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A spatial and temporal analysis of trichloroethylene contamination in the aquifers under the former Fort Ord landfill

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**A Spatial and Temporal Analysis of
Trichloroethylene Contamination
in the Aquifers Under the Former Fort Ord Landfill**

A Capstone Project

Presented to the Faculty of the Earth Systems Science and Policy Department

in the

Center for Science, Technology, and Information Resources

at

California State University - Monterey Bay

in Partial Fulfillment of the Requirements for the

Degree of Bachelor of Science

By

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ABSTRACT

Trichloroethylene (TCE) is a volatile organic compound the U.S. Army used extensively on the former Fort Ord prior to the post's closure. TCE is a probable human carcinogen and can cause a range of health effects depending on the quantity and duration of exposure. Fort Ord operated a group of landfills located on the post. The Army used these landfills for disposal of TCE-containing waste, and TCE subsequently leached into and contaminated the A-, 180-foot (Upper), and 180-foot restricted (Lower) aquifers. My project goals were to compile relevant information on the landfill and trichloroethylene, determine where the areas of highest TCE contamination exist in the aquifers of concern, provide an easy-to-read graphical representation of how the TCE plume has changed over time in the aquifers of concern, and ascertain if the current remediation strategy is appropriate for these aquifers. Using quarterly monitoring well data provided by the United States Army Corps of Engineers, I produced layers of annual TCE concentration gradients for each of the three aquifers using a geographic information system (GIS). I imported these images into an animation program and produced digital movies of the change in TCE concentration per year in each aquifer. Using these images, I determined that there is small but significant evidence of TCE plume flow. The areas of current highest TCE concentration include: pockets of relatively high concentration north and northwest of landfill Cell A and to the north and northeast of Cell F in the A-aquifer; areas of relatively high concentration located north, northwest, and southwest of Cell A of the 180-foot (Upper) aquifer; and an area of relatively high TCE concentration northwest of Cell A in the 180-foot restricted (Lower) aquifer. The Army's current remediation strategy for this site includes a pump-and-treat system. I concluded this is the most appropriate methodology given the unique properties of the site and the current technology available. However, I also feel it will be necessary in the future to re-evaluate the feasibility of the Army's goal to reduce TCE concentrations to EPA drinking water standards.

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1. INTRODUCTION

Trichloroethylene (TCE) is a volatile organic compound (VOC) that finds its way as a waste product into many municipal and industrial landfills. TCE is not known to occur naturally in the environment. Around 42% of hazardous waste sites on the National Priorities List (NPL), commonly known as Superfund sites, are contaminated with TCE. It is the second-most frequently detected contaminant of concern in NPL sites, ranking only behind lead. Studies by both the Environmental Protection Agency (EPA) and the Agency for Toxic Substances and Disease Registry (ATSDR) estimate there are 4.1 million people living within one mile of the 725 NPL sites for which there is population data. Of them, 1.9 million are women of childbearing age, young children, or elderly – populations that are known to be at a higher risk from chemical exposure (National Research Council, 1991).

Because of the widespread use of trichloroethylene and its prevalence in waste sites across the United States, TCE contamination of groundwater is becoming an increasing threat. Around one half of the population of the United States and about 95% of the rural population rely on groundwater as a source of drinking water (National Research Council, 1991). While TCE is estimated to already have contaminated about 34% of the nation's potable groundwater sources, there is no method of determining exactly how widespread the contamination may be (Campos-Outcalt, 1992). According to the United States Congress' Office of Technology Assessment, "...EPA has no site discovery program, has no budget for site discovery, and does not allow States to spend Superfund monies for site discovery..."(U.S. Congress, 1989). In addition, the EPA requires industries to report only the spills of TCE that exceed 1,000 pounds (ATSDR, 1997).

The former Fort Ord is one of roughly 425 NPL sites contaminated with trichloroethylene. My research project focused on spatial and temporal changes in TCE contamination of the groundwater under the former Fort Ord. During my project I addressed the following research questions:

- How has the current remediation strategy affected the plume of trichloroethylene in the A-, Upper 180-foot, and Lower-180-foot aquifers under the landfill at the former Fort Ord?
- Where are the areas of highest TCE contamination in these aquifers currently?
- Is the current remediation strategy appropriate for these aquifers?

My initial hypotheses were:

- The current remediation strategy has adequately captured the plumes. Plume concentrations should be declining.
- The areas of highest current contaminant concentration are near the original landfill cells.
- The current remediation strategy is probably appropriate for the site.

The goals for this project were to:

1. Compile relevant information on the site and contaminant of concern, trichloroethylene (TCE).
2. Provide an easy-to-read graphical representation of how the TCE plume has changed over time in the aquifers of concern.

This report synthesizes current information available on the landfill site, called Operable Unit Two (OU2), and trichloroethylene. I obtained quarterly monitoring well data from the United States Army Corps of Engineers. I decided to use this data in a geographic information system (GIS) software to produce map layers of TCE concentration. I exported the images to an animation program and produced digital movies of the change in TCE concentration per year in each aquifer. I analyzed these movies and applied concepts from related literature to answer my specific research questions.

2. STUDY SITE DESCRIPTION

2.1. Historical Data on the Former Fort Ord and Environmental Concerns

Fort Ord is located in Monterey County, California (See Figure 1). It was founded in 1917 and covered approximately 27,827 acres. Agriculture was the primary land use prior to its purchase by the Army. Fort Ord served mainly as a training facility for the Army. However, activities on the post included many related industrial functions as well, including vehicle maintenance, photographic processing, painting, a plastics shop, sewage treatment, maintenance of a small airport, and laundry/dry cleaning. In addition, the Army used 8,000 acres as a firing range. These activities, in addition to others, required disposal of chemicals and hazardous wastes. Most of these wastes were managed through hazardous waste storage areas, unregulated disposal areas, and a landfill (U.S. Army, 2000).

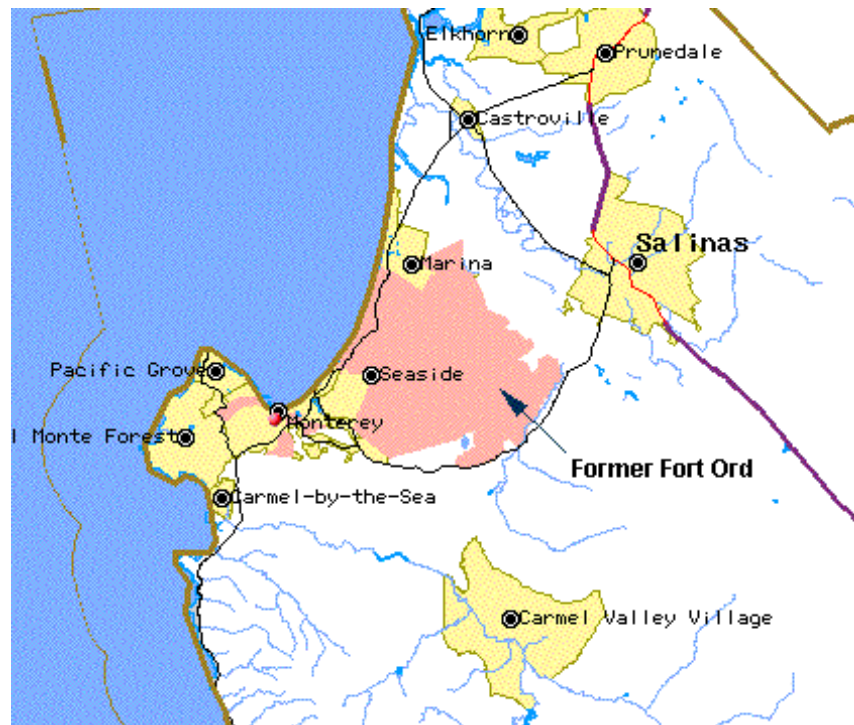


Figure 1: Location of Former Fort Ord (U.S. Army, 2000)

In 1984, local water districts suspected groundwater contamination but were unsure of the source. The California Regional Water Quality Control Board - Central Coast Region (RWQCB) issued Cleanup and Abatement Orders 84-92, 86-86, and 86-315. These orders initiated investigations at the Fritzsche Army Airfield (FAAF) Fire Drill Area (called OU1) on Fort Ord in 1984 (IT Corporation, 2001a). By 1985 groundwater samples in Fort Ord and the Marina Coast Water District showed traces of volatile organic compounds (VOCs) including carbon tetrachloride, tetrachloroethylene, trichloroethylene, 1,1,1-trichloroethane, and trans-1,2-dichloroethylene (U.S. EPA, 1990). The Army decided to close the landfill in 1985 following this discovery. By 1986 the Army began investigations into groundwater contamination at the landfill site, now called Operable Unit Two (OU2) in reference to its remediation system. These investigations continued through 1988 (ATSDR, 1996). During the late 1980s, the Fort Ord Directorate of Engineering and Housing (DEH), Sacramento District of the Corps of Engineers (CE), and Harding-Lawson Associates (HLA) evaluated the groundwater quality and hydrogeologic characteristics of the aquifers beneath the post. In all, a total of 43 sites were studied by a wide variety of organizations. In 1990, Fort Ord was placed on the National Priorities List (NPL), making it subject to the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) of 1977. This listing included the entire facility. As a result, the EPA identified Fort Ord as a federal Superfund Site. In 1991, Fort Ord was placed on the Base Realignment and Closure (BRAC) list. However, the post did not officially close until 1994 (U.S. Army, 2000).

Several agencies work together on the remediation plans at Fort Ord. The U.S. Army, Federal Environmental Protection Agency, the California Environmental Protection Agency

Department of Toxic Substances Control, and the Central Coast Regional Water Quality Control Board all work together under a Federal Facilities Agreement (FFA) on the Ford Ord site to ensure both the quality and speed of the remediation efforts (ATSDR, 1996).

The Agency for Toxic Substances and Disease Registry (ATSDR) made its first site visit on June 26 and 27, 1991 (ATSDR, 1996). ATSDR formed in 1983 as a result of a lawsuit and expanded with the ratification of the Superfund Amendments and Reauthorization Act (SARA) of 1986. The ATSDR is required to conduct a health assessment of every NPL site, both proposed and listed, as well as compile toxicological profiles and priority listings of substances found at each site (National Research Council, 1991). After the initial visit, the ATSDR visited the site again July 26, 1994; June 21 through 23, 1995; and May 13 and 14, 1996. They found no past apparent health hazards, no current exposure, and no likely future exposures from Fort Ord wells used for drinking water by residents. In addition, they stated that Seaside water supplies are unaffected because Seaside draws from the Seaside Basin Aquifer while Marina and Fort Ord draw from the Salinas Basin. These basins represent different groundwater units.

The ATSDR tested water wells 10 and 11 used by the Marina Coast Water District for current municipal use (see Figure 2). They determined those well were unaffected by the contaminants because they are drilled deeper in the 900-foot aquifer. Fort Ord maintains three water supply wells (FO29 through FO31) in the East Garrison region of the post completed in the 180-foot Lower and 400-foot aquifers (Harding Lawson Associates, 1995b). Figure 2 shows the locations of these wells as well as those currently used by the Marina Coast Water District for municipal water (wells 10, 11, and 12).

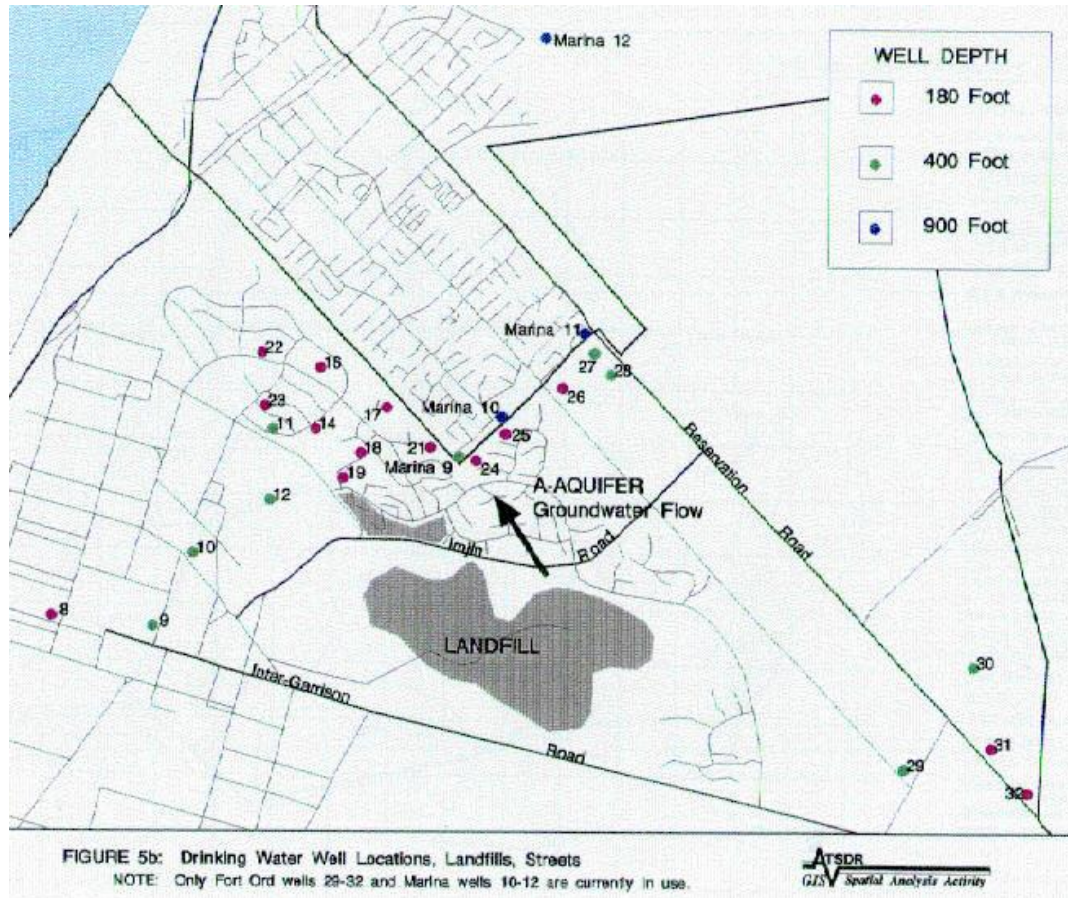


Figure 2: Drinking Wells by Aquifer (ATSDR, 1996)

Concerning past exposures in Fort Ord and Marina, the ATSDR determined that the concentration of contaminants was low and the duration of exposure was short. Adverse health effects would likely not result. Finally, they pointed out that contaminant levels in drinking water supplies would be lower than direct well samples. Blended, finished tap water supplied to residents would be treated and pumped to reservoir tanks where VOCs could “off-gas.” Lastly, the ATSDR found no lifetime exposures (over 70 years). Their final analysis was there is “no apparent public health hazard” at Fort Ord and ranked the site as a Category D site (ATSDR, 1996).

2.3. Hydrostratigraphy of the Study Site

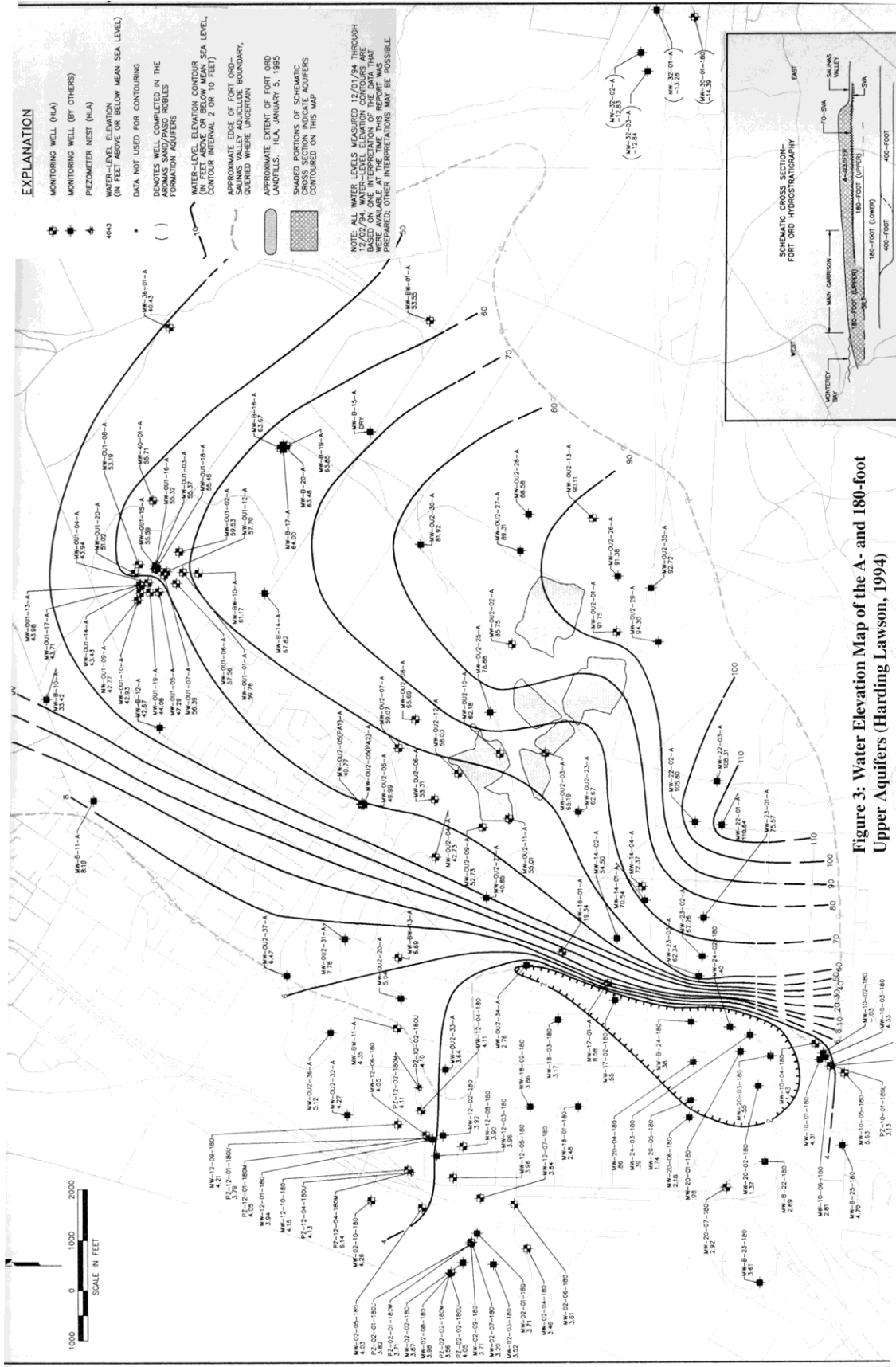
Fort Ord rests on over 100 feet of fluvial and marine deposits overlying granitic basement rock. It is situated in the Salinian Block and has the generalized stratigraphy noted in Table 1. The King City Fault projects either through or near part of the lands, making it tectonically active. The King City Fault is part of the San Andreas Fault system (Harding Lawson Associates, 1995).

Table 1: Stratigraphy of Fort Ord (Gill, et al., 1998)

Geologic Formation	Description	Geologic Age	Associated Aquifer
Beach Sand	Well-sorted quartz and feldspar sand particles of fine to course grain	Holocene	
Recent Dune Sand	Finer-grained quartzose sand	Holocene	
Alluvium	Fluvial sediments	Holocene	
Older Dune Sand	Medium-grained quartz and feldspar sand with paleosols and some silt	Pleistocene	A-aquifer
Valley Fill Deposits	Marine and estuary clay deposits as well as sand and gravel fluvial deposits	Pleistocene	Fort-Ord-Salinas Valley Aquitard, 180-foot unrestricted aquifer, intermediate 180-foot aquitard, and 180-foot restricted aquitard
Aromas Sand	Eolian sand (mostly quartz and feldspar) and flood plain deposits	Pleistocene	400-foot aquifer and Aromas Sand aquifer
Paso Robles Formation	Beds of sand, gravel, silt, and clay that are poorly sorted	Pleistocene-Pliocene	400-foot aquifer and Paso Robles aquifer
Santa Margarita Formation	Quartzose sand and sandstone	Miocene-Pliocene	900-foot aquifer
Monterey Formation	Shale, mudstone, and sandstone containing diatoms	Miocene	
Salinian Block Basement	Granitic and metamorphic rocks	Mesozoic	

Fort Ord is part of the Salinas Groundwater Basin. The hydraulic conductivities of the A-, Upper 180-foot, and Lower 180-foot aquifers are relatively high as a result of their coarse-grained nature (Harding Lawson Associates, 1995a). There is a steep hydraulic gradient and groundwater depression near the edge of the Fort Ord-Salinas Valley Aquitard west of the landfill site. Groundwater flow is divided between the Main Garrison and the East Garrison extending north through Fritzsche Army Airfield. In addition, there is a linear trough in the water table oriented northwest beneath OU2 (Harding Lawson Associates, 1995b).

There are five main aquifers associated with the Salinas Groundwater Basin: the A-aquifer, 180-foot aquifer, 180-foot restricted aquifer, 400-foot aquifer, and the 900-foot aquifer. In addition, there are two small aquifers in the southeastern portion of the post named after the formations in which they occur: Aromas Sand and Paso Robles Formation. The Aromas Sand and Paso Robles Formation aquifers are distinct aquifers, meaning they are separate from the other aquifers. These two aquifers are not well studied, and there is very little subsurface data available on them (Harding Lawson Associates, 1995a). My project involves only the A-, upper 180-foot, and lower 180-foot (restricted) aquifers because these aquifers are the only ones at this site to show current contamination. Figure 4 provides a cross-sectional view of these three aquifers with the location of the landfill noted.



Schematic Hydrostratigraphic Cross-Section

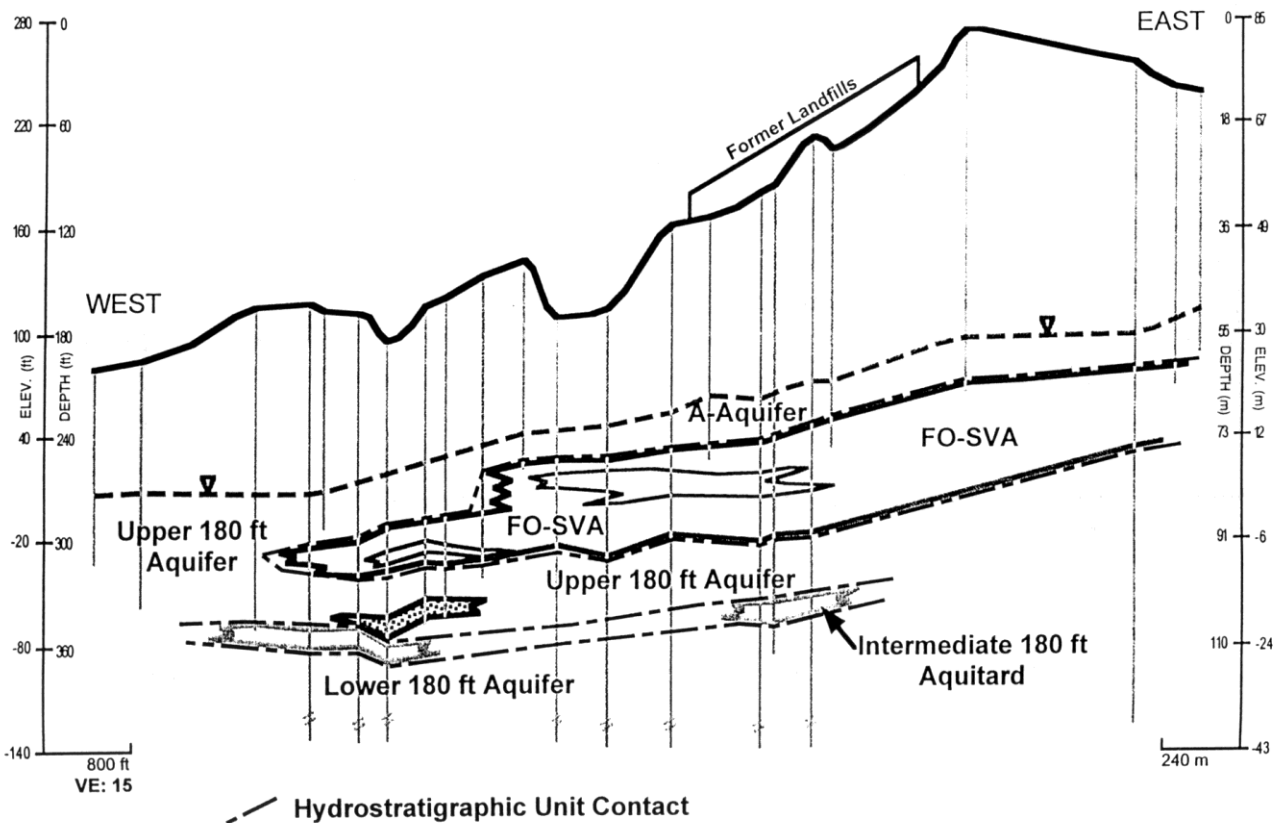


Figure 4: Cross-section of the Aquifers Beneath the Former Fort Ord Landfill (Gill, et al., 1998)

The A-aquifer is composed mainly of fine to medium grained, well-sorted sands. These sands are Pleistocene-age older dune sands. It is found about 100 to 150 feet below the ground surface. Its saturation thickness is 20 feet on average. The A-aquifer is recharged through infiltration of precipitation and anthropogenic recharge. The water levels rise and fall only a few feet with recharge events. The aquifer discharges into the 180-foot aquifer where the Fort Ord-Salinas Valley Aquitard is absent. It also seeps to the ground surface from the bluffs along the eastern boundary of the former Fort Ord (Harding Lawson Associates, 1995a). The hydraulic

conductivity (K_H) of the A-aquifer ranges from about 1.6 to 95.0 feet per day. This measurement was obtained from both slug and constant-rate discharge tests (Harding Lawson Associates, 1994).

The Fort Ord-Salinas Valley Aquitard (FO-SVA) separates the A- and 180-foot aquifers. The FO-SVA is composed mostly of clay and silt from the Pleistocene epoch. There are several sand beds present throughout the FO-SVA. The FO-SVA is not present between the aquifers along their entire length (it is discontinuous) and pinches out under the western portion of the former post. It is about 100 feet thick but thins considerably along its edges. The vertical permeability of the FO-SVA is 2.0×10^{-6} to 1.1×10^{-5} feet per day, making it relatively impermeable (Harding Lawson Associates, 1995b).

The 180-foot aquifer lies underneath the A-aquifer at about 110 to 220 feet below the ground surface (IT, 2001b). It is confined by the FO-SVA where the FO-SVA is present; where the FO-SVA is not present it is an unconfined aquifer. The 180-foot aquifer, also known as the Upper 180-foot aquifer, is composed mostly of sand with some gravel. It is about 30 to 120 feet thick but thins out in the southern region (Harding Lawson Associates, 1995b). The 180-foot aquifer has a K_H of 0.04 to 365 feet per day. This range was determined using slug tests, specific capacity tests, and constant-rate discharge tests (Harding Lawson Associates 1994). Where there is no confining FO-SVA, this aquifer is recharged by infiltration of precipitation and anthropogenic recharge. In addition, the 180-foot aquifer receives recharge from the A-aquifer at the western edge of the FO-SVA. There are small seasonal fluctuations in the water level due to pumping in the Salinas Valley for agricultural use (Harding Lawson Associates, 1995b).

Directly underneath the 180-foot aquifer lies the Intermediate 180-foot Aquitard. This aquitard is composed of silt and clay, and it is about 10 to 20 feet thick. The Intermediate 180-foot Aquitard provides hydraulic separation between the 180-foot (Upper) and 180-foot restricted (Lower) aquifers (Harding Lawson Associates, 1995b).

The 180-foot restricted, also called the Lower 180-foot aquifer, is a confined aquifer. It is about 50 to 150 feet thick and is composed of alluvial gravel and sand. There is interbedding of clay and silt as well (Harding Lawson Associates, 1995b). The K_H of this aquifer is between 1.7 and 623 feet per day, determined from slug and specific capacity tests (Harding Lawson Associates, 1994). This aquifer crops out in the offshore sea floor. It was heavily pumped in the past, leading to seawater intrusion beneath the coastal lands. The 180-foot restricted aquifer is recharged from Monterey Bay seawater and from downward groundwater flow from the 180-foot aquifer. There are seasonal fluctuations in water levels from pumping in the Salinas Valley (Harding Lawson Associates, 1995b).

While not part of my case study, it is important to mention the 400-foot aquifer. This aquifer appears to be hydraulically connected in some way to the 180-foot restricted aquifer near OU2. It is composed of two different geologic units, and its groundwater flow patterns are not well understood (Gill, et al., 1998). Constant-rate discharge tests produced a K_H value of 14.0 feet per day in this aquifer (Harding Lawson Associates, 1994). It is possible the 400-foot aquifer recharges from the 180-foot aquifer where the aquitard is discontinuous, especially during high pumping events of the 400-foot aquifer.

2.3. Landfill Specifications

The Fort Ord Landfill encompasses about 150 acres in a minimal flooding area. There were six landfill cells at the time of base closure (designated Cells A through F). Figure 5 shows the location of these cells. Cell A, located on the north side of Imjin Road, covers about 25 acres. Cells B through F are found on the south side of Imjin Road and include about 93 acres. Residential, on-base commercial, and military wastes were accepted at OU2 while in operation from 1956 through May 1987. However, no one kept detailed records of exactly what wastes were disposed here during that period of time. The Army found evidence of domestic waste, construction debris, medical waste, and decontamination and test kits during their test pit investigations. Initial inspection of the site did not rule out the presence of unexploded ordnance (UXO) and chemical warfare material (CWM) as well (Harding Lawson Associates, 1995c). Recent information indicates it is unlikely there will ever be a definitive records of what is contained in the unexcavated landfill cells (Eisen, 2002).

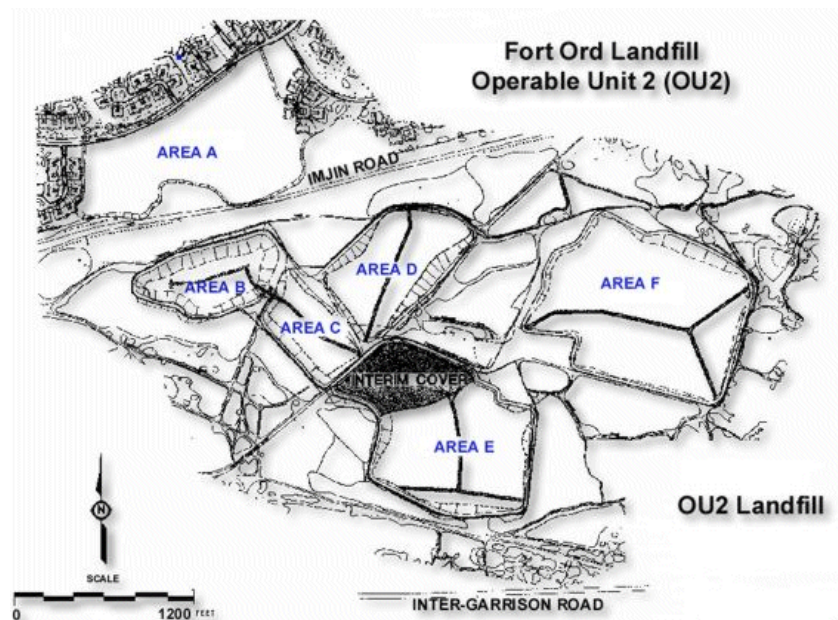


Figure 5: Site OU2 (U.S. Army, 2000)

The Army signed the Record of Decision (ROD) for OU2 in July 1994. This document outlined the proposed remedial actions for the site. Cell A was excavated and consolidated with one of the other cells. In addition, contaminated wastes, soils, and debris from 41 other sites on the former Fort Ord were consolidated into the remaining landfill areas to decrease transportation and cleanup costs. Areas B, C, D, and F have a cap covering the top of the landfill debris. Area E has an interim cap over the top of seven acres of its debris. These caps prevent infiltration of precipitation, which could cause further contaminant leaching into the underlying groundwater aquifers (U.S. Army, 2000). The area, located in uneven sand dunes, is covered with a variety of low-lying vegetation including grass, shrubs, and bushes (Harding Lawson Associates, 1995c). Initial investigations showed 11 chemicals of concern (COCs) at OU2:

benzene	carbon tetrachloride
chloroform	1,1-dichloroethane (1,1-DCA)
1,2-dichloroethane (1,2-DCA)	cis-1,2-chloroethene (cis-1,2-DCE)
1,2-dichloropropane (1,2-DCP)	methylene chloride
tetrachloroethene (PCE)	trichloroethylene (TCE)
vinyl chloride	

Of these chemicals, TCE was the most common and widespread found (IT Corporation, 2001b).

3. CONTAMINANT OF CONCERN: TRICHLOROETHYLENE

3.1. Physical and Chemical Description of Trichloroethylene

Trichloroethylene (TCE) is a nonflammable, colorless or blue liquid with an ether or chloroform-like odor (ATSDR, 1997). It can be detected by human olfactory glands at a concentration of about 0.5 to 160 ppm and can be tasted in water at concentrations of 0.5 ppm (Lakes, 1995). According to the Environmental Protection Agency (EPA) Office of Water, TCE has the following trade names and synonyms (1998):

1,1,2-Trichloroethylene	Acetylene Trichloroethylene
Trichloroethene	Algylen
Anameth	Benzinol
Chlorilen	CirCosolv
Germalgene	Lethurin
Perm-a-chlor	Petzinol
Philex	TRI-Plus M
Vitran	Westrosol

Because it is widely used by manufacturers, TCE has numerous other synonyms and brand names.

Trichloroethylene has a molecular formula of C_2HCl_3 and a molecular mass of 131.39 g/mol (Lakes, 1995). TCE is soluble in organic compounds like acetone, ethanol, chloroform, and ether. TCE has a low flammability and high vapor density, characteristics that make it an ideal solvent. TCE is a dense non-aqueous phase liquid (DNAPL), meaning it has a density greater than the density of water. Table 2 below lists relevant physical properties of TCE.

Table 2: Physical Properties of Trichloroethylene (Montgomery, 2000).

<i>Physical Property</i>	<i>Value</i>
<i>Density</i>	1.461 to 1.464 g/cm ³ at 20/4° C
<i>Water Solubility</i>	1,100 mg/L at 20° C
<i>Henry's Law Constant</i>	7.42 x 10 ⁻³ to 10.1 x 10 ⁻³ atm•m ³ /mol at 20° C
<i>Melting Point</i>	-86.4 to -87.1° C
<i>Boiling Point</i>	86.7 to 87.2° C
<i>Vapor Pressure</i>	74 mm Hg at 25° C

These properties contribute to the high mobility, persistence, and volatilization potential of TCE.

3.2. Historical and Current Uses of Trichloroethylene

Trichloroethylene was first synthesized in 1864 and became widely used in the United States in the 1940s. According to 1990 data, TCE is produced primarily in Michigan and Pennsylvania at the rate of about 100,000 tons annually. In return, at that time about 91,000 tons of the chemical were released into the environment per year (Harte, et al., 1991). By 1992, the amount released fell to about 14,802 tons per year (Dorgan, 1995).

Trichloroethylene is used for a variety of purposes including as a cleaner, degreaser, solvent, and refrigerant. It can be found in common products like correction fluid, paint removers and strippers, adhesives, spot removers, and rug cleaning fluids (Lakes, 1995). In addition, TCE is used in some disinfectants and is a common inert ingredient used in fungicides and insecticides. TCE was widely used to decaffeinate coffee and produce some spice extracts. Manufacturers are slowly phasing out TCE's use during food production and replacing it with methylene chloride. However, the Food and Drug Administration (FDA) still allows up to 25 parts per million (ppm) of TCE in decaffeinated ground coffee and 30 ppm in spice extracts. Historic uses include as a dry-cleaning solvent, a fumigant, and as a general anesthetic (Harte, et al., 1991).

3.3. Mobility of Trichloroethylene in Aquifers

Trichloroethylene moves through an aquifer by mechanical, longitudinal, and transverse dispersion. It sticks to sediment particles it encounters due to the hydrophobic effect of the compound. Once TCE is spilled onto the ground, it soaks through the soil into the subsurface areas. TCE moves vertically downward through the vadose zone, the area of the subsurface that is unsaturated with water. It will also migrate horizontally through this layer if it encounters a

heterogeneous layer such as sands with horizontal bedding. TCE continues to migrate down vertically due to gravitational pull until it reaches the zone saturated with water. Here it continues to travel downward vertically until it reaches an aquitard. It accumulates on the surface of the aquitard. The TCE pooling on the aquitard moves laterally along it in a direction that is down-dip of the aquitard. There are also horizontal stringers coming from the vertical migration layer due to TCE overcoming capillary pressure. These stringers will move in the direction of the flow of water in the aquifer (Fetter, 1999). Figure 6 shows the flow of a TCE spill in a generic aquifer.

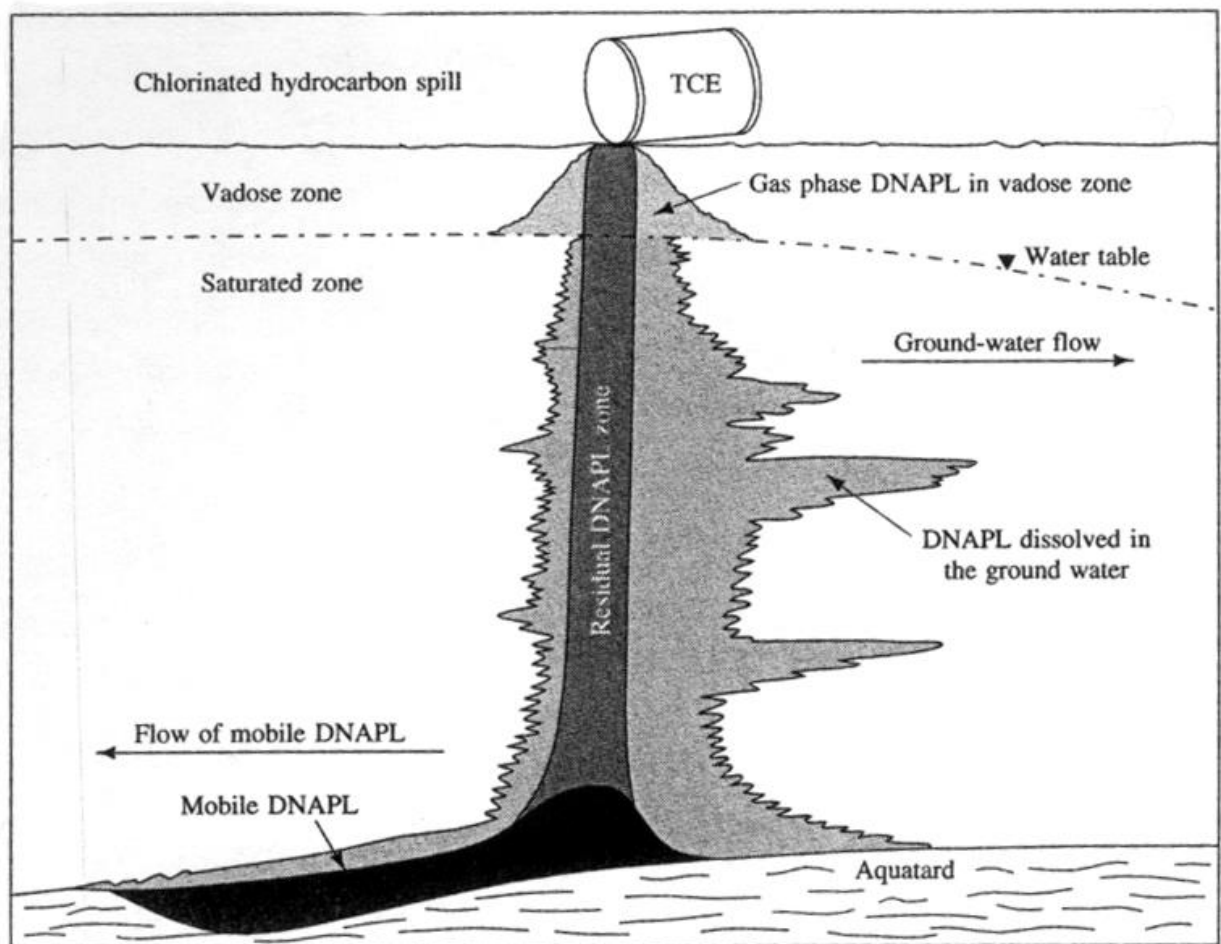


Figure 6: Distribution of TCE in an Aquifer (Fetter, 1999)

The organic solids in the soil or aquifer attract the TCE molecules. Water in the aquifer can be pumped out and treated; however, this will not swiftly remediate the aquifer. Even though TCE is no longer being introduced from the surface, TCE molecules bound to organic molecules in the aquifer and aquitard are attracted to and released continuously from the water in the aquifer. The organic molecules act as a time-delayed source of contamination in the aquifer. This slow release of TCE from within the aquifer may persist for many years. In actuality, TCE exists in the aquifers in three different phases at equilibrium: TCE bound to solids as described above, aqueous TCE, and TCE as a non-aqueous phase liquid (NAPL) (see Figure 7). Removing only one type of TCE contamination will not restore the aquifer. The three phases of TCE make remediation of TCE-contaminated aquifers difficult.

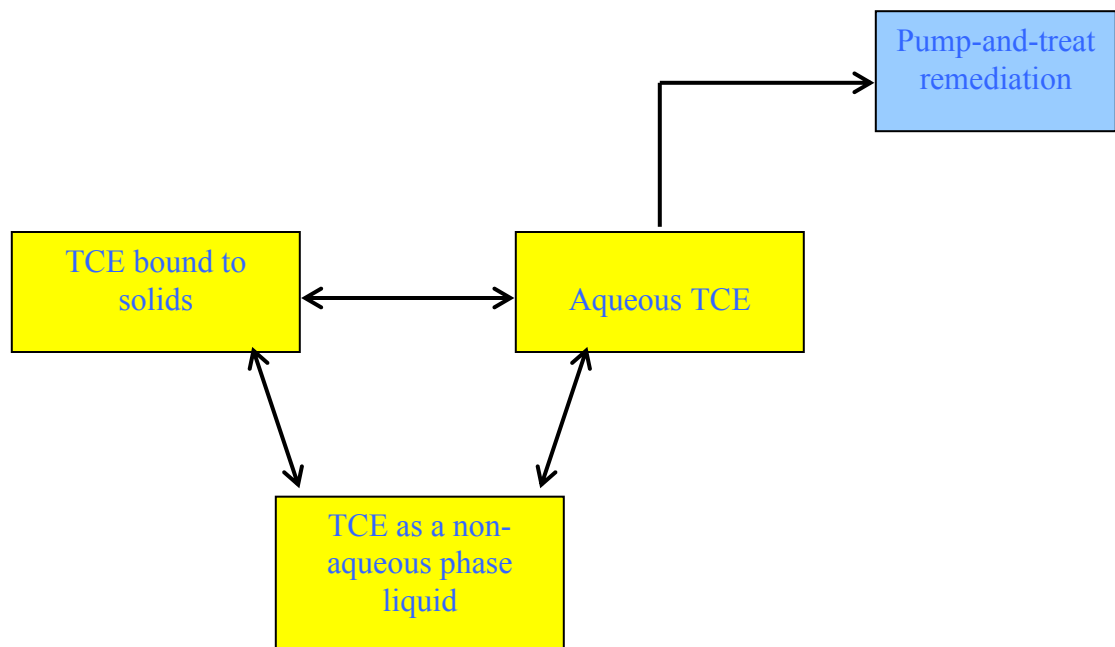


Figure 7: Three Phases of TCE Contamination in Aquifers

3.4 Drinking Water Standards for Trichloroethylene

The Safe Water Drinking Act of 1974 sets Maximum Contaminant Level Goals (MCLG) for chemicals found in drinking water. These levels are non-enforceable and based on potential health risks to exposure. The MCLG for TCE is zero. However, the Environmental Protection Agency (EPA) is able to enforce its standards, called Maximum Contaminant Levels (MCL). The MCL for TCE is set at five parts per billion (ppb), or five micrograms (μg) per liter. The EPA believes this is the lowest standard to which TCE in drinking water can realistically be removed given current technology (U.S. EPA, 1998). It is relatively easy to contaminate water to the MCL for TCE. One barrel of TCE spilled in an open water source would contaminate 10 billion gallons of water to the EPA MCL of five ppb (Abelson, 1990).

3.5. Toxicology and Epidemiology of Trichloroethylene

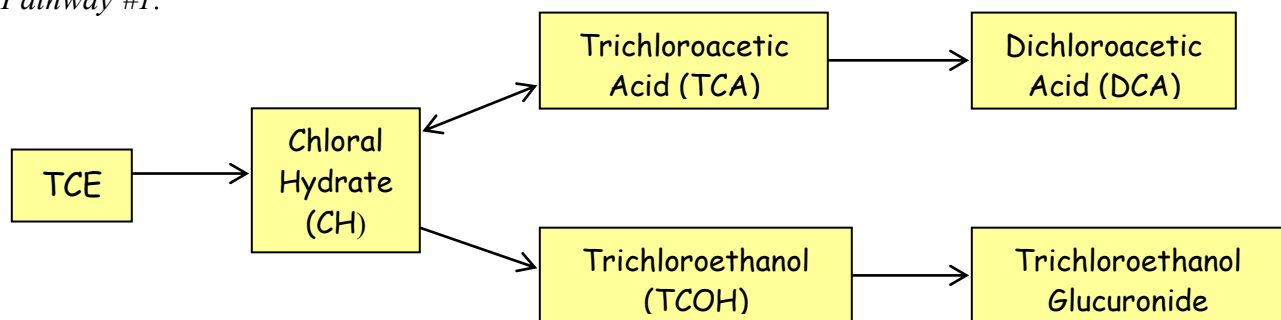
The ATSDR ranks the chemicals for which it has toxicological profiles. TCE is listed as a Priority Group One substance (National Research Council, 1991). Occupational exposures and laboratory rodent studies are the source of most of the data on TCE toxicology. Humans are exposed to TCE by inhalation of contaminated air, from contact with contaminated soil and/or water, or from ingestion of contaminated soil and/or water. TCE exposure is more severe when it is ingested or inhaled than by dermal exposure. For example, showering with contaminated water is harmful mainly because the TCE volatilizes into air and is breathed in while bathing rather than being absorbed through the skin.

Trichloroethylene bioaccumulates at low levels in fish. However, levels drop once the fish are removed from the contaminated water (ATSDR, 1997). TCE is also found in some foods that are processed with contaminated water or pass through equipment cleaned with TCE.

TCE has been reported in the United States and United Kingdom in butter and margarine, peanut butter, ready-to-eat cereals, highly processed foods, and cheese products. The Third National Health and Nutrition Examination Survey (NHANES III) recently estimated about 10% of the population has detectable levels of TCE in their blood (Wu and Schaum, 2000).

Once ingested most of the TCE will pass into the blood stream. From there it is transported throughout the body, especially to the liver, kidneys, lungs, and brain. TCE is metabolized primarily in the liver. There, through a complex process, it is metabolized into several products (see Figure 8). The metabolites chloral hydrate (CH), trichloroacetic acid (TCA), free trichloroethanol (TCOH), and dichloroacetic acid (DCA) are toxic to humans as well (Pastino, et al., 2000). While the half-life of TCE in the body is only about five hours, the half-life of these metabolites ranges from 10 hours to up to 52 hours in the body (Campos-Outcalt, 1992). Metabolized TCE and its byproducts are excreted in urine or released through exhalation (Harte, et al., 1991). Not all TCE ingested is metabolized, however. Unmetabolized TCE is deposited and stored in adipose tissue. Fat tissue retains unmetabolized TCE because of its high liposolubility (Nakashima and Ikegami, 2001). Because of this, unmetabolized TCE can bioconcentrate in humans if exposure is prolonged.

Pathway #1:



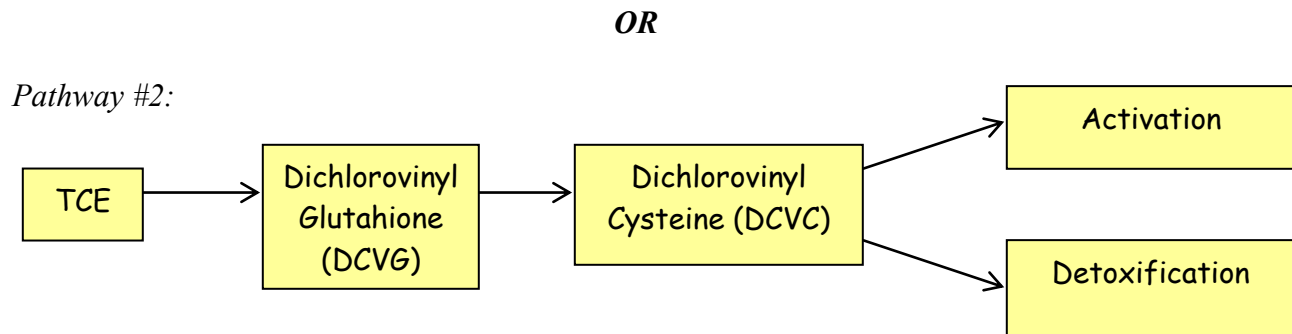


Figure 8: Pathways for TCE Metabolism in Humans (Pastino, et al., 2000)

Exposure to TCE has a variety of side effects, the most common of which are related to the central nervous system (CNS). According to Pastino, et al., the effects of low level, short-term exposures include:

Dizziness	Headaches
Drowsiness	Nausea
Confusion	Blurred Vision
Malaise	Rash

Of a more serious nature are one-time large exposures or small dose exposures over long periods of time. These types of exposures can result in (ATSDR, 1997):

Liver Damage	Kidney Damage
Convulsions	Cardiac Arrhythmia
Impaired Immune System	Facial Paralysis
Coma	Death

The debate continues as to whether or not TCE should be classified as a human carcinogen. The EPA classifies TCE between Group B2, which means there is sufficient evidence in animals for carcinogenicity, and Group C, meaning there is limited evidence of carcinogenicity in humans. Based on extensive studies of a military base in Utah, the International Agency for Research on Cancer (IARC) found liver cancer and non-Hodgkin's

lymphoma associated with occupational and drinking water exposure. Therefore, the IARC now classifies TCE as Group 2A, a probable carcinogen in humans (Pastine, et al., 2000). Other cancers associated with but not directly linked to TCE exposure are kidney cancer, breast cancer, cervical cancer, and lung cancer.

While TCE is associated with certain cancers, there is no direct evidence TCE actually causes cancer or reproductive effects. To date the evidence needed to demonstrate a clear causal relationship is inconclusive. Studies based on animal experiments and human exposures are varied and have demonstrated conflicting results. One cause for this may be that occupational exposures are rarely limited to one chemical. Most often workers are exposed to other solvents at the same time, making TCE-specific evaluations difficult (Wartenberg, et al., 2000). In addition, many studies do not include well-documented exposures (Campos-Outcalt, 1992). Others suggest this is due to the fact most studies assume all people of a certain age group are equally susceptible to environmental hazards. Health status or diseases (diabetes, obesity), behavioral factors (diet, exercise, stress), and other factors like smoking or alcohol consumption are generally not taken into account. Most animal studies are done with inbred animal strains. They have homogeneous populations, and their diet and living conditions are identical. Human populations are more heterogeneous and have a great variety of behaviors, diets, and living conditions. The use of biomarkers of exposure and effect is one tool that may aid in the epidemiological analysis of TCE (Pastino, et al., 2000).

4. TRICHLOROETHYLENE REMEDIATION

4.1. *Groundwater Treatment Strategy at the Study Site*

The original groundwater remediation system for OU2 began operations in 1995. The Water Development Corporation of Woodland, California, was the agency contracted for drilling services. The U.S. Army Corps of Engineers and their contractors completed all fieldwork in accordance with the Groundwater Remedial Action Work Plan (GRAWP) as well as guidelines set by the Monterey County Health Department and the California Department of Water Resources (IT Corporation, 2001c). The U.S. Army Corps revised their treatment system in 1999 largely due to the fact that the system was not adequately capturing the TCE plume in the A and 180-foot aquifers. The remediation system used at Operable Unit One (OU1) was the model for the new system. The revised system consists of (IT Corporation, 2001b):

- 22 extraction wells

- 2 infiltration galleries

- 3 backup injection wells

- Recharge pipeline to the Sites 2/12 groundwater treatment plant

- OU2 groundwater treatment plant itself, composed of:

 - Four granular activated carbon (GAC) adsorption vessels

 - 2 backwash tanks

 - 1 effluent tank

 - Ancillary pumps, piping, electrical power, instrument control

 - SCADA system to communicate with each installed programmable logic controller (PLC)

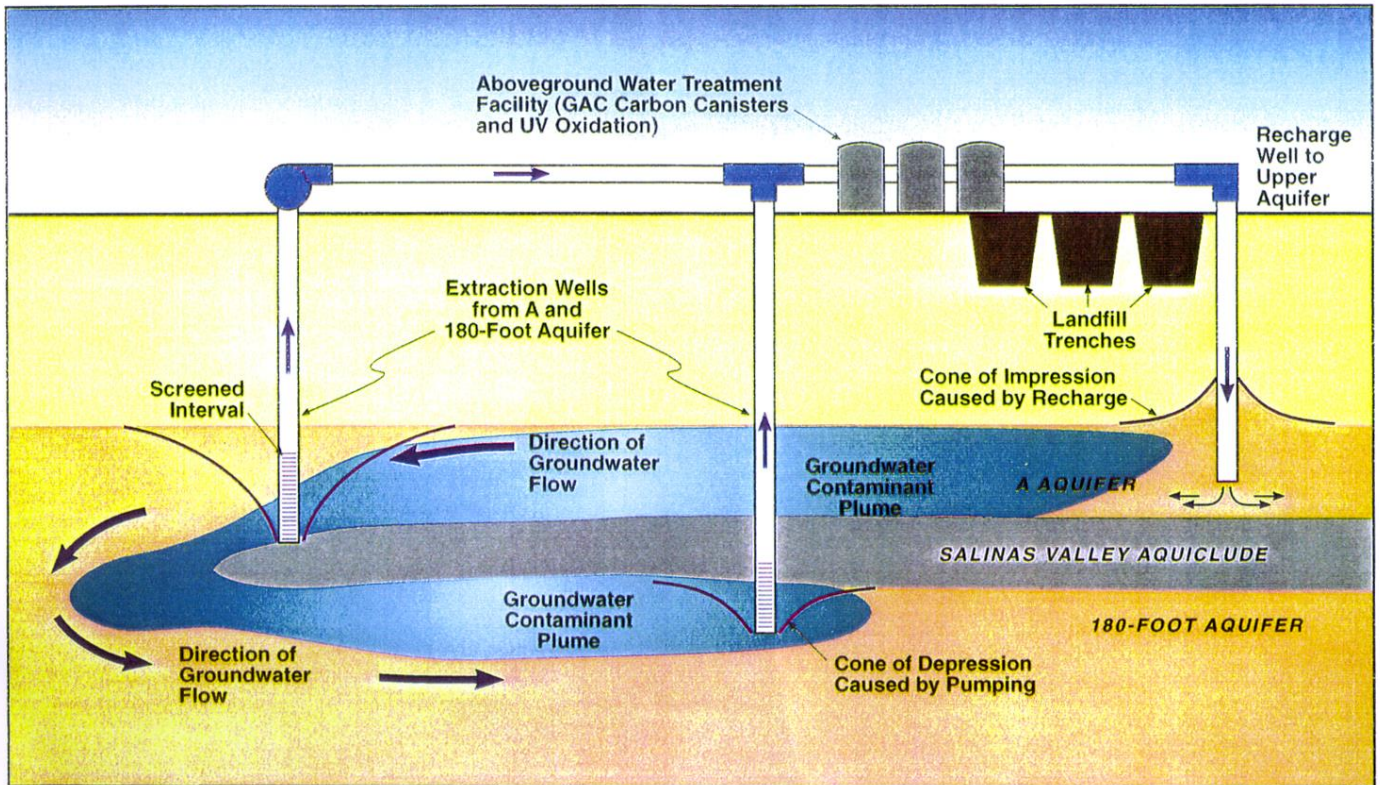


Figure 9: OU2 Groundwater Pump-and-Treat System (U.S. Army, 2000)

The four GAC beds are normally operated in series with two in the northern containment berm and two in the eastern containment berm (See Figure 10). In September 2001 the system achieved 96.28% operability of the average flow rate of 996 gallons per minute (gpm). Between October 23, 1995, and September 28, 2001, the cumulative treated flow of water equaled 1,632 billion gallons (Harding Lawson Associates, 2001).

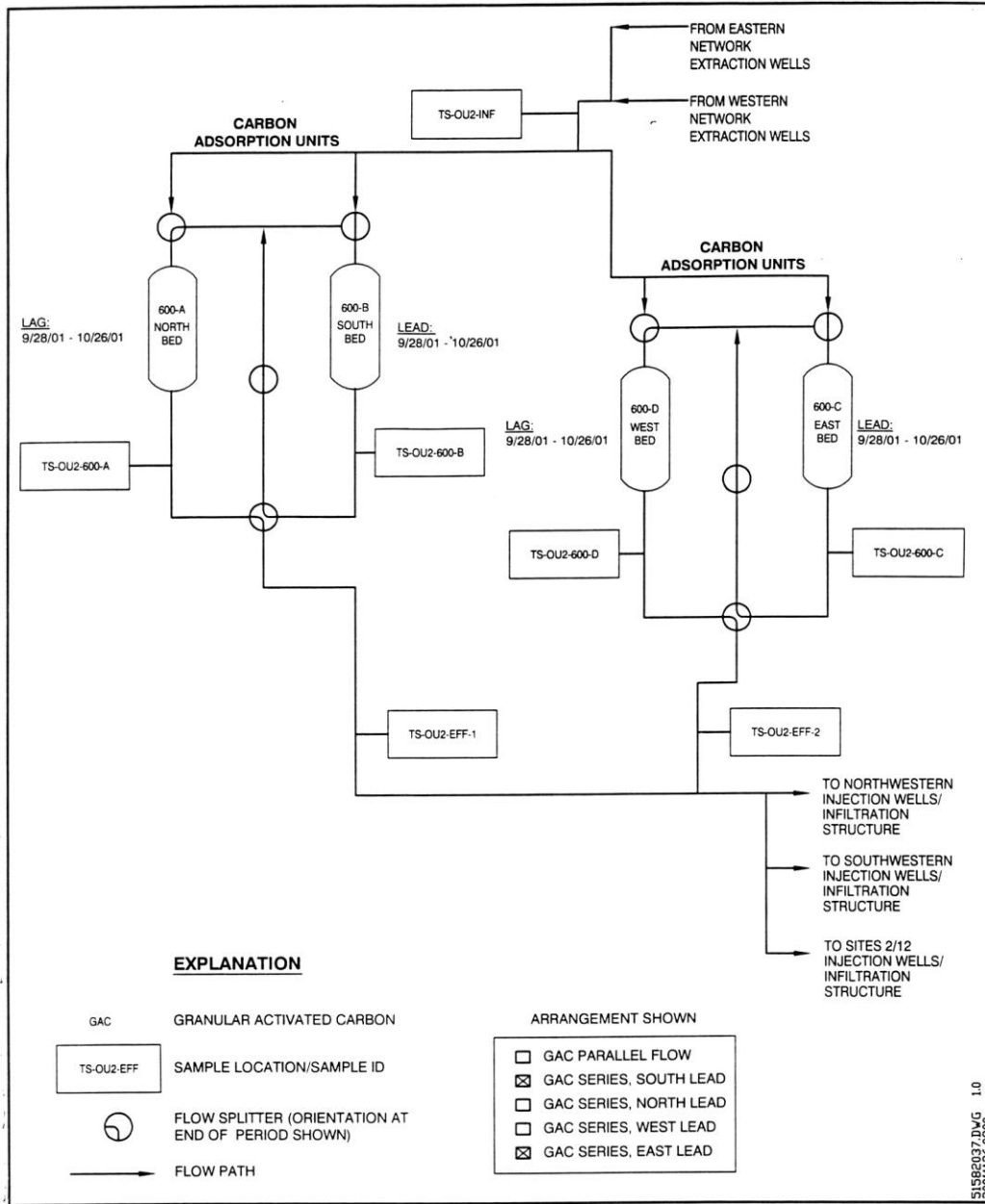


Figure 10: OU2 Groundwater Treatment Schematic (Harding Lawson Associates, 2001).

Each quarter the U.S. Army Corps of Engineers samples the wells of OU2.

Trichloroethylene is detected using the EPA test methods 8010 and 8020 for organic analysis.

They look at the relative percent difference (RPD) between data for the current sampling event

and the moving annual average. A RPD greater than 50 for a given well demonstrates a significant increase in chemical concentration over the previous sampling event. A RPD of less than -50 shows a significant decrease in chemical concentration. RPDs between +50 and -50 indicate no significant change in the well's concentration (Harding Lawson Associates, 1995b).

There are several features that make the aquifers here challenging to remediate. The heterogeneity of each aquifer complicates the picture. There are different layers of different materials in the aquifers. In addition, it is difficult to characterize the subsurface. The only place where the subsurface is well defined is where there is a well sunk and bore data available. These factors combine to make groundwater flow patterns under the former landfill difficult to predict and model.

As mentioned earlier, the U.S. Army Corps of Engineers uses the pump-and-treat method of remediation at this site, which is the only treatment method to date approved by the EPA for removing trichloroethylene (U.S. EPA, 1998). About 68% of all Superfund sites choose this remediation strategy (Abelson, 1990). This site's facility uses granular activated carbon (GAC) beds during the treatment process. Organic carbon is lipophilic and very reactive, making it an ideal substance with which to absorb TCE from contaminated water (Allen-King, et al., 1997). In addition, the Safe Drinking Water Act Amendments of 1986 specify granular activated carbon (GAC) adsorption as the best treatment technology available for drinking water supplies contaminated with synthetic organic contaminants like TCE (Kilduff and Wigton, 1999). Given this, it is surprising to discover that pump-and-treat methods are generally expensive, time intensive, and rarely effective at reducing TCE concentrations below EPA drinking water standards (Stiber, et al., 1999).

4.2. Alternate Remediation Strategies

The pump-and-treat process is questionable as a remediation strategy. A recent study at the Oak Ridge National Laboratory examined its effectiveness at 16 sites. This study found that while pump-and-treat systems are very effective in terms of plume containment and contaminant mass reduction, pump-and-treat is unable to return aquifers to EPA standards within a reasonable time frame. In fact, at the time of completion the study was unable to find confirmed evidence of any aquifer in the United States successfully remediated to EPA drinking water standards through the pump-and-treat process (Doty and Travis, 1991). A joint study by the Water Science and Technology Board, the Board on Radioactive Waste Management, and the Commission on Geosciences, Environment, and Resources came to many of the same conclusions. They point out that the government and industries "...might be wasting large amounts of money on ineffective remediation efforts" (Water Science and Technology Board, et al., 1994). When the aquifers involve contamination with high quantities of non-aqueous phase liquids (NAPLs), the Oak Ridge study states that the aquifer cannot be restored to drinking water standards within a reasonable time frame. Additionally, they state when the dense non-aqueous phase liquids (DNAPLs) like TCE pool at the bottom of the aquifer, drinking water standards will not be reached at any cost (Doty and Travis, 1991).

There are a few alternative treatment strategies currently available. In situ bioremediation is one such alternative. Microbial populations are utilized to metabolize the contaminants inside the aquifer. However, there are problems with this method. There must be a very thorough understanding of the site's physiochemical, hydrogeological, and microbial components as well as an understanding of how nutrients and oxygen flow through the system

(Nelson, 1993). In the case of chlorinated solvents and TCE specifically, metabolism is aerobic. Oxygen must be added to the aquifer and acts as an electron acceptor. There must also be an electron donor present for the process to work, and all components of the bioremediation system (including the contaminant) must be present in the same location at the same time in the appropriate concentrations (Lang, et al., 1997).

Several electron donors have been studied; the ones with the most promise are methane and phenol. At the Savannah River, South Carolina, Superfund site researchers injected methane, air, N_2O , and triethyl phosphate ($TEPO_4$) into the TCE contaminated aquifer at a test site to stimulate the existing methanotrophic bacteria with limited success. One problem was as stated above. It was difficult to ensure all of the components were in the correct place at once. Another problem was understanding the complex microbial ecology. When the microbial growth rate was high, so was the rate of TCE degradation. In addition, they found that the products of TCE degradation are toxic to the methanotrophs. The faster TCE was degraded the more toxic products were created, causing the number of living methanotrophs to decrease (Travis and Rosenberg, 1997). Researchers have used phenol as an electron donor in several studies, including one at the Moffett Naval Air Station in Mountain View, California (Hopkins, et al., 1993). Laboratory and field studies show that phenol-aided TCE transformation is quicker than methane-aided TCE transformation. However, phenol itself is a contaminant. Adding phenol to an aquifer would require complete containment of the treatment area as well as an additional remediation step to rid the aquifer of the phenol (Lang, et al., 1997).

Regardless of which electron donor is used, a problem with bioremediation remains. In general, the products of degrading chlorinated chemicals are more toxic and more mobile in the

aquifer than the original contaminant itself. TCE breaks down into 1-1-dichloroethylene (DCE) or other DCE isomers as well as vinyl chloride (VC) (Kao and Prosser, 1999). VC is a known human carcinogen (Lang, et al., 1997). Until an effective technology becomes available that does not result in harmful contaminants, bioremediation of TCE appears to be limited to laboratory models and experiments. Other factors that contribute to the current failure of bioremediation at many sites include (Fredrickson, et al., 1993, and Water Science and Technology Board, et al., 1994):

- The presence of additional toxins like heavy metals that inhibit biodegradation
- Slow reaction rates due to abiotic factors like low temperature in the aquifer
- Heterogeneous distribution of contaminants
- Small populations of microbial colonies or the absence of microbial colonies that are able to degrade the chemical of concern
- Lack of expertise in the area of bioremediation
- Determining liability if the treatment fails
- Lack of adequate costs/benefit analyses
- Federal regulations discouraging new technologies

Natural attenuation of the aquifer is another treatment strategy. Natural attenuation is also known as intrinsic remediation. This involves leaving the aquifer to degrade the contaminant on its own without additional technology or treatment of the water. Aerobic and anaerobic biodegradation are the main processes that affect the chemicals of concern (Kao and Prosser, 1999). The EPA and the U.S. Air Force developed a protocol for evaluating natural attenuation at TCE sites. Reduction in contaminant mass is the primary goal, and reductive dechlorination appears to be the primary process. The eventual end results of natural attenuation are benign substances like carbon dioxide and water. Benefits of this process over bioremediation include its relatively low cost and lack of need for sophisticated technical equipment. However, the harmful intermediate byproducts produced with bioremediation

strategies like vinyl chloride (VC) still exist with this method. In addition, natural attenuation does not prevent the migration of the contaminant, and it is not a particularly rapid process (Stiber, et al., 1999).

5. METHODS

5.1. Community Assistance/Project Guidance

My community partner for this project was the United States Army Corps of Engineers (U.S.A.C.E.). The U.S.A.C.E. maintains offices on the Former Fort Ord at the Presidio of Monterey Annex. David Eisen, a geologist with the U.S.A.C.E., assisted me in narrowing the scope of my project. He works at the Presidio's Environmental and Natural Resources Division. Mr. Eisen also provided me with an extensive database in Excel format containing quarterly well monitoring data and well locations for the OU2 site. This data included the name of each well, each well's global positioning system (GPS) northing and easting in State Plane/NAD 1983, the date of each sampling event, the name of the chemical for which the sample was analyzed and its chemical class, the result of the sampling event in micrograms per liter ($\mu\text{g/L}$), and the sample number. In all, Mr. Eisen forwarded the data on approximately 1500 well samples taken from January 1997 through May 2001 at the OU2 site.

5.2. Data Processing

Taking the database provided by the U.S.A.C.E., I processed the information into a usable format. I sorted the Excel files by grouping the sampling data by aquifer, well type, well number, and date of sampling event. I merged the sampling database with the well location database. At this point I averaged each well's sampling results from a year's four quarterly

sampling events to form an annual mean concentration for each well of the three studied aquifers. This mean decreased artificial spikes in TCE concentrations formed by “sludge flows.” These sludge flows are often the result of a large quantity of pumped water flowing through the system after pumping has been halted for a period of time for maintenance purposes. Because of the three phases of TCE found in the aquifers discussed previously (see Figure 7), sludge flows show unusually high concentrations of contaminants. I converted these sorted and processed Excel files to DBase IV files. This was necessary as ArcView 3.2, the geographic information systems (GIS) software I utilized in a later step, does not recognize files in Excel format.

5.3. Verifying Well Locations with Global Position Systems (GPS) Technology

The fieldwork for this project consisted of taking GPS readings with a Trimble GeoExplorer II system on a subset of the site’s accessible extraction and monitoring wells. I used this data for my accuracy assessment. I was able to find and take GPS measurements on 14 of the total 100 extraction and monitoring wells for the site. Many of the wells lie in restricted access areas. I downloaded the data collected into Pathfinder Office and differentially corrected it. Product specifications state the GeoExplorer II with differential correction is accurate to within two to five meters. I then converted the data into the appropriate coordinate system and units to match the data provided by the U.S.A.C.E. and exported it to ArcView 3.2. I viewed both the U.S.A.C.E.’s well positions and the positions I recorded in ArcView. Using the measuring tool, I calculated an average accuracy of 9.60 feet with a standard deviation of 5.88 feet (see Figure 11). The median was 8.97 feet.

I also took GPS readings of the perimeter of Cell A, the only open access area of the landfill site. I overlaid my readings on the aerial photograph. This was more of a qualitative

check rather than a true quantitative accuracy assessment.

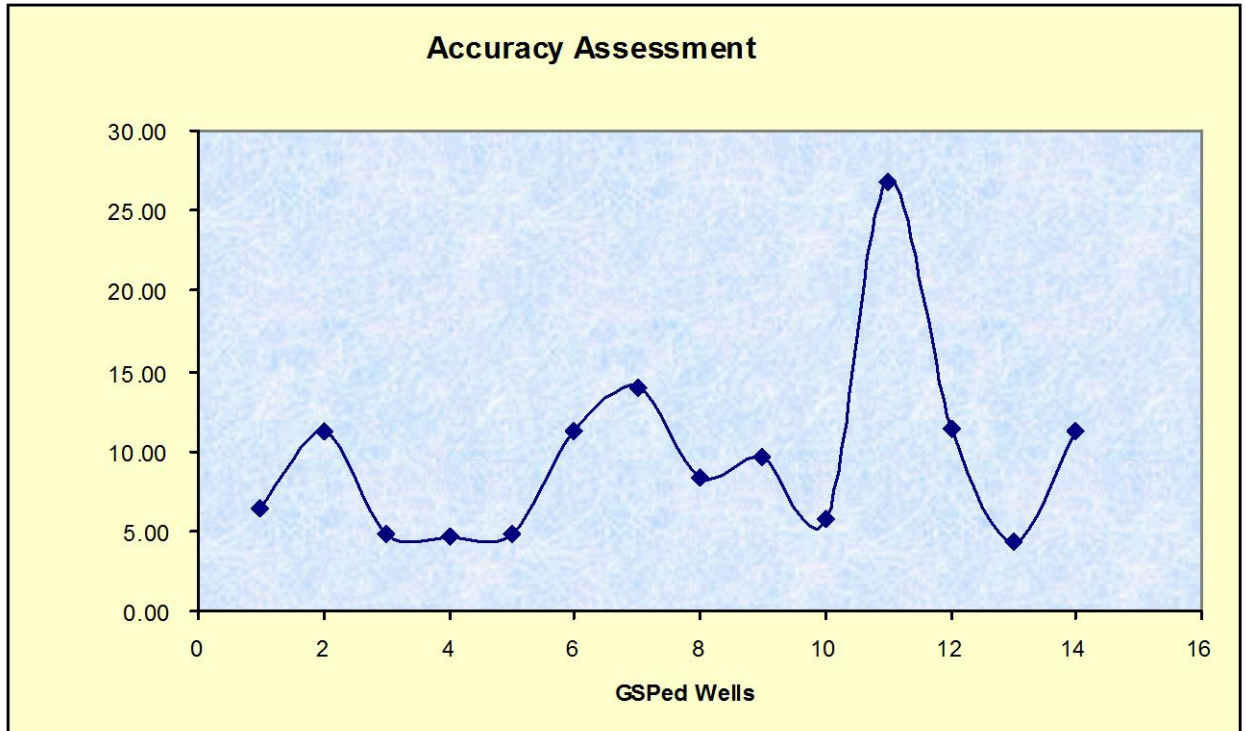


Figure 11: Accuracy Assessment for Site OU2 Well Locations

5.4. Use of Geographic Information Systems (GIS) Software

I located an aerial photograph of the Marina area from the California State University-Monterey Bay's Spatial Information and Visual Analysis database to use as a background image for the data. I converted the image to U.S. State Plane 1983 and feet in TNT Mips to match the datum and coordinate system of the information provided by the U.S.A.C.E. I imported this re-georeferenced aerial image into my ArcView project. In addition, I imported the DBase IV files containing the sampling data and GPS coordinates of the wells into the project. I created a layout showing all the wells of my study site and exported the image as a jpeg.

The first layout I produced of the site shows all monitoring and extraction wells drilled in

each of the aquifers along with the locations of the wells on which I took GPS readings. This map provides a framework for beginning to orient oneself to where the site is with respect to populated areas of the community (see figure 12). The source area for the TCE is marked on the map. I also labeled each of the landfill cells on this view. Some of the wells are located in close proximity to one another and are hidden behind another well in the view.

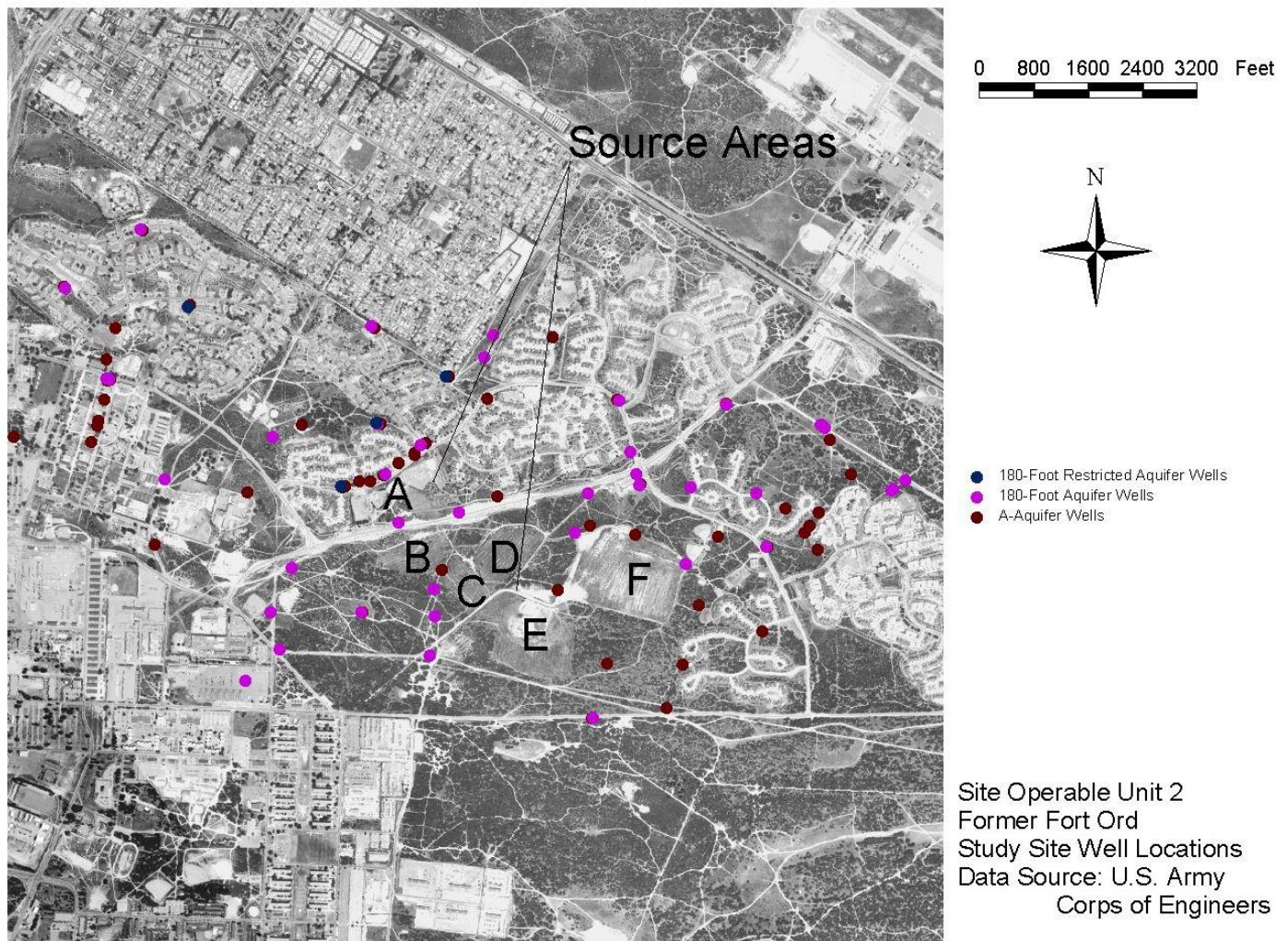


Figure 12: Groundwater Extraction and Monitoring Wells of the Former Fort Ord Landfill

Using the “Create TIN from Surface Feature” in the 3D Analyst Extension of ArcView, I formed triangulated annual concentration gradients for two of the three aquifers. I constructed

one gradient per year from 1995 through 2001 for the A and Upper 180-foot aquifers. I formed a separate layout in ArcView for each year of results per aquifer and outlined the original source of TCE contamination, the OU2 landfill site, on each image. I exported these images as jpegs.

Because the 180-foot restricted (Lower) aquifer has only four wells sunk in it, the triangulated computer generation did not work well. I decided to use a color gradient of the well symbols to demonstrate TCE concentration in this aquifer. I constructed one layer of color gradients per year from 1995 through 2001. I formed a separate layout in ArcView for each year of results and outlined the original source of TCE contamination on each image as above. I exported these images as well as jpegs.

5.5. Aquifer Image Animation

Using the exported jpegs created in ArcView, I animated each aquifer's yearly concentration images. I used Adobe ImageReady to import each aquifer's images as a folder and created an animation of them. ImageReady produced higher-quality images than some alternative animation programs but limited my choices for exporting to QuickTime movies. A QuickTime player or other movie player will be required to view the animations.

6. RESULTS AND DISCUSSION

The images produced are not as accurate as a statistical analysis of the difference between concentrations sampled from quarter to quarter at each well site. However, they demonstrate an overall pattern that is easier to read than contour lines on a map or statistical tables. I feel they are advantageous to contour maps when discussing the landfill remediation operations in general terms. They present the information in a way that allows the general public to gain a sense of the

trends in the trichloroethylene plumes' movements and concentrations over time.

The following pages are the animated images of average annual trichloroethylene concentration gradients in the A-, 180-foot (Upper), and 180-foot restricted (Lower) aquifers from 1997 to 2001. The legend shows how the gradient is classified as well as which aquifer is being demonstrated. Click on the filmstrip icon in the lower left corner of the image to view the QuickTime movie if you are viewing an electronic copy of this report. If you are viewing a printed copy of this report, you will be unable to view the following animations. I have added thumbnail images of each layer below for the appropriate aquifer in the printed version. In addition, each layer is printed at normal size in Appendix 8.1.in both versions.

6.1. A-Aquifer

The A-aquifer had four main areas of relatively high concentration from 1997 to 2001. The first area is the lobe directly north of Cell A. The maximum yearly average trichloroethylene (TCE) concentration in this location ranged from 35 to 40 µg/l (micrograms per liter) each year from 1999 to 2001 except during 2000. In 2000 the maximum yearly average TCE concentration ranged from 30 to 35 µg/l. The second area, located to the northwest of Cell A, showed maximum yearly average TCE concentrations ranging from 15 to 20 µg/l from 1997 to 1999. In 2000 the concentration reduced to 10 to 15 µg/l then increased to 25 to 30 µg/l in 2001. Another lobe of relatively high TCE concentration is located to the north of Cell F. This lobe had an initial maximum yearly average TCE concentration of 10 to 15 µg/l in 1997. The concentration increased to 25 to 30 µg/l by the end of the 2001 data. The last main area of relatively high TCE concentration is a lobe located northeast of Cell F. This lobe had maximum yearly average TCE concentrations in the 25 to 30 µg/l range during 1997, 1999, 2000, and

2001. During 1998 the maximum concentration range increased to 30 to 35 $\mu\text{g/l}$ in this area.

Plume flow appears to be controlled by the hydraulic high located just to the south of OU2. Groundwater flows down-gradient from this high to the north, east, and west. I believe the two main areas of concern are the sections of high concentration peripheral to the landfill cells. These lobes are isolated from the predicted areas of high concentration adjacent to the landfill but are expected due to groundwater flow patterns in the aquifer. It is important to monitor this area to insure complete capture of the plume. Concentrations in the lobes decreased from 1997 to 2000 but continue to persist at relatively high levels, with a maximum yearly average TCE concentration in the 35 to 40 $\mu\text{g/l}$ range in the lobe north of Cell A and 25 to 30 $\mu\text{g/l}$ in the lobe north of Cell F. At this time, the plume appears to be adequately captured, and the data support my original hypothesis concerning this. However, additional data from wells drilled east of the plume in this aquifer would be necessary to confirm this.



A.mov

6.2. Upper 180-Foot Aquifer

The 180-foot aquifer had three main areas of relatively high TCE concentrations during 1997 to 2001. These areas are located north/northwest and southwest of Cell A and north of Cell F. The first lobe of relatively high maximum yearly average TCE concentration is located north/northwest of Cell A. This lobe maintained a maximum yearly average TCE concentration of 25 to 30 $\mu\text{g/l}$ from 1997 to 2001. However, the shape and size of the lobe changed. The second area is located to the southwest of Cell A. The maximum yearly average TCE concentrations in this lobe ranged from 20 to 25 $\mu\text{g/l}$ in 1997 and 1998. In 1999 the concentration increased to 30 to 35 $\mu\text{g/l}$ and remained at that level through the end of the 2001 data. The final area of relatively high TCE concentration in this aquifer is located to the north of Cell F. The 1997 maximum yearly annual TCE concentration range was 15 to 20 $\mu\text{g/l}$. This decreased in 1998 to 10 to 15 $\mu\text{g/l}$ and 5 to 10 $\mu\text{g/l}$ in 1999. However, the maximum yearly average concentration increased to 10 to 15 $\mu\text{g/l}$ in 2000 and to 15 to 20 $\mu\text{g/l}$ in 2001.

Maximum yearly average concentrations in the area to the north/northwest of the landfill cells persist in the range of 25 to 30 $\mu\text{g/l}$ range through 2001 data. The lobe southwest of Cell A increased to the 30 to 35 $\mu\text{g/l}$ range in 2001. These areas of relatively high TCE concentration appear to be consistent with where the A-aquifer is in contact with the 180-foot aquifer due to the pinching out of the Fort Ord-Salinas Valley Aquitard (see Figure 4). The data from this aquifer does not support my original hypothesis that plume concentrations should be declining, perhaps due to this aspect of the aquifer's unique hydrogeology. However, my hypothesis regarding the remediation strategy's effectiveness in capturing the TCE plume is supported by the data. From the images produced of this aquifer's TCE concentrations from 1997 to 2001, the

plume appears to be adequately captured during this time. The original plume flow was westward. However, current flow appears to be in a slight northeastern direction from the source area. The shift in flow direction can be attributed in part to a high volume of water being pumped from these aquifers in the Salinas Valley for seasonal agricultural use. This is a highly irregular event for an aquifer and has led to many complications in the pump-and-treat process.

Further complicating the issue is pumping from private wells sunk in the Marina region. The Monterey County Board of Supervisors passed Monterey County Ordinance Number 04011 on April 27, 1999. This ordinance regulates new well drilling in the area around the landfill by creating Prohibition and Consultation Zones (see Figure 13) determined by the Monterey County Health Department (Monterey County, 1999). While the goal of this policy is to limit the impact of private wells on the plume's flow, the impact on the aquifers still exists.

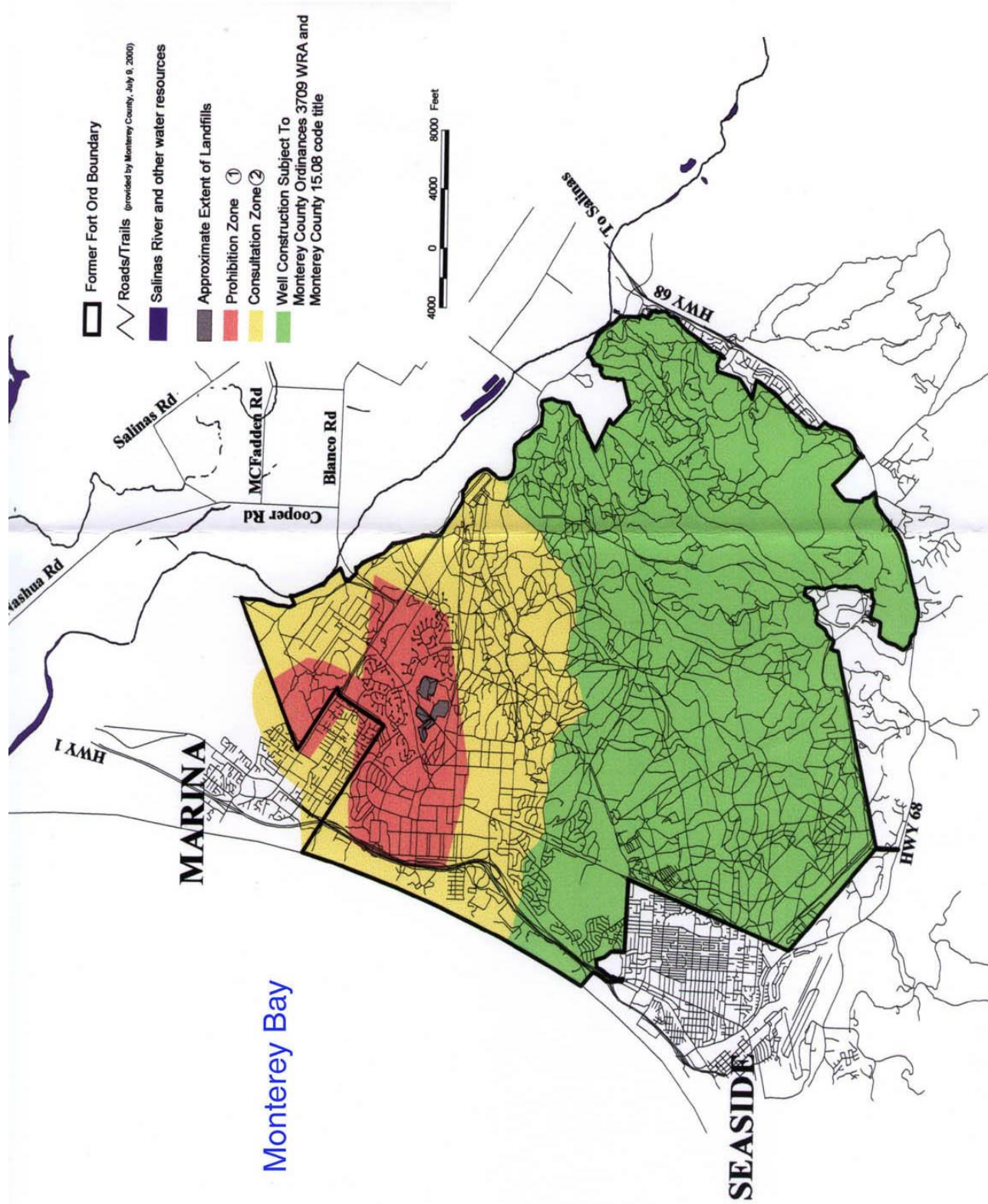


Figure 13: Special Zones for Well Drilling (Harding ESE, 2001)



6.3. Lower 180-Foot Restricted Aquifer

There are only four wells drilled in the 180-foot (Lower) restricted aquifer. The maximum average annual TCE concentration initially ranged from 10 to 15 µg/l in 1997. This increased to 15 to 20 µg/l in 1998 and 20 to 25 µg/l in 1999. Maximum annual averages decreased to 15 to 20 µg/l in 2000 and 2001. There does appear to be one well sampled with relatively high TCE concentrations compared to the other three wells. This is Monitoring Well Number 6 at the OU2 site and is located north of Cell A. The samples from one well to the northwest of the landfill cells remained consistently below EPA drinking water standards for TCE.

There may be only four wells drilled in this aquifer because of the risk associated with drilling wells in deep aquifers near plumes of contaminants. It is possible to drill down into a lower aquifer than the target aquifer and spread the plume of contaminants down into the “clean” aquifer through the new well. It is also possible to increase the amount of contamination in the target aquifer through improper screening of the well, funneling the chemicals from an upper, more contaminated aquifer down and worsening the problem in the target aquifer. Cost is certainly a prohibitive factor as well. It costs enormous sums of money to drill and test the wells of OU2. Pumping in the Salinas Valley impacts the 180-foot restricted (Lower) and 400-foot aquifers the most (Harding Lawson Associates, 1995b). The majority of the groundwater used in the Salinas Valley comes from these two aquifers. This also complicates the monitoring situation here. Whatever the reason for the limited number of wells, it makes it difficult to develop a complete understanding of the dynamics of this aquifer.

Given the small number of wells drilled, I was unable to accurately determine the extent

of the TCE contamination in the groundwater of this aquifer. I was not able to validate my hypothesis of adequate plume containment using the data available. I would recommend drilling an additional two to three wells north and northeast of Cell A to get a better idea of the size and direction of this plume if high levels of TCE persist in this well.



6.4. Effectiveness of Current Remediation Plan

The former Fort Ord Site OU2 uses the pump-and-treat remediation strategy. The U.S. Department of the Army established this system in accordance with the Record of Decision, Basewide Remedial Investigation/Feasibility Study, and it was approved with the Federal Facility Agreement (FFA). The landfill site has a complex subsurface, is contaminated with a dense non-aqueous phase liquid (DNAPL), and has ten other chemicals of concern in its upper aquifers. Their treatment strategy is likely the most effective in terms of contaminant reduction and plume containment that can be hoped to accomplish under these circumstances and with the current technologies available. Pump-and-treat systems are effective when used for plume containment and contaminant mass reduction. The Army is very concerned with plume containment at this site given the complex issues surrounding pumping and water resources in the Salinas Valley and seawater intrusion.

Compared to other NPL sites nationwide, the level of contaminants in these aquifers is relatively low. However, I am unsure that the Army will ever reach their goals of bringing the TCE levels in the A- and 180-foot aquifers below EPA drinking water standards of five parts per billion (ppb), or five micrograms per liter ($\mu\text{g/l}$). The literature I reviewed demonstrated that in most cases pump-and-treat operations would reduce plume mass to a point where the contaminant concentrations leveled off. In cases of initial concentrations of less than 100 ppb like the OU2 site, leveling occurred at 0% to 50% reduction of initial maximum concentrations (Doty and Travis, 1991). While my analysis shows some areas of the initial plume have been reduced to below 5 $\mu\text{g/l}$, many areas seem to be showing signs of leveling by the Spring 2001 sampling event. For instance, in the A-aquifer of OU2 Extraction Well Number 2 showed signs

of leveling above EPA standards during the timeframe encompassed by my data set. The maximum yearly average TCE concentration for this well was 13.33 $\mu\text{g/l}$ in 1997. The sampling result fell to 9.99 $\mu\text{g/l}$ and 8.35 $\mu\text{g/l}$ in 1998 and 1999 respectively. By 2000 the concentration was 8.00 $\mu\text{g/l}$ with the level rising slightly to 8.40 $\mu\text{g/l}$ in 2001. The well demonstrated a reduction of about 63% of the initial maximum concentrations (1997 data) with the leveling trend beginning in 1999. Monitoring Well Number 12 in the same aquifer had sampling results consistently in the 15 to 20 $\mu\text{g/l}$ range during the time for which I had data, suggesting leveling above EPA standards may have already occurred. In the 180-foot aquifer Monitoring Well Number 50 show a 65% reduction in maximum concentrations from 1997 to 2001. After a result of 23.60 $\mu\text{g/l}$ in 1997, the sampled concentrations remained in the 15 to 16 $\mu\text{g/l}$ range except for 1999 when the level dropped to 11.90 $\mu\text{g/l}$. Given the erratic change of concentrations in many wells of this site from 1997 to 2001, I feel that long-term studies including sampling data from years prior to 1997 would be needed to establish leveling trends with any degree of certainty.

Areas of relatively high concentrations in the A- and 180-foot (Upper) aquifers had the same general trend from 1997 to 2001. While individual wells demonstrated concentration reductions, the shape and location of the plume shifted due to groundwater flow and pumping. Overall, the lobes of the plume had roughly the same maximum yearly average range of TCE concentrations in 2001 as they did in 1997. Only the size, shape, and position of the lobes were affected. This suggests that while the remediation system may be capturing the large plumes in these aquifers, the remediation process itself of the areas of highest concentration will proceed gradually. The 180-foot restricted (Lower) aquifer has too few wells to make such generalizations.

I also feel that were the pumping to cease, contaminant levels would rise again due to pools of TCE that may exist on the Fort Ord-Salinas Valley Aquitard (FO-SVA) and because of the nature of properties of TCE. While not included in my analysis, the U.S. Army Corps has one monitoring well screened at the top of the Fort-Ord-Salinas Valley Aquitard (MW-OU2-38-SVA). The samples from this well had a maximum yearly average of 1.82 µg/l in 1997. By June of 1998 the level spiked to 97.0 µg/l, falling to 26.9 µg/l in August 1998 and to below EPA standards by 2001. This suggests pooling on the aquitard may be present in some locations as a result of a non-aqueous phase liquid (NAPL) secondary source of TCE contamination there and TCE pools could possibly be migrating down-dip of the Fort Ord-Salinas Valley Aquitard. If this is the case, the Army likely will not be able to reach EPA standards in a reasonable timeframe. In addition, if TCE exists as a NAPL on the aquitard, the U.S. Army Corps may feel it appropriate to pump and treat this area more aggressively.

There is no question pumping operations must continue to insure plume containment at this time. Without pumping the plume of TCE would undoubtedly spread and foul other agriculture and drinking water supplies. However, in the future it may be wise to re-evaluate the treatment system. I would recommend a study of the microbial colonies present in the aquifers to determine if bioremediation would be a feasible alternative once plume containment is no longer an issue. Perhaps natural attenuation could be utilized in conjunction with the current pumping strategy if the essential microbial colonies are present and pumping to contain the plume is still necessary.

7. CONCLUSIONS

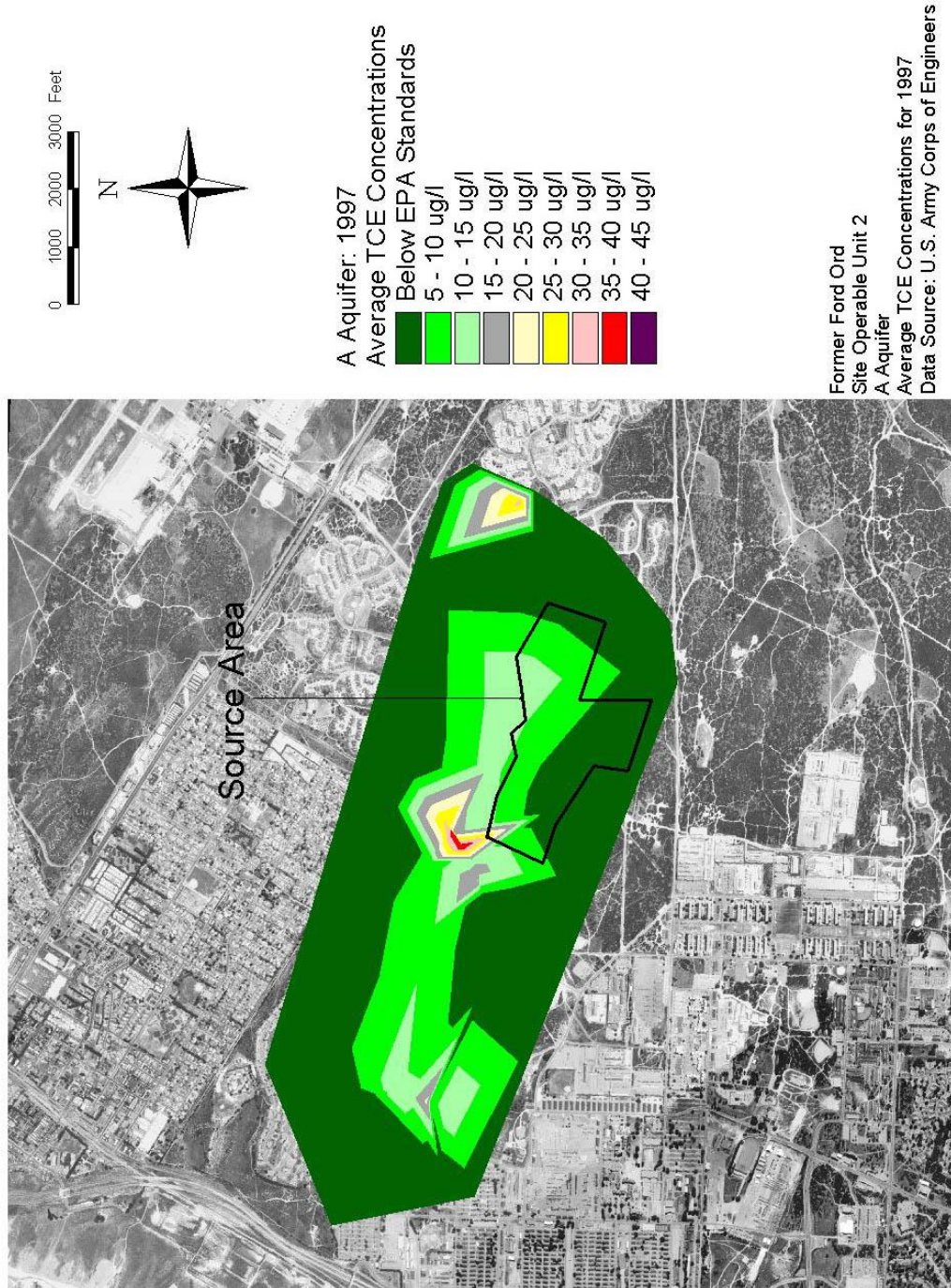
Increases in trichloroethylene (TCE) concentration outside of the source area are more relevant than those found inside the area. My initial hypothesis that areas of high concentration are located near the landfill cells was not supported by the data. It is expected TCE will continue to be found in high concentrations under the landfill for many years to come because of the complex nature of TCE contamination and the hydrogeography of the aquifers. The data supported my hypothesis regarding adequate plume contamination in the 180-foot aquifer. More data would be needed to confirm my hypothesis in both the A- and 180-foot restricted aquifers. I feel I met my project goals of compiling relevant information on the site and trichloroethylene as well as providing an easy-to-interpret representation of how the TCE plume has changed over time in the A-, 180-foot, and 180-foot restricted aquifers. In addition, I think it is important to continue this project using available well data prior to 1997 and data available from sampling events after Spring 2001.

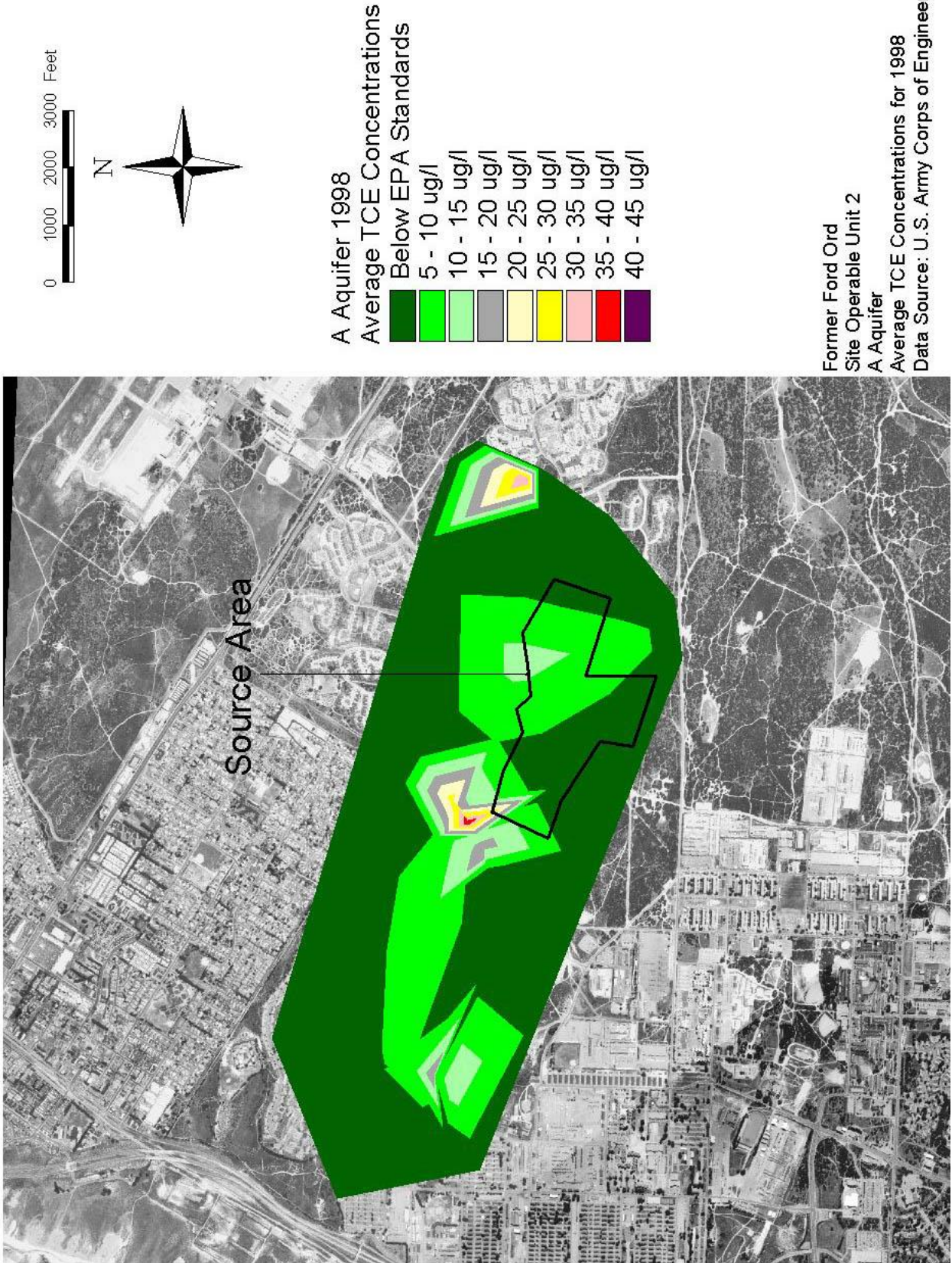
I believe the data and the scientific literature reviewed supported my final hypothesis that the current remediation strategy is appropriate for the OU2 site. However, I feel it will be necessary in the future to re-evaluate the feasibility of the Army's goal to reduce TCE concentrations below EPA drinking water standards. At that time, I suggest developing a cost/benefit analysis that includes a risk analysis for using natural attenuation in combination with pumping or bioremediation to reduce TCE contaminant levels to their lowest possible levels.

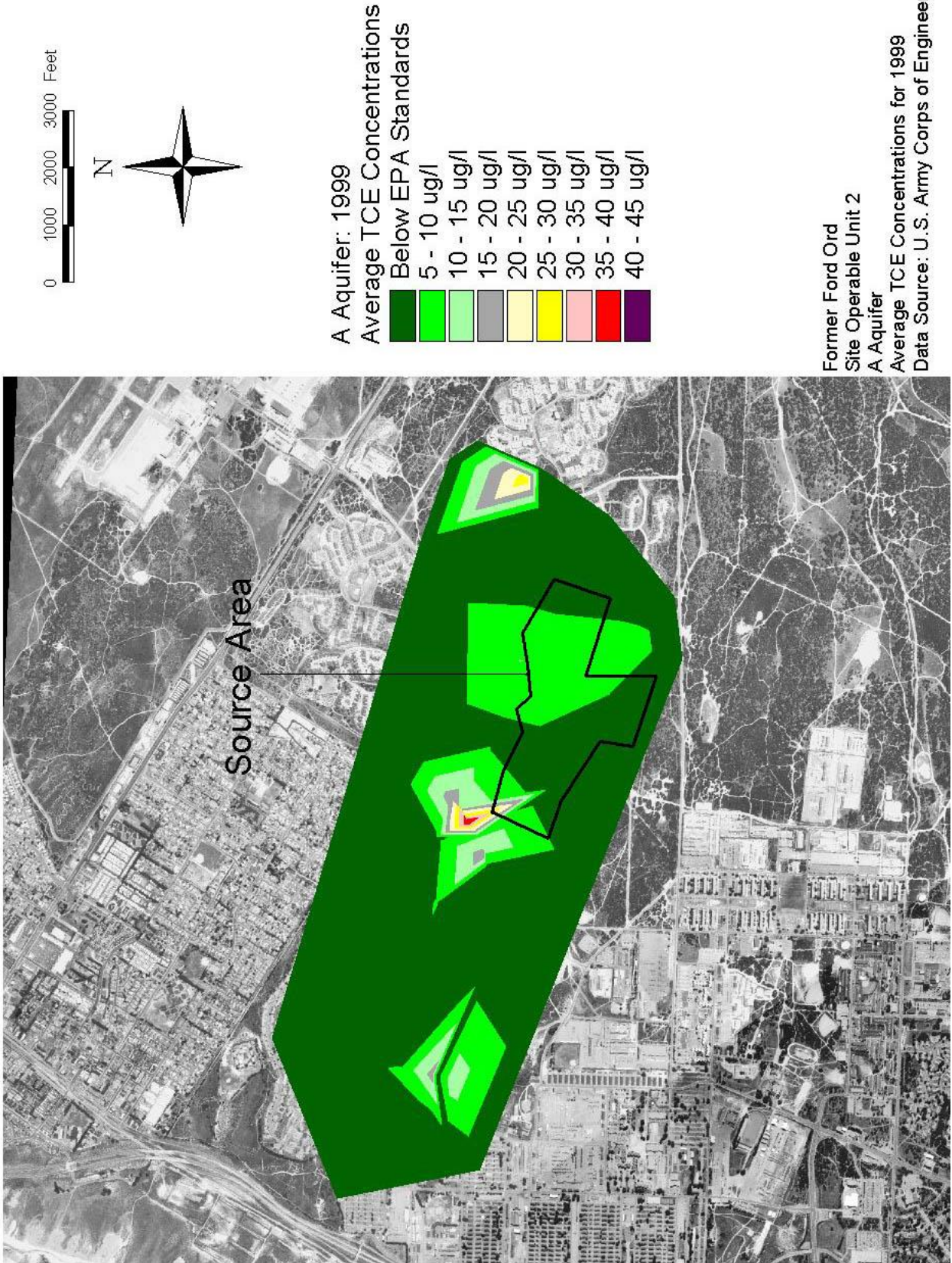
8. APPENDIX OF FIGURES AND TABLES

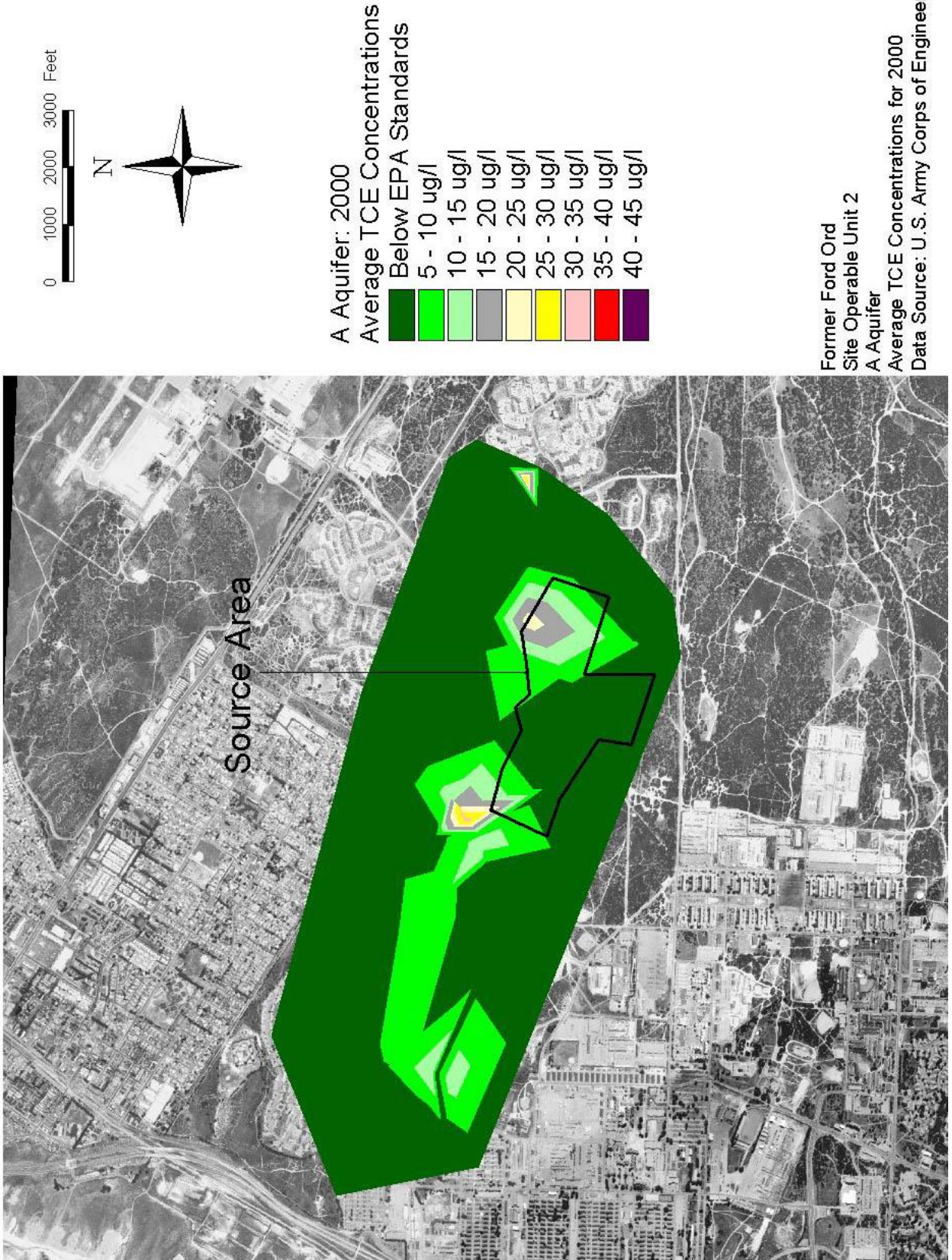
8.1. Images of ArcView Layers

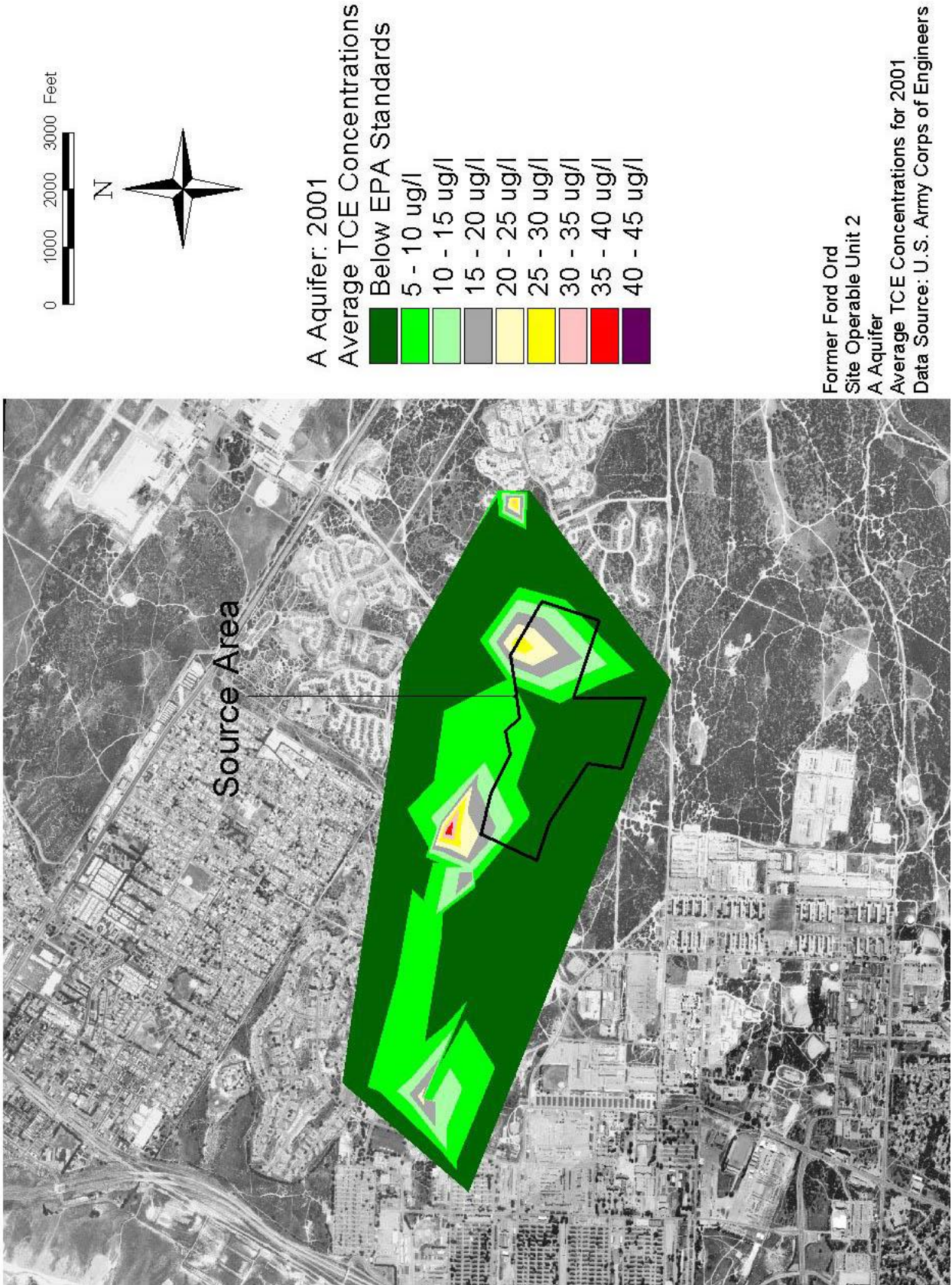
8.1.1. A-Aquifer



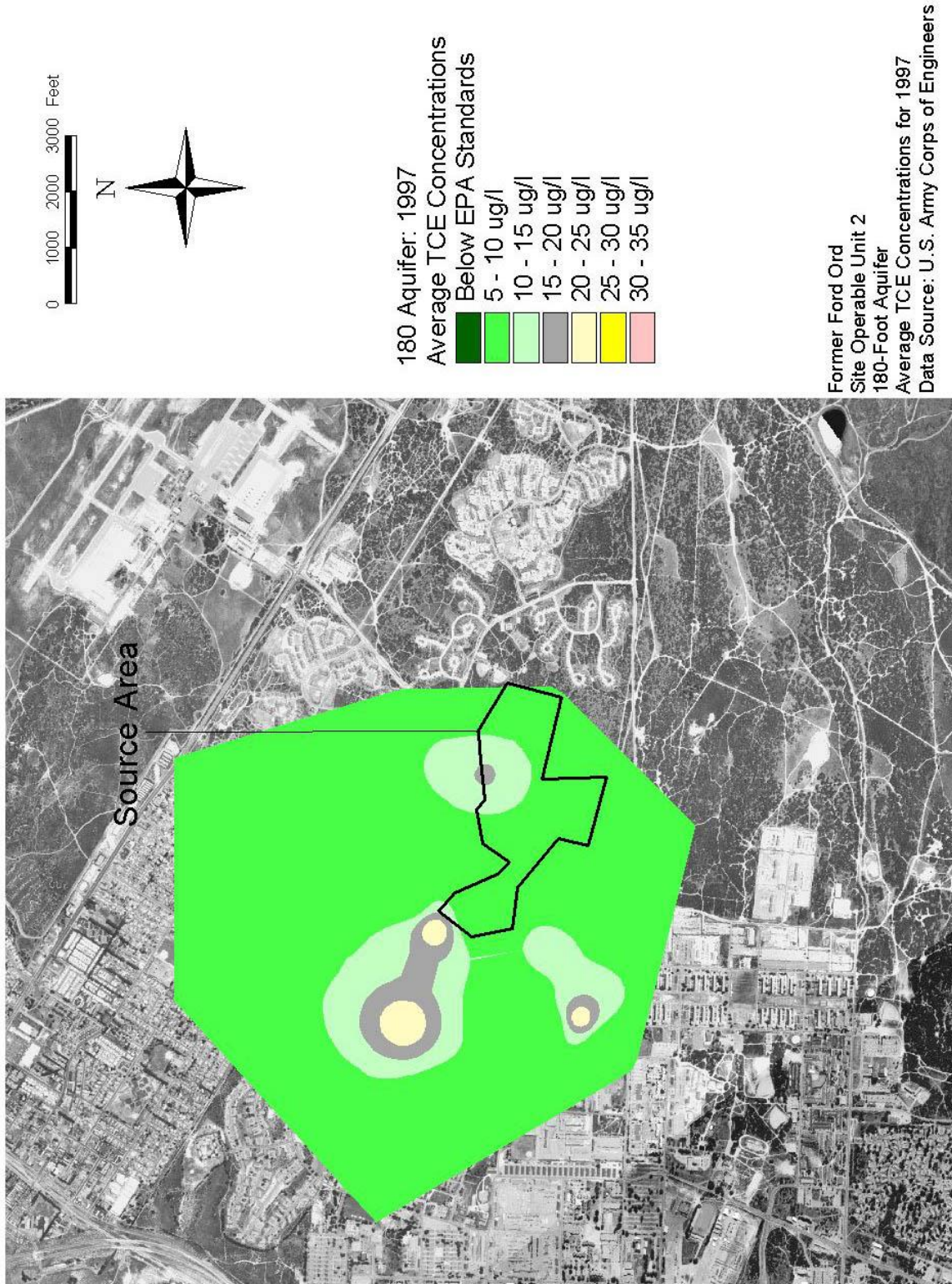


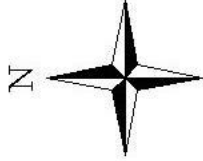
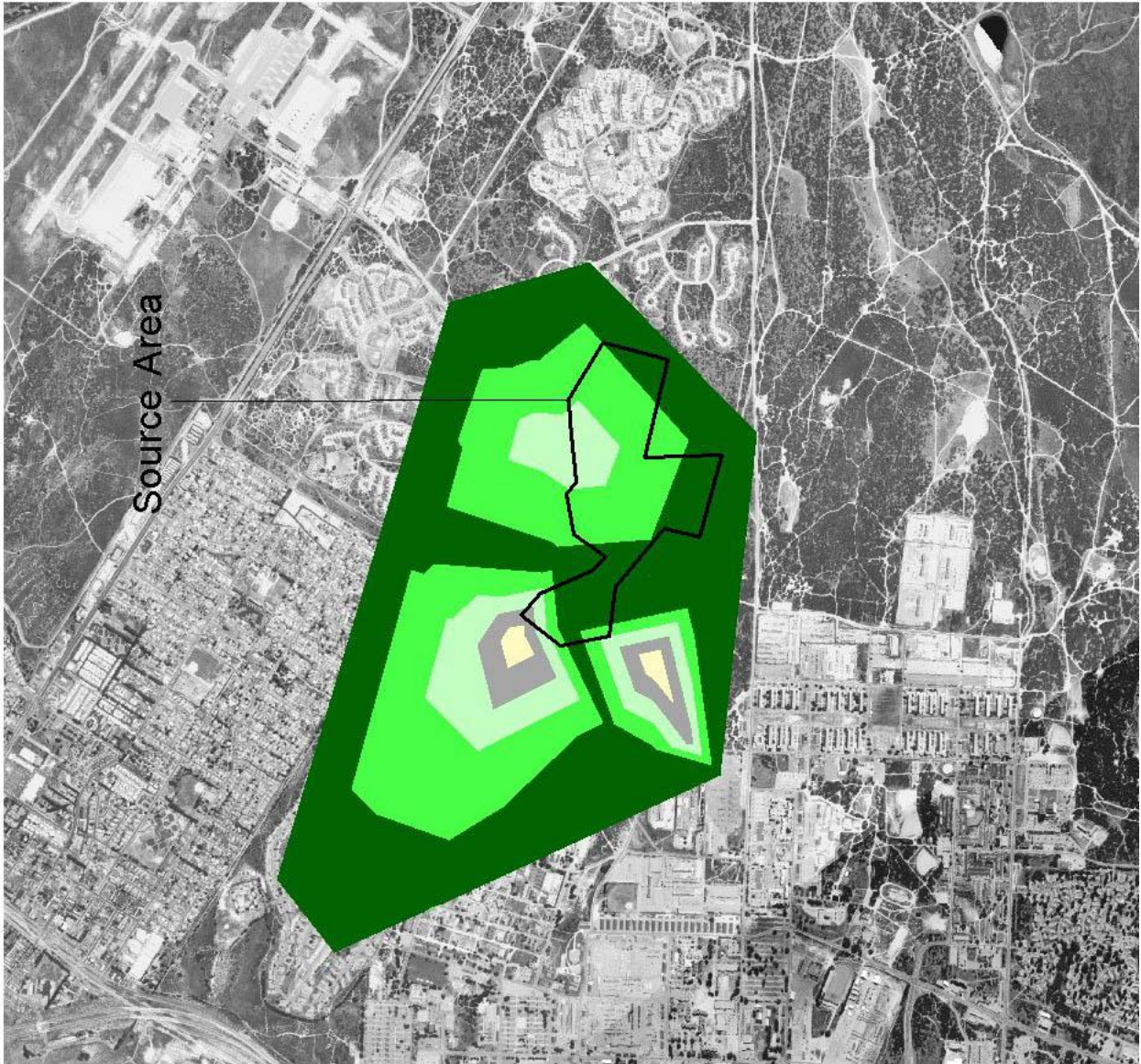






8.1.2. 180-foot Aquifer

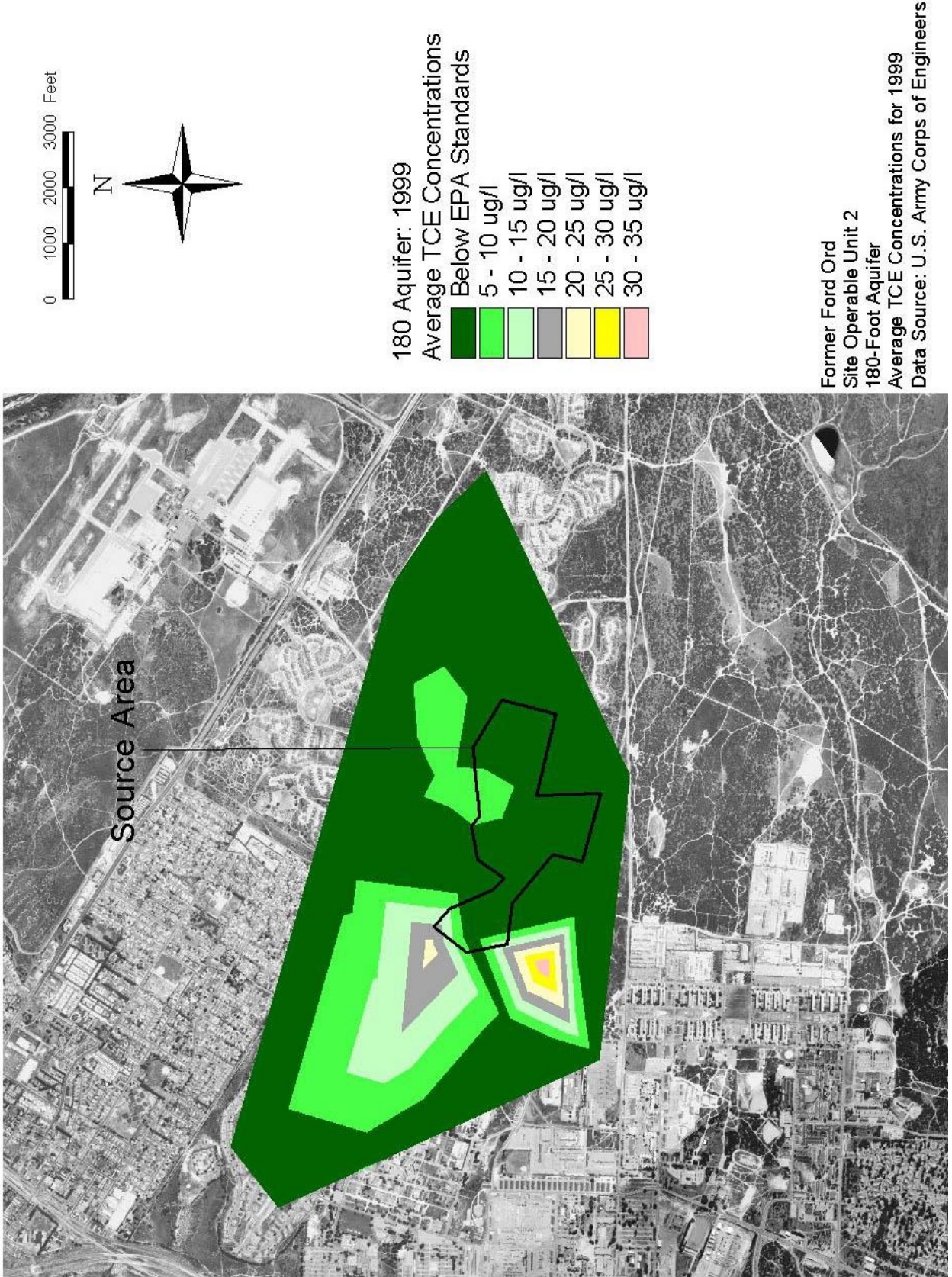


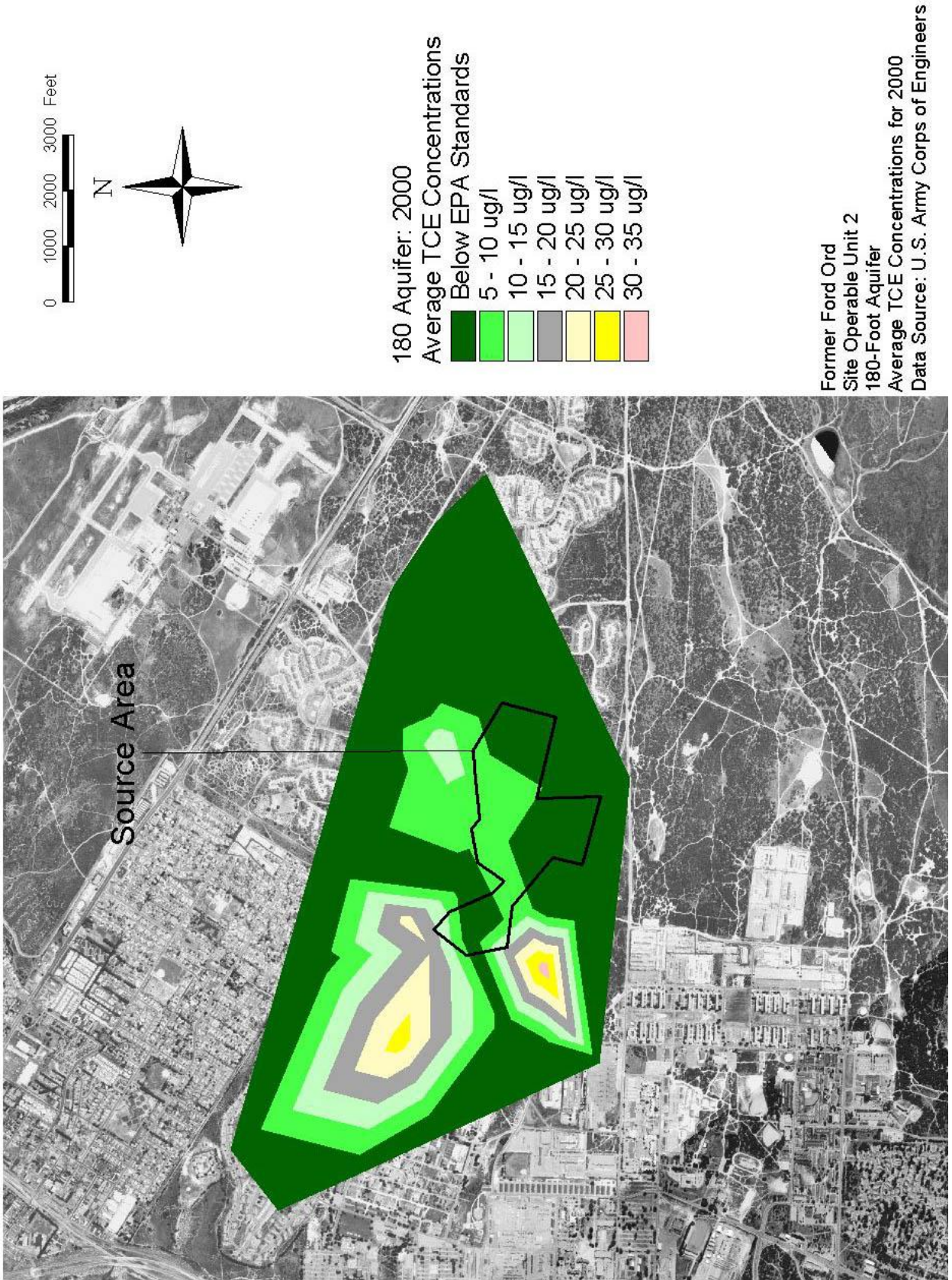


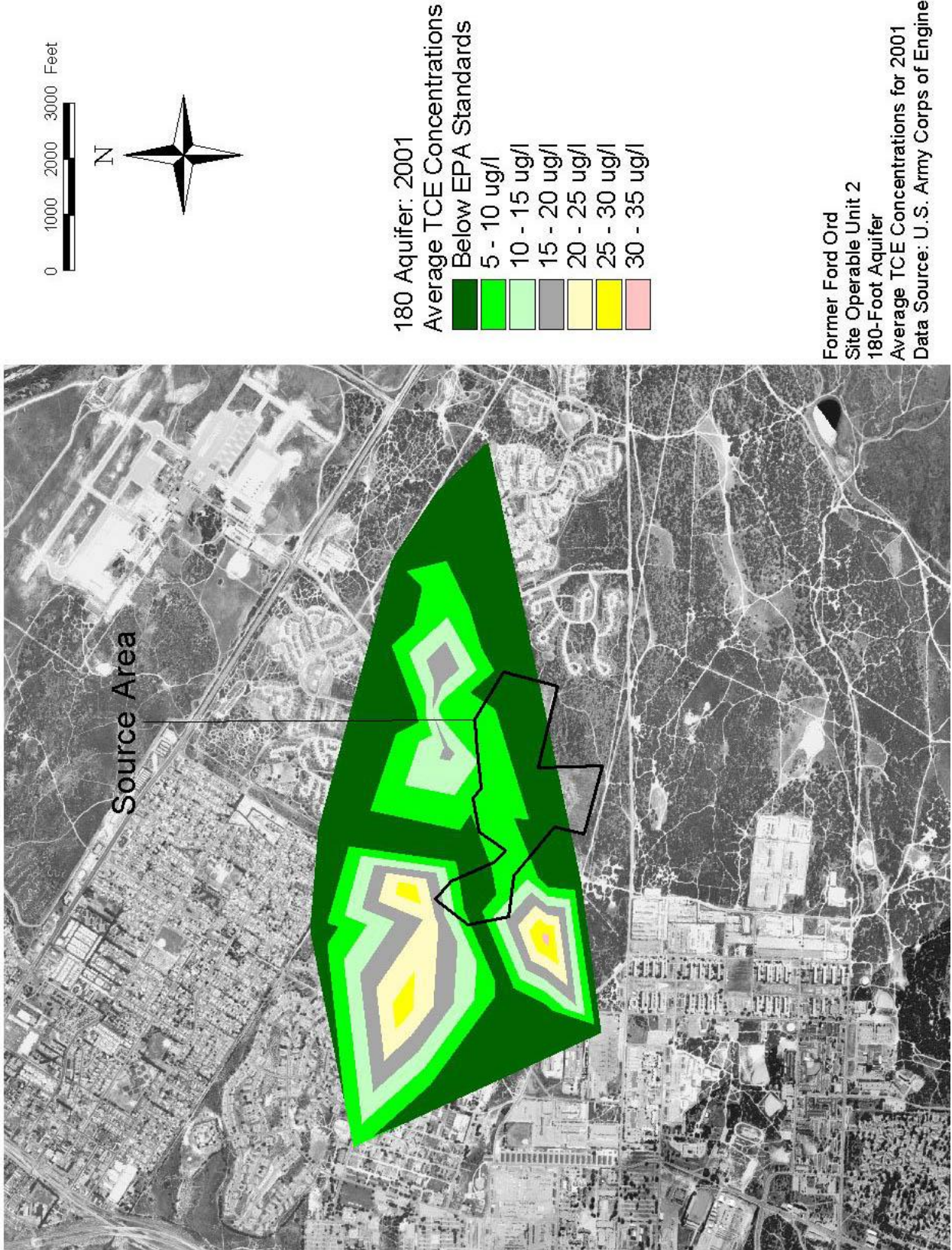
180 Aquifer: 1998
Average TCE Concentrations
Below EPA Standards

Dark Green	5 - 10 ug/l
Light Green	10 - 15 ug/l
Medium Green	15 - 20 ug/l
Yellow-Green	20 - 25 ug/l
Yellow	25 - 30 ug/l
Orange	30 - 35 ug/l

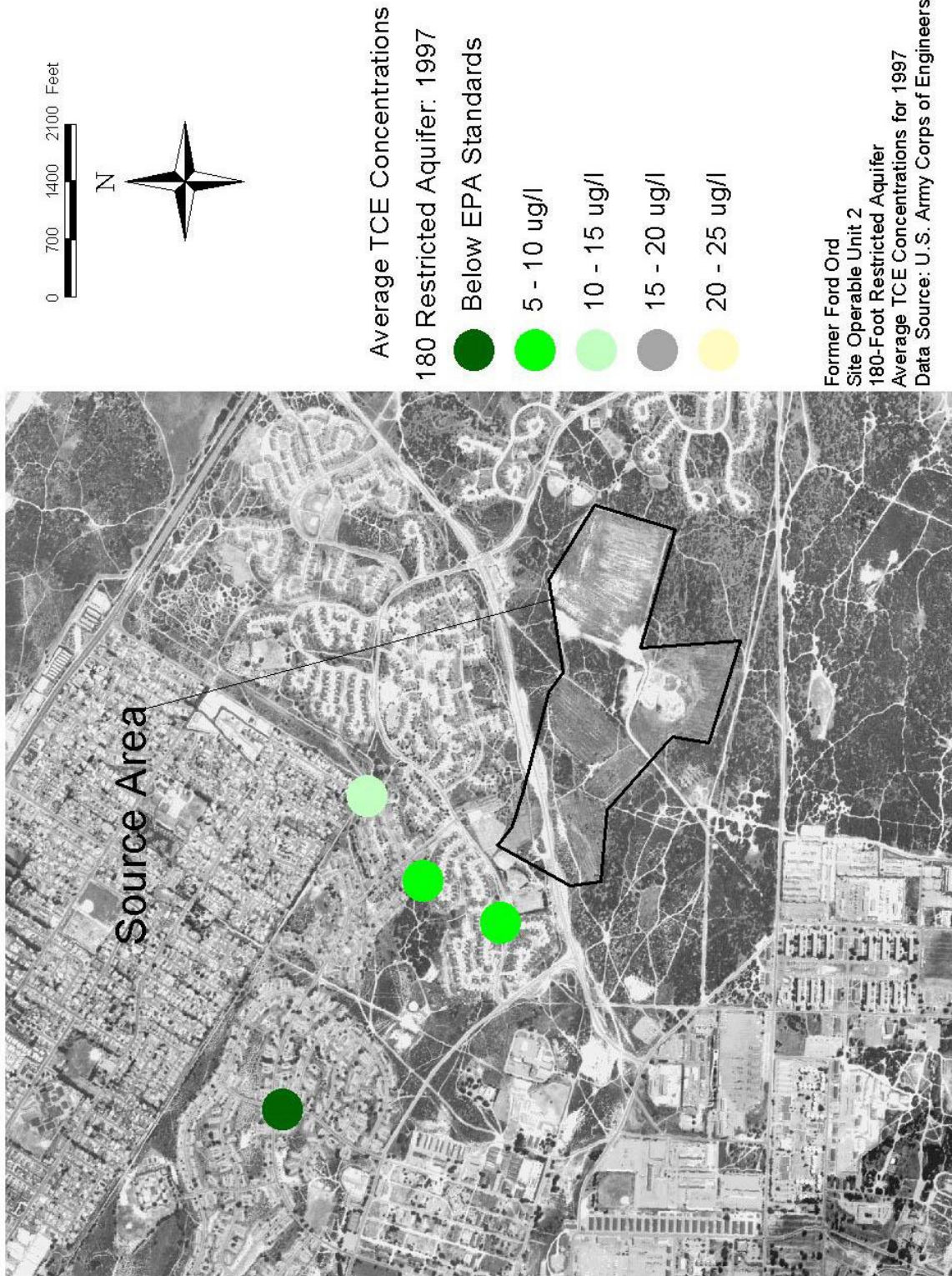
Former Ford Ord
Site Operable Unit 2
180-Foot Aquifer
Average TCE Concentrations for 1998
Data Source: U.S. Army Corps of Engineers

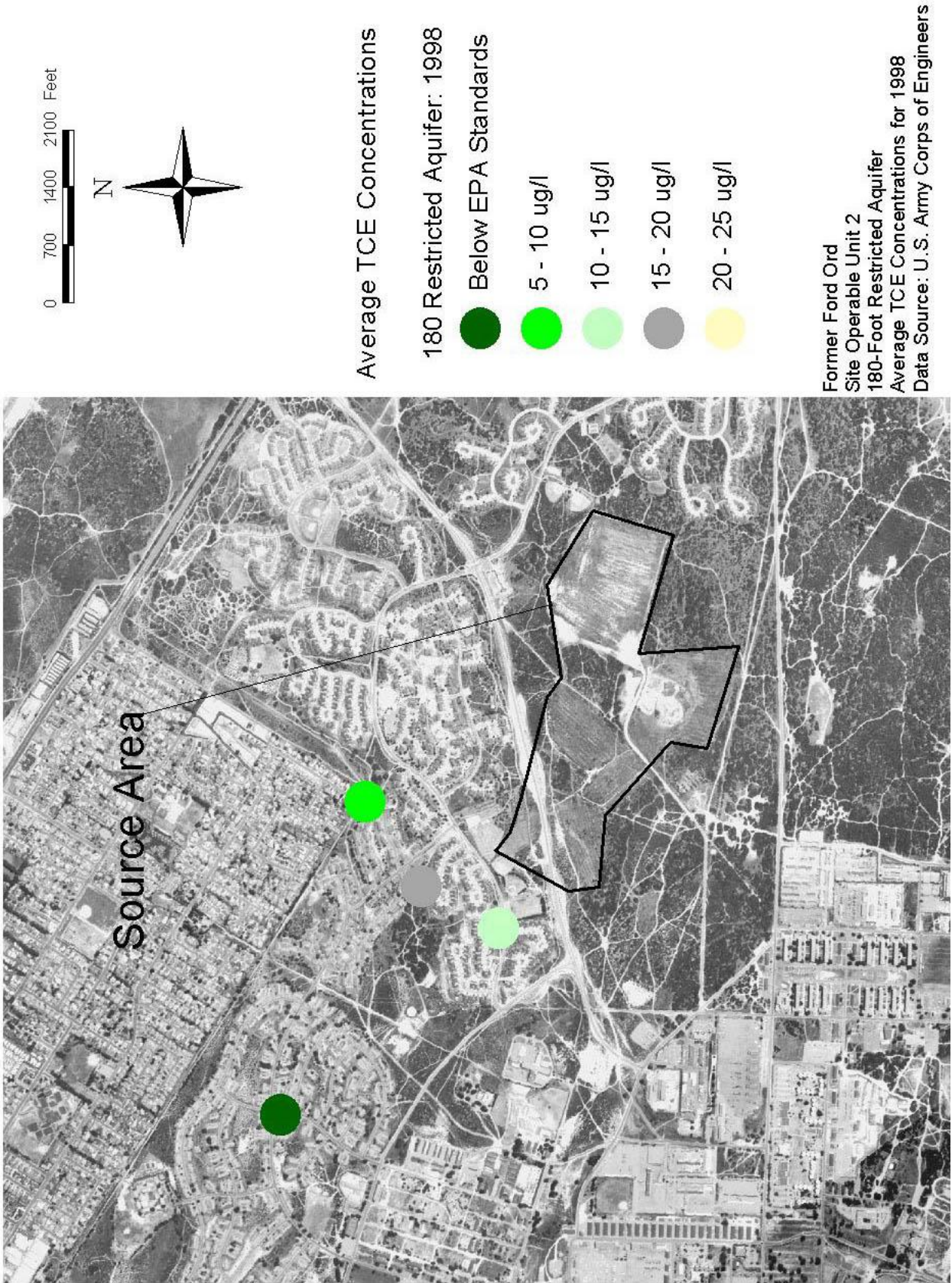


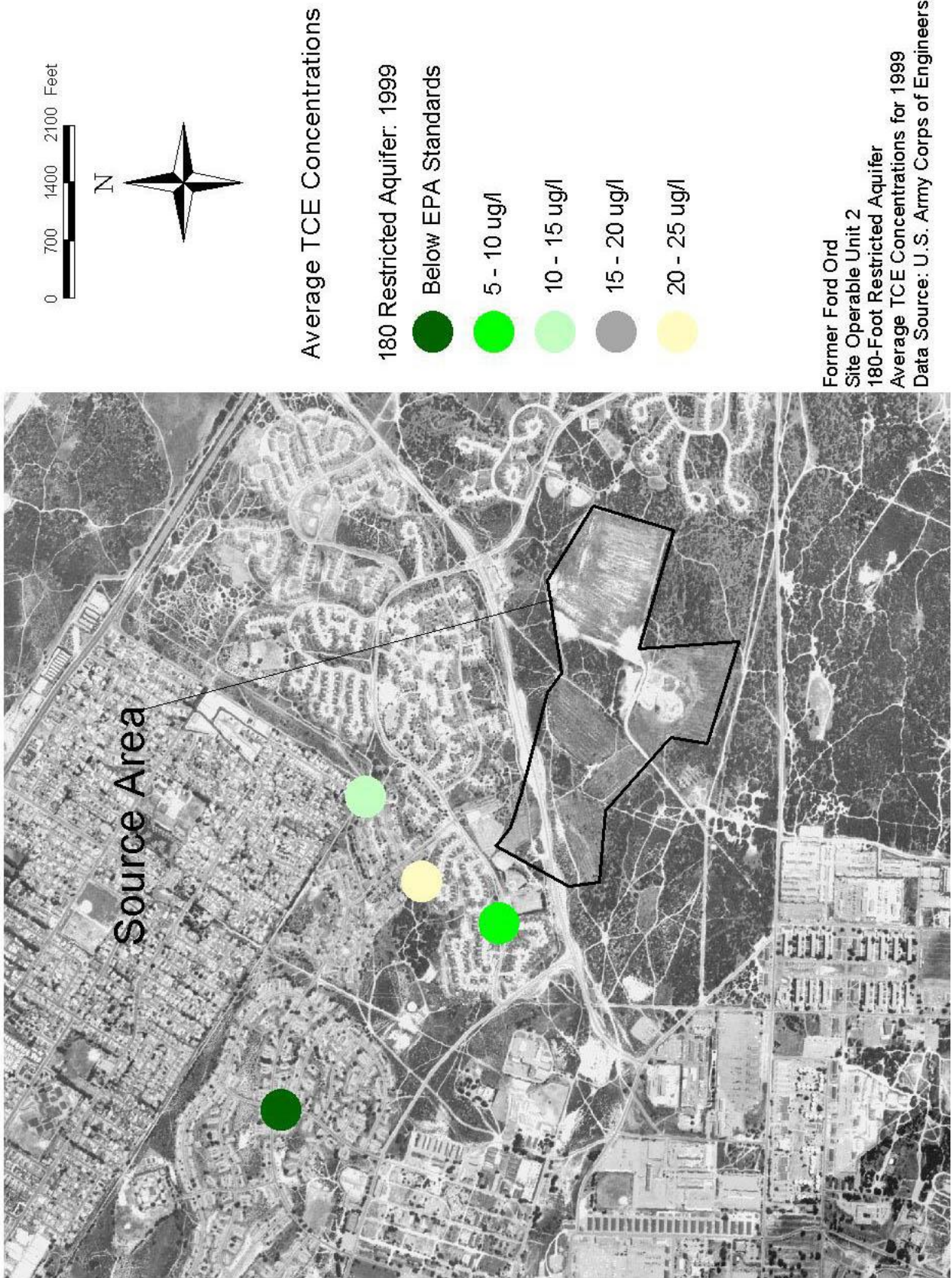


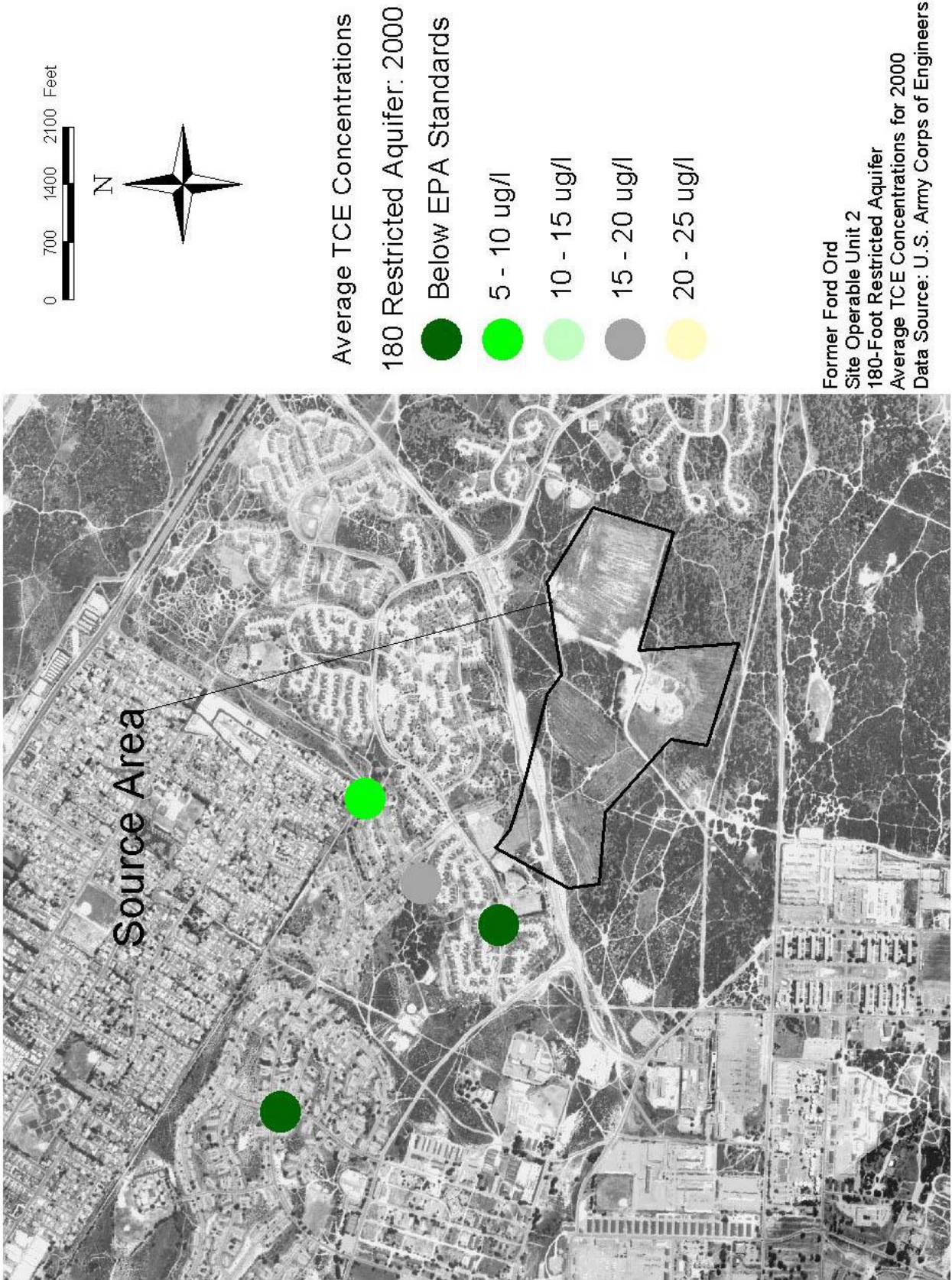


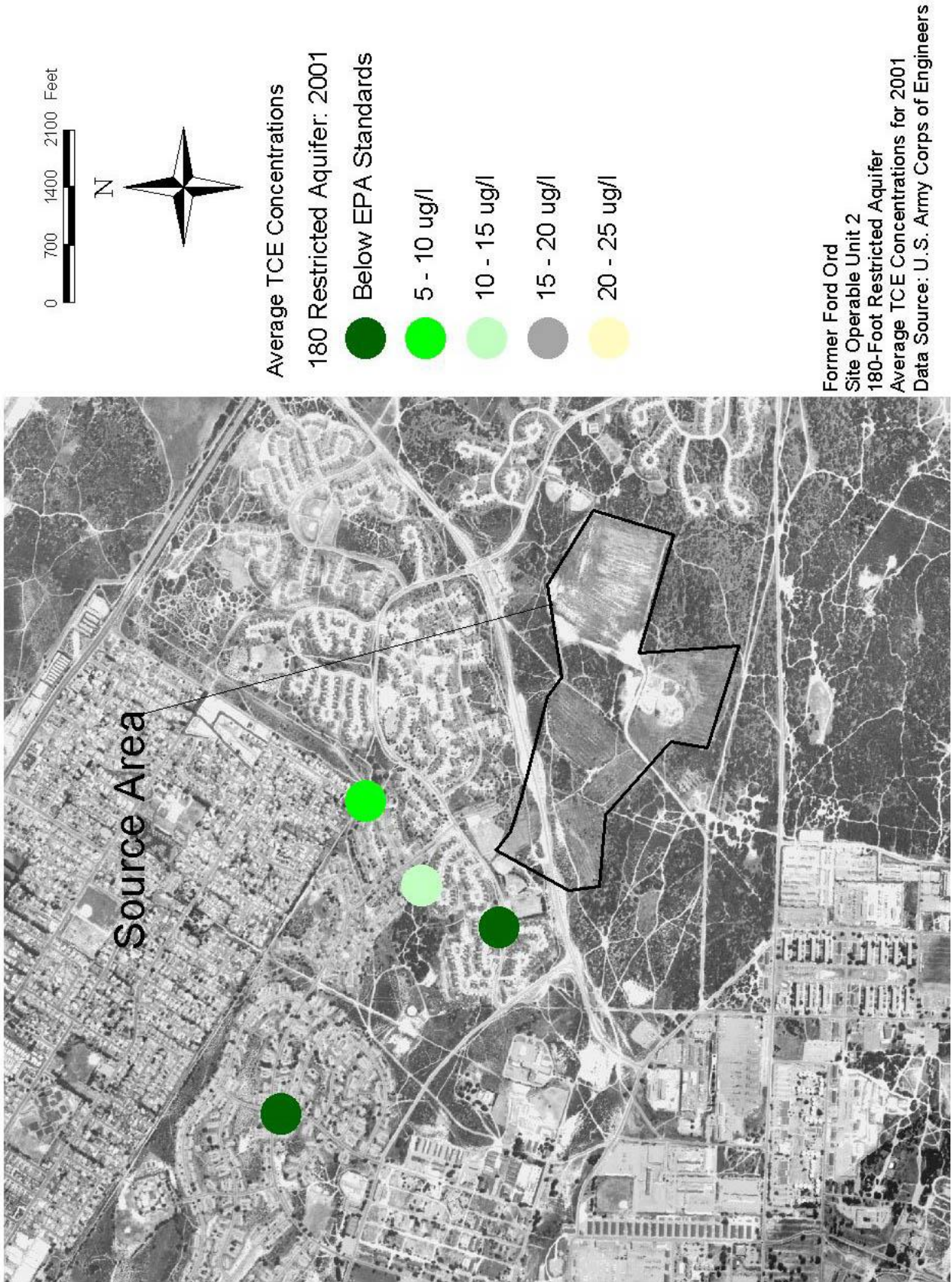
8.1.3. 180-foot Restricted Aquifer











8.2. Processed Quarterly Well Monitoring Data for Trichloroethylene

8.2.1. A-Aquifer

Former Fort Ord
 Monterey County, California
 Well Sample Data
 OU2 A-Aquifer
 Source: United States Army Corps of Engineers
 Datum: NAD 1983
 Coordinate System: State Plane
 Zone: California IV
 Dates: 1/9/1997 – 5/24/2001
 Chemical: Trichloroethylene
 Average Detection Limit: 0.5 µg/l

Well Name	Year	Ave Result/Yr (µg/l)	Std Dev (µg/l)	Northing	Easting
EW-OU2-1-A	1997	4.05	1.96	2138522.200000	5740009.400000
EW-OU2-2-A	1997	13.33	1.16	2138206.040000	5740027.320000
EW-OU2-3-A	1997	2.00	0.17	2138978.700000	5740144.700000
EW-OU2-4-A	1997	11.67	0.58	2137930.300000	5739987.200000
EW-OU2-5-A	1997	21.00	3.74	2137621.400000	5739893.500000
EW-OU2-6-A	1997	14.67	1.15	2137304.085000	5739797.322000
EW-OU2-7-A	1997	6.90	1.71	2136659.839000	5743510.584000
EW-OU2-8-A	1997	20.25	3.20	2136726.062000	5743718.828000
EW-OU2-9-A	1997	17.00	5.66	2136734.494000	5743881.910000
EW-OU2-10-A	1997	13.67	1.53	2136827.779000	5744073.578000
EW-OU2-11-A	1997	40.00	7.07	2136992.396000	5744294.794000
EW-OU2-12-A	1997	39.00	3.46	2137143.904000	5744531.125000
EW-OU2-13-A	1997	31.00	8.00	2137291.750000	5744698.336000
MW-OU2-1-A	1997	4.02	1.65	2134065.499000	5747348.574000
MW-OU2-2-A	1997	14.14	1.45	2136083.549000	5747104.673000
MW-OU2-3-A	1997	0.15	0.30	2135440.196000	5744935.053000
MW-OU2-4-A	1997	9.02	7.31	2137557.945000	5742879.634000
MW-OU2-5-A	1997	0.00	0.00	2138971.351000	5743945.159000
MW-OU2-6-A	1997	5.94	3.92	2137574.935000	5744024.209000
MW-OU2-7-A	1997	0.00	0.00	2138271.008000	5745037.204000
MW-OU2-8-A	1997	0.00	0.00	2137949.167000	5745600.726000
MW-OU2-9-A	1997	2.98	0.69	2136650.451000	5743471.147000
MW-OU2-12-A	1997	16.58	5.46	2137121.853000	5744537.732000
MW-OU2-13-A	1997	0.00	0.00	2134525.562000	5749618.204000
MW-OU2-20-A	1997	12.03	7.16	2138219.198000	5740073.302000
MW-OU2-21-A	1997	0.00	0.00	2136575.221000	5742074.261000
MW-OU2-23-A	1997	0.00	0.00	2134810.734000	5743765.085000
MW-OU2-25-A	1997	12.03	5.19	2136504.300000	5745740.787000

MW-OU2-26-A	1997	0.00	0.00	2134038.639000	5748465.219000
MW-OU2-27-A	1997	0.25	0.50	2135926.168000	5748968.072000
MW-OU2-28-A	1997	2.50	1.27	2135766.437000	5749700.265000
MW-OU2-29-A	1997	0.00	0.00	2133265.303000	5747134.863000
MW-OU2-30-A	1997	0.00	0.00	2137863.037000	5749086.916000
MW-OU2-31-A	1997	1.02	0.94	2139315.473000	5741245.469000
MW-OU2-32-A	1997	0.00	0.00	2139269.429000	5737751.158000
MW-OU2-33-A	1997	0.00	0.00	2137374.052000	5738654.582000
MW-OU2-34-A	1997	3.30	2.60	2135805.066000	5740727.459000
MW-OU2-35-A	1997	0.00	0.00	2133412.883000	5748214.983000
MW-OU2-36-A	1997	0.88	0.95	2139579.504000	5739394.859000
MW-OU2-37-A	1997	0.00	0.00	2140414.329000	5740540.625000
MW-OU2-40-A	1997	6.03	0.87	2137547.000000	5739880.000000
MW-OU2-41-A	1997	0.40	0.80	2136794.000000	5738251.000000
MW-OU2-45-A	1997	31.93	7.70	2135985.864000	5750245.071000
MW-OU2-57-A	1997	0.00	0.00	2134909.848000	5748699.696000
MW-OU2-58-A	1997	0.00	0.00	2137331.221000	5750607.287000
MW-OU2-59-A	1997	0.00	0.00	2136830.170000	5750924.768000
MW-OU2-60-A	1997	2.25	0.35	2135729.642000	5750438.987000
EW-OU2-1-A	1998	3.61	0.13	2138522.200000	5740009.400000
EW-OU2-2-A	1998	9.99	0.88	2138206.040000	5740027.320000
EW-OU2-3-A	1998	1.40	0.14	2138978.700000	5740144.700000
EW-OU2-4-A	1998	8.85	1.01	2137930.300000	5739987.200000
EW-OU2-5-A	1998	18.70	1.41	2137621.400000	5739893.500000
EW-OU2-6-A	1998	13.96	0.29	2137304.085000	5739797.322000
EW-OU2-7-A	1998	6.02	1.34	2136659.839000	5743510.584000
EW-OU2-8-A	1998	18.25	3.34	2136726.062000	5743718.828000
EW-OU2-9-A	1998	17.24	0.96	2136734.494000	5743881.910000
EW-OU2-10-A	1998	11.20	0.54	2136827.779000	5744073.578000
EW-OU2-11-A	1998	38.85	2.79	2136992.396000	5744294.794000
EW-OU2-12-A	1998	30.53	6.10	2137143.904000	5744531.125000
EW-OU2-13-A	1998	26.88	5.13	2137291.750000	5744698.336000
MW-OU2-1-A	1998	7.50	5.82	2134065.499000	5747348.574000
MW-OU2-2-A	1998	11.90	1.43	2136083.549000	5747104.673000
MW-OU2-3-A	1998	0.17	0.34	2135440.196000	5744935.053000
MW-OU2-4-A	1998	9.14	8.12	2137557.945000	5742879.634000
MW-OU2-5-A	1998	0.00	0.00	2138971.351000	5743945.159000
MW-OU2-6-A	1998	5.25	0.69	2137574.935000	5744024.209000
MW-OU2-7-A	1998	0.00	0.00	2138271.008000	5745037.204000
MW-OU2-8-A	1998	0.00	0.00	2137949.167000	5745600.726000
MW-OU2-9-A	1998	1.94	0.33	2136650.451000	5743471.147000
MW-OU2-12-A	1998	16.46	8.40	2137121.853000	5744537.732000
MW-OU2-13-A	1998	0.00	0.00	2134525.562000	5749618.204000
MW-OU2-20-A	1998	6.46	4.46	2138219.198000	5740073.302000
MW-OU2-21-A	1998	0.00	0.00	2136575.221000	5742074.261000
MW-OU2-23-A	1998	0.00	0.00	2134810.734000	5743765.085000
MW-OU2-25-A	1998	5.26	3.12	2136504.300000	5745740.787000
MW-OU2-26-A	1998	0.00	0.00	2134038.639000	5748465.219000

MW-OU2-27-A	1998	0.00	0.00	2135926.168000	5748968.072000
MW-OU2-28-A	1998	1.99	0.68	2135766.437000	5749700.265000
MW-OU2-29-A	1998	0.00	0.00	2133265.303000	5747134.863000
MW-OU2-30-A	1998	0.00	0.00	2137863.037000	5749086.916000
MW-OU2-31-A	1998	0.52	0.35	2139315.473000	5741245.469000
MW-OU2-32-A	1998	0.00	0.00	2139269.429000	5737751.158000
MW-OU2-33-A	1998	0.00	0.00	2137374.052000	5738654.582000
MW-OU2-34-A	1998	3.33	2.94	2135805.066000	5740727.459000
MW-OU2-35-A	1998	0.00	0.00	2133412.883000	5748214.983000
MW-OU2-36-A	1998	0.00	0.00	2139579.504000	5739394.859000
MW-OU2-37-A	1998	0.00	0.00	2140414.329000	5740540.625000
MW-OU2-40-A	1998	5.76	2.38	2137547.000000	5739880.000000
MW-OU2-41-A	1998	0.00	0.00	2136794.000000	5738251.000000
MW-OU2-45-A	1998	35.02	8.87	2135985.864000	5750245.071000
MW-OU2-57-A	1998	0.00	0.00	2134909.848000	5748699.696000
MW-OU2-58-A	1998	0.00	0.00	2137331.221000	5750607.287000
MW-OU2-59-A	1998	0.00	0.00	2136830.170000	5750924.768000
MW-OU2-60-A	1998	1.19	0.31	2135729.642000	5750438.987000
EW-OU2-1-A	1999	2.65	0.11	2138522.200000	5740009.400000
EW-OU2-2-A	1999	8.35	0.46	2138206.040000	5740027.320000
EW-OU2-3-A	1999	1.11	0.05	2138978.700000	5740144.700000
EW-OU2-4-A	1999	10.42	1.17	2137930.300000	5739987.200000
EW-OU2-5-A	1999	17.23	1.93	2137621.400000	5739893.500000
EW-OU2-6-A	1999	12.78	1.24	2137304.085000	5739797.322000
EW-OU2-7-A	1999	3.19	0.38	2136659.839000	5743510.584000
EW-OU2-8-A	1999	17.96	3.78	2136726.062000	5743718.828000
EW-OU2-9-A	1999	13.83	0.49	2136734.494000	5743881.910000
EW-OU2-10-A	1999	9.08	0.16	2136827.779000	5744073.578000
EW-OU2-11-A	1999	40.23	2.42	2136992.396000	5744294.794000
EW-OU2-12-A	1999	29.94	1.69	2137143.904000	5744531.125000
EW-OU2-13-A	1999	17.60	1.62	2137291.750000	5744698.336000
MW-OU2-1-A	1999	7.42	3.95	2134065.499000	5747348.574000
MW-OU2-2-A	1999	10.09	3.01	2136083.549000	5747104.673000
MW-OU2-3-A	1999	0.44	0.30	2135440.196000	5744935.053000
MW-OU2-4-A	1999	5.15	2.92	2137557.945000	5742879.634000
MW-OU2-5-A	1999	0.00	0.00	2138971.351000	5743945.159000
MW-OU2-6-A	1999	3.05	0.28	2137574.935000	5744024.209000
MW-OU2-7-A	1999	0.00	0.00	2138271.008000	5745037.204000
MW-OU2-8-A	1999	0.00	0.00	2137949.167000	5745600.726000
MW-OU2-9-A	1999	1.63	0.12	2136650.451000	5743471.147000
MW-OU2-12-A	1999	14.39	8.57	2137121.853000	5744537.732000
MW-OU2-13-A	1999	0.00	0.00	2134525.562000	5749618.204000
MW-OU2-20-A	1999	2.92	1.26	2138219.198000	5740073.302000
MW-OU2-21-A	1999	0.11	0.10	2136575.221000	5742074.261000
MW-OU2-23-A	1999	0.00	0.00	2134810.734000	5743765.085000
MW-OU2-25-A	1999	3.10	3.02	2136504.300000	5745740.787000
MW-OU2-26-A	1999	0.00	0.00	2134038.639000	5748465.219000
MW-OU2-27-A	1999	0.00	0.00	2135926.168000	5748968.072000

MW-OU2-28-A	1999	2.47	0.65	2135766.437000	5749700.265000
MW-OU2-29-A	1999	0.22	0.15	2133265.303000	5747134.863000
MW-OU2-30-A	1999	0.00	0.00	2137863.037000	5749086.916000
MW-OU2-31-A	1999	0.13	0.08	2139315.473000	5741245.469000
MW-OU2-32-A	1999	0.00	0.00	2139269.429000	5737751.158000
MW-OU2-33-A	1999	0.00	0.00	2137374.052000	5738654.582000
MW-OU2-34-A	1999	0.74	0.15	2135805.066000	5740727.459000
MW-OU2-35-A	1999	0.00	0.00	2133412.883000	5748214.983000
MW-OU2-36-A	1999	0.09	0.09	2139579.504000	5739394.859000
MW-OU2-37-A	1999	0.00	0.00	2140414.329000	5740540.625000
MW-OU2-40-A	1999	2.57	0.94	2137547.000000	5739880.000000
MW-OU2-41-A	1999	0.30	0.61	2136794.000000	5738251.000000
MW-OU2-45-A	1999	28.58	5.85	2135985.864000	5750245.071000
MW-OU2-57-A	1999	0.02	0.04	2134909.848000	5748699.696000
MW-OU2-58-A	1999	0.00	0.00	2137331.221000	5750607.287000
MW-OU2-59-A	1999	0.02	0.04	2136830.170000	5750924.768000
MW-OU2-60-A	1999	1.41	0.38	2135729.642000	5750438.987000
EW-OU2-1-A	2000	2.11	0.13	2138522.200000	5740009.400000
EW-OU2-2-A	2000	8.00	0.77	2138206.040000	5740027.320000
EW-OU2-3-A	2000	0.86	0.09	2138978.700000	5740144.700000
EW-OU2-4-A	2000	9.91	0.51	2137930.300000	5739987.200000
EW-OU2-5-A	2000	15.18	1.82	2137621.400000	5739893.500000
EW-OU2-6-A	2000	12.90	1.47	2137304.085000	5739797.322000
EW-OU2-7-A	2000	3.33	1.04	2136659.839000	5743510.584000
EW-OU2-8-A	2000	13.86	0.43	2136726.062000	5743718.828000
EW-OU2-9-A	2000	13.25	1.09	2136734.494000	5743881.910000
EW-OU2-10-A	2000	8.47	0.64	2136827.779000	5744073.578000
EW-OU2-11-A	2000	32.24	7.27	2136992.396000	5744294.794000
EW-OU2-12-A	2000	30.18	2.18	2137143.904000	5744531.125000
EW-OU2-13-A	2000	12.42	1.10	2137291.750000	5744698.336000
EW-OU2-14-A	2000	17.90	1.10	2136084.770000	5750314.410000
EW-OU2-15-A	2000	4.39	2.72	2136267.680000	5750447.230000
EW-OU2-16-A	2000	0.27	0.35	2136693.830000	5747841.450000
MW-OU2-1-A	2000	5.28	2.58	2134065.499000	5747348.574000
MW-OU2-2-A	2000	7.30	2.86	2136083.549000	5747104.673000
MW-OU2-3-A	2000	0.33	0.06	2135440.196000	5744935.053000
MW-OU2-4-A	2000	7.80	2.96	2137557.945000	5742879.634000
MW-OU2-5-A	2000	0.00	0.00	2138971.351000	5743945.159000
MW-OU2-6-A	2000	1.79	0.07	2137574.935000	5744024.209000
MW-OU2-7-A	2000	0.53	1.16	2138271.008000	5745037.204000
MW-OU2-8-A	2000	0.00	0.00	2137949.167000	5745600.726000
MW-OU2-9-A	2000	1.22	0.10	2136650.451000	5743471.147000
MW-OU2-12-A	2000	19.42	9.73	2137121.853000	5744537.732000
MW-OU2-13-A	2000	0.00	0.00	2134525.562000	5749618.204000
MW-OU2-20-A	2000	6.81	4.03	2138219.198000	5740073.302000
MW-OU2-21-A	2000	0.06	0.07	2136575.221000	5742074.261000
MW-OU2-23-A	2000	0.00	0.00	2134810.734000	5743765.085000
MW-OU2-25-A	2000	4.38	4.20	2136504.300000	5745740.787000

MW-OU2-26-A	2000	0.00	0.00	2134038.639000	5748465.219000
MW-OU2-27-A	2000	0.09	0.20	2135926.168000	5748968.072000
MW-OU2-28-A	2000	1.59	0.23	2135766.437000	5749700.265000
MW-OU2-29-A	2000	0.34	0.05	2133265.303000	5747134.863000
MW-OU2-30-A	2000	0.00	0.00	2137863.037000	5749086.916000
MW-OU2-31-A	2000	0.08	0.15	2139315.473000	5741245.469000
MW-OU2-32-A	2000	0.02	0.05	2139269.429000	5737751.158000
MW-OU2-33-A	2000	0.00	0.00	2137374.052000	5738654.582000
MW-OU2-34-A	2000	0.92	0.17	2135805.066000	5740727.459000
MW-OU2-35-A	2000	0.00	0.00	2133412.883000	5748214.983000
MW-OU2-36-A	2000	0.04	0.06	2139579.504000	5739394.859000
MW-OU2-37-A	2000	0.00	0.00	2140414.329000	5740540.625000
MW-OU2-40-A	2000	2.78	1.29	2137547.000000	5739880.000000
MW-OU2-41-A	2000	0.00	0.00	2136794.000000	5738251.000000
MW-OU2-45-A	2000	31.67	5.58	2135985.864000	5750245.071000
MW-OU2-57-A	2000	0.00	0.00	2134909.848000	5748699.696000
MW-OU2-58-A	2000	0.00	0.00	2137331.221000	5750607.287000
MW-OU2-59-A	2000	0.00	0.00	2136830.170000	5750924.768000
MW-OU2-60-A	2000	1.75	0.39	2135729.642000	5750438.987000
MW-OU2-73-A	2000	22.74	3.13	2135943.488800	5747760.232600
MW-OU2-74-A	2000	4.16	1.30	2135135.544400	5746631.556600
MW-OU2-75-A	2000	0.00	0.00	2137931.353500	5747505.819900
MW-OU2-76-A	2000	0.01	0.02	2138841.421200	5746550.255200
EW-OU2-1-A	2001	2.25	0.00	2138522.200000	5740009.400000
EW-OU2-2-A	2001	8.40	0.00	2138206.040000	5740027.320000
EW-OU2-3-A	2001	0.76	0.00	2138978.700000	5740144.700000
EW-OU2-4-A	2001	11.30	0.00	2137930.300000	5739987.200000
EW-OU2-5-A	2001	22.00	0.00	2137621.400000	5739893.500000
EW-OU2-6-A	2001	13.65	0.35	2137304.085000	5739797.322000
EW-OU2-7-A	2001	1.46	0.04	2136659.839000	5743510.584000
EW-OU2-8-A	2001	19.50	0.00	2136726.062000	5743718.828000
EW-OU2-9-A	2001	12.00	0.00	2136734.494000	5743881.910000
EW-OU2-10-A	2001	20.20	0.00	2136827.779000	5744073.578000
EW-OU2-11-A	2001	26.40	0.00	2136992.396000	5744294.794000
EW-OU2-12-A	2001	39.30	0.00	2137143.904000	5744531.125000
EW-OU2-13-A	2001	11.90	0.00	2137291.750000	5744698.336000
EW-OU2-14-A	2001	18.10	0.00	2136084.770000	5750314.410000
EW-OU2-15-A	2001	6.78	0.00	2136267.680000	5750447.230000
EW-OU2-16-A	2001	1.32	0.00	2136693.830000	5747841.450000
MW-OU2-1-A	2001	6.27	0.00	2134065.499000	5747348.574000
MW-OU2-2-A	2001	5.26	0.67	2136083.549000	5747104.673000
MW-OU2-3-A	2001	0.34	0.00	2135440.196000	5744935.053000
MW-OU2-4-A	2001	7.05	2.28	2137557.945000	5742879.634000
MW-OU2-6-A	2001	1.69	0.00	2137574.935000	5744024.209000
MW-OU2-7-A	2001	0.00	0.00	2138271.008000	5745037.204000
MW-OU2-21-A	2001	0.00	0.00	2136575.221000	5742074.261000
MW-OU2-25-A	2001	9.96	1.05	2136504.300000	5745740.787000
MW-OU2-27-A	2001	0.00	0.00	2135926.168000	5748968.072000

MW-OU2-28-A	2001	1.49	0.00	2135766.437000	5749700.265000
MW-OU2-29-A	2001	0.30	0.00	2133265.303000	5747134.863000
MW-OU2-34-A	2001	0.40	0.00	2135805.066000	5740727.459000
MW-OU2-40-A	2001	6.65	5.81	2137547.000000	5739880.000000
MW-OU2-41-A	2001	0.00	0.00	2136794.000000	5738251.000000
MW-OU2-45-A	2001	33.00	0.00	2135985.864000	5750245.071000
MW-OU2-57-A	2001	0.00	0.00	2134909.848000	5748699.696000
MW-OU2-60-A	2001	1.30	0.00	2135729.642000	5750438.987000
MW-OU2-73-A	2001	28.50	7.56	2135943.488800	5747760.232600
MW-OU2-74-A	2001	2.33	0.01	2135135.544400	5746631.556600
MW-OU2-75-A	2001	0.00	0.00	2137931.353500	5747505.819900
MW-OU2-77-A	2001	0.00	0.00	2136330.161100	5749960.556800

8.2.2. 180-Foot Aquifer

Former Fort Ord
 Monterey County, California
 Well Sample Data
 OU2 180-Foot (Upper) Aquifer
 Source: United States Army Corps of Engineers
 Datum: NAD 1983
 Coordinate System: State Plane
 Zone: California IV
 Dates: 3/4/1997 – 5/22/2001
 Chemical: Trichloroethylene
 Average Detection Limit: 0.5 µg/l

Well Name	Year	Ave Result/Yr (µg/l)	Std Dev (µg/l)	Northing	Easting
EW-OU2-1-180	1997	7.90	1.32	2138239.610000	5740014.450000
EW-OU2-2-180	1997	24.75	2.87	2136836.547000	5744096.986000
MW-OU2-20-180	1997	2.54	0.77	2138224.988000	5740051.952000
MW-OU2-23-180	1997	13.25	0.96	2134808.260000	5743754.470000
MW-OU2-24-180	1997	5.18	3.58	2137258.454000	5744618.912000
MW-OU2-28-180	1997	0.00	0.00	2135769.557000	5749679.975000
MW-OU2-29-180	1997	0.00	0.00	2133265.903000	5747143.424000
MW-OU2-30-180	1997	0.00	0.00	2137855.526000	5749087.146000
MW-OU2-36-180	1997	0.00	0.00	2139561.904000	5739410.159000
MW-OU2-37-180	1997	0.00	0.00	2140414.958000	5740516.684000
MW-OU2-39-180	1997	2.62	0.49	2136119.598000	5744290.431000
MW-OU2-42-180	1997	1.53	0.46	2136764.107000	5740872.617000
MW-OU2-43-180	1997	24.60	5.93	2137387.963000	5742446.559000
MW-OU2-44-180	1997	11.85	4.96	2136550.000000	5747073.000000
MW-OU2-46-180	1997	1.58	1.10	2136641.970000	5748574.750000
MW-OU2-47-180	1997	9.95	4.12	2137157.235000	5747685.982000
MW-OU2-48-180	1997	0.00	0.00	2138871.737000	5745687.390000

MW-OU2-49-180	1997	0.06	0.17	2138546.913000	5745543.490000
MW-OU2-50-180	1997	23.60	10.37	2134263.492000	5742548.473000
MW-OU2-51-180	1997	4.10	1.36	2134813.007000	5742414.310000
MW-OU2-52-180	1997	1.23	0.40	2135456.988000	5742727.973000
MW-OU2-53-180	1997	1.82	1.56	2136278.812000	5745184.835000
MW-OU2-54-180	1997	0.16	0.36	2133808.990000	5742053.417000
MW-OU2-55-180	1997	0.00	0.00	2134182.756000	5744756.498000
MW-OU2-56-180	1997	16.03	5.34	2135972.384000	5746877.486000
EW-OU2-1-180	1998	5.36	0.40	2138239.610000	5740014.450000
EW-OU2-2-180	1998	23.68	0.91	2136836.547000	5744096.986000
MW-OU2-6-180	1998	12.90	0.00	2137572.065000	5743984.079000
MW-OU2-20-180	1998	1.05	0.18	2138224.988000	5740051.952000
MW-OU2-23-180	1998	23.90	1.88	2134808.260000	5743754.470000
MW-OU2-24-180	1998	11.25	9.05	2137258.454000	5744618.912000
MW-OU2-28-180	1998	1.12	0.85	2135769.557000	5749679.975000
MW-OU2-29-180	1998	0.00	0.00	2133265.903000	5747143.424000
MW-OU2-30-180	1998	0.00	0.00	2137855.526000	5749087.146000
MW-OU2-36-180	1998	0.00	0.00	2139561.904000	5739410.159000
MW-OU2-37-180	1998	0.00	0.00	2140414.958000	5740516.684000
MW-OU2-39-180	1998	1.31	0.49	2136119.598000	5744290.431000
MW-OU2-42-180	1998	0.83	0.11	2136764.107000	5740872.617000
MW-OU2-43-180	1998	10.11	4.87	2137387.963000	5742446.559000
MW-OU2-44-180	1998	12.34	8.36	2136550.000000	5747073.000000
MW-OU2-46-180	1998	2.88	0.95	2136641.970000	5748574.750000
MW-OU2-47-180	1998	7.04	3.04	2137157.235000	5747685.982000
MW-OU2-48-180	1998	0.85	0.66	2138871.737000	5745687.390000
MW-OU2-49-180	1998	1.32	1.30	2138546.913000	5745543.490000
MW-OU2-50-180	1998	16.63	5.28	2134263.492000	5742548.473000
MW-OU2-51-180	1998	3.75	0.24	2134813.007000	5742414.310000
MW-OU2-52-180	1998	3.36	1.95	2135456.988000	5742727.973000
MW-OU2-53-180	1998	3.42	0.14	2136278.812000	5745184.835000
MW-OU2-54-180	1998	0.00	0.00	2133808.990000	5742053.417000
MW-OU2-55-180	1998	0.00	0.00	2134182.756000	5744756.498000
MW-OU2-56-180	1998	13.28	3.92	2135972.384000	5746877.486000
EW-OU2-1-180	1999	5.66	0.29	2138239.610000	5740014.450000
EW-OU2-2-180	1999	21.85	1.56	2136836.547000	5744096.986000
MW-OU2-20-180	1999	0.88	0.06	2138224.988000	5740051.952000
MW-OU2-23-180	1999	34.18	4.65	2134808.260000	5743754.470000
MW-OU2-24-180	1999	13.59	7.00	2137258.454000	5744618.912000
MW-OU2-28-180	1999	0.69	0.32	2135769.557000	5749679.975000
MW-OU2-29-180	1999	0.00	0.00	2133265.903000	5747143.424000
MW-OU2-30-180	1999	0.00	0.00	2137855.526000	5749087.146000
MW-OU2-36-180	1999	0.00	0.00	2139561.904000	5739410.159000
MW-OU2-37-180	1999	0.00	0.00	2140414.958000	5740516.684000
MW-OU2-39-180	1999	0.90	0.11	2136119.598000	5744290.431000
MW-OU2-42-180	1999	0.59	0.06	2136764.107000	5740872.617000
MW-OU2-43-180	1999	14.63	5.29	2137387.963000	5742446.559000
MW-OU2-44-180	1999	5.94	3.13	2136550.000000	5747073.000000

MW-OU2-46-180	1999	8.59	4.08	2136641.970000	5748574.750000
MW-OU2-47-180	1999	4.33	0.39	2137157.235000	5747685.982000
MW-OU2-48-180	1999	0.37	0.33	2138871.737000	5745687.390000
MW-OU2-49-180	1999	1.38	0.76	2138546.913000	5745543.490000
MW-OU2-50-180	1999	11.90	2.53	2134263.492000	5742548.473000
MW-OU2-51-180	1999	2.47	1.63	2134813.007000	5742414.310000
MW-OU2-52-180	1999	2.71	1.01	2135456.988000	5742727.973000
MW-OU2-53-180	1999	2.41	0.63	2136278.812000	5745184.835000
MW-OU2-54-180	1999	0.43	0.31	2133808.990000	5742053.417000
MW-OU2-55-180	1999	0.00	0.00	2134182.756000	5744756.498000
MW-OU2-56-180	1999	6.53	0.35	2135972.384000	5746877.486000
MW-OU2-61-180	1999	2.01	0.86	2136550.619500	5749529.757600
MW-OU2-62-180	1999	0.02	0.05	2135528.586300	5748496.148200
MW-OU2-63-180	1999	0.00	0.00	2137909.322300	5747522.312900
MW-OU2-64-180	1999	0.02	0.05	2137557.418300	5750482.499600
MW-OU2-65-180	1999	0.02	0.04	2137538.850600	5750511.299900
MW-OU2-66-180	1999	2.88	1.40	2137520.568600	5750538.426500
MW-OU2-67-180	1999	0.00	0.00	2136604.722800	5751514.869700
MW-OU2-68-180	1999	0.00	0.00	2136620.935600	5751547.596000
MW-OU2-69-180	1999	0.21	0.20	2136744.508200	5751723.410300
MW-OU2-70-180	1999	0.00	0.00	2135885.214300	5752535.456400
MW-OU2-71-180	1999	0.00	0.00	2135863.760100	5752559.512100
MW-OU2-72-180	1999	0.44	0.29	2135840.040100	5752575.730400
EW-OU2-1-180	2000	4.46	0.70	2138239.610000	5740014.450000
EW-OU2-2-180	2000	19.50	0.56	2136836.547000	5744096.986000
EW-OU2-3-180	2000	7.33	6.24	2135150.750000	5744805.940000
EW-OU2-4-180	2000	0.00	0.00	2134751.160000	5744827.690000
EW-OU2-5-180	2000	12.17	2.82	2136831.220000	5747785.360000
EW-OU2-6-180	2000	12.45	2.23	2136668.270000	5747823.940000
MW-OU2-5-180	2000	0.04	0.06	2139007.819900	5743892.173500
MW-OU2-20-180	2000	1.02	0.37	2138224.988000	5740051.952000
MW-OU2-23-180	2000	32.94	6.02	2134808.260000	5743754.470000
MW-OU2-24-180	2000	21.70	17.66	2137258.454000	5744618.912000
MW-OU2-28-180	2000	0.58	0.14	2135769.557000	5749679.975000
MW-OU2-29-180	2000	0.00	0.00	2133265.903000	5747143.424000
MW-OU2-30-180	2000	0.00	0.00	2137855.526000	5749087.146000
MW-OU2-36-180	2000	0.00	0.00	2139561.904000	5739410.159000
MW-OU2-37-180	2000	0.00	0.00	2140414.958000	5740516.684000
MW-OU2-39-180	2000	1.21	0.45	2136119.598000	5744290.431000
MW-OU2-42-180	2000	0.61	0.25	2136764.107000	5740872.617000
MW-OU2-43-180	2000	27.39	10.89	2137387.963000	5742446.559000
MW-OU2-44-180	2000	10.08	8.15	2136550.000000	5747073.000000
MW-OU2-46-180	2000	4.00	1.23	2136641.970000	5748574.750000
MW-OU2-47-180	2000	6.70	6.61	2137157.235000	5747685.982000
MW-OU2-48-180	2000	0.04	0.07	2138871.737000	5745687.390000
MW-OU2-49-180	2000	0.27	0.28	2138546.913000	5745543.490000
MW-OU2-50-180	2000	16.08	2.52	2134263.492000	5742548.473000
MW-OU2-51-180	2000	2.66	1.51	2134813.007000	5742414.310000

MW-OU2-52-180	2000	1.87	0.31	2135456.988000	5742727.973000
MW-OU2-53-180	2000	2.39	2.04	2136278.812000	5745184.835000
MW-OU2-54-180	2000	0.50	0.07	2133808.990000	5742053.417000
MW-OU2-55-180	2000	0.00	0.00	2134182.756000	5744756.498000
MW-OU2-56-180	2000	8.62	2.81	2135972.384000	5746877.486000
MW-OU2-61-180	2000	4.80	1.79	2136550.619500	5749529.757600
MW-OU2-62-180	2000	0.12	0.14	2135528.586300	5748496.148200
MW-OU2-63-180	2000	0.02	0.03	2137909.322300	5747522.312900
MW-OU2-64-180	2000	0.00	0.00	2137557.418300	5750482.499600
MW-OU2-65-180	2000	0.00	0.00	2137538.850600	5750511.299900
MW-OU2-66-180	2000	3.14	0.75	2137520.568600	5750538.426500
MW-OU2-67-180	2000	0.00	0.00	2136604.722800	5751514.869700
MW-OU2-68-180	2000	0.00	0.00	2136620.935600	5751547.596000
MW-OU2-69-180	2000	0.37	0.32	2136744.508200	5751723.410300
MW-OU2-70-180	2000	0.00	0.00	2135885.214300	5752535.456400
MW-OU2-71-180	2000	0.00	0.00	2135863.760100	5752559.512100
MW-OU2-72-180	2000	0.81	0.24	2135840.040100	5752575.730400
EW-OU2-1-180	2001	6.29	0.00	2138239.610000	5740014.450000
EW-OU2-2-180	2001	21.60	8.77	2136836.547000	5744096.986000
EW-OU2-3-180	2001	9.98	0.00	2135150.750000	5744805.940000
EW-OU2-4-180	2001	0.00	0.00	2134751.160000	5744827.690000
EW-OU2-5-180	2001	14.90	0.00	2136831.220000	5747785.360000
EW-OU2-6-180	2001	7.72	0.23	2136668.270000	5747823.940000
MW-OU2-5-180	2001	0.00	0.00	2139007.819900	5743892.173500
MW-OU2-23-180	2001	32.05	12.23	2134808.260000	5743754.470000
MW-OU2-24-180	2001	28.81	27.00	2137258.454000	5744618.912000
MW-OU2-28-180	2001	0.38	0.00	2135769.557000	5749679.975000
MW-OU2-30-180	2001	0.00	0.00	2137855.526000	5749087.146000
MW-OU2-39-180	2001	0.87	0.00	2136119.598000	5744290.431000
MW-OU2-42-180	2001	0.45	0.03	2136764.107000	5740872.617000
MW-OU2-43-180	2001	27.73	3.62	2137387.963000	5742446.559000
MW-OU2-44-180	2001	16.33	7.35	2136550.000000	5747073.000000
MW-OU2-46-180	2001	20.05	2.90	2136641.970000	5748574.750000
MW-OU2-47-180	2001	3.14	0.00	2137157.235000	5747685.982000
MW-OU2-48-180	2001	0.00	0.00	2138871.737000	5745687.390000
MW-OU2-49-180	2001	0.00	0.00	2138546.913000	5745543.490000
MW-OU2-50-180	2001	15.20	0.00	2134263.492000	5742548.473000
MW-OU2-51-180	2001	1.76	2.49	2134813.007000	5742414.310000
MW-OU2-52-180	2001	1.46	0.00	2135456.988000	5742727.973000
MW-OU2-53-180	2001	1.10	0.00	2136278.812000	5745184.835000
MW-OU2-54-180	2001	0.50	0.00	2133808.990000	5742053.417000
MW-OU2-55-180	2001	0.00	0.00	2134182.756000	5744756.498000
MW-OU2-56-180	2001	9.59	2.00	2135972.384000	5746877.486000
MW-OU2-61-180	2001	9.45	1.91	2136550.619500	5749529.757600
MW-OU2-62-180	2001	1.70	0.00	2135528.586300	5748496.148200
MW-OU2-63-180	2001	0.00	0.00	2137909.322300	5747522.312900
MW-OU2-64-180	2001	0.00	0.00	2137557.418300	5750482.499600
MW-OU2-65-180	2001	0.00	0.00	2137538.850600	5750511.299900

MW-OU2-66-180	2001	3.54	1.48	2137520.568600	5750538.426500
MW-OU2-67-180	2001	0.00	0.00	2136604.722800	5751514.869700
MW-OU2-68-180	2001	0.00	0.00	2136620.935600	5751547.596000
MW-OU2-69-180	2001	0.60	0.04	2136744.508200	5751723.410300
MW-OU2-70-180	2001	0.00	0.00	2135885.214300	5752535.456400
MW-OU2-71-180	2001	0.00	0.00	2135863.760100	5752559.512100
MW-OU2-72-180	2001	0.65	0.06	2135840.040100	5752575.730400

8.2.3. 180-Foot Restricted Aquifer

Former Fort Ord
 Monterey County, California
 Well Sample Data
 OU2 180-Foot (Lower) Restricted Aquifer
 Source: United States Army Corps of Engineers
 Datum: NAD 1983
 Coordinate System: State Plane
 Zone: California IV
 Dates: 3/4/1997 – 3/1/2001
 Chemical: Trichloroethylene
 Average Detection Limit: 0.5 µg/l

Well Name	Year	Ave Result/Yr (µg/l)	Std Dev (µg/l)	Northing	Easting
MW-OU2-6-180R	1997	8.76	2.60	2137595.000000	5743968.000000
MW-OU2-7-180R	1997	12.90	3.83	2138271.347000	5744986.405000
MW-OU2-9-180R	1997	6.00	3.38	2136655.989000	5743459.598000
MW-OU2-31-180R	1997	4.33	1.12	2139288.476000	5741211.837000
MW-OU2-6-180R	1998	15.67	12.54	2137595.000000	5743968.000000
MW-OU2-7-180R	1998	8.64	1.50	2138271.347000	5744986.405000
MW-OU2-9-180R	1998	11.10	12.82	2136655.989000	5743459.598000
MW-OU2-31-180R	1998	2.80	0.36	2139288.476000	5741211.837000
MW-OU2-6-180R	1999	24.80	3.22	2137595.000000	5743968.000000
MW-OU2-7-180R	1999	11.12	1.46	2138271.347000	5744986.405000
MW-OU2-9-180R	1999	5.08	1.43	2136655.989000	5743459.598000
MW-OU2-31-180R	1999	2.31	0.35	2139288.476000	5741211.837000
MW-OU2-6-180R	2000	17.03	9.96	2137595.000000	5743968.000000
MW-OU2-7-180R	2000	5.64	0.56	2138271.347000	5744986.405000
MW-OU2-9-180R	2000	1.52	0.74	2136655.989000	5743459.598000
MW-OU2-31-180R	2000	1.88	0.12	2139288.476000	5741211.837000
MW-OU2-6-180R	2001	18.22	11.22	2137595.000000	5743968.000000
MW-OU2-7-180R	2001	5.50	0.00	2138271.347000	5744986.405000
MW-OU2-9-180R	2001	2.17	0.00	2136655.989000	5743459.598000
MW-OU2-31-180R	2001	1.29	0.00	2139288.476000	5741211.837000

8.3. GPS Readings from Accuracy Assessment

Accuracy Assessment
Accessible Wells
Site OU2
November 24, 2001

Well Name	Difference between GPSed location & given location (in feet)
MW-OU2-50-180	6.34
MW-OU2-47-180	11.16
MW-OU2-63-180	4.89
EW-OU2-13-A	4.65
EW-OU2-12-A	4.76
EW-OU2-11-A	11.24
EW-OU2-2-180	13.91
EW-OU2-10-A	8.38
EW-OU2-9-A	9.56
EW-OU2-8-A	5.77
EW-OU2-7-A	26.77
EW-OU2-6-180	11.43
EW-OU2-16-A	4.33
EW-OU2-5-180	11.24
Average (in feet):	9.60
Standard Deviation (feet):	5.88
Median (feet):	8.97

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