ERI EVALUATION OF INJECTATES USED TO REMEDIATE A DRY CLEANING SITE, JACKSON, TENNESSEE

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Abstract

A former dry cleaning site in Jackson, Tennessee has undergone remediation to treat TCE and PCE contamination in the subsurface. The dry cleaning operation closed in 1977. In 2002, a series of injections were made at the site including corn syrup, vegetable oils, and Simple Green®. In 2004, approximately 200 cubic yards of contaminated soil was excavated and the bottom of the excavation covered with sodium lactate.

In 2009, the site was characterized using electrical resistivity imaging (ERI) and follow up confirmation soil borings that targeted anomalies detected via the geophysical work. The results indicate an extremely conductive (< 1 ohm-m) vadose zone downgradient from the injection wells, and extremely resistive areas (> 10,000 ohm-m) near the injection area. Sample data indicate that the electrically resistive zones in the subsurface contain moderate to high concentrations of undegraded dry cleaning compounds. Electrically conductive zones are interpreted to be areas of biological activity generated by the injected amendments to the site due to the extreme conductivity values detected, the chemical composition, and the dominant vadose zone location of the conductive zones.

Introduction

Site characterization of NAPL (Non Aqueous Phase Liquid) contaminated sites is complicated as there are many difficulties in understanding the distribution of NAPL products. They generally do not exist as free phase product in the subsurface, but rather a combination of high saturation areas of free phase and additional dissolved species. Degradation creates new compounds to monitor which may be more hazardous than the original compounds. The variations in density and capillary forces create separation of the areas into blobs that are independent in their location from other areas on the site (Halihan et al., 2005a). Additionally, there are commonly multiple sources in time and space.

To further the difficulties of characterizing these sites, multiple remediation schemes are often attempted by multiple contractors and may include the injection of a range of compounds in lightly monitored injection schemes. If these remediation schemes do not solve the problems for a site, the remaining subsurface distribution of original compounds, degradates and injectates is a complicated three dimensional distribution that changes over time. Geophysical approaches are seemingly the only reasonable approaches for solving these types of site characterization issues. Unfortunately in the past, the resolution and accuracy of the geophysical methods were not sufficient to solve these site characterization problems and thus became suspect as potential methods to apply to these complicated sites.

Evaluation of these sites using high resolution electrical resistivity imaging (ERI) as a “scan first, then drill” tool mimics the approach that the petroleum and mining industries use for site characterization. This approach is also related to “evidence-based medicine” approaches in the medical industry. ERI made significant advances in the last 20 years in both acquisition and processing (Dailey et al., 2004). Evaluation of petroleum impacted sites indicated the biological processes were strongly affecting the data in these sites (Atekwana and Atekwana, 2010). Some researchers focused on imaging insulators to better detect undegraded NAPL, which exist as subsurface insulators (Halihan et al, 2005b). The techniques have also been used to evaluate injections, however, many injection programs are completed before practitioners realize that the injectate did not uniformly distribute itself in the subsurface (Nyquist, 1999; Albano, 2010). The reactions that occur after injection may not establish themselves as a geophysical signal for months to years after the injection, so understanding the initial distribution is only part of the puzzle.

A former dry cleaners in Jackson, TN provided a site to evaluate the results of injecting a range of compounds into a site impacted by DNAPL and LNAPL compounds. On an urban site with multiple facilities over a range of time, the site characterization challenge is significant. On this site, the objectives were to determine if ERI could evaluate areas impacted by NAPL that were previously uncharacterized, if ERI could evaluate the efficiency of the injection program, and if ERI provided any indication of biological activity in the subsurface.

Site Description

The project site is a former dry cleaning site, Boone Dry Cleaners, located in Jackson, Tennessee (Figure 1). The site operated as a dry cleaner between the mid-1940's and the mid-1970's, at which time it was converted to a welding facility. In 2003 a tornado destroyed the structure and the site became a parking lot for a convenience store that also is an operating retail gas station using underground storage tanks. Subsequently the site was capped with a thick layer of concrete in some areas (approximately 2-3 feet).

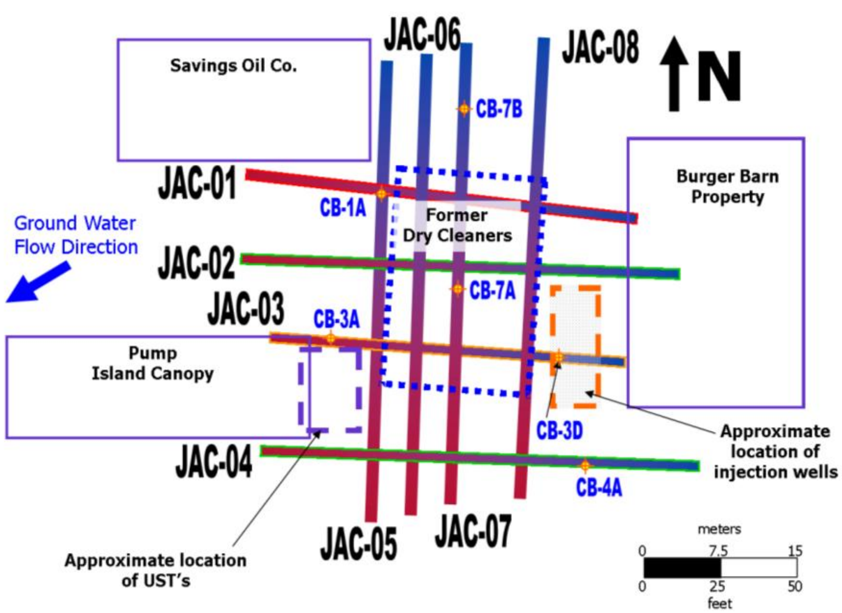

Figure 1: Site map of former Boone Dry Cleaner site in Jackson, TN. Locations of ERI lines are shown in heavy red/blue lines with JAC-0X labels. Locations of confirmation borings shown with blue labels.

The upper ten feet of the site is a silt deposit with some sand and clay stringers, below which lies a sand unit. The site contained approximately 34 existing monitoring wells drilled to a depth of approximately 6 meters (20 feet) to evaluate the hydrogeology and distribution of contaminants (Figure 2). The water table on the site was approximately 2.75 meters (9 feet) BGS in 2003. More current water levels were not available, but were assumed to be similar to levels from 2003. The hydraulic gradient trends towards the southwest. Site investigations have detected TCE and PCE and their daughter products from the dry cleaning operation as well as BTEX compounds from the adjacent facilities that have gasoline in underground storage tanks.

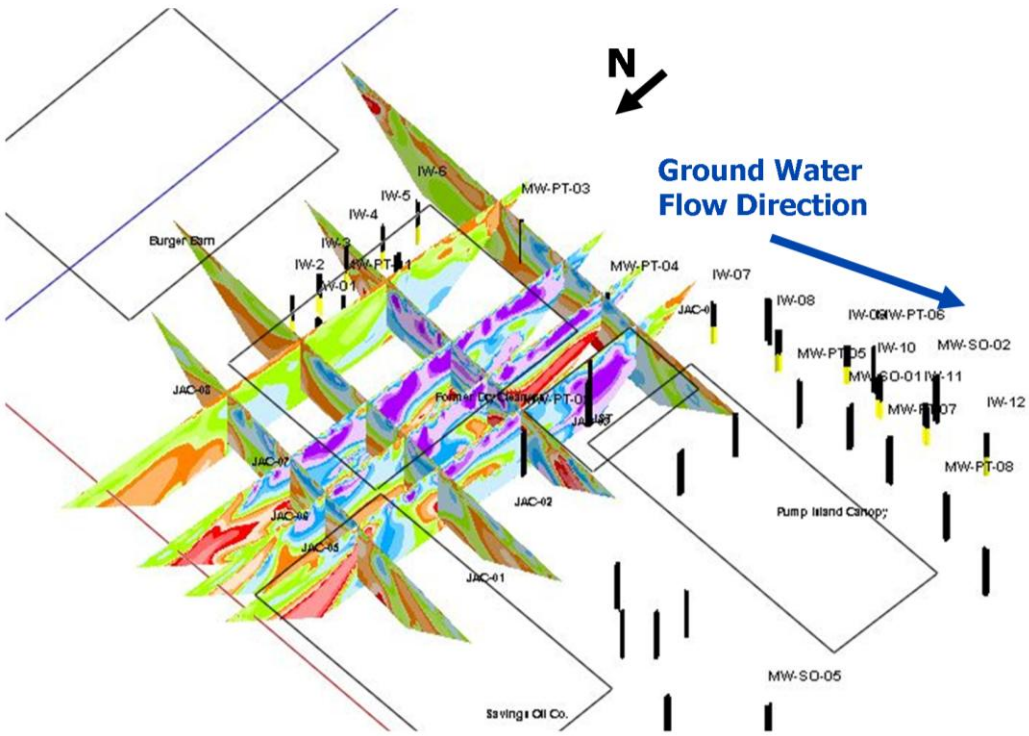

Figure 2: Three dimensional site model of former Boone Dry Cleaner site, Jackson TN. Monitoring well network shown as vertical black lines with yellow screened intervals (where known). Resistive areas on the north end of the site (red areas in ERI data) are confirmed as previously unknown locations for largely undegraded PCE. The extremely conductive areas (purple areas in center of site) correspond to degraded chlorinated solvents including PCE, TCE and related daughter products. ERI scale shown in Figure 4.

Several phases of remedial action have been taken at the site, including the injection of corn syrup, Simple Green®, and vegetable oil into the subsurface every two weeks between May and August, 2002 The total volume of injectate is not known. A one-time injection of soy bean oil occurred in December, 2002. In December of 2004, approximately 215 cubic yards of contaminated soil was excavated from the site, although the excavation location is unclear. The bottom of the excavation was covered in sodium lactate before being filled with #57 stone and clean fill material. Since the time of the injections, remedial activity been limited and some ground water sampling has occurred.

Concerns that the remediation program may have missed some source areas and questions regarding the effectiveness of the program led to using a surface ERI geophysical scanning program to evaluate the subsurface at the site in areas that were poorly constrained by existing monitoring wells.

Six confirmation borings were drilled to depths of 4.0-7.6 meters (13-25 feet) on the site after the ERI data were evaluated.

Methods

Eight high resolution electrical resistivity images (ERI) were collected using the Halihan/Fenstemaker method (available commercially as Aestus, LLC's GeoTrax Survey™ technology; Halihan and Fenstemaker, 2004). The data were collected during night shift work to allow the convenience store/gas station to continue operating during the ERI data collection activities (Figures 1 and 3). Surveys were first laid out using a measuring tape, and then electrode stakes were installed in the ground at specified intervals. Electrodes were installed with a hand sledge hammer in grassy areas. In areas covered with asphalt and/or concrete, a hammer drill was used to drill a 3/8-inch hole, which allowed electrodes to be installed and contact material below the concrete. Once installed, contact resistance was checked to ensure good electrical contact with the ground. In some areas the concrete cap was too thick to fully penetrate with rotary hammers and the electrodes were installed in the drillholes that allowed the contact resistance to drop to an acceptable level for imaging. The surveys were conducted using 56 electrodes at spacings ranging from 0.65-0.85 meters yielding total line lengths ranging from 35.75-46.75 meters (117-153 feet). This facilitated data collection from the ground surface to depths of 7-9 meters (23-31 feet).

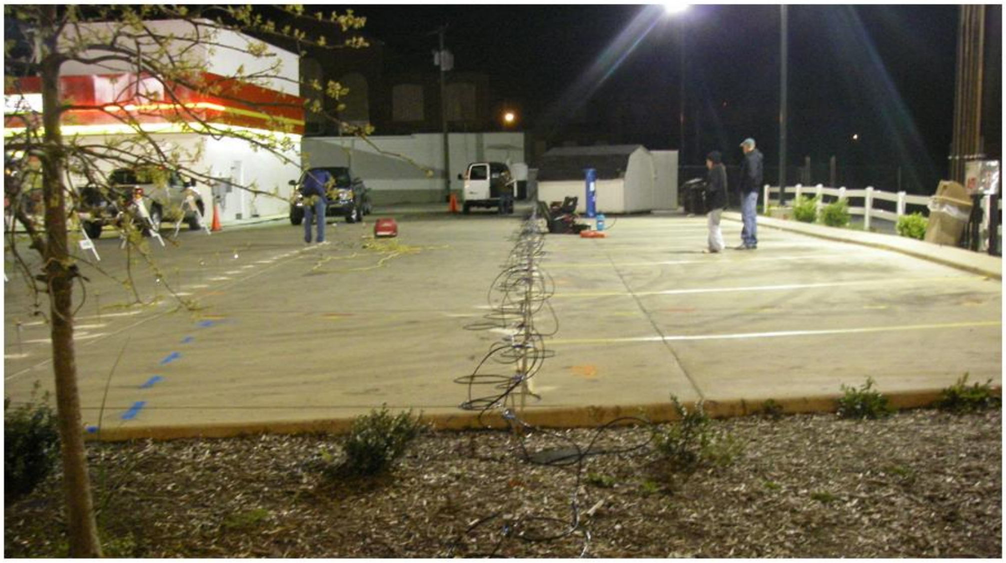

Figure 3: View of ERI line JAC-07 looking north at the former Boone Dry Cleaning facility in Jackson, TN. Data were collected at night to minimize disruptions to businesses currently located on the site.

Six confirmation borings were drilled through both strongly conductive and strongly resistive electrical anomalies in the ERI data. Data collected during confirmation boring activities included geologic logs, PID readings, groundwater analytical data, and soil analytical data. The soil and ground water samples were tested for TCE, PCE and related daughter products (see Table 1), BTEX compounds, and basic ground water chemistry.

Results

The ERI data demonstrate a wide range of resistivity values in the inverted model resistivity data. In the area where the injections took place, values range from approximately 5-500 ohm-meters (Figure 4). The variability in the data show dominantly vertical trends instead of the expected horizontal trends that would be generated by the horizontally bedded native geology. The sandy interval below 10 feet is over 100 ohm-meters in the area north from the injection wells (orange colors on right side in Figure 4), but is more conductive (<20 ohm-meters) in the area where the injections occurred (blue colors on left side in Figure 4). The increase in conductivity generally occurs beneath the water table in the injection zone.

Downgradient from the injection zone, resistivity values span seven orders of magnitude, from less than 0.1 ohm-meter to over 100,000 ohm-meters. This trend is apparent in several lines downgradient of the injection zone. The highly conductive area (<1 ohm-meter) tends to occur in the vadose zone just above the water table. The zone does extend below the water table in some areas. The highly conductive area tends to be broken into 5-6 pieces that roughly correspond to the number of injection wells (Figure 2 and Figure 4 lower figure). The highly resistive areas (>10,000 ohm-meters) tend to be located laterally adjacent to the injection well flowpath and vertically below the injection well flowpath (Figure 2). In the laterally adjacent highly resistive areas, the resistive areas occur both above and below the water table, but the majority of these areas are below the water table. (Figures 2 and 4). The resistive areas are interpreted as resulting from the saturation of NAPL in the pore spaces in the saturated zone, while the extremely conductive areas are interpreted as a microbial bloom in the unsaturated zone due to either injected compounds or the sodium lactate addition to the source area.

Chemical sampling of groundwater and soils indicate that the background fluids for the site are fresh with chloride concentrations of less than 20 mg/l. The background chemistry for major ions does not provide any reasonable interpretation for the extremely high or extremely low resistivity areas in the dataset due to the concentration of these ions. However, the concentration of iron species is highly variable and may be indicative of bioactivity for the site. Correlation with TCE and PCE related constituent chemistry indicate highly resistive areas correspond to areas with minimal degradation of PCE (Figure 4 and Table 1). Confirmation borings with ten times as much PCE as cis-1,2-Dichloroethene were above 1,000 ohm-meters (PCE/DCE >10). The extremely resistive values had PCE/DCE ratios above 25. BTEX compounds are found along with PCE in some of these areas (CB-3A, 3D and 4A), and may cause an increase in conductivity compared to an areas impacted with only PCE (CB-7B) (Table 1). The conductive areas correspond to areas with degraded PCE/TCE, but have little to no BTEX concentrations in the ground water samples such as in CB-4A and CB-7A (Table 1 and Figure 2). The PCE/DCE ratio in these areas is approximately unity.

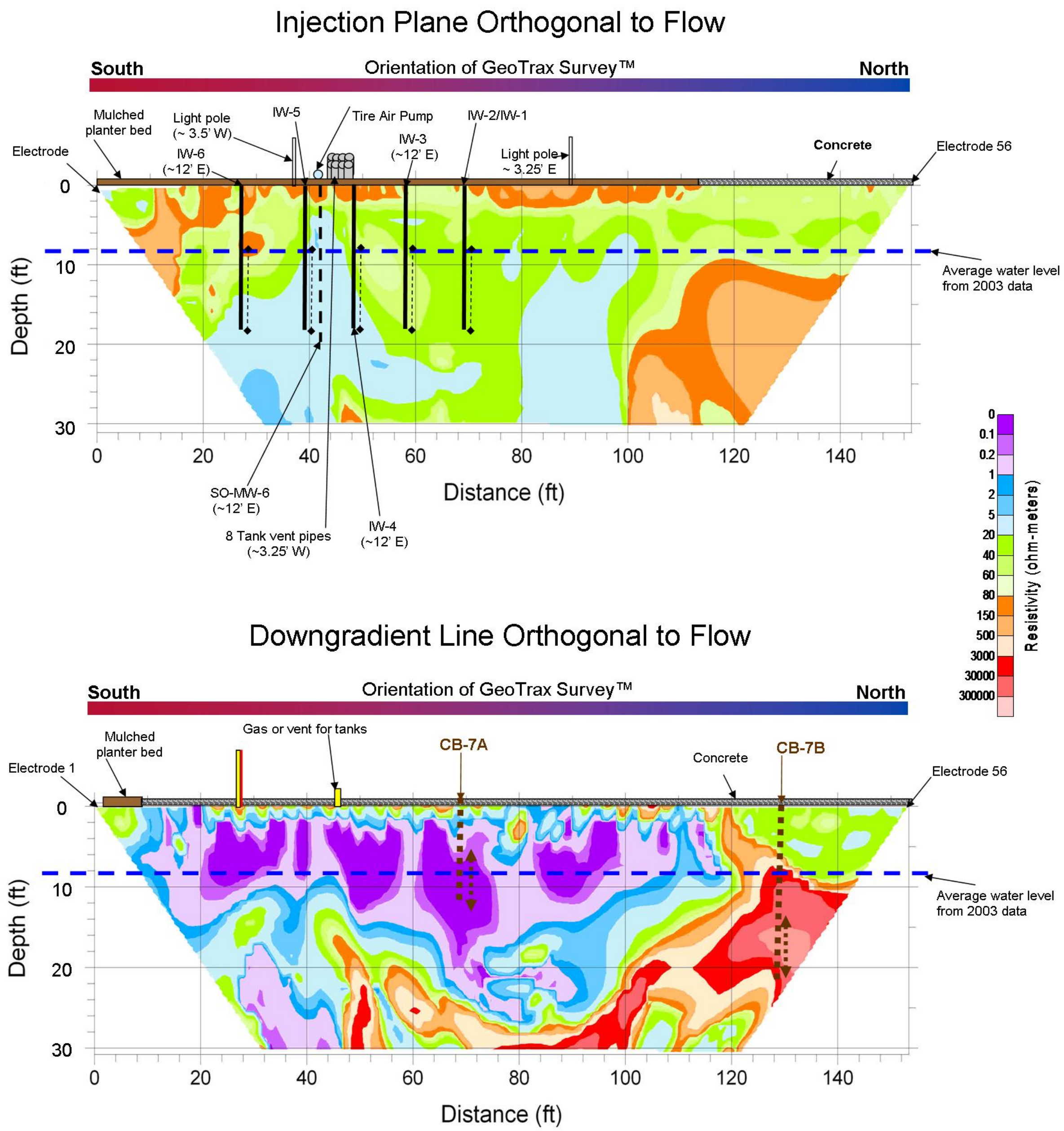

Figure 4: ERI inverted model data for parallel images. The upper image is located proximate to (12 feet west of) the plane of the injection wells for the site. The lower image is downgradient from the injection area. The brown dotted lines represent the location of confirmation borings.

Table 1: Ground water sample and ERI data from screened intervals of confirmation borings. Ground water samples collected Mar 1-2, 2010. Bolded italicized values indicate values exceeding MCL's. Highly conductive and highly resistive areas highlighted with red and purple.

Boring Name	***MCL's***	**CB-1A**	**CB-3A**	**CB-7B**	**CB-3D**	**CB-4A**	**CB-7A**
Distance along ERI survey (m)		14.0	4.9	39.3	28.7	31.7	20.7
Mid Screen Depth (m)		3.2	3.7	5.3	5.5	6.9	3.2
TCE/PCE Parameters (µg/L)							
Tricholoroethene (TCE)	***5***	U	0.670J	0.610J	***1340***	***62.6***	***317***
Tetrachloroethene (PCE)	***5***	3.97	***97.9***	***39.2***	***43000***	***187***	***925***
cis-1,2-Dicholoroethene (DCE)	***6***	U	0.930J	1.45	***4310***	***211***	***1070***
Vinyl Chloride	***0.5***	U	U	U	***2.28***	***13.8***	***1.16***
PCE/DCE ratio		U	105	27.0	10.0	0.89	0.86
BTEX Parameters (µg/L)							
Benzene	***1***	U	***1.32***	U	***1.52***	0.62	U
Toluene	***150***	U	0.69	U	U	U	U
Ethylbenzene	***300***	U	6.66	U	0.62	U	U
Total Xylenes	***1750***	U	13.59	U	5.18	U	U
Other Constituents (mg/L)							
Chloride	***250***	4.3	8.3	16	NS	9.8	11
Nitrate	***10***	1.9	0.19	U	NS	0.95	U
Nitrite	***1***	0.022	0.0067J	0.0061J	NS	U	0.0077J
Sulfate	***250***	170	150	51	NS	84	100
Sulfide	***NE***	U	NS	U	NS	NS	U
Total Organic Carbon	***NE***	1	4.4	3.4	NS	1.9	2.1
Ferrous Iron	***NE***	0.47	29.2	39.3	NS	7.94	18.6
Iron	***0.3***	1.99	79.4	58.6	NS	85.1	17.3
ERI data (ohm-meters)							
Geometric mean resistivity along screen		1,010	12,879	168,663	1,875	24.3	0.04

NS- not sampled, U- undetected, J- estimated value from laboratory, NE- not established

Discussion

The high resolution ERI data was successful at delineating areas of impacts for TCE and PCE at the site. The impacted areas were not successfully delineated by the existing monitoring well network due to inherent low data density with this methodology. Additionally, the ERI data and confirmation drilling data indicate that the vertical extent of contamination has likely not been bounded at this site to date. With the range of resistivity values in the dataset, the site makes a good testing area for using resistivity to observe biochemical changes as the data indicates that strong signals are generated by TCE and PCE reactions.

The electrical signals from impacted areas appear to differ strongly in weathered and unweathered TCE and PCE. Weathered areas are electrically conductive and are present predominantly in the vadose zone. The magnitude of resistivity measurements are extremely low and often correspond to values well below what would be typical for native ground water or diluted injectate. Therefore, these areas are interpreted as microbial blooms associated with degradation of TCE and PCE in the presence of the injected or sprayed compounds. This conclusion is consistent with what would be expected based on laboratory and field results showing increased conductivity for zones of microbial degradation (Atekwana and Atekwana, 2010). To date, no microbial analysis was performed on the samples to confirm the interpretation or to determine which species were present.

Compounds such as PCE and TCE are inherently resistive, and are expected to appear in electrical surveys as highly resistive anomalies. However, strongly resistive zones associated with the undegraded TCE and PCE areas at this site are in some areas more resistive than areas found on similar sites impacted by PCE and TCE that show values on the order of 10,000 ohm-meters. These high resistivity values may be caused by the pore structure of the sands on the site. No pore structure data is available to confirm this interpretation.

The results of the ERI data confirmed that a monitoring well investigation of this site could provide only limited results. The ERI data provided targets for a range of compounds and a range of degradation levels. Samples collected in the saturated zone using a monitoring well network would strongly limit the interpretation at this site. The addition of three dimensional (3-D) modeling of ERI data and historical datasets allow a greater understanding of the site with additional hypotheses generated for the future remediation of the site. Transient ERI data would be useful for evaluating the reaction rate for the site. Data from longer ERI lines would provide data to better bound the vertical extent of remaining TCE and PCE on the site.

Conclusions

High resolution ERI data were collected at a former dry cleaning site impacted by PCE and TCE and related daughter products. The results indicate that the highly electrically conductive zones in the subsurface correspond to the presence of moderate to high levels of weathered PCE and TCE and daughter products, and largely reside in the vadose zone. The highly resistive areas correspond to zones containing moderate to high concentrations of largely unweathered TCE and PCE. The shift from highly resistive to highly conductive appears to indicate the presence of a strong bacterial bloom in the vadose zone due to the biological activity presumably generated by the injectates interacting with the chlorinated solvent compounds at the site. The resulting high data density ERI data set visualized in 2-D and 3-D was used as a framework to integrate historical monitoring well data. The collective results confirm that monitoring wells alone were insufficient to adequately characterize this former dry cleaners site.

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