

**Evaluation of Natural Attenuation of Chlorinated Solvents in Ground Water at the  
Twin Cities Army Ammunition Plant – Site A.**

Final Report  
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## OVERVIEW AND GOAL OF STUDY

Past disposal of solvents in the soils at Site A at the Twin Cities Army Ammunition Plant (TCAAP) resulted in the contamination of the shallow aquifer with perchloroethylene and trichloroethylene, in addition to other contaminants. Contaminated ground water moved in a northwesterly direction from the contaminant sources toward private wells of residences just north of the TCAAP boundary. Remediation efforts have included soil excavation and the placement of pumping wells intended to prevent further migration of contaminated groundwater. The long-term fate of the ground water plume is still in question.

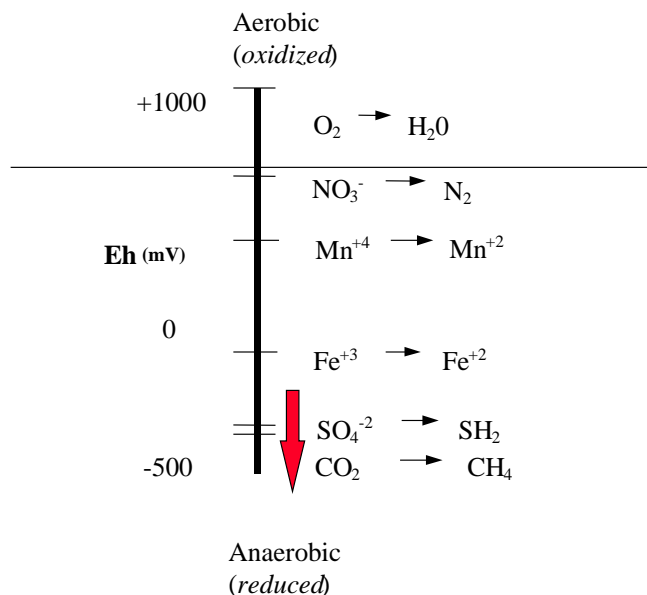
The presence of the *cis*- isomer of dichloroethylene demonstrates that perchloroethylene is biologically degrading through reductive dehalogenation at the site. This is important because natural attenuation studies at other sites have demonstrated that natural attenuation (which includes biological degradation) is a large factor in the extent of ground water contamination and the time to ground water restoration.

The goal of this study was to assess how natural attenuation has influenced the development of the ground water plume at Site A and its role in the eventual restoration of the aquifer.

## BACKGROUND

### Natural Attenuation

Laboratory and field research have demonstrated that chlorinated solvents are biodegradable under certain environmental conditions. However, unlike the monoaromatic hydrocarbons benzene, toluene, ethylbenzene, and xylenes (BTEX) that biologically degrade aerobically, chlorinated solvents such as perchloroethylene (PCE) or trichloroethylene (TCE) degrade optimally under strongly reducing conditions (Figure 1). The reductive dehalogenation may be rapid under sulfate reducing or methanogenic conditions in ground water. Demonstrating that the ground water environment is favorable to reductive dehalogenation processes is therefore important in an assessment of natural attenuation at a site and the long term fate of a contaminant plume (8). In addition, the metabolites of TCE or PCE degradation, *cis*-dichloroethylene (cDCE) and vinyl chloride (VC), may break down under iron reducing (1) or manganese reducing (2) conditions in addition to sulfate reducing or methanogenic conditions. Hydrogen concentration in ground water is correlated to the geochemistry at the site, and is a useful indicator of the potential for reductive dehalogenation (7).



**Figure 1. Reductive dehalogenation of chlorinated solvents is most favorable under sulfate or carbon dioxide reducing conditions, indicated by the arrow.**

The combined effect of dispersion, sorption, and biological degradation on ground water contaminants can be quantified in terms of the natural attenuation capacity (4) at the site. This capacity may be large enough to contain the contamination within regulatory boundaries and contribute substantially to the collapse of the plume and restoration of the ground water. Simulating the effect of natural attenuation on the contaminants using computer models can assist in evaluating plume development and lead to cost-effective remediation decisions.

## Site A History and Description

Site A is located on the north end of TCAAP (Figure 2). The water table is 15 to 19 feet below ground surface, with the Unit 1 aquifer ranging in thickness from 15 feet near the source area to 28 feet to the west (Figure 3). The soils consist of loamy, fine sands with layers of iron oxide rich zones. The Unit 1 aquifer sediments are composed of lacustrine silt and fine or medium sands. This is underlain by the Twin Cities Till (Unit 2) which, due to its high clay content, serves as an effective aquitard to the Unit 1 aquifer. Unit 2 is approximately 12 to 88 feet thick at Site A.

Ground water flows in a northwesterly direction toward Rice Creek with a horizontal hydraulic gradient in the area ranging from 0.0025 to 0.005 ft/ft. Assuming an aquifer thickness of 17 feet at the site, IT Corp. estimated in 1988 that the ground water hydraulic conductivity for Unit 1 was  $8.3 \times 10^{-3} \text{ cm sec}^{-1}$  ( $8.59 \times 10^3 \text{ ft yr}^{-1}$ ) (6). Using a gradient of 0.005 and a porosity of 0.2, ground water velocity is estimated at 200 feet per year at Site A.

Although it is unknown when solvents were disposed at the site, aerial photographs suggest that trenches and pits were used at the site for waste in the early 1940s, shortly after TCAAP was constructed (9). Historical ground water data appear to indicate the presence of multiple sources at the site but are difficult to define and fully delineate; however, the ground water contaminant concentrations at monitoring well 01U108 are the highest detected at the site historically. Thus, for the purposes of this study, the area near well 01U108 is generally considered the primary source of chlorinated solvents to the Unit 1 aquifer.

The ground water investigation at the site began in 1983. The primary concern was for the residences with private wells to the north and northwest of the site that were in the path of the contaminant plume (Figure 4). Subsequent sampling of these wells showed that TCE and cDCE were present in some of these wells, though none of the contaminants were detected above Minnesota Health Risk Limits (HRLs). No PCE was found in these residential wells. The highest concentrations of cDCE at monitoring wells 01U902 and 01U904 situated on the north side of County Road I were roughly 100 µg/L in the early 1990s, with concentrations of TCE at 2 to 3 µg/L. At monitoring well 01U108, PCE concentrations exceeded 1000 µg/L in 1985, with TCE and DCE concentrations over 500 µg/L from 1985-1990. Attachment A contains plume maps from 1991, 1992, 1995, 1996, 1997, and 1999 showing the approximate spatial distributions of cDCE, TCE, and PCE in ground water at the site. In addition, plots of PCE, TCE, and cDCE concentrations as a function of time are also included for monitoring wells 01U108, 01U117, 01U115, 01U902, and 01U904.

Prior to 1999, contour maps show the plume consisting of two lobes, one emanating from the area of monitoring well 01U108 and one from the area of monitoring well 01U102, to the west of well 01U108. This conceptual understanding of the plume changed with analysis in the 1999 Annual Performance Report, when it was discovered that monitoring well 01U125 was screened at the water table. As a result, water from this well did not contain the contaminants of wells with larger well screens and was therefore unrepresentative of ground water contamination in this area. The ground water contamination is now configured as one large plume, and not two as reported previously.

In September of 1988, extraction well 350 was installed near monitoring well 01U108 as part of an interim response action intended to remove and treat the high concentrations of contaminants found at this location. Well 350 operated at 4 gallons per minute (gpm). Pumping at this well

was stopped in 1994 based on an evaluation of its effectiveness. In 1994, eight additional extraction wells were installed downgradient of the source area (Figure 4) intended to prevent contaminants from migrating further downgradient with a combined pumping rate of approximately 30 gpm (5).

## RESULTS

Monitoring wells 01U108, 01U117, 01U115, 01U902, and 01U904 were sampled on three occasions from June, 1997 through June, 1998 as part of this study (Figure 5). In addition, monitoring well 01U067, which is upgradient of the source area, was included as a background monitoring location.

It is reasonable to assume that PCE and TCE were the only contaminants released at the site. Thus, the presence of cDCE shows that PCE/TCE is being reductively dechlorinated in the ground water. However, similar to the chemistry of the deep ground water at TCAAP, no vinyl chloride (VC) has been detected in Site A ground water. In addition, no ethene (the ultimate product of reductive dehalogenation) was found at the site from 1997 through 1998. The absence of VC and ethene suggests that the degradation of PCE is incomplete, leading to the accumulation of cDCE with distance from the source.

Table 1 shows the geochemistry of the ground water sampled at Site A from 1997 through 1999. The ground water is manganese reducing from the source area (01U108) to the downgradient well 01U904. The very low concentrations of methane indicate that the ground water is not methanogenic. Ground water hydrogen concentrations are generally in the range of 0.5 to 1.0 nanomolar, indicating that the terminal electron acceptor is probably Fe(III). This is generally consistent with the geochemistry at the site. However, three ground water samples collected at different times contained hydrogen in excess of 1.0 nanomolar; the highest concentration was found at well 01U108 at 2.4 nanomolar. These concentrations are indicative of redox conditions consistent with sulfate reduction processes.

These ground water conditions are not generally considered favorable to the reductive dehalogenation of chlorinated aliphatic compounds such as TCE (8). Nonetheless, the presence of cDCE at this site is evidence that reductive dehalogenation of PCE and TCE is occurring. Thus, it was not clear whether a) natural attenuation is effectively reducing contaminant mass in ground water as it moves away from the source area, or b) if the contaminant degradation stops with cDCE, which simply accumulates in the ground water with distance.

To determine which of the two scenarios is more plausible, we modeled the contaminant plume with the fate and transport model BIOPLUME III (11) to discover whether or not considerable mass removal due to natural attenuation processes is required to account for the observed contaminant concentrations. First, development of the PCE plume was modeled assuming that biological degradation of PCE was negligible. Under this scenario, the effect of the ground water extraction system is included, starting with well 350 in 1988 and continuing with the other eight wells in 1994. In the second simulation, the effect of biological degradation is added. Finally, assuming that the source of contamination will remain constant without intervention, the third simulation includes the effect of source removal in addition to pumping and biological degradation.

### Model Simulation 1:

#### No PCE Biodegradation with Ground Water Extraction Starting in 1988

The PCE contaminant plume was modeled using BIOPLUME III using the ground water transport data for the site but no biodegradation. The model assumes that the initial concentration of PCE in the source area near well 01U108 was approximately 20 mg/L in 1950.

Records indicate that well 350 began operating in 1988 at approximately 4 gpm and was discontinued in 1994. A second system of eight extraction wells downgradient of the source area was started in 1994 with a combined pumping rate of about 30 gpm. The effect of these extraction systems were incorporated in the model.

The source area was simulated in BIOPLUME III by placing an “injection well” near the source area. The source begins in 1950 at an estimated concentration of 20 mg/L PCE which gradually decreases to a constant source of 1 mg/L to the ground water since 1990. This simulates the actual ground water PCE concentrations in well 01U108 since monitoring began in 1985.

Without the contribution of biodegradation, the model predicts that the concentration of PCE would have exceeded 1000 µg/L downgradient of monitoring well 01U904 prior to installation of the pumpout well 350 in 1988 (Figures 6 - 11). Further downgradient, the model predicts that in 1994 PCE would have exceeded concentrations of 200 µg/L in wells 234377 and 5553 (both private wells approximately 1650 feet from the source area).

Historical data shows that in 1994, PCE was below detection limits in wells 01U904, 234377 and 5553; only cDCE was found in 234377 at 0.4 µg/L. No contamination was discovered in well 5553. This simulation shows that dilution and adsorption cannot account for the actual development of the ground water plume over time. In order to explain the development of the plume at the site, the model must include a mechanism for the *in situ* destruction of PCE.

#### PCE Biodegradation Rate Estimate

Table 2a shows the data collected from the 1998 natural attenuation study. The slope of the regression of PCE as a function of distance is 0.009 ft<sup>-1</sup>, and represents the total attenuation rate (k) of PCE divided by the ground water velocity of 200 ft yr<sup>-1</sup>. Thus, from the 1998 data, k = -1.9 yr<sup>-1</sup>. For comparison, Table 2b includes the highest concentrations ever observed in the same wells (1994 Annual Monitoring Report). The slope of the regression from this data is -0.007 ft<sup>-1</sup>, with k = -1.4 yr<sup>-1</sup>.

The biodegradation rate can be estimated by subtracting the effects of dilution and sorption from the overall attenuation rate (3):

$$\lambda = \left| \frac{v_c}{4\alpha} \right| \left[ \left( 1 + (2)(\alpha) \left| \frac{k}{v_x} \right| \right)^2 - 1 \right]$$

Where

$v_c$  = velocity of contaminant transport in ground water, estimated by dividing the ground water velocity by the retardation constant for the site,  $R^*$ . For site A,  $v_c$  is estimated at 64 ft/yr;

$\alpha$  = contaminant dispersion in ground water, estimated at 2.5% or 18 feet for this site;

$\lambda$  = rate of PCE biodegradation in ground water, and

$k$  = the total attenuation rate of -1.9 per year (1998 data, Table 2a), or -1.4 per year (highest PCE concentrations ever found, Table 2b).

Solving for  $\lambda$ , the PCE biodegradation rate ranges from -0.5 per year (data from Table 2b) to -0.7, (data from Table 2a). Thus, we selected a biodegradation rate estimate of -0.6 yr<sup>-1</sup> for PCE at Site A for modeling.

Monitoring well location and screen length can have an effect on the accuracy of this rate estimate. Table 3 shows the specifications for the monitoring wells used in this analysis. Most of the wells have 10-15 foot screens. The exception is monitoring well 01U904, which spans the thickness of the aquifer (approx. 25 feet) with a 40 foot well screen. While contaminant concentrations from this well may be diluted to a greater extent than the other wells because of this screen length, dilution cannot account for the absence of PCE at this location or the magnitude of contaminant concentration reduction. Ground water modeling efforts in this study took into account the variations in the aquifer thickness and well screen length.

#### **Model Simulation 2:**

##### **Inclusion of Biodegradation at -0.6 yr<sup>-1</sup> with Ground Water Extraction Starting in 1988**

In this simulation, BIOPLUME III retains all of the calibrations as in Simulation 1 except that a biodegradation rate of PCE is included at -0.6 yr<sup>-1</sup>. Under these conditions, the model predicts that concentrations in monitoring well 01U108 should be approximately 40 µg/L by 1998. This is similar to the concentrations now observed in well 01U108 (Figures 12-17). This simulation predicts that the PCE plume should reach monitoring well 01U115 at 3 µg/L in 1998; no PCE should be found in monitoring well 01U904, and no PCE is expected to migrate beyond well 01U904 over the entire 50 years of plume development. This is in contrast to Simulation 1 which predicted that, without the effect of biodegradation, PCE should have migrated 1600 feet downgradient of the source area at concentrations greater than 200 µg/L. Simulation 2 accurately describes the development of the plume at Site A.

Assuming that the source area is not actively remediated and remains constant from now on, the model predicts that these PCE concentrations should remain constant in ground water in the future.

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\*  $R = 1 + \frac{(\rho)(K_{oc})(foc)}{n}$ , where  $\rho$ ,  $n$ , and  $foc$  are estimated at 1.7 g/cm<sup>3</sup>, 0.25, and 0.001, respectively. The literature value for  $K_{ocPCE}$  is 370 L/Kg.

### **Model Simulation 3:**

#### **Biodegradation at $-0.6 \text{ yr}^{-1}$ with Ground Water Extraction Starting in 1988 Complete Source Removal in 2000**

In the previous two simulations, the source of PCE to the aquifer is assumed constant after 1990. With biodegradation and pumping included, the model predicts that PCE concentrations in the ground water will remain at approximately 40  $\mu\text{g/L}$  in monitoring well 01U108, with the plume extending a distance of approximately 420 feet from the source area. These concentrations would remain unaltered as long as the source of contamination is unaffected.

Army has proposed a combined soil vapor extraction and ground water sparging system in the source area near monitoring well 01U108 to eliminate any remaining contribution of PCE to the ground water. Simulation 3 includes the effect of a 90% source removal at Site A in 2001 while maintaining the initial release assumptions, the biological degradation rate, ground water transport parameters, and the effects of pumping that were included in the previous simulations (Figures 18-21). This was accomplished in BIOPLUME III by reducing the injection concentration (which simulates the source in the model) by 90%. The model shows that once the source of PCE is gone, the PCE contaminant plume should collapse rapidly (provided that the biodegradation rate is not adversely affected by ground water aeration), with ground water concentrations below 3  $\mu\text{g/L}$  by 2005.

### **Discussion and Conclusions**

Although the precise date of the contaminant release at Site A is unknown, varying the exact year of the release and the initial concentration does not significantly influence the outcome of the BIOPLUME III simulations. If biodegradation is really negligible in the ground water, Simulation 1 shows that very high concentrations of PCE should have been detected far downgradient of the source area by 1988 and that dilution/dispersion alone cannot account for the difference between observed concentrations and those predicted by BIOPLUME III. Incorporating a biodegradation rate of  $-0.6 \text{ yr}^{-1}$  is required to simulate the reduction in the PCE concentrations with distance to levels observed in the past 10 years (Table 4).

In addition, the PCE breakdown products, TCE and cDCE, are not accumulating with distance in the ground water (see trend graphs for individual wells, Attachment A). The loss of TCE can be attributed to its dehalogenation to cDCE. The fate of cDCE in the ground water is less clear: VC and ethene - the products of cDCE reductive dehalogenation - were never detected in ground water samples, indicating that cDCE is not reductively dehalogenated at this site. However, historical data show that the highest concentrations of cDCE discovered in the downgradient area of the plume were in the range of 100  $\mu\text{g/L}$  in monitoring well 01U902, with detections below the HRL in private wells 234377 and 5553 further downgradient. cDCE was never detected at concentrations in the range of 1000  $\mu\text{g/L}$  in downgradient ground water that would support the idea that the mass of contaminants, represented by PCE, TCE, and DCE, was ever conserved in the ground water as it moved from the source area to County Road I. Historical contour maps show that the contaminant plume has basically remained stable since 1991, with some indication that the plume is shrinking in size and concentration (see trend graphs and isoconcentration drawings in Attachment 1). It is possible, though not yet demonstrated at this site, that cDCE is degrading through anaerobic oxidation (2), a process that would not yield VC or ethene. Similarly, cDCE is also suspected of degrading without yielding VC or ethene in the deep ground water at TCAAP (10).



The combined effects of the ground water extraction system and biological degradation is effectively containing the contamination in the Unit 1 aquifer at Site A: the presence of TCE and cDCE demonstrate that PCE is biologically degrading. The attenuation modeling using BIOPLUME III shows that the contaminant mass is not conserved with distance along the ground water flow path. It also indicates that once the source of contamination to ground water is eliminated – either through attenuation or by an engineered removal – contaminant concentrations in ground water will rapidly decrease to regulatory limits across the site. Given the estimated biodegradation rate of  $-0.6 \text{ yr}^{-1}$  for PCE, removing approximately 90% of the contaminant source should result in ground water concentrations of PCE of roughly  $5 \text{ }\mu\text{g/L}$  within three years.

## References

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**Table 1. Geochemistry of the Site A ground water. Monitoring well 01U067 is a background well situated upgradient from the source area ground water.**

	<b>-Well No.-</b>				
	<b>01U067</b>	<b>01U108</b>	<b>01U117</b>	<b>01U115</b>	<b>01U904</b>
<b>O<sub>2</sub></b>	5.3	<1.	<1.	<1.	<1.
<b>NO<sub>3</sub><sup>-2</sup></b>	<0.1	1.3	0.12	0.72	0.82
<b>Mn<sup>+2</sup></b>	0.04	0.65	0.1	1.1	0.6
<b>Fe<sup>+2</sup></b>	<0.1	0.4	0.06	<0.1	<0.1
<b>SO<sub>4</sub><sup>-2</sup></b>	8.6	>80	41	36	32
<b>CH<sub>4</sub></b>	<0.001	0.003	0.011	0.006	0.008
<b>Eh (mv)</b>	240	55	-104	75	114
<b>H<sub>2</sub> (nM)</b>	0.4	2.4	0.43	0.97	0.56

**Table 2. Concentrations of PCE as a function of distance from the source area. a) 1998 data collected through the natural attenuation study, and b) the highest concentrations observed.**

a)

<b>Well</b>	<b>Distance (ft)</b>	<b>PCE (µg/L)</b>	<b>Ln[PCE]</b>
01U108	0	124	4.82
01U117	200	4.2	1.44
01U115	450	3	1.10
01U902	660	0.1	-2.30

b)

<b>Well</b>	<b>Distance (ft)</b>	<b>PCE (µg/L)</b>	<b>Ln[PCE]</b>
01U108	0	1100	7.00
01U117	200	78.2	4.35
01U115	450	1.2	0.18
01U904	960	1.7	0.53

**Table 3. Specifications of monitoring wells selected for the natural attenuation study.**

<b>Well Number</b>	<b>Well Depth</b>	<b>Well Diameter</b>	<b>Screened Interval</b>	<b>Screen Material</b>	<b>Riser Material</b>	<b>Depth to GW (ft)</b>
<b>01U108</b>	29	4"	10'	PVC	PVC	15.6
<b>01U902</b>	42	2"	10'	SS	S	17.3
<b>01U067</b>	9	2"	3'2"	PVC	PVC	6.7
<b>01U117</b>	29	4"	15'	PVC	PVC	16.9
<b>01U115</b>	34.5	4"	15'	PVC	PVC	15.7
<b>01U904</b>	47	4"	40'	SS	S	18.5

**Table 4. Comparisons of PCE concentrations (in µg/L) predicted by BIOPLUME III simulations for 1990 with actual 1990 field data. Simulation 1 is the simulation without biodegradation included; Simulation 2 includes biodegradation at –0.6 per year.**

<b>Well</b>	<b>Simulation 1</b>	<b>Simulation 2</b>	<b>1990 Field Data</b>
01U108	462	128	200
01U117	1658	12	10
01U115	2427	1	0.5
01U904	1663	0.1	1.3

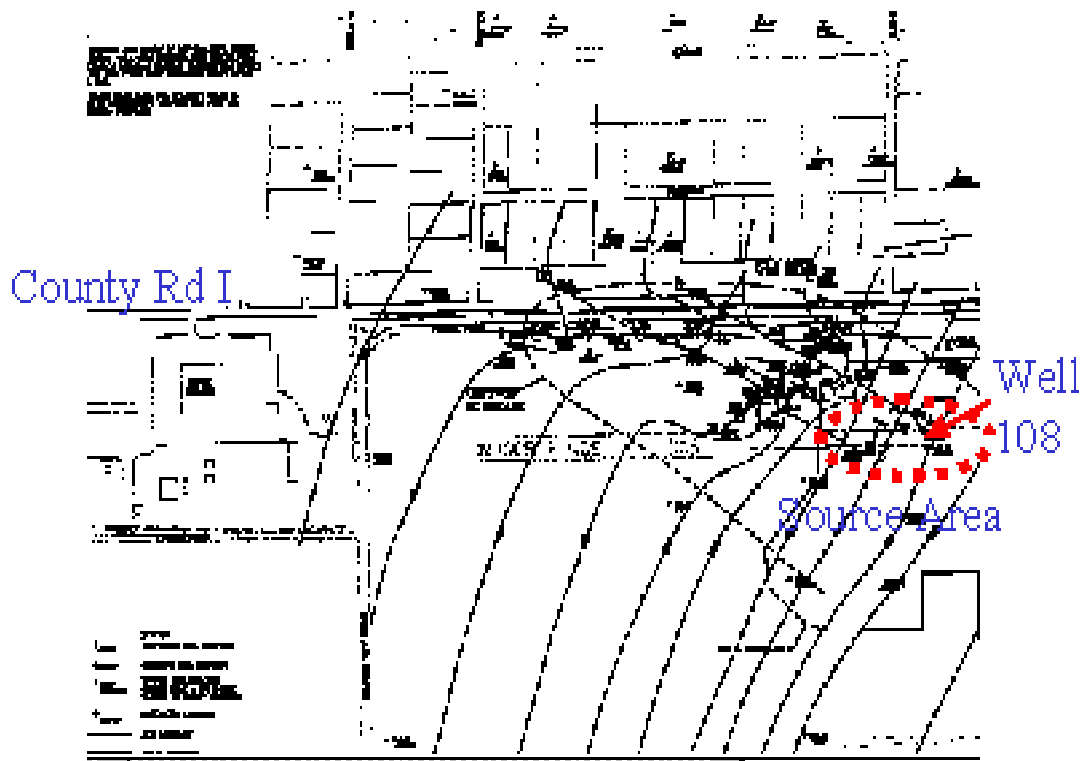


Figure 2: Site A.

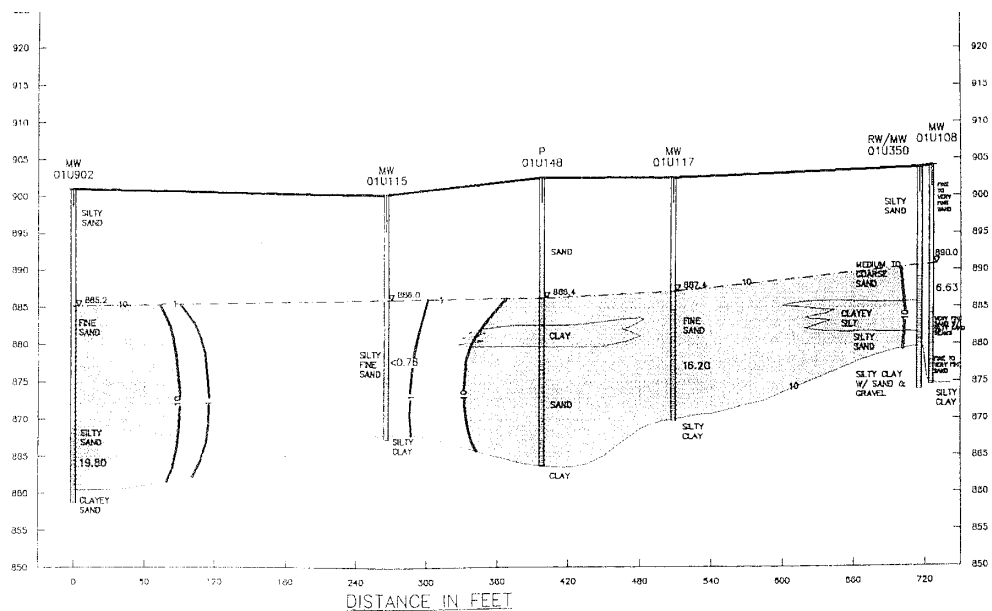


Figure 3. Vertical representation of Site A along the ground water flow path. The contaminant source is in the general location of monitoring well 01U108.

## Site A

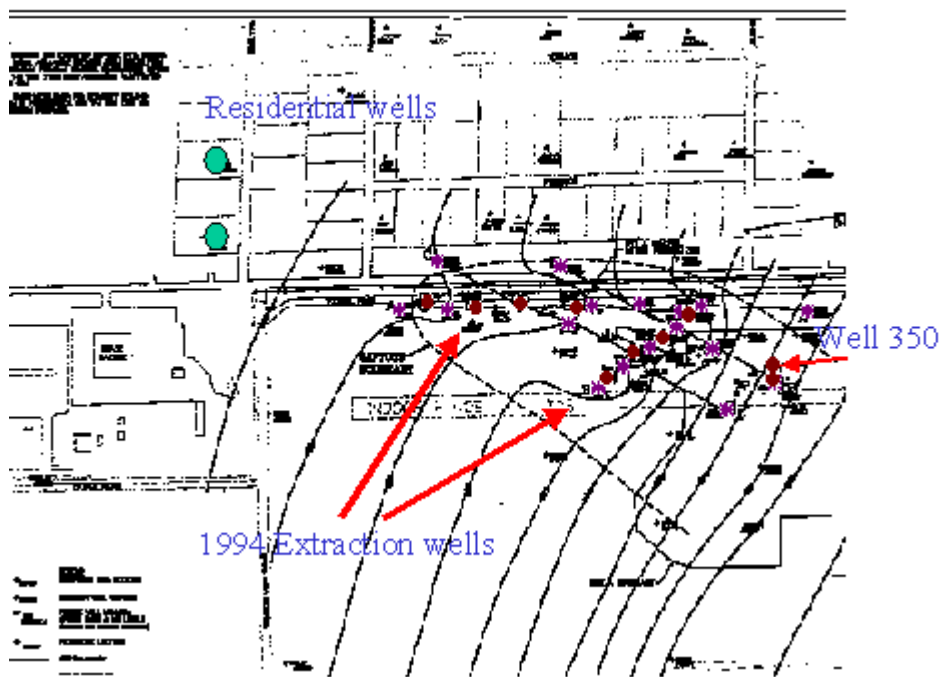


Figure 4. Relationship of two of the residential wells (green) to Site A and the location of the ground water recovery wells (maroon).

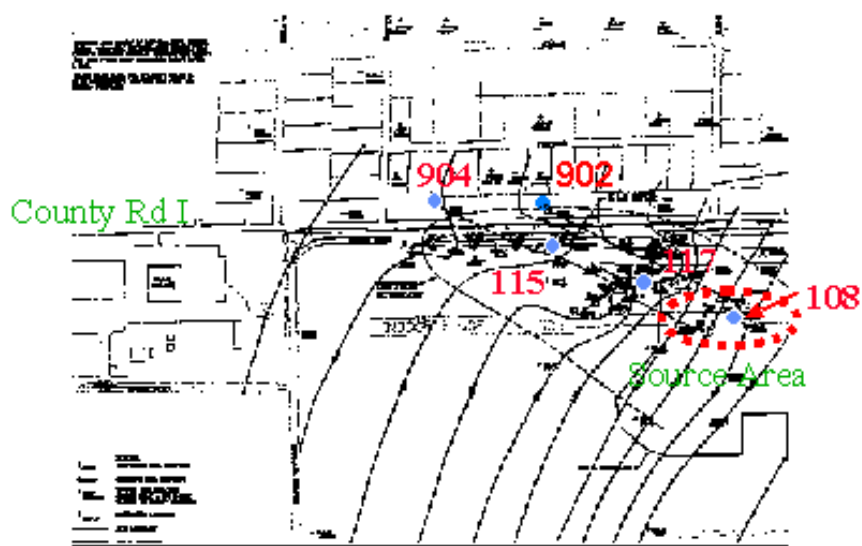


Figure 5. Location of wells that were sampled for the natural attenuation study.

**BIOPLUME SIMULATION 1:**  
**No biodegradation**  
**Pumping starts in 1998**

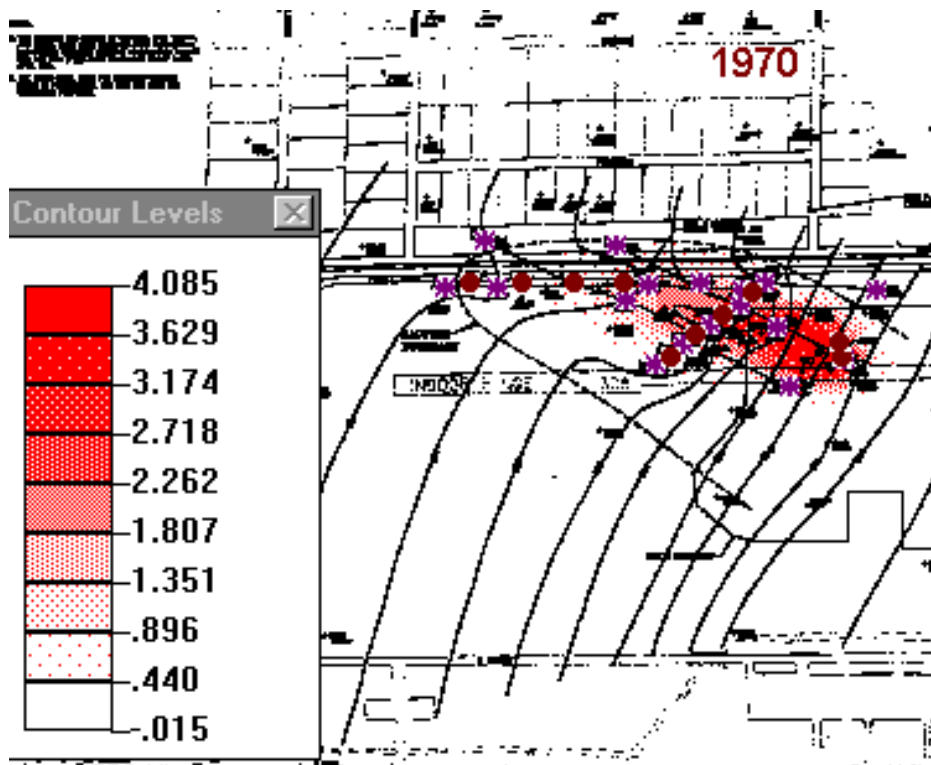


Figure 6

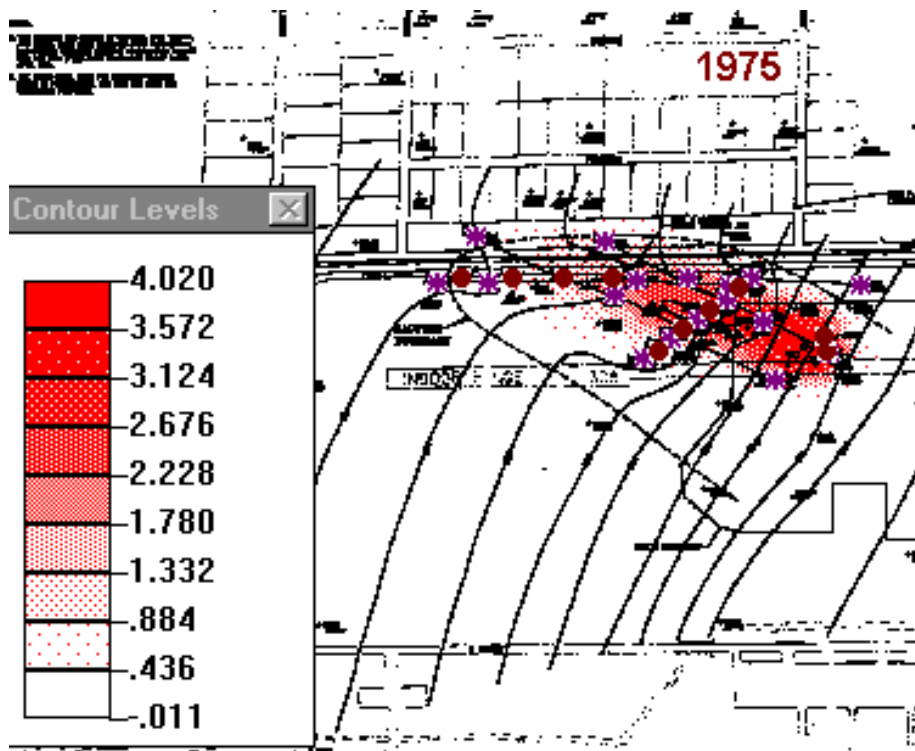


Figure 7



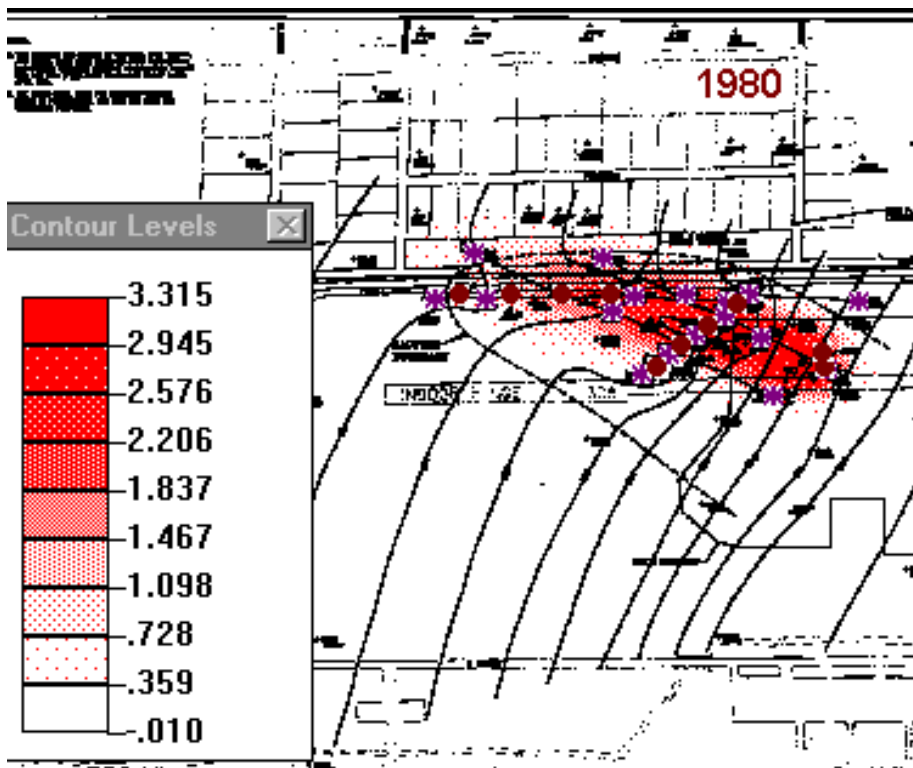


Figure 8

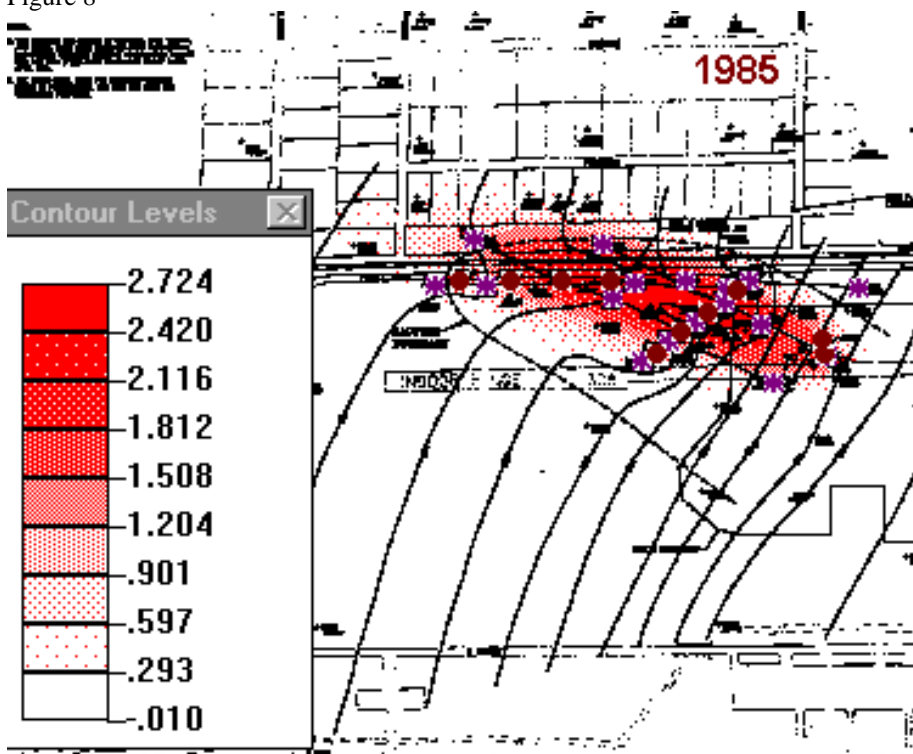


Figure 9

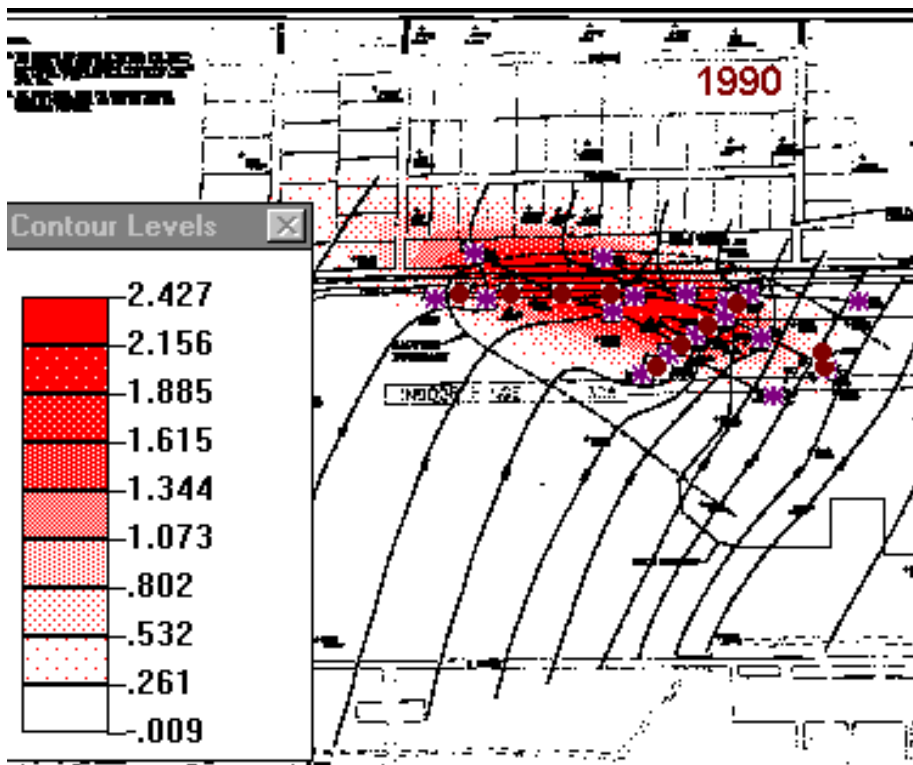


Figure 10

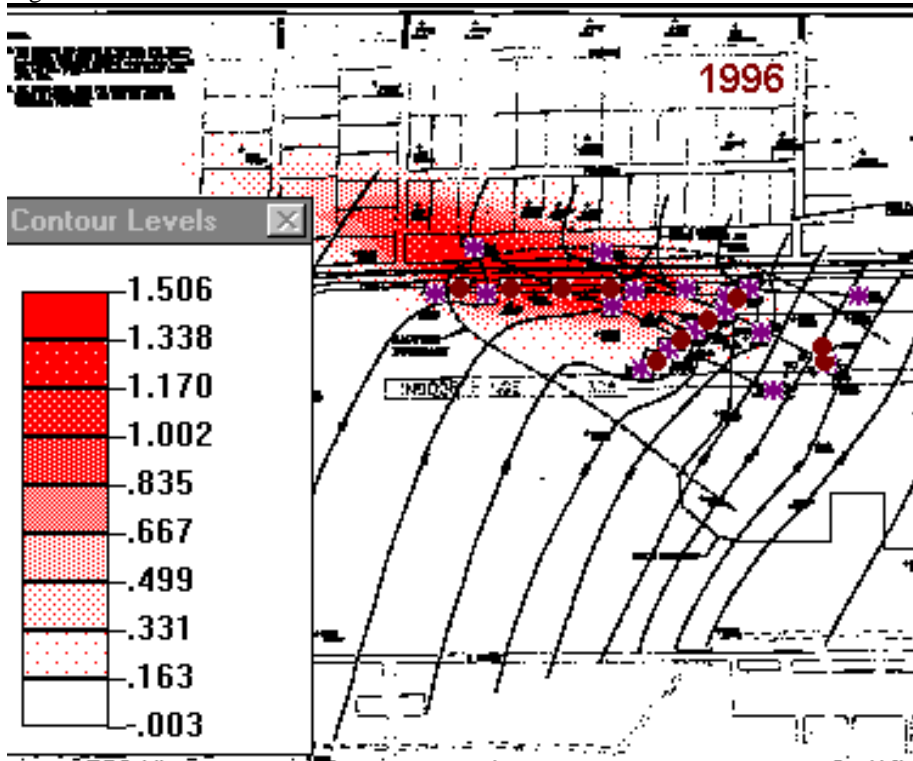


Figure 11

**BIOPLUME SIMULATION 2:**  
**Biodegradation at –0.6 per year**  
**Pumping starts in 1998**

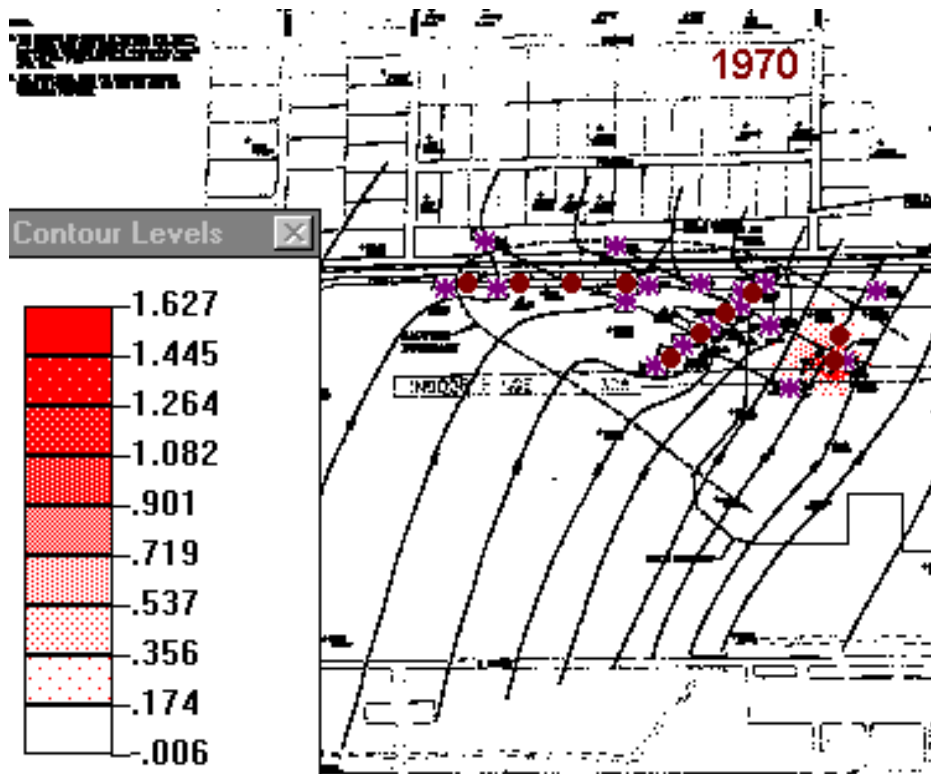


Figure 12

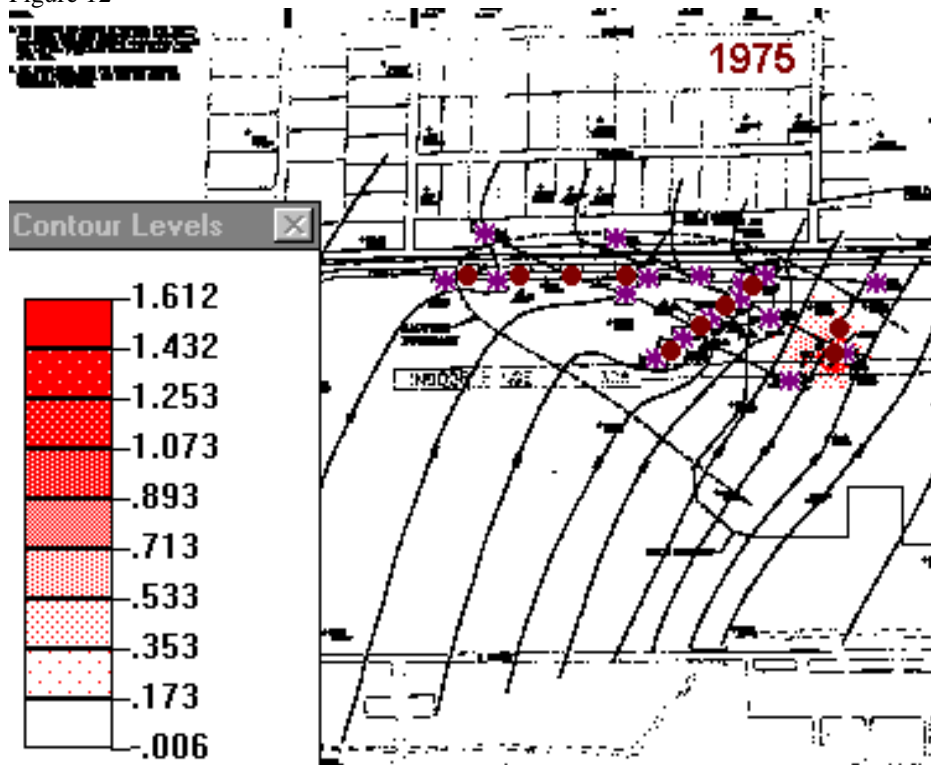


Figure 13

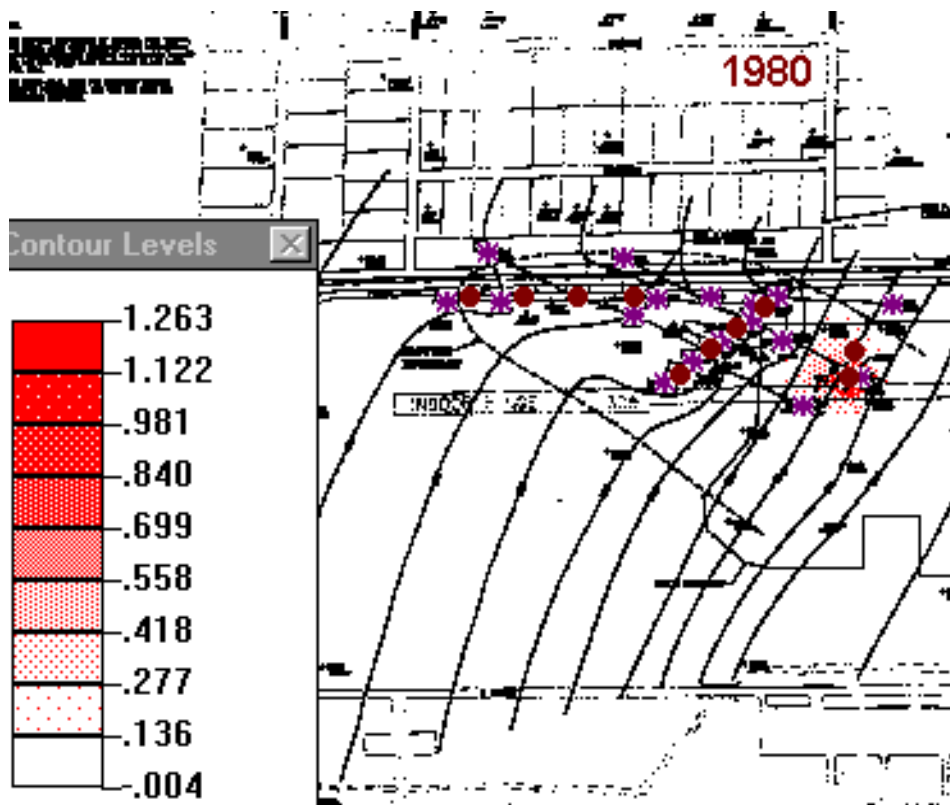


Figure 14

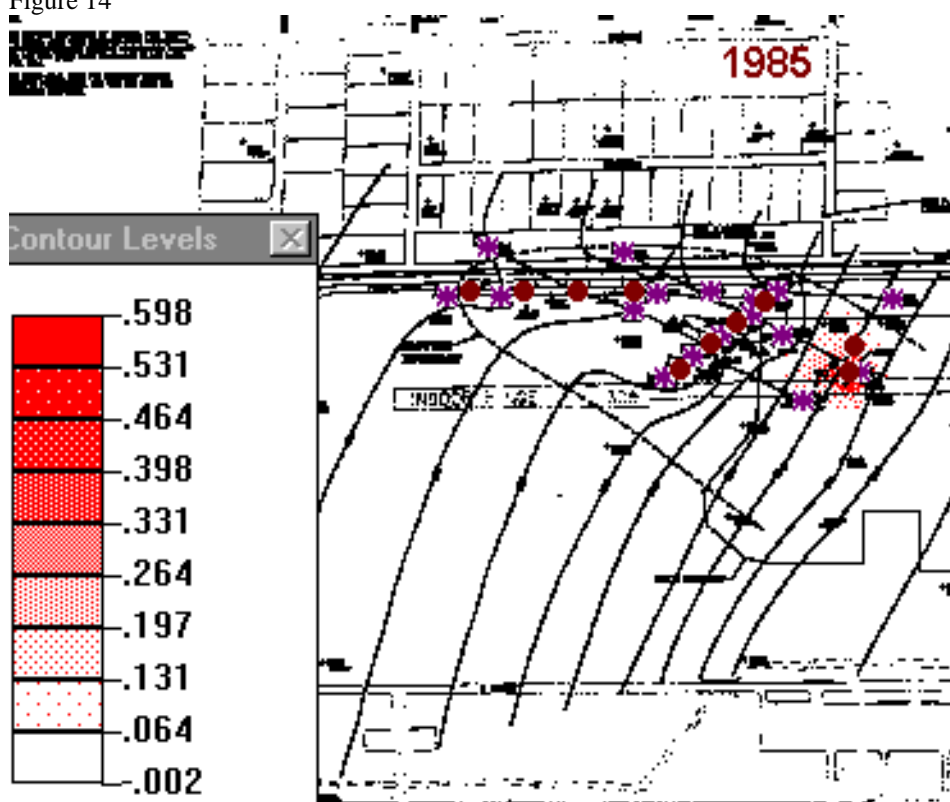


Figure 15

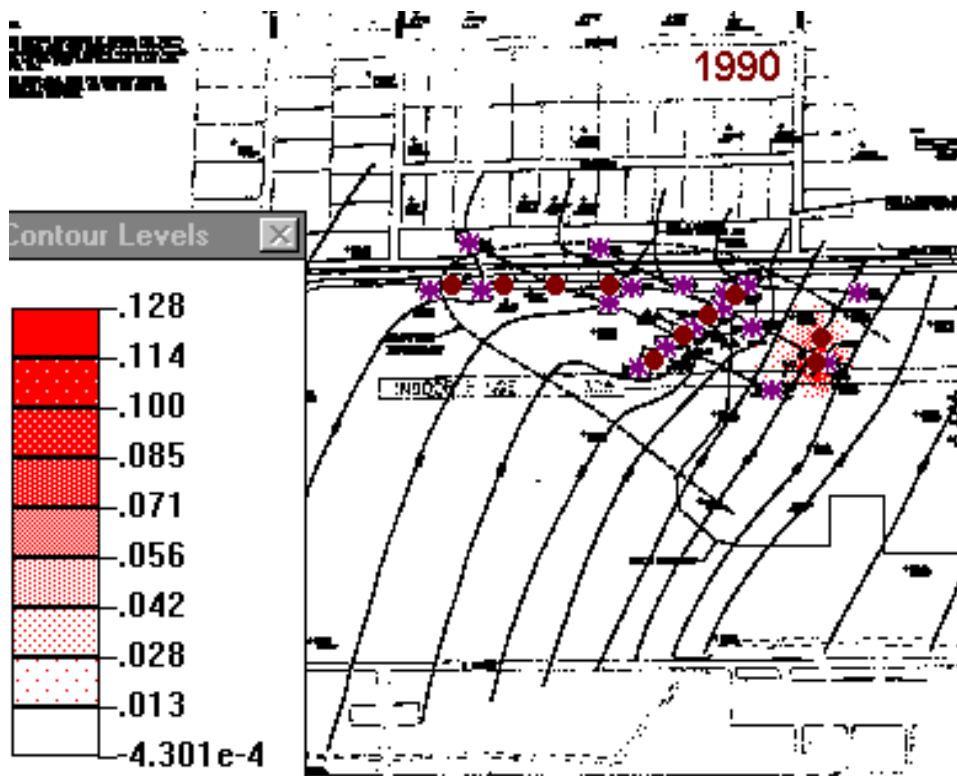


Figure 16

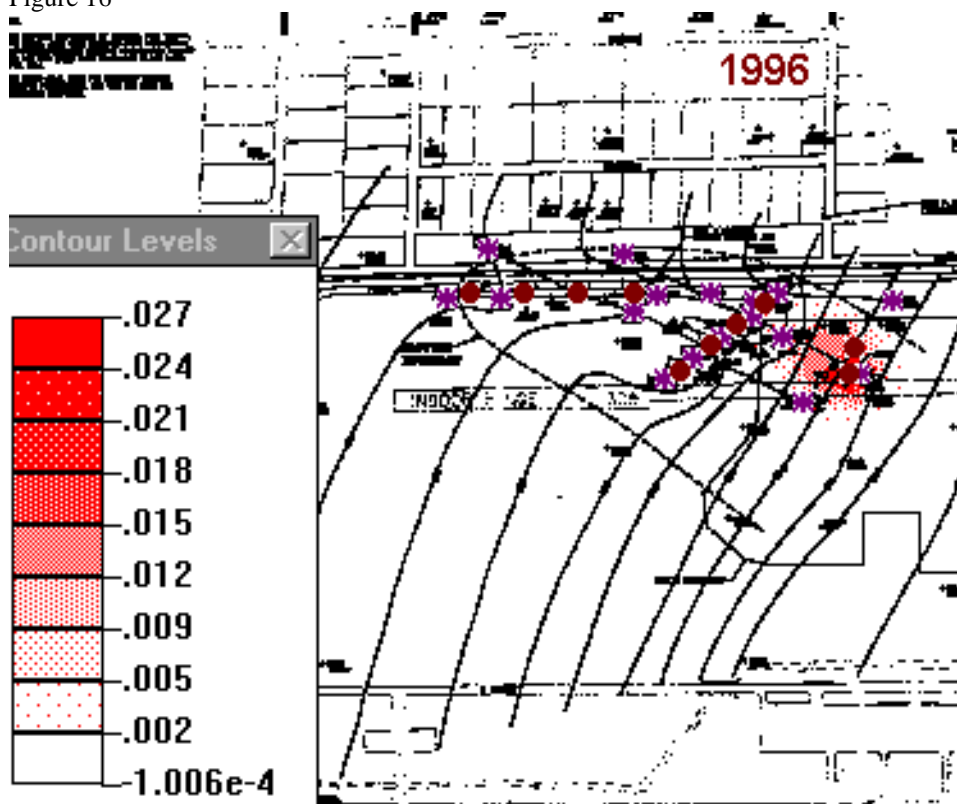


Figure 17

**BIOPLUME SIMULATION 3:**  
**Biodegradation at –0.6 per year**  
**Pumping starts in 1998**  
**90% Source removal in 2001**

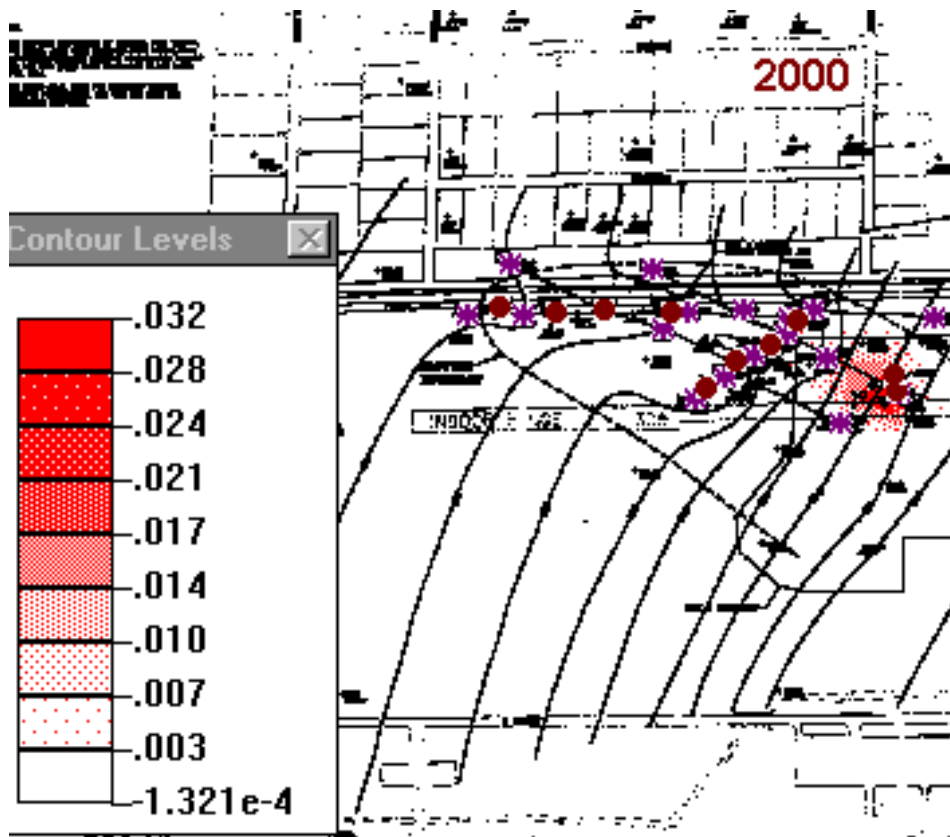


Figure 18

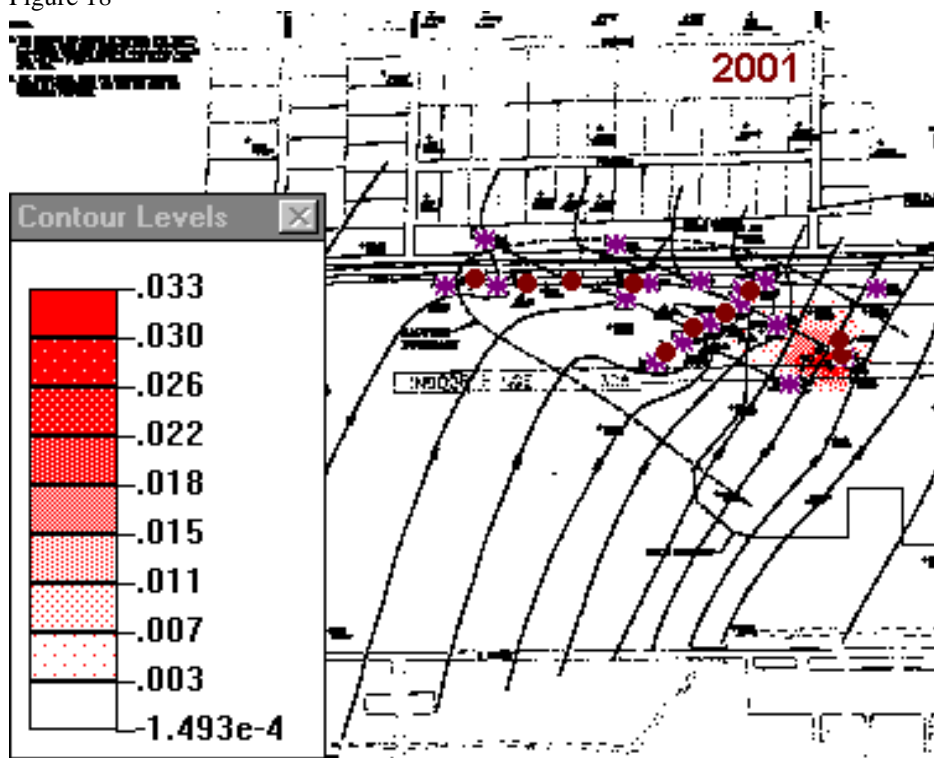


Figure 19



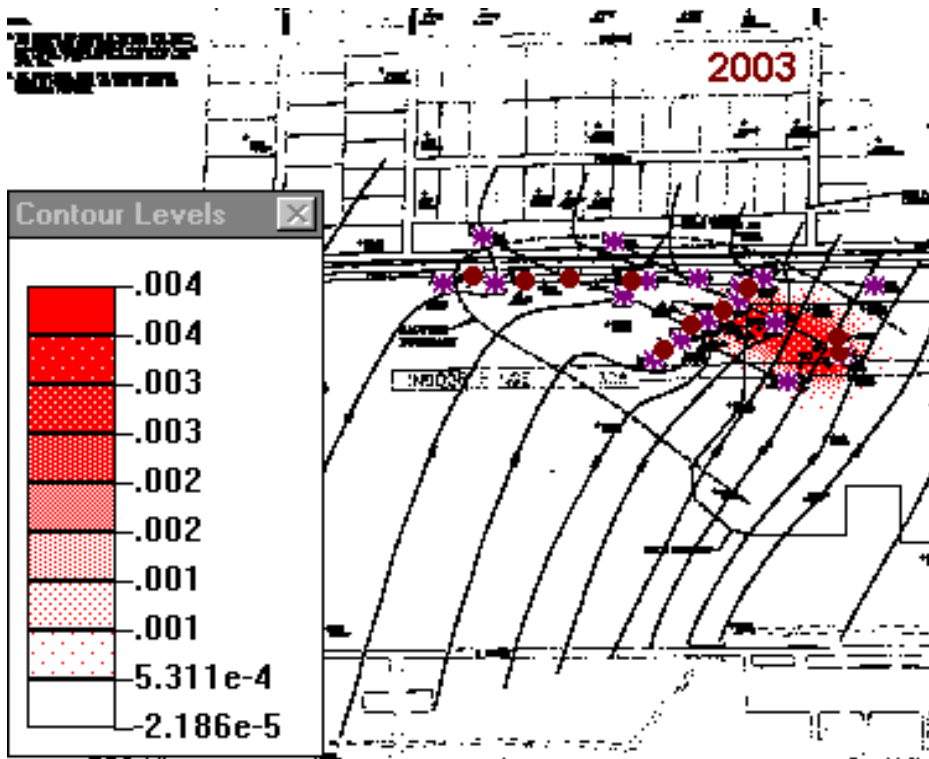


Figure 20

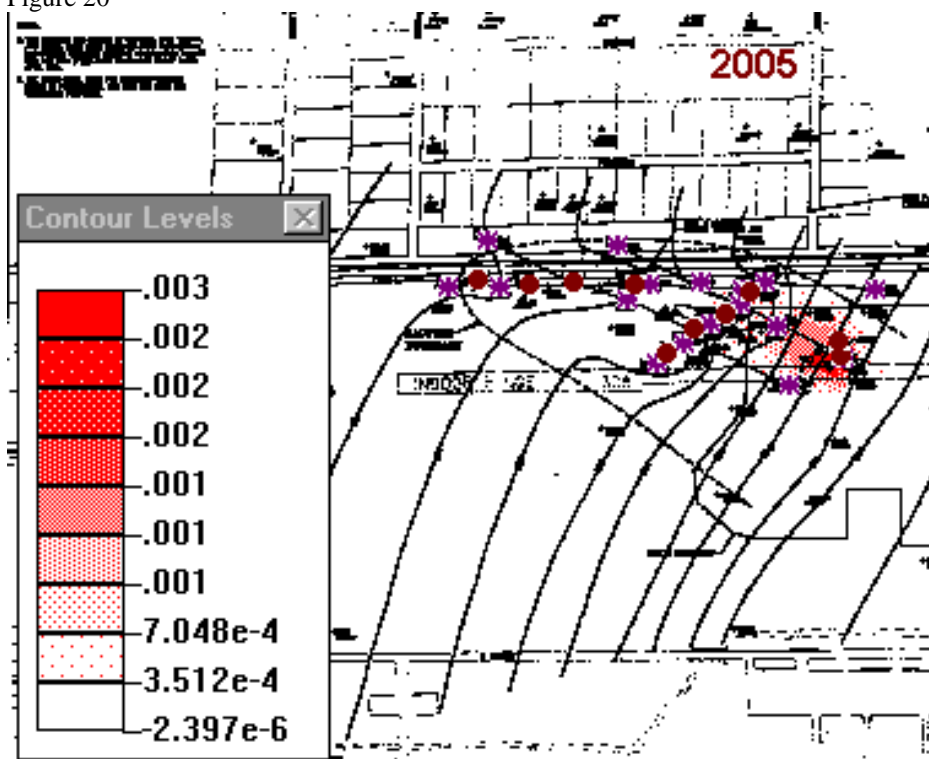
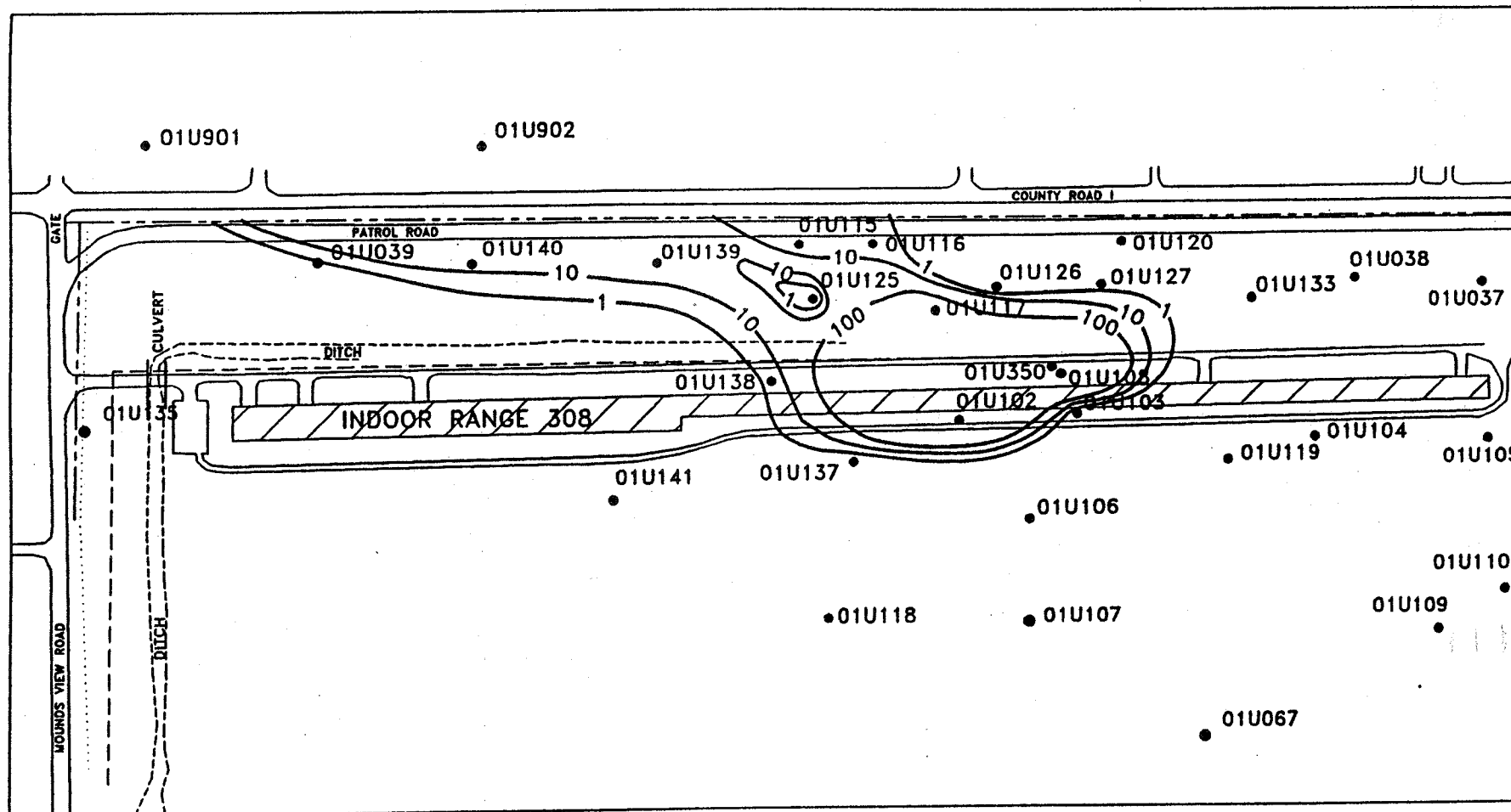


Figure 21

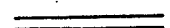
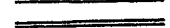
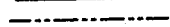



## **ATTACHMENT 1**

### **Isoconcentration Maps**

#### **Contaminant Trends vs. Time in Monitoring Wells**



**LEGEND:**

-  Primary Road
-  Secondary Road
-  Fence
-  Building
-  Existing Monitoring Wells  
(0) Level of Concentration
-  Line of Equal Concentrations

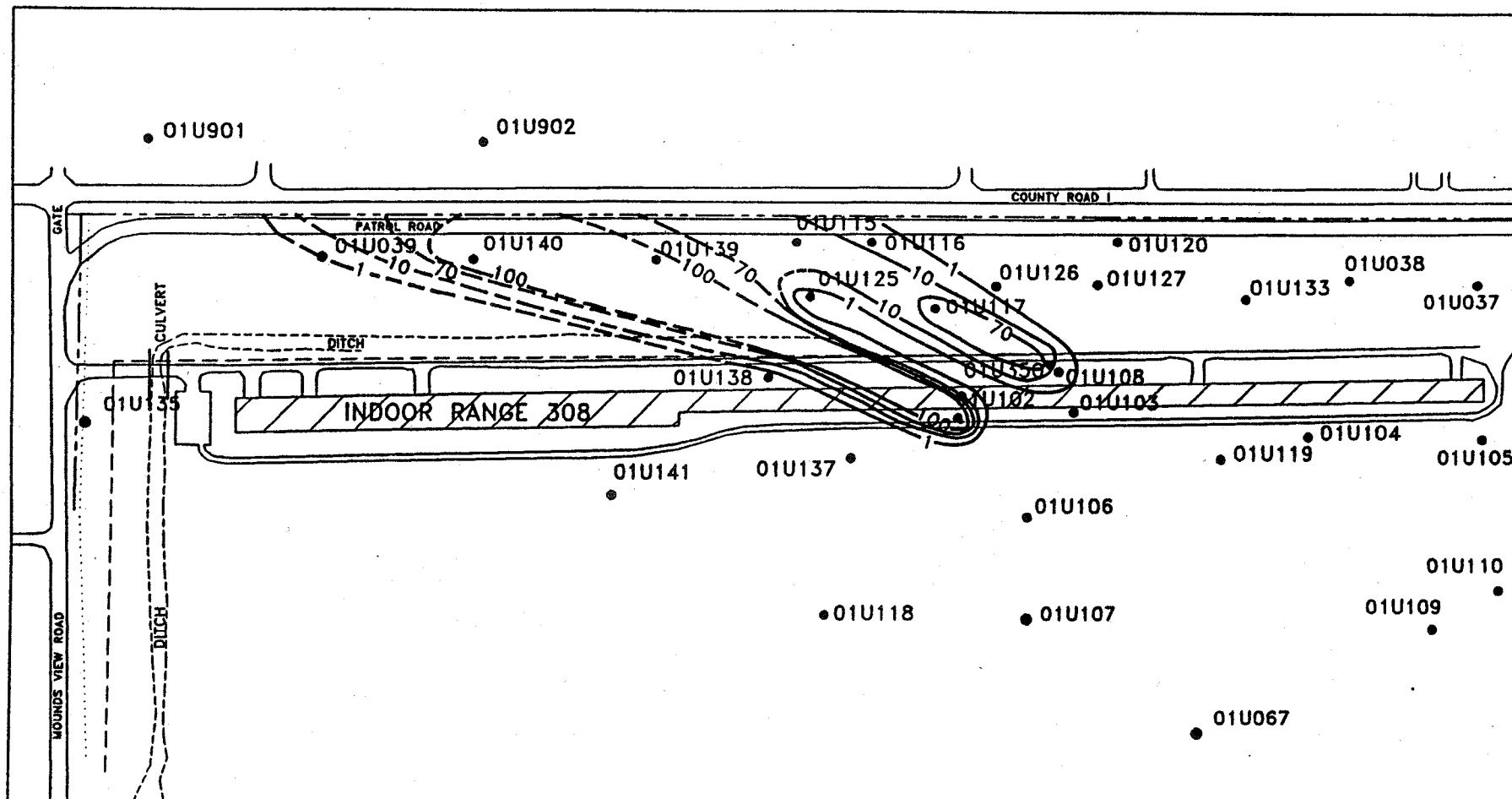
0' 100' 200' 300' 400' 500'  
APPROXIMATE SCALE IN FEET

Figure 1-6A  
VOC Plume Map  
July 1991  
prepared for  
Federal Cartridge Co.  
New Brighton, Minnesota

**IT** INTERNATIONAL  
TECHNOLOGY  
CORPORATION

Modified from: Wenck Associates Inc., 1989 and IT data digitized 1992-93.

IT\SP\12-92\EESP\302752\PLUME-2.DWG\JULY91-R



**LEGEND:**

- Primary Road
- Secondary Road
- Fence
- Building
- Existing Monitoring Wells
- Level of Concentration
- Line of Equal Concentrations

0' 100' 200' 300' 400' 500'  
APPROXIMATE SCALE IN FEET

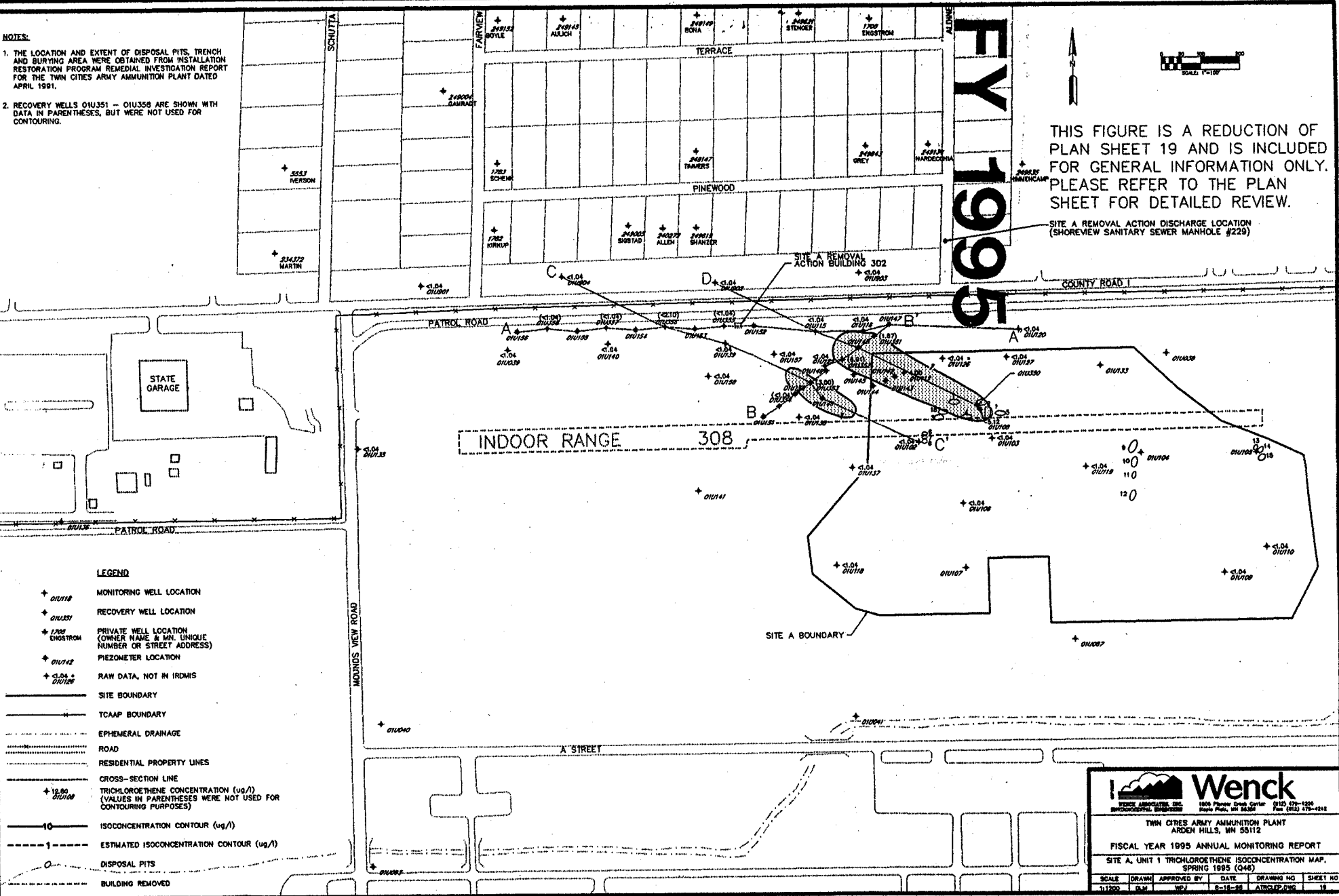
Figure 1-6B  
CIs 1,2 DCE Plume  
March 1992  
prepared for  
Federal Cartridge Co.  
New Brighton, Minnesota

**IT** INTERNATIONAL  
TECHNOLOGY  
CORPORATION

Modified from: Wenck Associates Inc., 1989 and IT data digitized 1992-93.

NOTES:

1. THE LOCATION AND EXTENT OF DISPOSAL PITS, TRENCH AND BURYING AREA WERE OBTAINED FROM INSTALLATION RESTORATION PROGRAM REMEDIAL INVESTIGATION REPORT FOR THE TWIN CITIES ARMY AMMUNITION PLANT DATED APRIL 1991.
2. RECOVERY WELLS 01U351 - 01U358 ARE SHOWN WITH DATA IN PARENTHESES, BUT WERE NOT USED FOR CONTOURING.



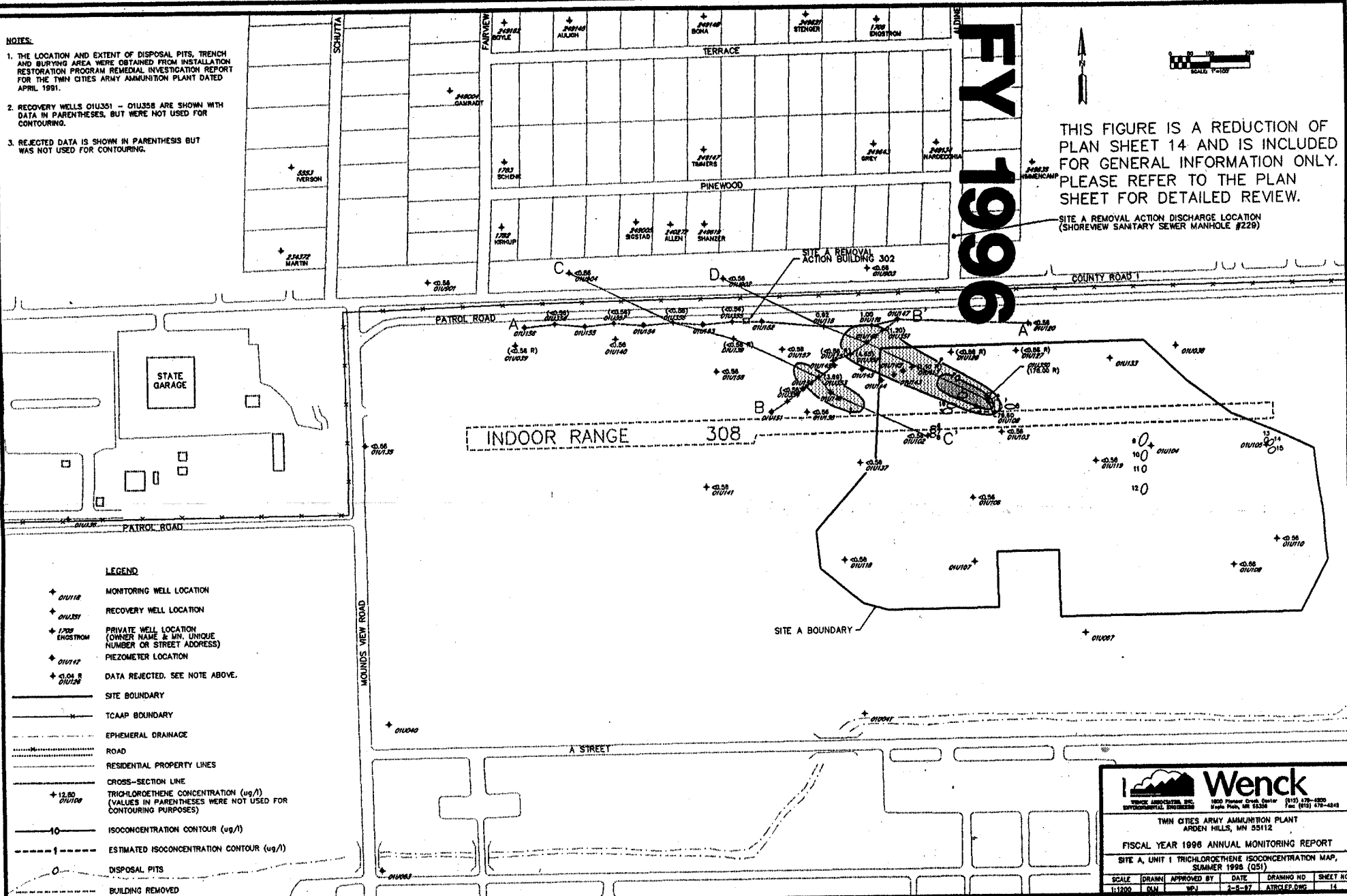
TWIN CITIES ARMY AMMUNITION PLANT  
Site A, Unit 1 Trichloroethene Isoconcentration Map,  
Spring 1995 (Q46)

**Wenck**  
Wenck Associates, Inc.  
Environmental Engineers  
1800 Pioneer Creek Center P.O. BOX 428  
Maple Plain, MN 55359-0428

SEPT. 1997

## NOTES:

1. THE LOCATION AND EXTENT OF DISPOSAL PITS, TRENCH AND BURNING AREA WERE OBTAINED FROM INSTALLATION RESTORATION PROGRAM REMEDIAL INVESTIGATION REPORT FOR THE TWIN CITIES ARMY AMMUNITION PLANT DATED APRIL 1991.
2. RECOVERY WELLS OIU351 - OIU358 ARE SHOWN WITH DATA IN PARENTHESES, BUT WERE NOT USED FOR CONTOURING.
3. REJECTED DATA IS SHOWN IN PARENTHESES BUT WAS NOT USED FOR CONTOURING.



TWIN CITIES ARMY AMMUNITION PLANT  
 Site A, Unit 1 Trichloroethene Isoconcentration Map,  
 Summer 1996 (Q51)

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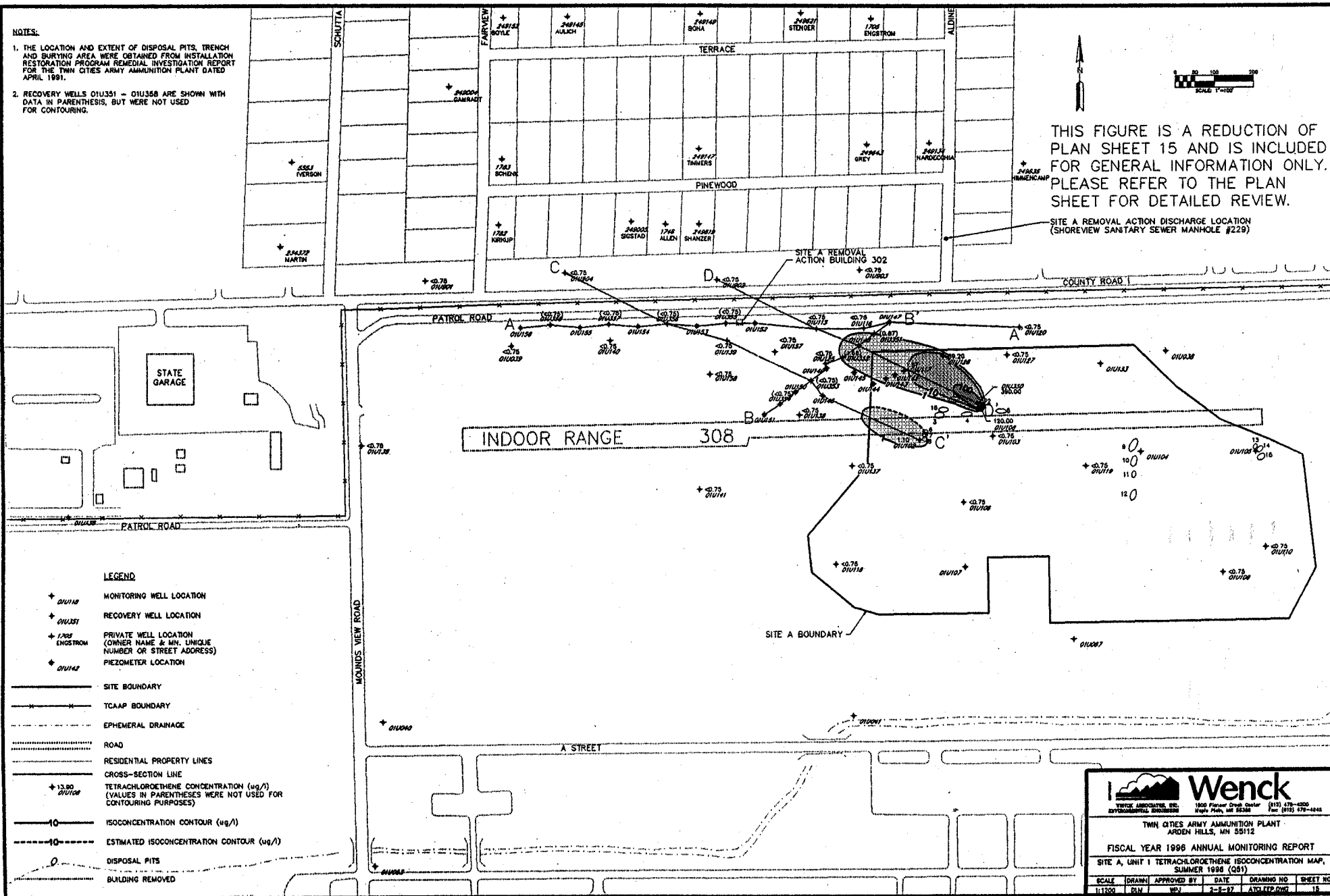
Fig. IV-8

# NOTES:

1. THE LOCATION AND EXTENT OF DISPOSAL PITS, TRENCH AND BURYING AREA WERE OBTAINED FROM INSTALLATION RESTORATION PROGRAM REMEDIAL INVESTIGATION REPORT FOR THE TWIN CITIES ARMY AMMUNITION PLANT DATED APRIL 1991.
2. RECOVERY WELLS 01U351 - 01U358 ARE SHOWN WITH DATA IN PARENTHESIS, BUT WERE NOT USED FOR CONTOURING.

THIS FIGURE IS A REDUCTION OF PLAN SHEET 15 AND IS INCLUDED FOR GENERAL INFORMATION ONLY. PLEASE REFER TO THE PLAN SHEET FOR DETAILED REVIEW.

SITE A REMOVAL ACTION DISCHARGE LOCATION (SHOREVIEW SANITARY SEWER MANHOLE #229)



## TWIN CITIES ARMY AMMUNITION PLANT

Site A, Unit 1 Tetrachloroethene Isoconcentration Map,  
Summer 1996 (Q51)

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Fig. IV-9

<b>Wenck</b> <small>TWICK ASSOCIATES, INC. ENVIRONMENTAL ENGINEERS</small>		<small>1800 Pioneer Creek Center Maple Plain, MN 55358</small> <small>(612) 475-4200 Fax: (612) 475-4248</small>	
<b>TWIN CITIES ARMY AMMUNITION PLANT</b> ARDEN HILLS, MN 55112			
<b>FISCAL YEAR 1996 ANNUAL MONITORING REPORT</b>			
<b>SITE A, UNIT 1 TETRACHLOROETHENE ISOCONCENTRATION MAP,</b> SUMMER 1996 (Q51)			
SCALE	DRAWN	APPROVED BY	DATE
1:1200	DLM	WJ	2-8-97
DRAWING NO.		SHEET NO.	
ATG/EEP/ONG		15	

