RCRA Showcase Pilot
Region 4

An Efficient Method for Demonstrating Plume Stability

Velsicol Chemical Corporation Facility
Memphis, Tennessee

This RCRA Showcase Pilot demonstrates the use of a volumetric assessment method developed to measure the effectiveness of a groundwater containment and recovery system in reducing contaminant concentrations and controlling contaminant migration at Velsicol's chemical manufacturing facility in Memphis, Tennessee. The method was developed in response to an EPA request for quantitatively profiling plume stability over time and the need for an easy to use, low cost and reliable means to determine the GPRA Environmental Indicator status for RCRIS Code CA 750 (Groundwater Releases Controlled).

<u>Site Background</u>

Pursuant the HSWA Permit, Velsicol is performing a site-wide RCRA Corrective Action Program (CAP) at this facility, which is located in an industrial area, several miles northeast of downtown Memphis. The CAP includes the operation of a system of three, approximately 100-foot deep recovery wells and a groundwater pretreatment system. The pretreated groundwater then enters the Memphis WWTP via NPDES discharge permit for final treatment. The groundwater containment and recovery system has been in operation since 1998. Several on-site source removals have been completed and a large scale Soil Vapor Extraction System (SVE) has also been in operation since 1999.

The CAP objectives are to achieve hydraulic containment of the contaminant plume and to remediate the contaminated groundwater to acceptable regulatory levels. The groundwater is recovered from the approximately 75-foot thick uppermost aquifer and is monitored in terms of its shallow, intermediate and deep zones. The contaminants of concern are comprised of three groups: volatile organic compounds (VOCs), semi-volatile organic compounds (SVOCs) and non-volatile organochloride compounds (NVOs), commonly referred to as pesticides.

The groundwater quality is monitored annually at 14 well clusters. Each cluster consists of two or three wells screened at different depths. Twenty-one of the 39 total monitoring wells are located on-site and the remaining 18 wells are off-site. A number of on-site and off-site piezometers are also used in monitoring hydraulic conditions. The largest contaminate plume with an areal footprint of approximately 340 acres occurred for VOC (carbon tetrachloride) in the intermediate aquifer zone.

Assessment Method

With dozens of chemicals of concern, differing analytical detection limits and cleanup standards for each chemical, a number of distinct plume source areas and three aquifer monitoring depths, it was difficult to effectively and efficiently answer the question, AIs the Migration of Contaminated Groundwater Under Control?@ The volumetric assessment method was developed to describe the plume size in terms of volume (acre-feet) and average plume concentration (micrograms per liter) for selected indicator compounds. These measurements are computed after each annual groundwater-monitoring round and compared to previous measurements to determine annual trends in plume conditions. For example, at the Velsicol facility, the following trends were identified based on data for the indicator chemicals for the period of 1998 to 2000:

	VOC (carbon tetrachloride):	40% concentration reduction,	plume volume stable.
·	SVOC (chlorobenzene):	30% concentration reduction,	48% volume reduction.
·	Pesticide (chlordane):	Concentration stable,	31% volume reduction.

Note that although chlorobenzene is considered a VOC, it was selected to represent the SVOC parameter group because many of the detected SVOCs at the facility are isomers of di-, tri- and tetrachlorobenzene and there is an identified chlorobenzene contaminant plume at the north end of the Site.

The assessment method uses a contouring software package, such as Surfer**7** by Golden Software, to generate iso-concentration plume maps using water quality data. Mathematical features of the software allow for calculation of the average concentration, as well as the volume of each contaminant plume. A detailed description of the development and use of the volumetric assessment method is presented in the linked paper, "Method for Evaluating Groundwater Contaminant Plume Stability". This technical paper was presented at the American Water Resources Association Annual Spring Specialty Conference on Water Quality Monitoring and Modeling, in San Antonio, Texas, during April 30 to May 2, 2001.

Benefits

This plume stability assessment method is easy to use. The Surfer**7** contouring software is simpler to setup and use than the more complex modeling software programs that use mass flux analyses and fate and transport modeling. The only data requirement for using Surfer**7** is the water quality monitoring results. The more complex methods require the input of large volumes of hydrogeologic data such as hydraulic conductivity, porosity, etc. and related calibration and verification effort.

The method is low cost. The software is relatively inexpensive to purchase and requires minimal time for the data analyst to become proficient in its use and to run the assessments.

The method is also reliable in comparing year-to-year measurements to indicate spatial and temporal trends. This benefit comes from its ease of operation and limited data input requirements, as well as the fact that the manipulation is done completely by the computer software, which leaves out any subjectivity of the data analyst.

Showcase Pilot Schedule

An assessment of the plume stability, using the method described herein, will be performed each year using groundwater quality data collected during annual monitoring events. The next annual monitoring event is scheduled to occur in July 2001 and subsequent annual monitoring events will occur at about the same time in future years. The plume stability assessment results will be included in Corrective Action Effectiveness Reports (CAERs), which are submitted to the Tennessee Department of Environment and Conservation (TDEC) and EPA Region 4 by October of each year. Upon TDEC and EPA acceptance of the CAERs, annual Showcase Pilot Progress Reports will be prepared by MEC for posting on the RCRA Corrective Action web site.

Applicability to Other Sites

This volumetric assessment method should be applicable to most sites with well-defined hydrogeologic conditions and a well designed monitoring well network. The assessment method has not been evaluated for use in Karst areas.

Stakeholder Involvement

Joe Ricker, P.E. of Memphis Environmental Center Inc. (MEC), an operating division of Velsicol Chemical Corporation, manages the groundwater recovery system and developed the assessment method presented herein. Gary Hermann, P.E. of MEC is Velsicol's Senior Environmental Projects Manager and has overall responsibility for the Corrective Action Program at this facility.

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Regulatory Oversight Contacts

EPA Region 4 issued the HSWA Permit in 1989 and has maintained CAP oversight authority at the facility until late-December 2000, at which time TDEC obtained full HSWA/RCRA Authorization for Corrective Action in the State of Tennessee.

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METHOD FOR EVALUATING GROUNDWATER CONTAMINANT PLUME STABILITY

Joe A. Ricker, P.E. [1]

ABSTRACT: This paper describes a method to evaluate the stability of a groundwater contaminant plume emanating from a chemical manufacturing plant in Memphis, Tennessee. Spatial and temporal changes in plume volume, area, and contaminant concentration were evaluated by using the mathematical features of Surfer®, by Golden Software, Inc. The area and average concentration were calculated for three zones within the contaminant plume (i.e., shallow, intermediate, and deep). By using the calculated area and concentration of each of the three aquifer zones along with the known thickness of each aquifer zone, the overall plume volume and average concentration were determined. This information was then evaluated for annual trends in plume area, volume, and average concentration. This method is relatively simple and inexpensive to implement when compared to other methods of contaminant plume stability evaluation such as mass flux analysis and fate and transport computer modeling.
KEY TERMS: groundwater; plume; stability

INTRODUCTION

The Velsicol Chemical Corporation (Velsicol) facility located in Memphis, Tennessee is performing a Resource Conservation and Recovery Act Corrective Action Program consisting of assessment and cleanup activities associated with historical contaminant releases. Velsicol initiated Groundwater Interim Corrective Measures due to the presence of site-specific constituents detected in the groundwater of the uppermost aquifer underlying the plant.

Pursuant to the Government Performance and Results Act of 1993 (GPRA), the United States Environmental Protection Agency (USEPA) is implementing a system to track changes in the quality of the environment through the use of Environmental Indicators (EI). One of the EI is concerned with migration of contaminated groundwater (EI CA750 - "Migration of Contaminated Groundwater Under Control"). An EI determination of YE, or Yes, indicates that the migration of contaminated groundwater is controlled. As a means of determining performance against the EI goal, USEPA requested that Velsicol develop a definitive method for evaluating changes in the area and volume of the groundwater contaminant plume emanating from its plant site.

The Velsicol plant is currently operating a groundwater extraction and treatment system, with three recovery wells screened within the uppermost aquifer underlying the site. The uppermost aquifer is approximately 75 feet thick. The groundwater contaminant plume is monitored via 14 monitoring well clusters which total 39 monitoring wells screened at various depths across the aquifer. The locations of the extraction and monitoring wells are shown on Figure 1.

Prior to developing the plume stability evaluation protocols described in this paper, groundwater monitoring results were reported graphically to USEPA using two-dimensional iso-concentration maps showing total contaminants in each of the three primary organic contaminant groups: volatile organic compounds (VOCs), semi-volatile organic compounds (SVOCs), and non-volatile organochloride compounds (pesticides).

Although that method was useful for presenting the magnitude of total contaminants in a given plume, it is not very meaningful when evaluating spatial and temporal changes in the contaminant plume. Consider the following example. There are numerous compounds represented in an iso-concentration map showing total VOCs. Also, many of the compounds have different detection limits, and in many cases have elevated detection limits due to the concentration of other contaminants present in the sample. Say, for example, that in a given year (sampling event), carbon tetrachloride was detected at 25,000 micrograms per liter (µg/l), whereas chloroform was not detected above the elevated detection limit of 5,000 µg/l. The following year (next sampling event) carbon tetrachloride is detected at 22,000 µg/l and chloroform is detected at 5,100 µg/l. Now there is a sudden jump in the total VOC concentration, essentially causing a biased elevated total VOC concentration. Additionally, the iso-concentration map could not be delineated to a specific cleanup level, as each compound within the plume would have a specific cleanup level. Therefore, it is simpler to evaluate plume stability by focusing on one representative compound for each contaminant group.

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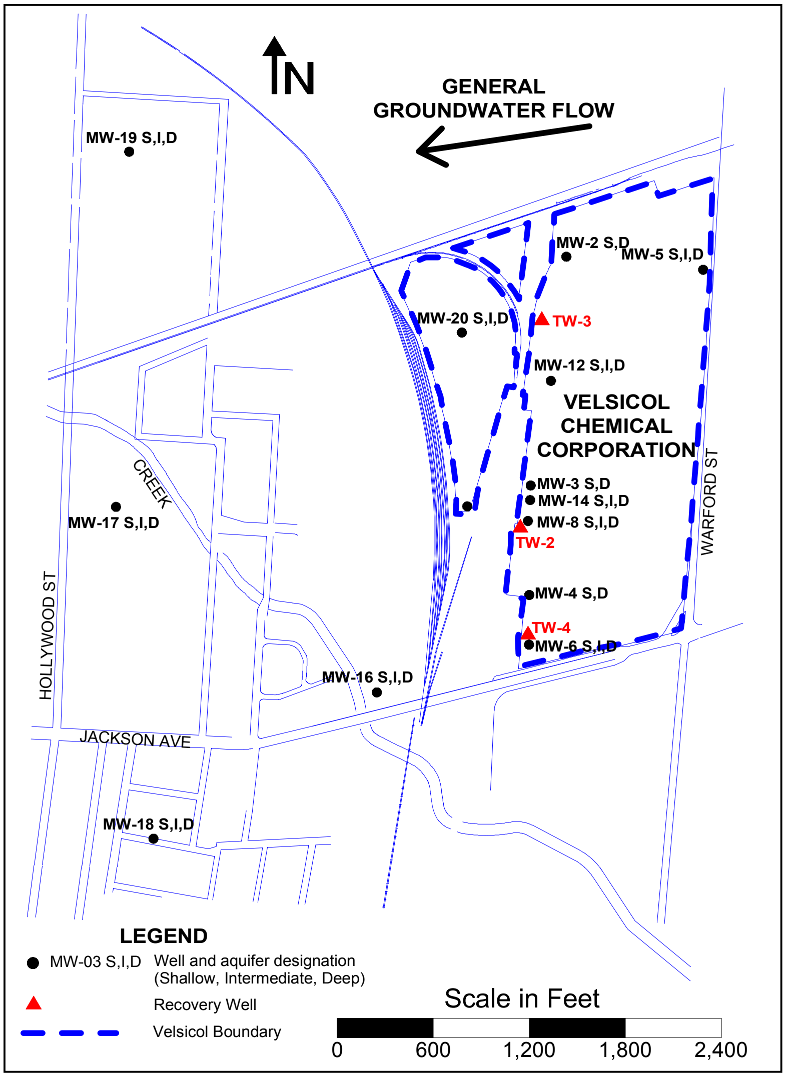

Figure 1. Site Plan - Velsicol Chemical Corporation

METHODOLOGY

One compound was selected to represent the plume behavior for each of the three primary contaminant groups. In each case, the compound selected was generally the most predominantly detected compound in its group, thus indicating that it is the most representative of the entire plume. The compounds selected to represent total VOCs, SVOCs, and pesticides were respectively, carbon tetrachloride, chlorobenzene, and chlordane. Although chlorobenzene is considered a VOC compound, it was selected to represent the SVOC parameter group because many of the SVOCs detected at the site are isomers of di-, tri-, and tetrachlorobenzene and there is an identified chlorobenzene contaminant plume at the north end of the site.

Because the monitoring well clusters at the Velsicol site consist of three wells screened at sequentially deeper zones across the aquifer (i.e., shallow, intermediate, deep), plume stability may be evaluated not only laterally, but vertically as well. This is particularly important when evaluating contaminants that are denser than water (e.g., carbon tetrachloride) since these compounds tend to migrate deeper as the distance from the source increases.

For each indicator compound, iso-concentration maps were developed for each of the three aquifer zones. The iso-concentration maps for each compound were delineated to the compound-specific cleanup level. Figure 2 shows the resulting iso-concentration maps for carbon tetrachloride in August 2000. The iso-concentration maps were generated using Surfer®, by Golden Software, Inc. using the kriging gridding method with the default linear variogram. As observed in Figure 2, each of the three sub-plumes has a reported area and average concentration of the carbon tetrachloride sub-plume. These data are compared to observe the difference in sub-plume area at different depths within the aquifer, as well as to compare changes in the sub-plume area over time. Additionally, the overall plume average concentration and the overall plume volume were calculated. All of these values were used to evaluate annual changes in overall plume area, volume, and concentration for each indicator compound. Three annual data sets were used in the evaluation, with sample analysis data from August 1998, August 1999, and August 2000.

Plume maps similar to Figure 2 were developed for all three indicator compounds for each of the years 1998, 1999, and 2000. The plume area, volume, and concentration data for each are summarized in Table 1. The plume stability data are discussed below.

Table 1. Groundwater Contaminant Plume Assessment Summary

Compound		Plume Area (Acres)			Plume Concentration (µg/l)			Overall Plume Volume[1] (acre-ft)	Average Plume Conc. (µg/l)
		Shallow	Inter.	Deep	Shallow	Inter.	Deep		
Carbon tetrachloride Z = 5 µg/l[2]	1998	145	338	196	6,280	6,834	1,314	16,958	5,122
	1999	184	331	187	4,089	8,027	841	17,523	5,083
	2000	114	337	201	2,536	4,843	500	16,293	3,104
Chlorobenzene Z = 100 µg/l[2]	1998	0	27.5	28.5	0	1,307	1,311	1,400	1,309
	1999	3.1	27.0	25.6	134	1,013	1,150	1,393	1,028
	2000	0.2	17.7	11.3	112	966	848	730	914
Chlordane Z = 2 µg/l[2]	1998	20.0	2.8	2.0	12.9	4.4	4.5	620	11.3
	1999	18.0	2.0	2.9	5.7	5.0	5.9	573	5.7
	2000	7.3	7.7	2.0	14.7	8.7	4.5	425	10.8

Notes: 1. The overall plume volume calculation assumes each aquifer zone has an average depth of 25 feet.
2. The Z value is the base level (contour interval) upon which the above calculation is based.

Area, Average Concentration, and Volume Calculations

Surfer® allows for the computation of planar area above a specified level of the input grid file. For example, Figure 2 shows three sub-plumes delineated to a carbon tetrachloride concentration level of 5 µg/l. This level represents the extent of the carbon tetrachloride plume, as 5 µg/l is the cleanup level for this compound. Thus, the area of the plume calculated by Surfer® would be defined as the planar area within the 5 µg/l contour line.

Similar to area calculations, Surfer® will also compute the volume above a specified level. Although this feature is well suited for determining cut and fill volumes for excavation projects, it may also be used along with the planar area to calculate the average contaminant concentration level. Consider the following analogy. The volume and planar area of a mound of soil is calculated by Surfer® to be 25 ft^3 and 10 ft^2, respectively. The average height (level) of the mound would be volume/area, or 2.5 feet. In a similar manner, when Surfer® calculates the volume of the plumes in Figure 2, the resulting units are ft^2-µg/l. When the volume is divided by the planar area in units of ft^2, the resulting value is the average level or concentration in units of µg/l.

As stated earlier, the overall plume is represented by three sub-plumes at different zones within the aquifer. The average concentration of the entire plume was calculated using a simple weighted average of the three sub-plumes, with the sub-plume area being the weighting factor. The overall plume volume was calculated by multiplying the area of each sub-plume by the assumed thickness of each aquifer zone (i.e., 25 feet), and then summing the three sub-plume volumes.

EVALUATION OF PLUME STABILITY

As shown in Table 1, the plume area for carbon tetrachloride in each uppermost aquifer zone has not changed significantly nor consistently since 1998. However, the concentration in all three zones has significantly decreased since 1998. The overall plume volume for carbon tetrachloride appears to be relatively stable and has decreased slightly since 1998. The average concentration, however, has consistently decreased since 1998. The average concentration has decreased from 5,122 µg/l in 1998 to 3,104 µg/l in 2000 (40 percent reduction).

As shown in Table 1, the plume area for chlorobenzene has not significantly changed in the shallow zone and has decreased significantly in the intermediate and deep zones since 1998. A similar pattern is also apparent for the concentration of chlorobenzene. The concentration has significantly decreased in the intermediate and deep zones since 1998. The overall plume volume and concentration for chlorobenzene have consistently decreased from 1998 to 2000. The plume volume has decreased from 1,400 acre-ft in 1998 to 730 acre-ft in 2000 (48 percent reduction) and the average concentration has decreased from 1,309 µg/l in 1998 to 914 µg/l in 2000 (30 percent reduction).

As shown in Table 1, the plume area for chlordane has significantly decreased in the shallow zone and has not significantly nor consistently changed in the intermediate and deep zones since 1998. The concentration of chlordane has increased in the intermediate zone, and has not consistently nor significantly changed in the shallow and deep zone since 1998. The overall plume volume for chlordane has consistently decreased from 1998 to 2000. The plume volume has decreased from 620 acre-ft in 1998 to 425 acre-ft in 2000 (31 percent reduction). The average plume concentration for chlordane has not significantly changed since 1998.

Based on the above discussion, the groundwater contaminant plume emanating from the site does not appear to be migrating further than its extent in 1998, indicating that it has stabilized (i.e., migration controlled). In fact, some of the data (e.g., chlorobenzene plume volume and concentration) are following an observed decreasing trend. Starting with the next data set (August 2001) trends in the plume stability will be further evaluated using statistical analysis.

CONCLUSIONS

Based on the results of the plume stability evaluation described in this paper, a recommendation was made by Velsicol to USEPA to change the Environmental Indicator status for CA 750, Groundwater Migration Controlled, from "More Information is Needed" to "Yes". The plume stability evaluation described in this paper provided the basis upon which to change the EI status.

Although other methods of plume stability analysis exist (e.g. mass flux analysis, fate and transport modeling, etc.), the method described in this paper is cost effective while being efficient and reliable. This method requires only the analytical data supplied by a laboratory to perform the assessment; whereas more complex methods require the use of additional subjective data (e.g., hydraulic conductivity, porosity, etc.). This method is reliable in that it is relatively simple to implement and the protocols are reproducible from year to year because the data manipulation is done completely by computer software, which leaves out any subjectivity of the data analyst. Contouring software, such as Surfer®, is relatively inexpensive compared to groundwater modeling software and it does not require a large volume of hydrogeologic information.

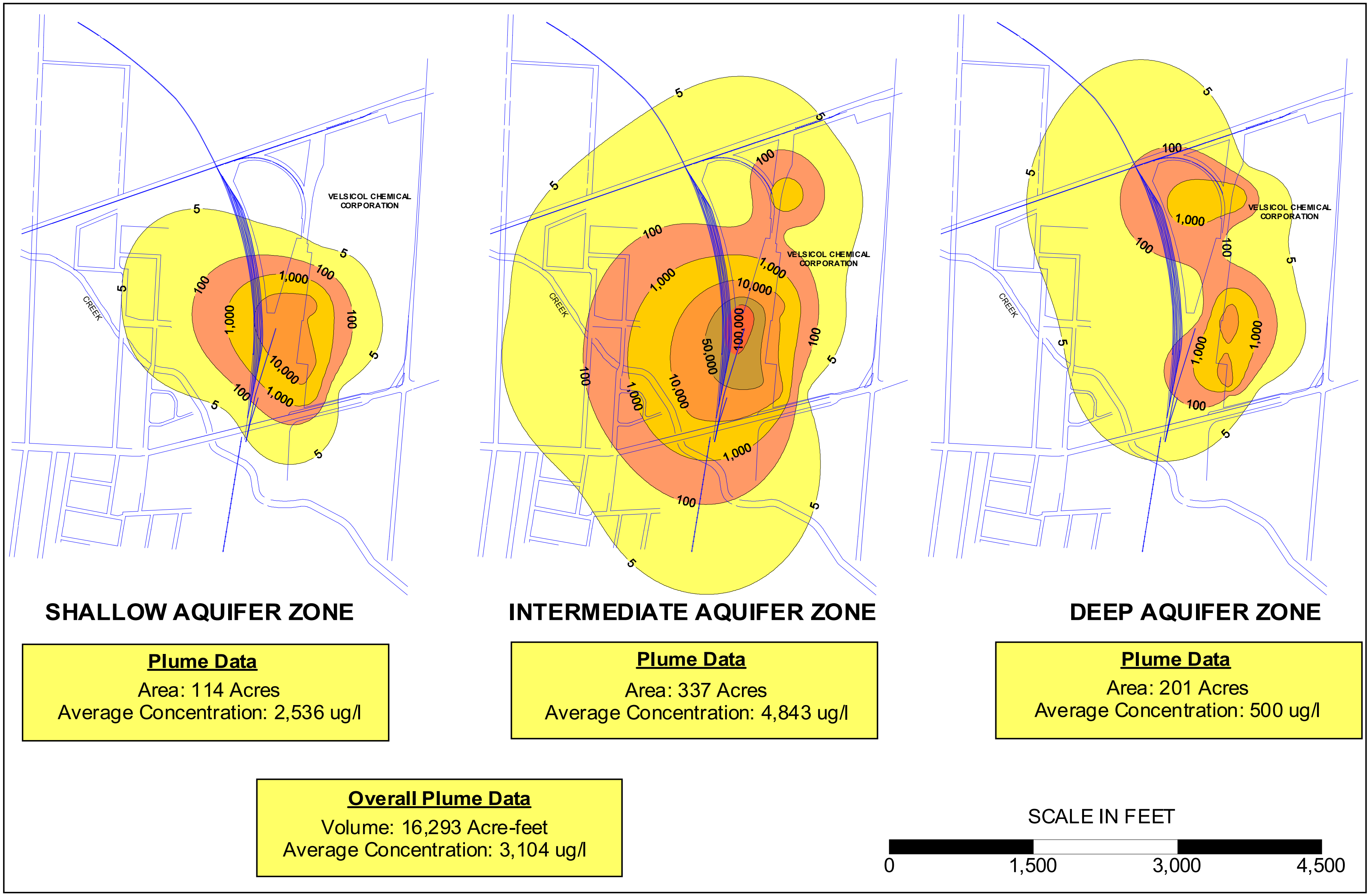

Figure 2. Iso-concentration Map of Carbon Tetrachloride - August 2000