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THERMAL REMEDIATION services inc.

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Our Word Is Who We Are

<u>Project Example</u> - Remediation of 1,1,2,2-Tetrachloroethane using ERH at the U.S. Naval Station Annapolis, US Naval Academy, Annapolis, Maryland

*This project represents the **second project ever implemented involving the remediation of 1,1,2,2-Tetrachloroethane (TeCA) using ERH for heat enhanced hydrolysis**.*

Project Reference: Ms. Jennifer Melton, Project Manager, U.S. Navy, Washington D.C., (202) 685-3275.
Contaminants Treated: 1,1,2,2-Tetrachloroethane
Technologies Applied: Electrical Resistance Heating
Geology: Sand, sandstone with an iron layer.
Hydrology: Groundwater - 60 ft bgs
Treatment Area, Average Depth Interval and Volume:
8,500 square feet, 29 – 70 ft bgs and 12,500 cubic yards.
Site Constraints: Below grade completion behind the Navy Commissary allowing unrestricted public access.
Beginning Contaminant Levels: 97 mg/kg and 10µg/l
Cleanup Levels: 90% reduction in soil to 9.7 mg/kg.
Goals Achieved: The final data is being reduced but the initial confirmatory soil samples were non-detect.
Remediation Time Period: Winter – spring 2006.
Total Price: about $900,000 or ~$72/yd^3 ($94/m3)
Contract Terms: Standard Fixed Price per Task.

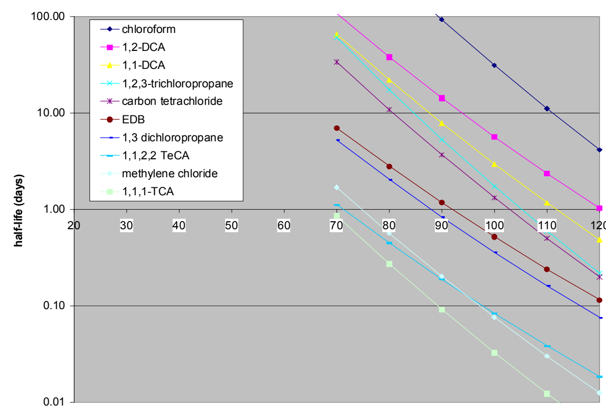

Figure 1. Hydrolysis of Halogenated Alkanes at Elevated Temperatures

<u>Problems Encountered and Corrective Actions:</u> Drilling at the Annapolis site was difficult due to the subsurface lithology consisting of very hard layers of sandstone and iron. The air rotary drilling technique was used initially to drill through the sandstone and iron followed by the hollow stem auger drilling technique for the remainder of the electrode bore hole.

The ERH remediation area required below grade completion of the electrodes, cables and piping to allow unrestricted access by pedestrians and vehicles during operations behind the Navy Commissary building (see Figure 3).

During ERH operations, a local resident about 100 feet away from the remediation area, complained about the sound of the vacuum blower. TRS immediately built a sound enclosure made from ¾-inch plywood sheets around the blower to mitigate the sound (see Figure 4).

Background

Thermal Remediation Services, Inc. (TRS) completed the remediation of 1,1,2,2-Tetrachloroethane (TeCA) in soil and groundwater, using ERH, at the Naval Station Annapolis, US Naval Academy, Annapolis, Maryland. TRS is worked as a subcontractor to Shaw Environmental & Infrastructure. The professional team at TRS is the only group of individuals that has implemented ERH for remediation of TeCA in soil and groundwater. This project is the second TeCA remediation using ERH that the professional team at TRS has performed.

TeCA is an interesting compound from a thermal remediation perspective. At elevated temperatures, TeCA rapidly converts to trichloroethene (TCE) through hydrolysis (Figure 1). Hydrolysis is a water substitution reaction; the TeCA hydrolysis reaction is also sometimes referred to as "dehydrohalogenation." During hydrolysis, TeCA reacts directly with water or soil moisture without regard to redox conditions; no inorganic or biochemical catalysts are required. The conversion of TeCA to TCE proceeds very rapidly when the site begins to heat. For example, the TeCA hydrolysis half-life is less than one day when the subsurface temperature exceeds 75°C (160°F). For this reason, remediation at this site can be considered to be a TCE remediation – the vast majority of the TeCA will convert to TCE and be removed from the subsurface as TCE, with TeCA forming only a small portion of the extracted VOCs. One pound of TeCA forms 0.78 pounds of TCE as determined by chemical stoichiometry.

Remedial Approach

The remediation area is approximately 96 ft. by 88 ft. elliptical shape with an area of about 8,500 sq. ft. The average heating depth interval was from 29 ft to 70 ft below grade surface (bgs). This provides a treatment volume of about 12,900 cubic yards.

TRS installed 24 electrodes – slightly closer together in the central hot spot and slightly farther apart near the treatment zone edges. A site plot plan is provided in Figure 2. Each electrode boring includes a co-located vapor recovery well. Such co-location saves drilling, trenching, and soil disposal costs while providing a tight recovery well spacing to ensure vapor capture. Each of the electrodes and co-located VR wells were installed below grade in rated vaults allowing unrestricted pedestrian and vehicle traffic (See Figure 3).

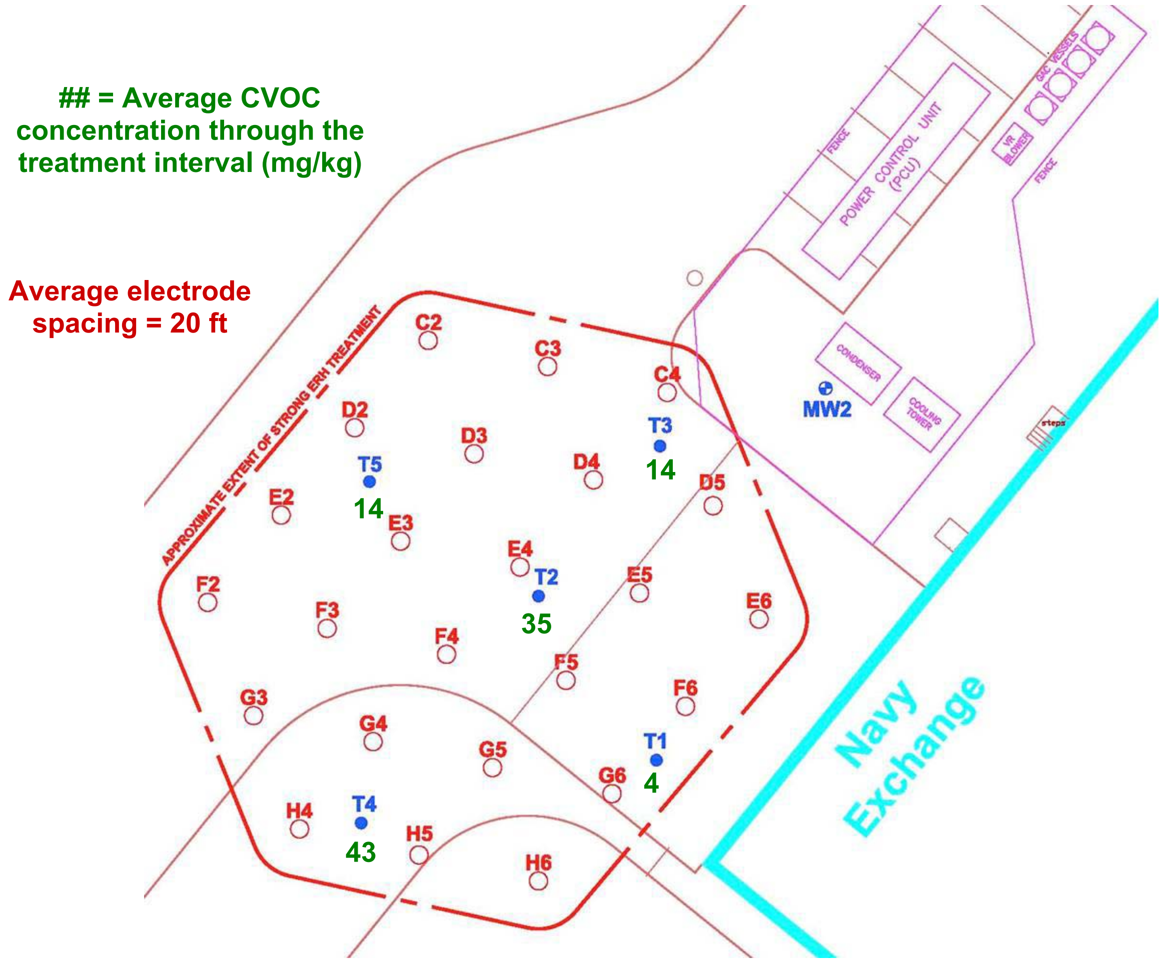

Figure 2. Site Plot Plan

TRS adds a small amount of water to the vadose zone portion of our electrodes. The added water ensures that the soil immediately adjacent to the electrodes remains moist and electrically conductive. TRS's advanced electrode design requires less water addition than older electrode styles. Unlike other ERH vendors, TRS never adds more water to the electrodes than we remove as steam; thus, TRS maintains hydraulic control of the site during ERH remediation. Co-locating the vapor recovery wells with the electrodes also helps to keep the electrodes moist.

TRS installed five temperature-monitoring points (TMPs), each of which contain from 9 to 15 thermocouples or thermistors for subsurface temperature measurement, monitoring temperatures at five-foot intervals from 5 ft to 75 ft bgs. The number of thermocouples in each TMP corresponds to the depth of treatment in the immediate area.

TMPs can be located anywhere in the remediation region; however, TRS recommends placing each TMP several feet from an electrode to ensure that the TMP is monitoring the bulk soil temperature. TMP borings are often used to collect "before ERH" soil samples. Alternatively, TMPs can be sited at the boring locations and the pre-existing soil samples can be used for the before ERH samples. TRS recommends locating the confirmatory soil sample borings immediately adjacent to the TMPs. This provides the ability to directly compare before-and-after soil samples and the treatment temperature history. If monitoring wells are desired in the treatment region, TRS provides proven designs for such multiple-use wells and EPA approved sampling procedures for removing both hot soil and groundwater.

System Construction and Startup

Construction of the ERH system began on November 7, 2005 with the placement of the surface equipment, which included the Power Control Unit (PCU), steam condenser, cooling tower and vapor recovery blower. Subsurface installation of the electrodes began the following week on November 16, 2005 and was concluded on January 17, 2006. The installation of the surface equipment and completion of the trenches that supply power and vapor recovery to the electrodes was completed the following week on January 25, 2006. Figure 3 shows the locations of the below grade electrodes, TMPs, piping and cables.

Figure 3. Electrodes and TMPs Installed Below Grade Allowing Unrestricted Access

System startup and shakedown began the week of January 23, 2006 with completion of all electrical and vapor recovery connections, power was applied to the vapor recovery blower and steam condenser for testing. Once proper operation of each component's internal and external interlock systems were verified TRS applied power to the electrodes for voltage safety testing. The electrodes were initially energized on January 26, 2006 for step and touch, and step and step voltage safety testing. Once the areas around the treatment area, inside the building and inside the job trailer were deemed safe, workers were allowed back into their respective areas. No voltage potential in any area around the site was greater than the TRS 15 volt limit. The applied voltage to the subsurface was slowly increased throughout the remainder of the day and with each increase voltage potentials to all conductive areas were measured.

The system was left offline overnight and continual safety and performance testing was conducted the following day.

Operations

The ERH system became fully operational on Friday, January 27, 2006. As of April 25, 2006, the average subsurface temperature was 98.6°C. Figure 4 shows the equipment compound. The PCU, steam condenser, air cooling tower and vacuum blower are shown in the top picture. The vacuum blower is inside a plywood sound enclosure. The Granular Activated Carbon (GAC) canisters (blue containers) are to the right of the blower and PCU in the lower picture.

Figures 5, 6, and 7 illustrate the subsurface temperatures for TMP locations 2, 4 and 5 over time from the initial baseline temperature on January 27, 2006 through April 20,

2006. The average subsurface temperature for each TMP does not include its 5 or 75-foot interval temperature as they are located outside the treatment area. The depth of treatment corresponding to each TMP has been included as well as the relative CVOC concentration for reference.

In Figures 5, 6 and 7 notice the correlation between the elevated subsurface temperature and the location of the relative contaminant concentrations. The black line represents the relative concentration of CVOCs. The brown line represents the ERH treatment interval. The blue line represents the start of ERH operations. Each of the other colored lines represents the subsurface temperatures at depth on a given day.

These Figures illustrate that the area of highest contaminant concentration is also the location of elevated subsurface temperatures as designed. This is expected because the electricity flows preferentially to low resistance pathways or areas of higher conductivity. As the TeCA undergoes heat-enhanced hydrolysis and converts to TCE, chloride ions break away from the degrading TeCA and create a chloride ion halo surrounding the contamination resulting in areas of higher conductivity. The areas of higher conductivity heat up slightly faster than the surrounding soil. As the TeCA converts to TCE by heat enhanced hydrolysis, the TCE is recovered in the vapor phase.

Figure 4. ERH Equipment Compound with Sound Enclosure (plywood) around Blower

Figure 8 illustrates the combined average subsurface temperatures at TMPs 1-5 from January 25 through April 25, 2006.

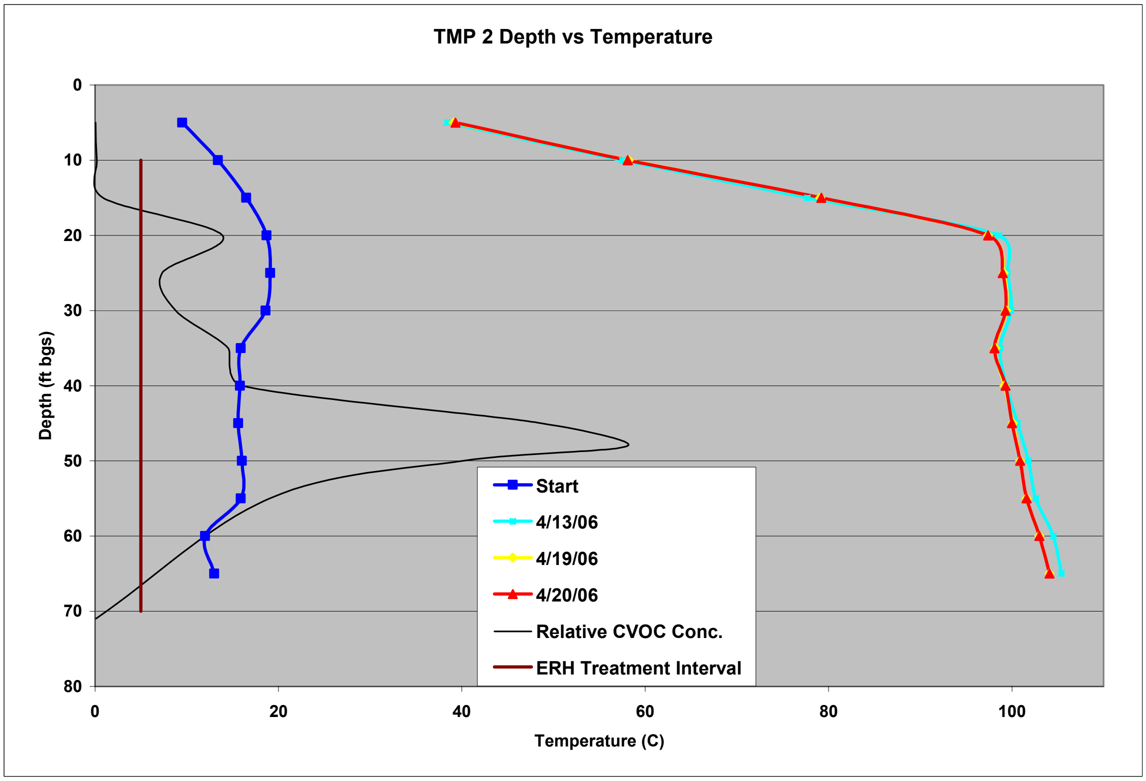

Figure 5. Subsurface Temperature at Depth vs Relative CVOC Concentration at TMP 2

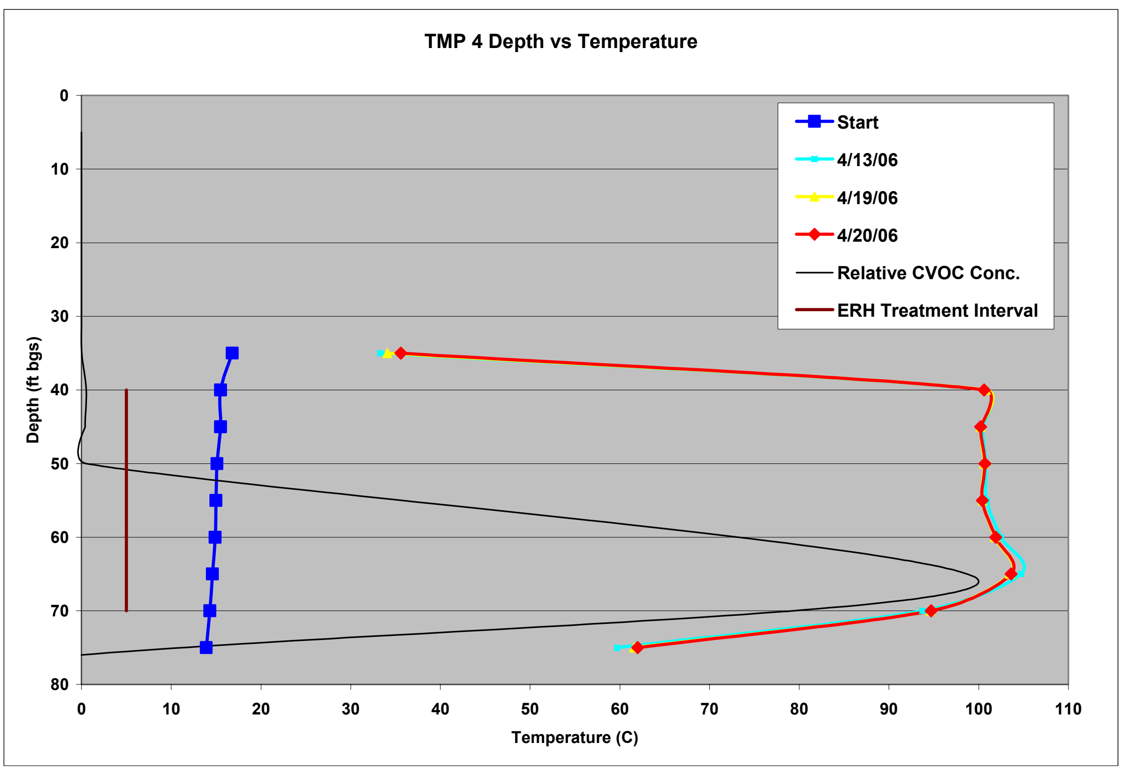

Figure 6. Subsurface Temperature at Depth vs Relative CVOC Concentration at TMP 4

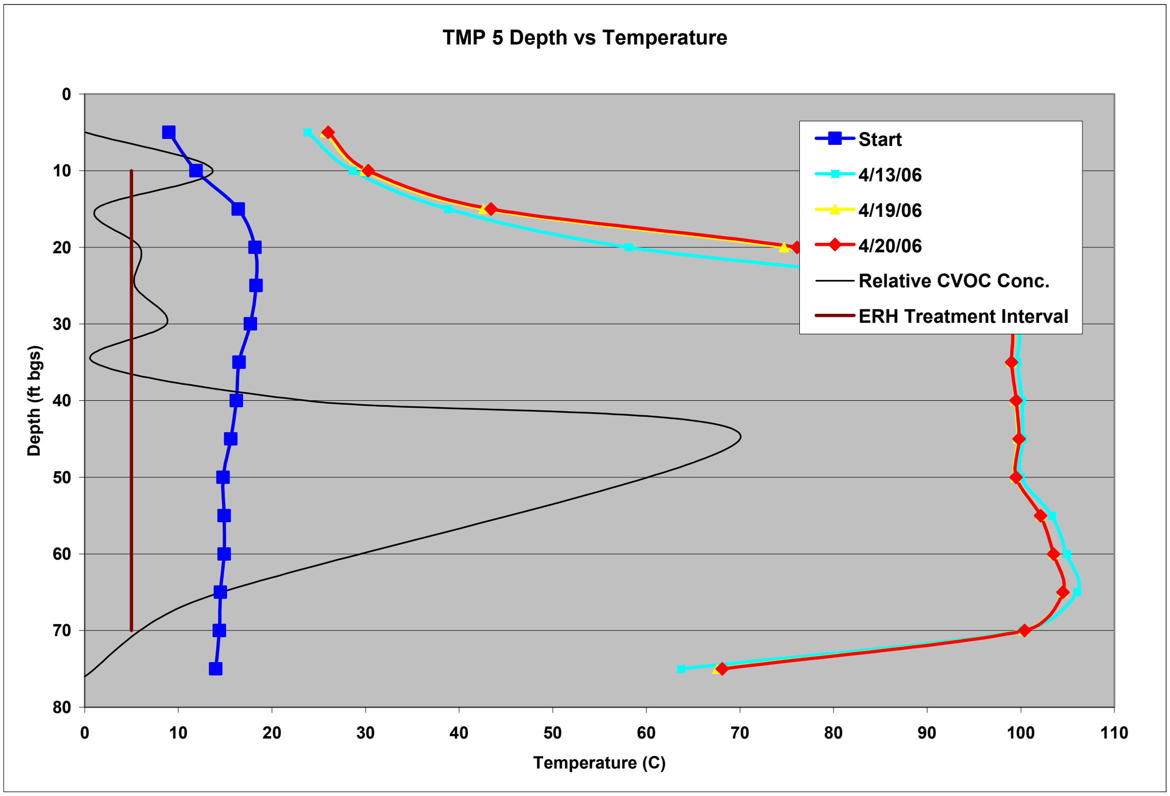

Figure 7. Subsurface Temperature at Depth vs Relative CVOC Concentration at TMP 5

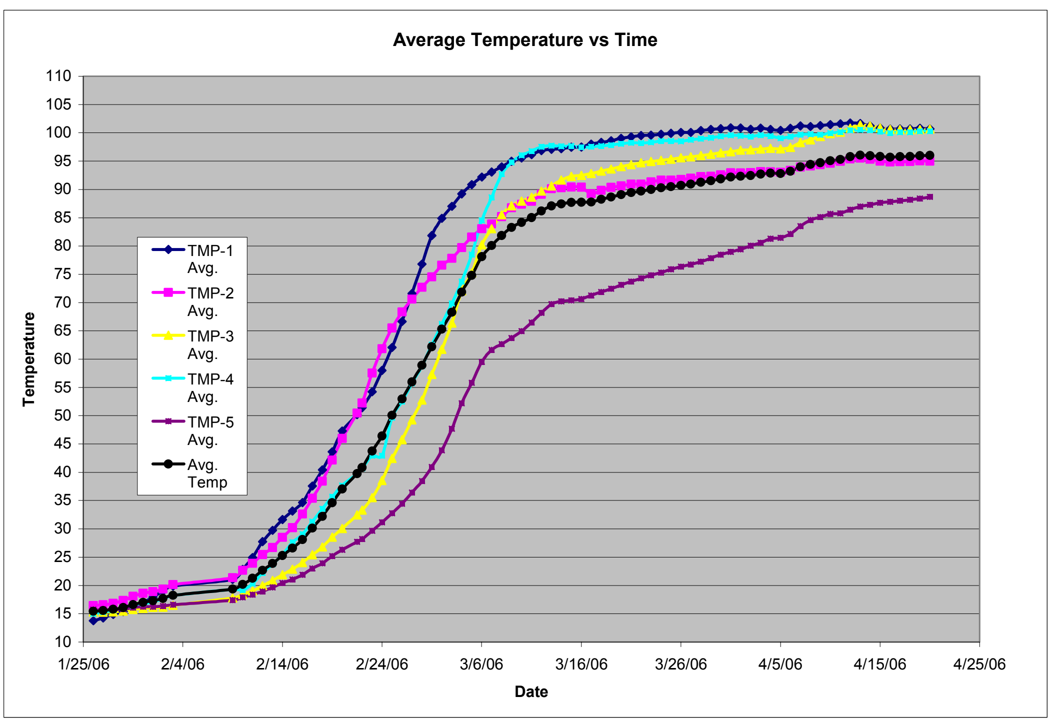

Figure 8. Average Subsurface Temperatures vs Time

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Results

Table 1 contains mass removal rates in pounds (lbs) per day for each contaminant as well as the rate of total lbs removed per day from January 31 to March 29, 2006.

Table 1. Vapor Stream Mass Removal Rate

Date	TeCA removal lbs/day	TCE removal lbs. day	cis-DCE removal lbs/day	1,1,2,TCA removal lbs/day	PCE removal lbs/day	Total removal lbs/day
1/31/06	14.3	3.7	0.2	0.1	1.0	19.3
2/15/06	4.6	1.6	0.1	0	0.3	6.8
2/22/06	6.6	3.6	0.1	0	0.4	10.9
3/1/06	6.1	14.8	0.1	0	0.4	21.4
3/8/06	10.1	32.3	0.1	0.1	0.4	42.9
3/16/06	46.4	46.3	0.1	0.4	1.5	94.8
3/22/06	42.8	11.1	0.1	0.1	0.4	54.4
3/29/06	9.7	3.0	0.0	0.0	0.1	12.8

Table 2 illustrates the cumulative estimated mass removed (lbs) in the vapor stream by contaminant and the cumulative total estimated mass removed (lbs) from January 31 to March 29, 2006.

Table 2. Vapor Stream Cumulative Mass Removal Estimate

Sample date	TeCA mass removed lbs.	TCE estimated mass removed lbs.	cis 1,2-DCE estimated mass removed lbs.	1,1,2-TCA estimated mass removed lbs.	PCE estimated mass removed lbs.	Total estimated mass removal lbs.
1/31/06	40.0	13.7	0.75	0.25	2.75	57.5
2/15/06	80.9	22.9	1.5	0.4	5.6	111.2
2/22/06	39.1	18.2	0.8	0.3	2.7	61.1
3/1/06	44.6	64.2	0.6	0.3	3.0	112.7
3/8/06	56.8	164.8	0.5	0.4	3.0	225.5
3/16/06	213.4	296.8	0.7	1.9	7.3	520.2
3/22/06	298.7	192.4	0.6	1.8	6.2	499.7
3/29/06	182.4	49.1	0.3	0.3	1.6	233.7
Total	**955.9**	**822.1**	**5.8**	**5.7**	**32.2**	**1,821.6**

As of March 29, 2006, approximately 956 lbs of TeCA and 822 lbs of TCE were recovered in the vapor stream. The total estimated mass removed including all target CVOCs was 1,821 lbs.

The final confirmatory results were validated. The initial confirmatory soil samples were non-detect (ND) for TeCA.

Figure 9 illustrates the vapor recovery of TeCA, TCE and total CVOCs in lbs per day at various subsurface temperatures during the ERH remediation from January – March 2006.

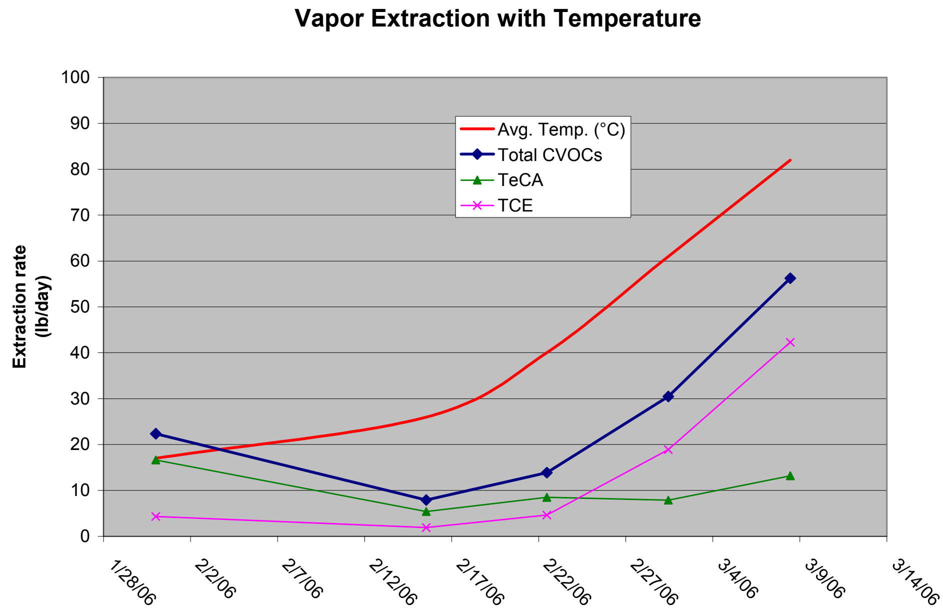

Figure 9. CVOC Extraction Rate (pounds per day) with Temperature over Time

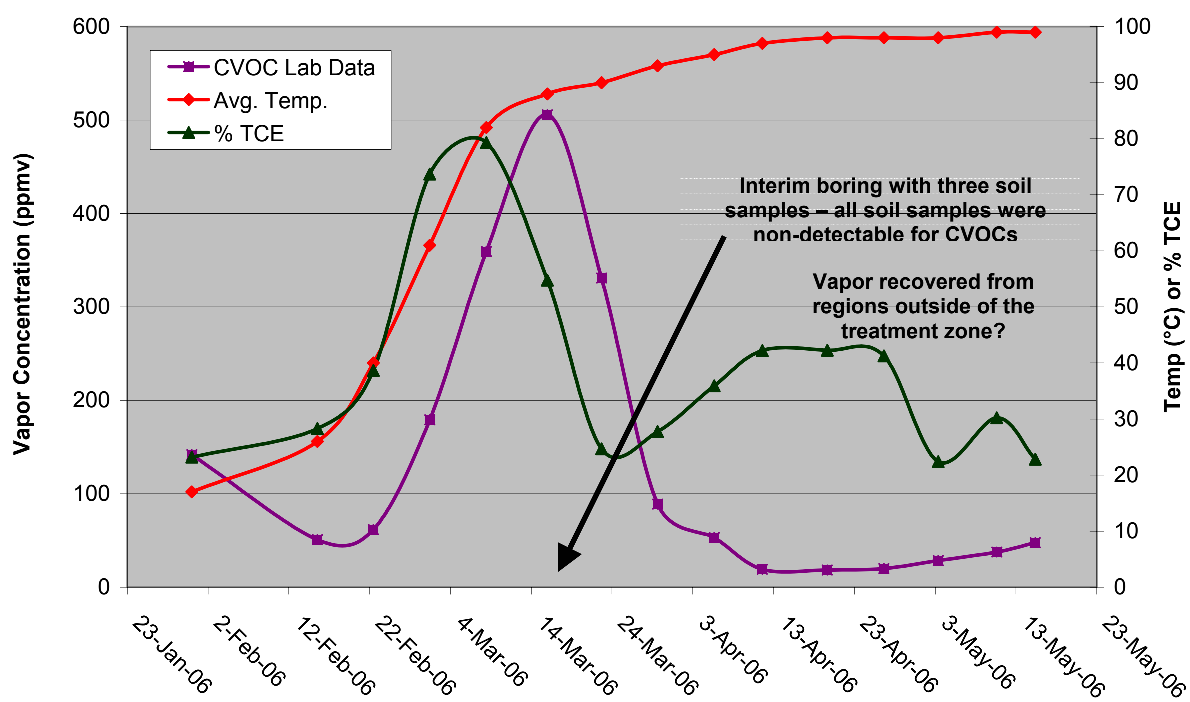

Figure 10. Recovery of Total CVOC (purple line) vs TCE (green line) with Temperature (red line) over Time

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Figure 10 illustrates the recovery of total CVOCs compared to the recovery of TCE with subsurface temperature during the ERH remediation. In March 2006, less than two months following startup, interim soil samples were collected inside the treatment region. All three interim soil samples were non-detect (ND) for CVOCs. Following the interim event, TRS continued to recover TCE vapors (green line in Figure 10) for a few more months which implores the question, were the TCE vapors coming from a region outside of the treatment area.

Table 3 compares the CVOC and chloride data in the three soil samples of the initial and interim sampling events. The three samples were collected from one boring at 46, 61, and 63 ft bgs. All three of the interim soil samples were ND for CVOCs. Chloride concentrations in soil increased between the initial and interim sampling events by as much as 12.5 times.

Table 3. Comparing CVOCs and Chlorides in Soil from the Initial and Interim Sampling Events

Depth (ft bgs)	Initial CVOCs (mg/kg)	Interim CVOCs (mg/kg)	Initial chlorides (mg/kg)	Interim chlorides (mg/kg)
46	82	<0.002	9	77
61	32	<0.002	9	113
63	N/A	<0.002	N/A	194

Conclusions

The original concentrations of CVOCs prior to the ERH remediation were 99% TeCA and 1% TCE. During the ERH remediation the concentrations of CVOCs extracted was 54% TeCA and 46% TCE indicating the hydrolysis reaction was occurring at an accelerated rate due to the elevated subsurface temperatures.

TRS treated 12,500 cubic yards (9,600 m3) from 10 to 70 ft bgs (3 to 21 m) and maintained steady-state operations from February 8 to May 19, 2006 (100 days). We recovered approximately 2,014 lb (915 kg) of CVOCs during ERH operations.

TRS completed the remediation 20 days ahead of schedule and under budget. All interim soil samples were ND for CVOCs.

The total cost of this ERH remediation was about $900,000 or $72/yd3 ($94/m3).