ERH in Soil and Groundwater
U.S. Army - Redstone Arsenal
Alabama

Remediation of TCE in Karst Bedrock

Project Summary

TRS Group, Inc. (TRS) is a subcontractor to CB&I (formerly Shaw Environmental), under contract to the U.S. Army Mission and Installation Contracting Command to perform electrical resistance heating (ERH) for the remediation of volatile organic compounds (VOCs) in the vadose zone soil and shallow groundwater on multiple sites located at Redstone Arsenal (RSA) near Huntsville, Alabama. Three of the four sites where ERH was applied (RSA-096, RSA-142, RSA-095) are highlighted in this project summary. All three of the sites have the same primary contaminant (TCE) and included treatment of Karst limestone bedrock. Project goals for the vadose zones are 5 mg/kg in soil and saturated zones are 80% reductions from baseline concentrations in ground water at each individual performance monitoring well.

Background

RSA is the home of the U.S. Army Aviation and Missile Command, the National Aeronautics and Space Administration George C. Marshall Space Flight Center, and numerous other tenant organizations. RSA occupies approximately 38,300 acres. The Department of the Army controls 36,459 acres, of which approximately 15,500 acres are woodlands, 5,360 acres is leased for agricultural use, and approximately 12,000 acres are used for test ranges. The George C. Marshall Space Flight Center leases 1,841 acres of land within the central portion of RSA. Approximately 2,900 acres are owned by the Tennessee Valley Authority, and 4,100 acres of Wheeler National Wildlife Refuge are within the boundaries of RSA.

Site Characteristics & Design Parameters

Sites RSA-096, RSA-142, and RSA-095 are located approximately 0.2 miles apart. Geology for the area is typically an overburden mix of silt and clay with a highly variable depth to bedrock. However, the limestone variation between the sites provides a comparison of the effects of secondary porosity in a karst environment.

The baseline TCE concentrations in soil and groundwater are described in Table 1.

Table 1. Baseline TCE Concentrations

Site	Peak Baseline Ground Water TCE Concentration (µg/L)	Peak Baseline Soil TCE Concentration (mg/kg)
RSA-096	949,000	1,070
RSA-142	301,000	2,670
RSA-095	1,104,000	1,800

The ERH system design parameters for each site are summarized in Table 2 below.

Table 2. ERH System Design Parameters

	Area	Average Treatment Depth	Volume	# of Electrodes
RSA-096 (3 treatment areas)	6,700 ft^2	Saturated zone – 3 to 68 ft bgs Vadose zone – ground surface to 13 ft bgs	10,700 yd^3	40
RSA-142 (9 treatment areas)	19,800 ft^2	Saturated zone – 2 to 48 ft bgs Vadose zone – 2 to 16 ft bgs	16,100 yd^3	145
RSA-095 (4 treatment areas)	57,396 ft^2	Saturated zone – 2 to 49 ft bgs Vadose zone – 2 to 17 ft bgs	96,300 yd^3	290

System Construction and Operations

The below grade installation of electrode materials at all three sites included hollow stem auger drilling for the vadose treatment areas, and roto-sonic drilling for the saturated zone areas.

Surface installation activities included: construction of electrode wetting system manifold; vapor recovery manifold construction; security system and fence installation; wiring of equipment and gauges, wiring of temperature monitoring point (TMP) and drip field boxes and, electrode supply cable connection and placement of equipment including the power control unit, vacuum blower, condenser, and vapor granular activated carbon (VGAC) units.

The application of electrical energy to the subsurface was optimized throughout the project in an effort to achieve the most efficient heat-up and TCE phase change in the subsurface per unit of energy applied. Through weekly analysis of power input, subsurface temperatures, and TCE recovery data, the optimal rate of energy application was determined. Continuous adjustments were made to the ERH system to maintain an optimal processing rate within system limitations. Table 3 describes the days required for construction and operations of each ERH remedial system.

Table 3. Construction and Operation Durations

Site	Construction Duration (days)	Operations Duration (days)
RSA-096	106	91
RSA-142	111	150
RSA-095	Estimated to total 310 over three phases	Estimated at 250 in three phases

Following are individual summaries of each of the RSA site remediation locations.

Redstone Arsenal Site 096

The ERH treatment area covered approximately 6,700 ft^2 with a corresponding treatment volume of approximately 10,700 yd^3. The total treatment volume was divided into two target treatment zones, Saturated and Vadose. Site lithology is an overburden mix of silt and clay with a highly variable depth to bedrock. The Karst limestone bedrock is weathered with fractures and observed voids throughout the treatment volume. Groundwater is encountered at approximately 11 to 12 ft bgs.

The Saturated Zone focus was the reduction of TCE in the groundwater located in both the saturated soils and sedimentary bedrock, but also included vadose soil treatment. The Saturated Zone treatment interval extended from 3 to 68 ft bgs along the western side of the Site. The Vadose Zone treatment area in the eastern portion of the site included three separate volumes, each requiring Vadose Zone treatment from ground surface to 13 ft bgs. The ERH treatment areas and other Site features are delineated on Figure 1.

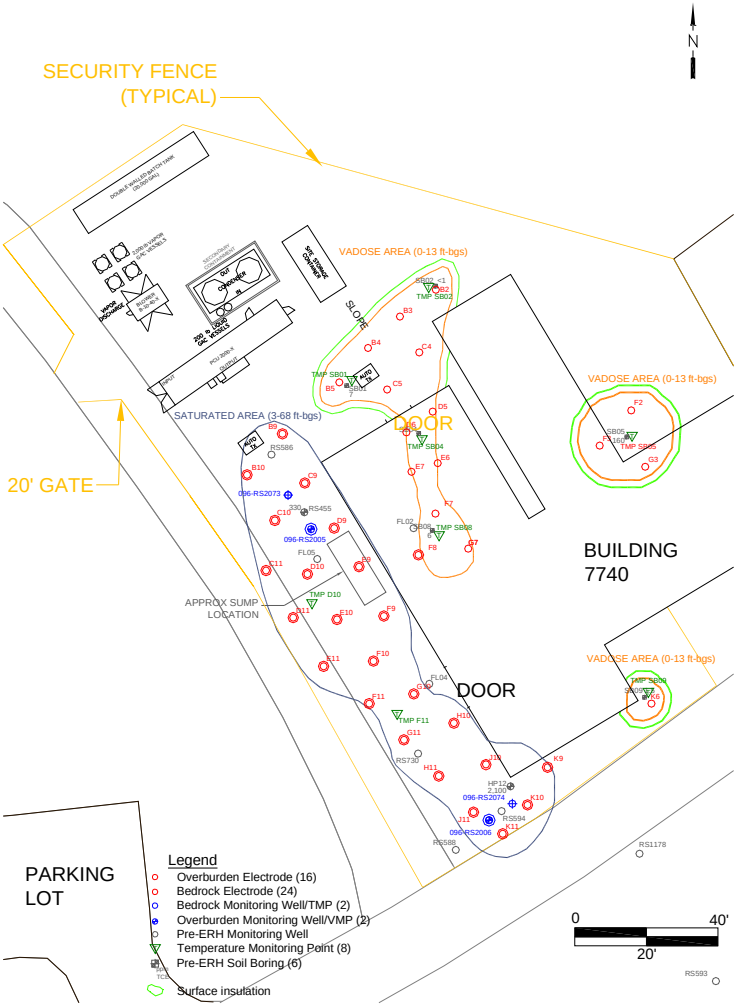

Figure 1. RSA-096 Site Overview Map

A total of 40 electrodes with co-located vapor recovery wells were installed. The system incorporated 12 saturated zone electrodes with vertical vapor recovery (VR) screens, 12 saturated zone electrodes with horizontal VR screens, and 16 vadose zone electrodes with vertical VR screens (Figure 2). Subsurface temperatures were measured at 10 temperature monitoring points (TMPs), each containing thermocouples spaced vertically at approximately five-foot intervals through the treatment volume. A total of 64 thermocouples provided a detailed subsurface temperature profile throughout the project.

Figure 2. RSA-096 Electrode Layout

The primary goal for the remediation at RSA-096 was to remove any source of TCE DNAPL within the treatment volume. Baseline groundwater samples indicated the presence of DNAPL, with an average pre-ERH concentration of 853,000 µg/L. To further ensure successful source removal, a goal of 5 mg/kg was set for the overburden soils within the treatment area. The baseline samples indicated concentrations as high as 1,070 mg/kg.

Construction of the ERH system began on July 9, 2013, and the system started operations on October 24, 2013. The ERH system operated 91 days and applied 2,039,980 kilowatt hours (kWh) of energy to the treatment volume. On average, subsurface temperatures increased at a rate of 1.4 degrees Celsius (ºC) per day as the treatment area temperature increased from ambient to 97.5º C.

Project Results

Based on weekly sample results and flow rates, it is estimated that over 2,800 lb of TCE were recovered from the treatment volume. During ERH treatment, TCE concentrations in the two performance monitoring wells with sufficient water to collect samples showed reductions between 66% and 99%. This reduction was at levels in line with the concentrations existing outside the treatment volume. The confirmatory samples collected two months after the end of ERH and VR operations showed that groundwater concentrations decreased to 90, 95 and 98% at all three performance monitoring wells, confirming that the groundwater goals had been met (Figure 3).

The results of all confirmatory soil borings in the Vadose Zone were below the goal of 5 mg/kg TCE with an average TCE concentration reduction of 98% as shown in Figure 4.

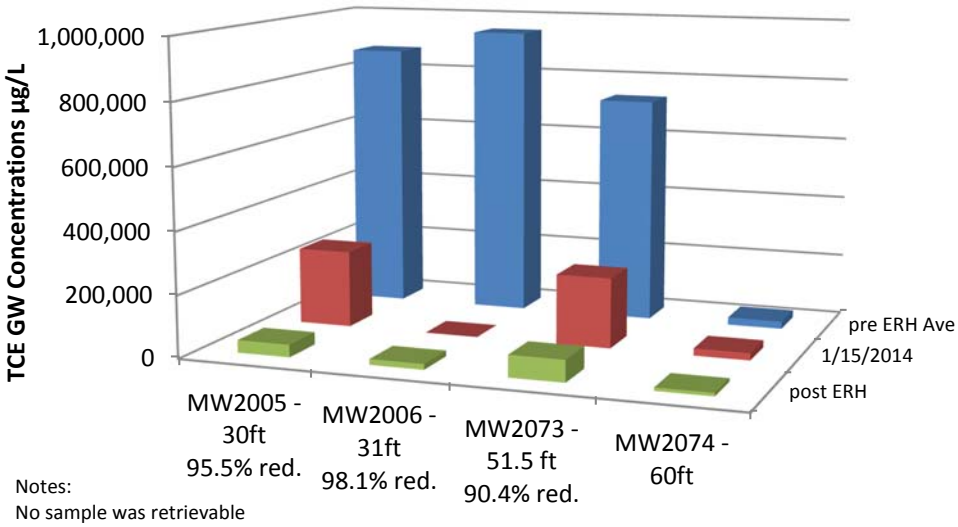

Figure 3. TCE concentrations pre-, during & post- ERH

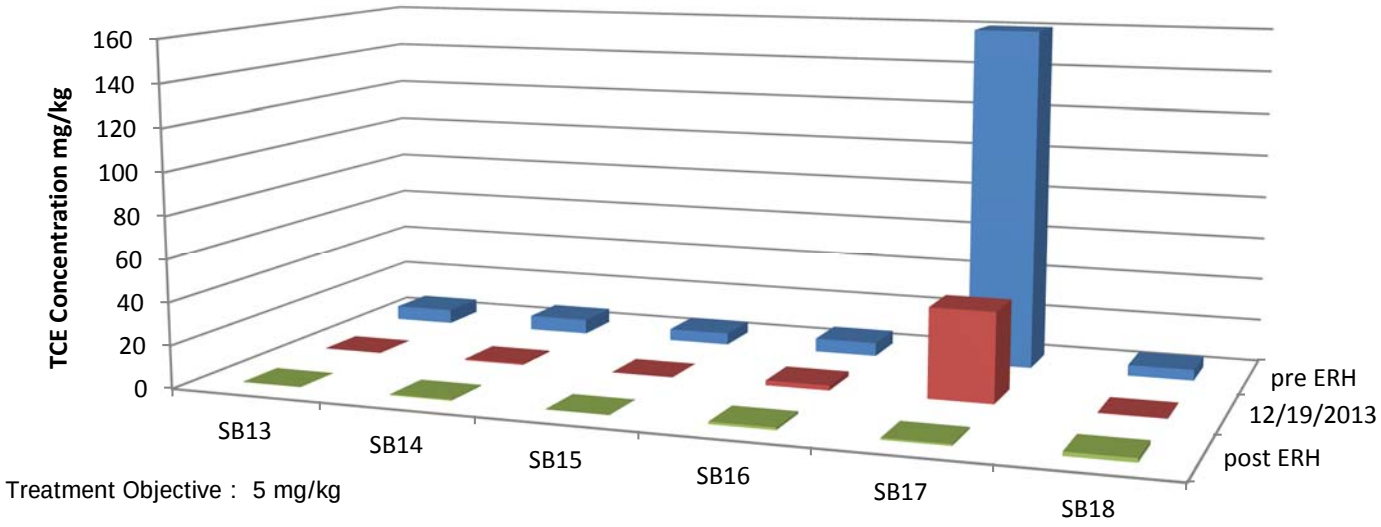

Figure 4. RSA-096 Vadose Zone results

Redstone Arsenal Site 142

The ERH treatment area encompassed approximately 19,800 ft^2 with a corresponding treatment volume of approximately 16,100 yd^3. The total treatment volume was divided into nine target treatment zones: T03, T04, T07, T08, T09, T10, T11, T12 and Area 4 (Figure 5). The treatment intervals extended from as shallow as 2 ft bgs to as deep as 60 ft bgs throughout the site.

An overburden mix of silt and clay with a highly variable depth to bedrock forms the Site lithology. The treatment volume also contained weathered Karst limestone bedrock with fractures and observed voids. Groundwater is encountered at approximately 11 to 12 ft bgs.

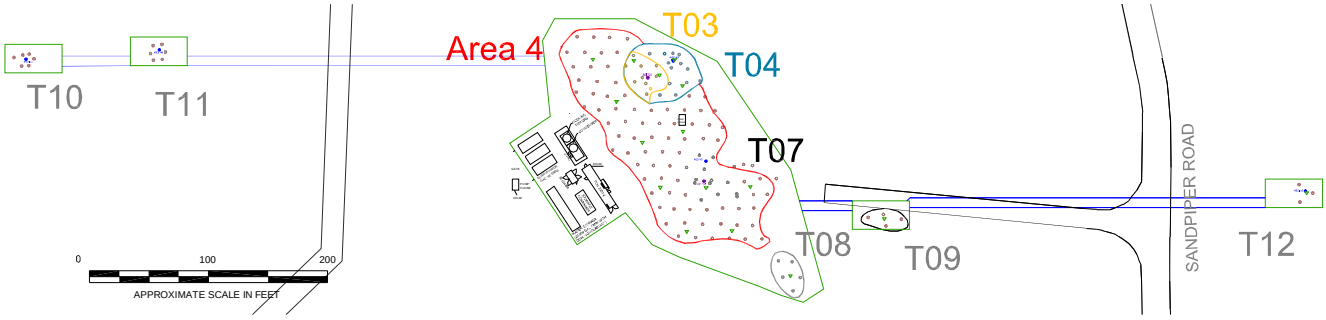

Figure 5. RSA-142 Site Overview

One hundred and forty-five electrodes with co-located vertical vapory recovery screens were installed. Subsurface temperatures were measured at 19 temperature-monitoring locations, each containing resistance temperature detectors (RTDs) spaced vertically at approximately five-foot intervals through the treatment volume. A total of 117 RTDs provided a detailed subsurface temperature profile throughout the duration of the project.

The primary goal for the remediation at RSA-142 was to remove any source of TCE DNAPL within the treatment volume. Baseline groundwater samples indicated the presence of DNAPL, with an average pre-ERH concentration of 180,000 µg/L. To further ensure successful source removal, a goal of 5 mg/kg was set for the overburden soils within the treatment area. The baseline samples indicated concentrations as high as 2,670 mg/kg.

Construction of the ERH system began on November 19, 2013 with the system starting operations on March 14, 2014. The ERH remediation system operated for 150 days with a total of 261 active days of construction, operation, and demobilization. On average, subsurface temperatures increased from ambient to a peak of 82 degrees Celsius within the active ERH area.

Project Results

Based on weekly vapor phase sample results and flow rates, it is estimated that over 4,900 pounds of TCE were recovered from the treatment volume. During ERH treatment, TCE concentrations in groundwater at the performance groundwater monitoring wells showed an average reduction of 90% over pre-ERH remediation concentrations (Figure 6).

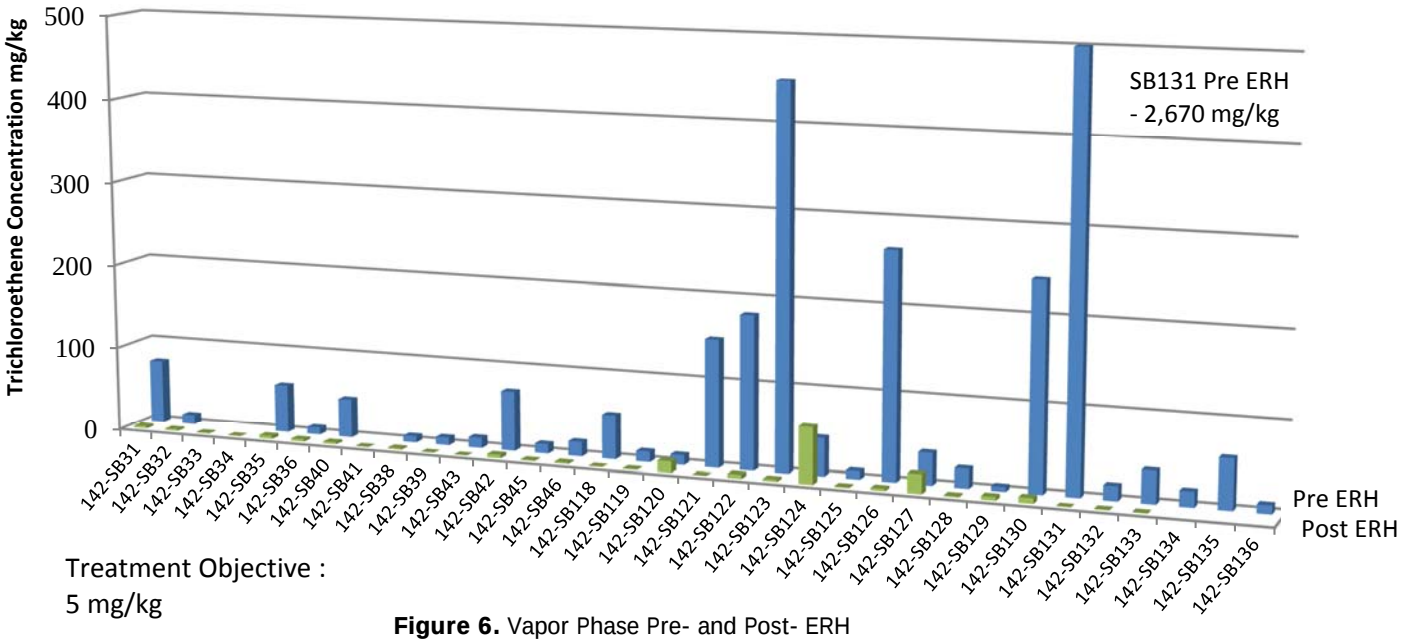

Figure 6. Vapor Phase Pre- and Post- ERH

The results of all confirmatory soil borings in the vadose zone were below the goal of 5 mg/kg TCE with the exception of four soil borings within Area 4 (SB123, SB127, SB130, and SB133; Figure 7). The treatment objectives were met in approximately 93% of treatment volume. An average TCE soil concentration reduction of 89% was observed.

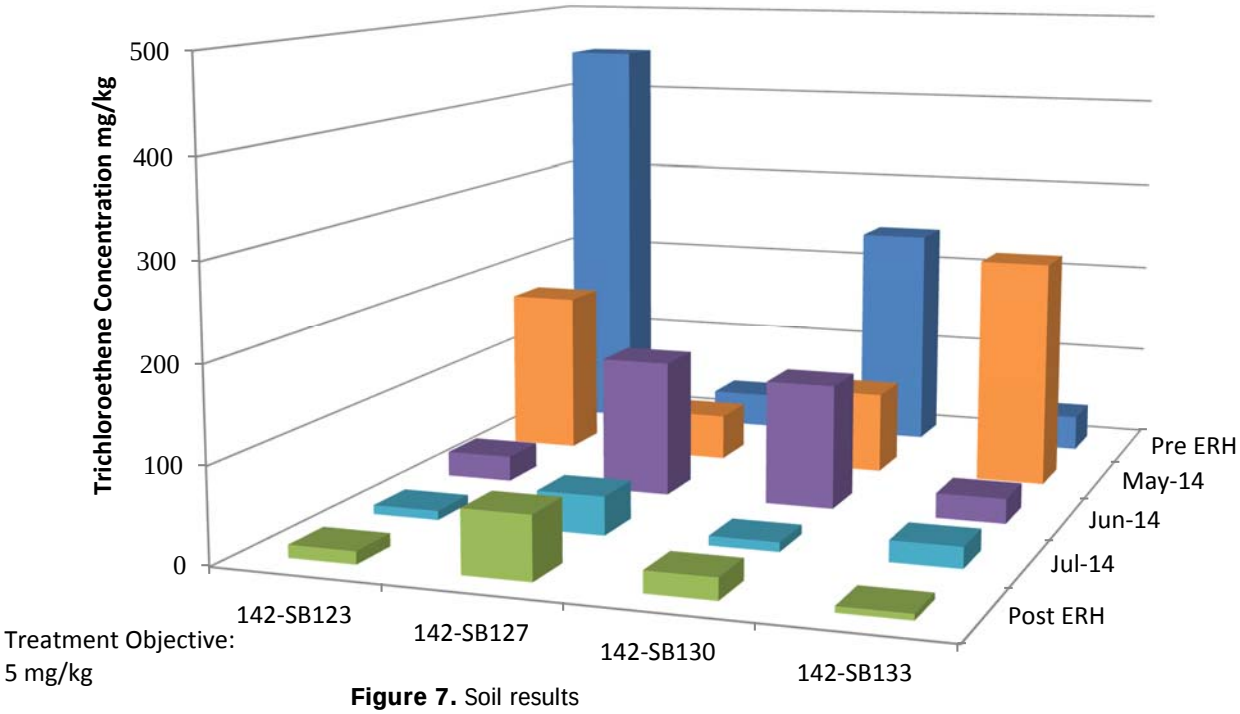

Figure 7. Soil results

Redstone Arsenal Site 095

RSA-095 is an approximately 10-acre site located in the southeastern portion of RSA. RSA-095 is in an industrial area that comprised the Redstone Ordnance Plant during the 1940s and the Redstone Arsenal Rocket Engine North Plant operated under lease to Thiokol Corporation from 1949 until 1995. The treatment area also includes RSA-093, the Reclaimed Empty Drum Storage Pad at Building 7368, which lies within the site boundary of RSA-095.

The site is divided into two parts (East Side = T01 & T04; West Side = T02 & T03) as shown in Figure 8. The ERH treatment area encompassed approximately 57,396 ft^2 with a corresponding treatment volume of approximately 96,300 yd^3. The treatment intervals extended from as shallow as 2 ft bgs to as deep as 63 ft bgs throughout the site.

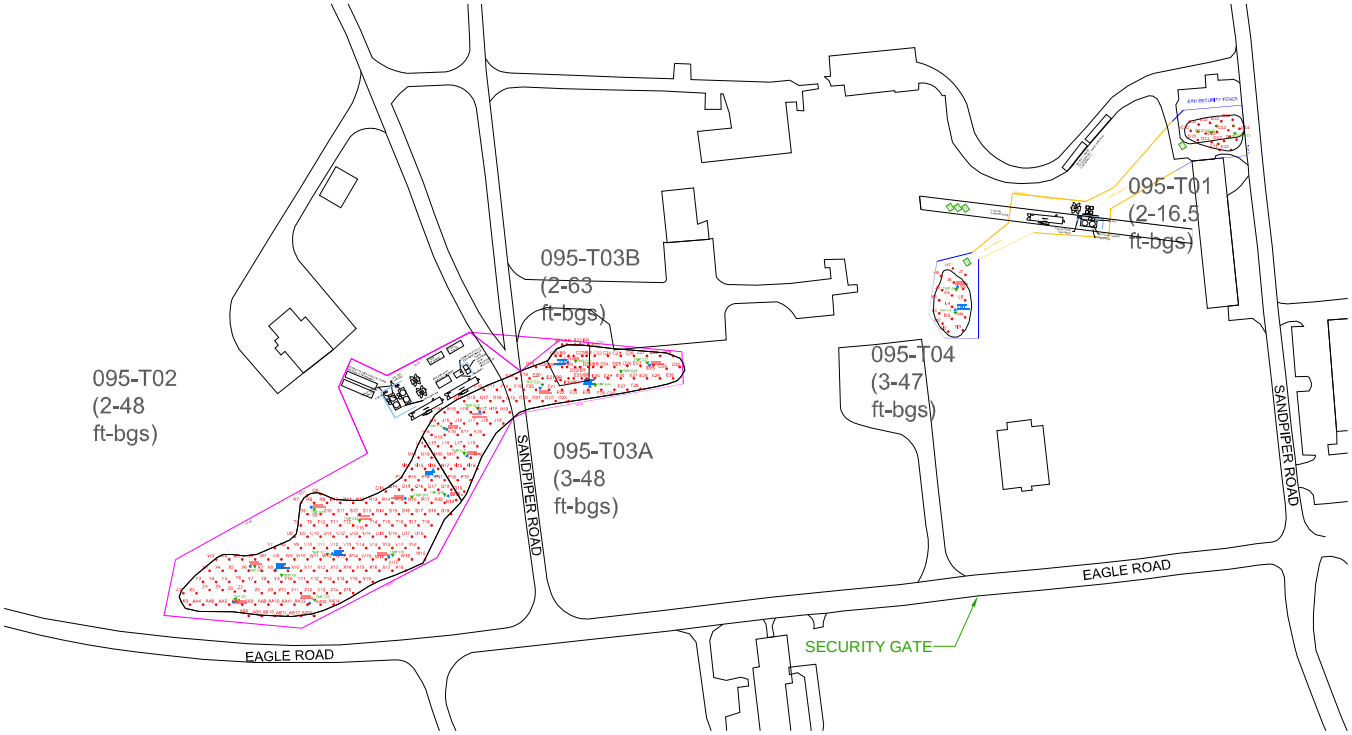

Figure 8. RSA-095 Site Overview

An overburden mix of silt and clay with a highly variable depth to bedrock forms the Site lithology. The treatment volume also contained weathered Karst limestone bedrock with fractures and observed voids. Groundwater is encountered at approximately 11 to 12 ft bgs.

The primary goal for the remediation at RSA-095 was to remove any source of TCE DNAPL within the treatment volume. Baseline groundwater samples indicated the presence of DNAPL, with an average pre-ERH concentration of 450,000 µg/L. The T01 Area shown below had vadose zone impacts but no DNAPL was observed in the saturated zone. To ensure the vadose mass did not make its way to the water table a 5 mg/kg goal was established for this area. The baseline samples indicated concentrations as high as 1,800 mg/kg.

In total, RSA95 contains over 275 multi-element electrode locations (a total of ~570 elements). ERH above ground treatment equipment for vapors and steam includes carbon (East) and a regenerative thermal oxidizer (West).

Project Status

- East side, T01 & T04: ERH operations occurred between January 7 and April 1, 2015. Treatment objectives were met and approximately 1,600 lbs of VOCs were removed. Figure 9 shows the ERH equipment compound.
- West side, T02 & T03: Currently under construction as shown on Figure 10. Startup of the ERH system on the West side is planned for Summer 2015.

Figure 9. East Side Equipment Compound

Figure 10. West Side Construction

Summary

TRS Project Managers/Senior Project Manager:	*Chad Crownover (RSA-096/142) and Lauren Soos (RSA-095)/Chris Thomas*
TRS Project Engineer	*Chad Crownover*
Site Geology and Hydrology:	*Silt and clay overburden with Karst limestone bedrock* *Groundwater 11-12 ft bgs*
Treatment Area Size, Volume, and Depth:	*RSA 096 – 6,700 ft², 10,700 yd³, 3 – 68 ft bgs* *RSA142 – 19,800 ft², 16,100 yd³, 2 – 48 ft bgs* *RSA095 – 57,396 ft², 96,300 yd³, 2 – 49 ft bgs*
Beginning Contaminant Concentrations:	*Average peak in soils of 1,850 mg/kg* *Average peak in groundwater 785,000 µg/L*
Remedial Goal(s):	*5 mg/kg TCE in soil* *80% TCE reduction from baseline monitoring well concentrations*
Actual Cleanup Achieved:	*Average reductions of 94% in Soils and 92% in groundwater* *For RSA-096: 98% soil, 94% water* *For RSA-142: 89% soil, 90% water*
Period of Performance:	*Approximately Average 105 days of construction and 98 days of operations*
Contract Terms:	*Standard Fixed Price Energy Contract*

TRS Contact Information

Mr. David Fleming, (425) 396-4266, dfleming@thermalrs.com, **www.thermalrs.com**