Sulfate	<20 mg/L

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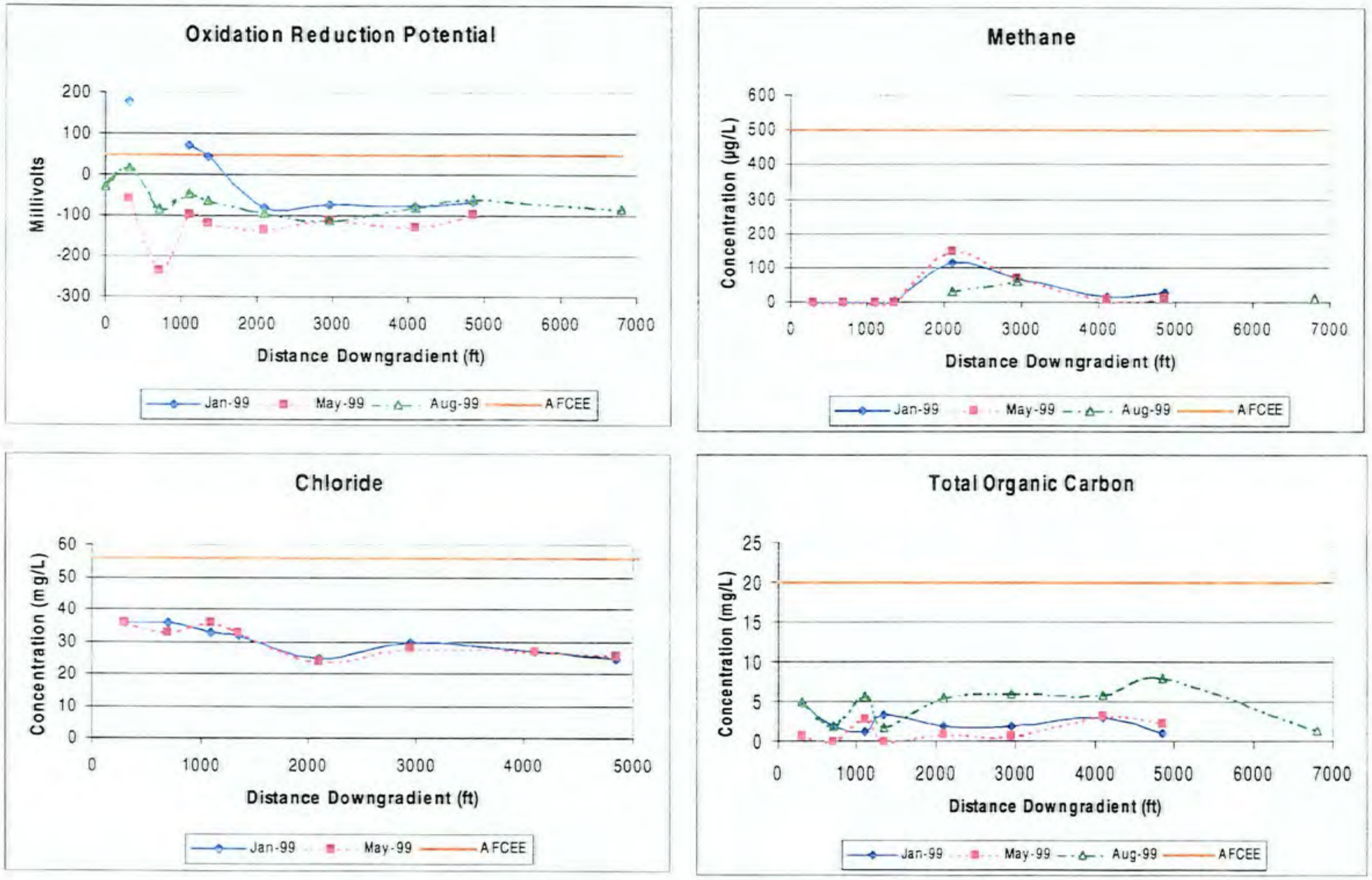
Figure 6-7

Electron Acceptors/Donors in Deep Groundwater

FFTA-MAAF RI



Parameter	Favorable Geochemical Conditions
Oxidation Reduction Potential	<50 mV
Methane	>500 µg/L
Chloride	>56 mg/L
Total Organic Carbon	>20 mg/L

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Figure 6-8

Geochemical Parameters in Deep Groundwater

FFTA-MAAF RI

Notes:
750 ft = Distance Between Wells Down Centerline of the Plume
Data from Data Summary Reports

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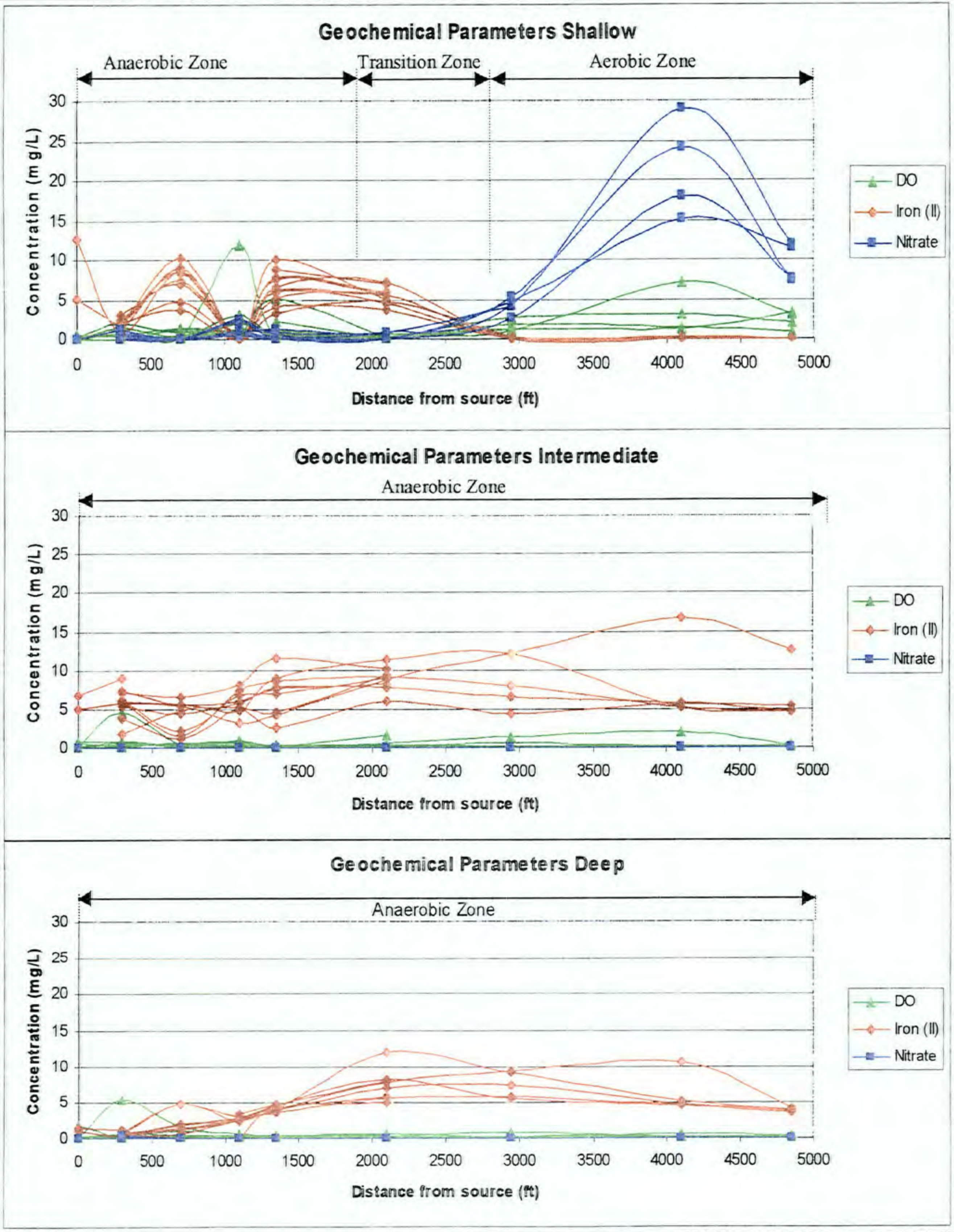
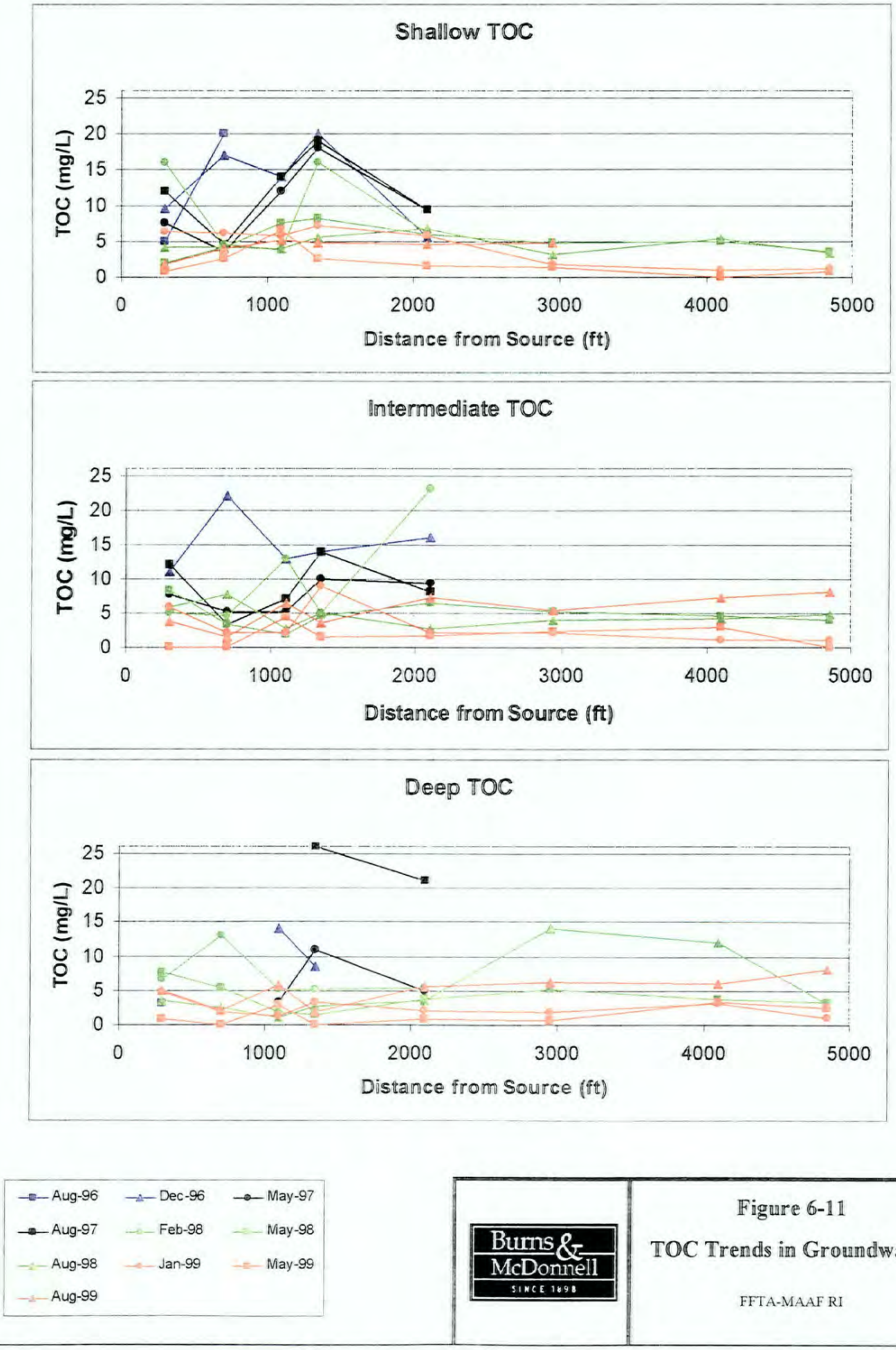
Figure 6-9
Natural Attenuation Trend Chart
FFTA-MAAF RI



Note: Each of the lines for the different parameters represents a different sampling round.

Figure 6-10

Degradation Zones


Shallow TOC

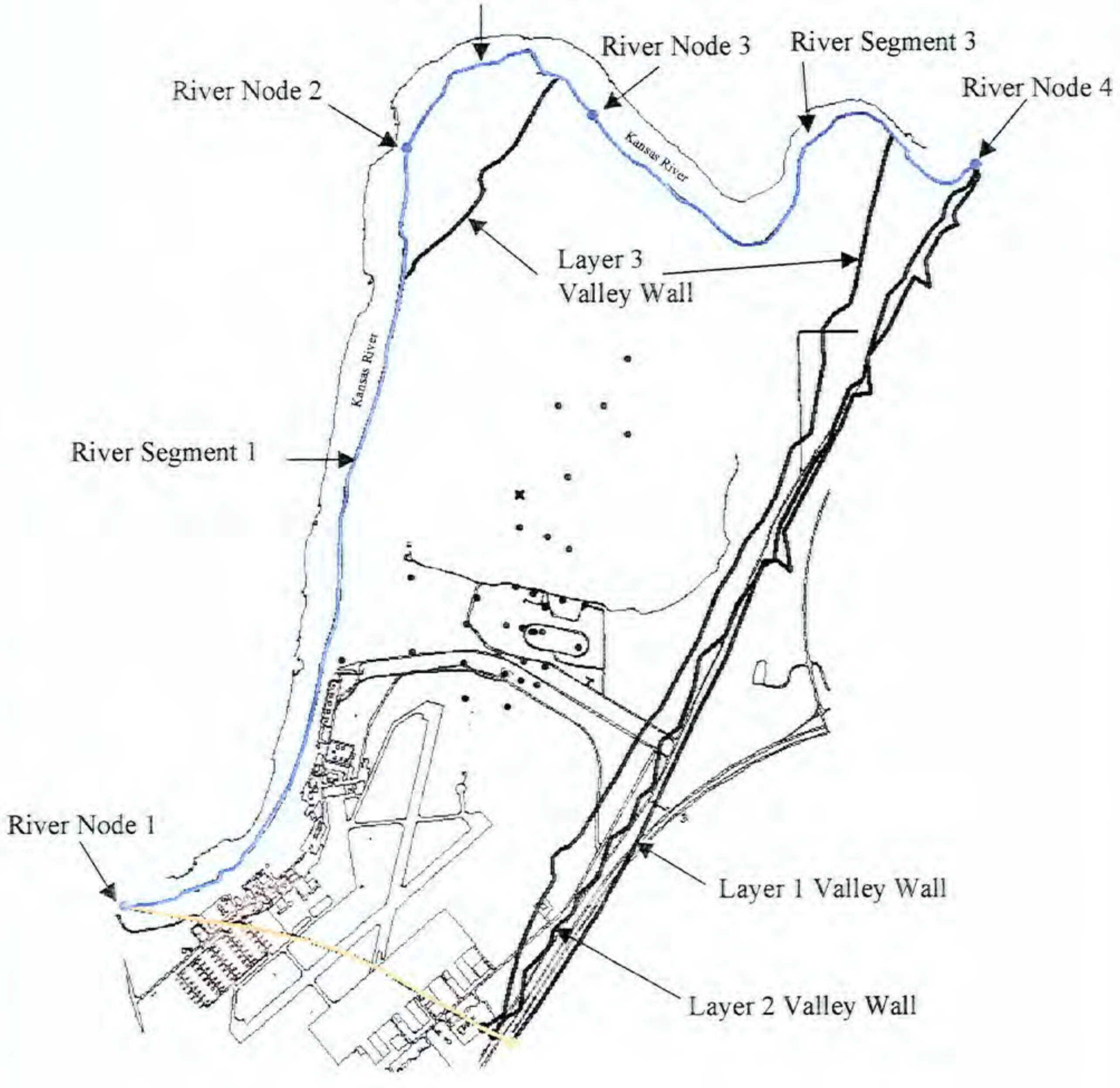
Intermediate TOC

Deep TOC

Figure 6-11

TOC Trends in Groundwater

FFTA-MAAF RI



LEGEND

- ● Monitoring Well
- × Irrigation Well (I-1)
- — River Boundary
- — General Head Boundary
- — No-Flow Boundary

N

NOT TO SCALE

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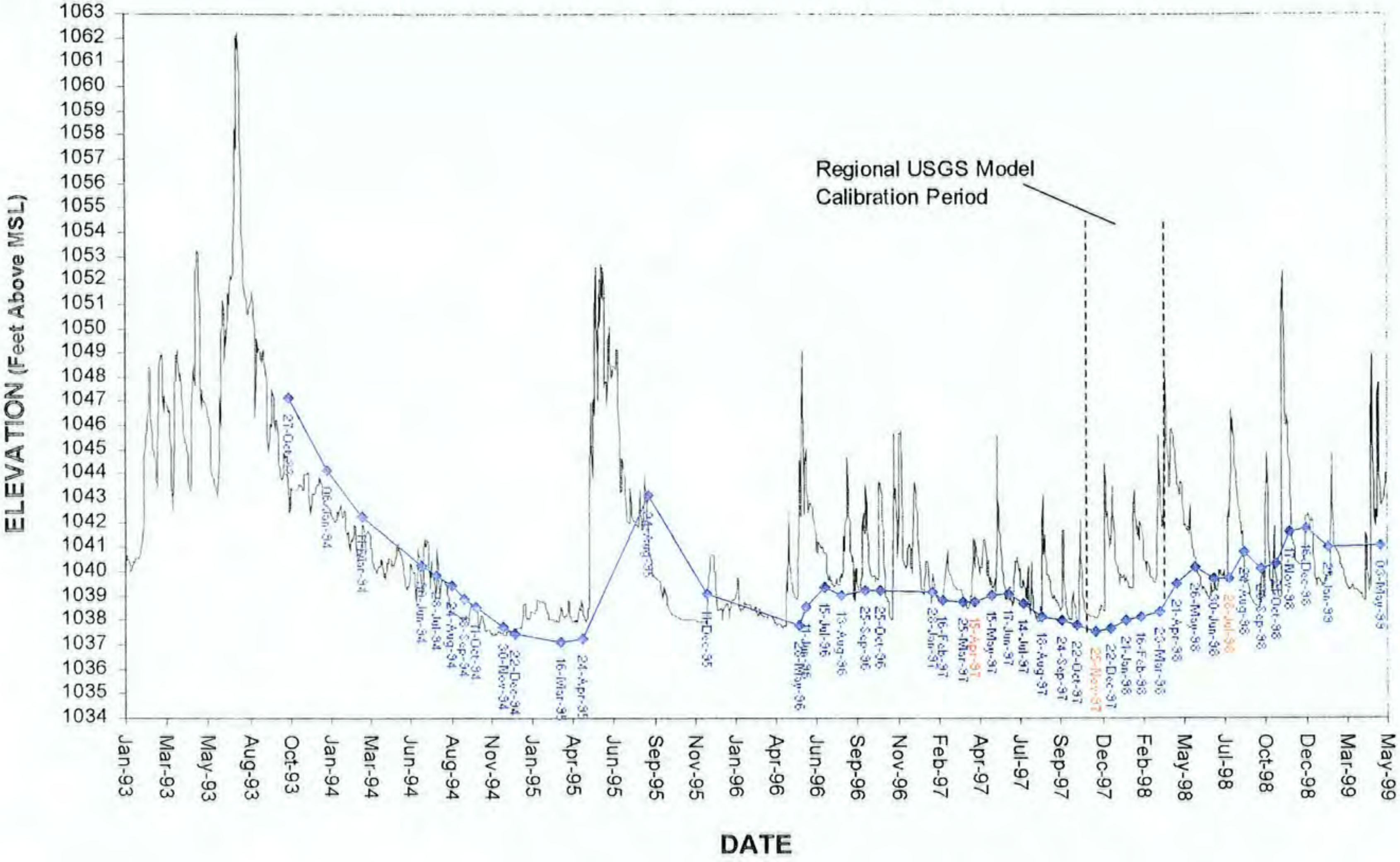
Figure 6-12

Conceptual Model

FFTA-MAAF RI



LEGEND

— Kansas River

— Monitoring Well FP-93-01

NOTE:

- Dates in blue represent groundwater elevation measurements at well FP-93-01.
- Dates in red represent data sets selected for calibration.

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Figure 6-13

Kansas River Valley Hydrograph

FFTA-MAAF RI

LEGEND

- Groundwater Surface
- × Irrigation Well (I-1)
- ● Monitoring Well
- Particle Track
- Calibration Point
  - 🟩 Calibration within 0.5 ft.
  - 🟨 Calibration within 1 ft.
  - 🟥 Calibration exceeds 1 ft.

NOT TO SCALE

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Figure 6-14

Model Calibration
July 28, 1998

FFTA-MAAF RI

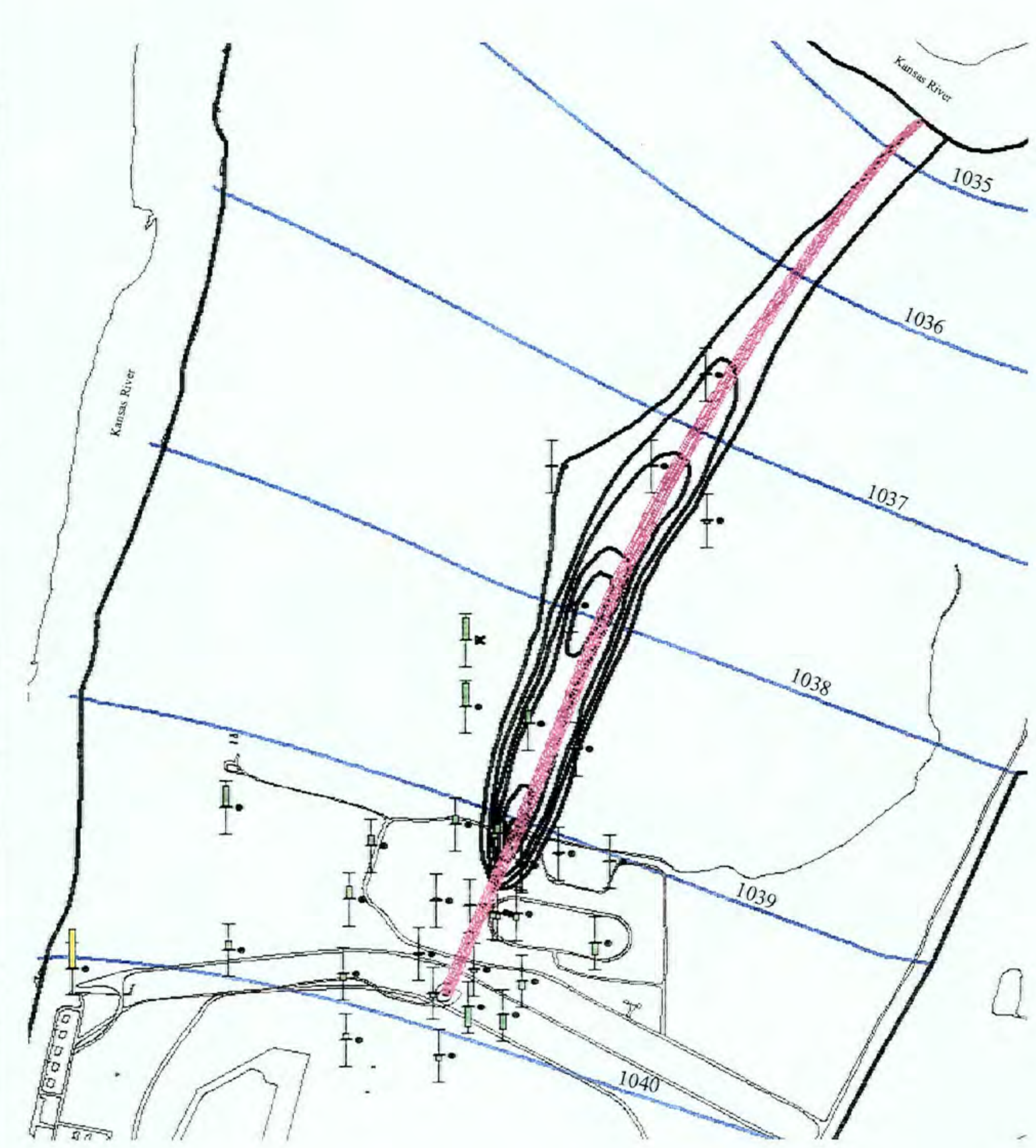

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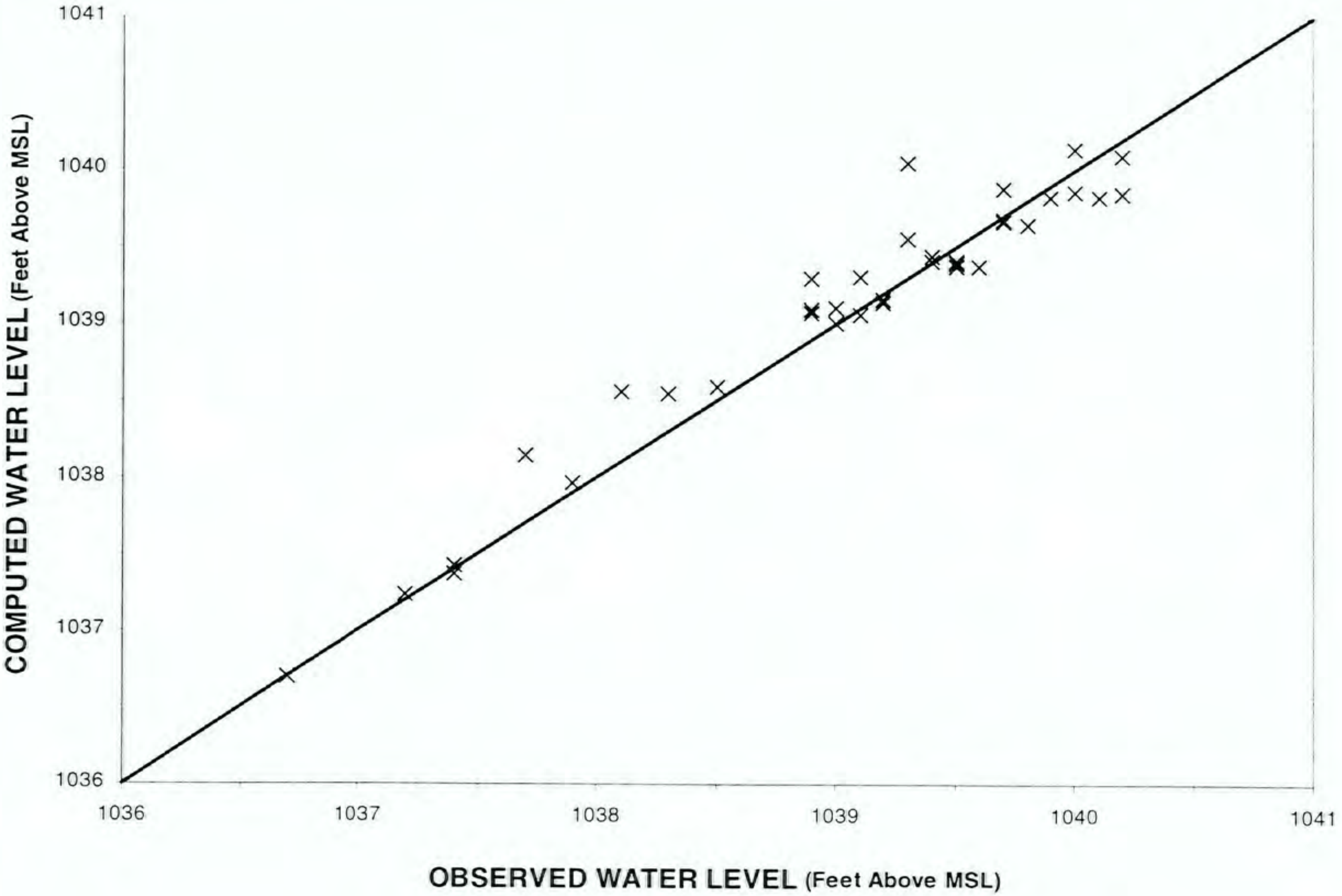
Figure 6-15

Model Calibration
July 28, 1998

FFTA-MAAF RI



LEGEND

× Monitoring Wells

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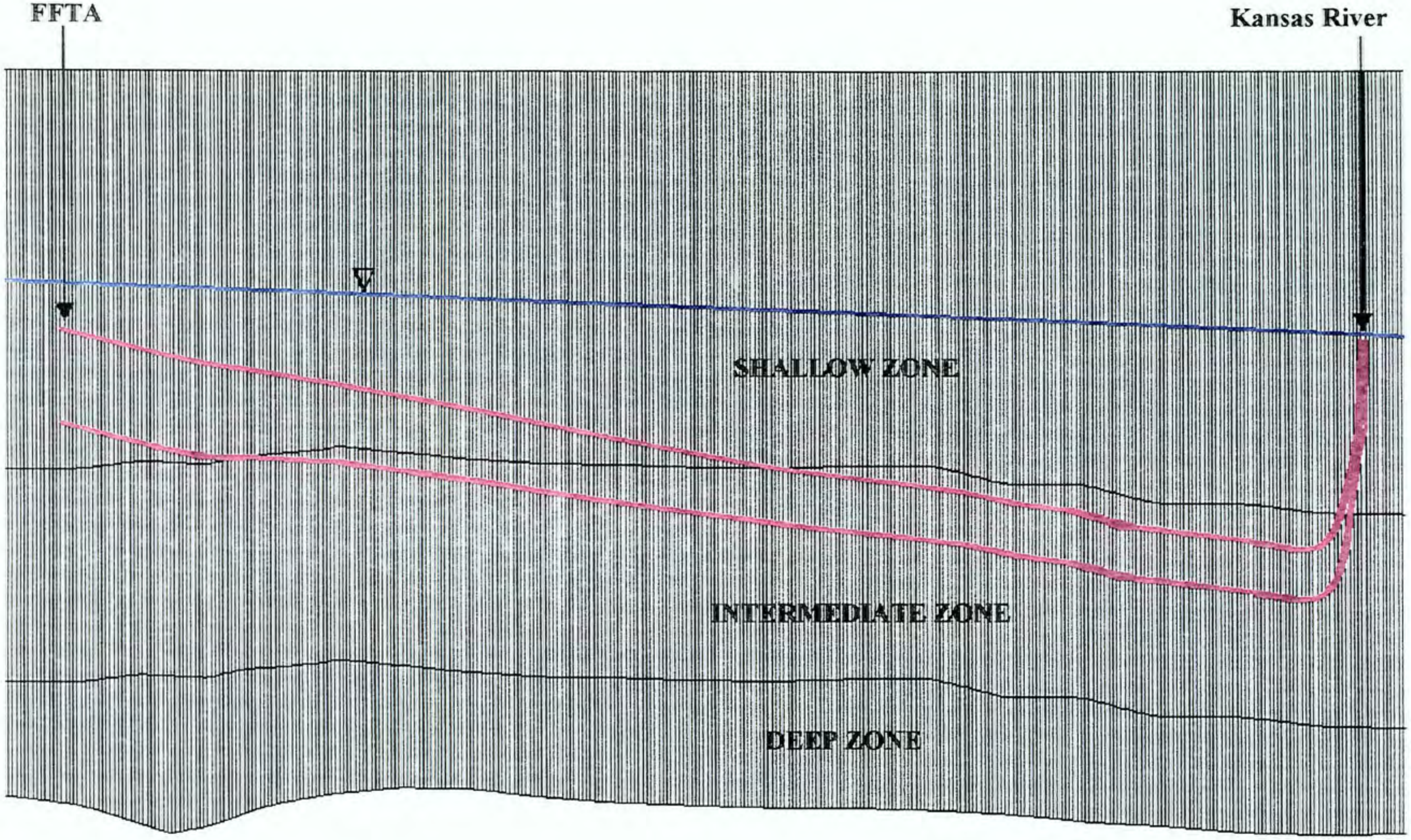
Figure 6-16

July 28, 1998 Calibration

FFTA-MAAF RI



LEGEND

▬ Water Table

▬ Particle Track

NOT TO SCALE

NOTE:

- Vertical exaggeration is 50X
- Particles were initiated at two elevations in the shallow zone.

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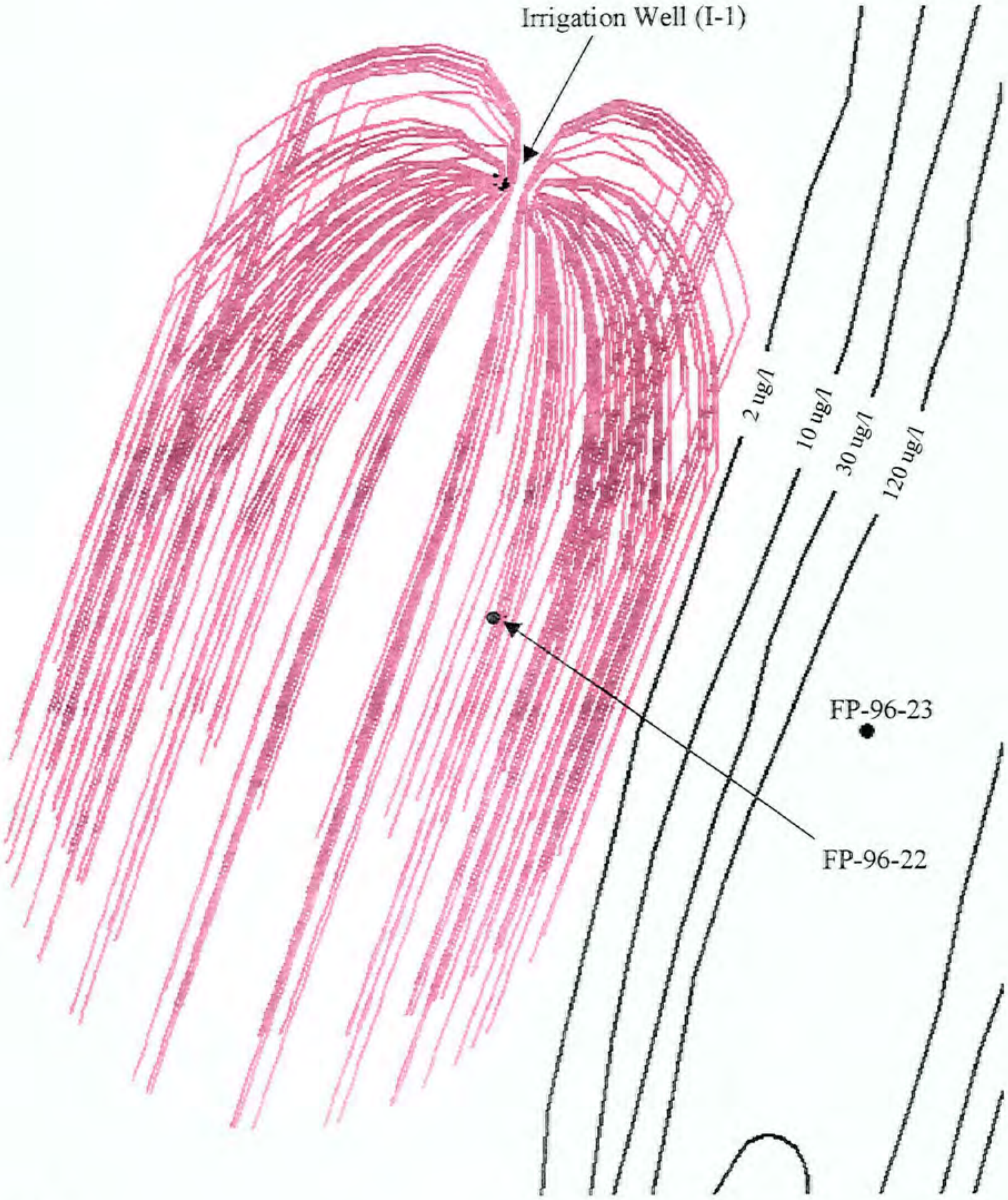
Figure 6-17

Particle Tracking Profile

FFTA-MAAF RI



LEGEND

▬ Particle Track
▬ cis-1,2-DCE Contour

NOTE:
Particle tracks represent one year duration

N

NOT TO SCALE

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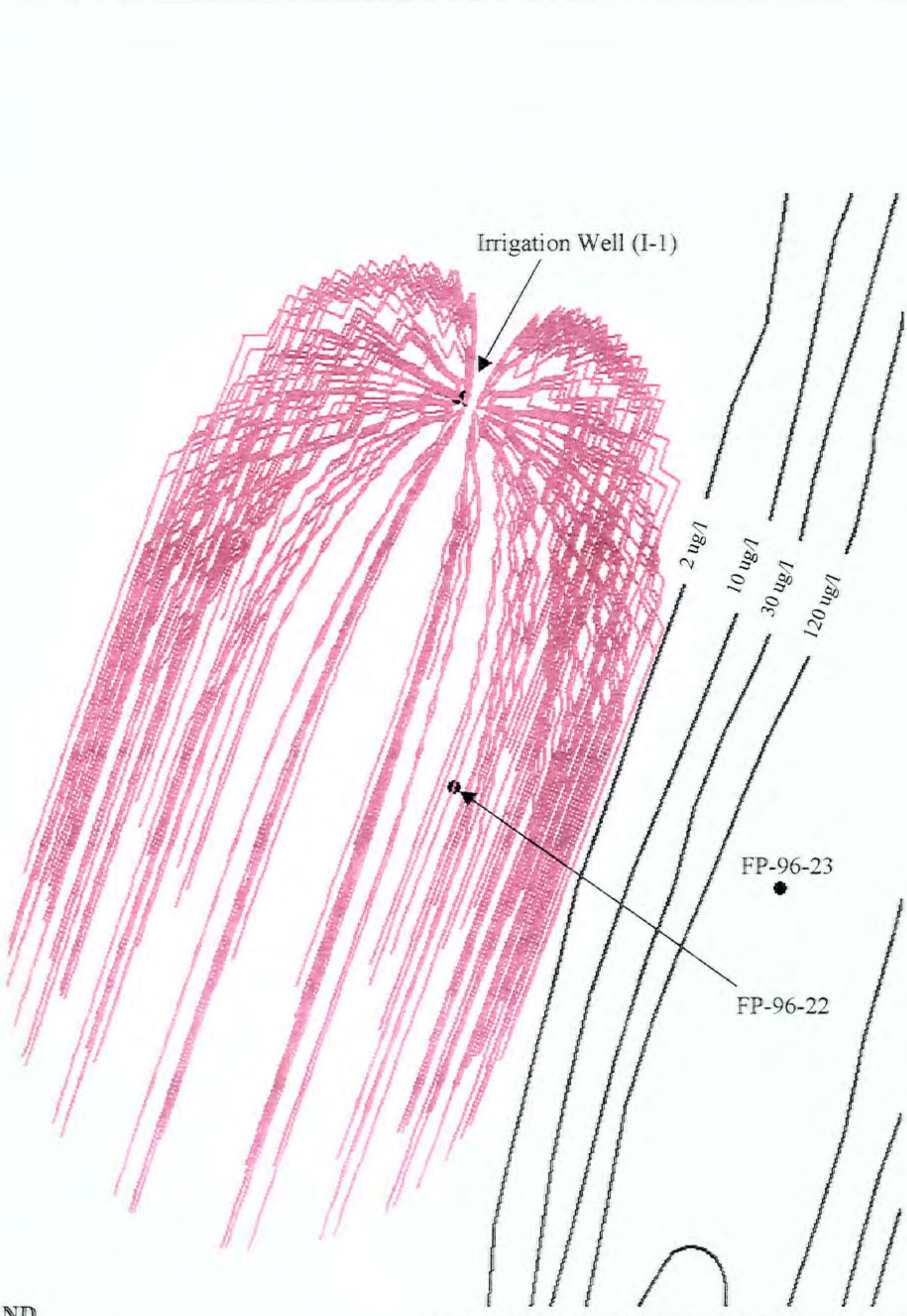
SINCE 1898

Figure 6-18

Backward Particle Tracking 120-Day Pumping Period

FFTA-MAAF RI



LEGEND

▬ Particle Track

▬ cis-1,2-DCE Contour

NOTE:
Particle tracks represent one year duration

NOT TO SCALE

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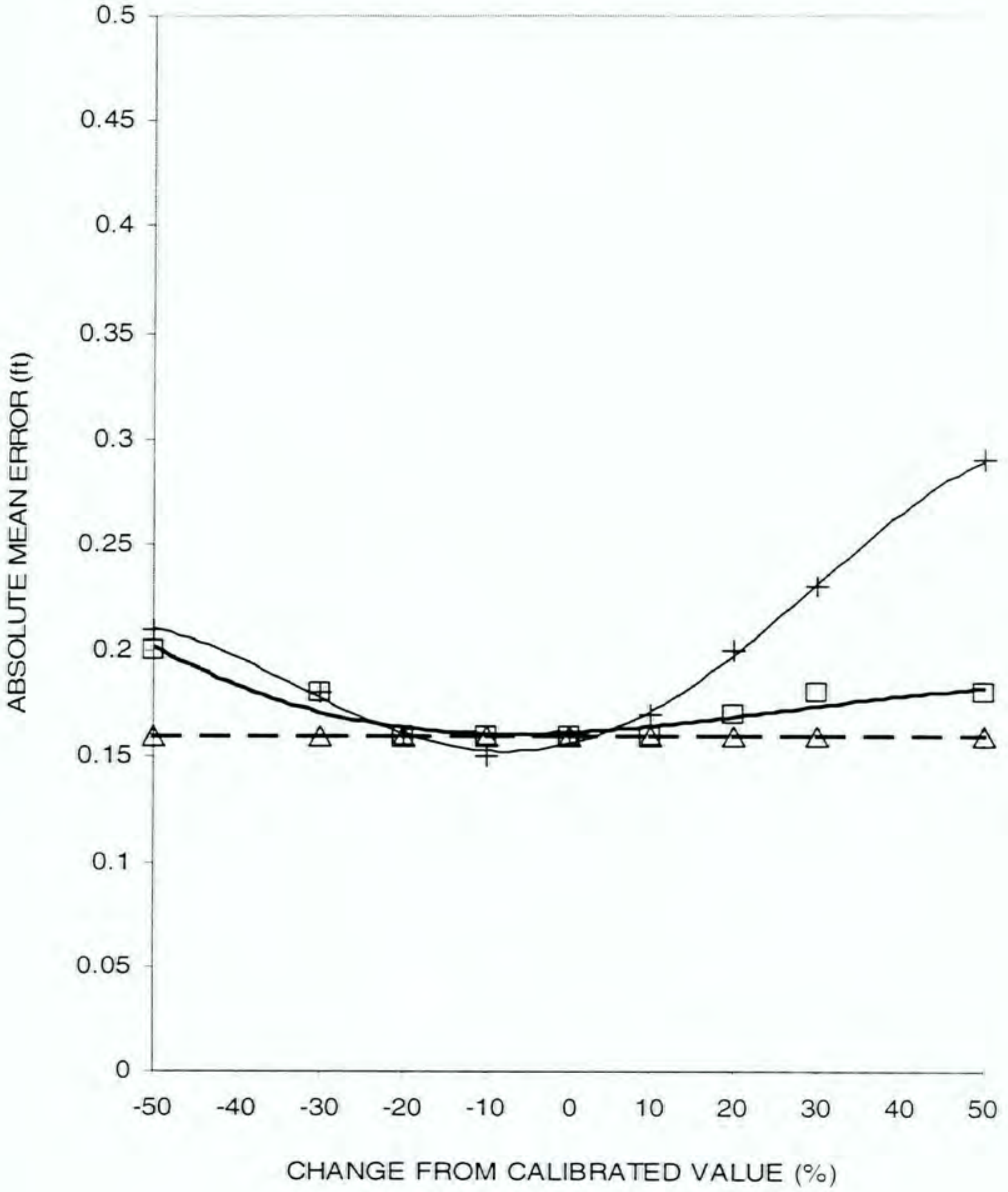
SINCE 1898

Figure 6-19
Backward Particle Tracking
72-hour Pumping Period

FFTA-MAAF RI



LEGEND

- □ Horizontal Hydraulic Conductivity
- Δ Vertical Hydraulic Conductivity
- \+ Recharge

Burns & McDonnell SINCE 1898

Figure 6-20

Groundwater Flow Model Sensitivity Analysis

FFTA - MAAF RI

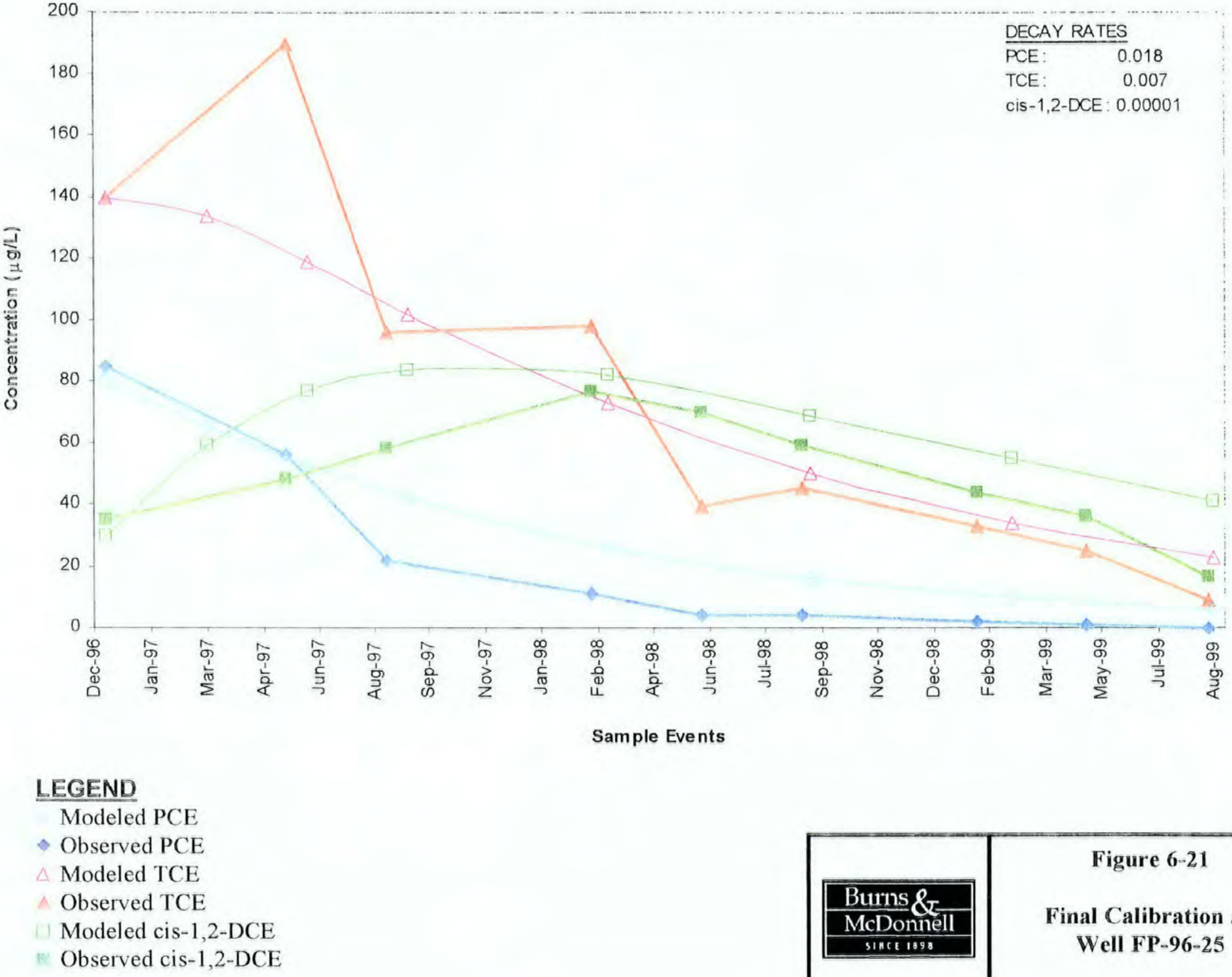


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Figure 6-21

Final Calibration at Well FP-96-25

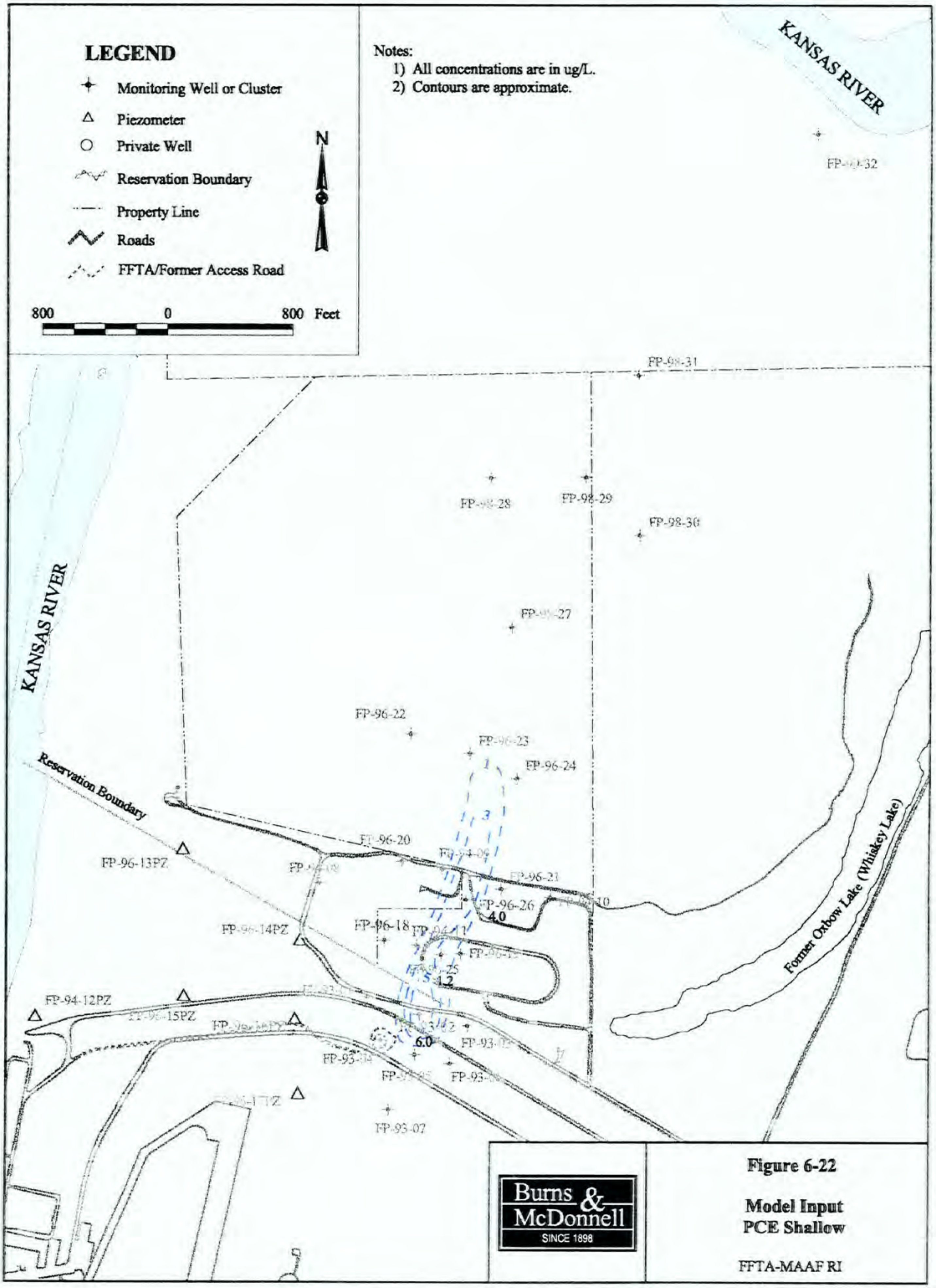

Figure 6-22

Model Input
PCE Shallow

FFTA-MAAF RI

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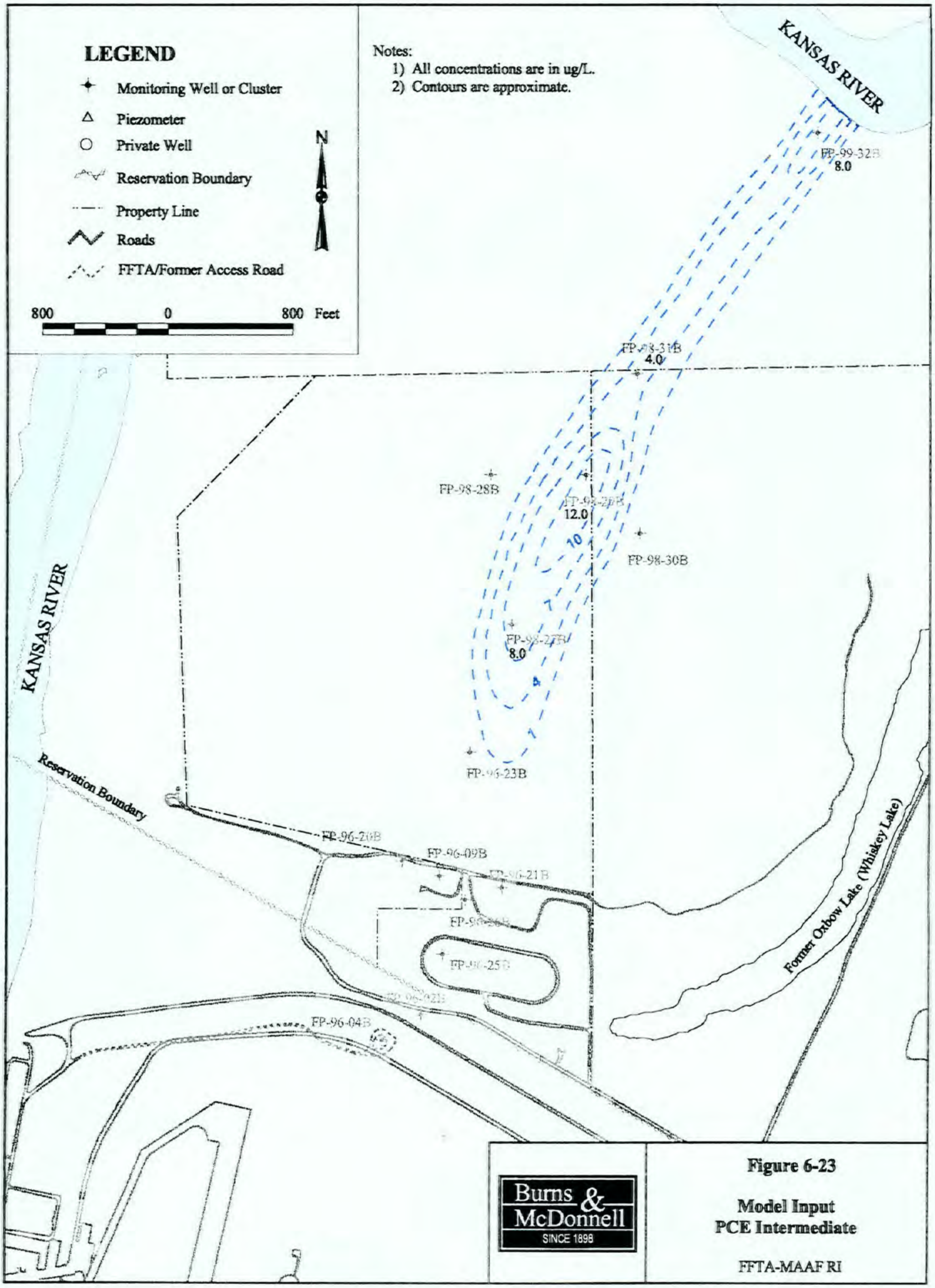

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Figure 6-23

Model Input
PCE Intermediate

FFTA-MAAF RI

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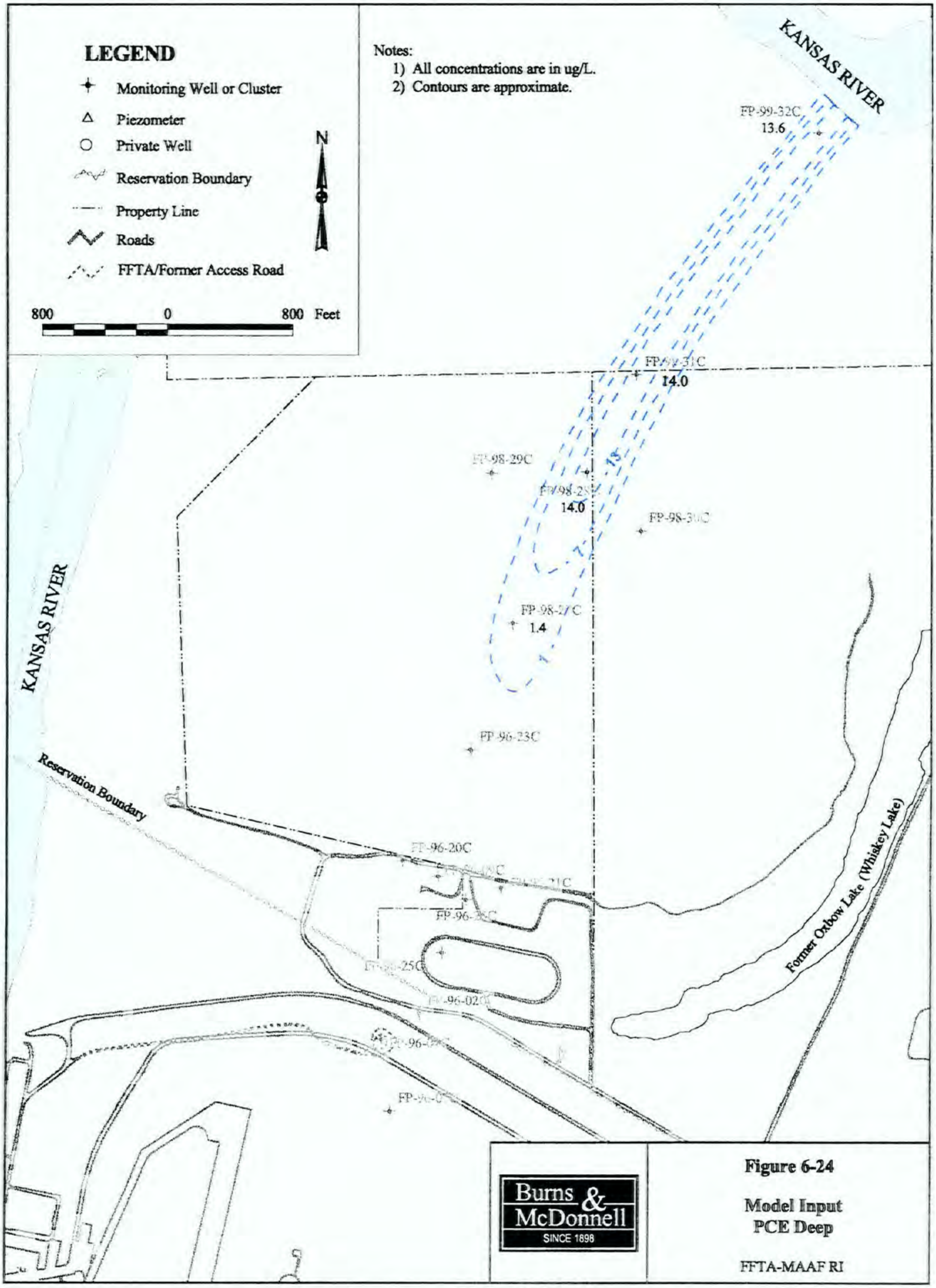

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Figure 6-24

**Model Input
PCE Deep**

FFTA-MAAF RI

U:/erc/usfr... .../view/ri_models.apr/pcedeep_view/pcedeep_Riformat_layout 12/10/99 LGB 19600

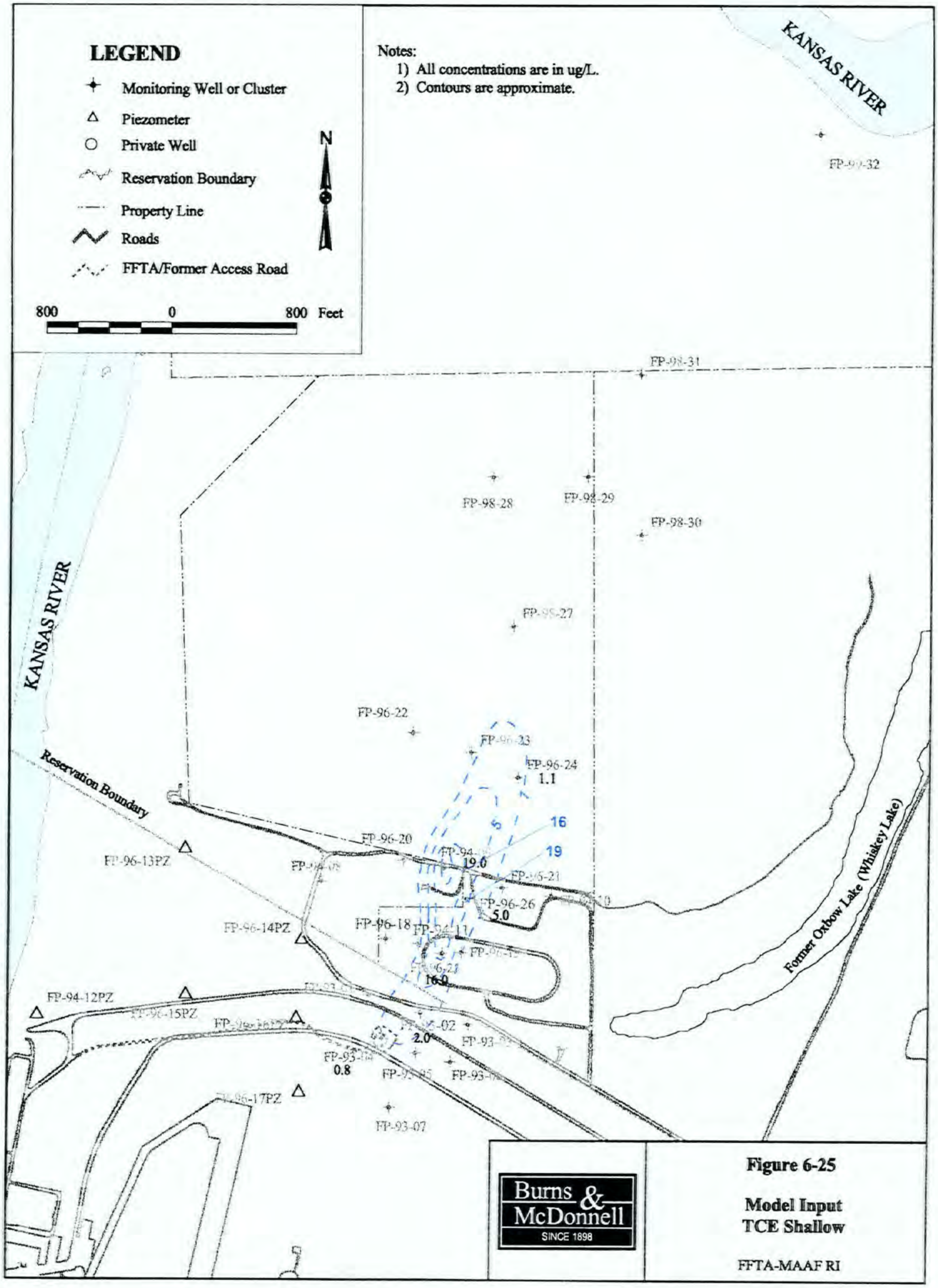
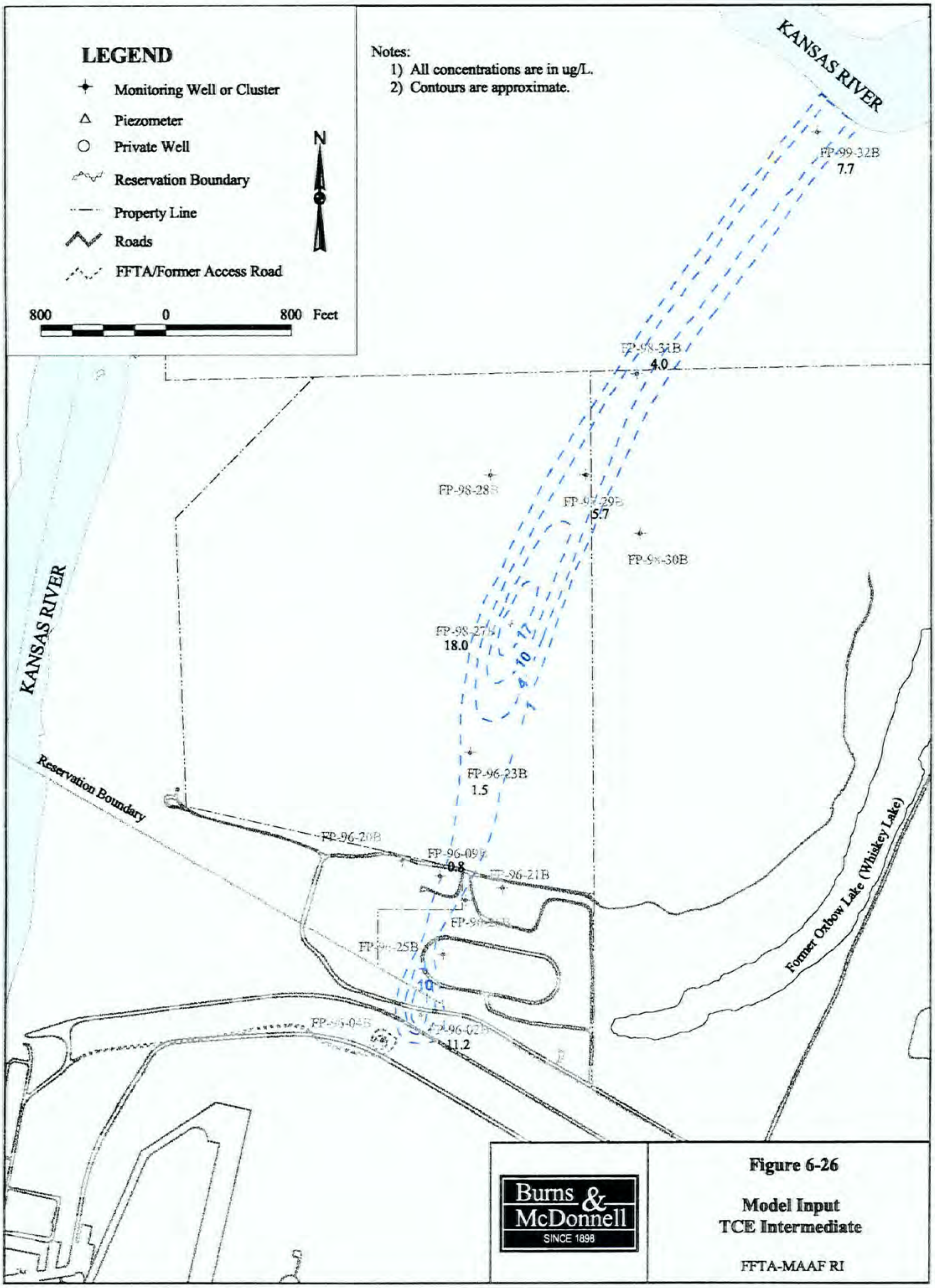


Figure 6-25

Model Input
TCE Shallow

FFTA-MAAF RI

U:/arc/ts .../viewfrl_models.apr/tceshal_viewtceshal_RIformal_layout 12/10/99 LGB 1:9600



Notes:
1) All concentrations are in ug/L.
2) Contours are approximate.

Figure 6-26

Model Input
TCE Intermediate

FFTA-MAAF RI

U:/arc/ush. rewrl_models.apr/tceint_view/tceint_RIformat_layout 12/10/99 LGB 1:9600

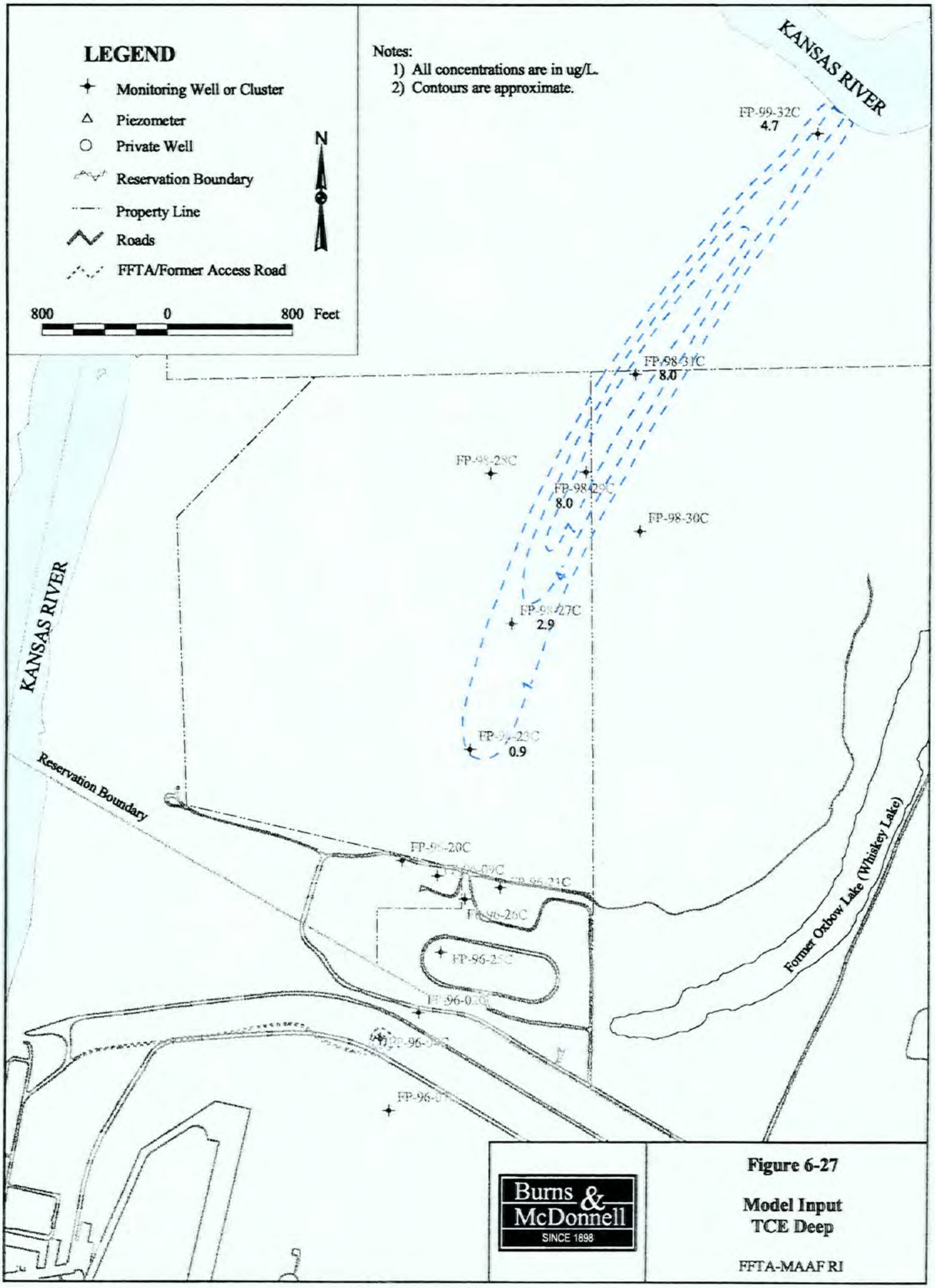
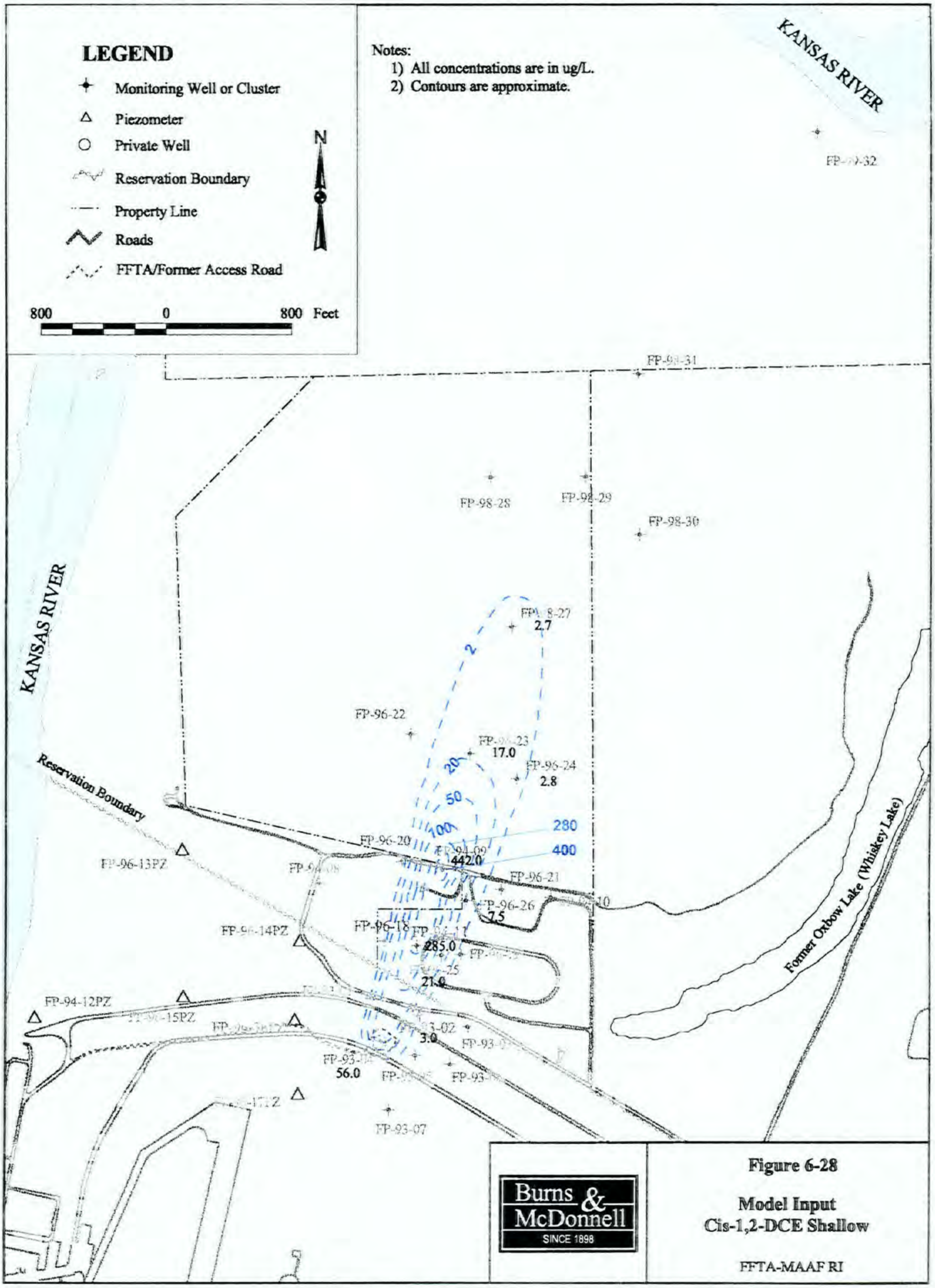


Figure 6-27

Model Input TCE Deep

FFTA-MAAF RI

U:/arc/usfm.../.../H_models.apr/tcedeep_view/tcedeep_RIformat_layout 12/10/99 LGB 1:9600



Notes:
1) All concentrations are in ug/L.
2) Contours are approximate.

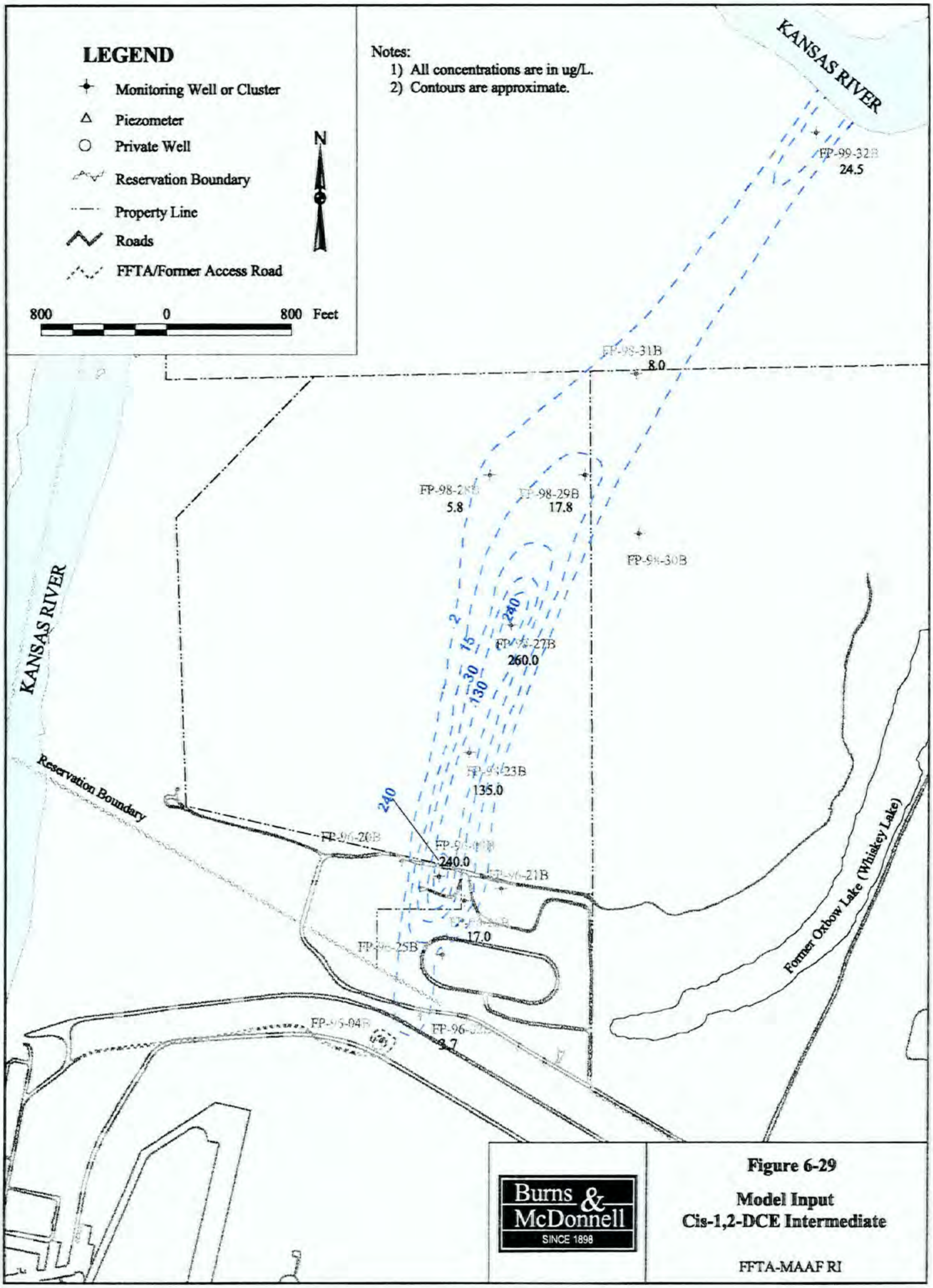
Burns & McDonnell SINCE 1898

Figure 6-28

Model Input
Cis-1,2-DCE Shallow

FFTA-MAAF RI

U:/arc/um... view/rl_models.apr/doeshal_view/doeshal_RIformat_layout 12/10/99 LGB 1:9600



Notes:
1) All concentrations are in ug/L.
2) Contours are approximate.

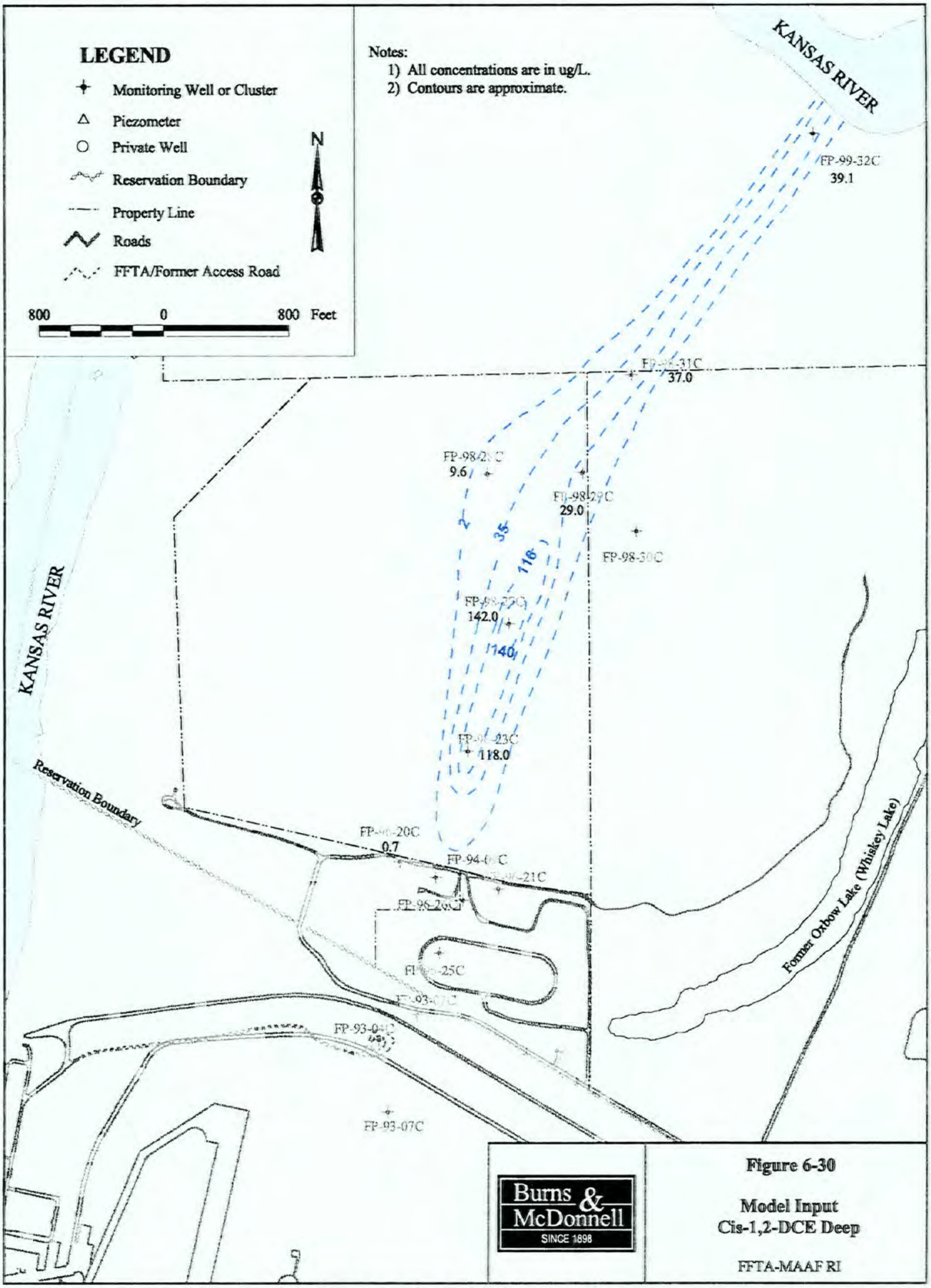
Burns & McDonnell
SINCE 1898

Figure 6-29

Model Input
Cis-1,2-DCE Intermediate

FFTA-MAAF RI

U:\archum... ..aview\rl_models.apr\doolnt_view\doolnt_RIformat_layout 12/10/99 LGB 1:9600



Notes:
1) All concentrations are in ug/L.
2) Contours are approximate.

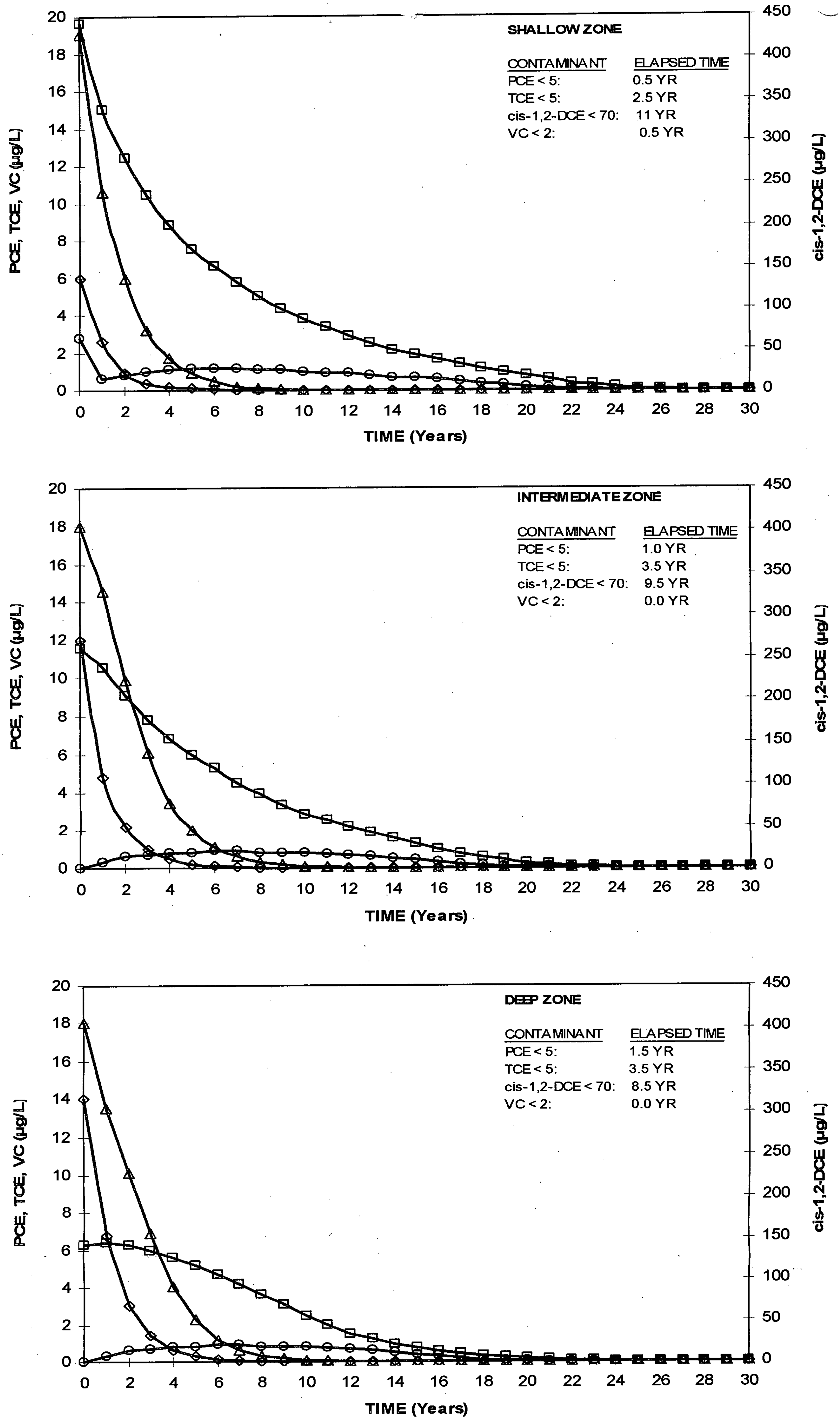
Burns & McDonnell
SINCE 1898

Figure 6-30

Model Input
Cis-1,2-DCE Deep

FFTA-MAAF RI

U:/arc/ush. ./view/ri_models.apr/docdeep_view/docdeep_RIformats_layout 12/10/99 LGB 1:9600



LEGEND

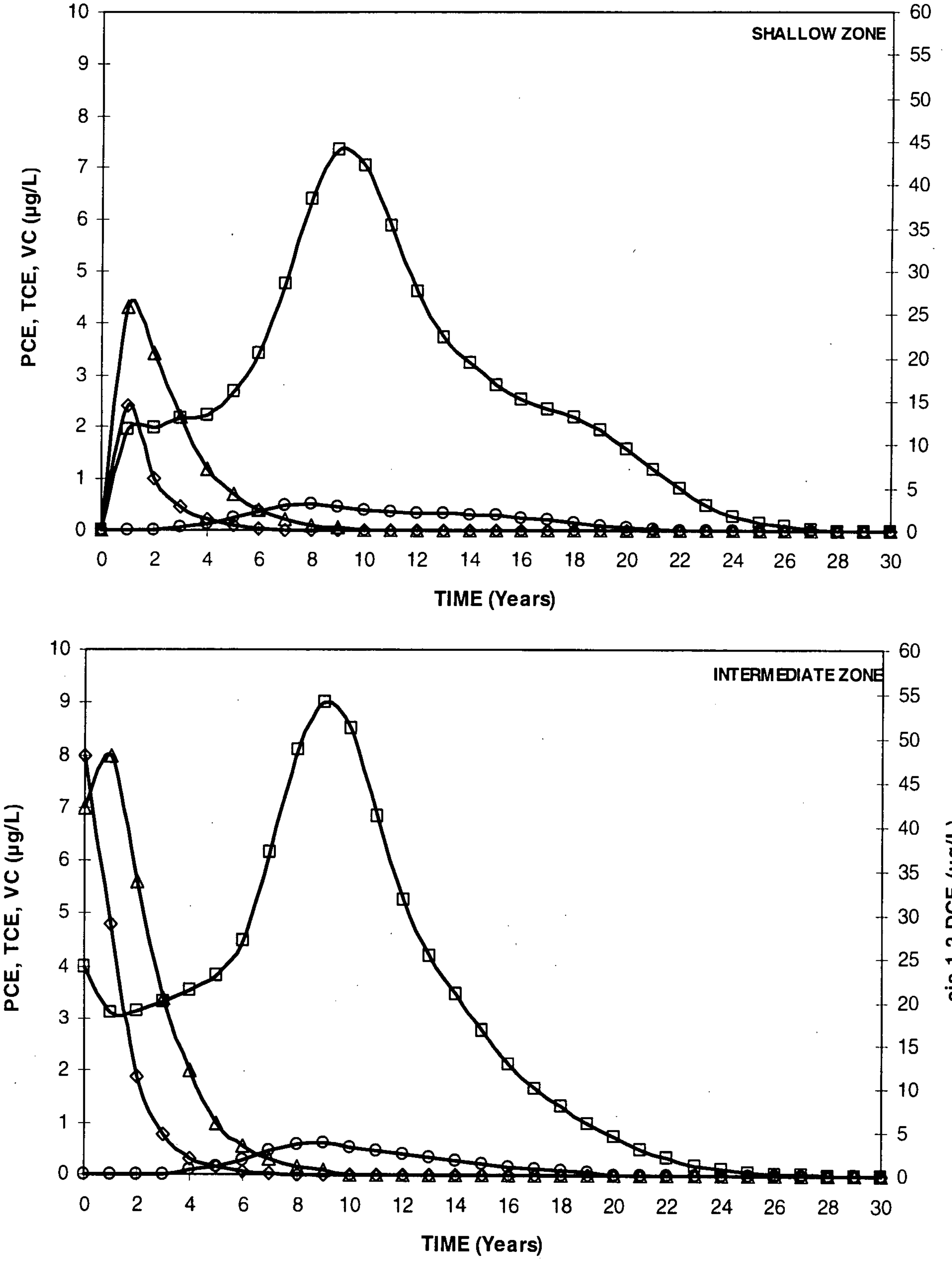
- ◇ PCE
- △ TCE
- □ cis-1,2-DCE
- ○ VC

Burns & McDonnell
SINCE 1898

Figure 6-31

Maximum Concentrations In Each Model Layer

FFTA-MAAF RI

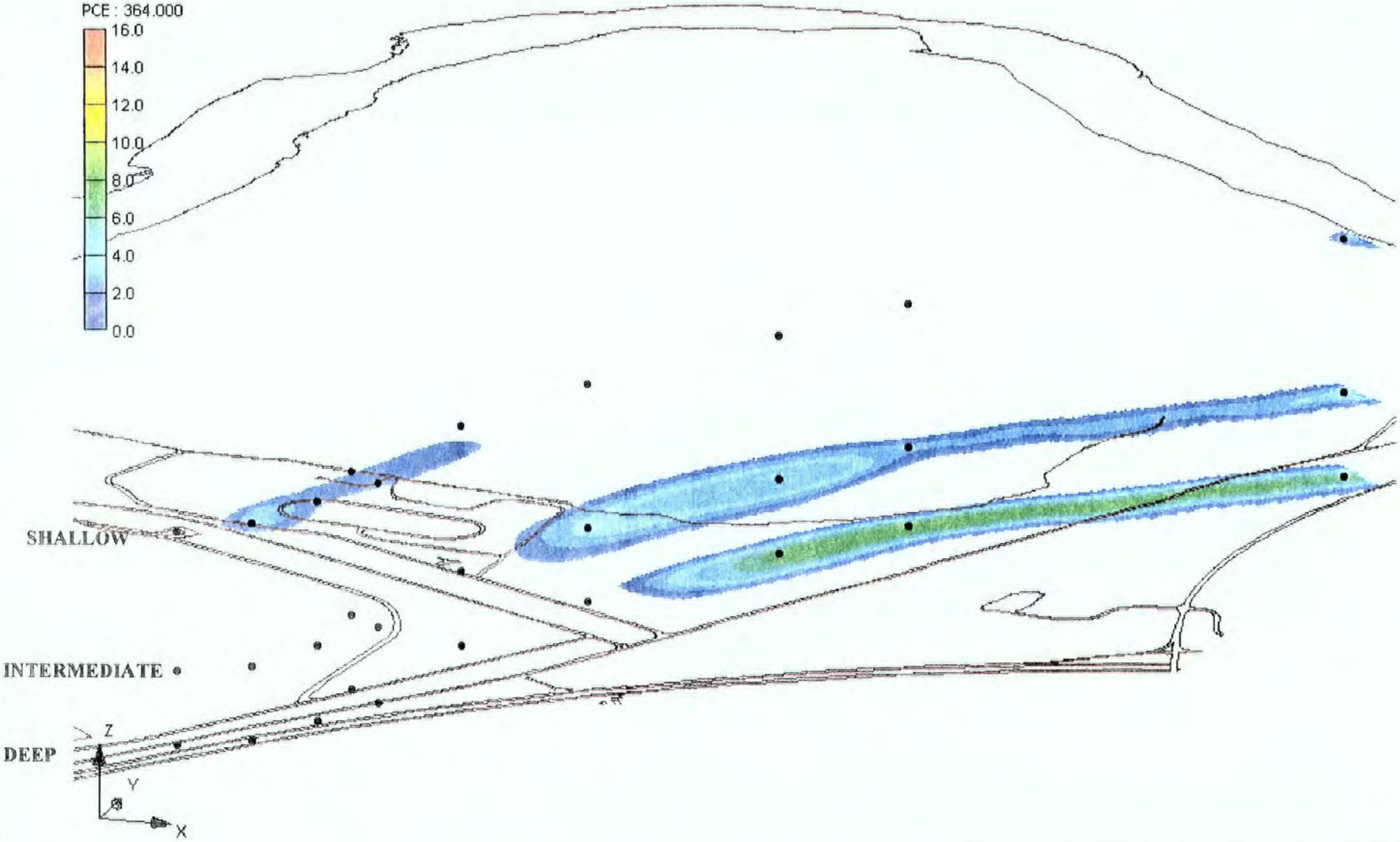


LEGEND
- ◇ PCE
- △ TCE
- □ cis-1,2-DCE
- ○ VC

Burns & McDonnell
SINCE 1898

Figure 6-32

Concentrations at the Kansas River



LEGEND

● Monitoring Well

NOTE:

- Only centerline monitoring wells are displayed
- Vertical exaggeration is 20X
- Concentrations below 1 ug/l are not displayed

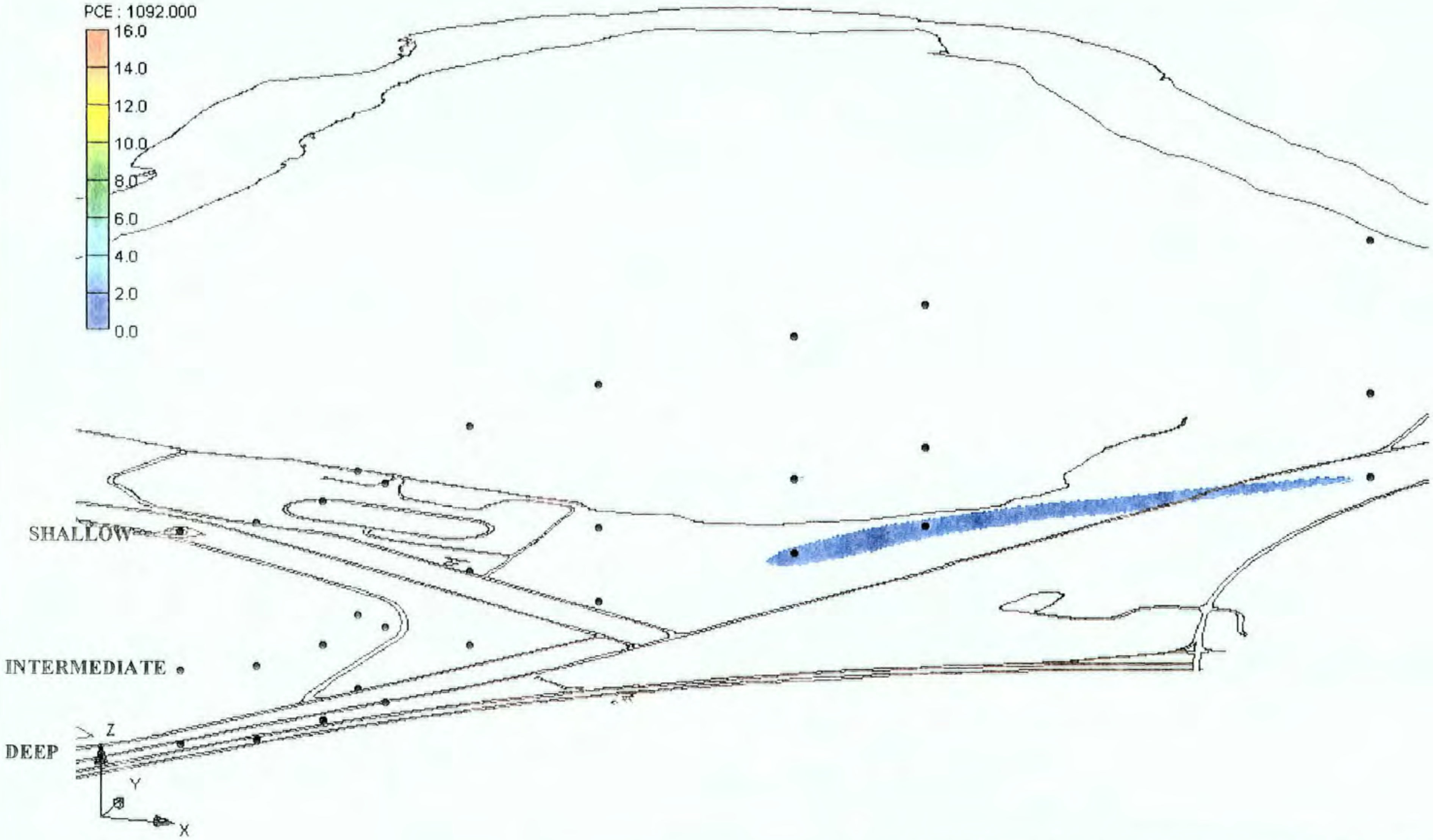
NOT TO SCALE

Burns & McDonnell
SINCE 1898

Figure 6-33

PCE Concentration at 1 year

FFTA-MAAF RI



LEGEND

● Monitoring Well

NOTE:

- Only centerline monitoring wells are displayed
- Vertical exaggeration is 20X
- Concentrations below 1 ug/l are not displayed

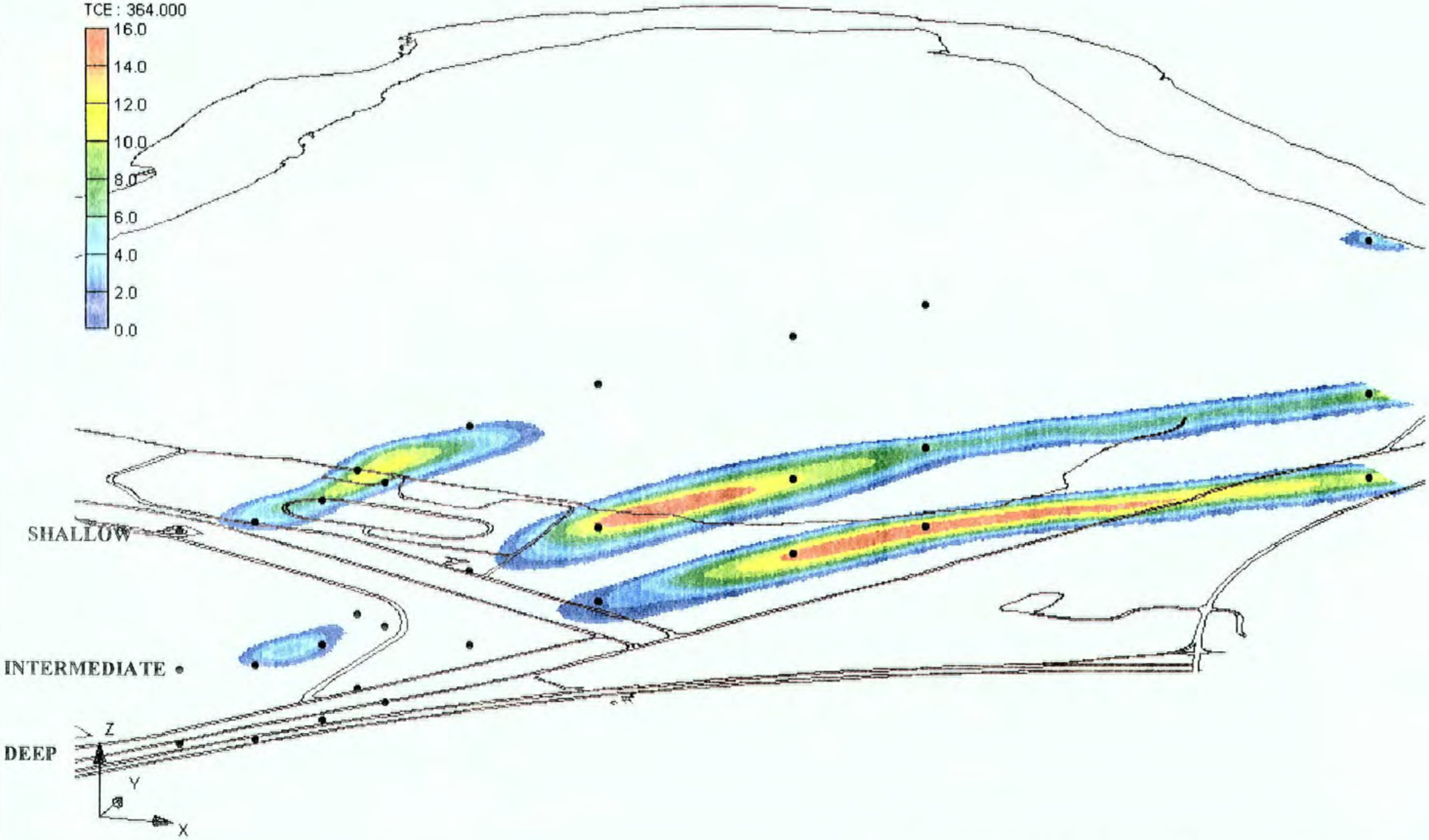
NOT TO SCALE

Burns & McDonnell
SINCE 1898

Figure 6-34

PCE Concentration at 3 years

FFTA-MAAF RI



LEGEND

● Monitoring Well

NOTE:

- Only centerline monitoring wells are displayed
- Vertical exaggeration is 20X
- Concentrations below 1 ug/l are not displayed

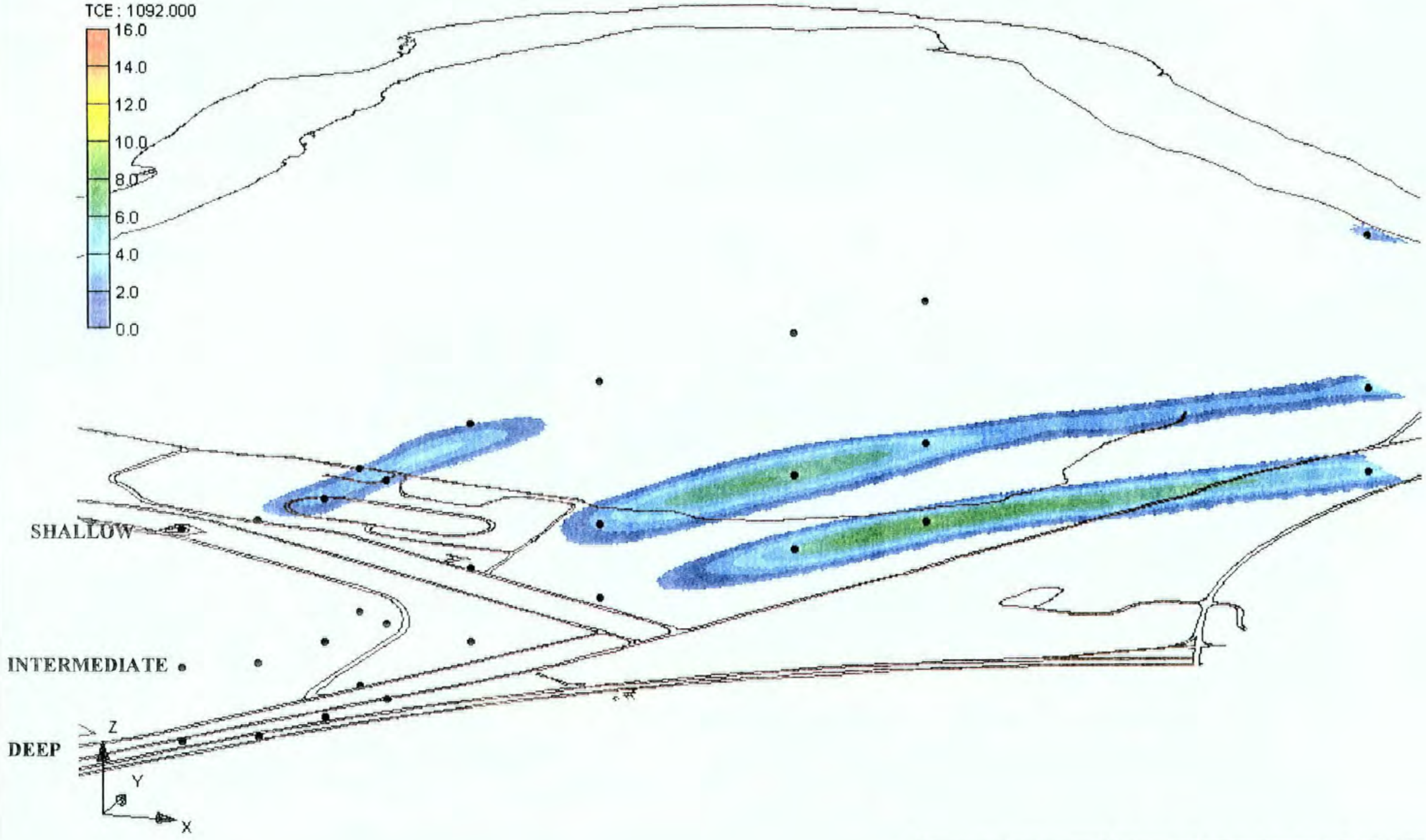
NOT TO SCALE

Burns & McDonnell
SINCE 1898

Figure 6-35

TCE Concentration at 1 year

FFTA-MAAF RI



LEGEND

● Monitoring Well

NOTE:

- Only centerline monitoring wells are displayed
- Vertical exaggeration is 20X
- Concentrations below 1 ug/l are not displayed

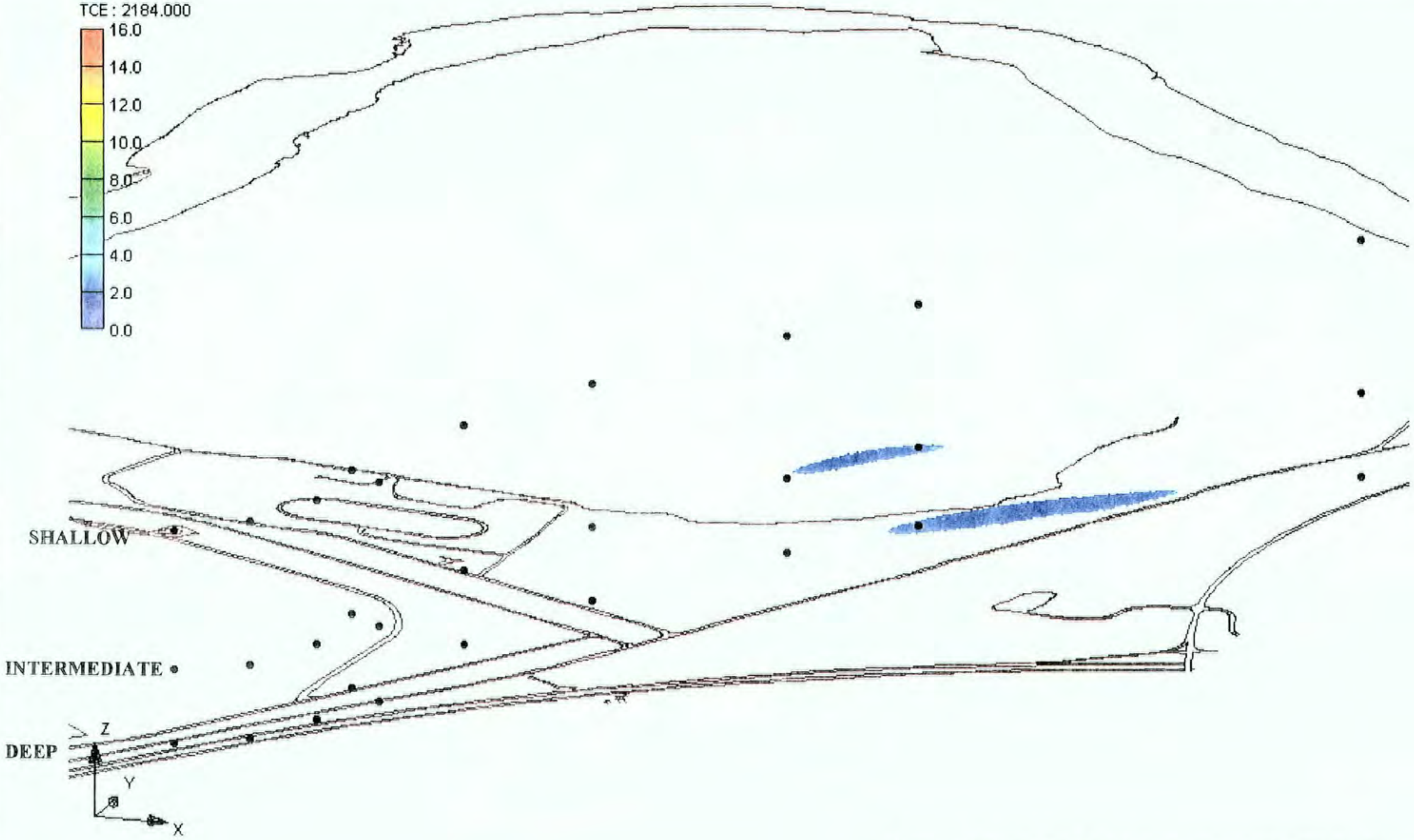
NOT TO SCALE

Burns & McDonnell SINCE 1898

Figure 6-36

TCE Concentration at 3 Years

FFTA-MAAF RI



LEGEND

- ● Monitoring Well

NOTE:

- Only centerline monitoring wells are displayed
- Vertical exaggeration is 20X
- Concentrations below 1 ug/l are not displayed

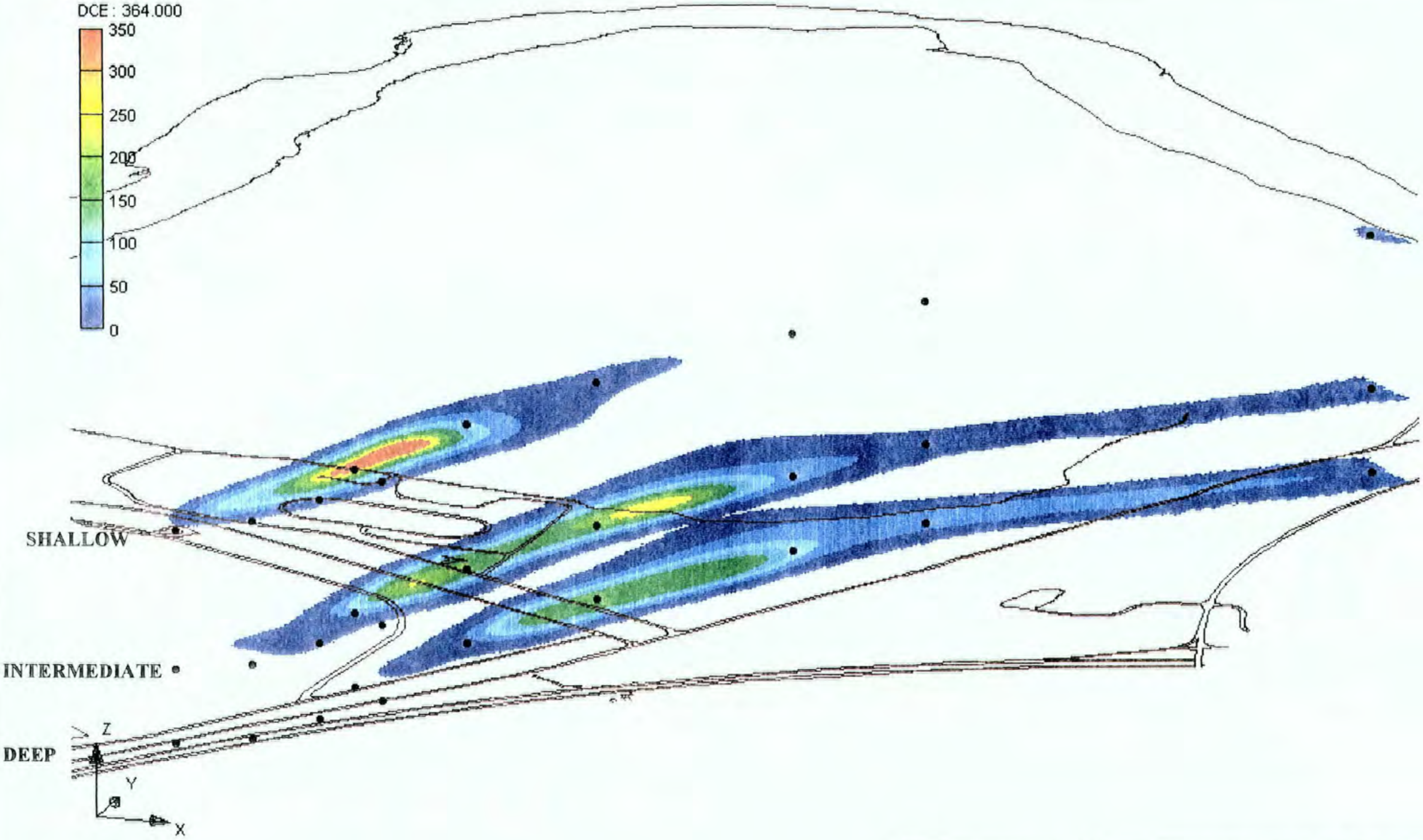
NOT TO SCALE

Burns & McDonnell
SINCE 1898

Figure 6-37

TCE Concentration at 6 Years

FFTA-MAAF RI



LEGEND

● Monitoring Well

NOTE:

- Only centerline monitoring wells are displayed
- Vertical exaggeration is 20X
- Concentrations below 5 ug/l are not displayed

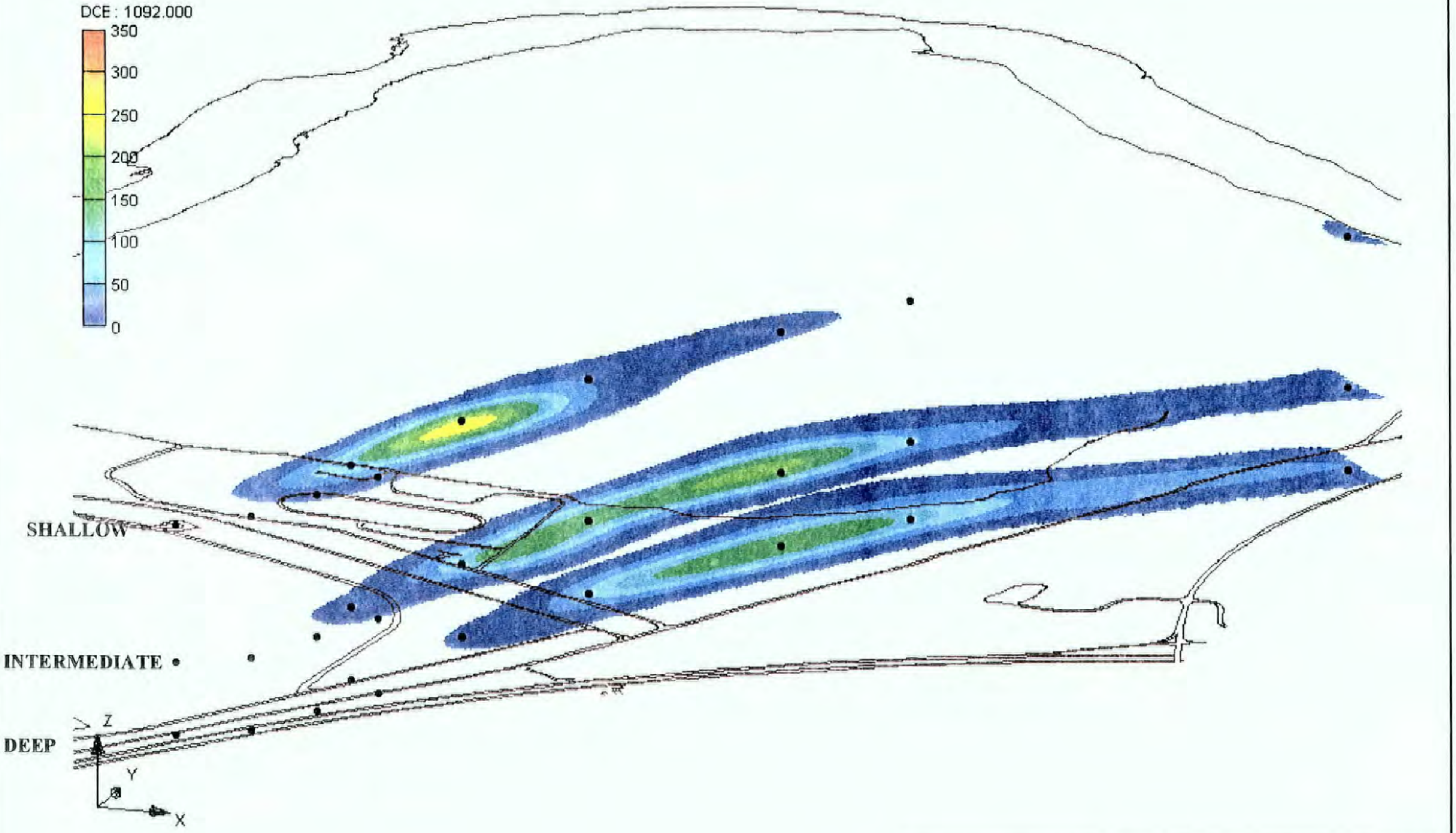
NOT TO SCALE

Burns & McDonnell
SINCE 1898

Figure 6-38

cis-1,2-DCE Concentration at 1 Year

FFTA-MAAF RI



LEGEND

● Monitoring Well

NOTE:

- Only centerline monitoring wells are displayed
- Vertical exaggeration is 20X
- Concentrations below 5 ug/l are not displayed

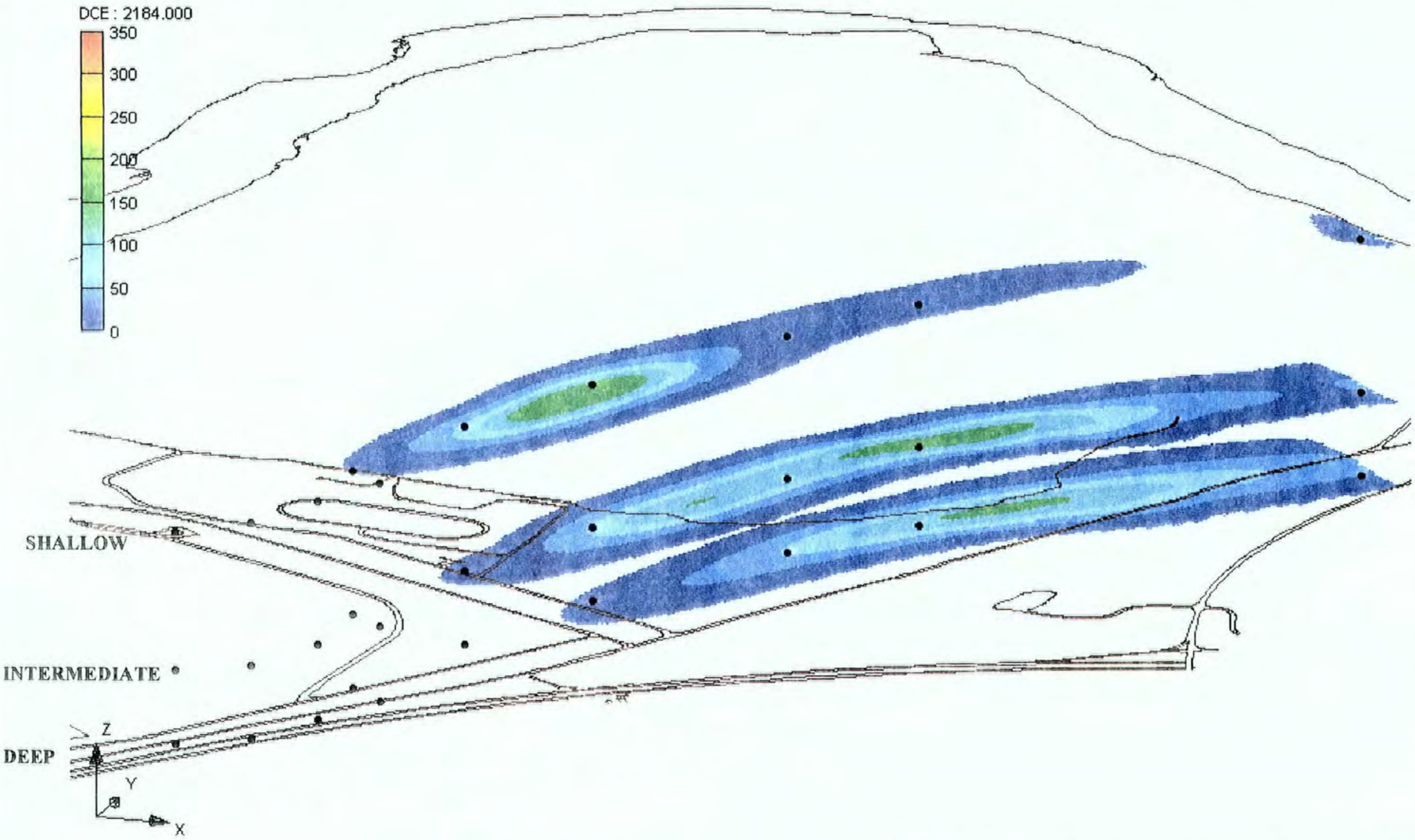
NOT TO SCALE

Burns & McDonnell
SINCE 1898

Figure 6-39

cis-1,2-DCE Concentration at 3 Years

FFTA-MAAF RI



LEGEND

● Monitoring Well

NOTE:

- Only centerline monitoring wells are displayed
- Vertical exaggeration is 20X
- Concentrations below 5 ug/l are not displayed

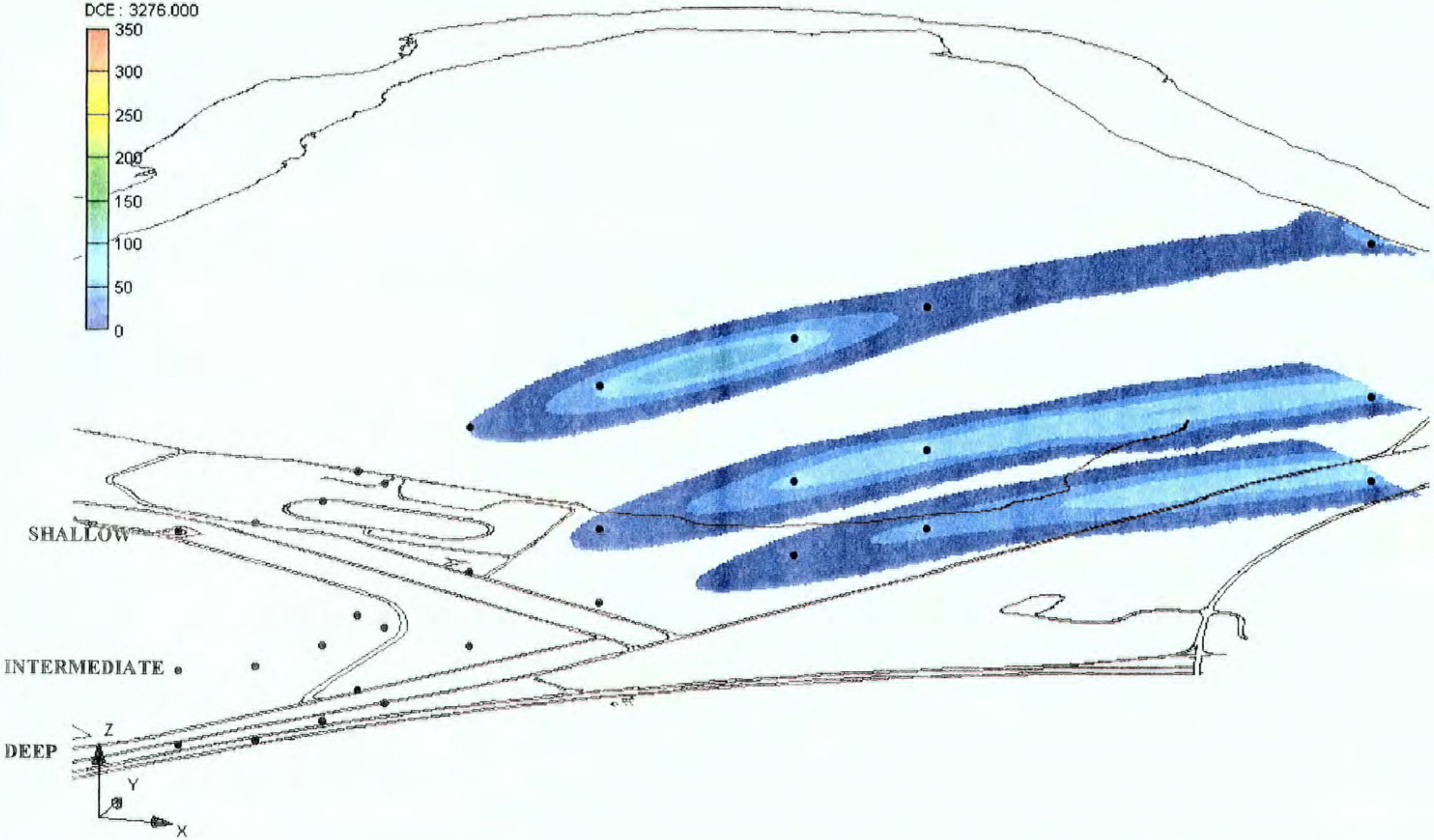
NOT TO SCALE

Burns & McDonnell
SINCE 1898

Figure 6-40

cis-1,2-DCE Concentration at 6 Years

FFTA-MAAF RI



LEGEND

● Monitoring Well

NOTE:

- Only centerline monitoring wells are displayed
- Vertical exaggeration is 20X
- Concentrations below 5 ug/l are not displayed

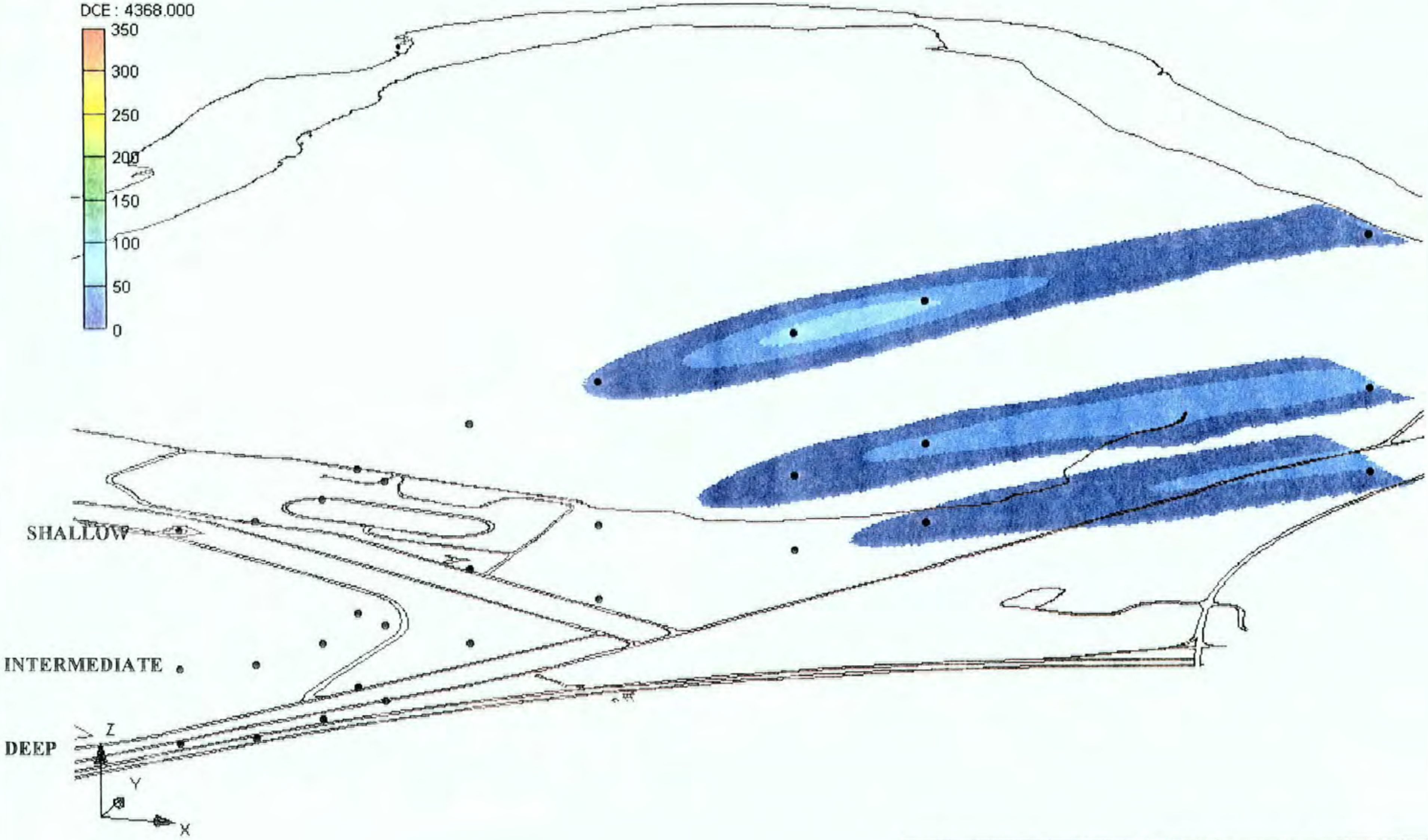
NOT TO SCALE

Burns & McDonnell
SINCE 1898

Figure 6-41

cis-1,2-DCE Concentration at 9 Years

FFTA-MAAF RI



LEGEND

● Monitoring Well

NOTE:
- Only centerline monitoring wells are displayed
- Vertical exaggeration is 20X
- Concentrations below 5 ug/l are not displayed

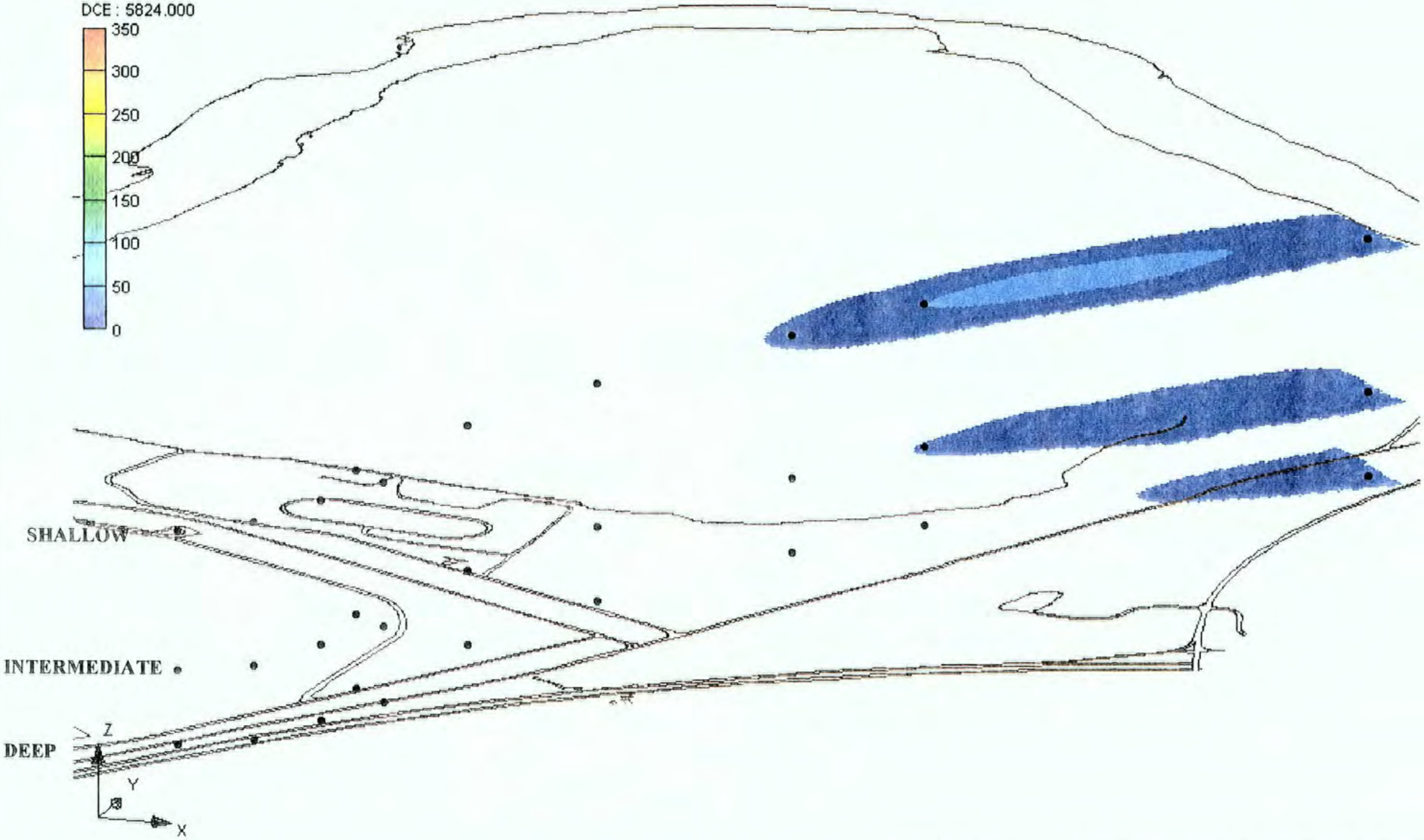
NOT TO SCALE

Burns & McDonnell
SINCE 1898

Figure 6-42

cis-1,2-DCE Concentration at 12 Years

FFTA-MAAF RI



LEGEND

● Monitoring Well

NOTE:

- Only centerline monitoring wells are displayed
- Vertical exaggeration is 20X
- Concentrations below 5 ug/l are not displayed

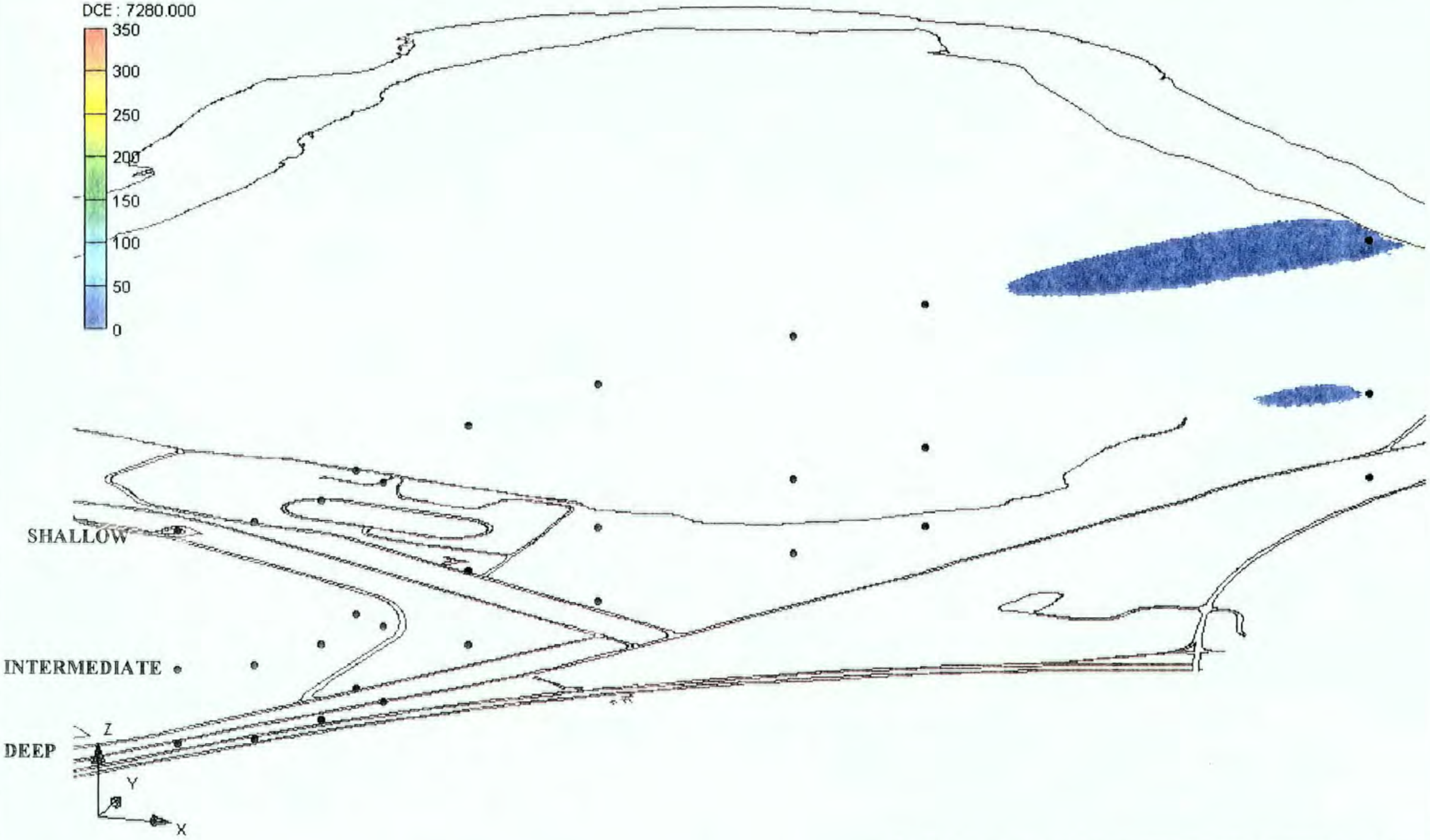
NOT TO SCALE

Burns & McDonnell
SINCE 1898

Figure 6-43

cis-1,2 DCE Concentration at 16 Years

FFTA-MAAF RI



LEGEND

- ● Monitoring Well

NOTE:

- Only centerline monitoring wells are displayed
- Vertical exaggeration is 20X
- Concentrations below 5 ug/l are not displayed

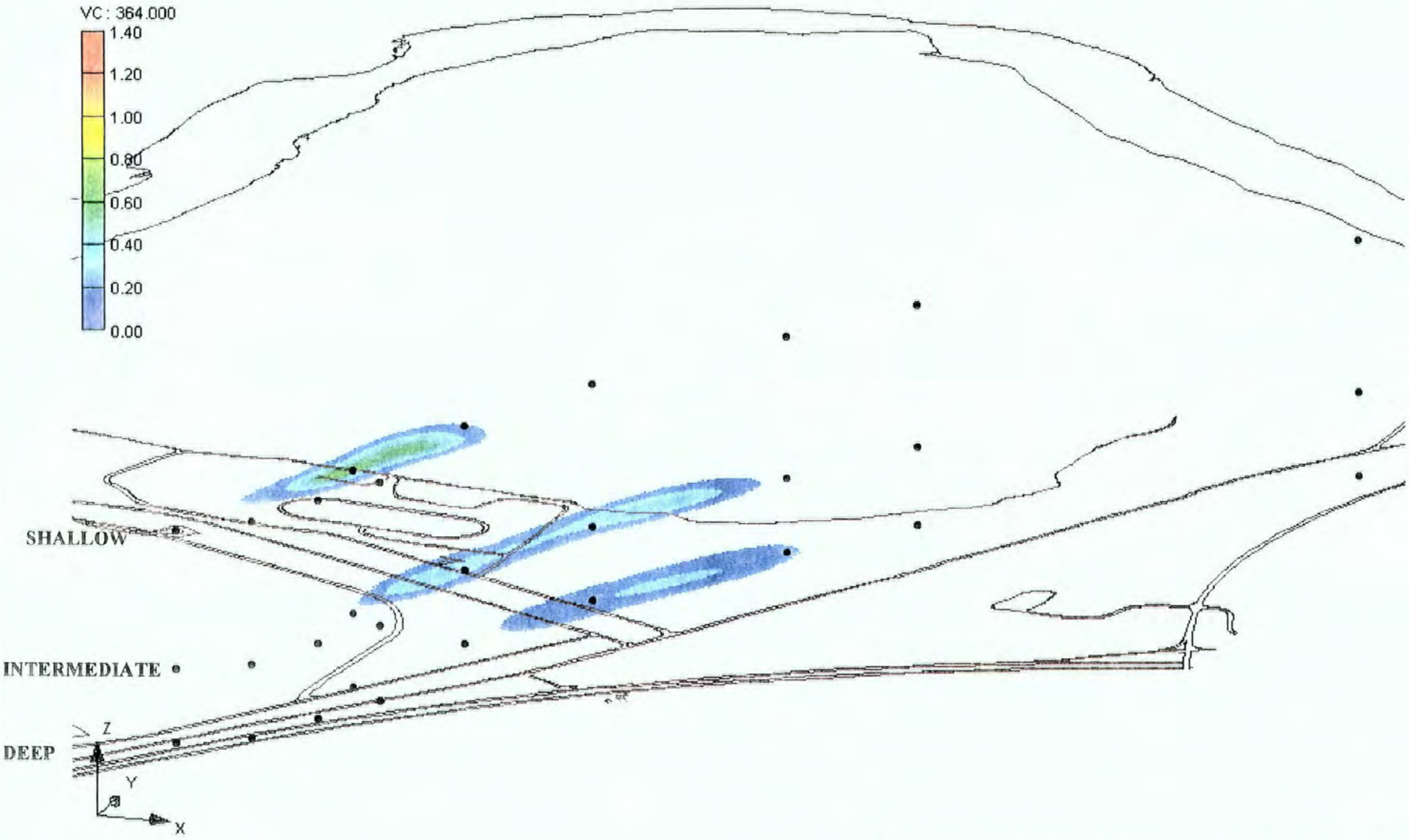
NOT TO SCALE

Burns & McDonnell
SINCE 1898

Figure 6-44

cis-1,2 DCE Concentration at 20 Years

FFTA-MAAF RI



LEGEND

● Monitoring Well

NOTE:
- Only centerline monitoring wells are displayed
- Vertical exaggeration is 20X
- Concentrations below 0.1 ug/l are not displayed

N

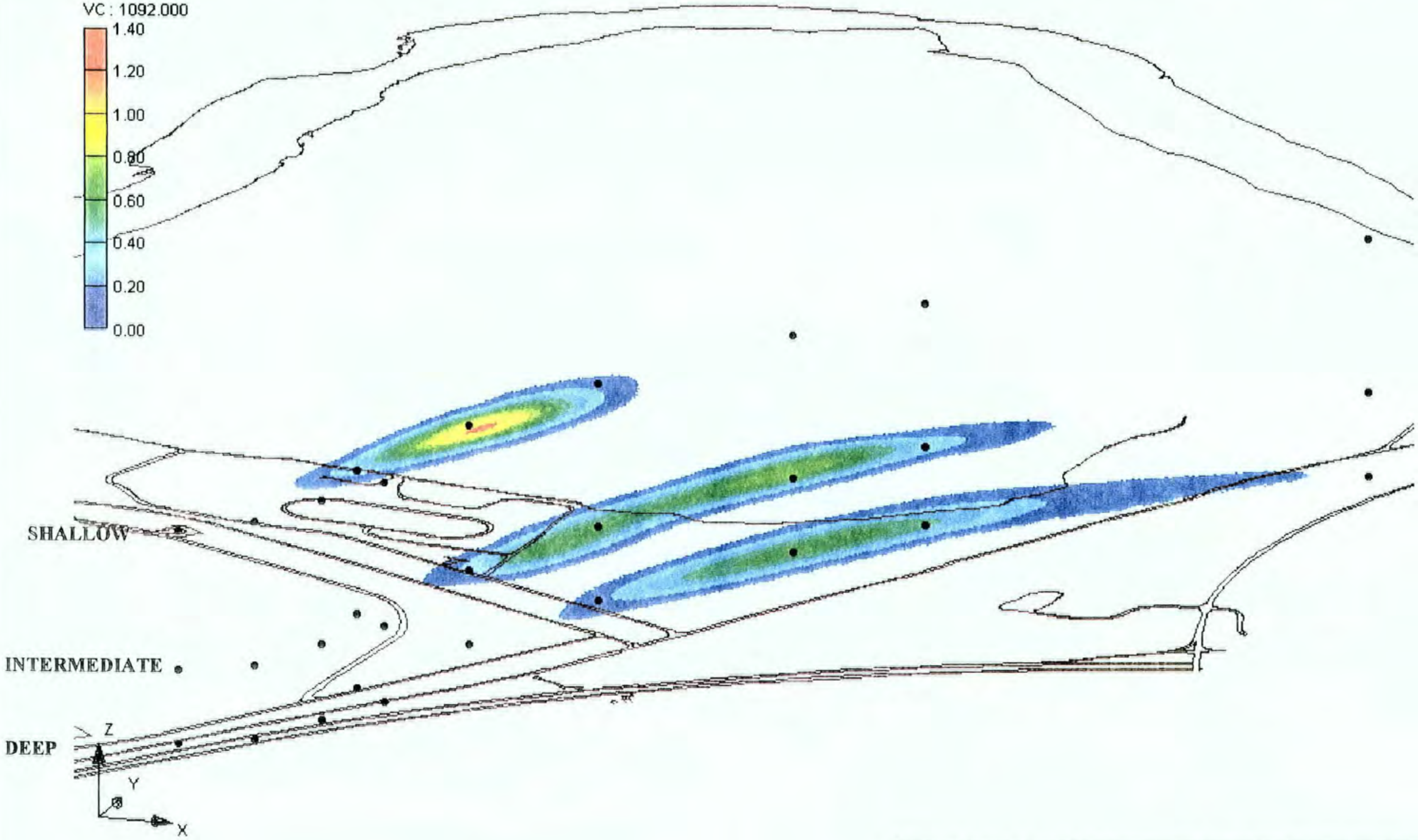
NOT TO SCALE

Burns & McDonnell
SINCE 1898

Figure 6-45

VC Concentration at 1 Year

FFTA-MAAF RI



LEGEND

● Monitoring Well

NOTE:

- Only centerline monitoring wells are displayed
- Vertical exaggeration is 20X
- Concentrations below 0.1 ug/l are not displayed

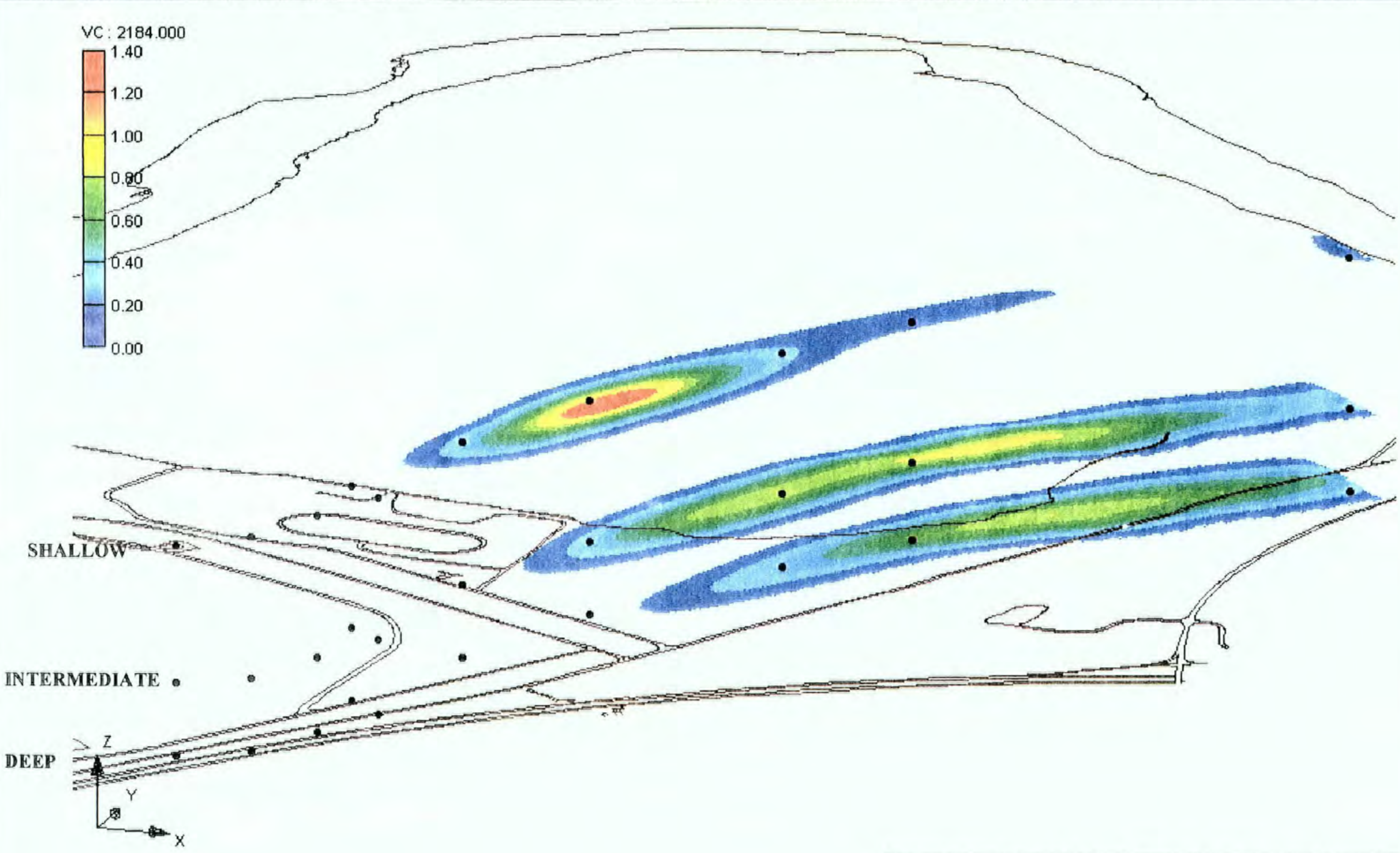
NOT TO SCALE

Burns & McDonnell
SINCE 1898

Figure 6-46

VC Concentration at 3 Years

FFTA-MAAF RI



LEGEND

● Monitoring Well

NOTE:

- Only centerline monitoring wells are displayed
- Vertical exaggeration is 20X
- Concentrations below 0.1 ug/l are not displayed

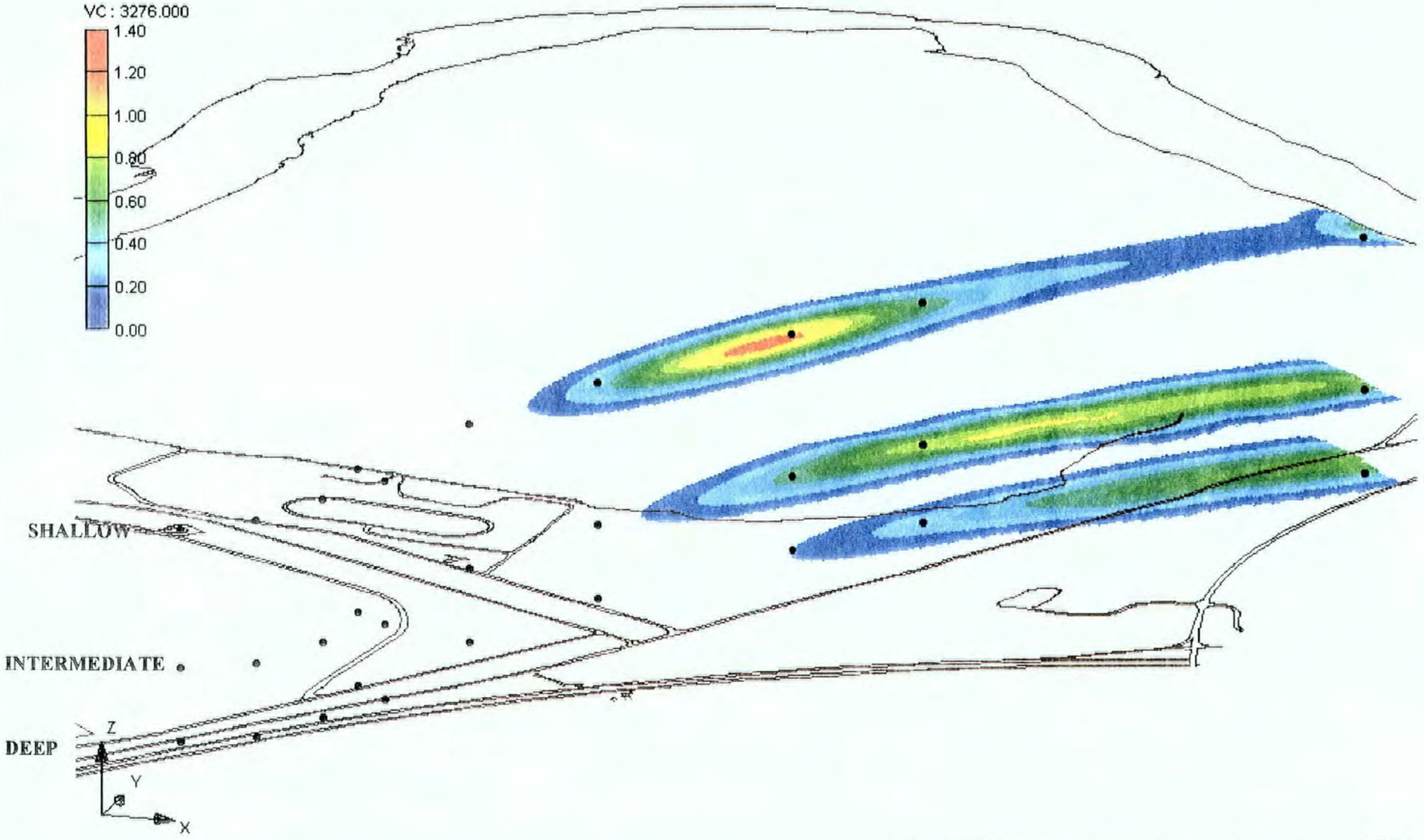
NOT TO SCALE

Burns & McDonnell
SINCE 1898

Figure 6-47

VC Concentration at 6 Years

FFTA-MAAF RI



LEGEND

● Monitoring Well

NOTE:
- Only centerline monitoring wells are displayed
- Vertical exaggeration is 20X
- Concentrations below 0.1 ug/l are not displayed

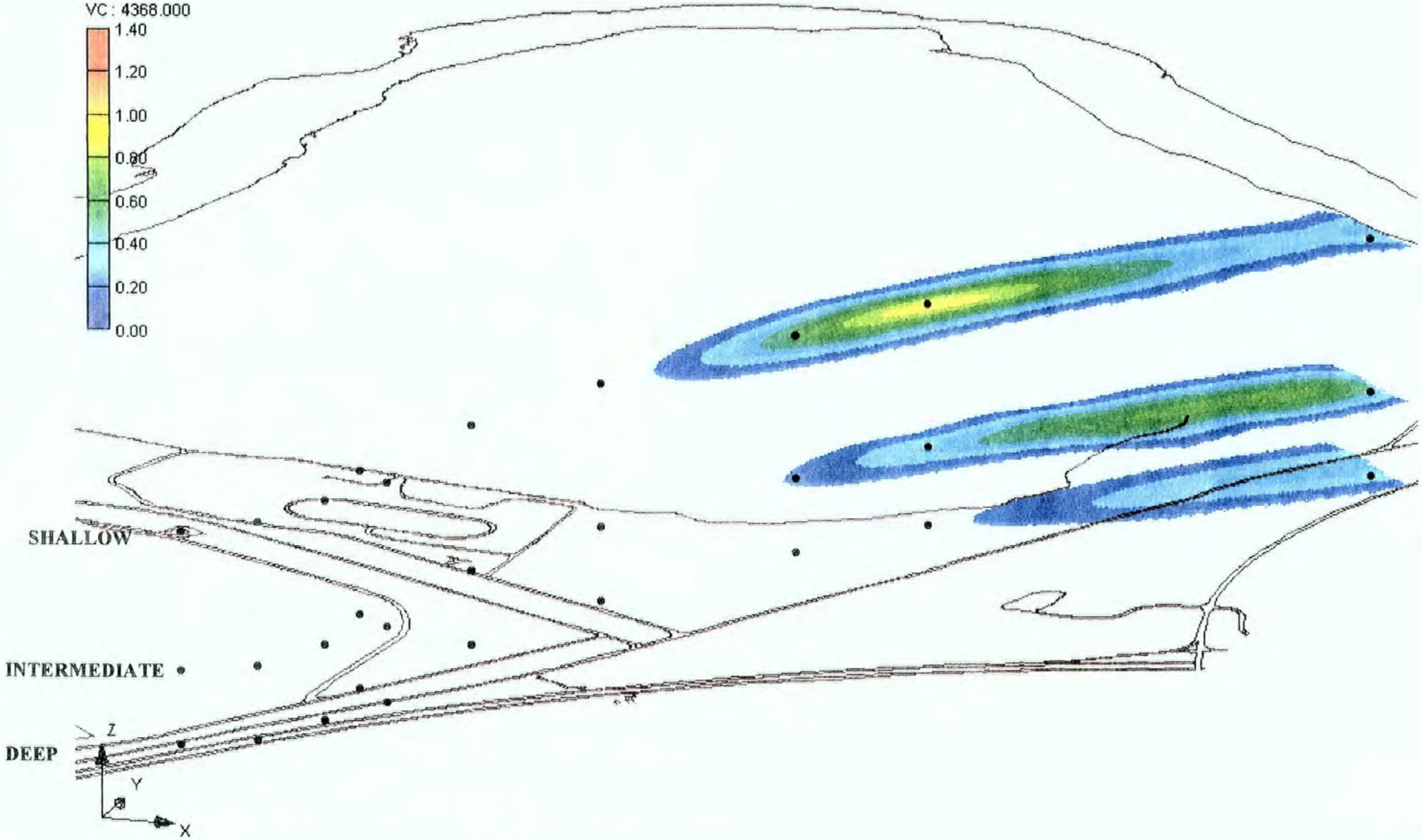
NOT TO SCALE

Burns & McDonnell SINCE 1898

Figure 6-48

VC Concentration at 9 Years

FFTA-MAAF RI



LEGEND

● Monitoring Well

NOTE:

- Only centerline monitoring wells are displayed
- Vertical exaggeration is 20X
- Concentrations below 0.1 ug/l are not displayed

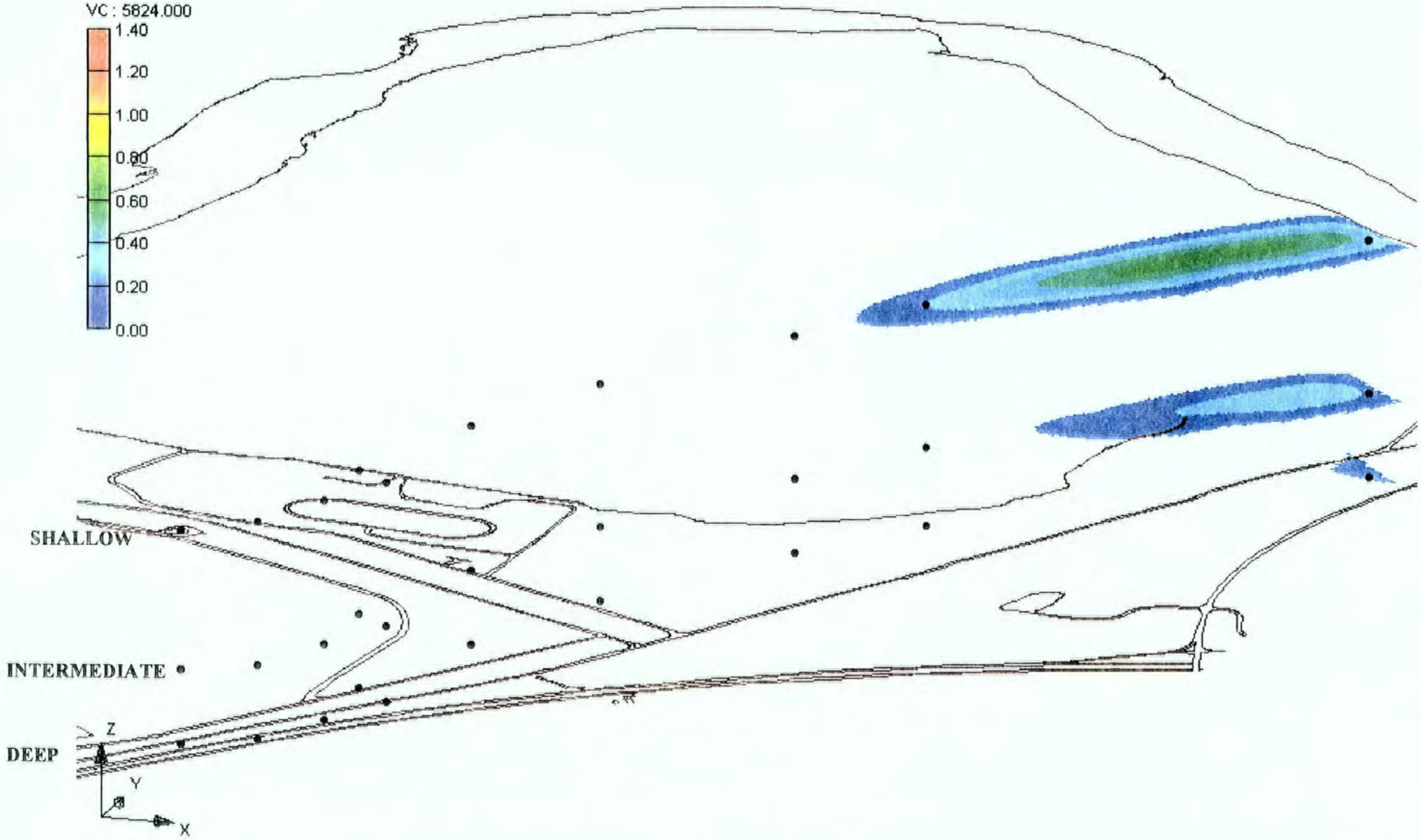
NOT TO SCALE

Burns & McDonnell
SINCE 1898

Figure 6-49

VC Concentration at 12 Years

FFTA-MAAF RI



LEGEND

- ● Monitoring Well

NOTE:

- Only centerline monitoring wells are displayed
- Vertical exaggeration is 20X
- Concentrations below 0.1 ug/l are not displayed

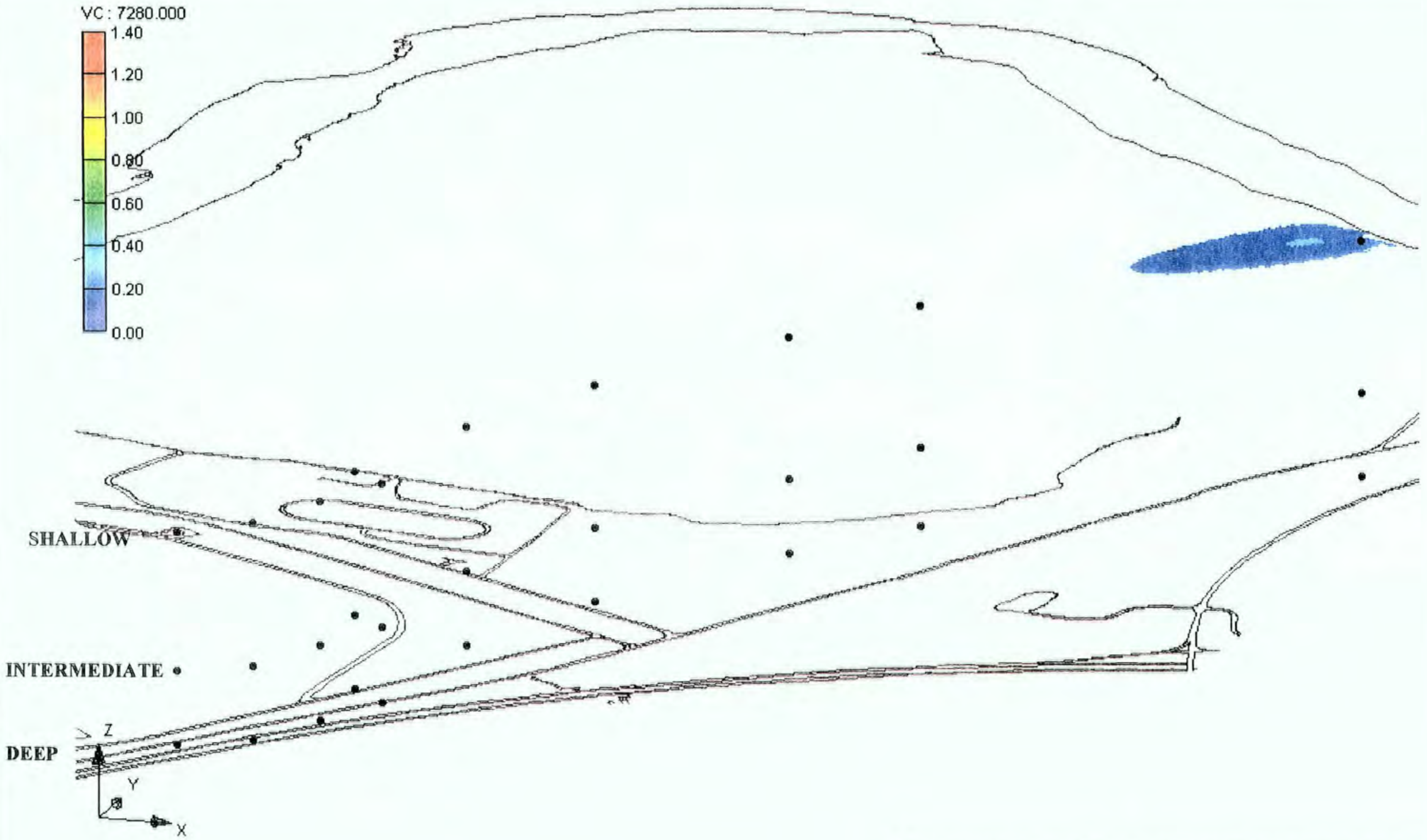
NOT TO SCALE

Burns & McDonnell
SINCE 1898

Figure 6-50

VC Concentration at 16 Years

FFTA-MAAF RI



LEGEND

● Monitoring Well

NOTE:

- Only centerline monitoring wells are displayed
- Vertical exaggeration is 20X
- Concentrations below 0.1 ug/l are not displayed

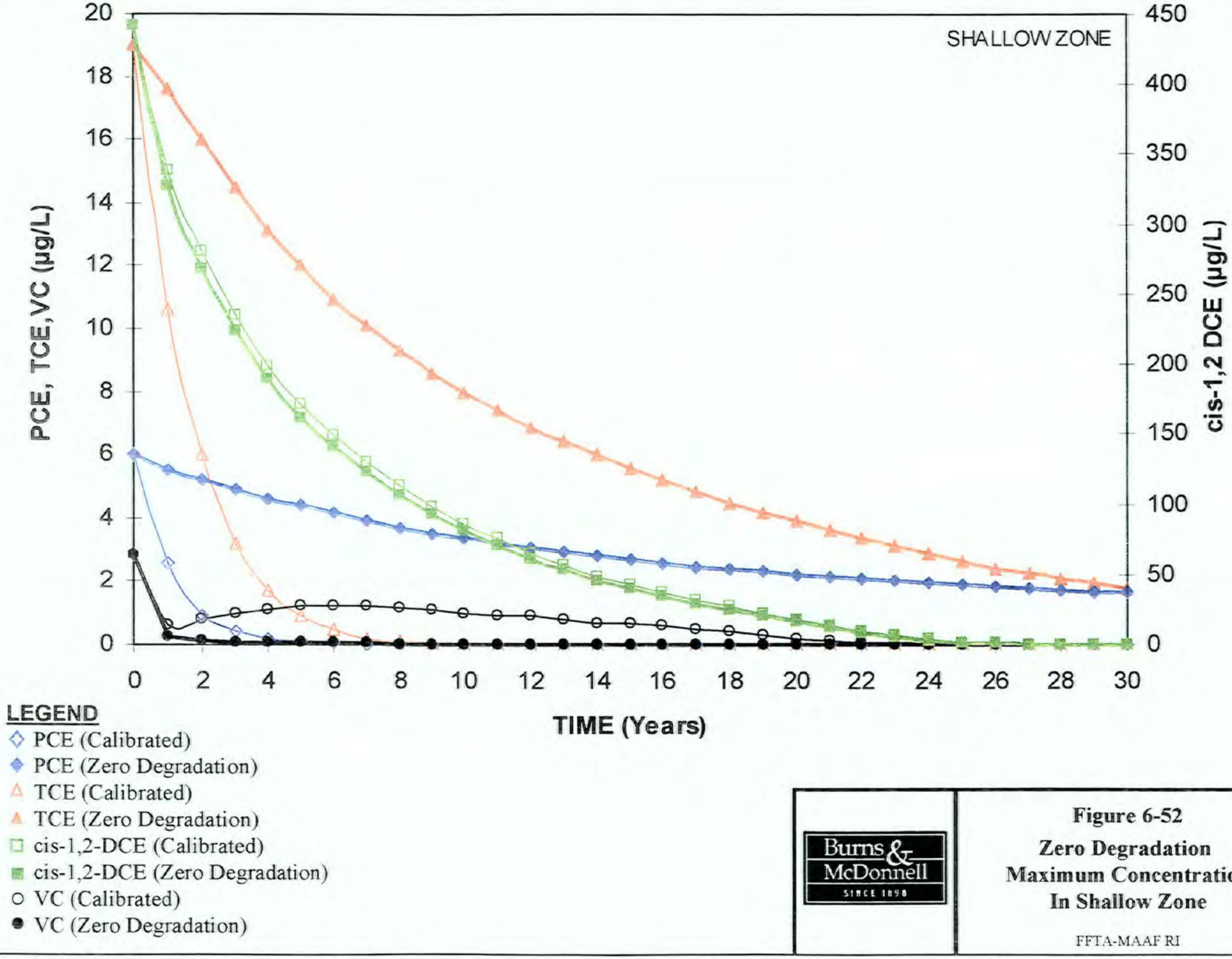
NOT TO SCALE

Burns & McDonnell
SINCE 1898

Figure 6-51

VC Concentration at 20 Years

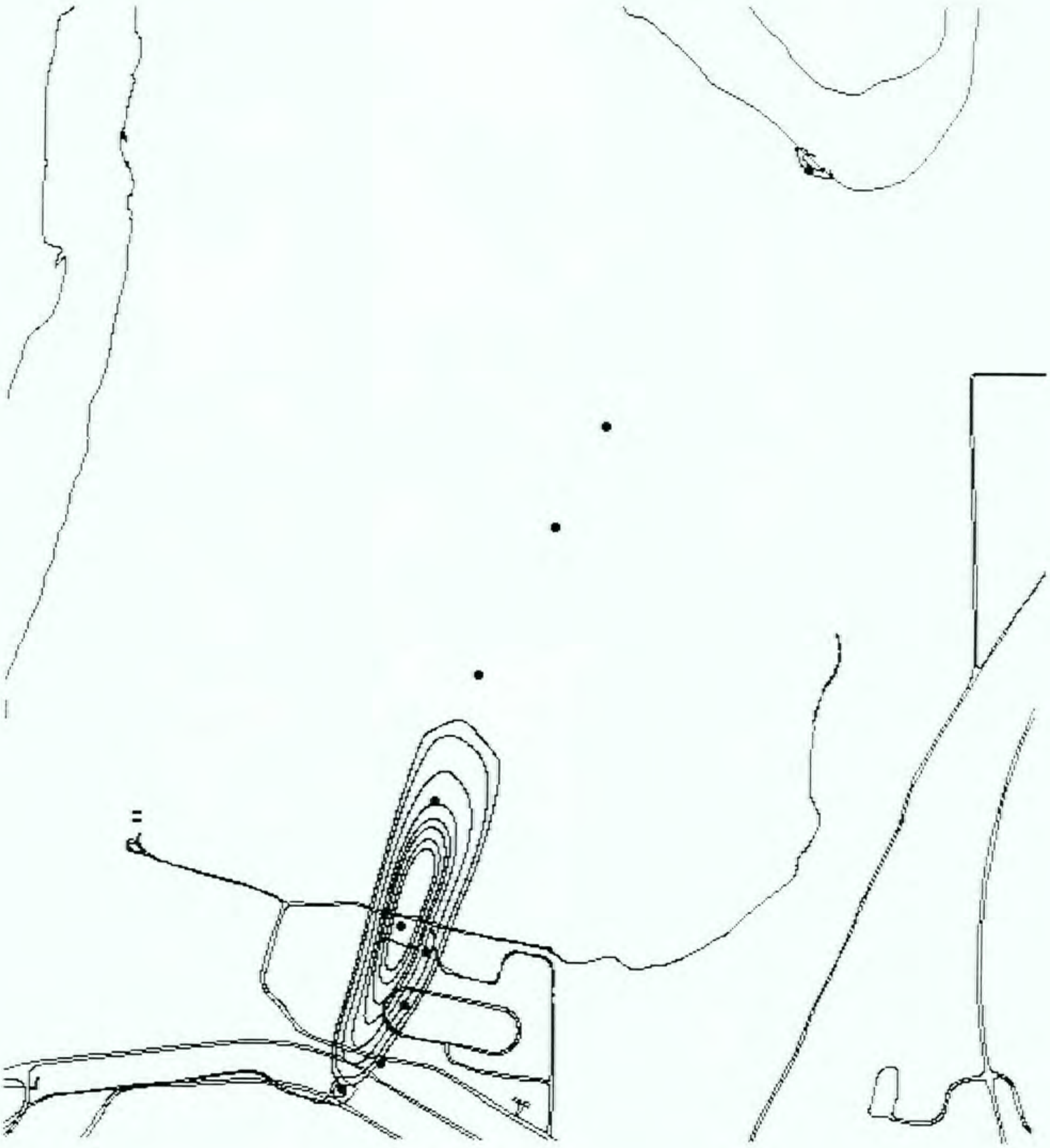
FFTA-MAAF RI



Burns & McDonnell
SINCE 1898

Figure 6-52
Zero Degradation
Maximum Concentration
In Shallow Zone

FFTA-MAAF RI



LEGEND

- ● Monitoring Well

NOTE:

- Only centerline monitoring wells are displayed
- Concentration interval is 5, 10, 25, 50, 75, 100, 150, and 200 µg/L

N

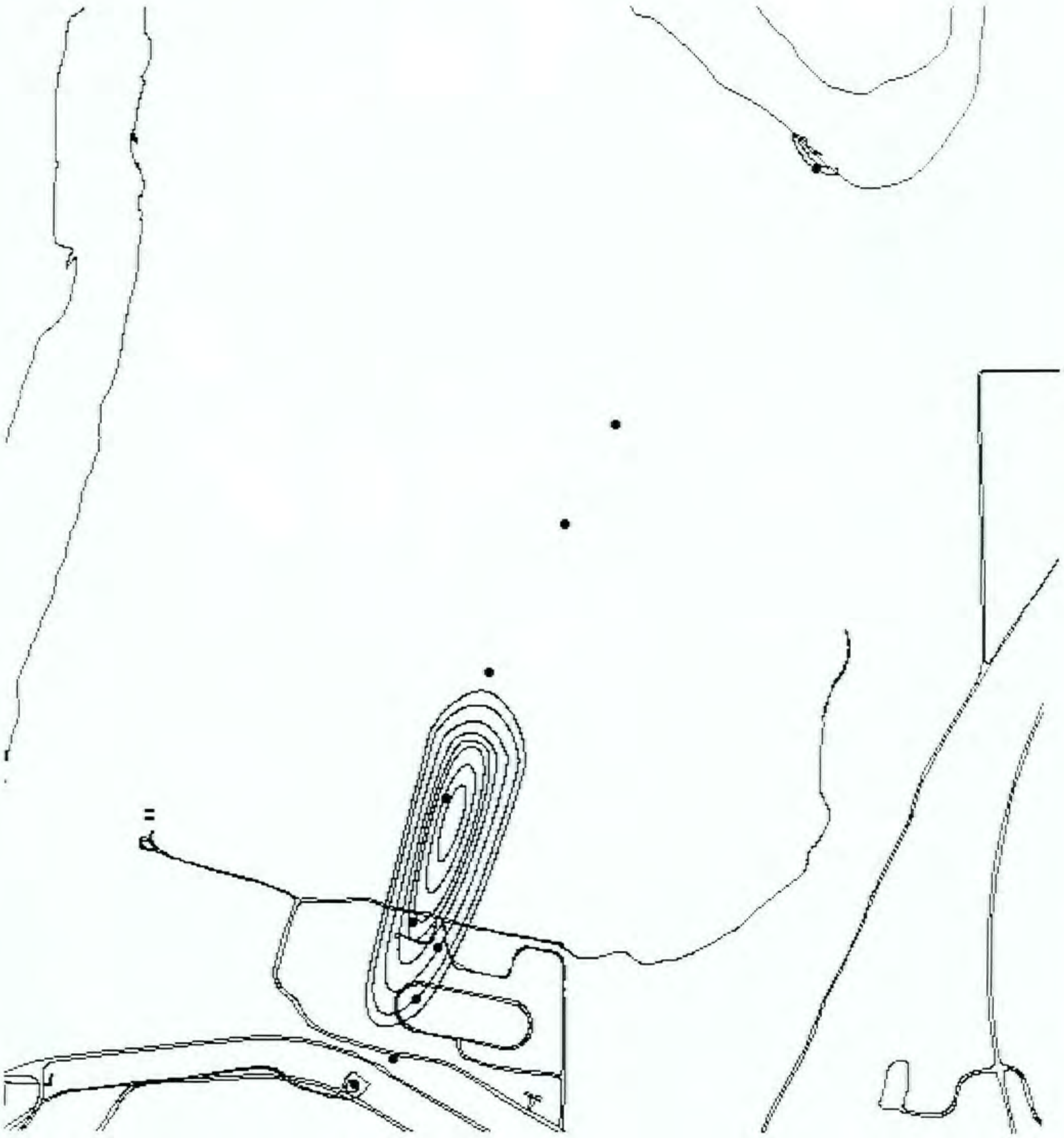
NOT TO SCALE

Burns & McDonnell
SINCE 1898

Figure 6-53

Aerobic Model cis-1,2-DCE Concentration at 1 Year

FFTA-MAAF RI



LEGEND

- ● Monitoring Well

NOTE:

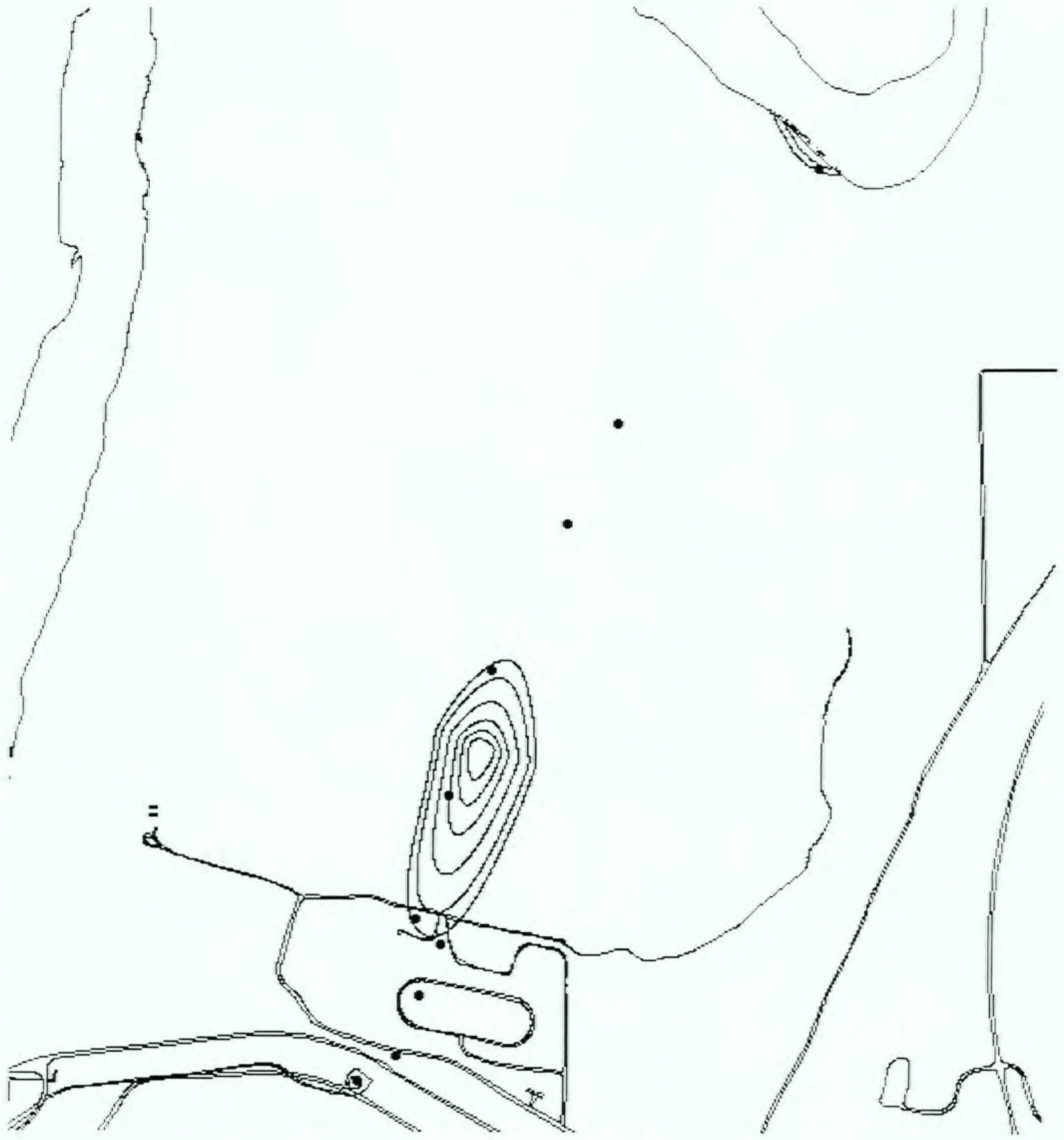
- Only centerline monitoring wells are displayed
- Concentration interval is 5, 10, 25, 50, 75, 100, 150, and 200 µg/L

NOT TO SCALE

Burns & McDonnell
SINCE 1898

Figure 6-54

Aerobic Model cis-1,2-DCE Concentration at 3 Years



LEGEND

- Monitoring Well

NOTE:

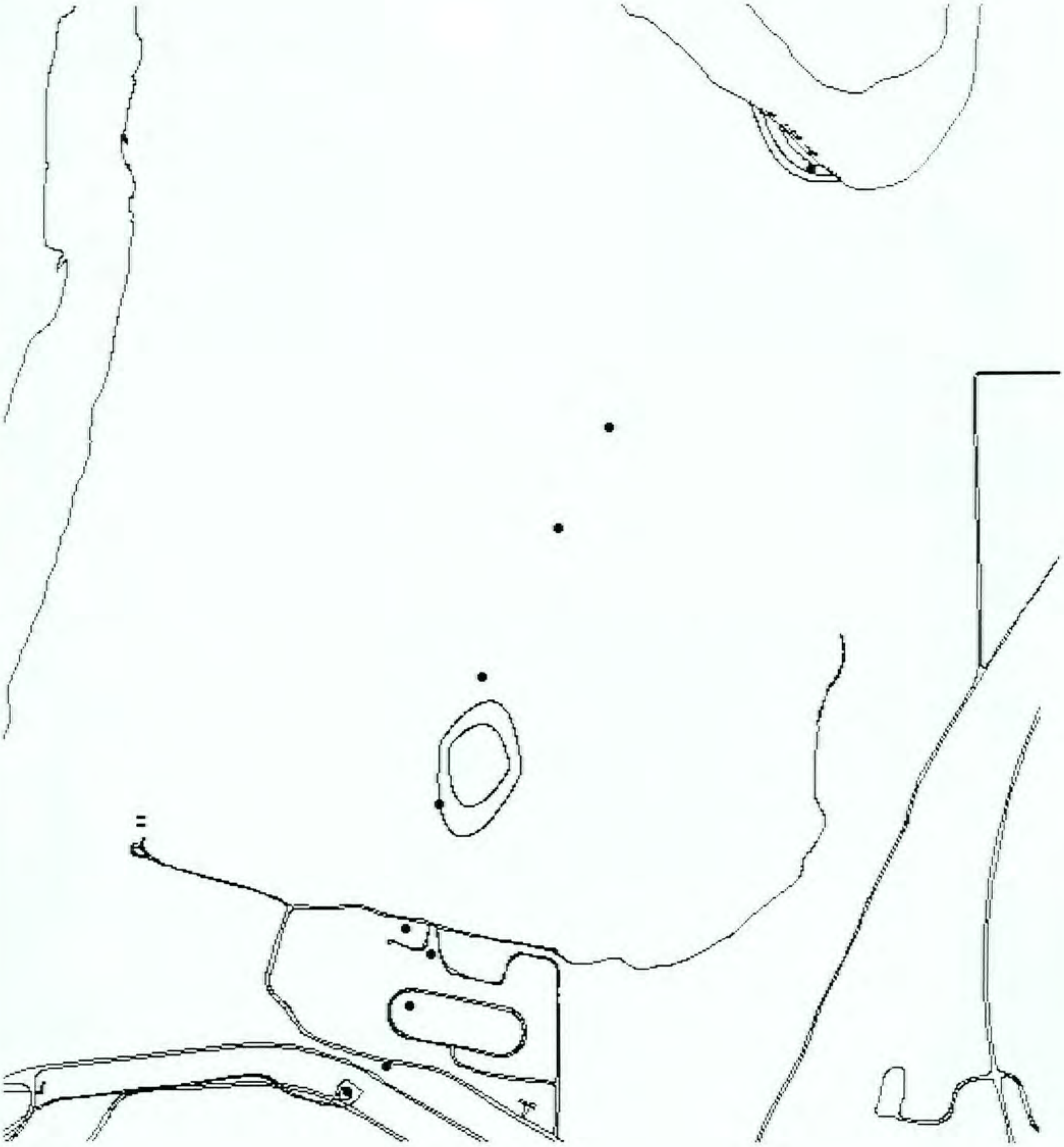
- Only centerline monitoring wells are displayed
- Concentration interval is 5, 10, 25, 50, 75, 100, 150, and 200 µg/L

Burns & McDonnell
SINCE 1898

Figure 6-55

Aerobic Model
cis-1,2-DCE Concentration
at 6 Years

FFTA-MAAF RI



LEGEND

- ● Monitoring Well

NOTE:

- Only centerline monitoring wells are displayed
- Concentration interval is 5, 10, 25, 50, 75, 100, 150, and 200 µg/L

N

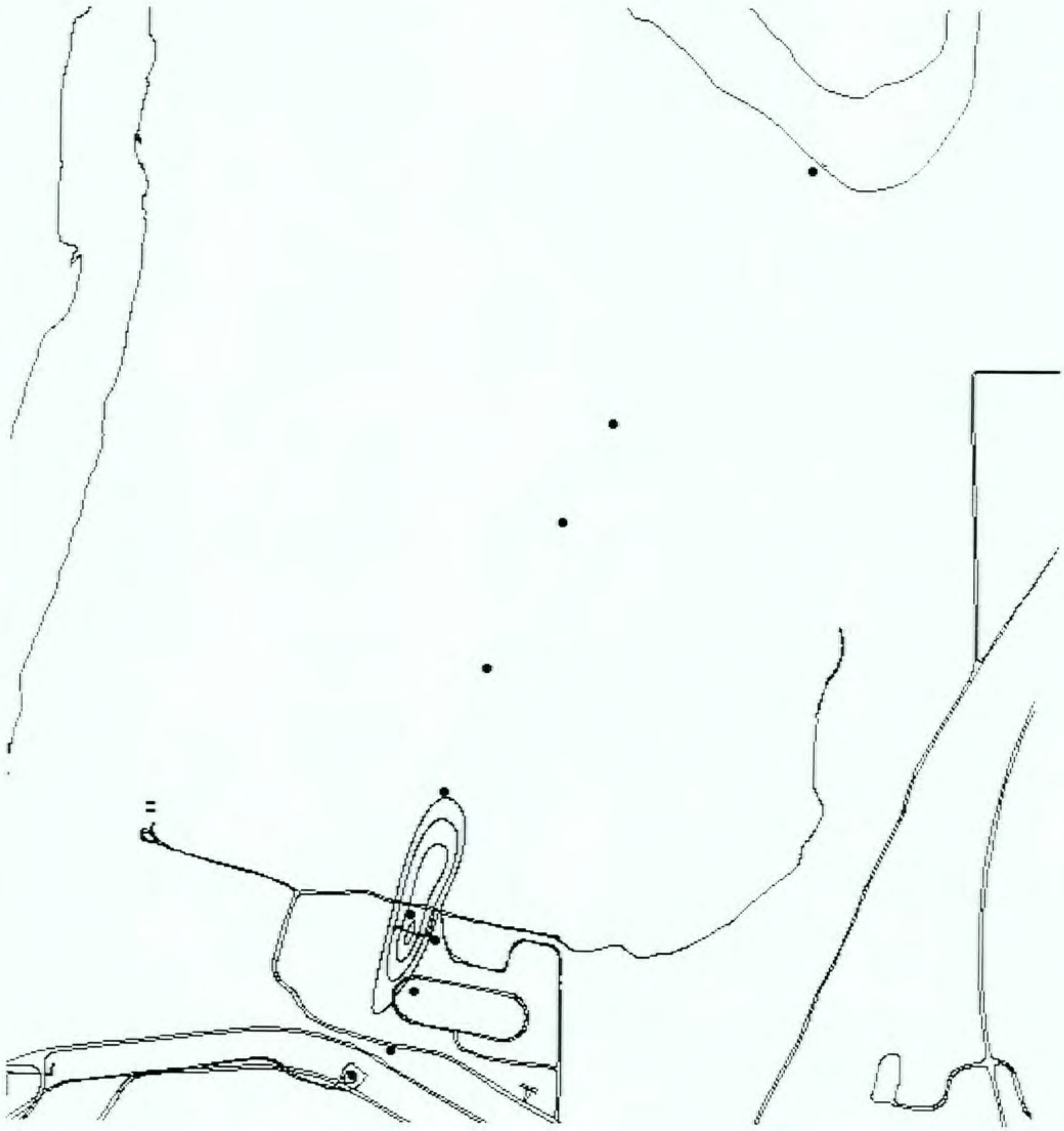
NOT TO SCALE

Burns & McDonnell
SINCE 1898

Figure 6-56

Aerobic Model
cis-1,2-DCE Concentration
at 9 Years

FFTA-MAAF RI



LEGEND

- Monitoring Well

NOTE:

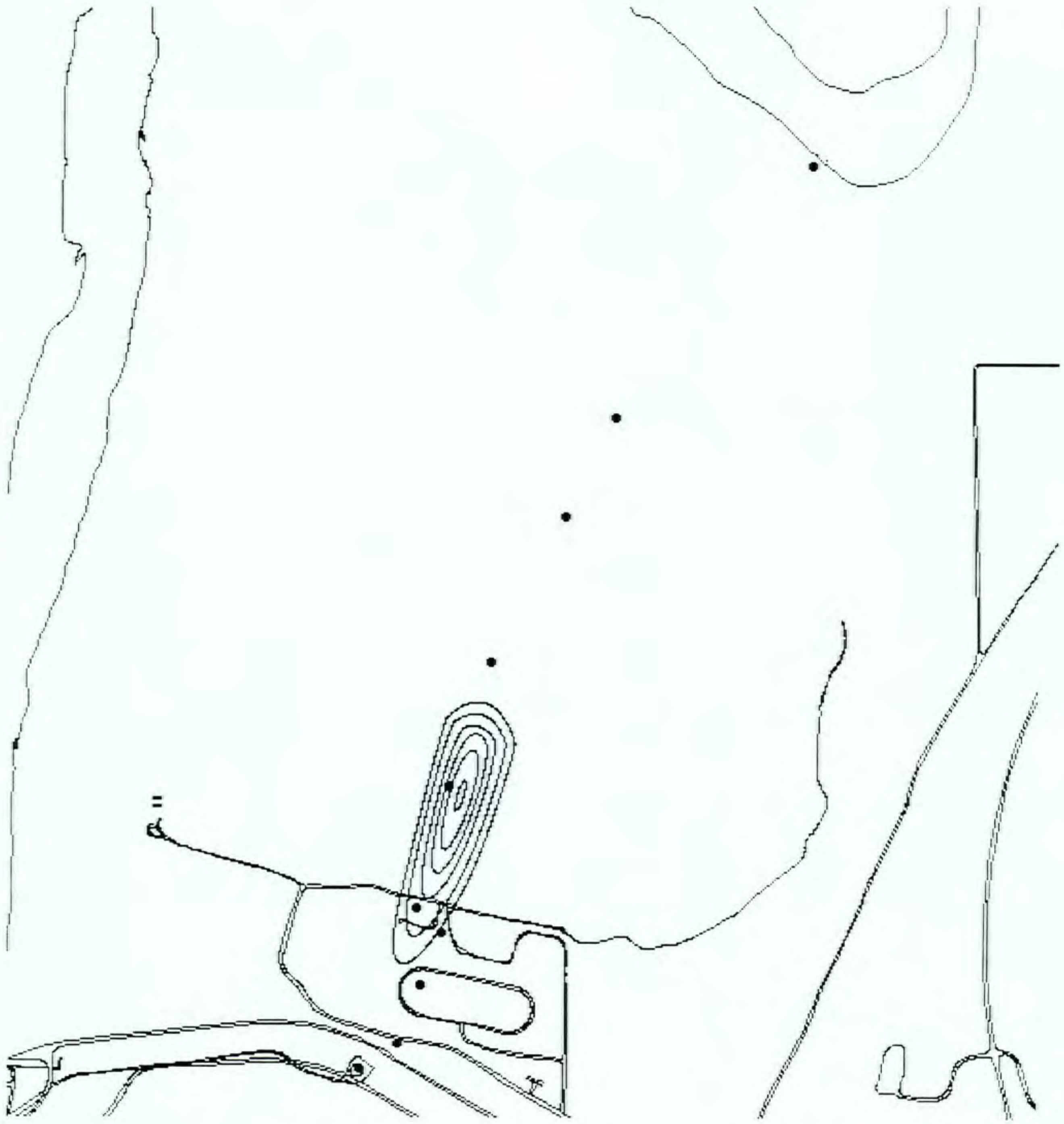
- Only centerline monitoring wells are displayed
- Concentration interval is 0.1, 0.2, 0.4, 0.6, 0.8, and 1 µg/L

Burns & McDonnell
SINCE 1898

Figure 6-57

Aerobic Model
VC Concentration
at 1 Year

FFTA-MAAF RI



LEGEND

- Monitoring Well

NOTE:

- Only centerline monitoring wells are displayed
- Concentration interval is 0.1, 0.2, 0.4, 0.6, 0.8, and 1 µg/L

N

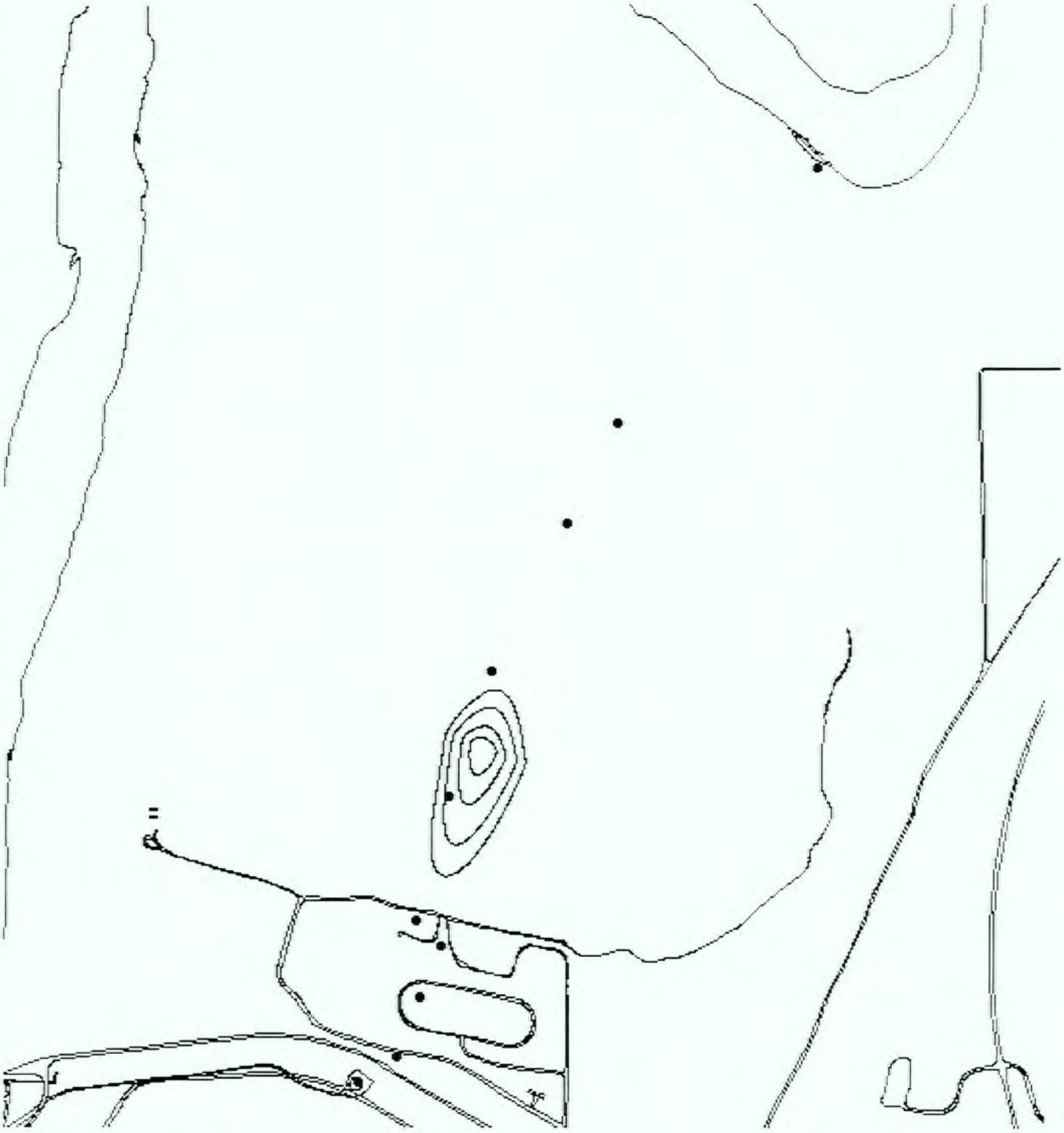
NOT TO SCALE

Burns & McDonnell
SINCE 1898

Figure 6-58

Aerobic Model VC Concentration at 3 Years

FFTA-MAAF RI



LEGEND

- Monitoring Well

NOTE:

- Only centerline monitoring wells are displayed
- Concentration interval is 0.1, 0.2, 0.4, 0.6, 0.8, and 1 µg/L

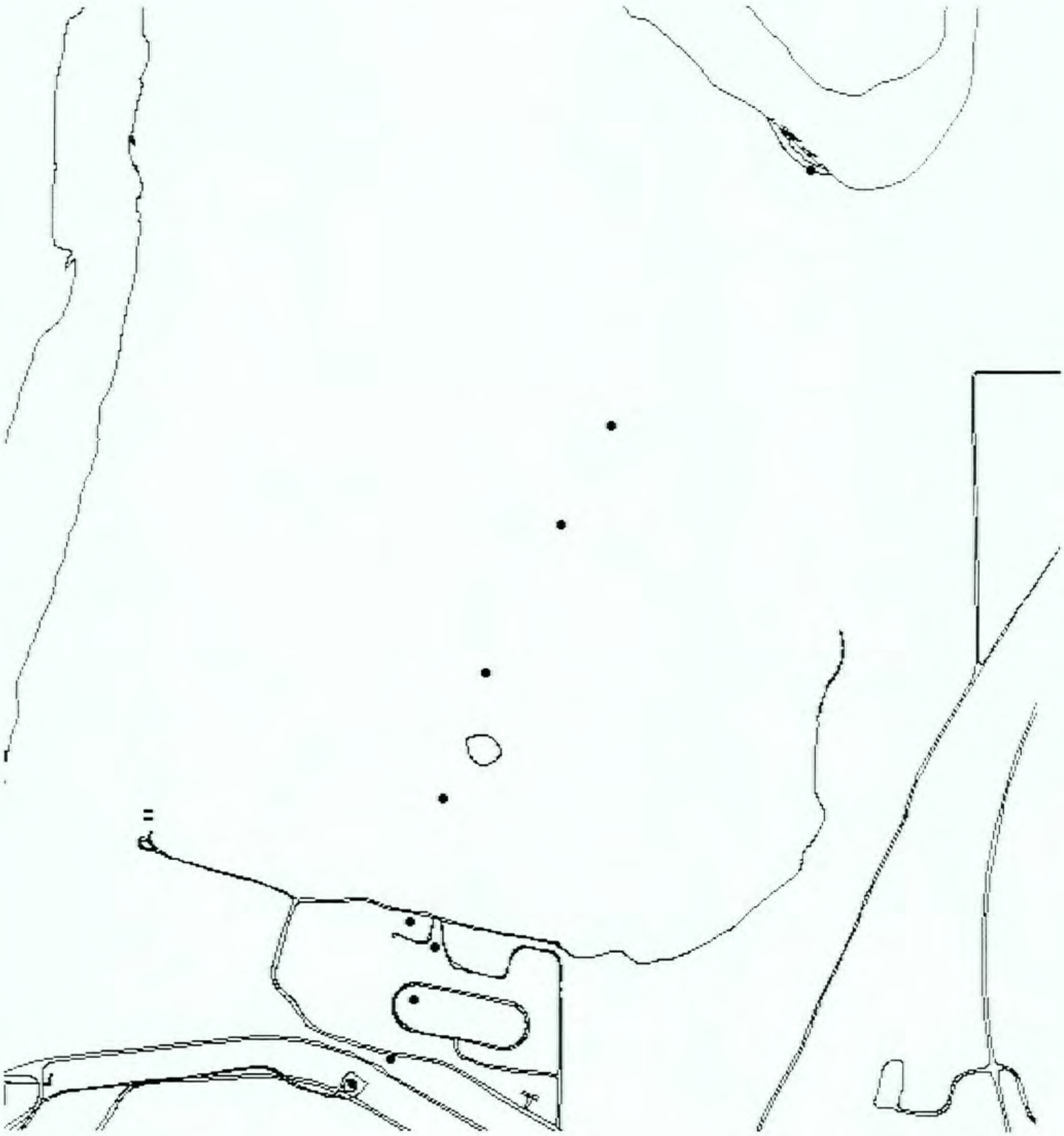
NOT TO SCALE

Burns & McDonnell
SINCE 1898

Figure 6-59

Aerobic Model
VC Concentration
at 6 Years

FFTA-MAAF RI



LEGEND

- ● Monitoring Well

NOTE:

- Only centerline monitoring wells are displayed
- Concentration interval is 0.1, 0.2, 0.4, 0.6, 0.8, and 1 µg/L

N

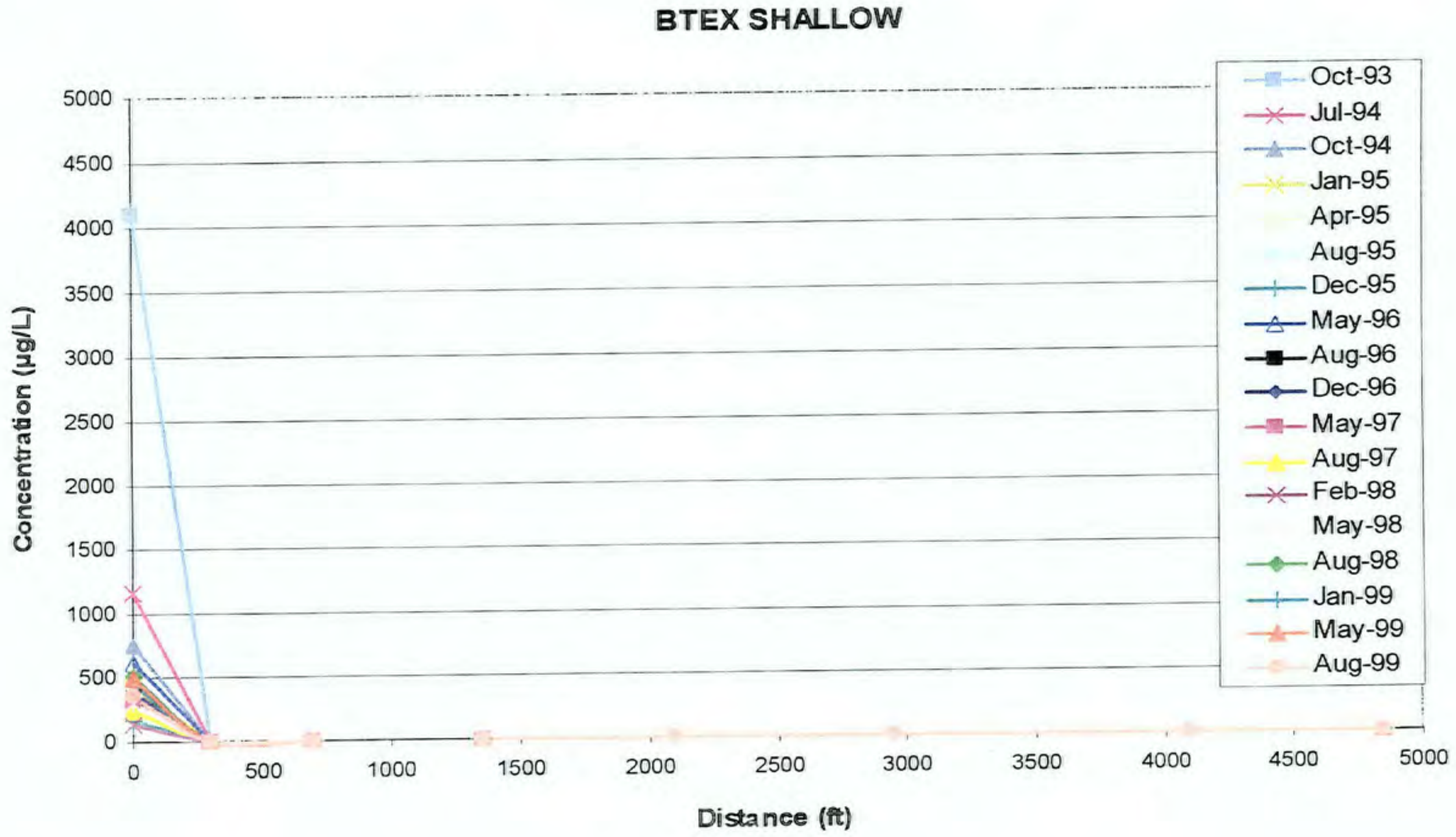
NOT TO SCALE

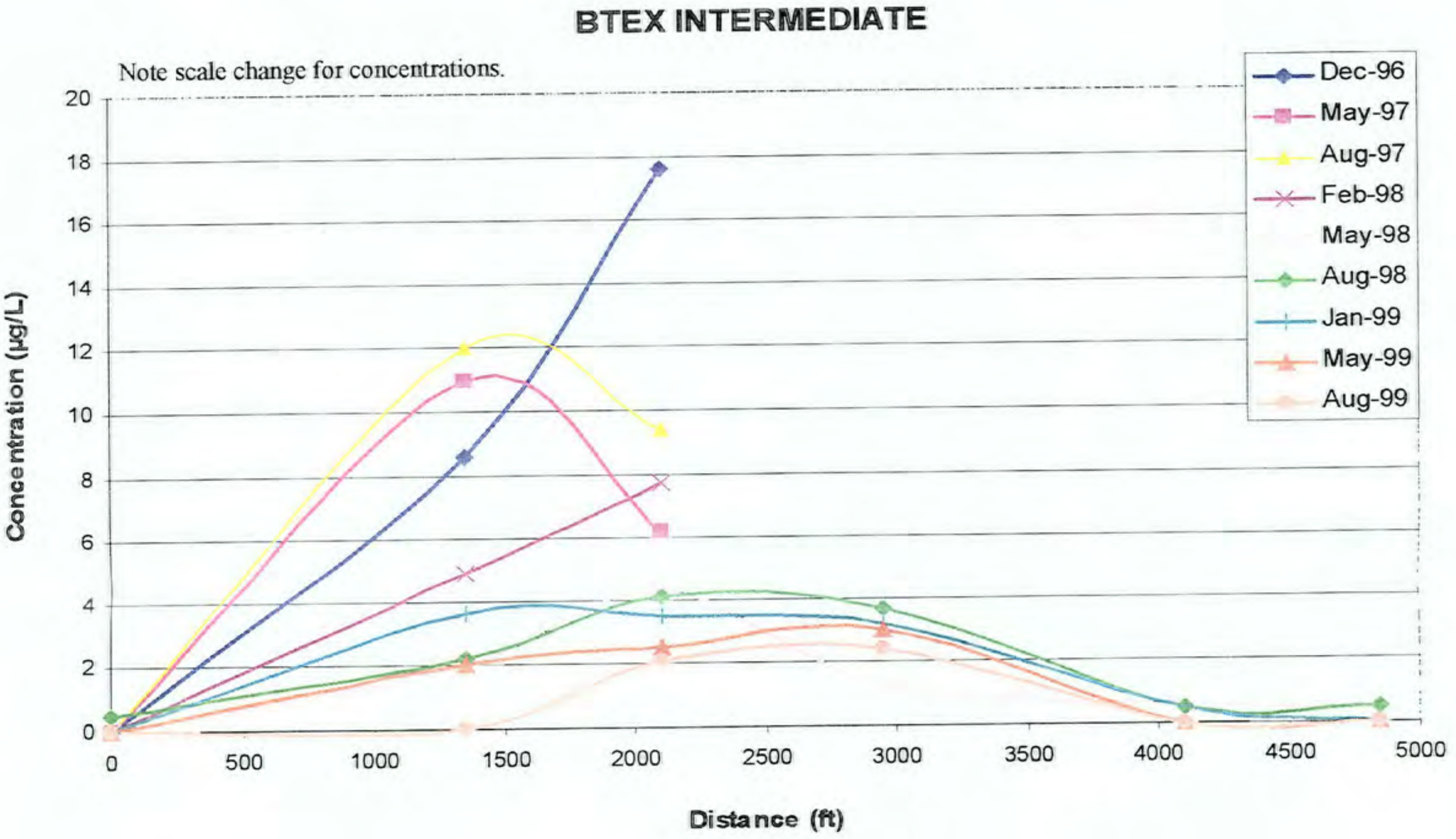
Burns & McDonnell SINCE 1898

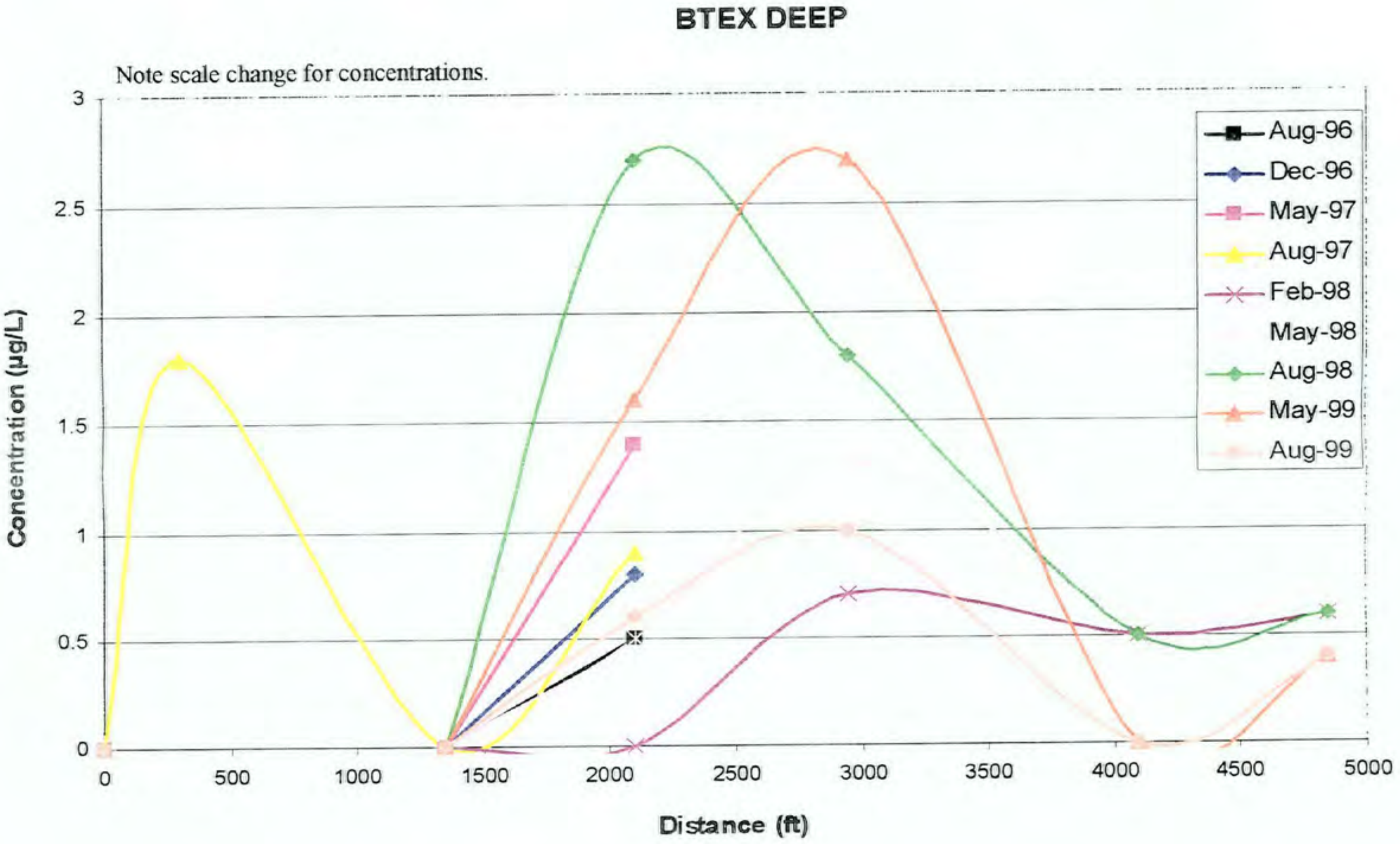
Figure 6-60

Aerobic Model VC Concentration at 9 Years

FFTA-MAAF RI







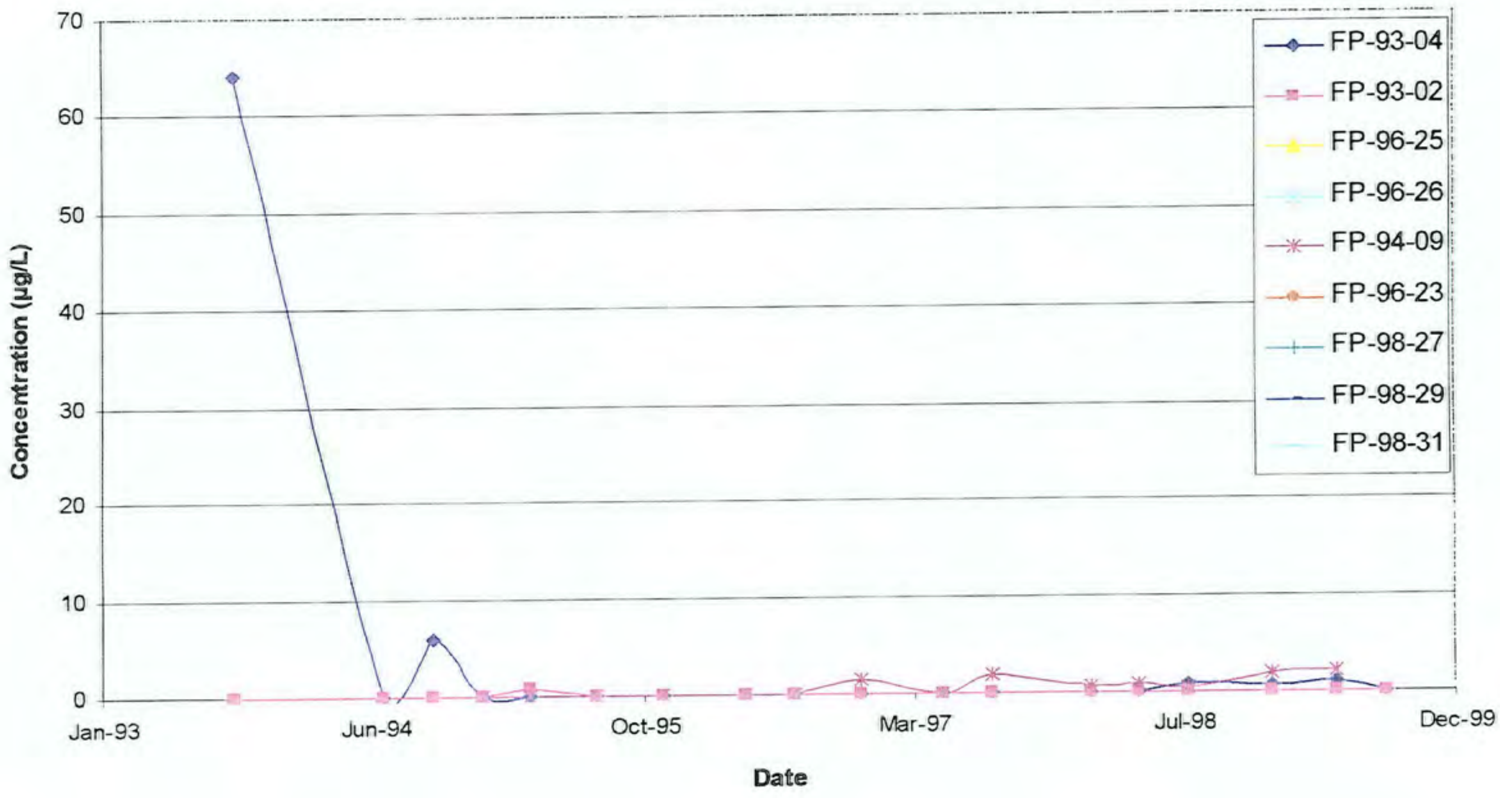
Burns & McDonnell
SINCE 1898

Figure 6-61

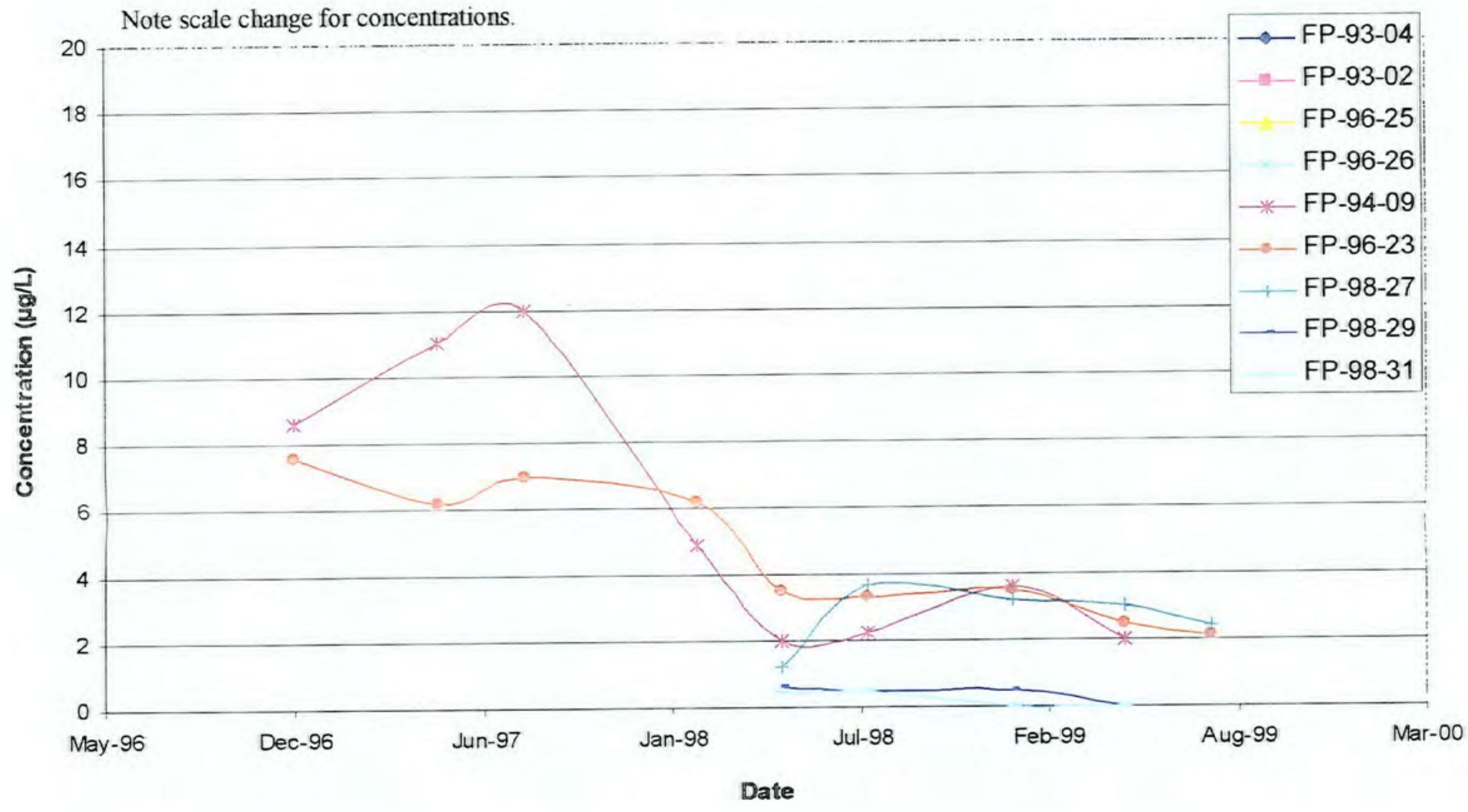
BTEX Trend with Distance

FFTA-MAAF RI

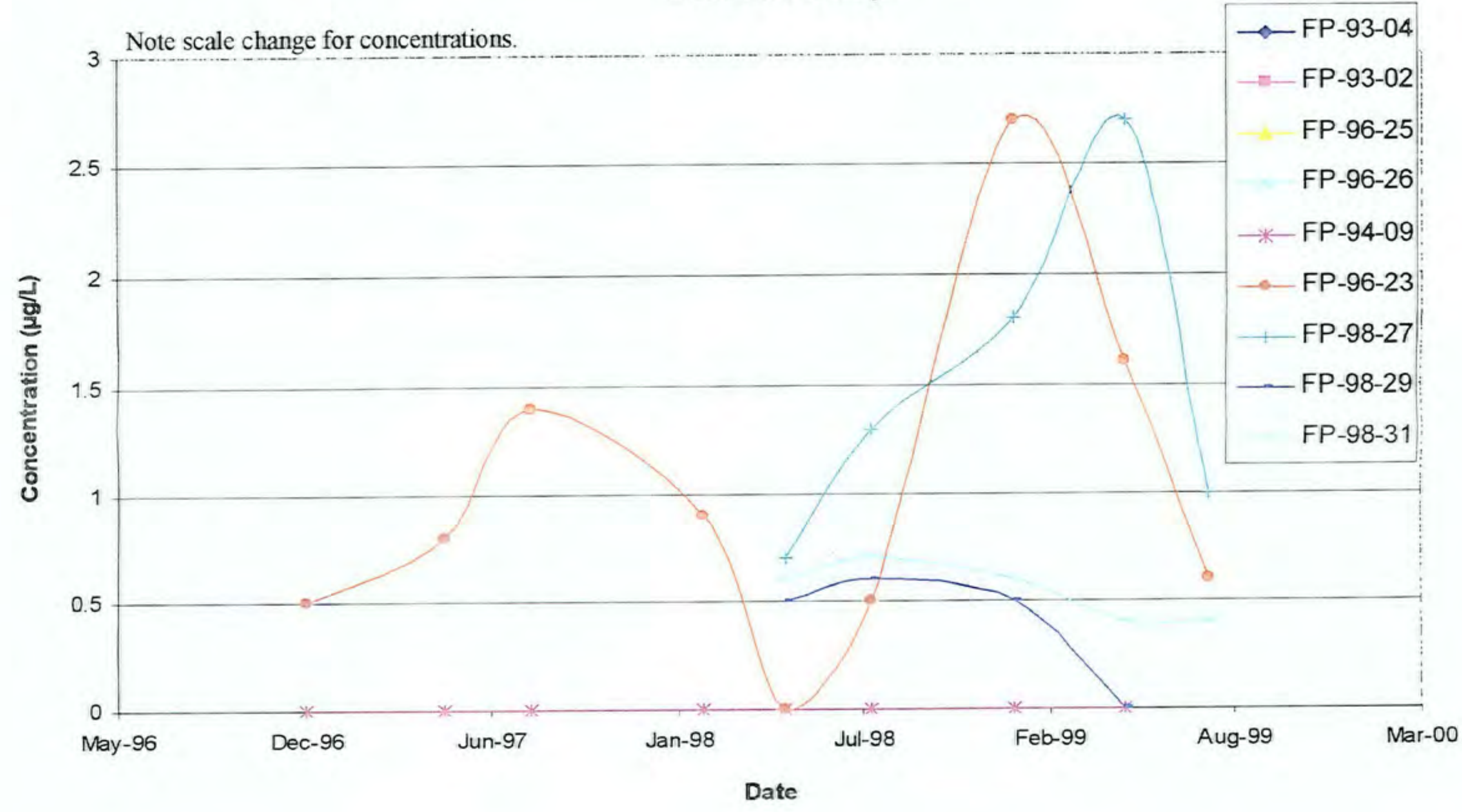
Benzene Shallow



Benzene Intermediate


Note scale change for concentrations.

Benzene Deep

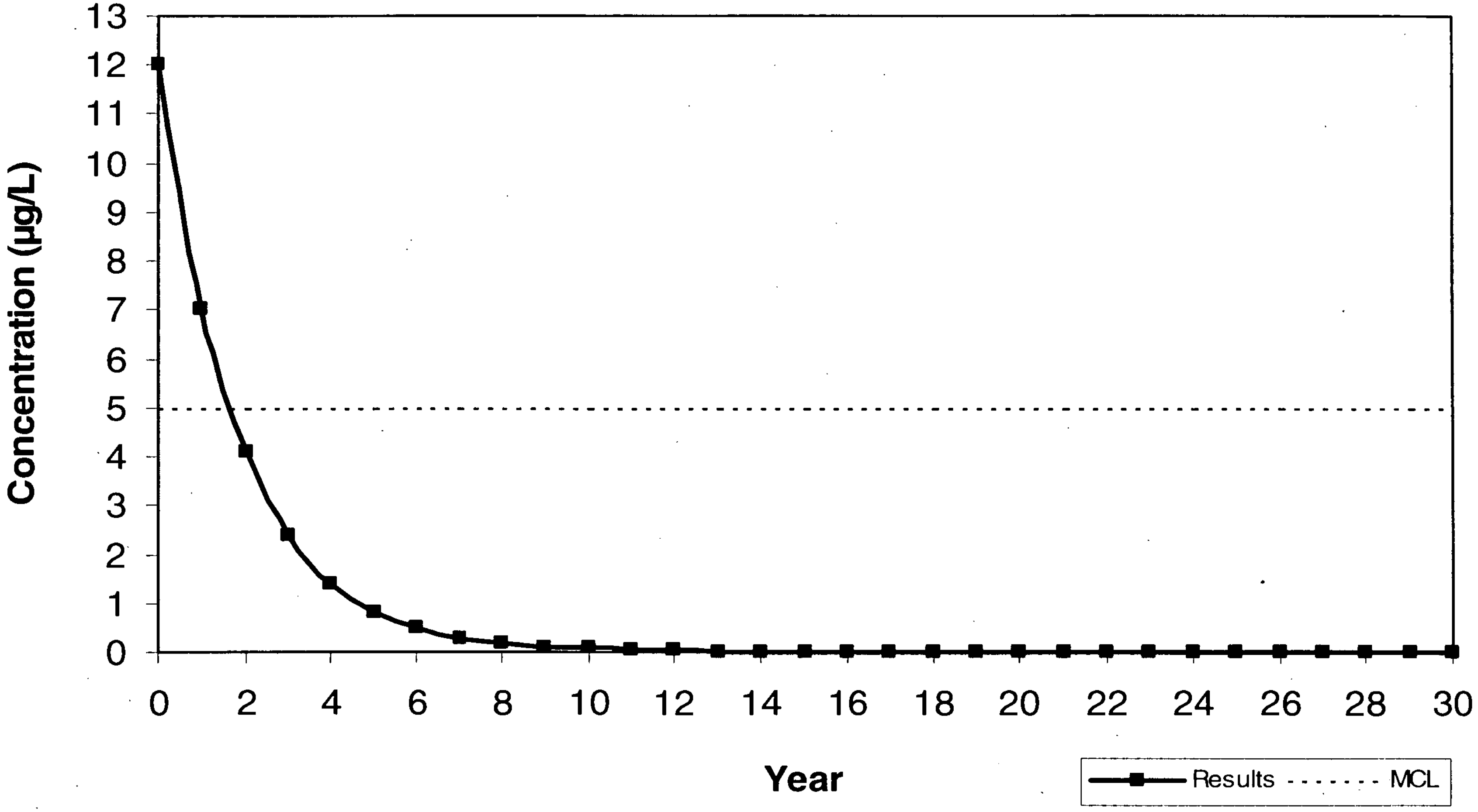

Note scale change for concentrations.

Burns & McDonnell
SINCE 1898

Figure 6-62

Benzene Trend with Time

FFTA-MAAF RI



NOTES:

Maximum Predicted Benzene Concentration with Time from BIOSCREEN

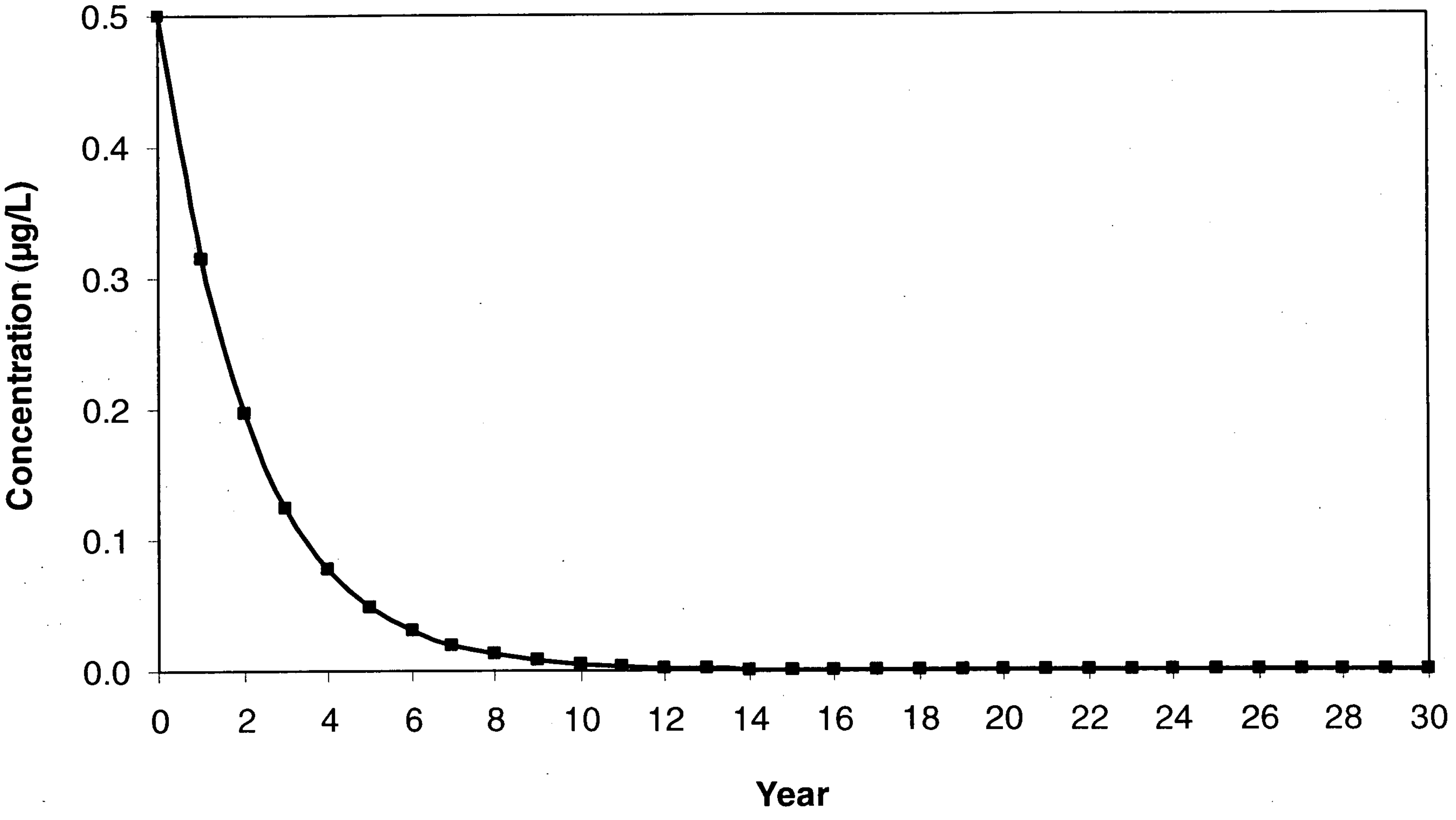
Benzene MCL = 5 µg/L

Burns & McDonnell
SINCE 1898

Figure 6-63

Predicted Benzene Concentrations

FFTA-MAAF RI



NOTES:

Maximum Predicted Toluene Concentration with Time from BIOSCREEN

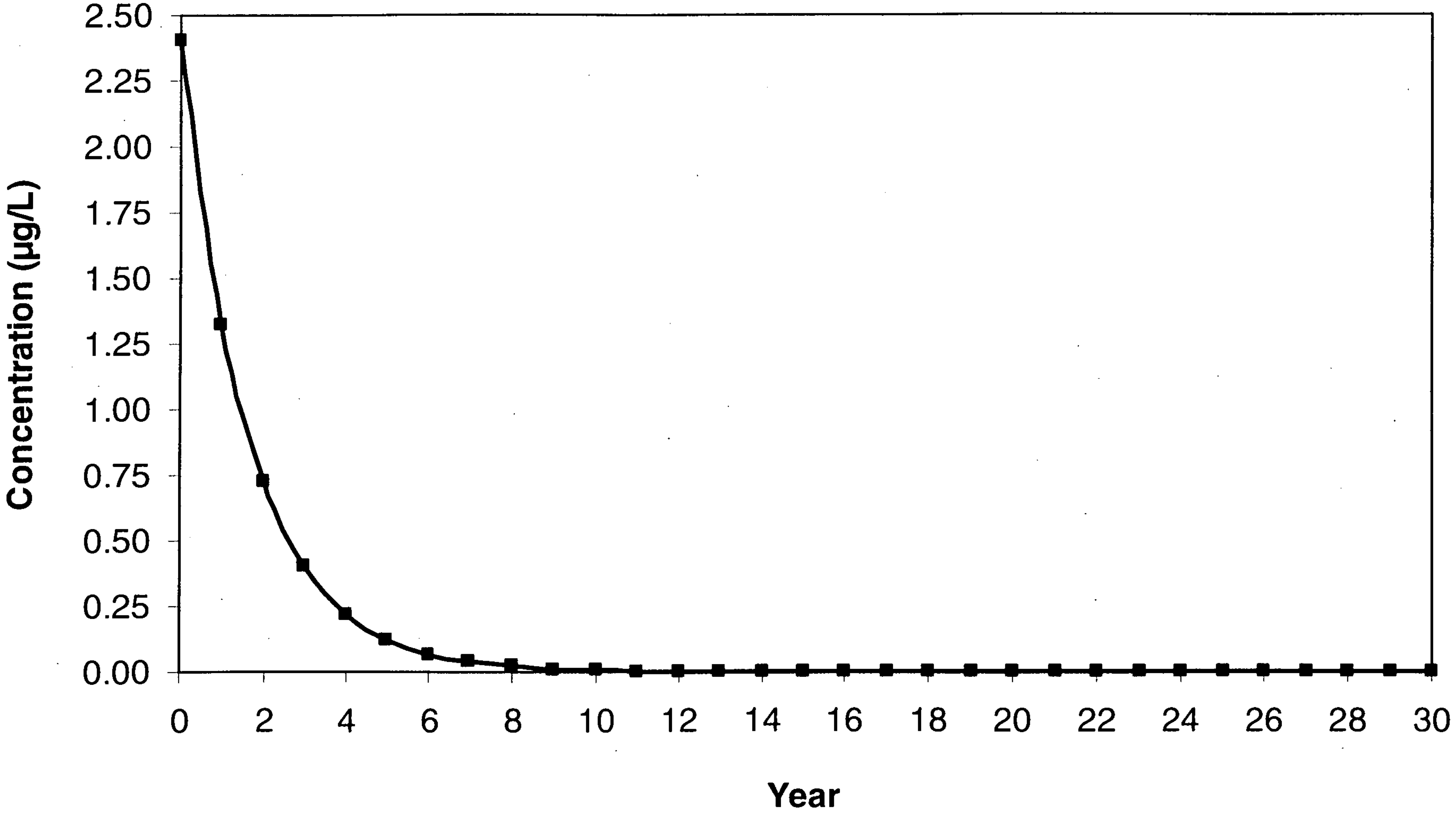
Toluene MCL = 1000 µg/L

Burns & McDonnell
SINCE 1898

Figure 6-64

Predicted Toluene Concentrations

FFTA-MAAF RI



NOTES:

Maximum Predicted Ethylbenzene Concentration with Time from BIOSCREEN

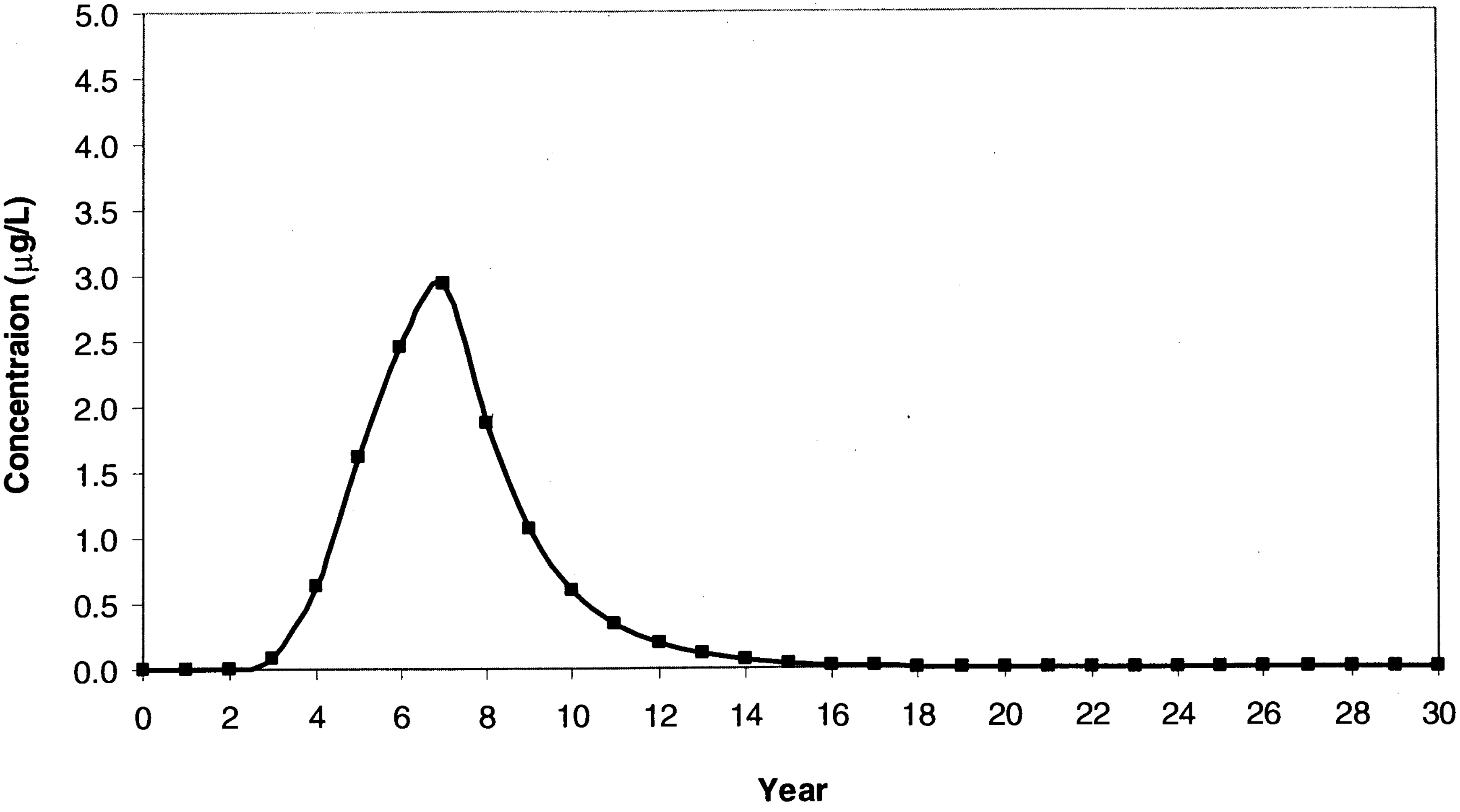
Ethylbenzene MCL = 700 µg/L

Burns & McDonnell
SINCE 1898

Figure 6-65

Predicted Ethylbenzene Concentrations

FFTA-MAAF RI



NOTES:

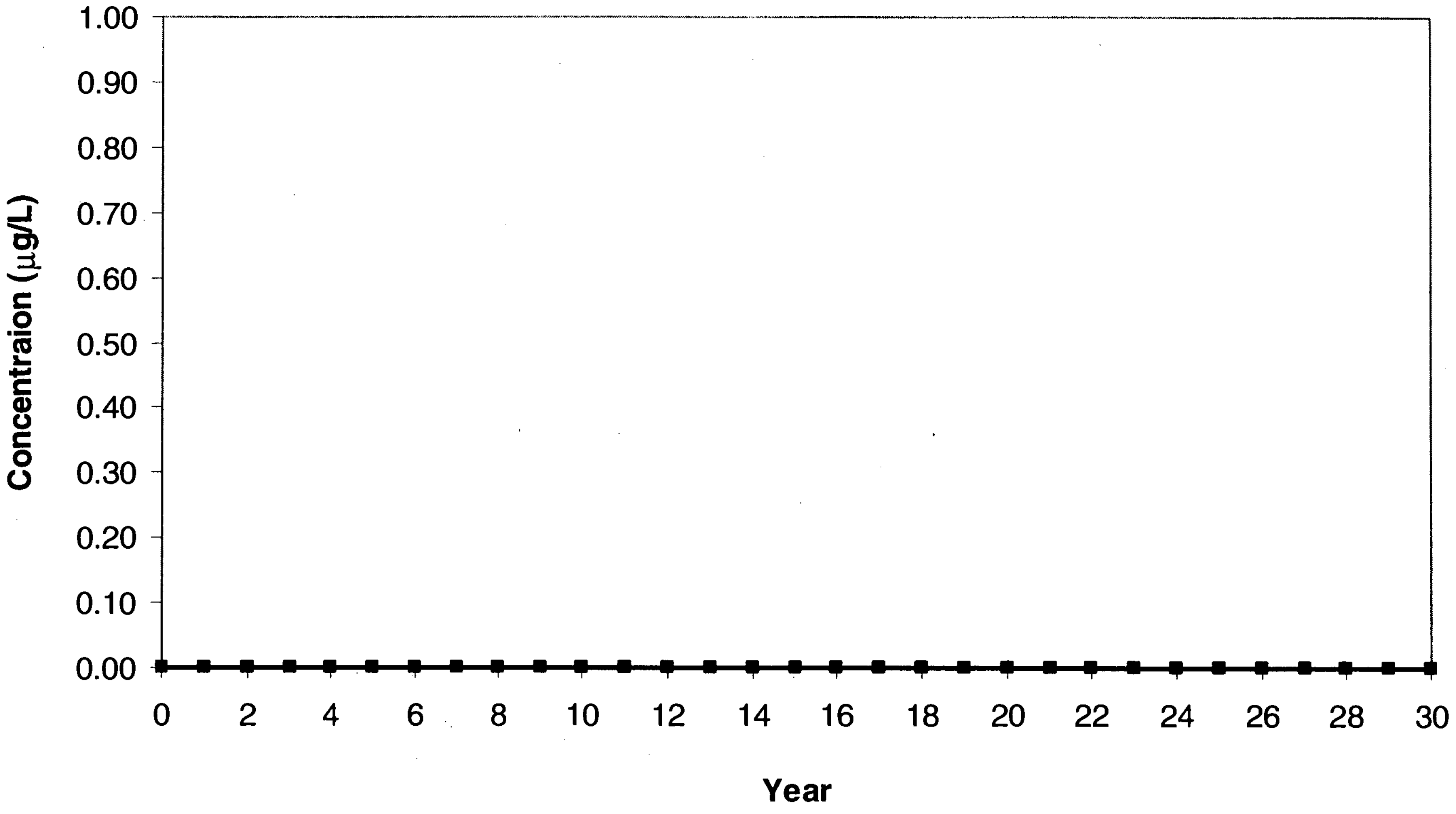
Maximum Predicted Xylene Concentration with Time from BIOSCREEN

Xylene MCL = 10,000 µg/L

Burns & McDonnell
SINCE 1898

Figure 6-66

Predicted Xylene Concentrations



NOTES:

Maximum Predicted Naphthalene Concentration with Time from BIOSCREEN

Naphthalene MCL = Not Available

Burns & McDonnell
SINCE 1898

Figure 6-67

Predicted Naphthalene Concentrations

FFTA-MAAF RI

7.0 HUMAN HEALTH BASELINE RISK ASSESSMENT

7.1 INTRODUCTION

7.1.1 Purpose

The purpose of this assessment is to evaluate baseline potential risks that might be experienced by human receptors coming into contact with soil and/or groundwater contamination related to the FFTA-MAAF. Both current and future potential exposure settings were assessed under the assumption that no further remediation at the Site takes place. Additionally, both on-post and off-post human receptor populations were evaluated since exposure opportunity differs due to variation in chemical concentrations in impacted media on and off the post.

7.1.2 HHBRA Organization

The human health baseline risk assessment (HHBRA) followed procedures outlined in USEPA, 1989 *RAGS Part A*, the U.S. Corps of Engineers *Risk Assessment Handbook, Volume 1: Human Health Evaluation* (USACE, 1999), and other USEPA supplemental guidance documents referenced throughout the text.

The HHBRA is organized into the following sections:

- Introduction (Section 7.1) - The first section states the purpose of the risk assessment and explains the report organization.

- Identification of COPCs (Section 7.2) – This section reviews analytical data collected at the Site and evaluates it as to the relevance of its use in the risk assessment. COPCs are identified based on accepted USEPA screening methodology.

- Toxicity Assessment (Section 7.3) - General noncarcinogenic and carcinogenic toxicities for COPCs are discussed and toxicity values for quantifying risks are presented in this section. Detailed toxicity summaries are provided in Appendix A of this report.

- Exposure Assessment (Section 7.4) - This section considers current and potential future land and water uses to identify possible receptor populations and potentially completed exposure pathways. Exposure point concentrations are estimated from available analytical data and/or the results of contaminant transport modeling. Chemical dose to receptors is then quantified using standard intake calculations.

- Risk Characterization (Section 7.5) - The risk characterization section evaluates the possible nature and magnitude of health risks associated with the Site. Cancer risks and the likelihood of noncancer adverse health effects are quantified by combining calculated chemical dose with chemical toxicity information. The results are then compared to accepted levels of risk.

- Uncertainties inherent in the process are described in Section 7.6. The last section (Section 7.7) presents a summary of the HHBRA results.

7.2 IDENTIFICATION OF CHEMICALS OF POTENTIAL CONCERN

7.2.1 Historical Data Evaluation

A preliminary human health baseline risk assessment (PHHBRA) was conducted as part of the *RI/FS WP*. Preliminary COPCs were identified from the post-pilot soil sampling data collected March/April 1996 and from groundwater samples collected November 1993 through July 1996 in on- and off-post monitoring wells and in off-post private wells.

During the post-pilot study, 232 soil samples were collected from 3 zones of contamination. Zone 1 designation was for the worst zone of contamination at the pit, with zones 2 and 3 stepping out from there. These zones had been established based on the results of soil and soil-gas sampling efforts during the SI, ESI, and prior to the pilot study operation (see Section 3.0). In an effort to avoid diluting the frequency of detection by including nondetects of VOCs and SVOCs, 14 of the 15 soil borings collected in zone 3 were eliminated from the data set. Five of the surface soil samples from these 14 boring locations contained residual levels of DRO, ranging from 6 mg/kg to 130 mg/kg. While these samples were impacted and could have been retained, they were still removed from the data set to avoid diluting the frequency of detection. The remaining data included 20 surface soil samples and 170 subsurface soil samples collected from the most contaminated area. For purposes of the PHHBRA, this area which measures approximately 200 feet by 300 feet was labeled as an exposure area. The groundwater samples were evaluated for chemical frequency of detection, collectively at first and then by on- and off-post sampling locations. Groundwater data from wells that have always been nondetect were eliminated from the data set. Soil and groundwater samples were analyzed for VOCs, SVOCs, metals, and TPH.

Detected concentrations of metals in soil and groundwater were determined to be within background ranges and therefore no longer considered in the preliminary risk assessment. TPH was detected in samples, but because it is a mixture of high variability it was not quantitatively evaluated. VOCs and SVOCs that were detected in greater than 5 percent of samples from any media were selected as COPCs. Also, benzene was retained as a COPC regardless of its detection frequency because it is a Class A carcinogen. Dichloromethane was detected in 6 percent of the soil samples, but was determined to be related to laboratory contamination and not considered as a preliminary COPC.

None of the VOCs or SVOCs was detected at greater than 5 percent in the twenty surface soil samples collected at FFTA-MAAF. Based on the low frequency of detection and given the likelihood that much of the surface soil at FFTA-MAAF is fill, surface soil was not considered a medium of concern in the PHHBRA.

Note that surface water is not present at FFTA-MAAF except after wet weather events. Five sediment samples were collected from the drainage ditch at the Site during Phase I of the SI, and like surface soil samples, were nondetect. Therefore, surface water and sediment at FFTA-MAAF were not considered media of concern in the preliminary risk assessment.

In summary, preliminary COPCs for the *RI/FS WP* included total xylenes, 2-methylnaphthalene, and naphthalene detected in subsurface soil, and benzene, ethylbenzene, toluene, total xylenes, total 1,2-DCE, PCE, TCE, and naphthalene detected in groundwater. These preliminary COPCs were taken into consideration during the RI data evaluation, as discussed in the following section.

7.2.2 RI Data Evaluation

7.2.2.1 Soil

Additional soil sampling was conducted at FFTA-MAAF in June 1999. A total of 144 samples, including duplicates, were collected and submitted for VOC and TPH analyses. Detailed discussions of the analytical results are provided in Section 5.4 of this Report. Of the soil samples collected, 6 were considered surface soil samples (0 to 6 inches bgs). These surface soil samples were collected along Axis D (see Figure 4-24, inset map) which intercepted both the former pit and drum storage area.

There were no VOCs detected in the surface soil samples, strengthening the position that surface soil is not a medium of concern (see discussion in Section 7.2.1). Chemicals detected in the subsurface samples (1 to 18 feet bgs) are shown in Table 7-1. Ethylbenzene, toluene, xylenes, cis-1,2-DCE, PCE, and TCE were detected. Only xylenes and PCE were detected above 5 percent frequency. Note that although naphthalene and 2-methylnaphthalene were not analytes during the RI, data from the *RI/FS WP* are shown on the table and considered in the HHBRA since naphthalene and 2-methylnaphthalene were identified as preliminary COPCs for the *RI/FS WP*.

7.2.2.2 Groundwater

Groundwater sampling results from May 1997, August 1997, February 1998, May 1998, August 1998, January 1999, May 1999, and August 1999 were evaluated to determine COPCs for this risk assessment. Analytes of interest for the HHBRA included VOCs and SVOCs. SVOCs were analytes during the May and August 1997 sampling events and thereafter only naphthalene was analyzed. Section 5.5 of this Report provides a detailed discussion of groundwater sampling results.

Only samples collected at impacted well locations were considered in the sample population for the purpose of identifying COPCs. Wells with positive detections during at least one sampling event and associated wells (i.e., wells at the same location but with different screening intervals) included the following: I-1, M-1, R-1, R-2, R-3, R-4, FP-93-01, FP-93-02, FP-93-02b, FP-93-02c, FP-93-03, FP-93-04, FP-93-04b, FP-93-05, FP-94-09, FP-94-09b, FP-94-11, FP-96-20b, FP-96-23, FP-96-23b, FP-96-23c, FP-96-24, FP-96-25, FP-96-25b, FP-96-25c, FP-96-26, FP-96-26b, FP-96-26c, FP-98-27, FP-98-27b, FP-98-27c, FP-98-28b, FP-98-28c, FP-98-29b, FP-98-29c, FP-98-31, FP-98-31b, FP-98-31c, FP-99-32b, and FP-99-32c. Chemical detections are summarized by on-post and off-post locations, as shown in Tables 7-2 and 7-3, respectively.

Petroleum constituents detected in on-post wells included ethylbenzene, naphthalene, toluene, and xylenes. All were detected at greater than 5 percent frequency. Chlorinated solvents detections included cis-1,2-DCE, trans-1,2-DCE, PCE, and TCE. All but trans-1,2-DCE were detected at greater than 5 percent frequency. There were no other VOCs detected in on-post wells.

Petroleum constituents detected in off-post wells included benzene, ethylbenzene, and xylenes, with only benzene being detected at a frequency greater than 5 percent. Chlorinated solvents detections included 1,1-DCE, cis-1,2-DCE, trans-1,2-DCE, PCE, TCE, and VC. All but 1,1-DCE and VC were detected at greater than 5 percent frequency. Other chemicals detected in the off-post wells at less than 5 percent frequency included the following: acetone, methylene chloride, chloroform (trichloromethane), phenols, and 4-methylphenol.

7.2.2.3 Surface Water

USGS collected 55 surface water samples for VOC analysis from five cross-section locations in the Kansas River during July 1999. The fifth cross-section location was downstream of the MAAF, but upstream of the Southwest Funston Landfill. VOCs were not detected in any of the samples. This sampling event is discussed in more detail in Section 5.6 of this Report.

7.2.3 Chemical Selection

USEPA screening methodology described in *RAGS Part A* was used to select chemicals of potential concern. During this selection process, consideration was given to detection frequency, impacted media, chemical mobility and toxicity, availability of toxicological information, and chemical family. Note that the initial screening for COPCs, i.e., comparison to background, was accomplished as part of the nature and extent evaluation (see Section 5.2). Concentrations of metals detected in soil and groundwater were compared to background levels and it was determined that, with the exception of isolated and minimal occurrences, metals at the Site are within their respective background ranges. As in the PHHBRA, metals were not considered as COPCs.

The following chemicals were selected as COPCs in subsurface soil: benzene, ethylbenzene, 2-methylnaphthalene, naphthalene, toluene, xylenes, cis-1,2-DCE, PCE, and TCE. Of these COPCs, only xylenes and PCE were detected above 5 percent frequency during the RI. The remaining chemicals in the list were retained as COPCs since the FFTA-MAAF soil is believed to be the originating source of contamination in groundwater. Benzene was not detected in soil during either the Post-Pilot Study or during the RI. Benzene is highly mobile in soil and has probably all leached to the groundwater, but because it is considered a Class A carcinogen (i.e., a known human carcinogen) and it may be present at concentrations below the detection limit, it was retained as a COPC.

For groundwater, the following were selected as COPCs: benzene, ethylbenzene, toluene, xylenes, naphthalene, 1,1-DCE, cis-and trans-1,2-DCE, PCE, TCE, and VC. 1,1-DCE and VC were not detected in on-post wells, but were detected at 2 percent frequency in off-post wells. Because they are considered daughter products of PCE degradation, 1,1-DCE and VC were retained as COPCs, as per *RAGS Part A* guidance. Further, VC is considered a Class A carcinogen. Although detected in on-post wells, naphthalene and xylenes have not been detected in off-post wells during the RI. The only historical detection of xylene was in Monitoring Well FP-94-11, located at the racetrack. Naphthalene has never been detected in off-post groundwater samples. This indicates that xylenes and naphthalene are not migrating significantly, if at all. However, to be conservative, xylenes and naphthalene were retained as COPCs in groundwater.

TPH data was not summarized in this section since it is not typically quantified in baseline risk assessments. (Refer to Section 5.0 for a presentation and discussion of analytical results.) The term TPH refers to a mixture of hydrocarbons that includes a large number of constituents. The composition of the mixture is greatly variable, as are the chemical characteristics of the individual components. Further complicating evaluation is the fact that as TPH weathers over time, its chemical composition changes. As a consequence, it is not possible to accurately quantify the toxicity and/or fate of TPH in the environment by treating TPH as a single substance with unique physical and toxicological properties. Since BTEX constituents are among the most hazardous components of TPH and are highly volatile and mobile, evaluating the human health risks associated with exposure to BTEX serves as an appropriate means of evaluating TPH. Therefore, TPH *per se* was not considered a COPC, but the BTEX constituents were retained.

Chemicals detected as a result of laboratory contamination were removed from consideration. These included the following: acetone, methylene chloride, chloroform (trichloromethane), phenol, and 4-methylphenol. All were detected only in off-post wells, at 2 percent or less frequency. Acetone was detected only in Well I-1, which is outside of the contaminant plume. Methylene chloride and chloroform were only detected in samples that were reanalyzed, while the initial analytical results were nondetect. The phenols were detected one time in an off-post well and do not appear to be site-related.

In summary, the COPCs for soil include benzene, ethylbenzene, 2-methylnaphthalene, naphthalene, toluene, xylenes, cis-1,2-DCE, PCE, and TCE. COPCs for groundwater include benzene, ethylbenzene, toluene, xylenes, naphthalene, 1,1-DCE, cis- and trans-1,2-DCE, PCE, TCE, and VC. These COPCs are presented in Table 7-4.

7.3 TOXICITY ASSESSMENT

In a risk assessment, toxicity of COPCs is evaluated for both carcinogenic potential and noncarcinogenic adverse health effects. Data regarding health effects are then used to derive numerical toxicity values. The USEPA gathers toxicological information from a variety of sources including experimental animal studies, epidemiological investigations, and clinical human studies. Well-conducted epidemiological studies that show a positive correlation between an agent and a disease represent the most convincing evidence about human risk. At present, human data adequate to serve as the sole basis for the development of toxicity values are available for only a few chemicals. In most cases where there is insufficient direct human data, USEPA uses toxicity information developed from experiments conducted on non-human mammals such as rats, mice, dogs, or rabbits.

The primary source of toxicological information for this report was the USEPA sponsored Integrated Risk Information System (USEPA, 2000) [*STSC*] or, secondarily, the USEPA Health Effects Assessment Summary Tables (USEPA, 1997a) [*HEAST*]. If toxicity values were not found in IRIS or HEAST, the USEPA National Center for Environmental Assessment Superfund Technical Support Center (STSC) was consulted for provisional information. Information received from STSC was incorporated into this risk assessment. STSC documentation (USEPA, 1999a) is provided in Appendix 7A. Appendix 7A also provides a summary of toxicity information for the COPCs.

The following sections detail information regarding both noncarcinogenic and carcinogenic toxicity values.

7.3.1 Noncarcinogenic Effects

The Reference Dose (RfD) and Reference Concentration (RfC) are the toxicity values used in assessing noncarcinogenic health effects from oral and inhalation exposures, respectively. For noncarcinogenic health effects, the level of exposure below which no adverse health effects develop is termed the threshold level or threshold dose. RfDs and RfCs represent exposure levels that are well below threshold. Each is an estimate of daily exposure to the general human population (including sensitive subpopulations) that is unlikely to pose an appreciable likelihood of adverse effects during a given term of exposure.

The RfD and/or RfC are derived from experimental NOAELs (no observed adverse effect levels) or LOAELs (lowest observed adverse effect levels) by application of uncertainty factors (UFs) or modifying factors (MFs). UFs of 10 are used to protect sensitive subpopulations, to account for interspecies variability, and to account for data being obtained from subchronic rather than chronic studies. A UF of 10 is also used when the toxicity value is derived from a LOAEL rather than a NOAEL. Modifying factors, usually a value of 10 or less, are applied for uncertainties not addressed by the UFs just listed.

Chronic RfDs and RfCs pertain to lifetime or other long-term exposures and may be overly protective if used to evaluate the potential for adverse health effects resulting from shorter exposures. For such situations, USEPA has developed some toxicity values specifically for subchronic exposure durations.

The subchronic RfD is developed using subchronic NOAELs from studies of appropriate exposure duration. In the absence of a subchronic RfD, the chronic RfD is adopted as the subchronic RfD. It is not uncommon for the chronic RfD to be used in evaluating exposure of children in order to be protective.

RfD values are expressed as milligrams of chemical per kilogram body weight per day (mg/kg/day), and RfC values are expressed as a chemical concentration in air in milligrams per cubic meter (mg/m^3). For consistency with the inhalation intake dose units, RfC values may be converted to inhalation RfD values, which are then expressed as mg/kg/day (USEPA, 1997a) [*HEAST*].

There are no dermal toxicity values currently available, necessitating the use of oral toxicity values. However, oral values are typically developed from laboratory animal studies and reflect an administered (in feed or water), rather than an absorbed (through the gastrointestinal tract) dose. The degree of gastrointestinal absorption varies between chemicals with some being readily absorbed and some being poorly absorbed. To reflect this, default gastrointestinal absorption efficiency factors are applied. Although consulted, STSC did not provide recommendations for absorption efficiency. For this assessment, an 80 percent absorption efficiency factor was used. This is more conservative than assuming 100 percent and is consistent with the USEPA Region 4 *Supplemental Guidance to RAGS: Region 4 Bulletins* (USEPA, 1995a)[*Region 4 Bulletin*] recommendation of 80 percent for VOCs.

Table 7-5 summarizes available RfDs and reference sources. By convention, RfD values, as with all toxicity numbers and risk assessment calculations, are expressed in scientific notation. For example, the oral RfD for benzene, 0.001, is expressed as 1 x 10^{-3} or 1E-03, as shown in the table.

7.3.2 Carcinogenic Effects

The toxicity values used in assessing carcinogenic risk are slope factors. A slope factor represents the 95 percent upper confidence limit on the probability that a carcinogen will cause cancer at a dose of one mg/kg/day over a lifetime. Unlike most noncarcinogenic health effects, carcinogenesis is not believed to conform to the concept of a threshold dose. Mechanistic data indicate that even the smallest dose of a carcinogen can lead to a clinical state of disease. For this reason, it is not possible to determine a no-response dose, but rather it is necessary to relate a specific dose to the statistical probability of a carcinogenic response.

For carcinogenic effects, the substance is given a weight-of-evidence classification and a slope factor is calculated. To determine the weight-of-evidence classification, the available evidence is evaluated to determine the likelihood that the agent is a human carcinogen. Table 7-6 shows the USEPA carcinogen weight-of-evidence classification system. Note that in 1996, USEPA proposed revised guidelines for evaluating research evidence for carcinogens, including a more descriptive classification scheme. The IRIS file for benzene is one of the few that has been updated to include the revised classification as well as traditional scheme shown in Table 7-6. The revised classification for benzene is, "a known human carcinogen for all routes of exposure based upon convincing human evidence as well as supporting evidence from animal studies."

Based on the potency of the agent as a carcinogen in experimental animals and/or humans, the slope factor is developed. Slope factors are available in IRIS or HEAST for many substances categorized by USEPA as A, B, or C carcinogens. Table 7-7 summarizes the available slope factors, reference sources, and weight-of-evidence classifications for the carcinogenic effects of the COPCs. Note that USEPA has proposed revised guidelines for a more descriptive characterization of carcinogens (USEPA, 1996b). Benzene is one of few chemicals in IRIS to now include an assessment based on the proposed guidelines.

As with RfDs, slope factors are not available for dermal exposure. For this assessment, the absorption efficiency factor of 80 percent was used to modify the oral slope factor values for assessing risk through dermal exposure (USEPA, 1995a) [*Region 4 Bulletin*].

7.4 EXPOSURE ASSESSMENT

In the exposure assessment, potentially exposed populations and potential pathways of exposure are identified. The assessment considers physical Site features, land use, and zoning in order to identify pathways and populations for exposure. Only completed exposure pathways (i.e., human receptors in contact with contaminated media) may actually pose a human health risk. While planning the RI, a conceptual site model (CSM) showing potentially completed pathways was developed. The RI/FS WP CSM is presented as Figure 7-1 in this document, for the convenience of the reader.

Section 7.4.1 presents a description of the exposure setting and Section 7.4.2 discusses the likelihood for a human population to have direct contact with contaminated media. Section 7.4.3 identifies potentially completed exposure pathways and Section 7.4.4 presents the equations and variables used to quantify chemical intake.

7.4.1 Characterization of the Exposure Setting

The first step in evaluating exposure is to characterize a Site with respect to its physical features, current and future land uses, and observed and predicted human activities so that potentially exposed populations at and near the Site can be identified. Section 2.0 of this Report presents a detailed discussion of land use and zoning at the Site and in the relevant surrounding area. This information is briefly summarized here.

The FFTA-MAAF is located in the southeastern part of the Fort Riley reservation and as such is not zoned by the county. DoD requires the establishment of aircraft safety zones near military airfields. FFTA falls between the aircraft accident potential zones APZ-I and APZ-II associated with MAAF, as shown in Figure 2-16. Also associated with MAAF are aircraft noise level zones, established based on noise as a nuisance or as a health concern (also shown in Figure 2-16). FFTA falls within noise level Zone II, defined as normally unacceptable, meaning 15 to 39 percent of a population would be highly annoyed with this level of noise (Robert and Company, 1993).

The FFTA is situated between the perimeter road of MAAF and within a few feet of the levee designed and built by the USACE to prevent flooding from the Kansas River. Typically, construction activities within 500 feet to the landward side of the toe of a levee are restricted, although each construction activity is evaluated for its own merit (Pers. Comm., 1996a). Additionally, there is a fiber optic cable (FOC), about 3 feet bgs, running northeast by southwest between the FFTA and the perimeter road (Pers. Comm., 1996c). These features combine to make it extremely unlikely that land use will change at the FFTA-MAAF in the future.

To the immediate north of FFTA-MAAF (and downgradient) is reservation property currently leased to the Plaza Speedway. The actual racetrack is developed on property owned by Plaza Speedway and zoned commercial by Geary County. Because it is in the 100-year flood plain, future development of this property for other commercial uses is unlikely.

Properties located to the north, east, and west of the racetrack are zoned by Geary County for agricultural use. Single-family dwellings are allowed, however the county does impose building restrictions within the 100-year flood plain (1,069feet above msl). This restriction requires that the floor of the structure be a minimum of one foot above flood level (Pers. Comm., 1996). There is a trailer home located beyond the racetrack, approximately 1,000 feet north of FFTA. Given the building restriction associated with the flood plain, it is unlikely that future residences will be built or that other land uses besides agricultural will occur in this area.

7.4.2 Potentially Exposed Populations

Potentially exposed populations are those persons whose locations and activities create an opportunity for contact with COPCs. The following sections discuss potentially exposed populations, as they are influenced by the on- and off-post land uses just described. Locations of the populations characterized in the risk assessment are shown in Figure 7-2.

7.4.2.1 On-Post Populations

There are no current activities or operations at the FFTA-MAAF property creating routine exposure opportunities for a given population. It is conceivable, however, that pedestrians or joggers along the airport road south of FFTA-MAAF could choose to stop and rest at this location, thus resulting in an exposure opportunity. Groundskeepers were determined to mow the MAAF a few times a year using a tractor pulled mowing deck (LBA, 1995) [*DCFA RI Report*]. Because exposure opportunity for a groundskeeper would be less than that for a daily pedestrian/jogger, only the latter population was evaluated in an on-post current exposure setting.

As previously discussed, given the proximity of the FFTA to MAAF with its associated noise and safety zoning, and FFTA's location between the road and levee, it is unlikely to be developed. For this reason, there are no routine, long-term exposure opportunities expected for any given population in the future. However, a short-term exposure opportunity may exist if maintenance/repair becomes necessary on the buried FOC or if another utility was installed adjacent to the FOC. Therefore, a future utility excavation worker population was evaluated.

7.4.2.2 Off-Post Populations

Activities at the racetrack downgradient of the FFTA-MAAF could result in exposure opportunity. During the racing season (typically May through September), racetrack workers volunteer their time, condition the racetrack, and control dust by applying water from Well R-2. This activity may result in a potentially completed pathway for contact with contaminants in groundwater.

Patrons at the racetrack may also experience exposure to contaminants in groundwater since water in the restrooms is drawn from Well R-1. However, the concession stand does not use water for drinking from any of the wells. Different exposure settings exist for the racetrack workers and patrons due to variation in chemicals and levels of contamination found in Wells R-1 and R-2, as well as variations in the types, frequency, and duration of exposures. For these reasons, racetrack workers and racetrack patrons were evaluated in separate off-post exposure settings.

Residents at the trailer home located further north of the racetrack may use groundwater from Well M-1. Since this represents an exposure opportunity, current off-post residents were identified for further evaluation in the assessment.

Although agricultural zoning north of the racetrack allows residential use, the building restrictions placed by Junction City would likely discourage it. Because of the contamination detected in groundwater beyond the racetrack, a future hypothetical residential family was assumed in the risk assessment. An exact location for a future residence was not assumed so that the maximum yearly contaminant concentrations (not occurring at the same location in the plume) could be considered collectively in estimating exposure concentrations. Further, it was assumed that the future adult resident also farms the land and would be exposed to vapors from irrigation water, again with the irrigation well location undetermined so that yearly maximum chemical concentrations could be conservatively used. Consumption of contaminated vegetation was not considered a likely completed pathway for the following reasons. Root absorption is unlikely because of the depth to groundwater. Due to the volatility of the COPCs, most are expected to evaporate from sprinkler irrigation water (studies show from 95 to 98 percent, EPA/540/R-98/502. September 1998) before being deposited on soil or vegetation. What concentrations might be deposited with the irrigation water are also likely to volatilize before migrating downward to the root zone or before being absorbed through the leaf.

The RI data confirms that the contaminant plume is not impacting the existing cross-gradient irrigation well (Well I-1). Therefore, the current farmer is not being exposed and was not assessed.

Children were evaluated in the racetrack patron scenario and in the current and future off-post resident scenarios as sensitive subpopulations. This was to provide a conservative estimate of risk, since children are generally more sensitive to contaminant exposure.

During the conceptual model development (see Figure 7-1), another future population was considered to be potentially exposed, a recreationist at the Kansas River. Based on what was known about the plume at the time of the PHHBRA and on the preliminary fate and transport modeling presented in the *RI/FS WP*, this population was qualitatively assessed as not being exposed to significant contaminant concentrations. This was due to the 160-fold dilution by the river of the minimal concentrations predicted to reach the river (BMcD, 1997). Based on chemical detections in RI Monitoring Well 98-32, which is located next to the river, it now appears that the contaminant plume has reached the river. With additional site information accounted for in the RI fate and transport modeling, predicted future maximum concentrations at the river, once diluted 160-fold, are still below detection limits and thus below risk-based levels of concern. Because of these predicted low concentrations and the fact that any opportunity for exposure is likely to be sporadic and short-term (due to the remoteness of the location), a river recreationist population was not evaluated further in this risk assessment.

7.4.3 Potential Exposure Pathways

Health risks may occur when there is contact with a chemical by a receptor population. Exposed populations must then either ingest, inhale, or dermally absorb COPCs to complete an exposure pathway and possibly experience a health risk. Table 7-8 presents the pathways for each of the potentially exposed populations. The following is a discussion of the likelihood of completed pathways.

7.4.3.1 Current Pedestrian/Jogger Scenario

As discussed in Section 7-2, surface soil is not a medium of concern since there were no COPCs detected in samples. Therefore, dermal contact with and incidental ingestion of surface soil are not completed exposure pathways for an on-post pedestrian/jogger. Nor is inhalation of fugitive dust a completed pathway. Similarly, a pedestrian/jogger is not likely to have direct contact with contaminated subsurface soil. However, vapors from volatile organic compounds in subsurface soil may migrate through soil and be present in the breathing atmosphere of a pedestrian/jogger. There are no direct access points (water wells, etc.) to groundwater at FFTA-MAAF; therefore, direct contact with groundwater is not likely. Due to the depth of the water table, from 20 to 25 feet bgs, it is not likely that appreciable vapors from impacted groundwater will migrate through soil to the surface.

In summary, the exposure pathway considered potentially complete for a pedestrian/jogger is:

- Inhalation of vapor phase chemicals from subsurface soil

7.4.3.2 Future Utility Excavation Worker Scenario

As discussed in Section 7.2, surface soil is not a medium of concern; therefore, exposures to soil do not represent completed pathways. However, should FOC repair work be required, or a new utility line be installed, an excavation worker may have direct contact with contaminated subsurface soil. Direct contact with subsurface soil could lead to incidental ingestion of soil and absorption through dermal contact with soil. It is possible for vapors from volatile organic compounds to migrate through subsurface soil and be present in the breathing atmosphere of a utility excavation worker. Fugitive dusts from excavated soil may be generated by wind and/or equipment and subsequently be inhaled by a worker. There are no direct access points (water wells, etc.) to groundwater at FFTA-MAAF and utility excavation for the FOC or a new utility is not likely to extend to the depth of the water table which is 20 to 25 feet bgs. For these reasons, direct contact with groundwater is not likely. Due to the depth of the water table, it is also unlikely that appreciable vapors from impacted groundwater will migrate to the surface.

In summary, the exposure pathways considered potentially complete for the utility excavation worker are:

- Incidental ingestion of chemicals in subsurface soil
- Absorption through dermal contact with chemicals in subsurface soil
- Inhalation of chemicals in fugitive dust
- Inhalation of vapor phase chemicals from subsurface soil

7.4.3.3 Current Racetrack Worker Scenario

Exposure opportunity exists for a racetrack worker since his/her activities include spraying the track with water from Well R-2 for dust control and conditioning the track. Inhalation of vapors may occur as a result of volatilization of organic compounds in the groundwater being applied to the track surface. Due to the depth of the water table, from 20 to 25 feet bgs, it is unlikely that appreciable vapors from impacted groundwater will migrate through soil and reach the surface.

Workers at the racetrack are knowledgeable about the condition of the groundwater and avoid contact (Pers. Comm., 1996d). In addition, there are numerous signs throughout the racetrack facility instructing personnel and patrons against drinking the water. However, to be conservative, it was assumed that workers drink groundwater from Well R-2 while on the job. Dermal contact with groundwater is possible while a worker is filling the water tanks; however, this exposure is likely to be of short duration and limited body contact. Should a worker "hose down" or "shower" with groundwater at the end of the workday, the exposure opportunity would be greater. The later dermal exposure opportunity was assumed in the risk assessment.

In summary, the exposure pathways considered potentially complete for a racetrack worker are:

- Inhalation of vapor phase chemicals from groundwater while working
- Ingestion of chemicals in groundwater
- Dermal contact with chemicals in groundwater while showering

7.4.3.4 Current Racetrack Patron Scenarios

Both adult and child racetrack patrons may have short-term contact with impacted groundwater (Well R-1) during restroom use. It is likely that racetrack patrons will directly contact groundwater through hand-washing. Although signs instruct otherwise, it is also possible for water in the restrooms to be ingested. Because of the short duration of restroom visits, it is unlikely that any significant exposure will occur through inhalation of organic vapors released from groundwater during restroom use. Due to the depth of the water table, from 20 to 25 feet bgs, it is unlikely that appreciable vapors from impacted groundwater will migrate to the surface and through the building foundation.

In summary, the exposure pathways considered potentially complete for adult and child racetrack patrons are:

- Ingestion of chemicals in tap water
- Dermal contact with chemicals in tap water

7.4.3.5 Current and Future Resident Scenarios

Adult and child residents were evaluated under both current and future exposure settings. The current setting addresses the possibility that residents of the trailer located north of the racetrack may be exposed to impacted groundwater from Well M-1. It was assumed that residents directly contact groundwater through dermal absorption while showering and through ingestion of drinking water. Additionally, inhalation of organic vapors generated during showering was assumed to occur. Due to the depth of the water table, from 20 to 25 feet bgs, it is unlikely that appreciable vapors from impacted groundwater will migrate to the surface.

Adult and child residents were also evaluated under future hypothetical exposure conditions. It was assumed that a new private well may be installed in the plume at a hypothetical location where the yearly maximum contaminant levels occur. The fate and transport modeling predicts that this location will vary for each contaminant and for each year. Thus, this ‘floating’ well is truly hypothetical and provides a conservative estimate of risk. The future adult and child residents were assumed to experience the same exposures just described for the current resident scenario. In addition, the adult resident was assumed to farm and be exposed to vapors from irrigation water.

In summary, the exposure pathways considered complete for current and future adult/child residents are:

- Ingestion of chemicals in tap water
- Dermal contact with chemicals while showering
- Inhalation of vapor phase chemicals while showering
- Inhalation of vapors from irrigation water (future adult resident farmer only)

7.4.4 Estimation of Intake

This section of the risk assessment presents the calculation of chemical intake through the exposure pathways identified in Section 7.4.3. Chemical intake is expressed in milligrams of chemical per kilogram of body weight per day (mg/kg/day). Intakes for all COPCs were quantified using pathway-specific equations taken from USEPA guidance (USEPA, 1989) [*RAGS Part A*]. These equations are presented in Tables 7-9 through 7-16. The exposure and chemical variables used in these equations are discussed in the following sections. The calculated chemical intakes are later used in conjunction with toxicity values to characterize risk, as discussed in Section 7.5, Risk Characterization.

7.4.4.1 Exposure Variables

Recommended exposure variable values from guidance documents were used and referenced, if available. If not, best professional judgment about expected Site conditions was employed to estimate values for the exposure scenarios. The recommended values and estimated values were specifically chosen to result in a reasonable maximum exposure (RME) estimate. An RME represents a high-end exposure situation, but one still within the realm of possible exposures. Values used for each pathway for all receptors characterized are shown on the appropriate intake tables (see Tables 7-9 through 7-16).

7.4.4.1.1 On-Post Pedestrian/Jogger Exposure Variables

The pedestrian/jogger was assumed to weigh 70 kilograms (USEPA, 1991a) [*Standard Default Factors*], the standard adult weight. For the inhalation intake calculation for organic vapors, it was assumed that the pedestrian/jogger breathes 3.2 cubic meters of air per hour (m^3/hr) (USEPA, 1997b) [*Exposure Factors Handbook*]. This represents the mean value for an adult based on a short-term heavy activity level. It was assumed that the pedestrian/jogger is either an on-post resident or regular full-time worker who is in this area of the FFTA-MAAF for 15 minutes a day, 350 days per year, for a duration of 30 years. This conservatively assumes that the pedestrian/jogger is in the same area of FFTA-MAAF for the same length of time regardless of weather or season. This is a likely overestimate of exposure conditions/opportunities and is thus overprotective.

7.4.4.1.2 On-Post Utility Excavation Worker Exposure Variables

A utility excavation worker was assumed to weigh 70 kilograms (USEPA, 1991a) [*Standard Default Factors*]. In calculating dermal absorption of chemicals from soil, 3160 cm^2 was used as the total area of exposed skin based upon the mean value for head, hands, and forearms of adult males (USEPA, 1992a) [*Dermal Guidance*]. The soil to skin adherence factor used in the dermal intake equation was calculated by averaging body part-specific adherence factors weighted by the surface area of the body part (USEPA, 1997b) [*Exposure Factors Handbook*]. The calculated value was 0.21 mg/cm^2, as shown in Table 7-17.

For the inhalation intake calculations for dust and vapors it was assumed that the utility excavation worker breathes 2.5 m^3/hr (USEPA, 1997b) [*Exposure Factors Handbook*]. This is mean value for an outdoor worker based on a short-term heavy activity level. An incidental soil ingestion rate of 100 milligrams per day (mg/day) (USEPA, 1997b) [*Exposure Factors Handbook*] was used to estimate intake for utility excavation workers. Although the handbook recommends a central value of 50 mg/day for adult ingestion, 100 mg/day may be more appropriate for the increased ingestion rate likely experienced during excavation activities due to the additional soil contact opportunity. The value of 100 mg/day represents the high end of the range reported in the handbook for a limited study conducted by Calabrese (1987) and is consistent with the value often used by USEPA risk assessors for an agricultural setting. The variable fraction of soil ingested from the contaminated source was assumed to be 1 for the utility excavation worker population.

For determining likely exposure time, frequency, and duration, the Directorate of Information Management (DOIM) was contacted (Pers. Comm., 1996e). The DOIM indicated that the FOC was only 5 years old at the time and had not yet required service. Time estimated for general utility excavation work at Fort Riley was reported previously as 6 days (LBA, 1995) [*DCFA RI Report*]. Based on this information, it was assumed that workers spend 6 days per year and 8 hours per day engaged in future utility excavation work at FFTA. The standard default exposure duration for workers, 25 years, was conservatively assumed (USEPA, 1991a) [*Standard Default Factors*].

7.4.4.1.3 Racetrack Worker Exposure Variables

The racetrack worker was assumed to weigh 70 kilograms (USEPA, 1991a) [*Standard Default Factors*]. He was assumed to ingest 1 liter of contaminated water per workday (USEPA, 1991a) [*Standard Default Factors*]. In calculating dermal absorption of chemicals from groundwater while hosing down or "showering" after work, 19,400 cm^2 was used which represents the 95th percentile total body surface area for adult males (USEPA, 1992a) [*Dermal Guidance*]. For the inhalation intake calculation for organic vapors, it was assumed that the racetrack worker breathes 2.5 m^3/hr (USEPA, 1997b) [*Exposure Factors Handbook*]. This is the mean value for an outdoor worker based on a short-term heavy activity level.

A discussion with one of the racetrack workers (Pers. Comm., 1996d) revealed that he typically volunteers 8 hours per day, 1 day per week throughout the duration of the racing season which lasts for 18 weeks. It was assumed that he inhales vapors for the full 8 hours that he is working. The duration of time spent for showering after work was assumed to be 15 minutes (USEPA, 1991a) *[Standard Default Factors*]. Because one of the current racetrack workers indicated that he had been working there since the track opened (15 years in 1996), the standard default exposure duration for workers of 25 years (USEPA, 1991a) *[Standard Default Factors]* was appropriate.

7.4.4.1.4 Racetrack Patron Exposure Variables

The adult racetrack patron was assumed to weigh 70 kilograms (USEPA, 1991a) [*Standard Default Factors*]. In calculating dermal absorption of chemicals from groundwater while washing hands, 1,980 cm^2 was used as the total area of exposed skin based upon the mean value for hands and forearms of adult males (USEPA, 1992a) [*Dermal Guidance*].

Based on best professional judgment, it was assumed that child racetrack patrons were 3 to 9 years of age; therefore, the exposure values used correspond to this age group. The body weight used for children is 21 kilograms (USEPA, 1997b) [*Exposure Factors Handbook*]. In calculating dermal absorption of chemicals from groundwater while washing hands, 990 cm^2 was used as the total area of exposed skin. This represents 10 percent (approximate for hands and forearms) of the 95 percentile value of the total skin area for children ages 3-9 (USEPA, 1992a) [*Dermal Guidance*].

It was assumed that an adult would ingest 2 liters of water per day (L/day), while a child would ingest 1 L/day (USEPA, 1991a) [*Standard Default Factors*]. These values were adjusted to reflect a 3 hour duration of time at the racetrack. This resulted in a drinking water ingestion rate of 0.4 L/day for adults and 0.2 L/day for children.

It is assumed that regular patrons of the racetrack attend the races 1 day each weekend for the duration of the 18 week racing season (Pers. Comm., 1996d). It was assumed that the average time spent in the restroom each evening was 15 minutes. The exposure duration for noncarcinogenic risk characterization was assumed to be 30 years for adults and 6 years for children (USEPA, 1989) [*RAGS Part A*]. The exposure duration for carcinogenic risk characterization was assumed to be 30 years.

7.4.4.1.5 Off-Post Resident Exposure Variables

Variable values used to estimate intake for both the current and future populations were the same except for chemical concentrations (discussed in Section 7.4.4.2) and inhalation exposure variables unique to the hypothetical future farmer.

The adult resident was assumed to weigh 70 kilograms (USEPA, 1991a) [*Standard Default Factors*]. In calculating dermal absorption of chemicals from groundwater while showering, 19,400 cm^2 was used as the total body surface area of adult males (USEPA, 1992a) [*Dermal Guidance*].

It was assumed that a child resident was 1 to 6 years of age; therefore, the exposure values used correspond to that age group. The body weight used for a child was 15 kilograms (USEPA, 1991a) [*Standard Default Factors*]. In calculating dermal absorption of chemicals from groundwater while showering, 8,023 cm^2 was used as the total body surface area (USEPA, 1992a) [*Dermal Guidance*]. This represents the 95 percentile for total body surface area for children ages 2-6.

For the inhalation intake calculations for organic vapors while showering, it was assumed that an adult breathes 1.0 m^3/hr (USEPA, 1997b) [*Exposure Factors Handbook*] and a child breathes 1.2 m^3/hr (USEPA, 1997b) [*Exposure Factors Handbook*]. These represent short-term light activity for an adult and short-term moderate activity for a child. For water consumption, it was assumed that an adult would ingest 2 L/day, while a child would ingest 1 L/day (USEPA, 1991a) [*Standard Default Factors*].

For dermal exposure, the daily times spent in the shower or bath were assumed to be 15 minutes and 20 minutes for an adult and child, respectively. For inhalation exposure, the daily times spent in the bathroom during showering/bathing and afterwards were 20 minutes for an adult and 25 minutes for a child (USEPA, 1997b) [*Exposure Factors Handbook*].

The future adult resident farmer was also assumed to spend one hour a day, each of 45 days in a growing season, tending to crops in the downwind vicinity of a sprinkler irrigation system. This best professional judgment represents a conservative estimate of vapor exposure since it is unlikely that daily irrigation of crops would be required for 25 recurring years and that a farmer would always be working in the downwind direction. An inhalation rate of 2.5 m3/hr was used to estimate exposure; this represents short-term outdoor worker heavy activity (USPA, 1997b) [*Exposure Factors Handbook].*

Consistent with USEPA guidance regarding residential exposure, both adults and children were assumed to spend 350 days of the year at home (USEPA, 1991a) [*Standard Default Factors*]. The exposure duration for noncarcinogenic risk characterization was assumed to be 30 years for adults and 6 years for children. The exposure duration for carcinogenic risk characterization was assumed to be 30 years, six of which were as a child. For carcinogens, this therefore necessitated the use of age-adjusted exposure factors for ingestion, inhalation, and dermal contact. These factors are derived following the equations shown in Tables 7-13, 7-14, and 7-16, respectively.

7.4.4.2 Chemical Variables

7.4.4.2.1 Current Exposure Concentrations

USEPA *Supplemental Guidance to RAGS, Calculating the Concentration Term* (USEPA, 1992b) specifies that the RME exposure concentration for a receptor population be calculated using the 95 UCL of the arithmetic mean of chemical concentrations. These values were calculated assuming a lognormal distribution of the data. However, there are instances where the 95 percent UCL can be greater that the maximum detected value, such as when there are elevated detection limits or small sample sizes with great variability. In these situations, USEPA recommends that the maximum detected concentration be used.

The maximum detected concentrations and the 95 percent UCLs are shown in Tables 7-18 through 7-21, with the values used in calculations specified. Table 7-18 presents the subsurface soil data (1-8 feet bgs) that were used in the on-post pedestrian/jogger scenario. Table 7-19 presents Well R-2 groundwater data that were used in the racetrack worker scenario. Table 7-20 presents Well R-1 groundwater data that were used in the adult and child racetrack patron scenarios. Table 7-21 presents Well M-1 groundwater data that were used in the adult and child resident scenarios.

Estimations of current vapor concentrations for the appropriate exposure scenarios are discussed later in this section. For estimating vapor exposure, as with direct exposure, the soil and groundwater concentrations were assumed to be steady state, i.e., constant over the scenario exposure durations.

7.4.4.2.2 Future Exposure Concentrations

Groundwater fate and transport modeling using computer code simulations was conducted to estimate future maximum chemical concentrations off post. The methods used to model chlorinated solvents (RT3D) and to model petroleum constituents (BIOSCREEN) are detailed in Section 6.0. The modeling results used to determine future exposure concentrations in the HHBRA are presented in Tables 6-9 and 6-11, for chlorinated solvents and petroleum constituents, respectively. These results are the yearly maximum chemical concentrations summarized by aquifer zones, over a 30-year period. These yearly maximum chemical concentrations do not necessarily occur at the same lateral location within an aquifer zone.

Table 7-22 summarizes the exposure concentrations used in the risk assessment for the future hypothetical child resident and adult resident farmer. These exposure concentrations were estimated using the modeling results presented in Tables 6-9 and 6-11, in the following manner. The yearly maximum chemical concentrations predicted in the shallow and intermediate aquifer zones, regardless of lateral location, were averaged over 6 years and 30 years for the child and adult resident exposures, respectively. The yearly maximum chemical concentrations predicted in the shallow, intermediate, and deep aquifer zones were averaged over 30 years to represent concentrations in an irrigation well. (The hypothetical irrigation well was used to predict the adult resident's additional exposure potential while farming.) This scheme for averaging groundwater concentrations across zones was based on the typical residential and irrigation well pumping rates. For the child, the averages included the years in which the maximum chemical concentrations were predicted. For vinyl chloride in the shallow and intermediate zones, the maximum concentrations occurred during the sixth year, therefore years 4 through 9 were averaged.

1,1-DCE and trans-1,2-DCE were identified as COPCs, but were not selected for modeling. The 95 percent UCL values were calculated using the off-post RI data from impacted wells (i.e., 244 samples). Following USEPA guidance, the maximum value was used for 1,1-DCE since the 95 percent UCL value was greater.

Concentrations of vapors from soil and water were modeled using simple algorithms, described in the following sections.

7.4.4.2.3 Vapor Modeling from Soil

This section presents the equations and assumptions used in the vapor transport modeling from soil to air. This approach was used to estimate chemical vapor concentrations that could be experienced by a current pedestrian/jogger or a future utility excavation worker. In both scenarios, current soil concentrations were used and assumed to be steady state for the duration of exposure. The vapor modeling from soil consists of three parts: contaminant partitioning from soil, vapor emission rate from soil to the ground surface, and vapor concentrations diluted in the breathing zone. Table 7-23 presents the partitioning equation and input values used to determine vapor concentrations in soil gas at the contaminated source. Table 7-24 presents the equation and variables for vapor emission rates from the subsurface source to the ground surface. The equation and variables for vapor concentrations in air are presented in Table 7-25. Discussions regarding each of these three parts of vapor modeling are presented in the following paragraphs.

A commonly used partitioning equation (Jury et al., 1990; Texas Natural Resource Conservation Commission [TNRCC], 1994; American Petroleum Institute [API], 1994; Jeng, et al., 1996) was used to estimate the chemical vapor concentrations in soil gas (mg/m^3) in equilibrium with the chemical concentrations in soil (mg/kg). This partitioning equation uses soil physical properties, such as soil bulk density, moisture content, porosity, and fraction organic carbon, as well as chemical-specific parameters, such as organic carbon partition coefficient and Henry's law constant. Chemical parameters that were used for the calculations were taken from the Risk*Assistant database (Hampshire Research Institute [HRI], 1995) [*Risk Assistant*]. Soil physical properties used in the calculations were either commonly accepted default values or based on information obtained during previous investigations and reported in the *RI/FS WP.*

The rate of vapor generation from subsurface soil was estimated using Farmer's emission rate calculation, as modified by Shen and Farino (USEPA, 1988) (Superfund Exposure Assessment Manual) [*SEAM*]. This vapor emission rate equation incorporates several conservative assumptions. It ignores biodegradation, removal by leaching, and the adsorption of vapor to soil. It also assumes no depletion of the source to reduce the emission rate and a zero concentration of the contaminant at the ground surface. Diffusion upward through soil to the ground surface is the controlling factor. The chemical vapor concentration values in soil at the source were determined from the partitioning equation calculations as previously discussed. The effective diffusion coefficient was calculated following the definition developed by Millington and Quirk (1961), using chemical-specific air diffusivity values (USEPA, 1988) [*SEAM*], and site-specific soil porosity. Representative air porosity measurements at specific sites are difficult to determine and seasonally variable; the value used in the equation was calculated based on average total porosity and moisture content values measured during the SI. The area assumed to be available for diffusion of vapors through soil gas was 5,435 m^2 (58,500 ft^2), approximating the area of impacted soil at FFTA-MAAF. The distance the vapors were assumed to travel upward through soil was set at 1 foot (0.3048 meters). In some areas this is a conservative assumption, since most contamination has been detected at greater soil depth.

The resultant vapor emission rates to the surface were entered into a near-field box model (USEPA, 1988) [*SEAM*] and (GRI, 1988) [*Gas Research Institute*] to estimate concentrations in breathing zone air. The near-field box model is a representation of the effective mixing zone in which evolved contaminants are diluted and delivered to a receptor point. The box defines the volume within which emissions from a source area are mixed with ambient air. Box dimensions are generally determined from the area of contamination, location of receptor, wind speed, and mixing height.

For this modeling effort, the near-field box width was sized to correspond to the downwind width of the impacted soil area. The near-field box height was set at two meters to correspond to the receptor breathing zone. Wind speed through the box (U_m) was calculated to be 5.4 meters/second, based on the annual mean wind speed which is measured at 10 meters (U_{10}) (meteorology is presented in Section 2.2). The results of the near-field box model were used as exposure point concentrations for both of the on-post scenarios characterized in this risk assessment.

7.4.4.2.4 Vapor Modeling from Applied Water

Vapor modeling from applied water was used to determine exposure concentrations that may be experienced by a racetrack worker. Vapor modeling from water to air was conducted in two steps. Chemical-specific vapor emission rates were calculated and then used in a near-field box model to determine diluted vapor concentrations in the breathing zone.

The equation used for modeling a vapor emission rate from water applied to the racetrack is a model normally used for surface water, and developed based upon the chemical concentration in the water, the flow rate of the water, and a water to air transfer factor. This approach was taken from methods presented in *Fate & Exposure Data* (Howard, 1993). Table 7-26 presents the equation, variables, and parameter values for calculating vapor emission rates.

The flow rate of the water was based upon capacity of the water tanks and the time required to empty the tanks. According to personnel that volunteer at the track, the capacities of the tanks are 900 gallons and 1,200 gallons, and the trucks will empty an entire load in about 10 minutes. From this it was estimated that the flow rate is 100 gpm. The volatilization factor was conservatively assumed to be 1, i.e., 100 percent of the COPCs in the groundwater were assumed to volatilize into air.

The resultant vapor emission rates were then used as input for the near-field box model (described previously in this section). The near-field box model uses the vapor emission rates, the height of the box, the width of the box, and the average wind speed at 10 m above the ground surface of 5.4 m/sec (see Section 2.2). The height of the box was assumed to be 2 m, which encompasses a typical breathing zone. The normal wind direction during the racing season is from the southwest, thus the widest southwesterly distance across the racetrack, 300 feet (or 91m), was used as the box width. The vapor concentrations inside the box for the racetrack worker scenario are presented in Table 7-27.

7.4.4.2.5 Vapor Modeling from Irrigation Water

Chemical vapor concentrations from irrigation water were estimated in a similar manner as described in the previous paragraphs. The differences between the two scenarios were in flow rates and near-field box sizes. The flow rate for irrigation water was assumed to be a 1,000 gpm which is considered typical for an irrigation well. The downwind near-field box (in which the farmer works and breathes air) was assumed to be 500 feet, based on best professional judgment. Tables 7-28 and 7-29 present the equations and input values used to calculate vapor concentrations for this scenario.

7.4.4.2.6 Chemical Volatilization Indoors

The Andelman (1990) model for chemical volatilization from groundwater while showering was used for the resident scenarios, as shown in Table 7-16. This model predicts possible peak air concentrations in the bathroom averaged over the time spent showering/bathing combined with the time spent in the bathroom subsequent to showering/bathing. The model also assumes that the contaminants volatilize at a constant rate, instantly mix uniformly in the room, and that there is ventilation with clean air. Thus, chemical concentrations in the air are assumed to increase linearly from zero to a maximum at the end of the shower and then remain constant. Model parameters include chemical concentrations in water, the fraction volatilized from water, water flow rate, volume of the bathroom, and time spent during and after showering. Concentrations in water were taken from Tables 7-21 and 7-22 for current and future exposure scenarios, respectively. For both scenarios, a volatilization factor of 1 was conservatively assumed. Parameter values for water flow rate (600 L/hr) and volume of the bathroom (9 m^3) were selected from the ranges recommended by John Schaum, et al., of the USEPA (Schaum et al., 1992).

7.4.4.2.7 Chemical Concentrations in Dust

Dust generation produces a potential chemical exposure situation for a future utility excavation worker. Since potential dust concentrations in a future exposure scenario cannot be measured, the Occupational Safety and Health Administration (OSHA) nuisance dust limit for respirable particles was used, 5 mg/m^3. It was also assumed that 100 percent of the dust in the air was derived from contaminated soil. As a further conservative measure, the chemicals were assumed to be evenly distributed over the entire exposure area generating the dust.

7.4.4.2.8 Dermal Absorption of Chemicals

In estimating absorption of chemicals in water, chemical-specific permeability constant (K_P) values in units of centimeters per hour (cm/hr) were used. Published K_P values were available for COPCs and are appropriately referenced in Table 7-14.

There is very limited information available on skin absorption of specific chemicals from a soil matrix. STSC was consulted, but did not provide information. A value of 0.01 for organics was used as the absorption factor. This is consistent with USEPA Region 4 guidance (USEPA, 1995a) [*Region 4 Bulletin*] and discussions provided in *Dermal Exposure Assessment: Principles and Applications* (USEPA, 1992a).

The use of permeability constants and absorption factors (for chemicals in water and soil, respectively) in the intake calculation for the dermal exposure route results in an estimate of absorbed dose. This absorbed dose must then be used in conjunction with an adjusted toxicity value to characterize risk. Oral toxicity values were adjusted to dermal toxicity values as described in Section 7.3.

7.5 RISK CHARACTERIZATION

To quantify the potential risk posed by exposure to chemicals through identified pathways, the intake of each chemical is combined mathematically with the appropriate toxicity value to estimate the likelihood of health risks. The following two sections define the general risk characterization process for evaluating noncarcinogenic and carcinogenic chemicals. Risk characterization for each potentially exposed population then follows.

7.5.1 General Noncarcinogenic Risk Discussion

To characterize the risk of noncarcinogenic effects, toxicity values for COPCs are used in conjunction with dose estimates for each exposure scenario to quantitatively estimate the potential for adverse health effects. Chemical-specific doses calculated for each exposure pathway are compared with the reference value, RfD, for that chemical. If the estimated dose does not exceed the reference value, then adverse noncarcinogenic health effects are not expected. The comparison of dose to reference value is expressed mathematically as a hazard quotient, which is the dose divided by the reference value:

$$\text{Hazard Quotient} = \text{Dose (mg/kg/day)} / \text{RfD (mg/kg/day)}$$

Hazard quotients for chemicals within a pathway are summed to give the pathway hazard index. Pathway hazard indices are then summed for a total exposure hazard index. The summation of chemical and pathway hazard indices is conservative and health-protective. If the total hazard index is greater than one, then COPCs are appropriately segregated by target organ to derive a separate hazard index for each chemical group. If the total hazard index is one or less, it is unlikely for even sensitive populations to experience adverse health effects within the described scenario.

7.5.2 General Carcinogenic Risk Discussion

Carcinogenic risk is expressed as a probability of developing a carcinogenic response as a result of exposure to a given chemical. The estimated dose for each cancer-causing substance is multiplied by the corresponding slope factor to calculate risk. The expression is as follows:

$$\text{Risk} = \text{Dose (mg/kg/day)} \times \text{Slope Factor (mg/kg/day)}^{-1}$$

For simultaneous exposure to several carcinogens, the calculated risks are summed within each pathway and then for all pathways to yield total excess cancer risk posed by a site.

This represents the probability of developing a carcinogenic response which is solely attributable to exposure from the site and is in excess of the general background risk. Based on National Cancer Institute statistics (NCI, 1990), background risk may be considered 0.33 (3.3×10^{-1} or 3.3E-01 in scientific notation), since approximately one in three people in the United States will develop some form of cancer during a lifetime.

Given the current assumption that any exposure to any carcinogen poses some risk, zero risk is not achievable in a practical sense. Therefore, ranges of risk have been developed by USEPA for use as remediation goals. To be protective of human health, USEPA believes that exposure to site-related carcinogens should be limited so as to result in an individual upper bound excess lifetime cancer risk level of one in 10,000 or less (Federal Register [FR], 1990). The risk range of one in 10,000 to one in a million is a commonly accepted remediation goal. In other words, a excess lifetime cancer risk greater than one in 10,000 would generally be considered unacceptably high, while risks within the range would be acceptable depending upon site use. Risks of one in a million or less are generally considered insignificant. The concept of insignificance can be numerically illustrated by adding the excess cancer risk of one in a million to the NCI background cancer risk in the United States. This results in a total lifetime cancer risk of 0.330001.

7.5.3 Risk Estimates for On-Post Pedestrian/Jogger Scenario

The following sections detail the results of the risk characterization for the on-post pedestrian/jogger scenario under current exposure conditions. Since there are no new sources of contamination and the existing sources of contamination are depleting, future risk potential for this receptor is expected to decrease over time and therefore was not characterized.

7.5.3.1 Noncarcinogenic Risk

Table 7-30 shows intake, reference values, and hazard indices for the on-post pedestrian/jogger. The total hazard index was 2E-03. This is below the USEPA level of concern for noncarcinogenic risk, which is a hazard index greater than 1.

7.5.3.2 Carcinogenic Risk

Table 7-31 presents intake, slope factors, and the excess lifetime cancer risk associated with chemical exposure for the on-post pedestrian/jogger. The total excess lifetime cancer risk was 4E-08. This is well below the 1E-04 to 1E-06 (one in 10,000 to one in a million) acceptable risk range.

7.5.4 Risk Estimates for On-Post Utility Excavation Worker Scenario

The following sections detail the results of the risk characterization for a future on-post utility excavation worker scenario. Current levels of soil contamination were used in this characterization and assumed to be steady state for future exposures.

7.5.4.1 Noncarcinogenic Risk

Table 7-32 shows intake, reference values, and hazard indices for a future on-post utility excavation worker. The total hazard index was 9E-04. This is below one, the USEPA level of concern for noncarcinogenic risk.

7.5.4.2 Carcinogenic Risk

Table 7-33 presents intake, slope factors, and the excess lifetime cancer risk associated with chemical exposure for the future on-post utility excavation worker. The total excess lifetime cancer risk was 1E-08. This is below the 1E-04 to 1E-06 (one in 10,000 to one in a million) acceptable risk range.

7.5.5 Risk Estimates for Racetrack Worker Scenario

The following sections detail the results of the risk characterization for the racetrack worker scenario under current exposure conditions (i.e., 95 percent UCLs for COPCs in Well R-2).

7.5.5.1 Noncarcinogenic Risk

Table 7-34 shows intake, reference values, and hazard indices for the current racetrack worker. The total hazard index was 2E-02. This is below the USEPA level of concern for noncarcinogenic risk, which is a hazard index of greater than 1.

7.5.5.2 Carcinogenic Risk

Table 7-35 presents intake, slope factors, and the excess lifetime cancer risk associated with chemical exposure for the current racetrack worker. The total excess lifetime cancer risk was 6E-07. This is below the 1E-04 to 1E-06 (one in 10,000 to one in a million) acceptable risk range.

7.5.6 Risk Estimates for Racetrack Patron Scenario

The following sections detail the results of risk characterizations for the racetrack patron scenario under current exposure conditions (i.e., 95 percent UCLs for COPCs in Well R-1). Results of the noncarcinogenic risk characterization are presented separately for the adult and child racetrack patrons with exposure durations of 30 and 6 years, respectively. Carcinogenic risk was calculated assuming an adult exposure duration of 30 years. Therefore, the results of the carcinogenic risk characterization are presented for an adult racetrack patron only.

7.5.6.1 Noncarcinogenic Risk

Table 7-36 shows intake, reference values, and hazard indices for the child racetrack patron. The total hazard index for all pathways combined was 1E-02. This is below one, the USEPA level of concern for noncarcinogenic risk.

Table 7-37 shows intake, reference values, and hazard indices for the adult racetrack patron. The total hazard index was 1E-02. This is below the USEPA level of concern for noncarcinogenic risk.

7.5.6.2 Carcinogenic Risk

Table 7-38 presents intake, slope factors, and the excess lifetime cancer risk associated with chemical exposure for the adult racetrack patron. The total excess lifetime cancer risk for all pathways combined was 6E-07. This is below the 1E-04 to 1E-06 (one in 10,000 to one in a million) acceptable risk range.

7.5.7 Risk Estimates for the Current Off-Post Resident Scenario

The following sections detail the results of the risk characterizations for the current off-post resident scenario under current exposure conditions (i.e., 95 percent UCLs for COPCs in Well M-1).

Results of the noncarcinogenic risk characterization are presented separately for the adult and child residents with exposure durations of 30 and 6 years, respectively. Carcinogenic risk was calculated assuming an age-adjusted exposure duration of 30 years (i.e., 6 years as a child and 24 years as an adult). The results of the carcinogenic risk characterization are presented for an adult resident only.

7.5.7.1 Noncarcinogenic Risk

Table 7-39 shows intake, reference values, and hazard indices for the current off-post child resident. The total hazard index was 2E-01. This is below the USEPA level of concern for noncarcinogenic risk which is greater than 1.

Table 7-40 shows intake, reference values, and hazard indices for the current off-post adult resident. The total hazard index was 1E-01. This is below the USEPA level of concern for noncarcinogenic risk.

7.5.7.2 Carcinogenic Risk

Table 7-41 presents intake, slope factors, and the excess lifetime cancer risk associated with chemical exposure for the current off-post adult resident. The total excess lifetime cancer risk was 2E-05. This is within the 1E-04 to 1E-06 (one in 10,000 to one in a million) acceptable risk range. Most of the excess cancer risk was posed from ingestion of vinyl chloride in tap water (1E-05) and from inhalation of vinyl chloride vapors while showering (6E-06).

7.5.8 Risk Estimates for the Future Off-Post Resident Scenario

The following sections detail the results of the risk characterizations for the future off-post resident scenario under future exposure conditions, i.e., modeled chemical concentrations in a hypothetical residential well. For the adult, assumed to be farming adjacent property, risk estimates also included exposure to vapor phase chemicals in irrigation water from a second hypothetical well.

Results of the noncarcinogenic risk characterization are presented separately for the adult and child residents with exposure durations of 30 and 6 years, respectively. Carcinogenic risk was calculated for an adult resident assuming an exposure duration of 30 years. Therefore, the results of the carcinogenic risk characterization are presented for an adult resident only.

7.5.8.1 Noncarcinogenic Risk

Table 7-42 shows intake, reference values, and hazard indices for the future off-post child resident. The total hazard index was 1E+00. This is at the USEPA level of concern for noncarcinogenic risk. Ingestion of cis-1,2-DCE in tap water produced most of the noncarcinogenic risk.

The potential risk posed by cis-1,2-DCE for the future child resident is likely overestimated as a result of conservative assumptions in the exposure and toxicity assessments. In developing the exposure concentrations, it was assumed that the future yearly maximum concentrations for all modeled chemicals will always occur at the same location in plume, i.e., at a hypothetical "floating" well. Additionally, the provisional reference dose for cis-1,2-DCE provided in HEAST, was developed by USEPA using a 3000-fold uncertainty factor. This means that the hazard index of 1 may be overestimated by a factor of 3000. The provisional reference dose for cis-1,2-DCE is considered by USEPA as nonverifiable and subject to change. Verified reference doses once placed in IRIS still have uncertainty spanning an order of magnitude and, according to USEPA, should not be viewed as a strict scientific demarcation between toxic and nontoxic levels (USEPA, 1989) [RAGS Part A].

Table 7-43 shows intake, reference values, and hazard indices for the future off-post adult resident farmer. The total hazard index was 3E-01. This is below the USEPA level of concern for noncarcinogenic risk.

7.5.8.2 Carcinogenic Risk

Table 7-44 presents intake, slope factors, and the excess lifetime cancer risk associated with chemical exposure for the future off-post resident farmer. The total excess lifetime cancer risk was 4E-05. This is within the 1E-04 to 1E-06 (one in 10,000 to one in a million) acceptable risk range. The greatest calculated excess lifetime cancer risk is from ingestion of vinyl chloride (1E-05) and 1,1-DCE (1E-05) in tap water, and inhalation of 1,1-DCE (1E-05) and vinyl chloride (7E-06) vapors while showering.

7.6 UNCERTAINTIES

Conducting a risk assessment requires making a number of assumptions which serve to introduce degrees of uncertainty in the final result. The following sections discuss the uncertainties resulting from chemical identification (Section 7-2), toxicity assessment (Section 7-3), and exposure assessment (Section 7-4). Refer to Table 7-45 for a summary of uncertainties and their potential effect on the risk assessment.

7.6.1 Uncertainty Associated with Chemical Identification

At any site, it is possible that there are more individual chemical substances present than identified in the sampling and analysis effort. The selection of media to be sampled, number of samples, and analyses requested are determined by a review of the history of the site, information on current conditions, and an evaluation as to which chemicals could potentially be present. Extensive historical information was available regarding the work performed, chemicals used, and waste management practices employed at the FFTA-MAAF.

Given the nature of the FFTA-MAAF and the level and identity of the chemicals analyzed in the sampling efforts, it is unlikely that significant chemical contamination went undetected. Further, the application of quality control throughout the sampling, analysis, and data validation phases reduced uncertainty in the results. Therefore, the chemical identification phase of the risk assessment does not appear to have introduced significant uncertainty.

7.6.2 Uncertainty from Toxicity Assessment

For some chemical substances, such as 2-methylnaphthalene, there is little or no toxicity information available and for many chemicals, what is available is typically from animal studies. The relative strength of the available toxicological information generates some uncertainty in the evaluation of possible adverse health effects and the exposure level at which they may occur. To provide for a margin of error, USEPA applies conservative adjustments to the toxicity values.

For noncarcinogenic substances, RfD and RfC values are typically established only after uncertainty and/or modifying factors are applied. These factors may result in an RfD/RfC that is as little as a thousandth or less of the "safe" dose level determined through animal studies.

For carcinogens, the slope factor represents the 95 percent upper confidence limit of an extrapolated low dose response curve. The actual carcinogenic potency of a substance at low doses is almost certainly less. Additionally, many substances identified as carcinogens in high-dose laboratory testing may not be carcinogenic at low doses and/or may not be carcinogenic to humans.

To quantify risk from posed by chemicals that do not have toxicity numbers posted in IRIS or HEAST, provisional numbers, which are generated by STSC, are occasionally used. These provisional numbers typically have not been subjected to the rigorous review process undergone by values in IRIS or HEAST.

Uncertainty is generated by the use of provisional numbers. However, this uncertainty is less than that generated by ignoring or qualitatively assessing risks.

Numerical toxicity values for dermal exposures have not been developed by USEPA. To quantitatively assess risk from dermal exposure, USEPA guidance recommends adjusting oral RfDs and slope factors, usually presented as administered instead of absorbed doses, by chemical-specific gastrointestinal absorption factors to account for the differing dose calculation. Because of potential differences in patterns of distribution, metabolism, and excretion between oral and dermal routes of exposure, use of adjusted oral toxicity values may over- or under-estimate risk, depending on the chemical.

7.6.3 Uncertainty from Exposure Assessment

When evaluating exposure, probable scenarios are developed to estimate conditions and duration of human contact with COPCs. Scenarios are based on observations or assumptions about the current or potential activities of human populations which could result in direct exposure. To prevent underestimation of any risk, scenarios incorporate exposure levels, frequencies, and durations at or near the top end of the range of probable values. This is sometimes termed a reasonable maximum exposure, one that may be unlikely or at the high end of a range of exposures, but still possible.

Default values, such as respiration rates, are used in the exposure calculations to quantify intakes. Although they are based on USEPA-validated data, there is uncertainty in the applicability of such values to any particular exposed population or individual. To compensate for this uncertainty, the default values are typically set to the upper end (usually the 90th or 95th percentile) of the normal range.

Exposure concentrations of COPCs are developed from analytical results then calculated or modeled for each applicable exposure route. For the current scenarios, it was assumed the contaminant levels used in the exposure calculations remained constant throughout the exposure period with no reduction due to chemical depletion or degradation. This is conservative and most likely results in overestimation of exposure. The associated uncertainty is again that actual risk is much less than estimated.

For the future resident exposure scenarios, the results of fate and transport contaminant modeling were used to estimate groundwater exposure concentrations. In applying the modeling results, it was conservatively assumed that the yearly maximum concentrations for all chemicals occur at the same location in the aquifer (which is not the predicted case) and that the receptor well "floats" with time so that it is always screened in the maximum concentrations. This uncertainty combined with the modeling assumptions discussed in Sections 6.5.3.6.3 and 6.5.4.5, likely results in an overestimate of chemical exposure.

The uncertainty associated with the exposure assessment is appreciable. However, the uncertainty is from conservative overestimation of exposure variables. This is protective of potentially exposed populations.

All of these factors contribute to significant uncertainty in the estimates of risk. However, the uncertainty is generally that risk has been overestimated, not underestimated.

7.7 SUMMARY

7.7.1 HHBRA Summary

The potential for human health risk due to exposure to chemicals at the Site was considered for the soil, water, and air media. Based on observed Site conditions, it was concluded that chemical exposure was possible to on-post populations through contact with subsurface soil and/or vapors from soil and to off-post populations through contact with groundwater and vapors. Potential intakes of the COPCs were calculated using standard USEPA exposure calculation equations for intake from ingestion, dermal contact, and inhalation of contaminants. Cancer and noncancer risks were calculated for the following scenarios: current on-post pedestrian/jogger exposure to vapors from impacted subsurface soil; future on-post utility worker exposure to impacted soil and vapors while excavating; current racetrack worker exposure to impacted groundwater and vapors while treating the racetrack with water for dust control; current racetrack patrons exposure to impacted groundwater; and both current and future off-post residents exposure to impacted groundwater and vapors while showering. The future adult resident exposure also included inhalation of vapors from irrigation water.

For exposure concentrations under current conditions, 95 percent UCLs of the mean were calculated assuming lognormally distributed soil and groundwater data. For exposure concentrations that might be experienced in the future by a utility excavation worker, soil chemical concentrations under current conditions were assumed to be steady state. The future resident child/adult exposure concentrations for COPCs in groundwater were based on the fate and transport modeling results, using 6-year and 30-year average maximum chemical concentrations, regardless of predicted location in the plume.

Vapor concentrations for the on-post exposure scenarios were determined by modeling contaminant partitioning from soil, migration to the surface, and dilution in the breathing zone at the receptor point. Vapor concentrations for the racetrack worker/farmer exposure scenarios were determined by modeling partitioning from applied/irrigation water and dilution of vapors in the breathing zone. Indoor vapor concentrations for the resident scenarios were determined from groundwater concentrations by use of the USEPA-accepted Andelman volatilization model.

The results of the risk characterization indicate that current concentrations of COPCs at the FFTA-MAAF pose insignificant risks of adverse health effects for both on-post populations characterized. Current concentrations of COPCs in groundwater also pose insignificant or minimal risk of adverse health effects for the off-post populations. The highest cancer risk was 2E-05 for the off-post adult resident, still within the USEPA acceptable excess cancer risk range of 1E-04 to 1E-06 (one in ten thousand to one in a million). Most of the potential for risk was posed by vinyl chloride.

For the future scenarios, the highest risk for adverse health effects was for the off-post child resident, at a hazard index of 1. The USEPA level of concern is a hazard index greater than 1. Most of the potential for risk in this scenario was posed by cis-1,2-DCE. The highest excess cancer risk was for the off-post future resident farmer at 4E-05, still within the USEPA acceptable excess cancer risk range of 1E-04 to 1E-06. Most of potential for risk was posed by vinyl chloride. A summary of the results of the risk characterization is presented in Table 7-46.

The potential risk posed by cis-1,2-DCE for the future child resident is likely overestimated as a result of conservative assumptions in the exposure and toxicity assessments. In developing the exposure concentrations, it was assumed that the predicted yearly maximum concentrations for all chemicals occur at the same location in the aquifer (which is not the predicted case), and that the receptor well "floats" with time so that it is always screened in the maximum chemical concentrations. Additionally, the provisional reference dose for cis-1,2-DCE, provided in HEAST, was developed by USEPA using a 3,000-fold uncertainty factor. This means that the hazard index of 1 may be overestimated by a factor of 3,000. The provisional reference dose for cis-1,2-DCE is considered by USEPA as nonverifiable and subject to change. Verified reference doses once placed in IRIS still have uncertainty spanning an order of magnitude and, according to USEPA, should not be viewed as a strict scientific demarcation between toxic and nontoxic levels (USEPA, 1989) [RAGS Part A].

Uncertainties in the risk assessment process were evaluated. It was concluded that, when combined, the uncertainty associated with each step most likely resulted in a conservative overestimate of risk.

7.7.2 Alternative Assessment of Future Resident Scenario

An alternative way of estimating exposure concentrations and thus potential risk for the future resident scenario was requested by regulators, following submittal of the draft report. Based on discussions with and concurrence of the EPA Region 7 risk assessor, it was determined that risk would be characterized for each well along the center-line of the plume (MW-04, MW-09, MW-11, MW-23, MW-25, MW-27, MW-29, MW-31, and MW-32) using the methodology described in the remainder of this paragraph. Chemical concentrations in these wells were assumed to remain constant at their present concentrations for the duration of the residential exposure (i.e., 30 years). Data from July 1998 through August 2000 from the shallow, intermediate, and deep sampling intervals at each well location were combined to determine the COPC 95 percent UCLs. The exception was at location MW-11, where there is only a shallow well. If the 95 percent UCL was greater than the maximum concentration detected, then the maximum concentration was considered representative of exposure concentration. For chemicals that have not been detected during sampling rounds, one-half the chemical detection limit was used as a proxy concentration. The February and August 2000 sampling events occurred after the draft was submitted, therefore the data from these sampling events are summarized in Appendix 7B, as Tables 7B-1 and 7B-2. Exposure concentrations for each COPC in each well are presented as Table 7B-3.

Completed exposure pathways assumed for this evaluation were the same as those summarized in Section 7.4.3.5 of the HHBRA and included ingestion of chemicals in groundwater, dermal absorption of chemicals while showering, and inhalation of chemical vapors while showering. The adult farmer was assumed to be additionally exposed to vapors from a sprinkler irrigation system. Exposure variables presented in Tables 7-13 through 7-14 of the HHBRA were used to calculate chemical intake. The results of the risk characterization are summarized in Table 7B-4 of Appendix 7B.

The hazard indices for a future child resident were above one at well locations MW-09, MW-11, and MW-27. The largest hazard index was 4 for both well locations MW-09 and MW-11. Ingestion of cis-1,2-DCE in tap water produced all of the significant noncarcinogenic risk at these well locations. The exposure concentrations for cis-1,2-DCE at well locations MW-09, MW-11, and MW-27 were based on the maximum concentrations detected in May 1999, August 1999, and August 1999, respectively.

The hazard indices for a future resident/farmer were above one at well locations MW-04, MW09, and MW-11. Inhalation of naphthalene produced the significant risk at the on-post well location, MW-04. Ingestion of cis-1,2-DCE in tap water produced the significant noncarcinogenic risk at the other two locations.

Carcinogenic risk was within the 1E-04 to 1E-06 (one in 10,000 to one in a million) acceptable risk range at all well locations, with 1E-04 being the greatest calculated excess lifetime cancer risk at MW-11. This potential risk was posed from ingestion of vinyl chloride in groundwater.

The uncertainty associated with the alternative risk characterization may be great. Although assuming steady-state conditions usually results in a conservative overestimate of exposure and thus risk, it may serve to underestimate exposure and risk in the case of chlorinated solvents. This can result if there is an accumulation over time of daughter products of PCE-TCE degradation, which are more potent carcinogens than the parent compounds. Use of a fate and transport model to predict chemical concentrations over time is one way of reducing the uncertainty associated with this temporal data gap. Site-specific data has been used to develop the fate and transport model presented in Section 6. By comparison to historical trends of contaminant concentrations and the predictions of the fate and transport model, the results of the alternative risk characterization presented in this section are likely an overestimate of exposure and risk.

* * * * *

Table 7-1
Exposure Area Soil Data Summary
FFTA-MAAF Remedial Investigation Report

Chemical	Number of Detections / Number of Samples	Frequency of Positive Detections	Range of Detected Concentrations (ug/kg)	Sample with Maximum Detection
Petroleum Constituents				
Benzene	0 / 138	0%		
Ethylbenzene	4 / 138	3%	690 - 14000	FP99-SB13 b
2-Methylnaphthalene	15 / 170	9%	740- - 46,000	PSB 4-2
Naphthalene	10 / 170	6%	680 - 18000	PSB 4-2
Toluene	3 / 138	2%	3700 - 39000	FP99-SB13 b
Xylenes	10 / 138	7%	2380 - 77000	FP99-SB13 b
Chlorinated Solvents				
1,1-DCE	0 / 138	0%		
cis 1,2-DCE	4 / 138	3%	55 - 580	FP99-SB13 b
trans 1,2-DCE	0 / 138	0%		
PCE	16 / 138	12%	15 - 150	FP99-SB59a (31a)
TCE	3 / 138	2%	14 JM - 19 J	FP99-SB01 d
Vinyl Chloride	0 / 138	0%		

Note:
Population includes RI samples collected from 1 to 17 ft bgs. Samples collected from 0 to 0.5 ft bgs were nondetect.

Napthalene and 2-methylnaphthalene data were taken from the RI Work Plan since these constituents were not analytes for the RI.

Table 7-2
On-Post Groundwater Data Summary
FFTA-MAAF Remedial Investigation Report

Chemical	Number of Detections / Number of Samples	Frequency of Positive Detections	Range of Detected Concentrations (ug/L)	Monitoring Well with Maximum Detection	Sample Date of Maximum Detection
Petroleum Constituents					
Benzene	3 / 71	4%	0.6 - 1	FP-93-04	5/20/99
Ethylbenzene	9 / 71	13%	52 - 95.5	FP-93-04	9/1/98
Naphthalene	8 / 71	11%	7.7 - 70.8	FP-93-04	9/1/98
Toluene	14 / 71	20%	0.5 - 6.6	FP-93-04	5/20/99
Xylenes	9 / 71	13%	1.3 - 418	FP-93-04	9/1/98
Chlorinated Solvents					
1,1-DCE	0 / 71	0%			
cis 1,2-DCE	22 / 71	31%	0.6 - 95.9	FP-93-04	5/20/99
trans 1,2-DCE	2 / 71	3%	0.8 - 1.2	FP-93-02b	2/3/99
PCE	9 / 71	13%	3.9 - 18.8	FP-93-02	9/7/98
TCE	17 / 71	24%	0.6 - 39.6	FP-93-02b	2/3/99
Vinyl Chloride	0 / 71	0%			
Other Chemicals					
Acetone	0 / 71	0%			
Methylene Chloride	0 / 71	0%			
Chloroform (Trichloromethane)	0 / 71	0%			
Phenols	0 / 18	0%			
4-Methylphenol	0 / 18	0%			

Note:
Population includes samples from all on-post wells with positive detections measured during the eight quarterly sampling events from 2/97 through 8/99:
FP-93-01, FP-93-02, FP-93-02b, FP-93-02c, FP-93-03, FP-93-04, FP-93-04b, FP-93-05

Table 7-3
Off-Post Groundwater Data Summary
FFTA-MAAF Remedial Investigation Report

Chemical	Number of Detections / Number of Samples	Frequency of Positive Detections	Range of Detected Concentrations (ug/L)	Monitoring Well with Maximum Detection	Sample Date of Maximum Detection
Petroleum Constituents					
Benzene	61 / 244	25%	0.4 - 12	FP-94-09b	8/30/97
Ethylbenzene	4 / 244	2%	0.8 - 2.4	FP-96-23b	8/29/97
Naphthalene	0 / 244	0%			
Toluene	7 / 244	3%	0.4 - 0.6	R-3	5/20/99
Xylenes	0 / 244	0%			
Chlorinated Solvents					
1,1-DCE	5 / 244	2%	0.8 - 1.2	FP-94-09	5/14/99
cis 1,2-DCE	157 / 244	64%	0.5 - 1100	FP-94-09b	8/30/97
trans 1,2-DCE	55 / 244	23%	0.5 - 4	FP-94-09	8/30/99
PCE	73 / 244	30%	1.1 - 56	FP-96-25	5/28/97
TCE	112 / 244	46%	0.7 - 190	FP-96-25	5/28/97
Vinyl Chloride	6 / 244	2%	1.1 - 2.8	FP-94-11	8/30/99
Other Chemicals					
Acetone	2 / 244	1%	160 - 220	I-1	3/3/98
Methylene Chloride	4 / 244	2%	1 - 27.5	R-3	5/20/99
Chloroform (Trichloromethane)	5 / 244	2%	0.7 - 14	R-1	5/29/97
Phenols	1 / 52	2%	- 17	R-3	9/2/97
4-Methylphenol	1 / 52	2%	- 140	R-3	9/2/97

Note:

Population includes samples from all wells with positive detections measured in at least one of the eight quarterly sampling events from 2/97 through 8/99:

I-1, M-1, R-1, R-2, R-3, R-4, FP-94-09, FP-94-09b, FP-94-11, FP-96-20b, FP-96-23, FP-96-23b, FP-96-23c, FP-96-24, FP-96-25, FP-96-25b, FP-96-25c, FP-96-26, FP-96-26b, FP-96-26c, FP-98-27, FP-98-27b, FP-98-27c, FP-98-28b, FP-98-28c, FP-98-29b, FP-98-29c, FP-98-31, FP-98-31b, FP-98-31c, FP-99-32b, FP-99-32c.

Table 7-4
Summary of Chemicals of Potential Concern
FFTA-MAAF Remedial Investigation Report

SOIL
Petroleum Constituents
Benzene
Ethylbenzene
2-Methylnaphthalene
Naphthalene
Toluene
Xylenes
Chlorinated Solvents
cis-1,2-DCE
PCE
TCE

GROUNDWATER
Petroleum Constituents
Benzene
Ethylbenzene
Toluene
Xylenes
Naphthalene
Chlorinated Solvents
1,1-DCE
cis-1,2-DCE
trans-1,2-DCE
PCE
TCE
Vinyl Chloride

Table 7-5
Noncarcinogenic Toxicity Information
FFTA-MAAF Remedial Investigation Report

Chemical	Oral RfD (mg/kg/day)	Ref.	Dermal RfD (mg/kg/day)	Ref.	Inhalation RfD (mg/kg/day)	Ref.
Petroleum Constituents						
Benzene	1E-03	S	8E-04	r	3E-03	S
Ethylbenzene	1E-01	I	8E-02	r	3E-01	I
2-Methyl Naphthalene	2E-02	S	2E-02	r	9E-04	S
Naphthalene	2E-02	I	2E-02	r	9E-04	I
Toluene	2E-01	I	2E-01	r	1E-01	I
Xylenes	2E+00	I	2E+00	r		
Chlorinated Solvents						
1,1-DCE	9E-03	I	7E-03	r		
1,2-DCE (cis)	1E-02	H	8E-03	r		
1,2-DCE (trans)	2E-02	I	2E-02	r		
PCE	1E-02	I	8E-03	r		
TCE						
Vinyl Chloride	5E-03	S	4E-03	r	3E-02	S

Notes:
H = USEPA Health Effects Assessment Summary Tables (USEPA, 1997a) [*HEAST*]
I = USEPA Integrated Risk Information System (USEPA, 2000) [*IRIS*]
r = Route to route extrapolation from oral toxicity values using an 80 percent absorption efficiency factor (USEPA, 1995a)
RfD = Reference dose
S = USEPA National Center for Environmental Assessment, Superfund Technical Support Center (USEPA, 1999) [*STSC*]

Blanks indicate that information is not currently available in IRIS, HEAST, or alternate sources.

Table 7-6
USEPA Carcinogen Classification*
FFTA-MAAF Remedial Investigation Report

CARCINOGEN CATEGORIES

A	Human carcinogen
B	Probable human carcinogen
C	Possible human carcinogen
D	Not classifiable
E	Evidence of noncarcinogenicity

WEIGHT-OF-EVIDENCE CLASSIFICATION MATRIX

	Animal Evidence				
Human Evidence	Sufficient	Limited	Inadequate	No Data	No Evidence
Sufficient	A	A	A	A	A
Limited	B1	B1	B1	B1	B1
Inadequate	B2	C	D	D	D
No Data	B2	C	D	D	E
No Evidence	B2	D	D	D	E

Note:
The B category is subdivided into B1 and B2, with the strength of any available human data being the deciding factor.

* FR, 1986; USEPA, 1989 [*RAGS Part A*]

Table 7-7
Carcinogenic Toxicity Information
FFTA-MAAF Remedial Investigation Report

Chemical	Weight of Evidence Classification *	Oral SF $(mg/kg/day)^{-1}$	Ref.	Dermal SF $(mg/kg/day)^{-1}$	Ref.	Inhalation SF $(mg/kg/day)^{-1}$	Ref.
Petroleum Constituents							
Benzene	A	2.9E-02	I	3.6E-02	r	2.9E-02	I
Ethylbenzene	D		I				
2-Methyl Naphthalene	under review						
Naphthalene	C		I				
Toluene	D		I				
Xylenes	D		I				
Chlorinated Solvents							
1,1-DCE	C	6.0E-01	I	7.5E-01	r	1.8E-01	S
1,2-DCE (cis)	D		I				
1,2-DCE (trans)	under review						
PCE	under review	5.2E-02	S	6.5E-02	r	2.0E-03	S
TCE	under review	1.1E-02	S	1.4E-02	r	6.0E-03	S
Vinyl Chloride	A	1.9E+00	H	2.4E+00	r	3.0E-01	H

Notes:
H = USEPA Health Effects Assessment Summary Tables (USEPA, 1997a) [*HEAST*]
I = USEPA Integrated Risk Information System (USEPA, 2000) [*IRIS*]
r = Route to route extrapolation from oral toxicity values using an 80 percent absorption efficiency factor (USEPA, 1995a)
S = USEPA National Center for Environmental Assessment, Superfund Technical Support Center (USEPA, 1999) [*STSC*]
SF = Slope Factor

* See previous table for definitions. Note that IRIS now provides additional carcinogenic information for benzene based on the proposed guidelines (USEPA, 1996b).

Blanks indicate that information is not currently available in IRIS, HEAST, or alternate sources.

Table 7-8
Summary of Pathways Considered for Human Health Risk Assessment
FFTA-MAAF Remedial Investigation Report

Potentially Exposed Populations	Media-Specific Exposure Pathways	Pathway Selected for Risk Characterization	Reason for Selecting or Excluding Pathways
Current Scenario			
On Post Pedestrian/Jogger	Surface Soil	NA	- No COPCs were determined for this medium.
	Subsurface Soil		
	Incidental ingestion	no	- Pedestrian/jogger does not typically come in direct contact with subsurface soil.
	Dermal absorption	no	
	Inhalation of particulates	no	
	Inhalation of vapors	yes	- Organic vapors from contaminated soil may migrate into ambient air.
	Groundwater		
	Ingestion	no	- There is no direct access point to groundwater.
	Dermal absorption	no	
	Inhalation of vapors	no	- Vapor migration to surface is unlikely due to depth of water table.
On Post Groundskeeper	Surface Soil	NA	- No COPCs were determined for this medium.
	Subsurface Soil		
	Incidental ingestion	no	- Groundskeeper does not typically come in direct contact with subsurface soil.
	Dermal absorption	no	
	Inhalation of particulates	no	- Since mowing is infrequent and of short duration, exposure opportunity is less than that estimated for pedestrian/jogger scenario.
	Inhalation of vapors	no	
	Groundwater		
	Ingestion	no	- Incomplete pathways; no direct access point to groundwater is available.
	Dermal absorption	no	
	Inhalation of vapors	no	- Vapor migration from groundwater unlikely due to depth of water table.
Off Post Racetrack Worker	Surface Soil	NA	- No COPCs were determined for this medium.
	Subsurface Soil	NA	- Contaminated soil and vapors are unlikely to migrate off post.
	Groundwater		
	Ingestion	yes	- Although workers are aware of water conditions, they are assumed to drink on the job.
	Dermal absorption	yes	- Workers may hose down or "shower" after work.
	Inhalation of vapors	yes	- Vapors escaping from applied water may be inhaled.

Table 7-8 (continued)
Summary of Pathways Considered for Human Health Risk Assessment
FFTA-MAAF Remedial Investigation Report

Potentially Exposed Populations	Media-Specific Exposure Pathways	Pathway Selected for Risk Characterization	Reason for Selecting or Excluding Pathways
Current Scenario (cont.)			
Off Post Racetrack Patron (Adult and Child)	Surface Soil	NA	- No COPCs were determined for this medium.
	Subsurface Soil	NA	- Contaminated soil and vapors are unlikely to migrate off post.
	Groundwater		
	Ingestion	yes	- Direct contact with groundwater (Well R-1) may occur during restroom use.
	Dermal absorption	yes	
	Inhalation of vapors	no	- Exposure unlikely due to short duration of restroom visits.
Off Post Resident (Adult and Child)	Surface Soil	NA	- No COPC were determined for this medium.
	Subsurface Soil	NA	- Contaminated soil and vapors are unlikely to migrate off post.
	Groundwater		
	Ingestion	yes	- Exposure to groundwater (Well M-1) is likely through direct contact and inhalation of vapors while showering
	Dermal absorption	yes	
	Inhalation of vapors	yes	
	Ingestion of vegetation	no	- COPCs are more likely to volatilize from irrigation water than to be absorbed by vegetation.
Future Scenario			
On Post Pedestrian/Jogger	Soil (subsurface)		
	Incidental ingestion	no	- Future conditions should result in either no change to risk or a reduction in risk, since there are no new sources of contamination and existing sources are depleting.
	Dermal absorption	no	
	Inhalation of particulates	no	
	Inhalation of vapors	no	
	Groundwater		
	Ingestion	no	- Incomplete pathways; no direct access point to groundwater is available.
	Dermal absorption	no	
	Inhalation of vapors	no	Vapor migration from groundwater unlikely due to depth of water table.
On Post Utility Excavation Worker	Soil (subsurface)		
	Incidental ingestion	yes	- In the event that a utility line is installed or repaired, a worker may be exposed through direct contact with contaminated soil as well as inhalation of vapors from soil.
	Dermal absorption	yes	
	Inhalation of particulates	yes	
	Inhalation of vapors	yes	
	Groundwater		
	Ingestion	no	- Incomplete pathways; no direct access point to groundwater is available.
	Dermal absorption	no	
	Inhalation of vapors	no	- Vapor migration from groundwater unlikely due to depth of water table.

Table 7-8 (continued)
Summary of Pathways Considered for Human Health Risk Assessment
FFTA-MAAF Remedial Investigation Report

Potentially Exposed Populations	Media-Specific Exposure Pathways	Pathway Selected for Risk Characterization	Reason for Selecting or Excluding Pathways
Future Scenario (cont.)			
<u>On Post</u> Full-time Worker	Soil Groundwater	no	- Land use is not expected to change in future due to proximity of the FFTA to MAAF, and subsequent aircraft safety and noise zones. Additionally, the levee is within a few feet of the site. Building within 500 feet of the landward side of levee is not recommended.
<u>On Post</u> Resident (Adult and Child)	Soil Groundwater	no	- Land use and zoning are not expected to change in the future. The reservation has been in operation since 1855 and is not scheduled for base closing.
<u>Off Post</u> Racetrack Worker	Soil	no	- Incomplete pathways; contaminated soil and vapors are unlikely to migrate off post.
	Groundwater		
	Ingestion	no	- Future exposure concentrations are not expected to exceed current concentrations.
	Dermal absorption	no	
	Inhalation of vapors	no	
<u>Off Post</u> Racetrack Patron (Adult and Child)	Soil	no	- Incomplete pathways; contaminated soil and vapors are unlikely to migrate off post.
	Groundwater		
	Ingestion	no	- Future exposure concentrations are not expected to exceed current concentrations.
	Dermal absorption	no	
	Inhalation of vapors	no	
<u>Off Post</u> Resident Child	Soil	no	- Incomplete pathways; contaminated soil and vapors are unlikely to migrate off post.
	Groundwater		
	Ingestion	yes	- A well may be installed for residential use and result in exposure opportunity that differs from current setting.
	Dermal absorption	yes	
	Inhalation of vapors	yes	

Table 7-8 (continued)
Summary of Pathways Considered for Human Health Risk Assessment
FFTA-MAAF Remedial Investigation Report

Potentially Exposed Populations	Media-Specific Exposure Pathways	Pathway Selected for Risk Characterization	Reason for Selecting or Excluding Pathways
Future Scenario (cont.)			
Off Post Adult Resident Farmer	Soil	no	- Incomplete pathways; contaminated soil and vapors are unlikely to migrate off post.
	Groundwater		
	Ingestion	yes	- Wells may be installed for residential or irrigation use and result in exposure opportunity that differs from current setting.
	Dermal absorption	yes	
	Inhalation of vapors while showering	yes	
	Inhalationof vapors while irrigating crops	yes	
Off Post River Recreationist	Surface Water		
	Incidental ingestion	no	- Fate and transport modeling predicts that maximum concentrations have yet to reach the river, however the 160-fold dilution by river water will result in levels below detection limits.
	Inhalation of vapors	no	
	Dermal absorption	no	
	Ingestion of fish	no	

Table 7-9
Formula for Incidental Ingestion of Chemicals in Soil[*]
FFTA-MAAF Remedial Investigation Report

Equation:
Intake (mg/kg/day) = CS x IR x CF x FI x EF x ED / (BW x AT)

Where:
CS = Chemical concentrations in soil (mg/kg)
IR = Ingestion rate (mg soil/day)
CF = Conversion factor (10^{-6} kg/mg)
FI = Fraction ingested from contaminated source (unitless)
EF = Exposure frequency (days/year)
ED = Exposure duration (years)
BW = Body weight (kg)
AT = Averaging time (days)

On-Post Utility Excavation Worker Variable Values:
CS = Chemical concentrations in soil (see Table 7-18)
IR = 100 mg/day (USEPA, 1997b) [*Exposure Factors Handbook*]
CF = 10^{-6} kg/mg
FI = 1 (assumed 100 percent from contaminated source)
EF = 6 days/year (see text)
ED = 25 years (USEPA, 1991a) [*Standard Default Factors*]
BW = 70 kg (USEPA, 1991a) [*Standard Default Factors*]
AT = 9,125 days for noncarcinogenic effects [25 years (ED) x 365 days/year] (USEPA, 1989) [*RAGS Part A*]
25,550 days for carcinogenic effects [70 years (lifetime) x 365 days/year] (USEPA, 1989) [*RAGS Part A*]

[*] USEPA, 1989 [*RAGS Part A*]

Table 7-10
Formula for Dermal Absorption of Chemicals in Soil[*]
FFTA-MAAF Remedial Investigation Report

Equation:
Absorbed Dose (mg/kg/day) = CS x CF x SA x AF x ABS x FC x EF x ED / (BW x AT)

Where:
CS = Chemical concentrations in soil (mg/kg)
CF = Conversion factor (10^{-6} kg/mg)
SA = Skin surface area available for contact (cm^2/event)
AF = Soil to skin adherence factor (mg/cm^2)
ABS = Chemical-specific absorption factor (unitless)
FC = Fractional contribution from contaminated source (unitless)
EF = Exposure frequency (events/year)
ED = Exposure duration (years)
BW = Body weight (kg)
AT = Averaging time (days)

On-Post Utility Excavation Worker Variable Values:
CS = Chemical concentrations in soil (see Table 7-18)
CF = 10^{-6} kg/mg
SA = 3,160 cm^2 (mean surface area for head, hands, and forearms of adult males) (USEPA, 1992a) [*Dermal Guidance*]
AF = 0.21 mg/cm^2 (Table 7-17)
ABS = 0.01 for VOCs (USEPA,1995a)
FC = 1 (assumed 100 percent from contaminated source)
EF = 6 days/year (see text)
ED = 25 years (USEPA, 1991a) [*Standard Default Factors*]
BW = 70 kg (USEPA, 1991a) [*Standard Default Factors*]
AT = 9,125 days for noncarcinogenic effects [25 years (ED) x 365 days/year] (USEPA, 1989) [*RAGS Part A*]
25,550 days for carcinogenic effects [70 years (lifetime) x 365 days/year] (USEPA, 1989) [*RAGS Part A*]

[*] USEPA, 1989 [*RAGS Part A*]

Table 7-11
Formula for Inhalation of Chemicals in Fugitive Dust*
FFTA-MAAF Remedial Investigation Report

Equation:
Intake (mg/kg/day) = CA x IR x ET x EF x ED / (BW x AT)

Where:
CA = Chemical concentrations in air (mg/m^3)
Where: CA = CS x D x CF
CS is the chemical concentration in soil (mg/kg)
D is the dust concentration (mg/m^3)
CF is a conversion factor (kg/mg)
IR = Inhalation rate (m^3/hr)
ET = Exposure time (hours/day)
EF = Exposure frequency (days/year)
ED = Exposure duration (years)
BW = Body weight (kg)
AT = Averaging time (days)

On-Post Utility Excavation Worker Variable Values:
CS = Chemical concentrations in soil (see Table 7-18)
D = 5 mg/m^3 (Nuisance dust limit for respirable particles) (OSHA, 29 CFR)
CF = 10^{-6} kg/mg
IR = 2.5 m^3/hr (mean value for outdoor worker short-term heavy activity) (USEPA, 1997b) [*Exposure Factors Handbook*]
ET = 8 hrs/day (see text)
EF = 6 days/year (see text)
ED = 25 years (USEPA, 1991a) [*Standard Default Factors*]
BW = 70 kg (USEPA, 1991a) [*Standard Default Factors*]
AT = 9,125 days for noncarcinogenic effects [25 years (ED) x 365 days/year] (USEPA, 1989) [*RAGS Part A*]
25,550 days for carcinogenic effects [70 years (Lifetime) x 365 days/year] (USEPA, 1989) [*RAGS Part A*]

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* USEPA, 1989 [*RAGS Part A*]

Table 7-12
Formula for Inhalation of Vapor Phase Chemicals from Soil*
FFTA-MAAF Remedial Investigation Report

Equation:
Intake (mg/kg/day) = CA x IR x ET x EF x ED / (BW x AT)

Where:
CA = Chemical concentrations in air (mg/m^3)
IR = Inhalation rate (m^3/hr)
ET = Exposure time (hours/day)
EF = Exposure frequency (days/year)
ED = Exposure duration (years)
BW = Body weight (kg)
AT = Averaging time (days)

On-Post Pedestrian/Jogger Variable Values:
CA = Modeled from soil sample concentrations (see Table 7-25)
IR = 3.2 m^3/hr (mean value for adult short-term heavy activity) USEPA, 1997b) [*Exposure Factors Handbook*]
ET = 0.25 hrs/day (see text)
EF = 350 days/year (USEPA, 1991a) [*Standard Default Factors*]
ED = 30 years (USEPA, 1991a) [*Standard Default Factors*]
BW = 70 kg (USEPA, 1991a) [*Standard Default Factors*]
AT = 10,950 days for noncarcinogenic effects [30 years (ED) x 365 days/year] (USEPA, 1989) [*RAGS Part A*]
25,550 days for carcinogenic effects [70 years (Lifetime) x 365 days/year] (USEPA, 1989) [*RAGS Part A*]

On-Post Utility Excavation Worker Variable Values:
CA = Modeled from soil sample concentrations (see Table 7-25)
IR = 2.5 m^3/hr (mean value for outdoor worker short-term heavy activity (USEPA, 1997b) [*Exposure Factors Handbook*]
ET = 8 hrs/day (see text)
EF = 6 days/year (see text)
ED = 25 years (USEPA, 1991a) [*Standard Default Factors*]
BW = 70 kg (USEPA, 1991a) [*Standard Default Factors*]
AT = 9,125 days for noncarcinogenic effects [25 years (ED) x 365 days/year] (USEPA, 1989) [*RAGS Part A*]
25,550 days for carcinogenic effects [70 years (Lifetime) x 365 days/year] (USEPA, 1989) [*RAGS Part A*]

* USEPA, 1989 [*RAGS Part A*]

Table 7-13
Formula for Ingestion of Chemicals in Water*
FFTA-MAAF Remedial Investigation Report

Equation:
Intake (mg/kg/day) = CW x IR x EF x ED / (BW x AT)

Residential Scenario Equation for Carcinogens:
Intake (mg/kg/day) = CW x IFW x EF / AT

Where:
CW = Chemical concentrations in water (mg/L)
IR = Ingestion rate (liters/day)
IFW = Age-adjusted ingestion factor for water (L-yr/kg-day)
Where: $IFW = (ED_{child} \times IR_{child} / BW_{child}) + (ED_{adult} \times IR_{adult} / BW_{adult})$
EF = Exposure frequency (days/year)
ED = Exposure duration (years)
BW = Body weight (kg)
AT = Averaging time (days)

Racetrack Worker Variable Values:
CW = Chemical concentrations in water (see Table 7-19)
IR = 1 liter/day (USEPA, 1991a) [*Standard Default Factors*]
EF = 18 days/year (see text)
ED = 25 years (see text)
BW = 70 kg (USEPA, 1991a) [*Standard Default Factors*]
AT = 9,125 days for noncarcinogenic effects [25 years (ED) x 365 days/year] (USEPA, 1989) [*RAGS Part A*]
25,550 days for carcinogenic effects [70 years (Lifetime) x 365 days/year] (USEPA, 1989) [*RAGS Part A*]

Child Racetrack Patron Variable Values:
CW = Chemical concentrations in water (see Table 7-20)
IR = 0.2 liter/day (see text)
EF = 18 days/year (see text)
ED = 6 years (see text)
BW = 21 kg (arithmetic mean for boys and girls, age 3-9 years) (USEPA, 1997b) [*Exposure Factors Handbook*]
AT = 2,190 days for noncarcinogenic effects [6 years (ED) x 365 days/year] (USEPA, 1989) [*RAGS Part A*]

Adult Racetrack Patron Variable Values:
CW = Chemical concentrations in water (see Table 7-20)
IR = 0.4 liter/day (see text)
EF = 18 days/year (see text)
ED = 30 years (see text)
BW = 70 kg (USEPA, 1991a) [*Standard Default Factors*]
AT = 10,950 days for noncarcinogenic effects [30 years (ED) x 365 days/year] (USEPA, 1989) [*RAGS Part A*]
25,550 days for carcinogenic effects [70 years (Lifetime) x 365 days/year] (USEPA, 1989) [*RAGS Part A*]

Table 7-13 (continued)
Formula for Ingestion of Chemicals in Water*
FFTA-MAAF Remedial Investigation Report

Off-Post Child Resident Variable Values:

CW = Chemical concentrations in water (see Table 7-21 for Current, Table 7-22 for Future)
IR = 1.0 liter/day (USEPA, 1991a) [*Standard Default Factors*]
EF = 350 days/year (USEPA, 1991a) [*Standard Default Factors*]
ED = 6 years (USEPA, 1991a) [*Standard Default Factors*]
BW = 15 kg (USEPA, 1991a) [*Standard Default Factors*]
AT = 2,190 days for noncarcinogenic effects [6 years (ED) x 365 days/year] (USEPA, 1989) [*RAGS Part A*]

Off-Post Adult Resident Variable Values:

CW = Chemical concentrations in water (see Table 7-21 for Current, Table 7-22 for Future)
IR = 2.0 liter/day (USEPA, 1991a) [*Standard Default Factors*]
IFW = 1.086 L-yr/kg-day (calculated)
EF = 350 days/year (USEPA, 1991a) [*Standard Default Factors*]
ED = 30 years for noncarcinogens (USEPA, 1991a) [*Standard Default Factors*]
24 years for carcinogens (see text)
BW = 70 kg (USEPA, 1991a) [*Standard Default Factors*]
AT = 10,950 days for noncarcinogenic effects [30 years (ED) x 365 days/year] (USEPA, 1989) [*RAGS Part A*]
25,550 days for carcinogenic effects [70 years (Lifetime) x 365 days/year] (USEPA, 1989) [*RAGS Part A*]

*USEPA, 1989 [*RAGS Part A*]

Table 7-14
Formula for Dermal Absorption of Chemicals in Applied Water[*]
FFTA-MAAF Remedial Investigation Report

Equation:
Absorbed Dose (mg/kg/day) = CW x CF x SA x KP x ET x EF x ED / (BW x AT)

Residential Scenario Equation for Carcinogens:
Absorbed Dose (mg/kg/day) = DCF x CW x CF x KP x EF / AT

Where:
CW = Chemical concentrations in water (mg/L)
CF = Volumetric conversion factor for water
SA = Skin surface area available for contact (cm^2)
DCF = Age-adjusted dermal contact factor (cm^2-hrs-yr/days-kg)
Where:
$DCF = (SA_{child} \times ET_{child} \times ED_{child} / BW_{child}) + (SA_{adult} \times ET_{adult} \times ED_{adult} / BW_{adult})$
KP = Chemical-specific dermal permeability constant (cm/hr)
ET = Exposure time (hours/day)
EF = Exposure frequency (days/year)
ED = Exposure duration (years)
BW = Body weight (kg)
AT = Averaging time (days)

Chemical-Specific Dermal Permeability Constants [a]

Chemical	KP (cm/hr)
Benzene	0.021
Ethylbenzene	0.074
Toluene	0.045
Xylenes	0.08
Naphthalene	0.069
1,1-DCE	0.016
1,2-DCE (cis)	0.01
1,2-DCE (trans)	0.01
PCE	0.048
TCE	0.016
Vinyl Chloride	0.0073

[a] (USEPA, 1992a) [*Dermal Guidance*]

Table 7-14 (continued)
Formula for Dermal Absorption of Chemicals in Water*
FFTA-MAAF Remedial Investigation Report

Adult Racetrack Worker Variable Values:
CW = Chemical concentrations in water (see Table 7-19)
CF = 1L/1,000 cm^3
SA = 19,400 cm^2 (represents 95th percentile total body surface area for adult males) (USEPA, 1992a) [*Dermal Guidance*]
KP = See table above (USEPA, 1992a) [*Dermal Guidance*]
ET = 0.25 hr/day (represents 50th percentile value for adults for total time spent in shower or bath) (USEPA, 1997b) [*Exposure Factors Handbook*]
EF = 250 days/year (USEPA, 1991a) [*Standard Default Factors*]
ED = 25 years (USEPA, 1991a) [*Standard Default Factors*]
BW = 70 kg (USEPA, 1991a) [*Standard Default Factors*]
AT = 9,125 days for noncarcinogenic effects [25 years (ED) x 365 days/year] (USEPA, 1989) [*RAGS Part A*]
25,550 days for carcinogenic effects [70 years (lifetime) x 365 days/year] (USEPA, 1989) [*RAGS Part A*]

Child Racetrack Patron Variable Values:
CW = Chemical concentrations in water (see Table 7-20)
CF = 1L/1,000 cm^3
SA = 990 cm^2 (represents 10 percent of the 95th percentile value for total body surface area, children ages 3-9) (USEPA, 1992a) [*Dermal Guidance*]
KP = See table above (USEPA, 1992a) [*Dermal Guidance*]
ET = 0.25 hr/day (see text)
EF = 18 days/year (see text)
ED = 6 years (see text)
BW = 21 kg (arithmetic mean for boys and girls, age 3-9 years) (USEPA, 1997b) [*Exposure Factors Handbook*]
AT = 2,190 days for noncarcinogenic effects [6 years (ED) x 365 days/year] (USEPA, 1989) [*RAGS Part A*]

Adult Racetrack Patron Variable Values:
CW = Chemical concentrations in water (see Table 7-20)
CF = 1L/1,000 cm^3
SA = 1980 cm^2 (mean surface area for hands and forearms of adult males) (USEPA, 1992a) [*Dermal Guidance*]
KP = See table above (USEPA, 1992a) [*Dermal Guidance*]
ET = 0.25 hr/day (see text)
EF = 18 days/year (see text)
ED = 30 years (see text)
BW = 70 kg (USEPA, 1991a) [*Standard Default Factors*]
AT = 10,950 days for noncarcinogenic effects [30 years (ED) x 365 days/year] (USEPA, 1989) [*RAGS Part A*]
25,550 days for carcinogenic effects [70 years (lifetime) x 365 days/year] (USEPA, 1989) [*RAGS Part A*]

Table 7-14 (continued)
Formula for Dermal Absorption of Chemicals in Water*
FFTA-MAAF Remedial Investigation Report

Off-Post Child Resident Variable Values:

CW = Chemical concentrations in water (see Table 7-21 for Current, Table 7-22 for Future)
CF = 1L/1,000 cm^3
SA = 8,023 cm^2 (mean value for total body surface area for children, ages 2-6) (USEPA, 1992a) [*Dermal Guidance*]
KP = See table above (USEPA, 1992a) [*Dermal Guidance*]
ET = 0.30 hr/day (represents 50th percentile value for children ages 1-4 for total time spent in shower or bath) (USEPA, 1997b) [*Exposure Factors Handbook*]
EF = 350 days/year (USEPA, 1991a) [*Standard Default Factors*]
ED = 6 years (USEPA, 1991a) [*Standard Default Factors*]
BW = 15 kg (USEPA, 1991a) [*Standard Default Factors*]
AT = 2,190 days for noncarcinogenic effects [6 years (ED) x 365 days/year] (USEPA, 1989) [*RAGS Part A*]

Off-Post Adult Resident Variable Values:

CW = Chemical concentrations in water (see Table 7-21 for Current, Table 7-22 for Future)
CF = 1L/1,000 cm^3
SA = 19,400 cm^2 (represents 95th percentile total body surface area for adult males) (USEPA, 1992a) [*Dermal Guidance*]
KP = See table above (USEPA, 1992a) [*Dermal Guidance*]
DCF = 2,626 cm^2-hrs-yr/days-kg (calculated)
ET = 0.25 hr/day (represents 50th percentile value for adults for total time spent in shower or bath) (USEPA, 1997b) [*Exposure Factors Handbook*]
EF = 350 days/year (USEPA, 1991a) [*Standard Default Factors*]
ED = 30 years for noncarcinogens (USEPA, 1991a) [*Standard Default Factors*]
24 years for carcinogens (see text)
BW = 70 kg (USEPA, 1991a) [*Standard Default Factors*]
AT = 10,950 days for noncarcinogenic effects [30 years (ED) x 365 days/year] (USEPA, 1989) [*RAGS Part A*]
25,550 days for carcinogenic effects [70 years (lifetime) x 365 days/year] (USEPA, 1989) [*RAGS Part A*]

*USEPA, 1989 [*RAGS Part A*]

Table 7-15
Formula for Inhalation of Vapor Phase Chemicals from Water Use Outdoors*
FFTA-MAAF Remedial Investigation Report

Equation:
Intake (mg/kg/day) = CA x IR x ET x EF x ED / (BW x AT)

Where:
CA = Chemical concentrations in air (mg/m^3)
IR = Inhalation rate (m^3/hr)
ET = Exposure time (hours/day)
EF = Exposure frequency (days/year)
ED = Exposure duration (years)
BW = Body weight (kg)
AT = Averaging time (days)

Racetrack Worker Variable Values:
CA = Modeled from chemical concentrations in water (see Table 7-27)
IR = 2.5 m^3/hr (outdoor worker short-term heavy activity) (USEPA, 1997b) [*Exposure Factors Handbook*]
ET = 8 hrs/day (see text)
EF = 18 days/year (see text)
ED = 25 years (USEPA, 1991a) [*Standard Default Factors*]
BW = 70 kg (USEPA, 1991a) [*Standard Default Factors*]
AT = 9,125 days for noncarcinogenic effects [25 years (ED) x 365 days/year] (USEPA, 1989) [*RAGS Part A*]
25,550 days for carcinogenic effects [70 years (Lifetime) x 365 days/year] (USEPA, 1989) [*RAGS Part A*]

Resident Farmer Variable Values:
CA = Modeled from chemical concentrations in water (see Table 7-29)
IR = 2.5 m^3/hr (outdoor worker short-term heavy activity) (USEPA, 1997b) [*Exposure Factors Handbook*]
ET = 1 hr/day (see text)
EF = 45 days/year (see text)
ED = 30 years (USEPA, 1991a) [*Standard Default Factors*]
BW = 70 kg (USEPA, 1991a) [*Standard Default Factors*]
AT = 9,125 days for noncarcinogenic effects [25 years (ED) x 365 days/year] (USEPA, 1989) [*RAGS Part A*]
25,550 days for carcinogenic effects [70 years (Lifetime) x 365 days/year] (USEPA, 1989) [*RAGS Part A*]

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* USEPA, 1989 [*RAGS Part A*]

Table 7-16
Formula for Inhalation of Vapor Phase Chemicals While Showering*
FFTA-MAAF Remedial Investigation Report

Equation:
Intake (mg/kg/day) = CA x IR x ET x EF x ED / (BW x AT)

Residential Scenario Equation for Carcinogens:
Intake (mg/kg/day) = CA x IF x EF / AT

Where:
CA = Chemical concentrations in air (mg/m^3)
Where:
CA= (CW x fs x Fw x t/V)/2
CW is the chemical concentrations in water (mg/L)
Fs is the fraction volatilized (unitless)
Fw is the water flow in shower (L/hr)
T is the time spent during and after shower or bath (hrs)
V is the volume of the bathroom (m^3)
IR = Inhalation rate (m^3/hr)
IF = Age-adjusted inhalation factor (m^3-yr/kg-day)
Where:
$IF = (IR_{child} \times ET_{child} \times ED_{child} / BW_{child}) + (IR_{adult} \times ET_{adult} \times ED / BW_{adult})$
ET = Exposure time (hours/day)
EF = Exposure frequency (days/year)
ED = Exposure duration (years)
BW = Body weight (kg)
AT = Averaging time (days)

Off-Post Racetrack Worker Variable Values:
CW = Chemical concentrations in water (see Table 7-19)
fs = 1 (assumed 100 percent from contaminated source)
Fw = 600 L/hr (Andelman, 1990)
t = 0.34 hrs (= ET)
V = 9 m^3 (Andelman, 1990)
IR = 1.0 m^3/hr (adult short-term light activity) (USEPA, 1997b) [*Exposure Factors Handbook*]
ET = 0.34 hrs/day (represents 50th percentile value for adults for total time in the bathroom during and after a shower or bath) (USEPA, 1997b) [*Exposure Factors Handbook*]
EF = 250 days/year (USEPA, 1991a) [*Standard Default Factors*]
ED = 25 years (USEPA, 1991a) [*Standard Default Factors*]
BW = 70 kg (USEPA, 1991a) [*Standard Default Factors*]
AT = 10,950 days for noncarcinogenic chemicals [25 yrs (ED) x 365 days/yr] (USEPA, 1989) [*RAGS Part A*]
25,550 day for carcinogenic chemicals [70 yrs (Lifetime) x 365 days/yr] (USEPA, 1989) [*RAGS Part A*]

Table 7-16 (continued)
Formula for Inhalation of Vapor Phase Chemicals While Showering*
FFTA-MAAF Remedial Investigation Report

Off-Post Child Resident Variable Values:

CW = Chemical concentrations in water (see Table 7-21 for Current, Table 7-22 for Future)
fs = 1 (assumed 100 percent from contaminated source)
Fw = 600 L/hr (Andelman, 1990)
t = 0.42 hrs (= ET)
V = 9 m^3 (Andelman, 1990)
IR = 1.2 m^3/hr (child short-term moderate activity (USEPA, 1997b) [*Standard Default Factors*]
ET = 0.42 hrs/day (represents 50th percentile value for children ages 1-4 for total time in the bathroom during and after a shower or bath) (USEPA, 1997b) [*Exposure Factors Handbook*]
EF = 350 days/year (USEPA, 1991a) [*Standard Default Factors*]
ED = 6 years (USEPA, 1991a) [*Standard Default Factors*]
BW = 15 kg (USEPA, 1991a) [*Standard Default Factors*]
AT = 2,190 days for noncarcinogenic effects [6 years (ED) x 365 days/year] (USEPA, 1989) [*RAGS Part A*]

Off-Post Adult Resident Variable Values:

CW = Chemical concentrations in water (see Table 7-21 for Current, Table 7-22 for Future)
fs = 1 (assumed 100 percent from contaminated source)
Fw = 600 L/hr (Andelman, 1990)
t = 0.34 hrs (= ET)
V = 9 m^3 (Andelman, 1990)
IR = 1.0 m^3/hr (adult short-term light activity) (USEPA, 1997b) [*Exposure Factors Handbook*]
IF = 0.318 (m^3-yr/kg-day) (calculated)
ET = 0.34 hrs/day (represents 50th percentile value for adults for total time in the bathroom during and after a shower or bath) (USEPA, 1997b) [*Exposure Factors Handbook*]
EF = 350 days/year (USEPA, 1991a) [*Standard Default Factors*]
ED = 30 years for carcinogens (USEPA, 1991a) [*Standard Default Factors*]
24 years for carcinogens (see text)
BW = 70 kg (USEPA, 1991a) [*Standard Default Factors*]
AT = 10,950 days for noncarcinogenic chemicals [30 yrs (ED) x 365 days/yr] (USEPA, 1989) [*RAGS Part A*]
25,550 day for carcinogenic chemicals [70 yrs (Lifetime) x 365 days/yr] (USEPA, 1989) [*RAGS Part A*]

* USEPA, 1989 [*RAGS Part A*]

Table 7-17
Population Activity-Specific Adherence Factor
FFTA-MAAF Remedial Investigation Report

Equation:

$$AF = \frac{(SAe \times AFe) + (SAa \times AFa) + (SAh \times AFh)}{SAe + SAa + SAh}$$

Where:

AF = Average adherence factor (mg/cm^2)
SAe = Surface area of head (cm^2)
AFe = Adherence factor for head (mg/cm^2)
SAa = Surface area of forearms (cm^2)
AFa = Adherence factor for forearms (mg/cm^2)
SAh = Surface area of hands (cm^2)
AFh = Adherence factor for hands (cm^2)

On-Post Utility Excavation Worker Variable Values:

SAe = 1180 (cm^2)
AFe = 0.1 (mg/cm^2)
SAa = 1140 (cm^2)
AFa = 0.25 (mg/cm^2)
SAh = 840 (cm^2)
AFh = 0.3 (mg/cm^2)
AF = 0.21 (mg/cm^2)

Notes:

Average individual body part adherence factors for Utility Worker field study groups Nos. 1 and 2 (USEPA, 1997b) [*Exposure Factors Handbook*]

Body part specific surface areas represent mean values for adult males (USEPA, 1997b) [*Exposure Factors Handbook*]

Table 7-18
Concentrations in Subsurface Soil (1-8 feet bgs)
On-Post Scenarios
FFTA-MAAF Remedial Investigation Report

Chemical	Maximum Detected Concentration or Detection Limit (ug/kg)	95% Upper Confidence Limit (UCL) (ug/kg)	Concentration Used in HHBRA (ug/kg)
Petroleum Constituents			
Benzene	320 U	8.9	8.9
Ethylbenzene	14,000	28	28
2-Methylnaphthalene	4,900	940	940
Naphthalene	25,000	690	690
Toluene	39,000	40	40
Xylenes	77,000	103	103
Chlorinated Solvents			
1,2-DCE (cis)	800	11	11
PCE	150	15	15
TCE	16	6.5	6.5

Notes:

RI sampling population from 1-8 ft bgs was 66 for all chemicals except for naphthalene and 2-methylnaphthalene. The post-pilot study data sets were used for these two COPCs and included 13 samples each.

The 95% UCL value was used in the risk assessment except when the 95% UCL value was greater than the maximum concentration detected. In those instances the maximum concentration was used (USEPA, 1992b).

Half the detection limit was used as a proxy concentration in calculating the 95% UCL for samples that were nondetect.

Table 7-19
Groundwater Concentrations at Well R-2
Racetrack Worker Scenario
FFTA-MAAF Remedial Investigation Report

Chemical	Maximum Detecte Concentration or Detection Limi (mg/L)	95% Upper Confidence Limit (UCL) (mg/L)	Concentration Used in HHBRA (mg/L)
Petroleum Constituents			
Benzene	0.0004 U	-	0.0002
Ethylbenzene	0.0007 U	-	0.00035
Toluene	0.0006	0.0004	0.0004
Xylenes	0.0006 U	-	0.0003
Naphthalene	0.005 U	-	0.0025
Chlorinated Solvents			
1,1-DCE	0.0006 U	-	0.0003
1,2-DCE (cis)	0.12	7.6	0.12
1,2-DCE (trans)	0.0023	0.0053	0.0023
PCE	0.0081	0.15	0.0081
TCE	0.0572	173	0.0572
Vinyl Chloride	0.0008 U	-	0.0004

Notes:

RI sample population for Well R-2 was 7.

The 95% UCL value was used for assessing current conditions except when the 95% UCL value was greater than the maximum concentration detected. In those instances, the maximum concentration was used (USEPA, 1992b).

Half the detection limit was used as a proxy concentration in calculating the 95% UCL for samples that were nondetect.

Table 7-20
Groundwater Concentrations at Well R-1
Racetrack Patron Scenario
FFTA-MAAF Remedial Investigation Report

Chemical	Maximum Detected Concentration or Detection Limit (mg/L)	95% Upper Confidence Limit (UCL) (mg/L)	Concentration Used in HHBRA (mg/L)
Petroleum Constituents			
Benzene	0.0005	0.0003	0.0005
Ethylbenzene	0.0014 U	-	0.0007
Toluene	0.0008 U	-	0.0004
Xylenes	0.0006 U	-	0.0003
Naphthalene	0.005 U	-	0.0025
Chlorinated Solvents			
1,1-DCE	0.0009	0.0006	0.0006
1,2-DCE (cis)	0.264	0.562	0.2640
1,2-DCE (trans)	0.002	0.0019	0.0019
PCE	0.039	0.167	0.0390
TCE	0.017	0.023	0.0170
Vinyl Chloride	0.0008 U	-	0.0004

Notes:

RI sample population for Well R-1 was 7.

The 95% UCL value was used for assessing current conditions except when the 95% UCL value was greater than the maximum concentration detected. In those instances, the maximum concentration was used (USEPA, 1992b).

Half the detection limit was used as a proxy concentration in calculating the 95% UCL for samples that were nondetect.

Table 7-21
Groundwater Concentrations at Well M-1
Current Off-Post Resident Scenario
FFTA-MAAF Remedial Investigation Report

Chemical	Maximum Detecte Concentration or Detection Limi (mg/L)	95% Upper Confidence Limit (UCL) (mg/L)	Concentration Used in HHBRA (mg/L)
Petroleum Constituents			
Benzene	0.0004 U	-	0.0002
Ethylbenzene	0.0007 U	-	0.00035
Toluene	0.0004 U	-	0.0002
Xylenes	0.0006 U	-	0.0003
Naphthalene	0.005 U	-	0.0025
Chlorinated Solvents			
1,1-DCE	0.0006 U	-	0.0003
1,2-DCE (cis)	0.0098	0.0098	0.0098
1,2-DCE (trans)	0.0005 U	-	0.00025
PCE	0.0011 U	-	0.00055
TCE	0.0006 U	-	0.0003
Vinyl Chloride	0.0008 U	-	0.0004

Notes:

RI sample population for Well M-1 was 7.

The 95% UCL value was used for assessing current conditions except when the 95% UCL value was greater than the maximum concentration detected. In those instances, the maximum concentration was used (USEPA, 1992b).

Half the detection limit was used as a proxy concentration in calculating the 95% UCL for samples that were nondetect.

Table 7-22
Modeled Groundwater Concentrations
Future Resident Scenario
FFTA-MAAF Remedial Investigation Report

Chemical	Hypothetical Residential Well 6-Yr Average (mg/L)	Hypothetical Residential Well 30-Yr Average (mg/L)	Hypothetical Irrigation Well 30-Yr Average (mg/L)
Petroleum Constituents			
Benzene	0.004033	0.000936	0.000936
Ethylbenzene	0.000752	0.000172	0.000752
Toluene	0.000185	0.000043	0.000043
Xylenes	0.001761	0.000397	0.000397
Napthalene	-	-	-
Chlorinated Solvents			
1,1-DCE	0.001200	0.001200	0.001200
1,2-DCE (cis)	0.221286	0.074264	0.064953
1,2-DCE (trans)	0.002500	0.002500	0.002500
PCE	0.002217	0.000502	0.000618
TCE	0.006936	0.001593	0.001679
Vinyl Chloride	0.001040	0.000494	0.000448

Notes:

Maximum modeled chemical concentrations were assumed to be at the same location in the plume.

Naphthalene was shown by the model to not migrate off post, as is supported by the historical nondetect data.

The shallow and intermediate zones yearly maximum concentrations were averaged for the residential well.

The shallow, intermediate, and deep zones yearly maximum concentrations were averaged for the irrigation well.

1,1-DCE and trans-1,2-DCE were not modeled. Therefore, the 95% UCLs were calculated using off-post RI data (244 samples). Because the 95% UCL exceeded the maximum for 1,1-DCE, the maximum value was used as the exposure concentration.

Table 7-23
Vapor Concentrations in Soil Gas *
On-Post Scenarios
FFTA-MAAF Remedial Investigation Report

Equation:

Cvapor = Csoil x [þb + (M x þw)] / [Pa + M / H' + (þb x Kd / H')]

Where:

Cvapor = Chemical vapor concentrations in soil gas at the source (mg/m^3)
H' = Henry's Constant (dimensionless) at 25°C, chemical-specific
Csoil = Chemical concentrations in soil (µg/kg)
þb = Soil bulk density (g/cm^3)
þw = Water density (g/cm^3)
M = Soil moisture content (cm^3/cm^3) = Pt - Pa
Kd = Soil-water partition coefficient (cm^3/g) = Koc x foc
Koc = Organic carbon partitioning coefficient (cm^3/g)
foc = Fraction organic carbon (unitless)
Pa = Air filled porosity (cm^3/cm^3)
Pt = Total porosity (cm^3/cm^3)

Variable Values:

H' = Chemical-specific (HRI, 1995) [Risk Assistant]
þb = 1.55 g/cm^3 (site-specific)
þw = 1 g/cm^3
M = 0.15 cm^3/cm^3 (site-specific)
Pa = 0.25 cm^3/cm^3 (calculated)
Pt = 0.4 cm^3/cm^3 (site-specific)
Koc = Chemical-specific (HRI, 1995) [Risk Assistant]
foc = 0.0072 unitless (site-specific)

Chemical	Csoil (µg/kg)	H' (unitless)	Koc (cm^3/g)	Kd (cm^3/g)	Cvapor (mg/m^3)
Petroleum Constituents					
Benzene	8.9	2.26E-01	3.10E+01	2.23E-01	6.15E+00
Ethylbenzene	28	3.30E-01	2.50E+02	1.80E+00	5.20E+00
2-Methylnaphthalene	940	2.05E-02	8.51E+03	6.13E+01	3.44E-01
Naphthalene	690	1.98E-02	8.71E+02	6.27E+00	2.35E+00
Toluene	40	2.72E-01	9.50E+01	6.84E-01	1.45E+01
Xylenes	103	2.89E-01	2.40E+02	1.73E+00	1.74E+01
Chlorinated Solvents					
1,2-DCE (cis)	11	1.38E-01	3.50E+01	2.52E-01	4.49E+00
PCE	15	7.54E-02	2.38E+02	1.71E+00	6.67E-01
TCE	6.5	4.22E-01	1.04E+02	7.49E-01	3.29E+00

* Jury et al., 1990; TNRCC, 1994; API, 1994; Jeng, et al., 1996

Table 7-24
Vapor Emission Rates to Surface *
On-Post Scenarios
FFTA-MAAF Remedial Investigation Report

Equation:

ER = (A x (Cvapor - Csurface) x Deff x CF)/L

Where:

ER = Emission rates to the surface (mg/sec)
A = Cross-sectional area available for diffusion (m^2)
Cvapor = Chemical vapor concentrations in soil at the source (mg/m^3)
Csurface = Chemical vapor concentrations in soil at the surface (mg/m^3)
Deff = Effective diffusion coefficient (cm^2/sec) (Millington and Quirk, 1961)
Where:
Deff = Dair x ($Pa^{3.33}/Pt^2$)
Dair is the diffusion coefficient in air (cm^2/sec)
Pa is the air-filled porosity (cm^3/cm^3) (Pt - Pw)
Pw is the water-filled porosity (cm^3/cm^3)
Pt is the total porosity (cm^3/cm^3)
L = Length of flow (m)
CF = Conversion factor (m^2/cm^2)

Variable Values:

A = 5,435 m^2 (exposure area = 58,500 ft^2)
Csurface = 0 mg/m^3
L = 0.3048 m (assumed depth to contamination = 1 ft)
Dair = Chemical-specific (USEPA, 1988) [SEAM]
Pt = 0.40 cm^3/cm^3 (site-specific)
Pw = 0.15 cm^3/cm^3 (site-specific)
Pa = 0.25 cm^3/cm^3 (calculated)
CF = 1E-04 m^2/cm^2

Chemical	Cvapor (mg/m^3)	Dair (cm^2/sec)	Deff (cm^2/sec)	ER (mg/sec)
Petroleum Constituents				
Benzene	6.15E+00	8.96E-02	5.51E-03	6.05E-02
Ethylbenzene	5.20E+00	6.86E-02	4.22E-03	3.91E-02
2-Methylnaphthalene	3.44E-01	6.22E-02	3.83E-03	2.35E-03
Naphthalene	2.35E+00	6.63E-02	4.08E-03	1.71E-02
Toluene	1.45E+01	8.06E-02	4.96E-03	1.28E-01
Xylenes	1.74E+01	7.37E-02	4.54E-03	1.41E-01
Chlorinated Solvents				
1,2-DCE (cis)	4.49E+00	9.11E-02	5.61E-03	4.49E-02
PCE	6.67E-01	7.62E-02	4.69E-03	5.58E-03
TCE	3.29E+00	8.35E-02	5.14E-03	3.02E-02

* USEPA, 1988

Table 7-25
Vapor Concentrations in Air *
On-Post Scenarios
FFTA-MAAF Remedial Investigation Report

Equation:

$CA = ER / (W \times Hb \times Um)$

Where:

CA = Vapor concentrations in near-field box air (mg/m^3)
ER = Emission rates (mg/sec)
W = Width of box (m)
Hb = Mixing height in box (m)
Um = Wind speed (m/sec)
Where :
$Um = 0.22 \times U10 \times \ln(2.5 \times Hb)$
U10 is the wind speed at 10 m elevation (m/sec)

Variable Values:

W = 60 m (N/S width of exposure area = 195 ft)
Hb = 2 m (default breathing zone height)
U10= 5.4 m/sec (see Section 2.2)
Um = 1.9 m/sec (calculated)

Chemical	Soil ER (mg/sec)	CA (mg/m^3)
Petroleum Constituents		
Benzene	6.05E-02	2.64E-04
Ethylbenzene	3.91E-02	1.71E-04
2-Methylnaphthalene	2.35E-03	1.03E-05
Naphthalene	1.71E-02	7.46E-05
Toluene	1.28E-01	5.58E-04
Xylenes	1.41E-01	6.15E-04
Chlorinated Solvents		
1,2-DCE (cis)	4.49E-02	1.96E-04
PCE	5.58E-03	2.43E-05
TCE	3.02E-02	1.32E-04

* GRI, 1988

Table 7-26
Vapor Emission Rates from Applied Water *
Racetrack Worker Scenario
FFTA-MAAF Remedial Investigation Report

Equation:

ER = CW x FR x VF

Where:

ER = Emission rate (mg/sec)
CW = Chemical concentration in water (mg/L)
FR = Flow rate (L/sec)
VF = Volatilization factor (unitless)

Variable Values:

FR = 6.31 L/sec (100 gal/min x 0.06309, see text)
VF = 1 (see text)

Chemical	CW (mg/L)	ER (mg/sec)
Petroleum Constituents		
Benzene	2.00E-04	1.26E-03
Ethylbenzene	3.50E-04	2.21E-03
Toluene	4.40E-04	2.78E-03
Xylenes	3.00E-04	1.89E-03
Naphthalene	2.50E-03	1.58E-02
Chlorinated Solvents		
1,1-DCE	3.00E-04	1.89E-03
1,2-DCE (cis)	1.20E-01	7.57E-01
1,2-DCE (trans)	2.30E-03	1.45E-02
PCE	8.10E-03	5.11E-02
TCE	5.72E-02	3.61E-01
Vinyl Chloride	4.00E-04	2.52E-03

* USEPA, 1988

Table 7-27
Vapor Concentrations in Air *
Racetrack Worker Scenario
FFTA-MAAF Remedial Investigation Report

Equation:

$CA = ER / (W \times Hb \times Um)$

Where:

CA = Vapor concentrations in near-field box air (mg/m^3)
ER = Emission rate (mg/sec)
W = Width of box (m)
Hb = Mixing height in box (m)
Um = Wind speed (m/sec)
Where :
$Um = 0.22 \times U10 \times \ln(2.5 \times Hb)$
U10 is the wind speed at 10 m elevation (m/sec)

Variable Values:

W = 91 m (N/S width of exposure area = 300 ft)
Hb = 2 m (default breathing zone height)
U10= 5.4 m/sec (see Section 2.2)
Um = 1.9 m/sec (calculated)

Chemical	Water ER (mg/sec)	CA (mg/m^3)
Petroleum Constituents		
Benzene	1.26E-03	3.63E-06
Ethylbenzene	2.21E-03	6.35E-06
Toluene	2.78E-03	7.98E-06
Xylenes	1.89E-03	5.44E-06
Naphthalene	1.58E-02	4.53E-05
Chlorinated Solvents		
1,1-DCE	1.89E-03	5.44E-06
1,2-DCE (cis)	7.57E-01	2.18E-03
1,2-DCE (trans)	1.45E-02	4.17E-05
PCE	5.11E-02	1.47E-04
TCE	3.61E-01	1.04E-03
Vinyl Chloride	2.52E-03	7.25E-06

* GRI, 1988

Table 7-28
Vapor Emission Rates from Irrigation Water *
Future Resident Farmer Scenario
FFTA-MAAF Remedial Investigation Report

Equation:

ER = CW x FR x VF

Where:

ER = Emission rate (mg/sec)
CW = Chemical concentration in water (mg/L)
FR = Flow rate (L/sec)
VF = Volatilization factor (unitless)

Variable Values:

FR = 63 L/sec (1000 gal/min x 0.06309, see text)
VF = 1 (see text)

Parameter	CW (mg/L)	ER (mg/sec)
Petroleum Constituents		
Benzene	9.36E-04	5.91E-02
Ethylbenzene	7.52E-04	4.74E-02
Toluene	4.30E-05	2.71E-03
Xylenes	3.97E-04	2.50E-02
Chlorinated Solvents		
1,1-DCE	1.20E-03	7.57E-02
1,2-DCE (cis)	6.50E-02	4.10E+00
1,2-DCE (trans)	2.50E-03	1.58E-01
PCE	6.18E-04	3.90E-02
TCE	1.68E-03	1.06E-01
Vinyl Chloride	4.48E-04	2.83E-02

* USEPA, 1988

Table 7-29
Vapor Concentrations in Air *
Future Resident Farmer Scenario
FFTA-MAAF Remedial Investigation Report

Equation:

$CA = ER / (W \times Hb \times Um)$

Where:

CA = Vapor concentrations in near-field box air (mg/m^3)
ER = Emission rate (mg/sec)
W = Width of box (m)
Hb = Mixing height in box (m)
Um = Wind speed (m/sec)
Where :
$Um = 0.22 \times U10 \times \ln(2.5 \times Hb)$
U10 is the wind speed at 10 m elevation (m/sec)

Variable Values:

W = 152 m (assumed width of exposure area = 500 ft)
Hb = 2.8 m (breathing zone height)
U10= 5.4 m/sec (see Section 2.2)
Um = 2.3 m/sec (calculated)

Parameter	Water ER (mg/sec)	CA (mg/m^3)
Petroleum Constituents		
Benzene	5.91E-02	5.99E-05
Ethylbenzene	4.74E-02	4.81E-05
Toluene	2.71E-03	2.75E-06
Xylenes	2.50E-02	2.54E-05
Chlorinated Solvents		
1,1-DCE	7.57E-02	7.67E-05
1,2-DCE (cis)	4.10E+00	4.15E-03
1,2-DCE (trans)	1.58E-01	1.60E-04
PCE	3.90E-02	3.95E-05
TCE	1.06E-01	1.07E-04
Vinyl Chloride	2.83E-02	2.87E-05

* GRI, 1988

Table 7-30
Hazard Index Estimates for On-Post Pedestrian/Jogger Scenario
FFTA-MAAF Remedial Investigation Report

Chemical	Daily Intake (mg/kg/day)	RfD (mg/kg/day)	Hazard Quotient	Pathway Hazard Index	Total Hazard Index
Exposure Pathway: Inhalation of vapor phase chemicals from soil					
Petroleum Constituents					
Benzene	2.9E-06	3E-03	1E-03		
Ethylbenzene	1.9E-06	3E-01	6E-06		
2-Methylnaphthalene	1.1E-07	9E-04	1E-04		
Naphthalene	8.2E-07	9E-04	9E-04		
Toluene	6.1E-06	1E-01	6E-05		
Xylenes	6.7E-06	NAv	NAp		
Chlorinated Solvents					
1,2-DCE (cis)	2.1E-06	Nav	NAp		
PCE	2.7E-07	Nav	NAp		
TCE	1.4E-06	NAv	NAp		
				2E-03	
					2E-03

Notes:
Nav = Not available
Nap = Not applicable

Table 7-31
Excess Lifetime Cancer Risk Estimate for On-Post Pedestrian/Jogger
FFTA-MAAF Remedial Investigation Report

Chemical	Daily Intake (mg/kg/day)	Slope Factor $(mg/kg/day)^{-1}$	Excess Cancer Risk	Pathway Cancer Risk	Total Cancer Risk
Exposure Pathway: Inhalation of vapor phase chemicals from soil					
Petroleum Constituents					
Benzene	1.2E-06	2.9E-02	4E-08		
Ethylbenzene	8.0E-07	NAv	NAp		
2-Methylnaphthalene	4.8E-08	NAv	NAp		
Naphthalene	3.5E-07	NAv	NAp		
Toluene	2.6E-06	NAv	NAp		
Xylenes	2.9E-06	NAv	NAp		
Chlorinated Solvents					
1,2-DCE (cis)	9.2E-07	Nav	NAp		
PCE	1.1E-07	2.0E-03	2E-10		
TCE	6.2E-07	6.0E-03	4E-09		
				4E-08	
					4E-08

Notes:
Nav = Not available
Nap = Not applicable

Table 7-32
Hazard Index Estimates for On-Post Utility Excavation Worker Scenario
FFTA-MAAF Remedial Investigation Report

Chemical	Daily Intake (mg/kg/day)	RfD (mg/kg/day)	Hazard Quotient	Pathway Hazard Index	Total Hazard Index
Exposure Pathway: Incidental ingestion of chemicals in soil					
Petroleum Constituents					
Benzene	2.1E-10	1E-03	2E-07		
Ethylbenzene	6.6E-10	1E-01	7E-09		
2-Methylnaphthalene	2.2E-08	2E-02	1E-06		
Naphthalene	1.6E-08	2E-02	8E-07		
Toluene	9.4E-10	2E-01	5E-09		
Xylenes	2.4E-09	2E+00	1E-09		
Chlorinated Solvents					
1,2-DCE (cis)	2.6E-10	1E-02	3E-08		
PCE	3.5E-10	1E-02	3E-08		
TCE	1.5E-10	Nav	NAp		
				2E-06	
Exposure Pathway: Dermal contact with chemicals in soil					
Petroleum Constituents					
Benzene	1.4E-11	8E-04	2E-08		
Ethylbenzene	4.4E-11	8E-02	5E-10		
2-Methylnaphthalene	1.5E-09	2E-02	9E-08		
Naphthalene	1.1E-09	2E-02	7E-08		
Toluene	6.2E-11	2E-01	4E-10		
Xylenes	1.6E-10	2E+00	1E-10		
Chlorinated Solvents					
1,2-DCE (cis)	1.7E-11	8E-03	2E-09		
PCE	2.3E-11	8E-03	3E-09		
TCE	1.0E-11	NAv	NAp		
				2E-07	
Exposure Pathway: Inhalation of chemicals in fugitive dust					
Petroleum Constituents					
Benzene	2.1E-10	3E-03	7E-08		
Ethylbenzene	6.6E-10	3E-01	2E-09		
2-Methylnaphthalene	2.2E-08	9E-04	2E-05		
Naphthalene	1.6E-08	9E-04	2E-05		
Toluene	9.4E-10	1E-01	8E-09		
Xylenes	2.4E-09	NAv	NAp		
Chlorinated Solvents					
1,2-DCE (cis)	2.6E-10	Nav	NAp		
PCE	3.5E-10	Nav	NAp		
TCE	1.5E-10	NAv	NAp		
				4E-05	

Table 7-32 (continued)
Hazard Index Estimates for
On-Post Utility Excavation Worker Scenario
FFTA-MAAF Remedial Investigation Report

Chemical	Daily Intake (mg/kg/day)	RfD (mg/kg/day)	Hazard Quotient	Pathway Hazard Index	Total Hazard Index
Exposure Pathway: Inhalation of vapor phase chemicals from soil					
Petroleum Constituents					
Benzene	1.2E-06	3E-03	4E-04		
Ethylbenzene	8.0E-07	3E-01	3E-06		
2-Methylnaphthalene	4.8E-08	9E-04	5E-05		
Naphthalene	3.5E-07	9E-04	4E-04		
Toluene	2.6E-06	1E-01	2E-05		
Xylenes	2.9E-06	NAv	NAp		
Chlorinated Solvents					
1,2-DCE (cis)	9.2E-07	Nav	NAp		
PCE	1.1E-07	Nav	NAp		
TCE	6.2E-07	NAv	NAp		
				9E-04	
					9E-04

Notes:
Nav = Not available
Nap = Not applicable

Table 7-33
Excess Lifetime Cancer Risk Estimate for On-Post Utility Excavation Worker Scenario
FFTA-MAAF Remedial Investigation Report

Chemical	Daily Intake (mg/kg/day)	Slope Factor $(mg/kg/day)^{-1}$	Excess Cancer Risk	Pathway Cancer Risk	Total Cancer Risk
Exposure Pathway: Incidental ingestion of chemicals in soil					
Petroleum Constituents					
Benzene	7.4E-11	2.9E-02	2E-12		
Ethylbenzene	2.3E-10	NAv	NAp		
2-Methylnaphthalene	7.9E-09	NAv	NAp		
Naphthalene	5.8E-09	NAv	NAp		
Toluene	3.4E-10	NAv	NAp		
Xylenes	8.6E-10	NAv	NAp		
Chlorinated Solvents					
1,2-DCE (cis)	9.2E-11	NAv	NAp		
PCE	1.2E-10	5.2E-02	6E-12		
TCE	5.5E-11	1.1E-02	6E-13		
				9E-12	
Exposure Pathway: Dermal contact with chemicals in soil					
Petroleum Constituents					
Benzene	4.9E-12	3.6E-02	2E-13		
Ethylbenzene	1.6E-11	NAv	NAp		
2-Methylnaphthalene	5.2E-10	NAv	NAp		
Naphthalene	3.8E-10	NAv	NAp		
Toluene	2.2E-11	NAv	NAp		
Xylenes	5.7E-11	NAv	NAp		
Chlorinated Solvents					
1,2-DCE (cis)	6.1E-12	NAv	NAp		
PCE	8.2E-12	6.5E-02	5E-13		
TCE	3.6E-12	1.4E-02	5E-14		
				8E-13	
Exposure Pathway: Inhalation of chemicals in fugitive dust					
Petroleum Constituents					
Benzene	7.4E-11	2.9E-02	2E-12		
Ethylbenzene	2.3E-10	NAv	NAp		
2-Methylnaphthalene	7.9E-09	NAv	NAp		
Naphthalene	5.8E-09	NAv	NAp		
Toluene	3.4E-10	NAv	NAp		
Xylenes	8.6E-10	NAv	NAp		
Chlorinated Solvents					
1,2-DCE (cis)	9.2E-11	Nav	NAp		
PCE	1.2E-10	2.0E-03	2E-13		
TCE	5.5E-11	6.0E-03	3E-13		
				3E-12	

Table 7-33 (continued)
Excess Lifetime Cancer Risk Estimate for On-Post Utility Excavation Worker Scenario
FFTA-MAAF Remedial Investigation Report

Chemical	Daily Intake (mg/kg/day)	Slope Factor $(mg/kg/day)^{-1}$	Excess Cancer Risk	Pathway Cancer Risk	Total Cancer Risk
Exposure Pathway: Inhalation of vapor phase chemicals from soil					
Petroleum Constituents					
Benzene	4.4E-07	2.9E-02	1E-08		
Ethylbenzene	2.9E-07	NAv	NAp		
2-Methylnaphthalene	1.7E-08	NAv	NAp		
Naphthalene	1.3E-07	NAv	NAp		
Toluene	9.4E-07	NAv	NAp		
Xylenes	1.0E-06	NAv	NAp		
Chlorinated Solvents					
1,2-DCE (cis)	3.3E-07	Nav	NAp		
PCE	4.1E-08	2.0E-03	8E-11		
TCE	2.2E-07	6.0E-03	1E-09		
				1E-08	
					1E-08

Notes:
Nav = Not available
Nap = Not applicable

Table 7-34
Hazard Index Estimates for Racetrack Worker Scenario
FFTA-MAAF Remedial Investigation Report

Chemical	Daily Intake (mg/kg/day)	RfD (mg/kg/day)	Hazard Quotient	Pathway Hazard Index	Total Hazard Index
Exposure Pathway: Ingestion of chemicals in water					
Petroleum Constituents					
Benzene	1.4E-07	1E-03	1E-04		
Ethylbenzene	2.5E-07	1E-01	2E-06		
Toluene	3.1E-07	2E-01	2E-06		
Xylenes	2.1E-07	2E+00	1E-07		
Naphthalene	1.8E-06	2E-02	9E-05		
Chlorinated Solvents					
1,1-DCE	2.1E-07	9E-03	2E-05		
1,2-DCE (cis)	8.5E-05	1E-02	8E-03		
1,2-DCE (trans)	1.6E-06	2E-02	8E-05		
PCE	5.7E-06	1E-02	6E-04		
TCE	4.0E-05	NAv	NAp		
Vinyl Chloride	2.8E-07	5E-03	6E-05		
				9E-03	
Exposure Pathway: Dermal contact with chemicals while showering					
Petroleum Constituents					
Benzene	1.4E-08	8E-04	2E-05		
Ethylbenzene	8.8E-08	8E-02	1E-06		
Toluene	6.8E-08	2E-01	4E-07		
Xylenes	8.2E-08	2E+00	5E-08		
Naphthalene	5.9E-07	2E-02	4E-05		
Chlorinated Solvents					
1,1-DCE	1.6E-08	7E-03	2E-06		
1,2-DCE (cis)	4.1E-06	8E-03	5E-04		
1,2-DCE (trans)	7.9E-08	2E-02	5E-06		
PCE	1.5E-05	8E-03	2E-04		
TCE	4.0E-06	NAv	NAp		
Vinyl Chloride	4.0E-06	4E-03	2E-06		
				7E-04	
Exposure Pathway: Inhalation of vapor phase chemicals from water					
Petroleum Constituents					
Benzene	4.3E-08	3E-03	1E-05		
Ethylbenzene	7.5E-08	3E-01	2E-07		
Toluene	9.4E-08	1E-01	9E-07		
Xylenes	6.4E-08	Nav	NAp		
Naphthalene	5.3E-07	9E-04	6E-04		

Table 7-34 (continued)
Hazard Index Estimates for Racetrack Worker Scenario
FFTA-MAAF Remedial Investigation Report

Chemical	Daily Intake (mg/kg/day)	RfD (mg/kg/day)	Hazard Quotient	Pathway Hazard Index	Total Hazard Index
Exposure Pathway: Inhalation of vapor phase chemicals from water (cont.)					
Chlorinated Solvents					
1,1-DCE	6.4E-08	NAv	NAp		
1,2-DCE (cis)	2.6E-05	NAv	NAp		
1,2-DCE (trans)	4.9E-07	NAv	NAp		
PCE	1.7E-06	NAv	NAp		
TCE	1.2E-05	NAv	NAp		
Vinyl Chloride	8.5E-08	3E-02	3E-06		
				6E-04	
					1E-02

Notes:
Nav = Not available
Nap = Not applicable

Table 7-35
Excess Lifetime Cancer Risk Estimate for Racetrack Worker Scenario
FFTA-MAAF Remedial Investigation Report

Chemical	Daily Intake (mg/kg/day)	Slope Factor (mg/kg/day)$^{-1}$	Excess Cancer Risk	Pathway Cancer Risk	Total Cancer Risk
Exposure Pathway: Ingestion of chemicals in water					
Petroleum Constituents					
Benzene	5.0E-08	2.9E-02	1E-09		
Ethylbenzene	8.8E-08	NAv	NAp		
Toluene	1.1E-07	NAv	NAp		
Xylenes	7.5E-08	NAv	NAp		
Naphthalene	6.3E-07	NAv	NAp		
Chlorinated Solvents					
1,1-DCE	7.5E-08	6.0E-01	5E-08		
1,2-DCE (cis)	3.0E-05	NAv	NAp		
1,2-DCE (trans)	5.8E-07	NAv	NAp		
PCE	2.0E-06	5.2E-02	1E-07		
TCE	1.4E-05	1.1E-02	2E-07		
Vinyl Chloride	1.0E-07	1.9E+00	2E-07		
				5E-07	
Exposure Pathway: Dermal contact with chemicals while showering					
Petroleum Constituents					
Benzene	5.2E-10	3.6E-02	2E-11		
Ethylbenzene	3.2E-09	NAv	NAp		
Toluene	2.5E-09	NAv	NAp		
Xylenes	3.0E-09	NAv	NAp		
Naphthalene	2.1E-08	NAv	NAp		
Chlorinated Solvents					
1,1-DCE	6.0E-10	NAv	NAp		
1,2-DCE (cis)	1.5E-07	NAv	NAp		
1,2-DCE (trans)	2.9E-09	NAv	NAp		
PCE	4.8E-08	6.5E-02	3E-09		
TCE	1.1E-07	1.4E-02	2E-09		
Vinyl Chloride	3.6E-10	3.1E+00	1E-09		
				6E-09	
Exposure Pathway: Inhalation of vapor phase chemicals from water					
Petroleum Constituents					
Benzene	5.7E-10	2.9E-02	2E-11		
Ethylbenzene	1.0E-09	NAv	NAp		
Toluene	1.3E-09	NAv	NAp		
Xylenes	8.6E-10	NAv	NAp		
Naphthalene	7.1E-09	NAv	NAp		

Table 7-35 (continued)
Excess Lifetime Cancer Risk Estimate for Racetrack Worker Scenario
FFTA-MAAF Remedial Investigation Report

Chemical	Daily Intake (mg/kg/day)	Slope Factor (mg/kg/day)$^{-1}$	Excess Cancer Risk	Pathway Cancer Risk	Total Cancer Risk
Exposure Pathway: Inhalation of vapor phase chemicals from water (cont.)					
Chlorinated Solvents					
1,1-DCE	8.6E-10	1.8E-01	2E-10		
1,2-DCE (cis)	3.4E-07	NAv	NAp		
1,2-DCE (trans)	6.6E-09	NAv	NAp		
PCE	2.3E-08	2.0E-03	5E-11		
TCE	1.6E-07	6.0E-03	1E-09		
Vinyl Chloride	1.1E-09	3.0E-01	3E-10		
				2E-09	
					5E-07

Notes:

Nav = Not available

Nap = Not applicable

Table 7-36
Hazard Index Estimates for Child Racetrack Patron Scenario
FFTA-MAAF Remedial Investigation Report

Chemical	Daily Intake (mg/kg/day)	RfD (mg/kg/day)	Hazard Quotient	Pathway Hazard Index	Total Hazard Index
Exposure Pathway: Ingestion of chemicals in tap water					
Petroleum Constituents					
Benzene	2.3E-07	1E-03	2E-04		
Ethylbenzene	3.3E-07	1E-01	3E-06		
Toluene	1.9E-07	2E-01	9E-07		
Xylenes	1.4E-07	2E+00	7E-08		
Naphthalene	1.2E-06	2E-02	6E-05		
Chlorinated Solvents					
1,1-DCE	2.7E-07	9E-03	3E-05		
1,2-DCE (cis)	1.2E-04	1E-02	1E-02		
1,2-DCE (trans)	9.1E-07	2E-02	5E-05		
PCE	1.8E-05	1E-02	2E-03		
TCE	8.0E-06	NAv	NAp		
Vinyl Chloride	1.9E-07	5E-03	4E-05		
				1E-02	
Exposure Pathway: Dermal contact with chemicals in tap water					
Petroleum Constituents					
Benzene	6.1E-09	8E-04	8E-06		
Ethylbenzene	3.0E-08	8E-02	4E-07		
Toluene	1.0E-08	2E-01	7E-08		
Xylenes	7.8E-09	2E+00	5E-09		
Naphthalene	6.5E-08	2E-02	4E-06		
Chlorinated Solvents					
1,1-DCE	5.3E-09	7E-03	7E-07		
1,2-DCE (cis)	1.5E-06	8E-03	2E-04		
1,2-DCE (trans)	1.1E-08	2E-02	7E-07		
PCE	1.5E-05	8E-03	1E-04		
TCE	4.0E-06	NAv	NAp		
Vinyl Chloride	4.0E-06	4E-03	4E-07		
				3E-04	
					1E-02

Notes:
Nav = Not available
Nap = Not applicable

Table 7-37
Hazard Index Estimates for Adult Racetrack Patron Scenario
FFTA-MAAF Remedial Investigation Report

Chemical	Daily Intake (mg/kg/day)	RfD (mg/kg/day)	Hazard Quotient	Pathway Hazard Index	Total Hazard Index
Exposure Pathway: Ingestion of chemicals in tap water					
Petroleum Constituents					
Benzene	1.4E-07	1E-03	1E-04		
Ethylbenzene	2.0E-07	1E-01	2E-06		
Toluene	1.1E-07	2E-01	6E-07		
Xylenes	8.5E-08	2E+00	4E-08		
Naphthalene	7.0E-07	2E-02	4E-05		
Chlorinated Solvents					
1,1-DCE	1.6E-07	9E-03	2E-05		
1,2-DCE (cis)	7.4E-05	1E-02	7E-03		
1,2-DCE (trans)	5.4E-07	2E-02	3E-05		
PCE	1.1E-05	1E-02	1E-03		
TCE	4.8E-06	NAv	NAp		
Vinyl Chloride	1.1E-07	5E-03	2E-05		
				8E-03	
Exposure Pathway: Dermal contact with chemicals in tap water					
Petroleum Constituents					
Benzene	3.7E-09	2E-02	2E-07		
Ethylbenzene	1.8E-08	6E-02	3E-07		
Toluene	6.3E-09	4E-02	2E-07		
Xylenes	8.4E-09	6E-02	1E-07		
Naphthalene	6.0E-08	6E-02	1E-06		
Chlorinated Solvents					
1,1-DCE	3.2E-09	1E-02	2E-07		
1,2-DCE (cis)	9.2E-07	8E-03	1E-04		
1,2-DCE (trans)	6.7E-09	8E-03	8E-07		
PCE	1.5E-05	4E-02	2E-05		
TCE	4.0E-06	NAv	NAp		
Vinyl Chloride	4.0E-06	6E-03	2E-07		
				1E-04	
					8E-03

Notes:
Nav = Not available
Nap = Not applicable

Table 7-38
Excess Lifetime Cancer Risk Estimate for Adult Racetrack Patron Scenario
FFTA-MAAF Remedial Investigation Report

Chemical	Daily Intake (mg/kg/day)	Slope Factor (mg/kg/day)$^{-1}$	Excess Cancer Risk	Pathway Cancer Risk	Total Cancer Risk
Exposure Pathway: Ingestion of chemicals in tap water					
Petroleum Constituents					
Benzene	6.8E-08	2.9E-02	2E-09		
Ethylbenzene	9.6E-08	NAv	NAp		
Toluene	5.5E-08	NAv	NAp		
Xylenes	4.1E-08	NAv	NAp		
Naphthalene	3.4E-07	NAv	NAp		
Chlorinated Solvents					
1,1-DCE	7.7E-08	6.0E-01	5E-08		
1,2-DCE (cis)	3.6E-05	NAv	NAp		
1,2-DCE (trans)	2.6E-07	NAv	NAp		
PCE	5.3E-06	5.2E-02	3E-07		
TCE	2.3E-06	1.1E-02	3E-08		
Vinyl Chloride	5.5E-08	1.9E+00	1E-07		
				5E-07	
Exposure Pathway: Dermal contact with chemicals in tap water					
Petroleum Constituents					
Benzene	1.6E-09	3.6E-02	6E-11		
Ethylbenzene	7.7E-09	NAv	NAp		
Toluene	2.7E-09	NAv	NAp		
Xylenes	3.6E-09	NAv	NAp		
Naphthalene	2.6E-08	NAv	NAp		
Chlorinated Solvents					
1,1-DCE	1.4E-09	7.5E-01	1E-09		
1,2-DCE (cis)	3.9E-07	NAv	NAp		
1,2-DCE (trans)	2.9E-09	NAv	NAp		
PCE	2.8E-07	6.5E-02	2E-08		
TCE	4.1E-08	1.4E-02	6E-10		
Vinyl Chloride	4.4E-10	2.4E+00	1E-09		
				2E-08	
					5E-07

Notes:
Nav = Not available
Nap = Not applicable

Table 7-39
Hazard Index Estimates for Current Child Resident Scenario
FFTA-MAAF Remedial Investigation Report

Chemical	Daily Intake (mg/kg/day)	RfD (mg/kg/day)	Hazard Quotient	Pathway Hazard Index	Total Hazard Index
Exposure Pathway: Ingestion of chemicals in tap water					
Petroleum Constituents					
Benzene	1.3E-05	1E-03	1E-02		
Ethylbenzene	2.2E-05	1E-01	2E-04		
Toluene	1.3E-05	2E-01	6E-05		
Xylenes	1.9E-05	2E+00	1E-05		
Naphthalene	1.6E-04	2E-02	8E-03		
Chlorinated Solvents					
1,1-DCE	1.9E-05	9E-03	2E-03		
1,2-DCE (cis)	6.3E-04	1E-02	6E-02		
1,2-DCE (trans)	1.6E-05	2E-02	8E-04		
PCE	3.5E-05	1E-02	4E-03		
TCE	1.9E-05	NAv	NAp		
Vinyl Chloride	2.6E-05	5E-03	5E-03		
				9E-02	
Exposure Pathway: Dermal contact with chemicals while showering					
Petroleum Constituents					
Benzene	6.5E-07	8E-04	8E-04		
Ethylbenzene	4.0E-06	8E-02	5E-05		
Toluene	1.4E-06	2E-01	9E-06		
Xylenes	3.7E-06	2E+00	2E-06		
Naphthalene	2.7E-05	2E-02	2E-03		
Chlorinated Solvents					
1,1-DCE	7.4E-07	7E-03	1E-04		
1,2-DCE (cis)	1.5E-05	8E-03	2E-03		
1,2-DCE (trans)	3.8E-07	2E-02	2E-05		
PCE	1.5E-05	8E-03	5E-04		
TCE	4.0E-06	NAv	NAp		
Vinyl Chloride	4.0E-06	4E-03	1E-04		
				6E-03	
Exposure Pathway: Inhalation of vapor phase chemicals while showering					
Petroleum Constituents					
Benzene	6.4E-06	3E-03	2E-03		
Ethylbenzene	1.1E-05	3E-01	4E-05		
Toluene	6.4E-06	1E-01	6E-05		
Xylenes	9.7E-06	Nav	NAp		
Naphthalene	8.1E-05	9E-04	9E-02		

Table 7-39 (continued)
Hazard Index Estimates for Current Child Resident Scenario
FFTA-MAAF Remedial Investigation Report

Chemical	Daily Intake (mg/kg/day)	RfD (mg/kg/day)	Hazard Quotient	Pathway Hazard Index	Total Hazard Index
Exposure Pathway: Inhalation of vapor phase chemicals while showering (cont.)					
Chlorinated Solvents					
1,1-DCE	9.7E-06	NAv	NAp		
1,2-DCE (cis)	3.2E-04	NAv	NAp		
1,2-DCE (trans)	8.1E-06	NAv	NAp		
PCE	1.8E-05	NAv	NAp		
TCE	9.7E-06	NAv	NAp		
Vinyl Chloride	1.3E-05	3E-02	4E-04		
				9E-02	
					2E-01

Notes:
Nav = Not available
Nap = Not applicable

Table 7-40
Hazard Index Estimates for Current Adult Resident Scenario
FFTA-MAAF Remedial Investigation Report

Chemical	Daily Intake (mg/kg/day)	RfD (mg/kg/day)	Hazard Quotient	Pathway Hazard Index	Total Hazard Index
Exposure Pathway: Ingestion of chemicals in tap water					
Petroleum Constituents					
Benzene	5.5E-06	1E-03	5E-03		
Ethylbenzene	9.6E-06	1E-01	1E-04		
Toluene	5.5E-06	2E-01	3E-05		
Xylenes	8.2E-06	2E+00	4E-06		
Naphthalene	6.8E-05	2E-02	3E-03		
Chlorinated Solvents					
1,1-DCE	8.2E-06	9E-03	9E-04		
1,2-DCE (cis)	2.7E-04	1E-02	3E-02		
1,2-DCE (trans)	6.8E-06	2E-02	3E-04		
PCE	1.5E-05	1E-02	2E-03		
TCE	8.2E-06	NAv	NAp		
Vinyl Chloride	1.1E-05	5E-03	2E-03		
				4E-02	
Exposure Pathway: Dermal contact with chemicals while showering					
Petroleum Constituents					
Benzene	2.8E-07	2E-02	2E-05		
Ethylbenzene	1.7E-06	6E-02	3E-05		
Toluene	6.0E-07	4E-02	2E-05		
Xylenes	1.6E-06	6E-02	2E-05		
Naphthalene	1.1E-05	6E-02	2E-04		
Chlorinated Solvents					
1,1-DCE	3.2E-07	1E-02	2E-05		
1,2-DCE (cis)	6.5E-06	8E-03	8E-04		
1,2-DCE (trans)	1.7E-07	8E-03	2E-05		
PCE	1.8E-06	4E-02	5E-05		
TCE	3.2E-07	NAv	NAp		
Vinyl Chloride	1.9E-07	6E-03	3E-05		
				1E-03	
Exposure Pathway: Inhalation of vapor phase chemicals while showering					
Petroleum Constituents					
Benzene	1.1E-05	3E-03	4E-03		
Ethylbenzene	1.8E-05	3E-01	6E-05		
Toluene	1.1E-05	1E-01	1E-04		
Xylenes	1.6E-05	Nav	NAp		
Naphthalene	1.3E-04	9E-04	1E-01		

Table 7-40 (continued)
Hazard Index Estimates for Current Adult Resident Scenario
FFTA-MAAF Remedial Investigation Report

Chemical	Daily Intake (mg/kg/day)	RfD (mg/kg/day)	Hazard Quotient	Pathway Hazard Index	Total Hazard Index
Exposure Pathway: Inhalation of vapor phase chemicals while showering (cont.)					
Chlorinated Solvents					
1,1-DCE	1.6E-05	NAv	NAp		
1,2-DCE (cis)	5.2E-04	NAv	NAp		
1,2-DCE (trans)	1.3E-05	NAv	NAp		
PCE	2.9E-05	NAv	NAp		
TCE	1.6E-05	NAv	NAp		
Vinyl Chloride	2.1E-05	3E-02	7E-04		
				1E-01	
					1E-01

Notes:
Nav = Not available
Nap = Not applicable

Table 7-41
Excess Lifetime Cancer Risk Estimate for Current Adult Resident Scenario
FFTA-MAAF Remedial Investigation Report

Chemical	Daily Intake (mg/kg/day)	Slope Factor $(mg/kg/day)^{-1}$	Excess Cancer Risk	Pathway Cancer Risk	Total Cancer Risk
Exposure Pathway: Ingestion of chemicals in tap water					
Petroleum Constituents					
Benzene	3.0E-06	2.9E-02	9E-08		
Ethylbenzene	5.2E-06	NAv	NAp		
Toluene	3.0E-06	NAv	NAp		
Xylenes	4.5E-06	NAv	NAp		
Naphthalene	3.7E-05	NAv	NAp		
Chlorinated Solvents					
1,1-DCE	4.5E-06	NAv	NAp		
1,2-DCE (cis)	1.5E-04	NAv	NAp		
1,2-DCE (trans)	3.7E-06	NAv	NAp		
PCE	8.2E-06	5.2E-02	4E-07		
TCE	4.5E-06	1.1E-02	5E-08		
Vinyl Chloride	5.9E-06	1.9E+00	1E-05		
				1E-05	
Exposure Pathway: Dermal contact with chemicals while showering					
Petroleum Constituents					
Benzene	1.5E-07	3.6E-02	5E-09		
Ethylbenzene	9.3E-07	NAv	NAp		
Toluene	3.2E-07	NAv	NAp		
Xylenes	8.6E-07	NAv	NAp		
Naphthalene	6.2E-06	NAv	NAp		
Chlorinated Solvents					
1,1-DCE	1.7E-07	NAv	NAp		
1,2-DCE (cis)	3.5E-06	NAv	NAp		
1,2-DCE (trans)	9.0E-08	NAv	NAp		
PCE	9.5E-07	6.5E-02	6E-08		
TCE	1.7E-07	1.4E-02	2E-09		
Vinyl Chloride	1.1E-07	2.4E+00	2E-07		
				3E-07	
Exposure Pathway: Inhalation of vapor phase chemicals while showering					
Petroleum Constituents					
Benzene	9.9E-06	2.9E-02	3E-07		
Ethylbenzene	1.7E-05	NAv	NAp		
Toluene	9.9E-06	NAv	NAp		
Xylenes	1.5E-05	NAv	NAp		
Naphthalene	1.2E-04	NAv	NAp		

Table 7-41 (continued)
Excess Lifetime Cancer Risk Estimate for Current Adult Resident Scenario
FFTA-MAAF Remedial Investigation Report

Chemical	Daily Intake (mg/kg/day)	Slope Factor $(mg/kg/day)^{-1}$	Excess Cancer Risk	Pathway Cancer Risk	Total Cancer Risk
Exposure Pathway: Inhalation of vapor phase chemicals while showering (cont.)					
Chlorinated Solvents					
1,1-DCE	1.5E-05	1.8E-01	3E-06		
1,2-DCE (cis)	4.8E-04	NAv	NAp		
1,2-DCE (trans)	1.2E-05	NAv	NAp		
PCE	2.7E-05	2.0E-03	6E-08		
TCE	1.5E-05	6.0E-03	9E-08		
Vinyl Chloride	2.0E-05	3.0E-01	6E-06		
				9E-06	
					2E-05

Notes:
Nav = Not available
Nap = Not applicable

Table 7-42
Hazard Index Estimates for Future Child Resident Scenario
FFTA-MAAF Remedial Investigation Report

Chemical	Daily Intake (mg/kg/day)	RfD (mg/kg/day)	Hazard Quotient	Pathway Hazard Index	Total Hazard Index
Exposure Pathway: Ingestion of chemicals in drinking water					
Petroleum Constituents					
Benzene	2.6E-04	1E-03	3E-01		
Ethylbenzene	4.8E-05	1E-01	5E-04		
Toluene	1.2E-05	2E-01	6E-05		
Xylenes	1.1E-04	2E+00	6E-05		
Chlorinated Solvents					
1,1-DCE	7.7E-05	9E-03	9E-03		
1,2-DCE (cis)	1.4E-02	1E-02	1E+00		
1,2-DCE (trans)	1.6E-04	2E-02	8E-03		
PCE	1.4E-04	1E-02	1E-02		
TCE	4.4E-04	NAv	NAp		
Vinyl Chloride	6.6E-05	5E-03	1E-02		
				1E+00	
Exposure Pathway: Dermal contact with chemicals while showering					
Petroleum Constituents					
Benzene	1.3E-05	8E-04	2E-02		
Ethylbenzene	8.6E-06	8E-02	1E-04		
Toluene	1.3E-06	2E-01	8E-06		
Xylenes	2.2E-05	2E+00	1E-05		
Chlorinated Solvents					
1,1-DCE	3.0E-06	7E-03	4E-04		
1,2-DCE (cis)	3.4E-04	8E-03	4E-02		
1,2-DCE (trans)	3.8E-06	2E-02	2E-04		
PCE	1.5E-05	8E-03	2E-03		
TCE	4.0E-06	NAv	NAp		
Vinyl Chloride	4.0E-06	4E-03	3E-04		
				6E-02	
Exposure Pathway: Inhalation of vapor phase chemicals while showering					
Petroleum Constituents					
Benzene	9.3E-05	3E-03	3E-02		
Ethylbenzene	1.7E-05	3E-01	6E-05		
Toluene	4.3E-06	1E-01	4E-05		
Xylenes	4.1E-05	Nav	NAp		
Chlorinated Solvents					
1,1-DCE	2.8E-05	NAv	NAp		
1,2-DCE (cis)	5.1E-03	NAv	NAp		
1,2-DCE (trans)	5.8E-05	NAv	NAp		
PCE	5.1E-05	NAv	NAp		
TCE	1.6E-04	NAv	NAp		
Vinyl Chloride	2.4E-05	3E-02	8E-04		
				3E-02	
					1E+00

Notes:
Nav = Not available
Nap = Not applicable

Table 7-43
Hazard Index Estimates for Future Resident Farmer Scenario
FFTA-MAAF Remedial Investigation Report

Chemical	Daily Intake (mg/kg/day)	RfD (mg/kg/day)	Hazard Quotient	Pathway Hazard Index	Total Hazard Index
Exposure Pathway: Ingestion of chemicals in tap water					
Petroleum Constituents					
Benzene	2.6E-05	1E-03	3E-02		
Ethylbenzene	4.7E-06	1E-01	5E-05		
Toluene	1.2E-06	2E-01	6E-06		
Xylenes	1.1E-05	2E+00	5E-06		
Chlorinated Solvents					
1,1-DCE	3.3E-05	9E-03	4E-03		
1,2-DCE (cis)	2.0E-03	1E-02	2E-01		
1,2-DCE (trans)	6.8E-05	2E-02	3E-03		
PCE	1.4E-05	1E-02	1E-03		
TCE	4.4E-05	NAv	NAp		
Vinyl Chloride	1.4E-05	5E-03	3E-03		
				2E-01	
Exposure Pathway: Dermal contact with chemicals while showering					
Petroleum Constituents					
Benzene	1.3E-06	8E-04	2E-03		
Ethylbenzene	8.5E-07	8E-02	1E-05		
Toluene	1.3E-07	2E-01	8E-07		
Xylenes	2.1E-06	2E+00	1E-06		
Chlorinated Solvents					
1,1-DCE	1.3E-06	7E-03	2E-04		
1,2-DCE (cis)	4.9E-05	8E-03	6E-03		
1,2-DCE (trans)	1.7E-06	2E-02	1E-04		
PCE	1.5E-05	8E-03	2E-04		
TCE	4.0E-06	NAv	NAp		
Vinyl Chloride	4.0E-06	4E-03	6E-05		
				9E-03	
Exposure Pathway: Inhalation of vapor phase chemicals while showering					
Petroleum Constituents					
Benzene	4.9E-05	3E-03	2E-02		
Ethylbenzene	9.1E-06	3E-01	3E-05		
Toluene	2.3E-06	1E-01	2E-05		
Xylenes	2.1E-05	Nav	NAp		

Table 7-43 (continued)
Hazard Index Estimates for Future Resident Farmer Scenario
FFTA-MAAF Remedial Investigation Report

Chemical	Daily Intake (mg/kg/day)	RfD (mg/kg/day)	Hazard Quotient	Pathway Hazard Index	Total Hazard Index
Exposure Pathway: Inhalation of vapor phase chemicals while showering (cont.)					
Chlorinated Solvents					
1,1-DCE	6.3E-05	NAv	NAp		
1,2-DCE (cis)	3.9E-03	NAv	NAp		
1,2-DCE (trans)	1.3E-04	NAv	NAp		
PCE	2.6E-05	NAv	NAp		
TCE	8.4E-05	NAv	NAp		
Vinyl Chloride	2.6E-05	3E-02	9E-04		
				2E-02	
Exposure Pathway: Inhalation of vapor phase chemicals while irrigating crops					
Petroleum Constituents					
Benzene	2.6E-07	3E-03	9E-05		
Ethylbenzene	2.1E-07	3E-01	7E-07		
Toluene	1.2E-08	1E-01	1E-07		
Xylenes	1.1E-07	Nav	NAp		
Chlorinated Solvents					
1,1-DCE	3.4E-07	NAv	NAp		
1,2-DCE (cis)	1.8E-05	NAv	NAp		
1,2-DCE (trans)	0.0E+00	NAv	NAp		
PCE	1.7E-07	NAv	NAp		
TCE	4.7E-07	NAv	NAp		
Vinyl Chloride	1.3E-07	3E-02	4E-06		
				9E-05	
					3E-01

Notes:
Nav = Not available
Nap = Not applicable

Table 7-44
Excess Lifetime Cancer Risk Estimate for Future Resident Farmer Scenario
FFTA-MAAF Remedial Investigation Report

Chemical	Daily Intake (mg/kg/day)	Slope Factor $(mg/kg/day)^{-1}$	Excess Cancer Risk	Pathway Cancer Risk	Total Cancer Risk
Exposure Pathway: Ingestion of chemicals in tap water					
Petroleum Constituents					
Benzene	1.4E-05	2.9E-02	4E-07		
Ethylbenzene	2.6E-06	NAv	NAp		
Toluene	6.4E-07	NAv	NAp		
Xylenes	5.9E-06	NAv	NAp		
Chlorinated Solvents					
1,1-DCE	1.8E-05	6.0E-01	1E-05		
1,2-DCE (cis)	1.1E-03	NAv	NAp		
1,2-DCE (trans)	3.7E-05	NAv	NAp		
PCE	7.5E-06	5.2E-02	4E-07		
TCE	2.4E-05	1.1E-02	3E-07		
Vinyl Chloride	7.3E-06	1.9E+00	1E-05		
				2E-05	
Exposure Pathway: Dermal contact with chemicals while showering					
Petroleum Constituents					
Benzene	7.1E-07	3.6E-02	3E-08		
Ethylbenzene	4.6E-07	NAv	NAp		
Toluene	7.0E-08	NAv	NAp		
Xylenes	1.1E-06	NAv	NAp		
Chlorinated Solvents					
1,1-DCE	6.9E-07	7.5E-01	5E-07		
1,2-DCE (cis)	2.7E-05	NAv	NAp		
1,2-DCE (trans)	9.0E-07	NAv	NAp		
PCE	8.7E-07	6.5E-02	6E-08		
TCE	9.2E-07	1.4E-02	1E-08		
Vinyl Chloride	1.3E-07	2.4E+00	3E-07		
				9E-07	
Exposure Pathway: Inhalation of vapor phase chemicals while showering					
Petroleum Constituents					
Benzene	4.6E-05	2.9E-02	1E-06		
Ethylbenzene	8.5E-06	NAv	NAp		
Toluene	2.1E-06	NAv	NAp		
Xylenes	2.0E-05	NAv	NAp		

Table 7-44 (continued)
Excess Lifetime Cancer Risk Estimate for Future Resident Farmer Scenario
FFTA-MAAF Remedial Investigation Report

Chemical	Daily Intake (mg/kg/day)	Slope Factor (mg/kg/day)$^{-1}$	Excess Cancer Risk	Pathway Cancer Risk	Total Cancer Risk
Exposure Pathway: Inhalation of vapor phase chemicals while showering (cont.)					
Chlorinated Solvents					
1,1-DCE	5.9E-05	1.8E-01	1E-05		
1,2-DCE (cis)	3.7E-03	NAv	NAp		
1,2-DCE (trans)	1.2E-04	NAv	NAp		
PCE	2.5E-05	2.0E-03	5E-08		
TCE	7.9E-05	6.0E-03	5E-07		
Vinyl Chloride	2.4E-05	3.0E-01	7E-06		
				2E-05	
Exposure Pathway: Inhalation of vapor phase chemicals while irrigating crops					
Petroleum Constituents					
Benzene	1.1E-07	2.9E-02	3E-09		
Ethylbenzene	9.1E-08	NAv	NAp		
Toluene	5.2E-09	NAv	NAp		
Xylenes	4.8E-08	NAv	NAp		
Chlorinated Solvents					
1,1-DCE	1.4E-07	1.8E-01	3E-08		
1,2-DCE (cis)	7.8E-06	NAv	NAp		
1,2-DCE (trans)	3.0E-07	NAv	NAp		
PCE	7.5E-08	2.0E-03	2E-10		
TCE	2.0E-07	6.0E-03	1E-09		
Vinyl Chloride	5.4E-08	3.0E-01	2E-08		
				5E-08	
					4E-05

Notes:
Nav = Not available
Nap = Not applicable

Table 7-45
Summary of Risk Assessment Uncertainty
FFTA-MAAF Remedial Investigation Report

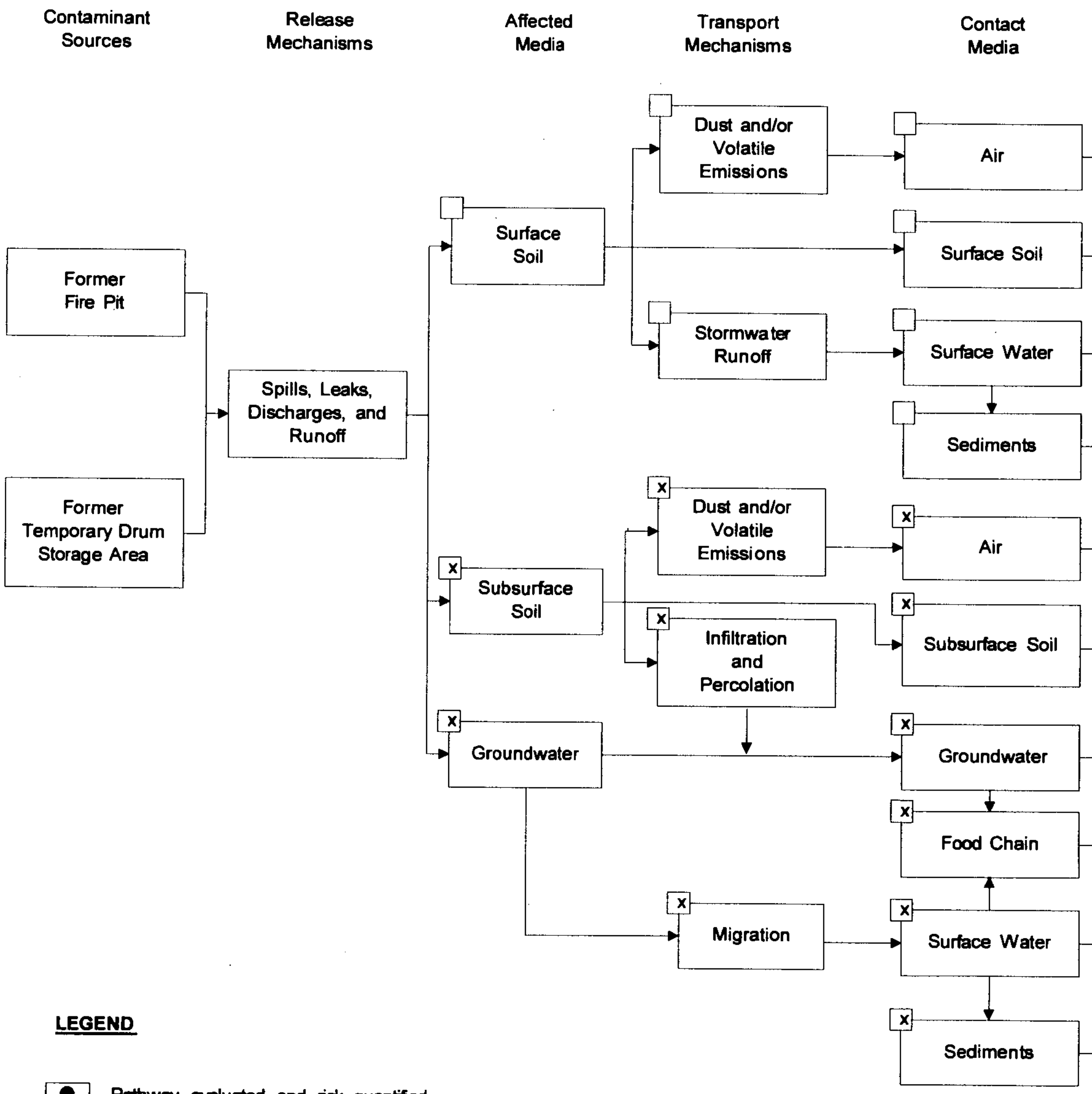
Assumption	Potential Magnitude for Over-Estimate of Risk	Potential Magnitude for Under-Estimate of Risk
Chemical Identification Uncertainty		
Characterization of the extent and magnitude of contamination	Low	Low
Major contaminant undetected	Low	Low
Systematic or random errors in the chemical analyses	Low	Low
Probability of insufficient samples taken to characterize the environmental media being evaluated	Low	Low
Systematic or random errors in chemical analyses may yield erroneous data	Low	Low
Proxy concentrations assigned as one-half the reporting limit for undetected concentrations	Low	Low
Use of 95 percent upper confidence limit or maximum detected chemical concentration as exposure point concentration	Moderate	Low
Exposure Uncertainty		
Relevant pathway omitted	Low	Low
Source concentration constant	High	Low
Physical attributes of receptors:		
- Body weight	Low	Low
- Inhalation rate	Low	Low
- Life expectancy	Low	Low
On-post pedestrian/jogger exposure assumptions: - Exposure time, frequency, and duration	High	Low
On-post excavation utility worker exposure assumptions: - Exposure time, frequency, and duration	High	Low
Off-post racetrack worker exposure assumptions: - Exposure time, frequency, and duration	Moderate	Low
Off-post racetrack patron exposure assumptions: - Exposure time, frequency, and duration	High	Low
Off-post resident exposure assumptions: - Daily lifetime exposure:	High	Low
Modeled future concentrations of COPCs in groundwater	Moderate	Moderate
Models used to estimate vapor concentrations in lieu of actual data	High	Low
Intake assumed to be constant over the exposure duration	High	Low
Toxicity Parameters		
Absorption efficiency factors used to adjust dermal toxicity values	Moderate	Low
Route-to-route extrapolations of oral toxicity values used for dermal risk characterization	Moderate	Low
Toxicity values for naphthalene used as provisional values for 2-methyl naphthalene	Moderate	Low

Note:
As a general guideline, assumptions marked as "low" may affect estimates of exposure by less than one order of magnitude, assumptions marked "moderate" may affect estimates of exposure by 1 to 2 orders of magnitude, and assumptions marked "high" may affect estimates by more than 2 orders of magnitude (USEPA, 1989) [*RAGS Part A*].

Table 7-46
Summary of Hazard Indices and Cancer Risks
FFTA-MAAF Remedial Investigation Report

Receptor Scenario	Current Conditions		Future Conditions		Notes
	Hazard Index	Cancer Risk	Hazard Index	Cancer Risk	
On-Post Pedestrian/Jogger	0.002	4E-08	-	-	Chemical concentrations from the RI sampling were assumed to be steady state and used to calculate 95% UCLs for current conditions. Future risk is expected to be less since concentrations will deplete over time.
On-Post Utility Excavation Worker	-	-	0.0009	1E-08	There are currently no excavation activities at MAAF-FFTA. Future risk was predicted using chemical concentrations measured during the RI. The 95% UCLs were calculated and assumed to be steady state.
Off-Post Racetrack Worker	0.02	6E-07	-	-	Chemical concentrations in Well R-2 were used to calculate 95% UCLs for current conditions. Future chemical concentrations at this receptor point are expected to decrease over time.
Off-Post Child Racetrack Patron	0.01	-	-	-	Chemical concentrations in Well R-1 were used to calculate 95% UCLs for current conditions. Future chemical concentrations at this receptor point are expected to decrease over time. Only adult cancer risk was calculated.
Off-Post Adult Racetrack Patron	0.008	5E-07	-	-	Chemical concentrations in Well R-1 were used to calculate 95% UCLs for current conditions. Future chemical concentrations at this receptor point are expected to decrease over time.
Off-Post Child Resident	0.2	-	1	-	Chemical concentrations in Well M-1 were used to calculate 95% UCLs for current conditions. Maximum modeled chemical concentrations in the shallow and intermediate zones, regardless of lateral location, were averaged over a 6-yr period for the future child resident. Cancer risk was age-adjusted (i.e., 6 yrs exposure as a child and 24 yrs as an adult). It is shown for an adult.
Off-Post Adult Resident	0.1	2E-05	0.3	4E-05	Chemical concentrations in Well M-1 were used to calculate 95% UCLs for current conditions. Future concentrations for the adult were calculated as described above, but averaged over a 30-year period. The deep aquifer zone was also included in averaging concentrations for the future adult resident, additionally exposed to vapors from irrigation well water.

Note:
USEPA level of concern for noncancer risk is a hazard index of 1, however a hazard index greater than 1 may not require remediation. (USEPA, 1989) [RAGS Part A]
USEPA acceptable range for excess lifetime cancer risk is 1E-04 to 1E-06. (FR, 1990)



Contact Media	Exposure Routes	Potential Receptors								
		On-post Full-Time Worker	On-post Utility Excavation Worker	On-post Groundskeeper	On-post Pedestrian/Jogger	On-post Resident	Off-post Resident	Off-post River Recreationist	Off-post Racetrack Worker	Off-post Racetrack Patron
Air	Inhalation of Fugitive Dust									
	Inhalation of VOCs									
Surface Soil	Ingestion									
	Dermal Contact									
Surface Water	Ingestion									
	Dermal Contact									
Sediments	Ingestion									
	Dermal Contact									
Air	Inhalation of Fugitive Dust		●							
	Inhalation of VOCs		●		●					
Subsurface Soil	Ingestion		●							
	Dermal Contact		●							
Groundwater	Ingestion						●			●
	Dermal Contact						●		●	●
	Inhalation of VOCs						●		●	
Food Chain	Ingestion of Vegetation						○			
	Ingestion of Fish							○		
Surface Water	Ingestion							○		
	Dermal Contact							○		
	Inhalation of VOCs							○		
Sediments	Ingestion							○		
	Dermal Contact							○		
	Inhalation of VOCs							○		

LEGEND

● Pathway evaluated and risk quantified
○ Pathway evaluated but risk not quantified
☐ Not a completed pathway

Burns & McDonnell
SINCE 1898

Figure 7.1
Human Health Conceptual Model
MAAF-FFTA RI

hh-scm.vsd 11/14/00

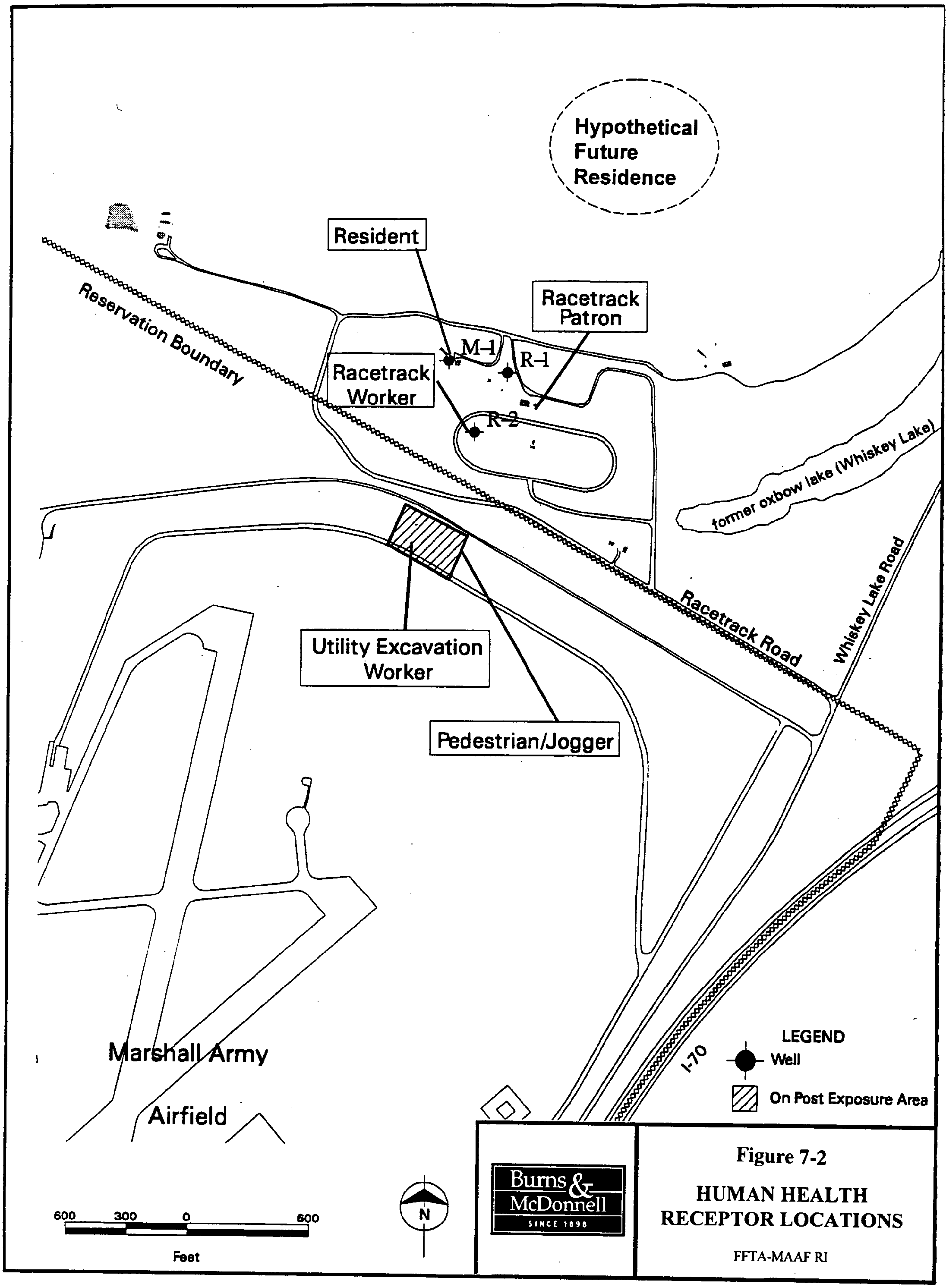


Figure 7-2

HUMAN HEALTH RECEPTOR LOCATIONS

FFTA-MAAF RI

8.0 ENVIRONMENTAL EVALUATION

8.1 INTRODUCTION

This component of the baseline risk assessment is designed to be a semi-quantitative evaluation of whether ecological receptors could potentially experience adverse effects from exposure to Site-related chemicals. An ecological risk does not exist unless (1) the chemical, or stressor has the inherent ability to cause one or more adverse effects, and (2) it co-occurs with or contacts an ecological receptor long enough and at a sufficient intensity to elicit the identified adverse effect (USEPA, 1992c). Identification of stressors, the potential of the stressor to cause adverse effects, the level at which the stressor is present in the environment, and the availability of the stressor to ecological receptors are necessary to assess the potential risk.

The purpose of this Environmental Evaluation is to assess the possible adverse effects to ecological receptors that may come in contact with media contaminated with organic solvents and petroleum constituents at the FFTA. Qualitative observations, calculated exposure estimates, and best professional judgement will be used to determine whether further evaluation of ecological risk is necessary.

This Environmental Evaluation was conducted following the procedures outlined in the USACE *Risk Assessment Handbook Volume II: Environmental Evaluation* (1996), and USEPA *Ecological Risk Assessment Guidance for Superfund: Process for Designing and Conducting Ecological Risk Assessment* (1997). The Environmental Evaluation is organized into the following sections:

- Ecological Site Characterization - This section provides a description of the FFTA and an overview of Section 2.9. Threatened, endangered, and rare species in the area are identified. Ecological conditions that influence the presence or absence of ecological receptors is detailed for the FFTA.

- Tier 1 Ecological Risk Assessment (ERA) Process – The methodology for this semi-quantitative screening and the process of elimination for the selection of Chemicals of Potential Ecological Concern (COPEC) is described. Probable ecological receptors are described in general for the FFTA and appropriate species for the screening evaluation are selected. The primary exposure pathways are identified.

- Risk Characterization - This section evaluates the likelihood of potential risk to ecological receptors for the area.

- Predicted Future Conditions and Potential Risk - Based on Section 5.0, Fate and Transport, the likelihood of future potential risk is discussed.

- Uncertainties - This section of the evaluation explains the uncertainties inherent in the process.

- Summary - The last section provides a summary of the Environmental Evaluation.

8.2 ECOLOGICAL SITE CHARACTERIZATION

The ecological site characterization is a description of the local ecology of the potentially impacted area including animals, plants, and soil organisms. Ecological clues, such as absence of typically present species, dead or dying vegetation, unusually high numbers of a less dominant species, are important to the data interpretation effort and risk characterization analysis and were investigated at the FFTA. Sensitive receptors and areas, including threatened or endangered species, wetlands, streams, lakes, etc., were identified by contacting appropriate agencies (U.S. Fish & Wildlife Service, Kansas Department of Parks

& Wildlife, U.S. Biological Survey) in addition to reconnaissance conducted by an ecologist familiar with the regional flora and fauna. Several endangered species and critical habitats for those species exist at Fort Riley (Section 2.9). However, these sensitive receptors do not exist within the FFTA.

While planning the RI, a conceptual site model (CSM) showing potentially completed pathways was developed. The RI/FS WP CSM is presented as Figure 8-1 in this document, for the convenience of the reader. The following sections give a description of the FFTA including a description of the ecological setting, potential ecological receptors, and exposure pathways.

8.2.1 Ecological Setting

The area surrounding the FFTA-MAAF is composed of hay fields and revegetated grassland. Hay fields are dominated by brome, fescue, and scattered annual forbs. The FFTA-MAAF is fenced and not hayed. It is regularly mowed and maintained and is within the active MAAF. The FFTA contains only marginal habitat for most regional receptors due to human disturbance associated with the active MAAF and the lack of adequate cover.

Revegetated grasslands occur on the levee north of the FFTA-MAAF and its adjacent sideslopes. Dominant vegetation is fescue and brome. However, numerous annual, perennial and woody species are becoming established on the north side between the levee and the entry road to the raceway. Additional species present include ground cherry (*Physalis* sp.), lamb's quarters (*Chenopium album*), prairie cordgrass (*Spartina pectinata*), foxtail, barnyard grass (*Echinochloa crusgalli*), goldenrod, morning glory, sunflower, crabgrass, bristle grass, ragweed, sumac, and saplings of rough-leafed dogwood, cottonwood, willow, hackberry, mulberry, green ash, bitternut hickory, and honey locust. Unvegetated areas around FFTA-MAAF were not observed during field reconnaissance in August 1996 and October 1999, nor during any field activities. The FFTA was similar in species composition to the adjacent hayfield. However, the FFTA-MAAF is fenced and not hayed. Additional species observed here included dandelion (*Taraxacum* sp.), primrose (*Oenothera* sp.), and velvetleaf (*Abutilon theophrastii*).

8.2.2 Potential Ecological Receptors and Exposure Pathways

Animal species expected to occur at the FFTA include a variety of songbirds (meadowlark, robin, grackle, barn swallow, cow bird, etc.) and small mammals (mice and voles). Because of the small area of the FFTA, bird species would mostly be transients, using the area for short periods when foraging for food. Limited habitat is available for ground nesting species such as meadowlarks. Structures at the FFTA provide potential nesting areas for swallows and house sparrows. However, no nests were observed and none are expected due to the human activities at the FFTA disturbing potentially nesting birds. A small number of small mammals (mice and voles) likely inhabit the FFTA on a more permanent basis. While the FFTA is not large enough to support a large population, suitable habitat and food are present on the FFTA to sustain a small population of rodents. Additionally, snakes such as the blue racer, prairie kingsnake, and gopher snake may temporarily reside on the FFTA. Larger mammals, such as deer, would not likely use the area due to the level of human activity, the fence surrounding the airfield area restricting their access, and the levee. Therefore, only smaller mammals were chosen as potential ecological receptors. Toxicity information is limited in other classes of animals, such as reptiles and amphibians; thus they were not used in the semi-quantitative screening process.

Five media have been sampled at the Site during investigations including surface soil, subsurface soil, sediment, surface water, and groundwater. These potentially impacted media may provide a contact point for ecological receptors. Exposure pathways for many species may not be completed for a particular media due to life history characteristics. Exposure due to consumption of chemicals passed through the food web was assumed to be insignificant, due to the lack of high level predatory consumers and the lack of bioaccumulative chemicals. Therefore, complex food web modeling was not utilized. The following discussion provides a description of the types of ecological receptors potentially exposed to each media along with wildlife species-specific characteristics that are utilized later in the COPEC screening process.

8.2.2.1 Surface and Subsurface Soil

Wildlife may be exposed to contaminated soil via ingestion during feeding, burrowing and/or cleaning activities. While some species may intentionally ingest soils that contain salts or other minerals, soil is not a standard dietary component. Typically, it is only ingested incidentally and composes only a small percentage of the total material consumed. If incidentally ingested soil is contaminated, potential risks may exist. All receptors chosen for this ERA are assumed to come in direct or indirect contact with contaminated soil either through burrowing or consuming prey that has come in contact with contaminated soil. However, it is important to note that VOCs were not detected in samples collected from 0 to 0.5 feet bgs during the RI, thus eliminating surface soil as a contact medium. This precludes exposure by larger non-burrowing receptors, such as deer, and thus limits the primary contact medium for this ERA to shallow subsurface soil (0.5-4 feet bgs). The initial soil data used in this screening is listed in Table 3-4, Table 4-9, and is discussed in Section 3.4.2.2.

Soil organisms, including microorganisms and earthworms, may be exposed to impacted soil. Plants may be exposed through root systems. During the field reconnaissance, potential effects to plants and soil organisms due to site related chemicals were qualitatively evaluated. Noticeable absence of flora or fauna, or an over abundance of less desirable species, unusually thick accumulation of organic litter, or the inability for some flora to reach maturity are possible observable effects of COPECs to these receptors (USACE, 1996). The ecology of the FFTA was compared to other sites with similar ecology not effected by past FFTA activities. Ecological differences between the FFTA and other non-affected sites were not observed. Furthermore, the diversity of plant species at the FFTA was minimal due to routine maintenance and mowing. Overt effects to plants and soil organisms were not directly or indirectly observed at the FFTA.

8.2.2.2 Sediment

Sediment was sampled at the FFTA. However, there are no significant aquatic habitats within the FFTA-MAAF capable of sustaining aquatic or semi-aquatic species such as fish, waterfowl, beaver, mink, and muskrat. Only invertebrate species with short aquatic larval stages or tolerant of extended dry periods would be capable of utilizing sediment sampled at the FFTA. The presence of water in these areas is sporadic and likely not sufficient in longevity to support significant aquatic ecological receptors including macroinvertebrates. Any detection of contaminants in sediment was evaluated as soil due to a completed exposure pathway for terrestrial receptors. Sediment samples are discussed in Section 3.2.2 and listed in Table 3-4.

It is important to note that sediment contamination was not found outside the boundary of the former fire training pit.

8.2.2.3 Surface Water

Surface water samples were collected from the Kansas River by USGS from July 26 through July 28, 1999 (Figure 4-31). Target chemicals were not detected in any of the samples. Therefore, surface water is not evaluated in this ERA. Surface water is further discussed in Section 4.3.

8.2.2.4 Groundwater

Groundwater would only be available to those plant species capable of extending root systems to a sufficient depth below ground surface to access it. Groundwater is generally at least 15 feet bgs for the Site. Trees and some shrubs could be capable of accessing groundwater at this depth. However, only a few trees exist at FFTA-MAAF and the adjacent areas; these ecological receptors probably do not get significant exposure to this media. Therefore, impacts of groundwater contamination to terrestrial receptors will not be assessed in this evaluation. Although groundwater is not being directly assessed for the ERA, it is modeled and assessed as surface water for possible future risk to macroinvertebrate receptors in the Kansas River.

8.3 TIER 1 ECOLOGICAL RISK ASSESSMENT PROCESS

This semi-quantitative assessment follows the USACE methodology for a Tier I Baseline ERA. The following sections highlight the screening methodologies employed for the FFTA ERA.

8.3.1 Chemicals of Potential Ecological Concern (COPECs)

Ecological receptors, including plants and animals, are exposed to a variety of elements and chemicals throughout their lives. While many of these substances are essential for the health, survival, and well-being of the individual, other naturally occurring and man-made substances may be of no value to the receptor, have no effect on the receptor, be beneficial, or have an adverse effect on the ability of the receptor to sustain itself. Additionally, the needs of an individual may change seasonally as a reflection of its various life functions, such as during egg production or other reproductive activities, hibernation, or migration. Chemicals that may elicit adverse effects to ecological receptors are considered COPEC. The first step in determining COPEC was a review of the analytical data collected for surface soil and subsurface soil, and sediment. Only organic compounds detected in soil above 4 feet bgs were considered as preliminary COPEC since metals, with the exception of minimal and localized concentrations, were determined to be background. (See Section 5.5.2 for a detailed discussion of the background evaluation.)

The following chemicals were selected as preliminary COPECs:

- cis-1,2-DCE
- Ethylbenzene
- PCE
- Toluene
- Xylene
- Acenaphthene
- Bis(2-ethylhexyl)phthalate
- Fluorene
- 2-Methyl naphthalene
- Naphthalene
- Phenanthrene
- Pyrene

Preliminary COPECs were further evaluated and compared to toxicological benchmarks in the preliminary semi-quantitative screening. The methods for further evaluation are discussed in the following sections.

8.3.2 Wildlife Benchmark Screening Methodology

Based on the ecology of the FFTA, potential wildlife receptors were identified (Section 8.2.2) and compared to a list of species for which benchmarks have been established Wildlife species used in the screening are listed in Table 8.1. If benchmarks were not available for a selected species, benchmarks for species representative of the various taxa and life histories expected to occur within the FFTA were selected as surrogate benchmark values. All surrogate substitutions were noted.

The semi-quantitative screening was done in two phases—a preliminary and a secondary screening (discussed further in the following sections). Both the preliminary and secondary screening used assumptions to calculate an Ecological Hazard Quotient (EHQ). The EHQ is calculated by comparing the estimated chemical intake to the benchmark. A benchmark value is a known concentration of a substance that elicits known effects ranging from no-effect to death for the ecological receptor under study. The calculation of the EHQ for wildlife is expressed mathematically in the following equation:

Ecological Hazard Quotient = estimated chemical intake (mg/kg/day)/benchmark (mg/kg/day)

An EHQ less than 1.0 indicates the contaminant is unlikely to cause adverse ecological effects. An EHQ greater than 1.0 indicates adverse effects to ecological receptors is possible. An EHQ greater than 1.0 does not indicate ecological effects exists but does indicate that further evaluation may be warranted.

8.3.2.1 Preliminary Screening Method for Wildlife

The preliminary screening used the NOAEL as the benchmark. The NOAEL is the highest level of a stressor evaluated in a toxicity test or biological field survey that causes no statistically significant difference in effect compared with the controls or reference site (USEPA, 1997). All contaminant exposure levels were assumed to equal the maximum detected concentrations. Conservative assumptions were used in determining the preliminary exposure factors. Exposure factors are those natural history characteristics that might influence receptor exposure. The *Wildlife Exposure Handbook Vol. I & II* were the sources of receptor exposure factors (USEPA, 1993). If exposure factors for a specific receptor were not available from the above source, factors for species with similar life histories were substituted and referenced.

Factors affecting wildlife exposure include foraging range, bioavailability, and food ingestion rate. In the preliminary screening extremely conservative assumptions were made. Receptors were assumed to spend 100 percent of their lives within the FFTA. The bioavailability of each chemical detected in FFTA soil was assumed to be 100 percent (i.e. all of the chemical ingested was absorbed in to the body).

For wildlife, the NOAEL was expressed in milligram (mg) of contaminant per kilogram (kg) of body weight per day. Preliminary ingestion dose was also expressed in milligram (mg) of contaminant per kilogram (kg) of body weight per day and therefore could be directly compared to the NOAEL. The preliminary ingestion dose was calculated by multiplying the food ingestion rate, the fraction of soil in diet, and the maximum detected concentration. The preliminary ingestion dose was divided by the NOAEL to yield the EHQ. The formula for calculating the preliminary ingestion dose is presented in Table 8-1.

8.3.2.2 Secondary Screening Method for Wildlife

The secondary screening was used to further refine the list of COPECs. The secondary screening differs from the preliminary screening by using the using the LOAEL. The LOAEL is the lowest level of a stressor evaluated in a toxicity test of biological field survey that has a statistically significant adverse effect on the exposed organisms compared with unexposed organisms in a control or reference site (USEPA, 1997). The secondary screening also incorporates the foraging range into the exposure calculations. To factor in the foraging range, the assumption was made that the receptors would spend equal foraging time in all areas of its foraging range. Based on this assumption, the receptor would consume an amount of soil reflective of the time spent foraging within the FFTA. The foraging ranges of each receptor were compared to the size of the FFTA to determine the fraction of the total foraging range that the FFTA represented. The foraging factor does not exceed 1.0 or 100 percent. Those chemicals exceeding benchmarks were considered COPECs and were retained for further evaluation. The formula for calculating the secondary ingestion dose is presented on Table 8-2.

8.3.3 Benthic Organism Screening Methodology

Benchmarks used for aquatic receptors were directly compared to maximum detected concentrations in groundwater near the Kansas River. These chemical concentrations were assumed to be representative of pore water. If chemical concentrations exceeded the aquatic receptor benchmarks, the chemical was considered a COPEC. The benchmark sources used in the screening included Department of Energy Oak Ridge National Laboratory (ORNL, 1996b) Kansas Surface Water Quality Criteria (KSWQC, 1999), National Ambient Water Quality Criteria (NAWQC)[USEPA, 1992d], National Recommended Water Quality Criteria (NRWQC)[FR, 1998], USEPA Tier II Secondary Chronic Value (USEPA, 1992e). The calculation of the EHQ for benthic organisms is expressed mathematically in the following equation:

Ecological Hazard Quotient = water concentration (mg/l)/benchmark (mg/l)

An EHQ less than 1.0 indicates the contaminant is unlikely to cause adverse effects to benthic organisms. An EHQ greater than 1.0 indicates adverse effects to these receptors is possible. An EHQ greater than 1.0 does not indicate that benthic organisms are adversely being effected but does indicate that further evaluation may be warranted.

8.3.4 Exception to Screening Methodology

Some chemicals, regardless of their concentrations or distribution, are included or excluded as COPEC due to individual toxicity characteristics. Chemicals such as biomagnifiers or bioaccumulators may become more concentrated, and thus more detrimental, as they pass through the food chain regardless of their media concentration. Many chemicals may not have any ecotoxicity data available and therefore, alternative methods must be used to semi-quantitatively assess risk. All of the above situations are exceptions to the screening methodology and are discussed in the following sections.

8.3.4.1 Biomagnification

Chemicals that have the potential to biomagnify require evaluation regardless of their detected levels (USACE, 1996). Biomagnification occurs when substances are ingested by organisms at low levels in the food chain. Because the substance is not metabolized, concentrations accumulate in organism tissue. Subsequent consumption of these organisms by others in the food chain may cause these higher trophic organisms to ingest levels of the chemicals greater than what may be naturally occurring. These organisms, in turn, retain the contaminant and the process repeats up the food chain. Higher trophic predators are especially susceptible to chemicals that biomagnify. Under such conditions, it is possible for the contaminant, even if present in very small amounts, to reach levels that can cause adverse effects in higher trophic species.

The COPEC at FFTA includes VOCs and SVOCs related to chlorinated solvent and petroleum contamination. VOCs and SVOCs tend not to bioaccumulate and show little tendency to biomagnify because they are readily metabolized by receptors (USACE, 1996). It was concluded that all chemicals detected in FFTA do not biomagnify.

8.3.4.2 Benchmarks Not Available

Benchmark values for all representative species, chemicals, and media were not available. However, toxicity values for chemicals with similar characteristics that were available were used as surrogate data. All surrogate toxicity data are identified in the appropriate screening table. In addition, a more qualitative assessment of potential risk was conducted for those chemicals using surrogate toxicity data. Ecological clues as to potential risk were noted during field investigation. Observations were then correlated to general ecological relationships as discussed in the previous section. Based on these correlations, the potential ecological effects were determined. Chemicals detected in soil without benchmarks include ethylbenzene, acenaphthene, fluorene, 2-methylnaphthalene, phenanthrene, and pyrene. Vinyl chloride was the only chemical detected in groundwater without benchmarks.

8.4 RISK CHARACTERIZATION

Risk characterization assesses the likelihood of adverse ecological effects associated with exposure to the Site contamination. This risk characterization combines the semi-quantitative evaluation with the qualitative assessment to conclude if significant risk to ecological receptors exists (USEPA, 1997).

USEPA acknowledges that, although a benchmark screening approach is appropriate for some risk assessments, many risk assessments are not based on benchmark decisions (FR, 1996). Rather, ecological risk management decisions may depend on a more qualitative assessment of ecosystem integrity, including sustainability, resiliency, and biodiversity as observed during a field study (USEPA, 1997). Therefore, this ERA will utilize a qualitative (observable) as well as a quantitative (screening) process to characterize the potential for risk. The ecological risk characterization results are presented in the following section.

8.4.1 Shallow Subsurface Soil at the FFTA

The following chemicals were detected in soil from 0 to 4 feet bgs at the FFTA: cis-1,2-DCE, ethylbenzene, PCE, toluene, xylene, acenaphthene, bis(2-ethylhexyl)phthalate, fluorene, 2-methylnaphthalene, naphthalene, phenanthrene, and pyrene. As stated previously in Section 8.2.2, large mammals are not expected to have a completed exposure pathway with contamination at the FFTA. Therefore, the representative wildlife species were limited to small mammals. The cottontail rabbit, meadow vole, short-tailed shrew, and white-footed mouse were selected as the representative wildlife species known to occur at the FFTA or representative of those that may occur. The bench sources used for this ERA did not contain toxicity information on birds for any of the COPECs. The results of the preliminary wildlife benchmark screening for soil is presented in Table 8-3.

Cis-1,2-DCE, ethylbenzene, 2-methylnaphthalene, phenanthrene, and pyrene lacked preliminary benchmarks and appropriate surrogate benchmarks were used. The toxicity characteristics of the surrogate benchmarks were similar to or more toxic than the chemical for which it was substituted. The ingestion rate COPECs by ecological receptors did not exceed preliminary benchmarks; therefore, they were not further evaluated in the secondary screening. Concentrations of VOCs and SVOCs detected in the shallow subsurface soil at the FFTA are not suspected to cause risk to potential ecological receptors at the Site. In addition, adverse effects to any possible ecological receptors were not observed during Site reconnaissance or field sampling activities.

8.5 PREDICTED FUTURE CONDITIONS AND POTENTIAL RISK

The migration of four chemicals (TCE, PCE, DCE, and VC) were modeled to predict estimated concentrations reaching the Kansas River north of FFTA-MAAF (see Section 6.5). The results of the modeling are presented in Figure 6-32. Present or future maximum concentrations of TCE, PCE, DCE, and VC predicted in either the shallow or intermediate zones were used for the ecological screening. Currently, TCE and PCE have reached the river or are expected to reach the river at their maximum concentrations within the next year. Both PCE and TCE will reach the river with estimated maximum concentration of 8 μg/L. respectively. DCE and VC are not expected to reach their estimated maximum concentration at the river for approximately 9 years. The projected concentrations for these chemicals are 54 μg/L and 0.61 μg/L, respectively. The above concentrations represent concentrations in groundwater at its convergence with the river. The above projected groundwater concentrations were conservatively screened as pore water concentrations. The ecological receptors used in the screening were sediment organisms or macroinvertebrates.

Benchmarks used in the quantitative screening included *Oak Ridge National Laboratories Lowest Chronic Value for Daphnids* (ORNL, 1996), *Kansas Surface Water Quality* (KSWQC, 1999), *National Recommended Water Quality Criteria* (FR, 1998), *EPA Tier II Secondary Chronic Value* (USEPA, 1992e), and the *National Ambient Water Quality Criteria* (USEPA, 1992d). If a benchmark for TCE, PCE, DCE, and VC was available from the above sources, the maximum concentrations (current or future) in groundwater was screened. Ecotoxicological information on VC effects to macroinvertebrates could not be obtained. All other chemicals had at least one benchmark from the above sources. TCE, PCE, and DCE projected maximum concentrations at the Kansas River were below all available benchmarks. Conclusions based on this information would indicate that ecological risk to macroinvertebrates in the Kansas River from infiltration of contaminated groundwater is minimal. The results of the screening are presented in Table 8-4.

The calculated current or future maximum concentrations of these contaminants were below all reviewed macroinvertebrate benchmarks for these chemicals. Although concentrations of these chemicals are expected to increase at the river in the future, they are not expected to pose risk to macroinvertebrate receptors.

Currently, levels of chemicals in FFTA soil were identified in surface and subsurface soil, sediment, and groundwater. Future ecological conditions at the FFTA are expected to remain the same as, or similar to, current conditions. Adverse ecological effects were not observed during field investigations conducted by BMcD biologists. Chemical concentrations within the FFTA are expected to naturally degrade and therefore concentrations will decrease in the future. Therefore, any potential risk would be expected to decrease over time. Provided new sources of contamination do not occur, the ecological risk at the FFTA should remain similar to the minimal risk currently exhibited.

8.6 UNCERTAINTIES

When evaluating the ecological risks, several inherent uncertainties exist. These uncertainties pertain to all aspects of the risk analysis. In order to evaluate the potential ecological risk, there must be confidence that the data used to qualify the risk are correct and complete. While the assessor may have confidence in the data, in actuality, the real-world conditions may be different. The uncertainties associated with this ERA include confidence in the following assumptions:

- All ecological receptors, including plants, wildlife, fisheries, threatened and endangered species, and sensitive natural communities are identified.
- All chemicals are identified.
- Reported chemical concentrations are accurate.
- Chemicals identified are not synergistic.
- All exposure pathways have been identified.
- Wildlife exposure values for representative species under laboratory conditions are applicable to natural conditions.
- Wildlife exposure values for representative species are applicable to species of similar size and life history.
- Ingestion rates for representative species are accurate.

- Reported home ranges for representative species appropriately represent home range of species within the project area.
- The FFTA is used by certain wildlife species for at least some portion of their lives and that use is a reflection of the percentage of the species range composed by the area.
- Percentage of soil ingested by ecological receptors is equal to the percentage of time those receptors spend within the FFTA.

8.7 SUMMARY

The FFTA was evaluated for the presence of ecological receptors and completed ecological exposure pathways. Although a completed exposure pathway for small mammals was present, the habitat provided by the FFTA was marginal for these receptors. All other receptors, including plants and soil organisms, were qualitatively determined to have minimal or no risk due to lack of visible adverse effects. Therefore, plants and soil organisms were not further assessed.

A semi-quantitative benchmark screening evaluation was performed. Analytical data were compared to chemical- and receptor-specific benchmarks obtained from literature review. The results of the semi-quantitative evaluation were combined with a qualitative (observable) assessment to determine if significant risk to ecological receptors existed due to site-related chemicals. A summary of the ecological characterization is provided in the following paragraphs.

No COPECs exceeded benchmarks for any receptors in the preliminary screening. There are no indications of potential for adverse ecological effects due to soil contamination at the FFTA. The result of this conservative screening indicates that adverse effects to these receptors, or those receptors with similar life histories, due to FFTA contamination is not expected. In addition, adverse effects to ecological receptors were not observed at the FFTA-MAAF or the Site. Ecological risk to flora and fauna inhabiting or possibly inhabiting is expected to be insignificant.

Migration of TCE, PCE, DCE, and VC were modeled and compared to aquatic life benchmarks to evaluate ecological risk to macroinvertebrate receptors in the Kansas River. The estimated maximum concentrations for each chemical were below all available benchmarks. Therefore, risk to macroinvertebrates due to infiltration of the above chemicals is expected to be minimal.

* * * * *

Table 8-1
Formula for Calculating Preliminary Ingestion Dose in FFTA Soil
MAAF-FFTA Remedial Investigation Report

Equation:
Preliminary Ingestion Dose (mg/kg/day) = FI x FS x MC

Where:
FI = Food Ingestion rate* (kg/kg/day) [converted from g/g/day]
FS = Fraction of soil in diet* (unitless)
MC = Maximum concentration detected in FFTA soil (mg/kg)

*USEPA, 1993

Representative Wildlife Species	Food Ingestion Rate[1] (kg/kg/day)	Percent Soil in Diet[1]
Cottontail Rabbit	3.08E-01[2]	6.3%[3]
Meadow Vole	3.50E-01	2.4%
Short-tailed Shrew	6.20E-01	4%[4]
White-footed Mouse[5]	1.90E-01	2%

Notes:

[1] USEPA, 1993 (Body Weights and Food Ingestion Rates given by the cited source were converted to kilogram units.)

[2] Food Ingestion Rate was not given by the cited source. Food Ingestion Rate was estimated to equal 25% of the Body Weight.

[3] The Percent Soil was not available for this species in the cited source. Soil ingestion rates for the jack rabbit was used as a surrogate for the cottontail rabbit.

[4] The Percent Soil was not available in the cited source, nor were values available for species with similar life histories. Values were conservatively estimated to be two times the value of the other small mammals used in this Environmental Evaluation.

[5] Characteristics for the white-footed mouse were not available from the cited source. Therefore, all characteristics for the white-footed mouse were assumed to be the same as the deer mouse for which values were available.

Table 8-2
Formula for Calculating Secondary Ingestion Dose in FFTA Soil
MAAF-FFTA Remedial Investigation Report

Equation:
Secondary Ingestion Dose (mg/kg/day) = FI x FS x (FR / FA) x MC

Where:
FI = Food Ingestion rate* (kg/kg/day) [converted from g/g/day]
FS = Fraction of soil in diet* (unitless)
FR = Species foraging range (acres)
FA = FFTA acreage (acres)
MC = Maximum concentration detected in FFTA soil (mg/kg)

*USEPA, 1993

Representative Wildlife Species	**Food Ingestion Rate[1] kg/kg/day)**	**Percent Soil in Diet[1]**	**Foraging Range[1] (acres)**
Cottontail Rabbit	3.08E-01[2]	6.3%[3]	7.4
Meadow Vole	3.50E-01	2.4%	0.05
Short-tailed Shrew	6.20E-01	4%[4]	1
White-footed Mouse[5]	1.90E-01	2%	0.15

Notes:
[1] USEPA, 1993 (Body Weights and Food Ingestion Rates given by the cited source were converted to kilogram units.)
[2] Food Ingestion Rate was not given by the cited source. Food Ingestion Rate was estimated to equal 25% of the Body Weight.
[3] The Percent Soil was not available for this species in the cited source. Soil ingestion rates for the jack rabbit was used as a surrogate for the cottontail rabbit.
[4] The Percent Soil was not available in the cited source, nor were values available for species with similar life histories. Values were conservatively estimated to be two times the value of the other small mammals used in this Environmental Evaluation.
[5] Characteristics for the white-footed mouse were not available from the cited source. Therefore, all characteristics for the white-footed mouse were assumed to be the same as the deer mouse for which values were available.

Table 8-3
Preliminary Soil Benchmark Screening for Wildlife
FFTA-MAAF Remedial Investigation Report

Chemical	Maximum Concentration Detected in FFTA Soil (mg/kg)	Representative Wildlife Species	Dose Received from FFTA Soil (mg/kg/day)	No Observed Adverse Effects Level (NOAEL)[1] (mg/kg/day)	Ecological Quotient (EQ)	Chemical of Potential Ecological Concern (COPEC)
VOCs						
cis-1,2-Dichloroethene	0.58	Cottontail Rabbit	7.15E-04	1.80E+01	0.00	no
		Meadow Vole	4.87E-03	4.11E+01	0.00	no
		Short-tailed Shrew	1.44E-02	5.38E+01	0.00	no
		White-footed Mouse	2.20E-03	4.88E+01	0.00	no
Ethylbenzene[2]	13	Cottontail Rabbit	1.60E-15	1.18E+00	0.00	no
		Meadow Vole	1.09E-01	2.40E+01	0.00	no
		Short-tailed Shrew	3.22E-01	3.13E+01	0.01	no
		White-footed Mouse	4.94E-02	2.85E+01	0.00	no
Tetrachloroethene (PCE)	0.12	Cottontail Rabbit	1.48E-17	5.60E-01	0.00	no
		Meadow Vole	1.01E-03	1.27E+00	0.00	no
		Short-tailed Shrew	2.98E-03	1.66E+00	0.00	no
		White-footed Mouse	4.56E-04	1.51E+00	0.00	no
Toluene	30	Cottontail Rabbit	3.70E-15	1.03E+01	0.00	no
		Meadow Vole	2.52E-01	2.36E+01	0.01	no
		Short-tailed Shrew	7.44E-01	3.09E+01	0.02	no
		White-footed Mouse	1.14E-01	2.81E+01	0.00	no
Xylene (mixed isomers)	49	Cottontail Rabbit	6.04E-15	8.35E-01	0.00	no
		Meadow Vole	4.12E-01	1.91E+00	0.22	no
		Short-tailed Shrew	1.22E+00	2.50E+00	0.49	no
		White-footed Mouse	1.86E-01	2.27E+00	0.08	no
Acenaphthene[3]	0.34	Cottontail Rabbit	4.19E-17	4.00E-01	0.00	no
		Meadow Vole	2.86E-03	9.10E-01	0.00	no
		Short-tailed Shrew	8.43E-03	1.19E+00	0.01	no
		White-footed Mouse	1.29E-03	1.08E+00	0.00	no
Bis(2-Ethylhexyl)Phthalate	0.2	Cottontail Rabbit	2.46E-17	7.30E+00	0.00	no
		Meadow Vole	1.68E-03	1.66E+01	0.00	no
		Short-tailed Shrew	4.96E-03	2.18E+01	0.00	no
		White-footed Mouse	7.60E-04	1.98E+01	0.00	no

Table 8-3 (continued)
Preliminary Soil Benchmark Screening for Wildlife
FFTA-MAAF Remedial Investigation Report

Chemical	Maximum Concentration Detected in FFTA Soil (mg/kg)	Representative Wildlife Species	Dose Received from FFTA Soil (mg/kg/day)	No Observed Adverse Effects Level (NOAEL)[1] (mg/kg/day)	Ecological Quotient (EQ)	Chemical of Potential Ecological Concern (COPEC)
SVOCs						
Fluorene[3]	0.34	Cottontail Rabbit	4.19E-17	4.00E-01	0.00	no
		Meadow Vole	2.86E-03	9.10E-01	0.00	no
		Short-tailed Shrew	8.43E-03	1.19E+00	0.01	no
		White-footed Mouse	1.29E-03	1.08E+00	0.00	no
2-Methylnaphthalene[3]	46	Cottontail Rabbit	5.67E-15	4.00E-01	0.00	no
		Meadow Vole	3.86E-01	9.10E-01	0.42	no
		Short-tailed Shrew	1.14E+00	1.19E+00	0.96	no
		White-footed Mouse	1.75E-01	1.08E+00	0.16	no
Naphthalene	18	Cottontail Rabbit	2.22E-15	4.00E-01	0.00	no
		Meadow Vole	1.51E-01	9.10E-01	0.17	no
		Short-tailed Shrew	4.46E-01	1.19E+00	0.38	no
		White-footed Mouse	6.84E-02	1.08E+00	0.06	no
Phenanthrene[3]	11	Cottontail Rabbit	1.36E-15	4.00E-01	0.00	no
		Meadow Vole	9.24E-02	9.10E-01	0.10	no
		Short-tailed Shrew	2.73E-01	1.19E+00	0.23	no
		White-footed Mouse	4.18E-02	1.08E+00	0.04	no
Pyrene[3]	2.8	Cottontail Rabbit	3.45E-16	4.00E-01	0.00	no
		Meadow Vole	2.35E-02	9.10E-01	0.03	no
		Short-tailed Shrew	6.94E-02	1.19E+00	0.06	no
		White-footed Mouse	1.06E-02	1.08E+00	0.01	no

Notes:

[1] (ORNL, 1996a)

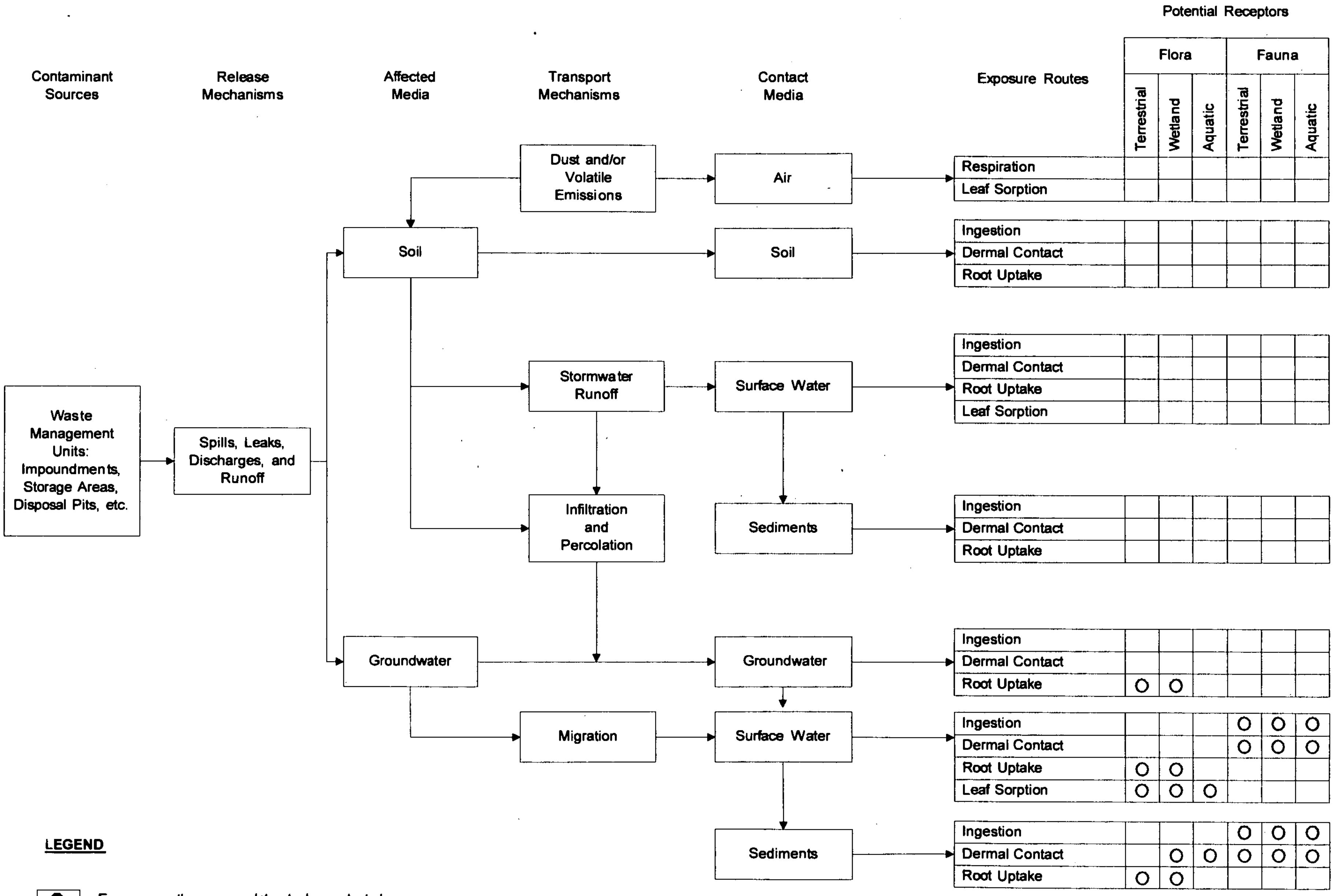
[2] Toxicity information was not available from the reference. Toxicity information for benzene was substituted for ethylbenzene.

[3] Toxicity information was not available from the reference. Toxicity information for benzo(a)pyrene was substituted for other PAHs.

Table 8-4
Macroinvertebrate Benchmark Screening for Surface Water
FFTA-MAAF - Remedial Investigation Report
Fort Riley, Kansas

Chemical	Source	Aquatic Life Benchmark[1] (μg/l)	Estimated Future Maximum Concentration Detected in Groundwater at the Kansas River (μg/l)	Ecological Quotient (EQ)	Chemical of Potential Ecological Concern[2] (COPEC)
VOCs					
1,2-Dichloroethene (DCE)	Lowest Chronic Value for Daphnids[1]	NA	54	--	no
	Kansas Surface Water Quality Criteria (Aquatic Life Chronic)[2]	NA		--	
	National Recommended Water Quality Criteria[3]	NA		--	
	EPA Tier II Secondary Chronic Value[4]	590		0.09	
	National Ambient Water Quality Criteria[5]	NA		--	
Tetrachloroethene (PCE)	Lowest Chronic Value for Daphnids[1]	750	8	0.01	no
	Kansas Surface Water Quality Criteria (Aquatic Life Chronic)[2]	840		0.01	
	National Recommended Water Quality Criteria[3]	NA		--	
	EPA Tier II Secondary Chronic Value[4]	98		0.08	
	National Ambient Water Quality Criteria[5]	NA		--	
Trichloroethene (TCE)	Lowest Chronic Value for Daphnids[1]	7257	8	0.00	no
	Kansas Surface Water Quality Criteria (Aquatic Life Chronic)[2]	21900		0.00	
	National Recommended Water Quality Criteria[3]	NA		--	
	EPA Tier II Secondary Chronic Value[4]	47		0.17	
	National Ambient Water Quality Criteria[5]	NA		--	
Vinyl Chloride[6]	Lowest Chronic Value for Daphnids[1]	7257	0.6	0.00	no
	Kansas Surface Water Quality Criteria (Aquatic Life Chronic)[2]	21900		0.00	
	National Recommended Water Quality Criteria[3]	NA		--	
	EPA Tier II Secondary Chronic Value[4]	47		0.01	
	National Ambient Water Quality Criteria[5]	NA		--	

Notes:
NA - Not Available
[1] ORNL, 1996b
[2] KSWQC, 1999
[3] FR, 1998
[4] USEPA, 1992e
[5] USEPA, 1992d
[6] Toxicity data for vinyl chloride was not available from the all utilized sources. Toxicity data for TCE was used as surrogate for vinyl cloride.



Contact Media	Exposure Routes	Flora Terrestrial	Flora Wetland	Flora Aquatic	Fauna Terrestrial	Fauna Wetland	Fauna Aquatic
Air	Respiration						
	Leaf Sorption						
Soil	Ingestion						
	Dermal Contact						
	Root Uptake						
Surface Water	Ingestion						
	Dermal Contact						
	Root Uptake						
	Leaf Sorption						
Sediments	Ingestion						
	Dermal Contact						
	Root Uptake						
Groundwater	Ingestion						
	Dermal Contact						
	Root Uptake	○	○				
Surface Water	Ingestion				○	○	○
	Dermal Contact				○	○	○
	Root Uptake	○	○				
	Leaf Sorption	○	○	○			
Sediments	Ingestion				○	○	○
	Dermal Contact		○	○	○	○	○
	Root Uptake	○	○				

LEGEND

● Exposure pathway complete; to be evaluated

○ Exposure pathway may be complete; to be determined

☐ Exposure pathway not complete

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SINCE 1898

Figure 8-1
Ecological Conceptual Model

MAAF-FFTA RI

eco-scm.vsd 11/14/00

9.0 CONCLUSIONS

The purpose of this Report is to document the evaluation of current conditions as they pertain to potential threats to human health and the environment associated with the FFTA/MAAF, Fort Riley, Kansas. Included within this Report are characterizations of the nature and extent of contamination, an evaluation of the fate and transport of contaminants, and human health and ecological risk assessments.

9.1 CONCEPTUAL MODEL OF SITE

In evaluating the nature and extent of contamination at the FFTA-MAAF Site, the levels of naturally occurring metals in soil and groundwater were taken into consideration. Metals have been evaluated in this Report by comparing detections to site-specific background levels as discussed in Section 5.2. Metals were detected above background levels in a limited number of soil samples; however, all metals were detected above background in fewer than 5-percent of samples collected. With a large data set such as this one, 5 percent of samples can reasonably be expected to exceed the 95 percent UTL value. Additionally, all metals detected above background levels were still within the range of naturally observed levels, with the exception of lead in soils at PSB-4. Although the maximum detected concentrations of lead were above background levels, the calculated 95 percent UCL values for lead were below background.

During the two rounds of RI groundwater sampling that included analysis of metals, only arsenic, nickel, and selenium were detected in more than 5 percent of the samples. Arsenic, nickel and selenium were all detected at levels below the respective MCLs, in diverse locations, and are not known to be associated with activities conducted at the Site. The evaluation of all metal detections indicates that with the exception of lead at PSB-4, activities at the Site have not contributed to current soil and groundwater metal levels.

COPCs for the Site were identified using a conservative approach (Section 7.2.3), and include: TPH-DRO, TPH-GRO, PCE, TCE, 1,2-DCE (cis and trans isomers), VC, 1,1-DCE, benzene, toluene, ethylbenzene, xylenes (total), naphthalene, dichloromethane, and 2-methylnaphthalene.

At the Site, contamination in soils is concentrated at the former fire-training pit. Limited detections of naphthalene and 2-methylnaphthalene in soil occurred around the elevation of 1,040 feet msl in the center of the former fire training pit. PCE, TCE, cis-1,2-DCE, TVPH, TPH as diesel, and TPH as C19 – C40 were detected at various depths in the center of the former fire training pit as well as several other locations adjacent to the former fire-training pit. The contamination encountered near the center of the former fire-training pit and at deep locations adjacent to the former fire-training pit can be attributed to the documented solvent release in August 1982 and firefighter training exercises. PCE and TPH were also detected near the former drum storage area, primarily at depths of less than 4 feet bgs. The source of this contamination appears to be solvent releases in the former drum storage area and spreading of soils during regrading of the area after operations ceased at the FFTA and the former drum storage area.

In the groundwater at the Site, chlorinated solvents, TPH, and BTEX are present. Detections of these compounds are first encountered in the shallow zone in the four wells closest to the former fire-training pit. The intermediate and deep aquifer zones show very little or no detections of any of these compounds until 1,200 feet downgradient of the former fire-training pit. In the intermediate depth aquifer zone, significant detections of volatiles are present approximately 1,350 feet from the source area. In the deep aquifer zone, 2,100 feet from the source, cis-1,2-DCE, TPH, and BTEX have recently been at higher levels than in earlier sampling rounds. This may be due to the vertical and horizontal migration of the peaks of these compounds previously observed in the upgradient intermediate zone. The last monitoring well before the Kansas River, Monitoring Well FP-99-32c, had detections of PCE, TCE, and cis-1,2-DCE when first sampled in August 1999.

The only documented release of a chlorinated solvent at the Site was PCE. Therefore, TCE and 1,2-DCE in groundwater at the Site are assumed to be daughter products from the breakdown of PCE. The highest PCE concentrations are approximately 400 ft from the source, the highest TCE levels are approximately 800 ft from the source, and the highest 1,2-DCE levels are approximately 1,500 ft from the source in the shallow depth. DCE has lingered at the Site and migrated laterally and vertically with the groundwater to the intermediate and deep depths. Advection and dispersion seem to be spreading the cis-1,2-DCE peak over time as it moves further from the source area.

Cis-1,2-DCE is less amenable to dechlorination in an anaerobic reducing environment, as compared to PCE and TCE. In this system, it appears that once the degradation pathway reaches cis-1,2-DCE, the reductive dechlorination process slows. VC has been detected in two locations in the plume, at Monitoring Wells FP-94-09 and FP-94-11, indicating the potential for further reductive dechlorination in the plume if appropriate reducing conditions are present. However, since detections of VC are limited, this suggests the reductive dechlorination process is stalling at cis-1,2-DCE. Another posibility for the few VC detections, is the potential for VC to degrade at a rate equilivant to the VC production rate. In other words, it is possible that VC is degrading almost immediately after it is produced, this is why there have been few detections. Although there is not sufficient data to support this scenario, the potential exists and should be considered.

Additional factors influencing reductive dechlorination, is the availability of primary carbon sources to act as electron donors. Close to the source area, BTEX and TPH concentrations are much higher than further downgradient. These organics, especially BTEX compounds, can serve as primary substrate for the microorganisms facilitating reductive dechlorination.

Abiotic degradative processes also may be occurring at the Site. These processes include hydrolysis, dehydrohalogenation, and oxidation-reduction reactions. The abiotic process of reduction of chlorinated solvents by Fe(II) present in the aquifer is currently being researched as a potential degradation process for chlorinated solvents

Contaminant concentration reduction can also occur through physical processes. The physical processes that are significant at the Site include dilution, dispersion, and sorption. Dilution and dispersion can further reduce the remaining contaminant concentrations in the plume once degradation stalls.

9.2 CONTAMINANT MODELING

Reactive contaminant transport modeling was performed to simulate the transport of chlorinated solvents in the subsurface, predict future concentrations at potential receptor locations, and to further evaluate natural attenuation processes occurring at the Site. Results of the transport modeling indicated that:

- Maximum concentrations for PCE in the plume have already been reached in all three zones at the Site. The 30-year average maximum concentrations were 0.331 µg/L, 0.673 µg/L, and 0.849 µg/L for the shallow, intermediate, and deep zones respectively. These values are considered very conservative when used for 30-year exposure assessments, since locations of the maximum values are not stationary over time.

- Maximum concentrations for TCE in the plume have already been reached in all three zones at the Site. The 30-year average maximum concentrations were 1.365 µg/L, 1.822 µg/L, and 1.851 µg/L for the shallow, intermediate, and deep zones respectively. Again, these values are considered very conservative for exposure assessment purposes.

- Maximum concentrations for cis-1,2-DCE in the plume have already been reached in the shallow and intermediate zones, but is predicted to peak at 144 μg/L in approximately one year for the deep zone. The 30-year average maximum concentrations were 87.174 μg/L, 61.355 μg/L, and 45.252 μg/L for the shallow, intermediate, and deep zones respectively. Again, these values are considered very conservative for exposure assessment purposes.

- Maximum concentrations for VC in the plume have already been reached in the shallow zone, but is predicted to peak at 0.9 μg/L in approximately six years for both the intermediate and deep zones. The 30-year average maximum concentrations were 0.627 μg/L, 0.360 μg/L, and 0.357 μg/L for the shallow, intermediate, and deep zones respectively. Again, these values are considered very conservative for exposure assessment purposes.

- PCE concentrations at the Kansas River are predicted to peak at 2.4 μg/L in approximately one year for the shallow zone. This does not imply that the PCE plume is moving through the shallow zone to reach the river. Rather, contamination is entering the shallow zone from the intermediate zone due to the upward groundwater flow near the river. The maximum PCE concentrations at the river have already been reached in the intermediate zone. The concentrations from the deep zone are included within the concentrations reported for the intermediate zone at the river, and are a result of the upward groundwater flow near the river.

- TCE concentrations at the Kansas River are predicted to peak at 4.4 μg/L in approximately one year for the shallow zone and at 8.0 μg/L in approximately one year for the intermediate zone. This does not imply that the TCE plume is moving through the shallow zone to reach the river. Rather, contamination is entering the shallow zone from the intermediate due to the upward groundwater flow near the river. Again, the concentrations from the deep zone are included within the concentrations reported for the intermediate zone at the river, and are a result of the upward groundwater flow near the river.

- Cis-1,2-DCE concentrations at the Kansas River are predicted to peak at 54 μg/L in approximately nine years for the shallow zone and at 44 μg/L in approximately nine years for the intermediate zone. Again, the concentrations from the deep zone are included within the concentrations reported for the intermediate zone at the river, and are a result of the upward groundwater flow near the river.

- VC concentrations at the Kansas River are predicted to peak at 0.51 μg/L in approximately eight years for the shallow zone and at 0.61 μg/L in approximately nine years for the intermediate zone. Again, the concentrations from the deep zone are included within the concentrations reported for the intermediate zone at the river, and are a result of the upward groundwater flow near the river.

9.3 RISK ASSESSMENT

9.3.1 Summary of Human Health Risk

9.3.1.1 HHBRA Summary

The potential for human health risk due to exposure to chemicals at the Site was considered for the soil, water, and air media. Based on observed Site conditions, it was concluded that chemical exposure was possible to on-post populations through contact with subsurface soil and/or vapors from soil and to off-post populations through contact with groundwater and vapors. Potential intakes of the COPCs were calculated using standard USEPA exposure calculation equations for intake from ingestion, dermal contact, and inhalation of contaminants. Cancer and noncancer risks were calculated for the following scenarios: current on-post pedestrian/jogger exposure to vapors from impacted subsurface soil; future on-post utility worker exposure to impacted soil and vapors while excavating; current racetrack worker exposure to impacted groundwater and vapors while treating the racetrack with water for dust control; current racetrack patrons exposure to impacted groundwater; and both current and future off-post residents exposure to impacted groundwater and vapors while showering. The future adult resident exposure also included inhalation of vapors from irrigation water.

For exposure concentrations under current conditions, 95 percent UCLs of the mean were calculated assuming lognormally distributed soil and groundwater data. For exposure concentrations that might be experienced in the future by a utility excavation worker, soil chemical concentrations under current conditions were assumed to be steady state. The future resident child/adult exposure concentrations for COPCs in groundwater were based on the fate and transport modeling results, using 6-year and 30-year average maximum chemical concentrations, regardless of predicted location in the plume.

Vapor concentrations for the on-post exposure scenarios were determined by modeling contaminant partitioning from soil, migration to the surface, and dilution in the breathing zone at the receptor point. Vapor concentrations for the racetrack worker/farmer exposure scenarios were determined by modeling partitioning from applied/irrigation water and dilution of vapors in the breathing zone. Indoor vapor concentrations for the resident scenarios were determined from groundwater concentrations by use of the USEPA-accepted Andelman volatilization model.

The results of the risk characterization indicate that current concentrations of COPCs at the FFTA-MAAF pose insignificant risks of adverse health effects for both on-post populations characterized. Current concentrations of COPCs in groundwater also pose insignificant or minimal risk of adverse health effects for the off-post populations. The highest cancer risk was 2E-05 for the off-post adult resident, still within the USEPA acceptable excess cancer risk range of 1E-04 to 1E-06 (one in ten thousand to one in a million). Most of the potential for risk was posed by vinyl chloride. For the future scenarios, using the predicted concentrations from the model, the highest risk for adverse health effects was for the off-post child resident, at a hazard index of 1. The USEPA level of concern is a hazard index greater than 1. Most of the potential for risk in this scenario was posed by cis-1,2-DCE. The highest excess cancer risk was for the off-post future resident farmer at 4E-05, still within the USEPA acceptable excess cancer risk range of 1E-04 to 1E-06. Most of potential for risk was posed by vinyl chloride. A summary of the results of the risk characterization is presented in Table 7-46.

Uncertainties associated with the risk characterization were evaluated. The potential risk posed by cis-1,2-DCE for the future child resident is likely overestimated as a result of conservative assumptions in the exposure and toxicity assessments. In developing the exposure concentrations, it was assumed that the predicted yearly maximum concentrations for all chemicals occur at the same location in the aquifer (which is not the predicted case), and that the receptor well "floats" with time so that it is always screened in the maximum chemical concentrations. Additionally, the provisional reference dose for cis-1,2-DCE, provided in HEAST, was developed by USEPA using a 3,000-fold uncertainty factor. This means that the hazard index of 1 may be overestimated by a factor of 3,000. The provisional reference dose for cis-1,2-DCE is considered by USEPA as nonverifiable and subject to change. Verified reference doses once placed in IRIS still have uncertainty spanning an order of magnitude and, according to USEPA, should not be viewed as a strict scientific demarcation between toxic and nontoxic levels (USEPA, 1989) [RAGS Part A].

9.3.1.2 Alternative Risk Assessment Summary

An alternative way of estimating exposure concentrations and thus potential risk for the future resident scenario was requested by regulators, following submittal of the draft report. Based on discussions with and concurrence of the EPA Region 7 risk assessor, it was determined that risk would be characterized for each well along the center-line of the plume (Section 7.7.2).

Completed exposure pathways assumed for this evaluation were the same as those summarized in Section 7.4.3.5 of the HHBRA and included ingestion of chemicals in groundwater, dermal absorption of chemicals while showering, and inhalation of chemical vapors while showering. The adult farmer was assumed to be additionally exposed to vapors from a sprinkler irrigation system. Exposure variables presented in Tables 7-13 through 7-14 of the HHBRA were used to calculate chemical intake. The results of the risk characterization are summarized in Table 7B-4 of Appendix 7B.

The hazard indices for a future child resident were above one at well locations MW-09, MW-11, and MW-27. The largest hazard index was 4 for both well locations MW-09 and MW-11. Ingestion of cis-1,2-DCE in tap water produced all of the significant noncarcinogenic risk at these well locations. The exposure concentrations for cis-1,2-DCE at well locations MW-09, MW-11, and MW-27 were based on the maximum concentrations detected in May 1999, August 1999, and August 1999, respectively.

The hazard indices for a future resident/farmer were above one at well locations MW-04, MW09, and MW-11. Inhalation of naphthalene produced the significant risk at the on-post well location, MW-04. Ingestion of cis-1,2-DCE in tap water produced the significant noncarcinogenic risk at the other two locations.

Carcinogenic risk was within the 1E-04 to 1E-06 (one in 10,000 to one in a million) acceptable risk range at all well locations, with 1E-04 being the greatest calculated excess lifetime cancer risk at MW-11. This potential risk was posed from ingestion of vinyl chloride in groundwater.

The uncertainty associated with the alternative risk characterization may be great, ranging from an overestimation to an underestimation of potential risk. Although assuming steady-state conditions usually results in a conservative overestimate of exposure and thus risk, it may serve to underestimate exposure and risk in the case of chlorinated solvents. This can result if there is an accumulation over time of daughter products of PCE-TCE degradation, which are more potent carcinogens than the parent compounds. Use of a fate and transport model to predict chemical concentrations over time is one way of reducing the uncertainty associated with this temporal data gap. Site-specific data has been used to develop the fate and transport model presented in Section 6.5. By comparison to historical trends of contaminant concentrations and the predictions of the fate and transport model, the results of the alternative risk characterization presented in this section are likely an overestimate of exposure and risk.

9.3.2 Summary of Ecological Risk

The FFTA was also evaluated for the presence of ecological receptors and completed ecological exposure pathways. Although a completed exposure pathway for small mammals was present, the habitat provided by the FFTA was marginal for these receptors. All other receptors, including plants and soil organisms, were qualitatively determined to have minimal or no risk due to lack of visible adverse effects. Therefore, plants and soil organisms were not further assessed.

The preliminary screening did not provide any indications of adverse ecological effect due to soil contamination. Therefore, a secondary screening was not necessary. Adverse effects to ecological receptors were not observed at the FFTA-MAAF or the Site. Ecological risk to flora and fauna inhabiting or possibly inhabiting is expected to be insignificant. Migration of TCE, PCE, DCE, and VC were modeled and compared to aquatic life benchmarks to evaluate ecological risk to macroinvertebrate receptors in the Kansas River. The estimated maximum present and future concentrations for each chemical were below all available aquatic life benchmarks. Therefore, risk to macroinvertebrates due to infiltration of the above chemicals is expected to be minimal.

* * * * *

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