

**Guaranteed Remediation Certainty
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**Project Example – Guaranteed Fixed Price Remediation of Tetrachloroethene (PCE) and Trichloroethene (TCE) in Soil using Electrical Resistance Heating.
Confidential Client-Chicago, IL**

Project Reference: Mr. William Bow, (847) 695-8855 x 101

Contracting and Pricing: Guaranteed Fixed Price Remediation

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Project Superintendent: Mr. Chris Blundy, project manager, TRS, Charleston, SC. (843) 225-6018, cblundy@thermalrs.com.

Contaminants Treated: PCE, TCE

Technology Applied: Electrical Resistance Heating (ERH)

Lithology: Lacustrine silty sand overlying glacial lake clay to 20 feet bgs.

Hydrology: Groundwater at 5 feet bgs, hydraulic conductivity estimated at 10^{-5} to 10^{-4} cm/sec, groundwater flow from west to east.

Treatment Area, Depth Interval, and Volume:

4,300 square feet, 5 to 20.3 feet bgs, representing approximately 2,400 cubic yards.

Beginning Contaminant Levels: Maximum contaminant concentrations were 1,310 mg/kg PCE and 4,990 mg/kg TCE in soil.

Remedial Goals: All soil samples less than 240 mg/kg PCE and 1,300 mg/kg TCE.

Numerical Values Achieved after ERH: Maximum 170 mg/kg PCE and 1,000 mg/kg TCE in soil representing 82% and 74% reductions from beginning maximum concentrations, respectively.

TRS Guaranteed Price: \$437,000.00.

Cost by Others: \$252,000.000.

Remediation Time Period: August 29 to December 12, 2006.



Figure 1. Sheet Pile Wall Separating Onsite and Offsite Contaminant Plumes

Background

TRS, as a subcontractor to Levine Fricke, provided Electrical Resistance Heating (ERH) design, construction, operations, and specialty equipment for the remediation of PCE and TCE in soil for a confidential client in Chicago, IL. Unique aspects of this project included using a sheet pile wall as one continuous electrode (see Figure 1) and using single sheet pile electrodes (see Figure 2) and co-located horizontal vapor and steam recovery wells. This site was selected by TRS for a screening level study to evaluate the effects of heat on the *in situ* biodegradation of PCE and TCE during ERH.

The TRS total guaranteed fixed price, including design, work plans, permitting support, equipment mobilization, utility connection, construction, operations, demobilization, site restoration, and a final report was \$437,000.00. The cost by others including drilling, waste disposal, trenching and restoration, sampling and analysis, electricity usage, and vapor treatment was \$252,000.00.

Site Information

The treatment area was approximately 4,300 square feet. The remediation depth interval extended from five to 20.3 feet below ground surface (bgs). The resulting target remediation volume was approximately 2,400 cubic yards. The site lithology in the remediation area consisted of fine silty sand overlying glacial lake clay at a depth of approximately 20 feet bgs.

This site represents the first use of sheet pile electrodes. The ERH system included 18 sheet pile electrodes with co-located vapor recovery (VR) wells, as well as a long sheet pile on the western edge of the site acting both as an electrode and as an isolation barrier (separating the offsite treatment area from the future onsite treatment area). The sheet pile wall acts as a barrier to contaminant plume migration from under the building into the offsite treatment area.

This remediation was focused on ERH treatment of the offsite plume. The plan is to continue the ERH remediation of the onsite PCE and TCE plume located under the building in 2008.

Figure 2 illustrates the installation of the sheet pile electrodes and a completed electrode with a co-located vapor and steam recovery well. Figure 3 is a site plot plan showing the various components of the ERH remediation system.

Six Temperature Monitoring Points (TMPs) with six thermocouples spaced vertically at set 5-foot intervals were installed providing approximately 30 points within the subsurface where discrete temperatures were recorded. These temperature readings were used to calculate an average site temperature and average temperatures at the set depth intervals to monitor remedial progress. (See Figure 4)

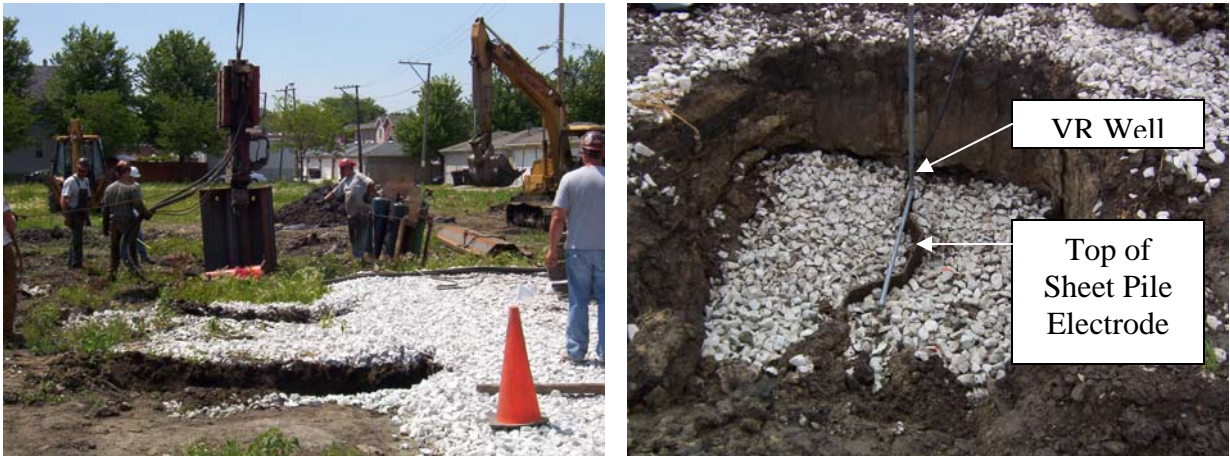


Figure 2. Installation of the Sheet Pile Electrodes (left picture) and a Completed Electrode with Co-located Vapor and Steam Recovery Well

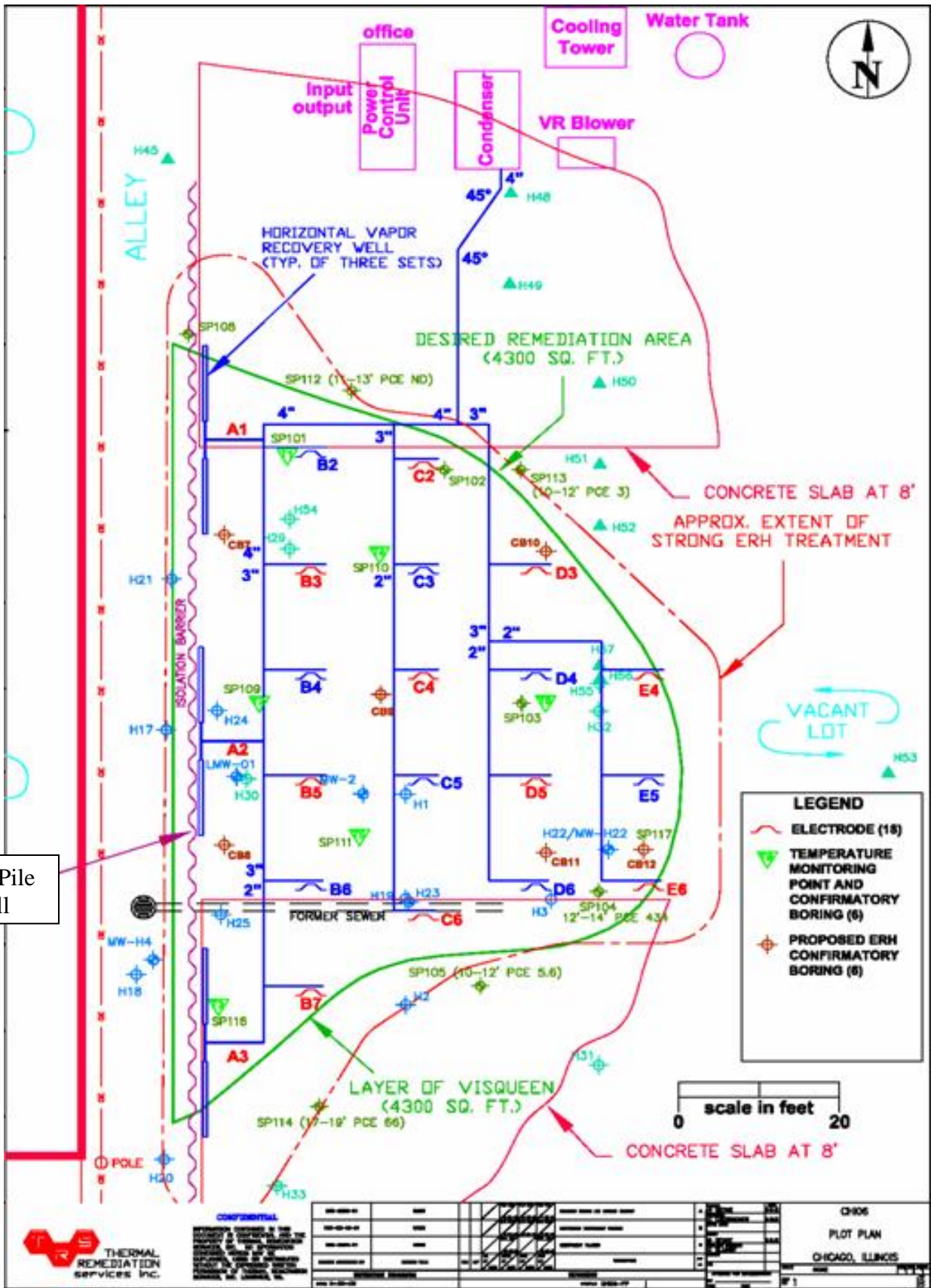


Figure 3. Site Diagram

Operations

The ERH specialty equipment from the TRS fleet included one custom-manufactured 700-kW Power Control Unit (PCU) for continuous power delivery to the treatment volume, one 15-horsepower blower for vapor recovery, and one condenser to separate water from the recovered vapor. Granular Activated Carbon (GAC) was used for vapor treatment to remove volatile organic compounds from the air stream.

ERH operations began on August 29, 2006 and were completed on December 7, 2006, representing 100 days of treatment. This compares to the modeled treatment period of 65 to 103 days.

Figure 4 illustrates the subsurface temperatures over time from six TMP locations inside the ERH remediation area. The decrease at TMP 3 (yellow) during the second week in October 2006 was due to the power being turned off at this location, because the remedial goals were reached, and redirected into the areas that had not yet reached the cleanup goals. This approach to subsurface power delivery saves money by decreasing the total amount of energy required to remediate the site.

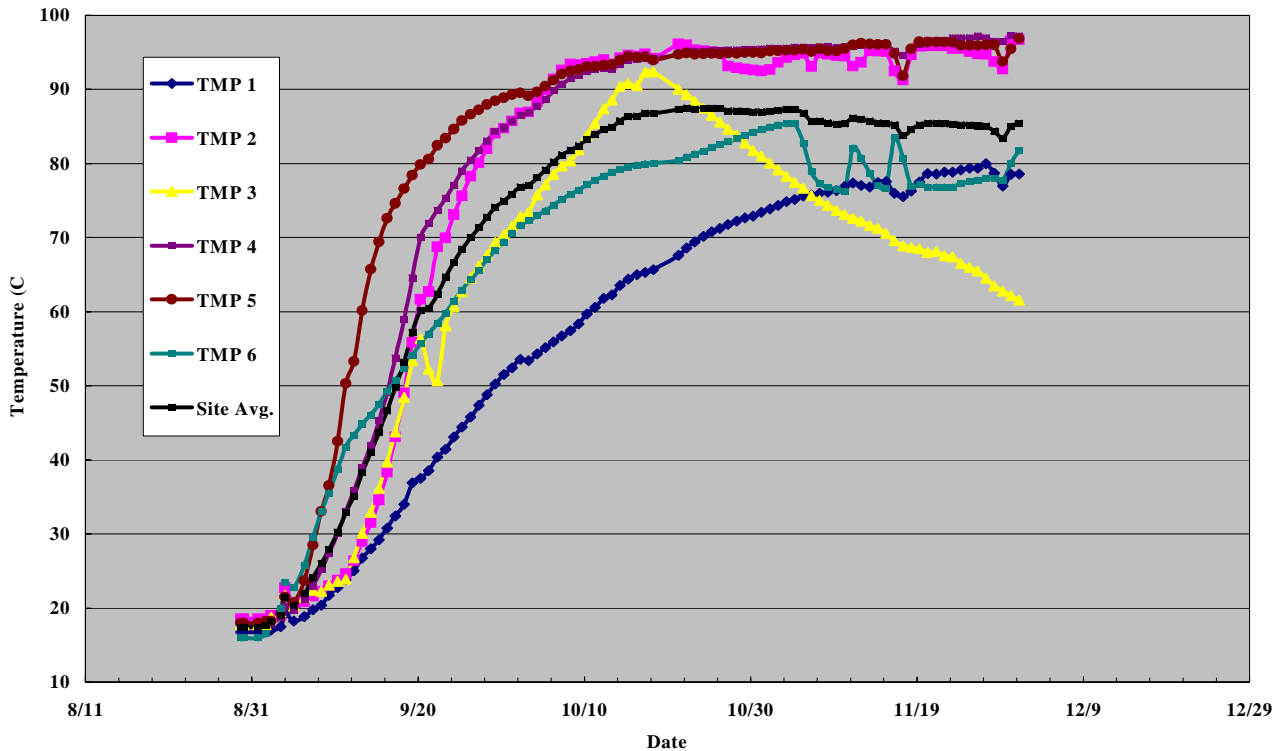


Figure 4. Subsurface Temperatures during ERH Remediation

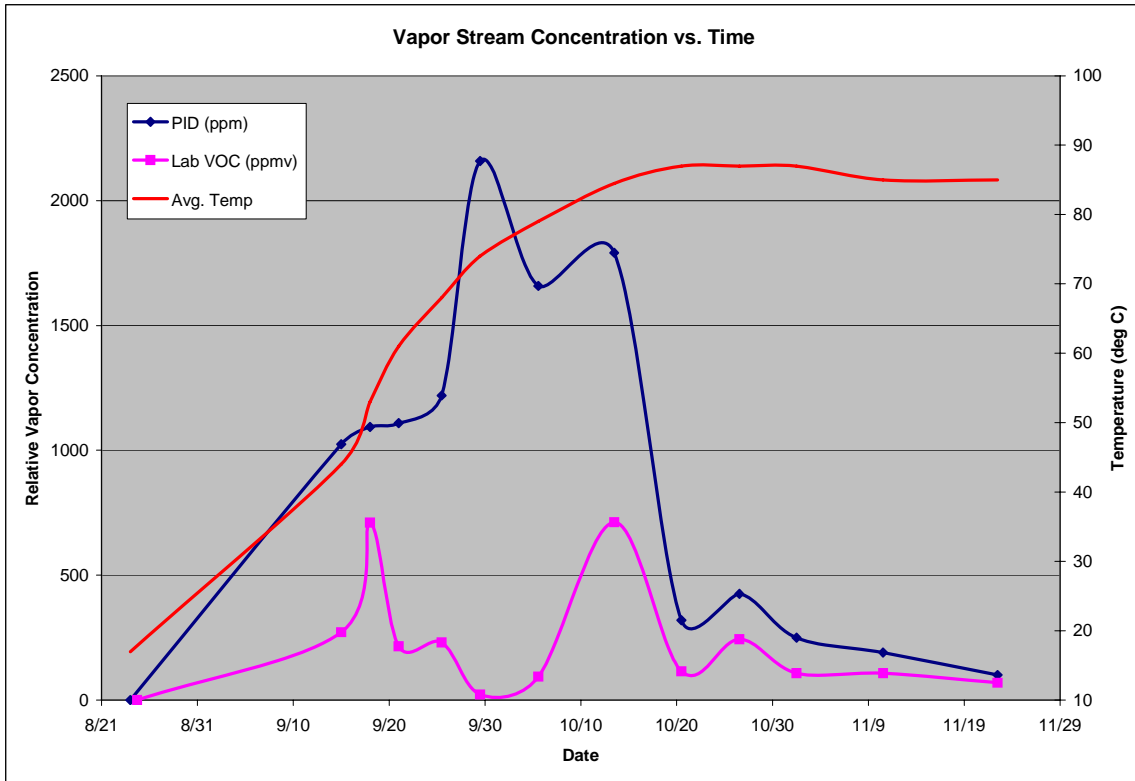


Figure 5. Contaminant Vapor Concentrations during ERH

Figure 5 illustrates the total contaminant vapor concentrations over time during the ERH remediation. The blue line represents the vapor concentration data (ppm) from the onsite Photoionization Detector (PID) and the magenta line is the vapor concentration data (ppmv) from the vapor sample analysis performed by the offsite laboratory. The red line represents the average subsurface temperature during ERH.

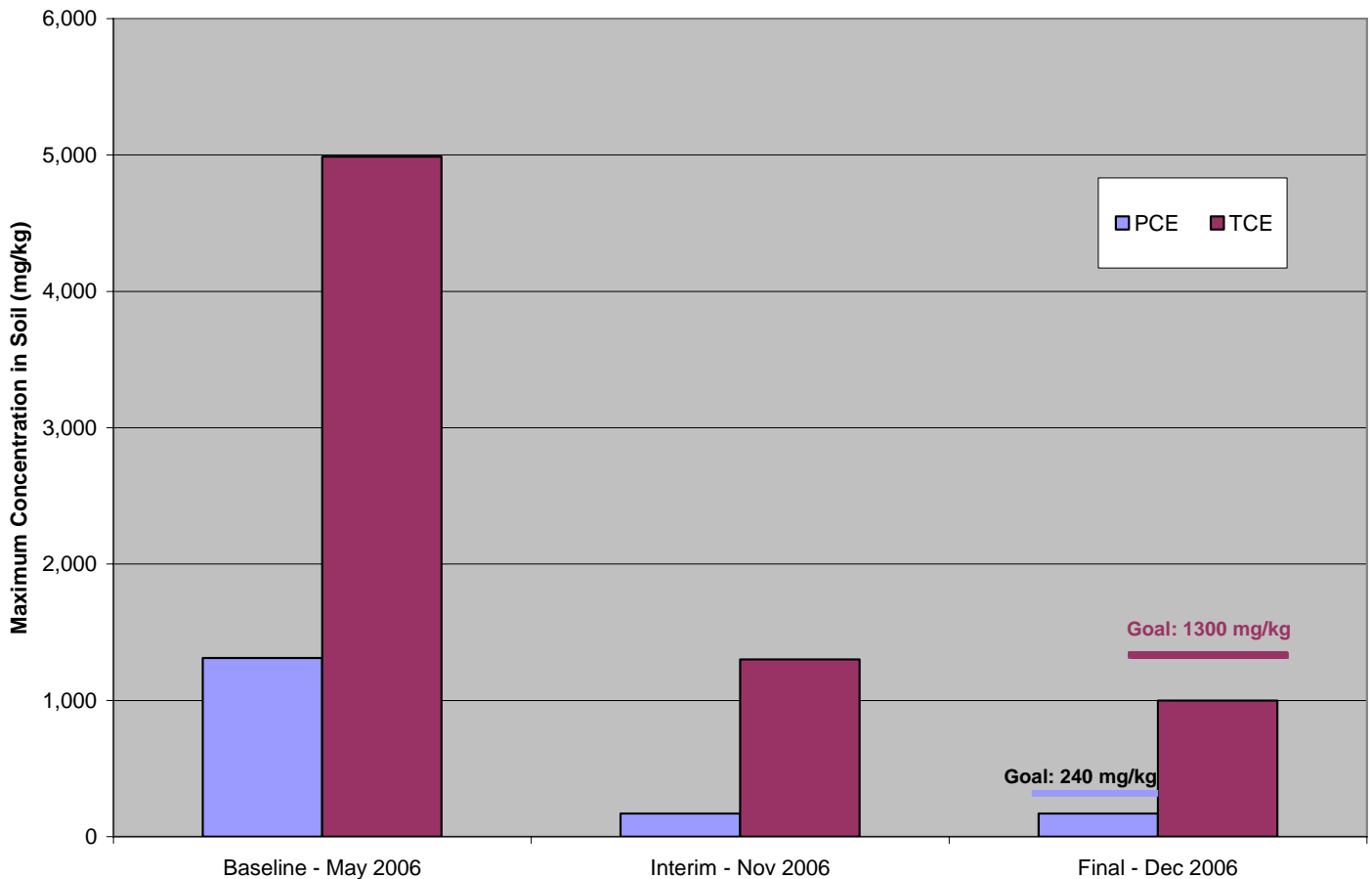


Figure 6. PCE and TCE Concentrations in Soil Before, During and After ERH

Remedial Goals and Results

The beginning maximum concentrations of PCE and TCE in soil were 1,310 mg/kg and 4,990 mg/kg, respectively. The remedial goals represented reductions in concentrations to below soil saturation conditions, which for PCE in soil is 240 mg/kg or a 82% reduction and for TCE is 1,300 mg/kg, which represented a 74% reduction from the initial maximum concentrations¹.

PCE and TCE concentrations in soil following the ERH remediation were 170 mg/kg and 1,000 mg/kg, respectively. These values represent a 87% and 80% reductions in PCE and TCE in soil, respectively, when compared to the beginning concentrations.

Figure 6 illustrates the baseline, interim and final concentrations of PCE and TCE before, during and following ERH.

¹ This represents a Tier 3 closure in Illinois. Tier 3 closures are allowed in Illinois where groundwater is not considered a resource through either site-specific conditions, usually protected by local ordinance and there is no potential for exposure to the chemicals by site workers or the general public.

Enhanced Biodegradation Screening Evaluation

This site was selected by TRS for a screening level study to evaluate biodegradation during ERH. To perform this screening, three sample events were selected: 1) baseline, prior to treatment; 2) during DNAPL vaporization, i.e., when temperatures were at or near the eutectic point of PCE in water; and 3) approximately one month after the eutectic point was achieved. Table 1 presents the major ion data for the three sampling events presented on a milliequivalents per liter basis. Total dissolved solids increased from the baseline value of 2,081 mg/l to 8,404 mg/l when the eutectic point of PCE was reached, to 13,404 mg/l in the final sampling. From Table 1, it can be seen that chloride was the ion that represented the most significant increase, increasing from 54% of total anions to 90% of total anions.

Table 1: Summary of Major Ions (concentration mg/l)

| Parameter | Concentration (mg/l) | | |
|-----------------|----------------------|----------|----------|
| | 8/25/06 Baseline | 10/04/06 | 11/15/06 |
| Ca | 393 | 1870 | 3270 |
| Fe2+ | 121 | 2.08 | 0.302 |
| K | 20.6 | 93.3 | 113 |
| Mg | 36.2 | 159 | 62.8 |
| Na | 43.6 | 417 | 687 |
| HCO3 | 545 | 722 | 872 |
| Cl | 377 | 3080 | 5680 |
| NO3, as N | ND | ND | 0.133 |
| SO4 | 10.3 | 70.7 | 139 |
| Sulfide | ND | ND | 1.6 |
| TOC (dissolved) | 473 | 1990 | 2580 |

During heating, concentrations of sulfate increased by an order of magnitude, while bicarbonate concentrations almost doubled. It is interpreted that the groundwater was under sulfate reducing to methanogenic conditions prior to ERH treatment. The heating may have resulted in increased dissolution of sulfate, potentially from gypsum ($\text{CaSO}_4 \cdot 2\text{H}_2\text{O}$) in the soils. Correspondingly, calcium also increased by an order of magnitude and is the dominant cation in the groundwater before and during the ERH treatment. Sodium, potassium, and magnesium also showed increases in groundwater concentration during heating.

Iron decreased throughout the heating from 121 mg/l initially, to 2.08 mg/l and finally to 0.302 mg/l. This information, plus hydrogen sulfide odors observed during heating indicated that the groundwater was under sulfate reducing conditions during ERH. Sulfate reducing conditions are desirable for the reductive dehalogenation of chlorinated ethenes.

To evaluate the changes in the chlorinated aliphatic hydrocarbon data, total organic chloride and organic carbon demand were determined using the method presented in Wiedemeier, et al., (1996)². Total organic chloride provides a means of normalizing the data, to track the concentration reduction with time (Table 2). Further, one of the end products of the dehalogenation process is elevated chloride levels in the water.

Table 2: Summary of Total Organic Chlorine and Total Organic Carbon (mg/l)

| Sample Date | PCE | TCE | DCE | TCA | DCA | 1,1-DCE | DCM | Total Organic Chloride | Organic Carbon Demand |
|-------------|-------|------|-------|------|--------|---------|-------|------------------------|-----------------------|
| 8/25/2006 | ND | 11.2 | 91.7 | 62.9 | 94.9 | | 14.2 | 205.8 | 36.43 |
| 10/4/2006 | 590 | 541 | 32.4 | ND | 37.1 | 12 | 106 | 1083.9 | 191.85 |
| 11/6/2006 | 0.894 | 6.08 | 0.138 | ND | 0.0817 | 0.0339 | 0.142 | 5.97 | 1.06 |

While the heating resulted in increases in inorganic compounds, total dissolved organic carbon increased from baseline concentrations of 473 mg/l to 1,990 mg/l, with a final concentration of 2,580 mg/l. Organic carbon represents a terminal electron acceptor for the reductive dehalogenation of chlorinated aliphatic compounds. From this, there was ample terminal electron donor available in the form of organic carbon for the reductive dehalogenation of the chlorinated aliphatic terminal electron acceptors throughout the ERH treatment. Coupled with the appropriate redox conditions, this indicates that ERH treatment did not negatively influence the conditions for reductive dehalogenation and likely enhanced the conditions.

Figure 7 presents the change in total organic chlorine and chloride over time. The baseline concentration of chlorinated aliphatic compounds normalized to total organic chloride was 206 mg/l, while the baseline chloride concentrations were 377 mg/l. The final chloride concentrations were 5,680 mg/l, an increase of 5,303 mg/l, while the final

² Wiedemeier, T.H., M.A. Swanson, D.E. Moutoux, E.K. Gordon, J.T. Wilson, B.H. Wilson, D.H. Kampbell, J.E. Hansen, P. Haas, and F.H. Chapelle (1996). *Technical Protocol for Evaluating Natural Attenuation of Chlorinated Solvents in Groundwater*. Air Force Center for Environmental Excellence, San Antonio, TX.

total organic chloride concentrations were 5.97 mg/l. There was a 6.4 times increase in total dissolved solids, while chloride concentrations increased 15-fold during the heating, indicating a separate source of the chloride other than increase dissolution of soil minerals; interpreted to be reductive dehalogenation of the chlorinated solvents. This reductive dehalogenation was observed to occur throughout ERH treatment and results in significant destruction of chlorinated aliphatic compounds *in situ*, estimated at 26% of the original mass at this site. The actual mechanisms (i.e., cometabolic or biotic) have not been fully evaluated.

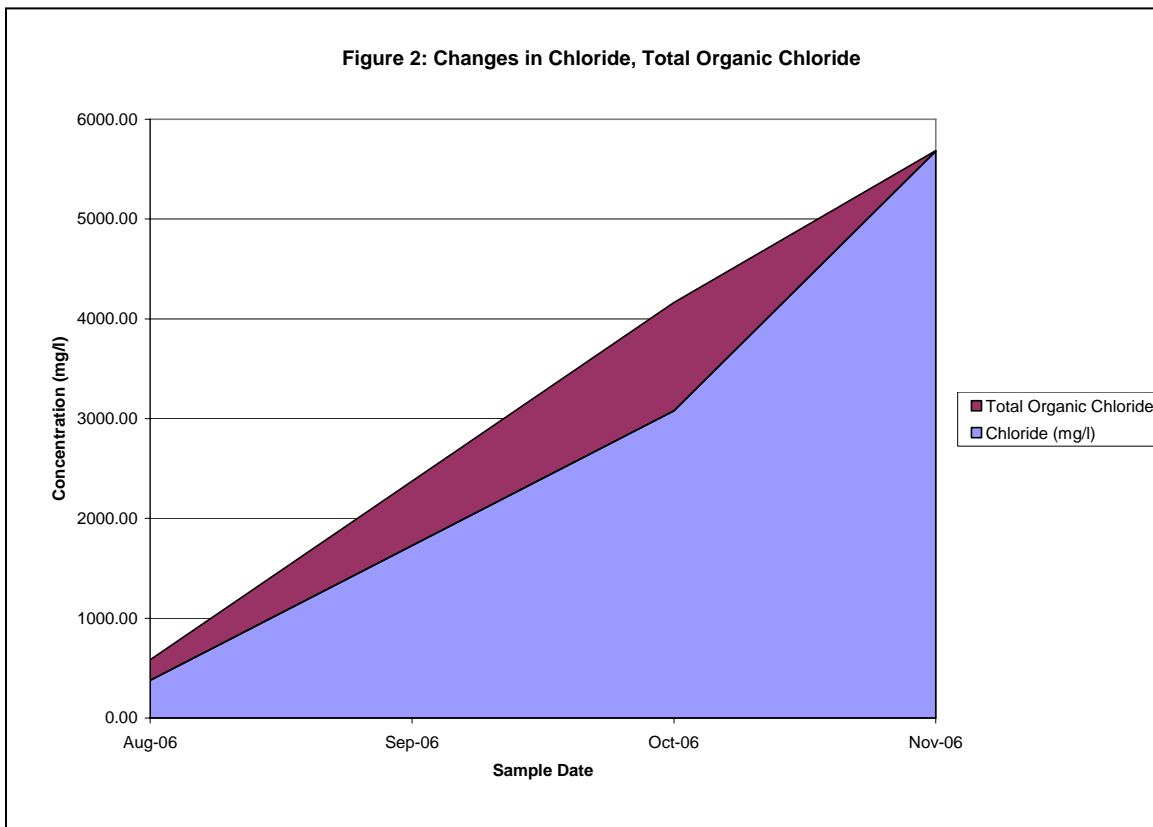


Figure 7. Changes in Chloride, Total Organic Chloride