Document Control No. 07030.06-100

October 1, 2012

Mr. Hector Santiago
USACE – Omaha
CENWO-PM-HA
1616 Capitol Ave., Suite 9000
Omaha, NE 68102

RE: Final In Situ Thermal Treatment Using Large-Diameter Auger Soil Mixing and Zero-Valent Iron Results
Former Offutt AFB Atlas "D" Missile Site 2, Arlington, Nebraska
Contract Number W91238-06-D-0022, Task Order Number DK05

Dear Mr. Santiago:

ITSI Gilbane Company (ITSI Gilbane) is pleased to submit the Final In Situ Thermal Treatment Using Large-Diameter Auger Soil Mixing and Zero-Valent Iron Results for the Former Offutt AFB Atlas "D" Missile Site 2 project, Arlington, Nebraska.

Should you have any questions or comments, please don't hesitate to contact me at (303) 808-4937. Thank you for your time and assistance.

Sincerely,

Kelly Ruder

Kelly Ruder, P.E.
ITSI Gilbane Company
Project Manager

cc: Project File
Distribution List

Enc: Final In Situ Thermal Treatment Using Large-Diameter Auger Soil Mixing and Zero-Valent Iron Results,
Former Offutt AFB Atlas "D" Missile Site 2 project, Arlington, Nebraska

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IN SITU THERMAL TREATMENT USING LARGE-DIAMETER AUGER SOIL MIXING AND ZERO-VALENT IRON RESULTS

Launch Service Building 2
Flame Pit Area

Former Offutt Air Force Base Atlas "D" Missile Site 2
Arlington, Nebraska

FINAL

Prepared for:
U.S. Army Corps of Engineers – Omaha District
1616 Capitol Ave., Ste. 9000
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Contract Number: W91238-06-D-0022
Task Order Number: DK05

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September 2012

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ABBREVIATIONS AND ACRONYMS

^{o}F	Degrees Fahrenheit
µg/kg	Micrograms per Kilogram
µg/L	Micrograms per Liter
bgs	Below Ground Surface
CFM	Cubic Feet per Minute
Cis-1,2-DCE	Cis-1,2-dichloroethene
COC	Contaminants / Chemicals of Concern
DAS	Data Acquisition System
DNAPL	Dense Non-Aqueous Phase Liquid
EPA	U.S. Environmental Protection Agency
FID	Flame Ionization Detector
FPA	Flame Pit Area
ft	Foot / Feet
GC	Gas Chromatograph
hp	Horsepower
IDW	Investigation-Derived Waste
ITSI	Innovative Technical Solutions, Inc.
ITSI Gilbane	ITSI Gilbane Company
lb	Pound
LDA	Large-Diameter Auger
LSB2	Launch Service Building 2
MCL	Maximum Contaminant Levels
mg/kg	Milligrams per Kilogram
MIP	Membrane Interface Probe
PID	Photoionization Detector
PVC	Polyvinyl Chloride
QAPP	Quality Assurance Project Plan
RSL	EPA Region 9 Regional Screening Level
SPLP	Synthetic Precipitation Leaching Procedure
Site 2	Former Offutt Air Force Base Atlas “D” Missile Site 2
TCE	Trichloroethene
TO	Task Order
UST	Underground Storage Tank
VC	Vinyl Chloride
VCP	Voluntary Cleanup Program
VCS	Vapor Conditioning System
VOC	Volatile Organic Compound
ZVI	Zero-Valent Iron

1.0 INTRODUCTION

This report was prepared by ITSI Gilbane Company (ITSI Gilbane) to present the results of the in situ thermal treatment using large-diameter auger (LDA) soil mixing and zero-valent iron (ZVI). This remedial technology was conducted at Launch Service Building 2 (LSB2) Flame Pit Area (FPA) at the former Offutt Air Force Base Atlas "D" Missile Site 2 (Site 2). The treatment was conducted under Task Order (TO) DK05 of United States Army Corps of Engineers, Omaha District Environmental Remediation Services Small Business Contract No. W91238-06-D-0022. Site 2 is a Formerly Used Defense Site that falls under the Defense Environmental Remediation Program. DK05 is a performance-based remediation TO that requires ITSI Gilbane to achieve Remedy in Place within 5 years of TO award and Response Complete within 10 years.

The treatment process was conducted at LSB2 FPA to mitigate both human health and environmental risk and to remediate highly impacted soil and groundwater at potential dense non-aqueous phase liquid (DNAPL) concentrations of trichloroethene (TCE). These detected concentrations were counterproductive to achieving the sitewide groundwater remedy of enhanced bioremediation currently under way at the site. The high concentrations would have made achieving Response Complete unattainable within the contract period of performance. As a result, this treatment technology was conducted to reduce the concentrations to levels that will allow the sitewide remedy to proceed on schedule.

1.1 Objectives and Approach

The objectives for the soil and groundwater at LSB2 FPA were:

- Eliminate LSB2 FPA soils as a potential hazard to human health and the environment, and as a continuing source of groundwater contamination above maximum contaminant levels (MCLs);
- Remove the suspected DNAPL source area to facilitate the sitewide groundwater remedy; and
- Minimize potential health hazards to on-site personnel performing the treatment using an in situ treatment method.

The approach to reduce contaminant levels was to use an in situ soil treatment using LDA for soil mixing with steam, hot air, and ZVI injection. This method was selected based on the results in the *Draft Technical Evaluation and Cost Summary LSB2* (ITSI, 2010a).

1.2 Report Organization

Background information is presented in **Section 2.0**, including a site description and a summary of the nature and extent of contamination. **Section 3.0** summarizes the field activities conducted at LSB2 FPA. **Section 4.0** presents a summary of the treatment cell results. **Section 5.0** presents the performance monitoring results to evaluate the effectiveness of the technology.

Section 6.0 presents a summary of the treatment results and lessons learned. **Appendix A** contains borelogs conducted to collect soil and groundwater samples both pre-treatment and post-treatment, well completion diagrams, well development data, and groundwater sampling reports. **Appendix B** contains all analytical data and validation reports. **Appendix C** contains the treatment data from individual cell locations.

2.0 BACKGROUND INFORMATION

The following section provides background information including a summary of the nature and extent of contamination at LSB2.

2.1 Site Description and Background

The site comprises about 274 acres and is located 3.75 miles northeast of Arlington in Washington County, Nebraska, in Section 33, Township 18 North, and Range 10 East. An area map showing the site location is presented as **Figure 2-1**.

The site was used for the maintenance, storage, and launch of Atlas "D" missiles. The Atlas "D" missile was a liquid-fueled, rocket-powered missile. The missile's power plant consisted of a cluster of three Rocketdyne engines (one sustainer main engine and two boosters) and two smaller vernier engines. The propellant was a combination of liquid oxygen and RP-1 (refined kerosene). TCE was used as a cleaner for rocket fuel system components.

Site facilities included three above-ground LSBs, each 130 feet (ft) long by 40 ft wide. Located on the western end of each LSB2 was an FPA where missile exhaust was directed during missile test-firing exercises. LSB2 is the only location where a "pit" existed behind the building. The FPA would seasonally fill with water from precipitation events. **Figure 2-2** illustrates the location of the LSB's and other Site 2 features.

2.2 Site Geology

The soils underlying the LSB2 FPA consist of silty clay loess deposits underlain by a mixture of glacially deposited clays (till), with traces of sand and gravel. This till deposit extends to depths of approximately 70 ft. The glacial till material consists primarily of dense clay with discontinuous interbedded layers of sand and gravel. Groundwater was encountered within a thin saturated interval at depths of 3 ft to 5 ft below the bottom of the FPA, and at the transition from the loess to glacial till. **Figure 2-3** displays the location of cross-section A-A'. Cross-section A-A' is illustrated in **Figure 2-4**.

Investigation activities were conducted at LSB2 in 2009 to determine the nature and extent of contaminants of concern (COCs): TCE, cis-1,2-dichloroethene (cis-1,2-DCE), and vinyl chloride (VC). Investigation activities included direct push borings using a membrane interface probe (MIP), surface water and sediment sampling, soil borings and soil sampling, hydropunch groundwater sampling, monitoring well installation, and groundwater sampling. Complete historic analytical results are presented in the *Final Volume Refinement Summary Report* (ITSI, 2011a).

2.2.1 Soils

MIP borings were conducted in 2009 at 16 locations (**Figure 2-3**) around LSB2. The MIP provides a qualitative evaluation of the total volatile organic compounds (VOCs).

The probe collects continuous readings as it is driven into the soil by direct push methods. The highest levels of total VOCs were detected in MIP borings located within the FPA just west the concrete pad (DPMIP09-01). The levels decreased in borings conducted further to the west and south, and remained elevated in locations located to the north (the direction of groundwater flow). The MIP results were used to select soil sampling locations as part of further investigative activities. A total of 23 soil samples were collected for VOC analysis, and 13 soil samples were also submitted for synthetic precipitation leaching procedure (SPLP) analysis. The maximum detection of TCE in soil was detected in a sample from DPSB09-85 at a concentration of 471 milligrams per kilogram (mg/kg) at a depth of 8 ft below ground surface (bgs). SPLP results indicated that this sample had leachable concentrations of TCE at 439 micrograms per liter (µg/L). Based on these sampling results, a permanent monitoring well was installed (SMW09-67) at location of DPSB09-85 (**Figure 2-3**). **Figure 2-4** illustrates a cross-section and analytical results from the FPA.

2.2.2 Groundwater

MIP results indicated that the highest levels of contamination existed below the water table at depths of approximately 20 ft to 35 ft bgs. TCE was detected in a sample collected from monitoring well SMW09-67, screened within this interval, at a concentration of 717,000 µg/L. This concentration is indicative of potential DNAPL. The concentration is approximately 70% of the solubility limit for TCE. DNAPL is suspected at concentrations above 10% of the solubility limit or approximately 100,000 µg/L (U.S. Environmental Protection Agency, 1992).

2.2.3 Surface Water and Sediment

No VOCs were detected in surface water or sediment samples collected within the FPA.

3.0 FIELD ACTIVITIES

The following sections describe the field activities conducted to implement this treatment technology. Field activities began with site preparation in July, 2010 and concluded in June 2011 with site restoration. The work was performed as described in the *Final In-Situ Thermal Treatment with ZVI Pilot Study Work Plan* (ITSI, 2010b) with the following exceptions.

- Post-treatment groundwater samples for dissolved gas analysis were collected from monitoring wells.
- SPLP analysis was not conducted on post-treatment soil samples because the previously unsaturated soil sample locations were now saturated as a result of the elevated groundwater table likely resulting from the treatment activities.

3.1 Site Preparation

ITSI Gilbane conducted the following activities to prepare the site for the thermal treatment technology.

The FPA behind LSB2 was dewatered prior to being backfilled. A sample of the surface water (SWLSB2-07142010) was collected prior to discharge. The water was discharged to the ground outside the FPA to evaporate. No VOCs were detected in the surface water above MCLs. The analytical data is presented in **Appendix B**.

The FPA was then backfilled with approximately 6,500 cubic yards of clean sandy clay loam soil to an approximate elevation of 1,247 ft. mean sea level. This elevation is the approximate existing grade of the area surrounding the FPA. The fill soil was sampled prior to delivery from the source area for VOCs by EPA Method SW8260B, semivolatiles by EPA Method SW8270C, pesticides by EPA Method SW8081A, and metals by EPA Method SW6010B and EPA Method SW7471A. The analytical results are presented in **Appendix B**. Fill was compacted using a vibratory roller and water as needed to ensure proper stability for the thermal treatment equipment.

Prior to backfilling the area, the existing concrete slab located between the wing walls was removed. The wing wall footers were left in place. The removed concrete was used as riprap material on-site.

Monitoring well SMW09-67 was abandoned according to Nebraska Title 178 well decommissioning standards. Several trees were also removed as necessary to allow sufficient work space to conduct the treatment technology. **Photo 1** shows the LSB2 FPA area prior to backfill and **Photo 2** shows the area following the completion of the site preparation activities.

Photo 1: LSB2 Flame Pit Area Prior to Site Preparation Activities

Photo 2: LSB2 Flame Pit Area After Site Preparation Activities

3.2 Mobilization

During the mobilization phase, all equipment and materials were brought to the site, and necessary utility connections were completed. Omaha Public Power District was contracted to bring 750 kilo watt, 3-phase power to a new transformer located at LSB2. The new service was activated on September 28, 2010. The following materials and equipment were delivered to the site, set up, and tested prior to beginning treatment.

- Drill rig with Kelly bar, swivel, and auger
- 200-ton crawler crane
- 400-horsepower (hp) boiler generating steam at 358 degrees Fahrenheit (^{o}F), trailer-mounted
- 250-hp boiler generating steam at 358^{o}F, trailer-mounted
- Vapor conditioning system (VCS), 70-ton chiller with blower unit, trailer-mounted
- Flameless thermal oxidizer, trailer-mounted
- Two 10,000-lb granular activated carbon vessels
- Data Acquisition System (DAS), trailer-mounted
- Batch plant
- Equipment storage trailer, 40 ft long with miscellaneous tools, equipment, and spares
- Support trucks with miscellaneous tools and equipment
- Track hoe
- Man lift
- Welder
- Spare auger blade
- Spare swivel.

3.3 In Situ Thermal and ZVI Treatment

The technology consists of three main units. The first unit consists of a track-mounted crane with a drill auger unit, and a hot air, steam, and reagent injection unit. The second is a vapor conditioning and treatment system. The third is a DAS, which is a process control system.

The technology operates one treatment cell at a time by advancing a single 8-ft diameter auger to the project selected depth of 40 ft bgs. During active mixing the soil is homogenized and the permeability increases, permitting the soil and groundwater to be treated evenly by the injected high-pressure steam and hot air. Steam heats the contaminated soil and groundwater, thermally desorbing the VOCs and volatilizing the non-adsorbed VOCs, while the hot air carries the volatilized off-gas contamination to the surface for capture and treatment.

The operation involves conducting an initial boring to total depth of approximately 40 ft bgs. The effluent gases are analyzed to create a profile of the contaminants in each treatment cell. Additional passes up and down the treatment cell are then conducted and targeted to the depths exhibiting the greatest contamination.

The process is continued until off-gas measurements are reduced to a project goal of approximately 500 parts per million. After the cell has reached the treatment goal, ZVI was injected into the cell. The ZVI slurry is injected and mixed into the preconditioned homogeneous soil/groundwater at the end of the thermal treatment.

3.3.1 Description of Large-Diameter Auger and Systems Equipment

Detailed descriptions of the system equipment follow.

3.3.1.1 Mixing Rig and Tool

The mixing rig and a 200-ton crane were mobilized to the site. A rubber-tire hydraulic crane was used to unload the equipment, build the crawler crane, and place the component parts of the mixing rig in the site staging area located on the south side of LSB2 for rig assembly. Soil-mixing equipment consists of a bladed, rotating mixing tool with a minimum diameter of 8 ft. A spare mixing tool of similar diameter was also maintained on-site. The mixing tool was attached to a hollow drill stem (Kelly bar), which is 70 ft long by 13.5 inches square. The Kelly bar and drill tool were supported by a high-torque transmission attached to a crawler-mounted lift crane. A 12-foot diameter steel shroud covers the treatment cell location to collect the off gases generated during treatment. The range of torque exerted by the drill transmission for normal mixing operations is between 100,000 and 453,000 foot-pounds. The mixing rig could extend outward from the toe of the crawler crane to reach two rows of treatment cell locations. The drill mixing rig was always operated on 1-ft thick by 4-ft wide hardwood mats butted together. The mats provided stability, maintained vertically plumb mixing, and minimized contamination of drill rig tracks. The mixing rig, crane, shroud, and hardwood mats are shown in **Photo 3**.

Photo 3: Mixing Rig, Crawler Crane, and Shroud

3.3.1.2 Batching and Injection

ZVI preparation and delivery equipment consisted of four 600-gallon tanks with piping, mixers and pumps, and a progressive cavity pump. Other miscellaneous equipment included a water meter and a high-viscosity material flow meter. The source water for batching and injection was provided by the on-site water well located upgradient of the plume near the ITSI Gilbane field trailer. The water has been tested for VOCs and was used as the clean water source for all site activities.

3.3.2 The Vapor Conditioning and Treatment System

The vapor conditioning system (VCS) pre-treated the vapor stream from the LDA shroud ducted to the carbon absorbers. The contaminated and water saturated air was suctioned by the blower on the VCS trailer from the LDA shroud with a vacuum at the shroud. The LDA shroud was connected to the VCS via a 10-inch flexible and hard duct assembly that varied in length from 100 ft to 250 ft depending on where the treatment area was located. The vapor stream from the LDA shroud was treated to remove dust and condensed water, and filtered. A 70-ton chiller was used to reduce the vapor stream from approximately 160^{o}F to less than 100^{o}F and then reheated to reduce the relative humidity to below 80%.

Design flow rates did not exceed 1,500 standard cubic ft per minute.

The individual components for the VCS and treatment system are described below.

3.3.2.1 Blower

A centrifugal pressure blower rated for 1,500 cubic ft per minute (CFM) at 31 inches total static pressure using a 15-hp motor.

3.3.2.2 Chiller Heat Exchanger

The chiller heat exchanger is sized to provide 840,000 British Thermal Unit cooling with chilled water entering at 45^{o}F and exiting at 60^{o}F. This unit will cool the gas flow temperature from approximately 160^{o}F to less than 100^{o}F at a flow of 1,300 CFM. The heat exchanger is 34.9-inch by 25-inch 6-row with copper fins on 518-inch copper tubing with a galvanized steel case. The housing for mounting the coil, inlet filters, inlet, and outlet (12-inch round) connections is 14-gauge galvanized steel. Included in the housing is a 25-inch by16-inch by 2-inch stainless steel mesh filter for particulates.

3.3.2.3 Flameless Thermal Oxidizer

The flameless thermal oxidizer was not used; all vapor was conditioned and sent through the carbon vessels described below.

3.3.2.4 Vapor Phase Carbon Absorbers

Two carbon absorbers in series, each with 20,000 lbs. of carbon were used to remove contaminants from the process stream. The off-gas was analyzed using a flame ionization detector (FID) at least once per treatment cell to confirm that no breakthrough of COCs occurred.

A 55-gallon drum of granular activated carbon was used to treat all condensate water generated by the vapor conditioning system.

3.3.3 Data Acquisition System

The data acquisition system (DAS) consists of two gas chromatographs (GCs) model 8610 C. One GC was configured with a FID that continuously monitored the off-gas while the other functioned as a GC where samples are analyzed at selected times. All data are considered screening level data. The DAS also monitors the following parameters:

- Air injection flow rate and pressure;
- Steam injection flow rate and temperature;
- Mixing auger depth versus time;
- Vapor phase effluent flow rate, temperature, pressure, and VOC content from containment shroud and vacuum level in the shroud in inches of water; and
- FID/GC monitoring of vapor phase effluent after removal of liquids and particulates.

3.4 Performance Monitoring

ITSI Gilbane installed a replacement monitoring well SMW010-67R in the treated area. The replacement well is located at approximately the same location and screen depth as well SMW09-67 that was abandoned during site preparation activities. The well was installed to depth of 40 feet below ground surface (bgs) to correspond with the original well depth of 25 feet bgs. The ground surface was raised approximately 15 feet during the backfilling of the FPA.

The monitoring well screen and riser casing was constructed of 2-inch-diameter, Schedule 40, flush-threaded polyvinyl chloride (PVC). The inside diameter of the auger was 4.25 inches with an outside diameter of approximately 8.5 inches. The screened interval of the monitoring well was 10 ft, with the bottom of the screen corresponding to the bottom of the well. The well screen slot size was 0.010-inch slotted screen. The well completion diagram is included in **Appendix A**.

Following well installation, the well was developed using the methods and procedures approved in the *Final Volume Refinement Work Plan* (ITSI, 2009). The well development record is included in **Appendix A**.

Groundwater samples were collected from SMW09-67 prior to treatment and the replacement well SMW010-67R was sampled approximately one month following treatment. The samples were analyzed for VOCs by EPA Method SW8260B and methane, ethane, and ethene by EPA Method RSK-175. The location of all sampling locations and wells are illustrated on **Figure 3-1**.

Wells IMW09-75, and DMW09-08 were also located within the anticipated treatment area. However, ITSI Gilbane treated around these wells.

Well SMW96-04 had an obstruction in the well and was no longer able to be sampled so it was abandoned according to Nebraska Title 178 well decommissioning standards. A replacement well was installed within close proximity by a separate contractor to investigate potential hydrocarbon contamination associated with a former underground storage tank (UST) at this location. The replacement well (SMW96-04R) was offset from the original well location by approximately 17.4 ft and is shown on **Figure 3-1**. ITSI Gilbane sampled this well after completion of thermal treatment and the results are presented as SMW96-04R.

Soil samples were collected from six direct push boreholes four locations (DPSB010-02, DPSB010-03, DPSB010-67R, and DPSB010-05) located within the thermal treatment area, and two locations (DPSB010-01, and DPSB010-04) located adjacent to the treatment area as illustrated on **Figure 3-1**. Soil samples were collected prior to treatment and 2 weeks after treatment to evaluate the effectiveness. Pre-treatment soil samples were collected from each boring: one from the unsaturated zone and one below the water table. Sample depths were selected from each zone exhibiting the highest readings for VOCs as indicated by field screening of the soil core with a photoionization detector (PID). A PID reading of the exposed soil core was collected at 1-ft intervals along the length of the exposed core and recorded. Post-treatment samples were collected from approximately the same location and intervals as the pre-treatment sampling. Samples were submitted to the laboratory for VOC analysis by EPA Method SW8260B. Soil boring logs for the pre-treatment and post-treatment soil sampling events are included in **Appendix A**.

Direct push groundwater samples were collected from five locations. Direct push groundwater samples were collected prior to treatment and 2 weeks post-treatment to evaluate the effectiveness of the treatment. The groundwater samples were collected by installing a 1-inch-inside-diameter, flush-treaded PVC casing and 5 ft of 0.010-inch screen into the direct push boring locations following soil sampling. The casing was allowed to fill with water and samples were collected using disposable bailers. Samples were analyzed for VOCs by EPA Method SW8260B. After the groundwater sample was collected, the casing was removed and the boreholes sealed with cement/bentonite grout.

3.5 Decontamination

All sampling equipment that directly contacted soil during well drilling activities was decontaminated after completion of each borehole. This included auger flights, direct push rods, sampling/purging devices, and monitoring instruments. Auger flights were steamed cleaned over a rack, allowing rinsate to be collected in the decontamination pad.

Sampling equipment was washed in a non-phosphate soap and water mixture, rinsed in fresh water, and then rinsed a second time in distilled or deionized water. The LDA auger and shroud were steam cleaned following the completion of all treatment cells.

All reusable measuring and purging equipment that came in contact with groundwater was decontaminated prior to use in each well.

Decontamination consisted of washing exterior surfaces that came in contact with groundwater with a non-phosphate soap, followed by a distilled or deionized water rinse, and then a final distilled or deionized water rinse.

3.6 Surveying

The pre-treatment soil and direct push groundwater sampling locations were surveyed using a global positioning system and the coordinates recorded. The post-treatment borings and groundwater samples were collected from the original location as determined by the global positioning system (GPS). Treatment cell locations were determined using Geographic Information System software prior to field activities. The center of each cell was then located in the field using a total surveying station.

Newly installed monitoring wells were surveyed for lateral and vertical coordinates. Monitoring wells were surveyed to within ± 0.1 ft horizontally and to within ± 0.01 ft vertically.

3.7 Investigation-Derived Waste

All investigation-derived waste (IDW) was managed according to the *Revised Final Investigation-Derived Waste Management Plan* (ITSI, 2011b). All vapor and condensate water generated during the thermal treatment process was piped through a series of granular activated carbon vessels as part of the treatment process. Following the completion of all treatment cells, a composite sample of the carbon was collected from each vessel and analyzed for toxicity characteristic leaching procedure VOCs. The first carbon vessel sample labeled CV1-05252011 had detections of chloroform, 1,1-DCE, TCE, and vinyl chloride at concentrations below regulatory limits. The sample for second carbon vessel in series labeled CV2-05252011 was non-detect for all VOCs. Both carbon vessels were returned to the manufacturer for recycling.

The condesate water was treated with GAC and stored in a 3000 gallon tank. A sample labeled FECC3000POLY-05312011 was collected from the tank and analyzed for VOCs by method 8260B. Acetone was detected in the sample at an estimated concentration of 10.2 µg/L, and TCE at an estimated concentration of 0.69 µg/L. The results were all below MCLs and the water was discharged. The complete analytical results are presented in **Appendix B**.

3.8 Demobilization

Demobilization activities began on May 13, 2011, and ended with removal of the granular activated carbon vessels on June 20, 2011.

3.9 Site Restoration

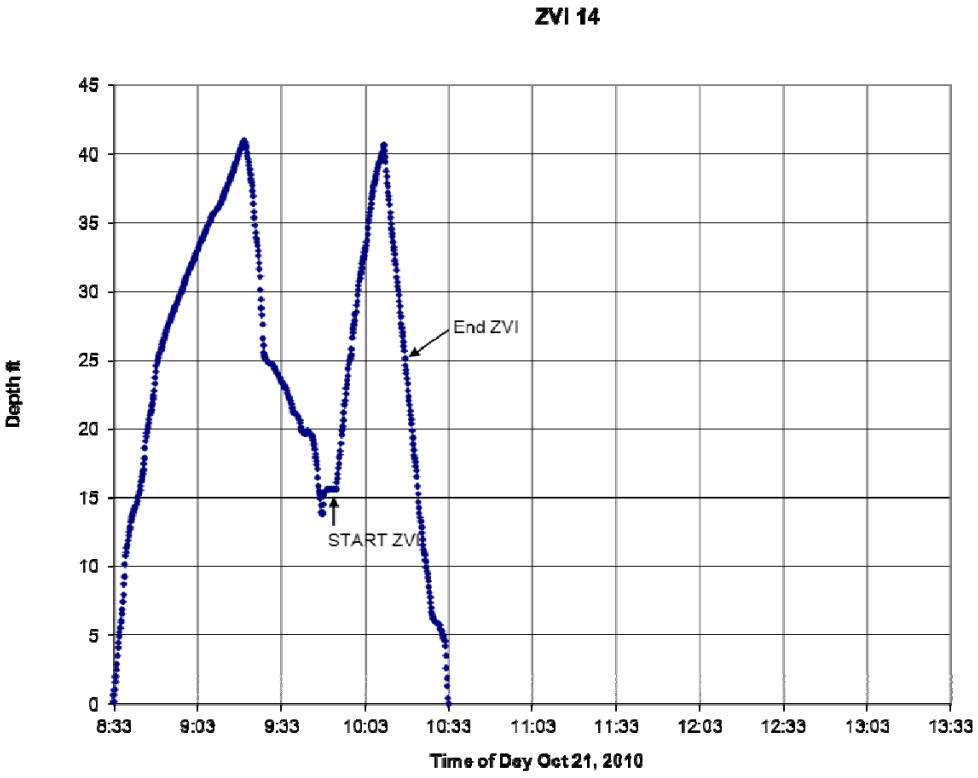
ITSI Gilbane conducted site restoration activities to return the area to useable pasture land following the completion of thermal and ZVI treatment at LSB2. Activities included a final grading of the area for drainage. The area was sloped to the north to allow precipitation to overland flow to the lower drainage area. A pasture grass seed mixture was applied evenly across the disturbed areas.

4.0 TREATMENT CELL SUMMARY

The following sections summarize the drilling information for all ZVI and thermal cells.

4.1 ZVI Barrier Cells

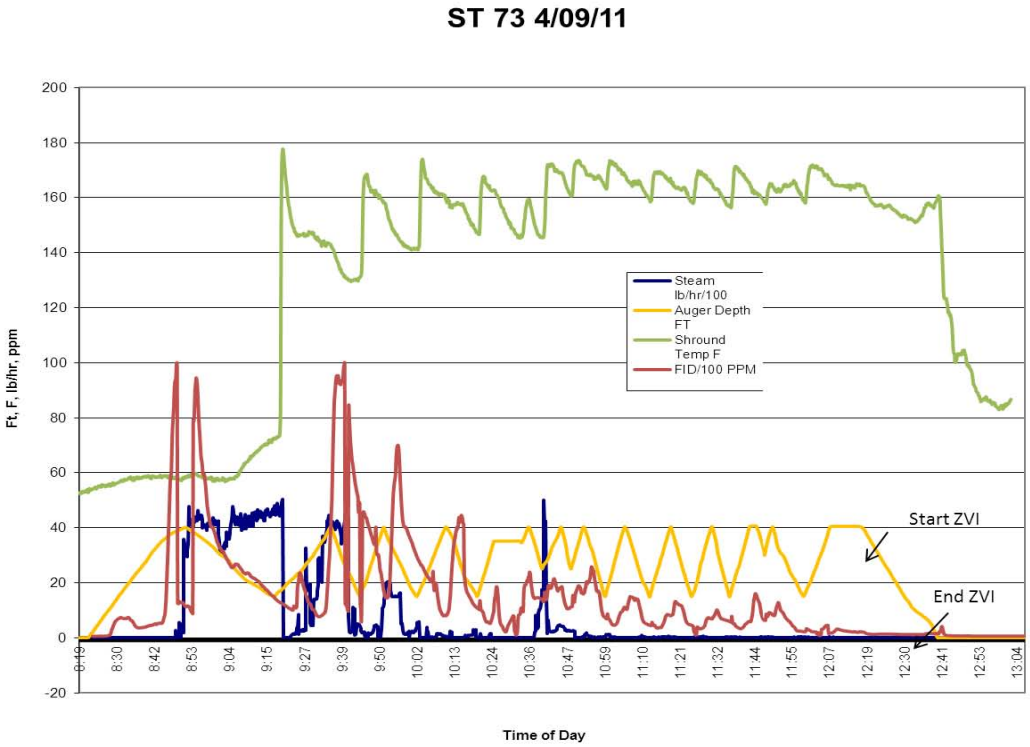
Prior to thermal treatment ZVI barrier cells were installed around the treatment area cells to provide containment of any TCE or breakdown products that were mobilized during the thermal portion of the treatment. ZVI was injected in situ at 57 cell locations to depths of 40 ft along the site perimeter. ZVI was implaced at 1% by weight of soil from 15 ft to 25 ft bgs and 2% from 25 ft to 40 ft bgs. The weight of soil was estimated at 100 pounds per cubic yard. A total of approximately 2,000 pounds of ZVI were injected in each perimeter cell location. The perimeter ZVI barrier is illustrated on **Figure 3-1**. A typical graph of the ZVI drilling information is presented below. Graphs presenting the drilling rates, depths, and ZVI placement for all ZVI perimeter cell locations are presented in **Appendix C**. The ZVI cell process consisted of drilling the LDA to total depth (approximately 40 feet) to loosen and mix the soil. The LDA was then returned back to 15 feet bgs and ZVI placement was started as the LDA was drilled back to total depth, and then retracted to 25 feet bgs, where ZVI injection was completed. This process allowed double the volume of ZVI added to the bottom 15 feet of the treatment cell (i.e. 1% from 15-25 feet bgs, and 2% from 25-40 feet bgs).



Typical Drilling Data from ZVI Treatment Cell

4.2 Thermal Treatment Cells

Thermal treatment with steam and hot air was conducted at 106 cell locations, followed by injection of ZVI at an average of 1.25% by weight of soil. Soil weight was estimated at 100 lbs. per cubic ft, or 1,500 pounds of ZVI per cell location. The center of treatment cell locations were located in field with a total station using the coordinates determined by GIS, and are illustrated on **Figure 3-1**. Approximately 5,000 cubic yards of soil from depths of approximately 15 ft bgs to 40 ft bgs were treated with steam and ZVI during the project. Exact treatment depths and drilling parameters for each treatment cell are summarized on **Table 4-1**. Data collected from each cell during treatment included steam in pounds per hour, auger depth, shroud temperature in degrees Fahrenheit, ZVI injection interval, ZVI injected pounds, and FID readings in parts per million. A graph of a typical thermal treatment cell data is shown below. Graphs presenting the drilling rates, depths, shroud temperature, FID readings, and ZVI placement for all treatment cells are presented in **Appendix C**. **Figure 4-1** illustrates the maximum FID readings measured in off-gas during thermal treatment at each cell location.



Typical Drilling Data from Thermal and ZVI Treatment Cell

Table 4-1
Results of In Situ Thermal Treatment, Thermal Treatment Cell Summary
Former Offutt AFB Atlas "D" Missile Site 2, Arlington, Nebraska

Cell Location	Date	Treatment Time Hours:Min	Total Treatment Depth	ZVI Injection Interval Feet bgs	ZVI Injected (pounds)	Steam pounds/hour/ 100	Max Shroud Temp (F)
ST-58	3/28/2011	2:39	40.3	15-40.3	1500	60.7	125.4
ST-59	3/29/2011	1:20	40.3	15-40.3	1500	0.0	127.1
ST-60	3/29/2011	1:08	40.4	15-40.4	1500	0.0	151.1
ST-61	3/30/2011	2:04	41.1	15-41.1	1500	93.2	185.3
ST-62	3/30/2011	1:42	40.4	15-40.4	1500	17.3	100.8
ST-63	3/30/2011	0:50	41.2	15-41.2	1500	0.0	65.2
ST-64	3/30/2011	1:54	42.1	15-42.1	1500	27.2	153.8
ST-65	3/31/2011	1:20	41.1	15-41.1	1500	44.8	102.3
ST-66	3/31/2011	2:32	41.9	15-41.9	1500	38.7	178.0
ST-67	3/31/2011	2:18	41.5	15-41.5	1500	28.2	195.5
ST-68	4/1/2011	3:14	41	15-41	1500	44.7	197.1
ST-75/ST-75A*	4/6/2011	8:04	40.8	15-40.8	1500	60.1	174.8
ST-90	4/7/2011	2:26	38.9	15-38.9	1500	41.6	162.8
ST-122**	4/7/2011	2:02	40	15-40	1500	na	160.8
ST-74	4/8/2011	3:57	40.4	15-40.4	1500	48.2	185.9
ST-72/ST-72A	4/9/2011	2:57	40.6	15-40.6	1500	43.1	172.7
ST-73	4/9/2011	4:46	40.6	15-40.6	1500	50.3	177.7
ST-79	4/11/2011	3:12	40.5	15-40.5	1500	89.0	167.6
ST-83	4/11/2011	5:16	40.6	15-40.6	1500	32.7	177.3
ST-80	4/12/2011	3:57	40.2	15-40.2	1500	46.7	177.7
ST-82	4/12/2011	3:49	40.5	15-40.5	1500	42.6	179.8
ST-71	4/14/2011	1:51	40.4	15-40.4	1500	50.4	162.4
ST-130	4/14/2011	3:43	40.5	15-40.5	1500	41.6	175.7
ST-163	4/14/2011	1:51	40.4	15-40.4	1500	50.4	164.2
ST-146	4/18/2011	1:44	40.2	15-40.2	1500	69.4	143.0
ST-97/ST-97A	4/19/2011	1:36	40.3	15-40.3	1500	88.9	149.7
ST-113	4/19/2011	2:04	40.3	15-40.3	1500	27.5	149.0
ST-129	4/19/2011	2:01	40.3	15-40.3	1500	82.1	166.8
ST-162	4/19/2011	1:20	40.3	15-40.3	1500	47.0	123.8
ST-96	4/20/2011	3:33	40.8	15-40.8	1500	44.7	175.2
ST-145	4/20/2011	2:23	40.4	15-40.4	1500	10.0	132.1
ST-81	4/21/2011	3:27	40.2	15-40.2	1500	60.6	184.5
ST-112	4/21/2011	1:52	40.4	15-40.4	1500	30.5	161.1
ST-161	4/21/2011	1:30	40.2	15-40.2	1500	31.1	135.4
ST-95	4/22/2011	4:10	40.2	15-40.2	1500	55.8	190.2
ST-128	4/22/2011	2:18	40.4	15-40.4	1500	33.1	176.1
ST-160	4/22/2011	1:44	40.9	15-40.9	1500	26.0	149.5
ST-94	4/23/2011	2:04	40.2	15-40.2	1500	52.9	191.8
ST-111	4/23/2011	1:36	40.6	15-40.6	1500	41.4	182.8
ST-144	4/23/2011	1:46	40.3	15-40.3	1500	48.6	179.2
ST-159	4/23/2011	2:17	40.2	15-40.2	1500	30.7	187.7
ST-93	4/26/2011	2:13	40.2	15-40.2	1500	33.3	173.9
ST-127/ST-127A	4/26/2011	3:02	40.4	15-40.4	1500	27.6	143.3
ST-143	4/26/2011	1:39	40.4	15-40.4	1500	58.6	128.7
ST-109	4/27/2011	2:46	40.4	15-40.4	1500	30.0	180.2
ST-110	4/27/2011	1:38	40.5	15-40.5	1500	58.9	155.3
ST-126	4/27/2011	1:31	40.4	15-40.4	1500	44.1	157.8
ST-142	4/27/2011	1:51	40.3	15-40.3	1500	41.0	163.1
ST-92	4/28/2011	2:32	40.4	15-40.4	1500	23.7	180.3
ST-158	4/28/2011	1:30	40.4	15-40.4	1500	41.4	175.5
ST-125/ST-125A	4/28 to 4/29	3:06	40.2	15-40.2	1500	46.5	185.7
ST-91	4/29/2011	2:01	40.3	15-40.3	1500	38.3	180.9
ST-107	4/30/2011	1:56	40.3	15-40.3	1500	30.7	190.5
ST-108	4/30/2011	1:36	40.3	15-40.3	1500	33.2	186.6
ST-140	4/30/2011	1:47	40.3	15-40.3	1500	26.9	178.5
ST-141	4/30/2011	1:30	40.4	15-40.4	1500	28.7	166.4
ST-157	4/30/2011	1:42	40.1	15-40.1	1500	25.2	151.7
ST-123	5/2/2011	1:42	38.7	15-38.7	1500	32.7	183.2
ST-124	5/2/2011	1:25	40.3	15-40.3	1500	45.9	162.2
ST-156	5/2/2011	1:10	40.3	15-40.3	1500	18.0	123.7
ST-89	5/3/2011	1:11	40.3	15-40.3	1500	44.4	128.9
ST-105	5/3/2011	1:22	40.3	15-40.3	1500	27.1	174.8
ST-106	5/3/2011	1:33	40.4	15-40.4	1500	45.5	183.3
ST-138	5/3/2011	1:09	40.2	15-40.2	1500	12.1	147.5
ST-139	5/3/2011	1:14	40.1	15-40.1	1500	30.9	162.1
ST-154	5/3/2011	1:26	40.2	15.40.2	1500	35.5	151.0
ST-155	5/3/2011	1:09	38.6	15-38.6	1500	27.0	162.4
ST-88	5/4/2011	2:07	40.3	15-40.3	1500	52.1	152.5
ST-104	5/4/2011	1:42	40.3	15-40.3	1500	22.5	174.4
ST-121	5/4/2011	1:14	40.2	15-40.2	1500	39.3	149.6
ST-137	5/4/2011	1:07	40.3	15-40.3	1500	30.2	143.0
ST-153	5/4/2011	1:01	40.4	15-40.4	1500	66.4	132.9

Table 4-1
Results of In Situ Thermal Treatment, Thermal Treatment Cell Summary
Former Offutt AFB Atlas "D" Missile Site 2, Arlington, Nebraska

Cell Location	Date	Treatment Time Hours:Min	Total Treatment Depth	ZVI Injection Interval Feet bgs	ZVI Injected (pounds)	Steam pounds/hour/ 100	Max Shroud Temp (F)
ST-102	5/5/2011	1:46	37.5	15-37.5	1500	14.9	163.5
ST-103	5/5/2011	1:29	37.9	15-37.9	1500	22.3	168.4
ST-120	5/5/2011	1:12	40.1	15-40.1	1500	28.4	111.6
ST-136	5/5/2011	1:19	40.2	15-40.2	1500	45.5	167.9
ST-152	5/5/2011	1:25	40.3	15-40.3	1500	16.9	138.7
ST-101	5/6/2011	1:32	40	15-40	1500	27.0	173.4
ST-118	5/6/2011	0:57	40.2	15-40.2	1500	38.2	143.3
ST-119	5/6/2011	0:55	40.1	15-40.1	1500	34.9	114.7
ST-135	5/6/2011	1:06	40.3	15-40.3	1500	35.7	155.2
ST-150	5/6/2011	1:31	40.1	15-40.1	1500	33.2	159.3
ST-151	5/6/2011	1:44	39.6	15-39.6	1500	26.6	157.7
ST-87	5/7/2011	1:54	38.1	15-38.1	1500	19.0	184.2
ST-117	5/7/2011	1:29	40.1	15-40.1	1500	37.9	159.7
ST-133	5/7/2011	1:23	40.4	15-40.4	1500	25.9	170.7
ST-134	5/7/2011	0:56	40.2	15-40.2	1500	36.9	123.4
ST-148	5/7/2011	1:47	40.2	15-40.2	1500	19.5	157.5
ST-149	5/7/2011	1:38	40.1	15-40.1	1500	29.1	158.4
ST-78	5/9/2011	1:25	40.1	15-40.1	1500	22.8	166.0
ST-100	5/9/2011	1:32	39.8	15-39.8	1500	16.1	152.7
ST-116	5/9/2011	0:50	40.2	15-40.2	1500	15.0	137.6
ST-131	5/9/2011	1:31	40	15-40	1500	15.5	164.1
ST-147	5/9/2011	1:18	40.1	15-40.1	1500	20.3	135.2
ST-85	5/10/2011	1:35	39.1	15-39.1	1500	10.7	140.9
ST-86	5/10/2011	1:09	40.3	15-40.3	1500	8.1	106.4
ST-99	5/10/2011	1:05	40.2	15-40.2	1500	9.3	131.2
ST-114	5/10/2011	1:09	40.4	15-40.4	1500	11.1	130.1
ST-115	5/10/2011	1:24	39.2	15-39.2	1500	12.8	155.1
ST-132	5/10/2011	1:03	40.3	15-40.3	1500	8.6	116.9
ST-69	5/11/2011	1:13	39.5	15-39.5	1500	16.1	133.6
ST-70	5/11/2011	1:07	40.4	15-40.4	1500	23.8	133.5
ST-76	5/11/2011	1:38	40.2	15-40.2	1500	15.4	115.3
ST-84	5/11/2011	1:02	40.1	15-40.1	1500	14.2	137.8
ST-98	5/11/2011	1:03	40.1	15-40.1	1500	53.5	104.5
ST-77	5/12/2011	1:00	40.2	15-40.2	1500	16.9	126.1
Totals					**159000**		

Notes:

* Locations that contain multiple identification numbers are locations where two separate drilling attempts were required to complete the location.

** Data file corrupted, information taken from daily field activity log

na = not available

CFM = cubic feet per minute

bgs = below ground surface

PPM = parts per million

FID = flame ionization detector

min = minutes

5.0 PERFORMANCE MONITORING RESULTS

Results of pre-treatment and post-treatment soil and groundwater sampling data are presented in the following sections.

5.1 Pretreatment Conditions

Soil samples were collected on August 9, 2010, from four locations DPSB010-67R, DPSB010-02, DPSB010-03, and DPSB010-05 located within the treatment area and two locations DPSB010-01, and DPSB010-04 located just outside the treatment area (**Figure 3-1**). Soil samples were collected from two depths at each location except DPSB010-04. No sample was collected from DPSB010-04 above the water table due to fill sand extending from above to below the water table. A former UST was removed from this location and the area was backfilled with sand (borelog DPSB010-04 in **Appendix A**). All samples were submitted for VOC analysis by EPA Method 8260B. TCE was detected in 4 of 5 soil samples collected from the vadose zone at concentrations ranging from non-detect in sample DPSB010-01 at 15 feet to 20,400 micrograms per kilogram (µg/kg) in sample DPSB010-67R at 16 feet. TCE was detected in 6 of 6 soil sample locations from the saturated zone at concentrations ranging from 4.8 µg/kg in sample DPSB011-01 at 32 feet bgs to 133,000 µg/kg in sample DPSB010-67R at 35 feet bgs. Complete soil analytical results are summarized in **Table 5-1** and are illustrated on **Figure 5-1**. The analytical results compare with the FID levels measured in the off-gas during treatment, indicating that the highest levels of TCE were present within the FPA just outside the concrete pad (location SMW010-67R).

Groundwater samples were collected on June 17, 2010 from well SMW09-67 and on August 10, 2010, from three locations DPGW010-02, DPGW010-03, DPGW010-05. All of the locations were within the treatment area. Two locations DPGW010-01 and DPGW010-04 located just outside the treatment area were also sampled on August 10, 2010. Groundwater samples were also collected prior to the thermal treatment as part of the site wide groundwater remedy from eight permanent monitoring wells located downgradient of the treatment area. All samples were submitted for VOC analysis by EPA Method 8260B. TCE was detected in all groundwater samples at concentrations ranging from 92.6 µg/L in sample DPSB010-04 to a maximum concentration of 430,000 µg/L in sample SMW09-67. Complete groundwater analytical results are summarized in **Table 5-2** and the results are illustrated on **Figure 5-2**. Dissolved gases methane, ethane, and ethene gases were also analyzed by Method RSK-175. The analytical results are presented in **Table 5-3**.

5.2 Post-Treatment Soil Conditions

Soil samples were collected from two locations DPSB010-02 and DPSB010-67R on May 8, 2011, just prior to project completion to provide an initial evaluation of treatment effectiveness prior to demobilization. Sample DPSB010-02 at 20 ft had an initial (pre-treatment) TCE concentration of 5,160 µg/kg.

Table 5-1
Results of In Situ Thermal Treatment, Volatile Organic Compounds Detected in Soil
Former Offutt AFB Atlas "D" Missile Site 2, Arlington, Nebraska

Location	Field Sample ID	Sample Date	cis-1,2-Dichloroethene (µg/kg)	Trichloroethylene (µg/kg)	Vinyl Chloride (µg/kg)
Regulatory Limits: USEPA Residential Regional Screening Level, November, 2011			160,000	910	60
Nebraska Department of Environmental Quality VCP Remediation Goals, August, 2006			200,000	80	98
Vadose Zone					
DPSB010-01	DPSB010-01-(15)	08/09/2010	**33.8**	1.80 U	2.30 U
	DPSB011-01(15)	06/13/2011	**908**	**2.30 J**	**14.5**
DPSB010-02	DPSB010-02-(20)	08/09/2010	**3470**	**5160**	**47.3**
	DPSB011-02-(20)	05/08/2011	1.90 U	1.50 U	1.90 U
	DPSB011-02(20)	06/13/2011	2.00 U	1.60 U	2.00 U
DPSB010-03	DPSB010-03-(15)	08/09/2010	**52.9**	**200**	2.50 U
	DPSB011-03(15)	06/13/2011	**38.1 J**	1.40 U	1.80 U
DPSB010-05	DPSB010-05-(12)	08/09/2010	**72.7**	**223**	2.40 U
	DPSB011-05 (12)	06/14/2011	1.70 U	1.30 U	1.70 U
DPSB010-67R	DPSB010-67R-(16)	08/09/2010	**7390**	**20400**	290 U
	DPSB011-67R-(16)	05/08/2011	**706**	**18.3**	**11.8**
	DPSB011-67R-(16)	07/08/2011	**387 J**	1.40 U	**40.2 J**
Saturated Zone					
DPSB010-67R	DPSB010-67R-(35)	08/09/2010	580 U	**133000**	1200 U
	DPSB011-67R-(35)	05/08/2011	**205 J**	**10.7**	**2.20 J**
	DPSB011-67R-(35)	07/08/2011	**184 J**	1.30 UJ	**87.9 J**
DPSB011-01	DPSB010-01-(32)	08/09/2010	**19.0**	**24.8**	2.20 U
	DPSB011-01(32)	06/13/2011	**461 J**	**2.20 J**	**24.6 J**
DPSB011-02	DPSB010-02-(32)	08/09/2010	**523**	**813**	**3.50 J**
	DPSB011-02-(32)	05/08/2011	2.10 UJ	1.70 UJ	2.10 UJ
	DPSB011-02(32)	06/13/2011	**3.30 J**	1.40 U	**2.70 J**
DPSB011-03	DPSB010-03-(34)	08/09/2010	**659 J**	**49900**	2.20 UJ
	DPSB011-03(34)	06/13/2011	**10.7 J**	**4.50 J**	1.80 U
DPSB011-04	DPSB010-04-(36)	08/09/2010	**2590**	**9890**	**33.8**
	DPSB011-04(36)	06/13/2011	380 U	**40700**	380 U
DPSB011-05	DPSB010-05-(38)	08/09/2010	**1000 J**	**12700**	250 U
	DPSB011-05 (38)	06/14/2011	1.80 U	1.40 U	1.80 U

Notes:
µg/kg = micrograms per kilogram
non-detections are reported down to the limit of detection (LOD).
bolded values indicate that the associated analyte was detected at a concentration above the LOD.
USEPA Regional Residential Soil Screening Levels (RSL) November, 2011.
grey highlighted values indicate that the analyte was detected at a concentration greater than or equal to the RSL, or VCP remediation goals.
J = Estimated: The analyte was detected; however, the result is estimated due to discrepancies in meeting certain analyte-specific quality control criteria.
U = Undetected: The analyte was analyzed for, but not detected.
UJ = The analyte was not detected; however, the result is estimated due to discrepancies in meeting certain analyte-specific quality control criteria.

Table 5-2
Results of In Situ Thermal Treatment, Volatile Organic Compounds Detected in Groundwater
Former Offutt AFB Atlas "D" Missile Site 2, Arlington, Nebraska

Location	Field Sample ID	Sample Date	cis-1,2-Dichloroethene (µg/L)	Trichloroethene (µg/L)	Vinyl Chloride (µg/L)
		MCL	70	5	2
DPSB010-01	DPGW010-01-08102010	08/10/2010	**216 J**	**560**	2.80 U
	DPGW011-01-06152011	06/15/2011	**0.290 J**	0.260 UJ	0.220 U
DPSB010-02	DPGW010-02-08102010	08/10/2010	**3150 J**	**2780 J**	**54.6 J**
	DPGW011-02-06162011	06/16/2011	**34.0**	**0.430 J**	**13.1**
DPSB010-03	DPGW010-03-08102010	08/10/2010	**14600 J**	**142000 J**	560 UJ
	DPGW011-03-06152011	06/15/2011	5.20 U	**1160**	4.40 U
DPSB010-04	DPGW010-04-08102010	08/10/2010	**39.4 J**	**92.6 J**	**0.920 J**
	DPGW011-04-06152011	06/15/2011	**15400**	**10900**	55.0 U
DPSB010-05	DPGW010-05-08102010	08/10/2010	**3810**	**93300**	280 U
	DPGW011-05-06152011	06/15/2011	0.260 U	**0.330 J**	0.220 U
IMW09-75	IMW09-75-07232009	07/23/2009	**13,300**	**104,000**	300 U
	IMW09-75-06282011	06/28/2011	**72,000**	260 U	**6,270**
SMW09-76/SMW010-67R	SMW09-67-07242009	07/24/2009	**2430 J**	**717000**	3000 U
	SMW09-67-06172010	06/17/2010	1600 U	**430000**	1400 U
	SMW010-67R-07082011	07/08/2011	**43.0**	**730 J**	2.20 U

Notes:
Gray Highlighted areas are values detected above the Maximum Contaminant Level (MCL) µg/L = micrograms per liter
non-detections are reported down to the limit of detection (LOD).
bolded values indicate that the associated analyte was detected at a concentration above the LOD.
J = Estimated: The analyte was not detected; however, the result is estimated due to discrepancies in meeting certain analyte-specific quality control criteria.
U = Undetected: The analyte was analyzed for, but not detected.
UJ = The analyte was not detected; however, the result is estimated due to discrepancies in meeting certain analyte-specific quality control criteria.

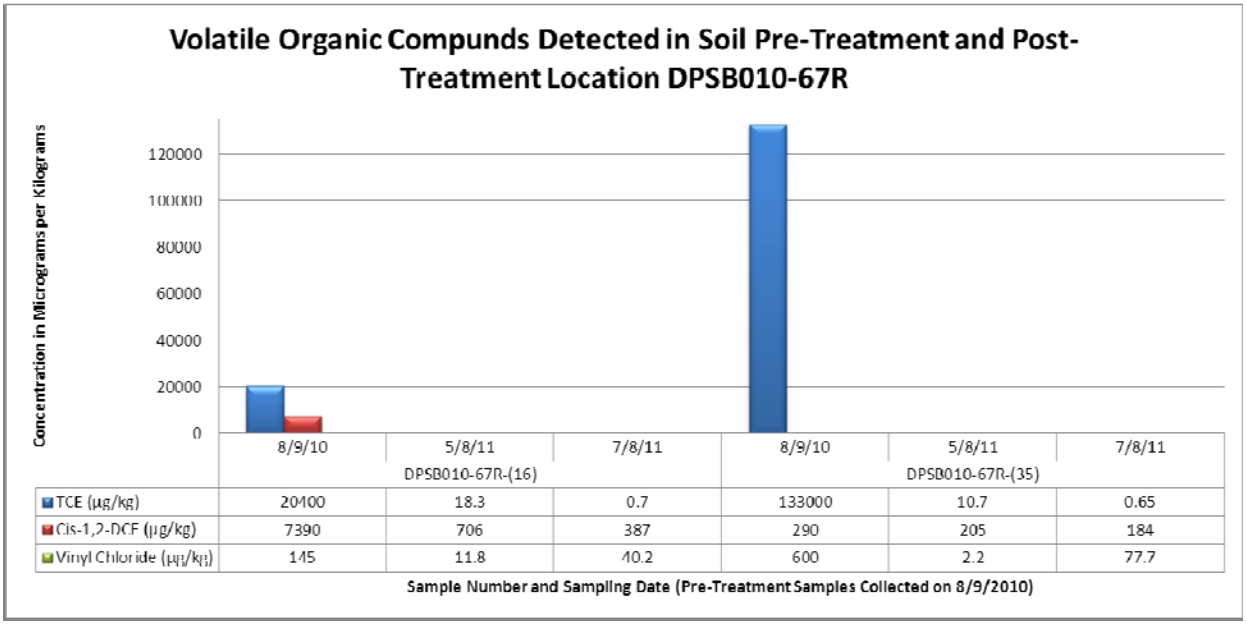
Table 5-3
Results of In Situ Thermal Treatment, Methane, Ethane, and Ethene Detected in Groundwater
Former Offutt AFB Atlas "D" Missile Site 2, Arlington, Nebraska

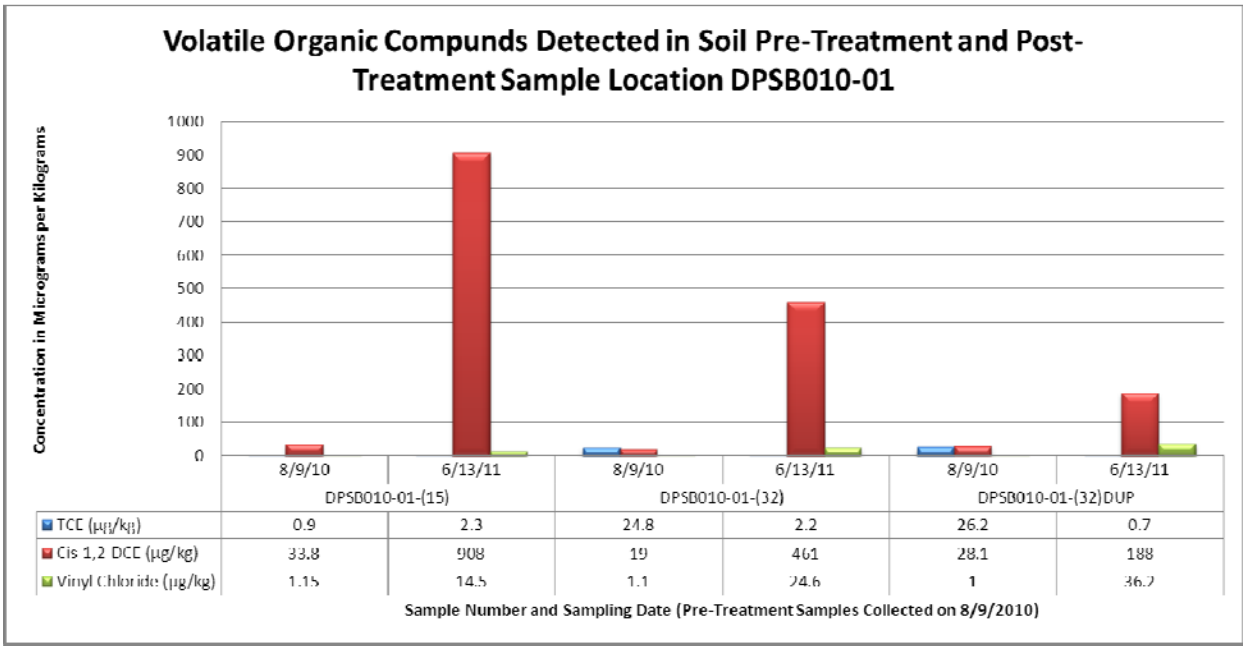
Location	Field Sample ID	Sample Date	Ethane (µg/L)	Ethene (µg/L)	Methane (µg/L)
DPSB010-01	DPGW010-01-08102010	08/10/2010	**0.350 J**	**0.590 J**	**535**
DPSB010-02	DPGW010-02-08102010	08/10/2010	**4.80**	**6.65**	**80.4**
DPSB010-03	DPGW010-03-08102010	08/10/2010	**1.13**	**2.01**	**98.0**
DPSB010-04	DPGW010-04-08102010	08/10/2010	**2.90**	**2.09**	**12.2**
DPSB010-05	DPGW010-05-08102010	08/10/2010	**3.49**	**3.90**	**6.32**
SMW010-67R	SMW010-67R-08092011	08/09/2011	**153**	**2.77**	**42.5**
SMW96-04R	SMW96-04R-06272011	06/27/2011	**9.35**	0.430 U	**7.28**

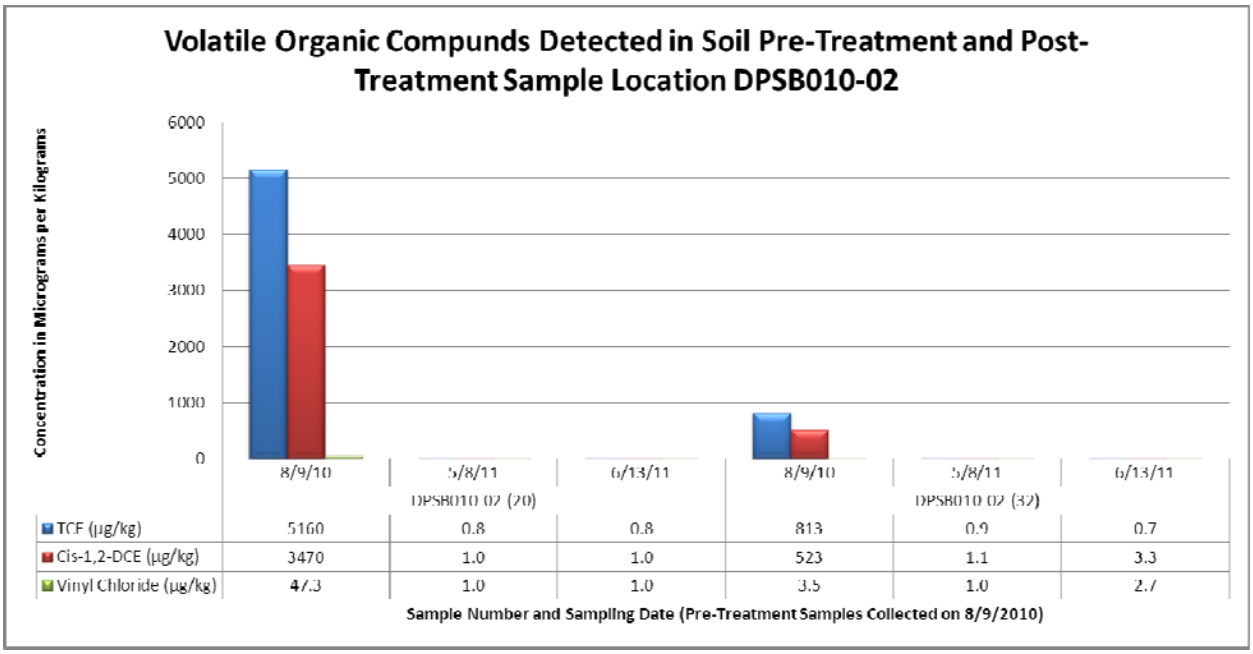
Notes:
µg/L = micrograms per liter
non-detections are reported down to the limit of detection (LOD).
bolded values indicate that the associated analyte was detected at a concentration above the LOD.
J = Estimated: The analyte was not detected; however, the result is estimated due to discrepancies in meeting certain analyte-specific quality control criteria.
U = Undetected: The analyte was analyzed for, but not detected.
UJ = The analyte was not detected; however, the result is estimated due to discrepancies in meeting certain analyte-specific quality control criteria.

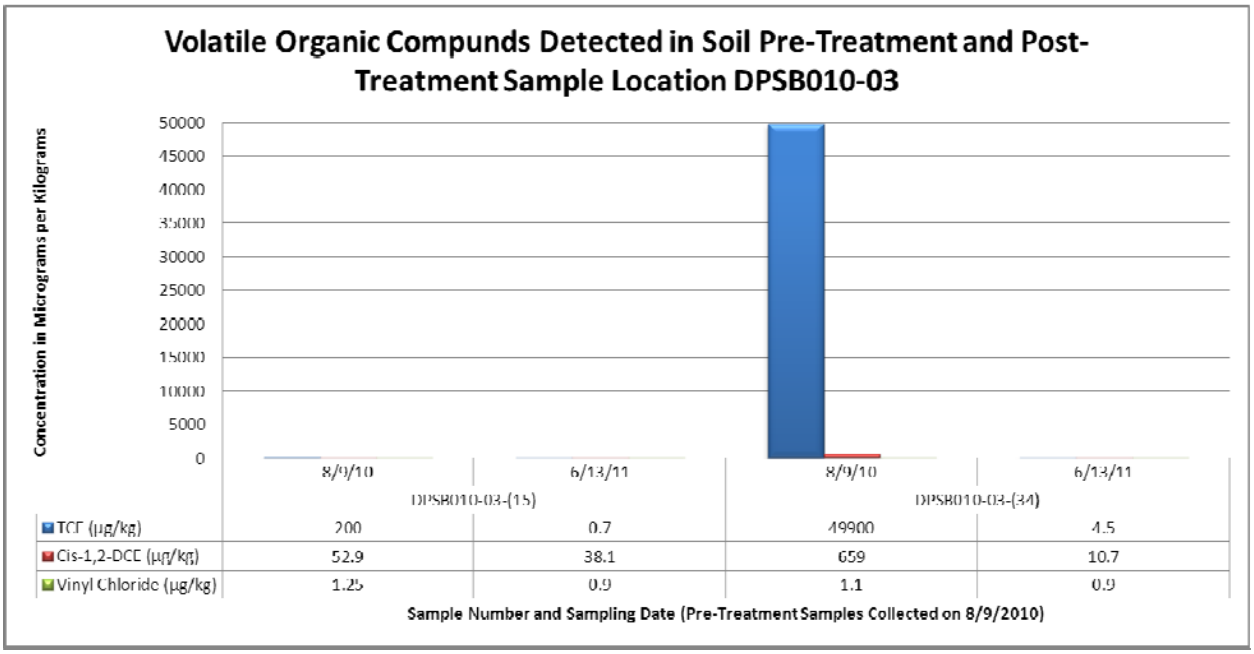
Following treatment the sample collected on May 8, 2011 from the same approximate location and depth contained no detectable concentration of TCE. Sample DPSB010-67R at 35 ft had an initial (pre-treatment) TCE concentration of 133,000 µg/kg. Following treatment the sample collected on May 8, 2011 from the same approximate location and depth had a TCE concentration of 10.7 µg/kg.

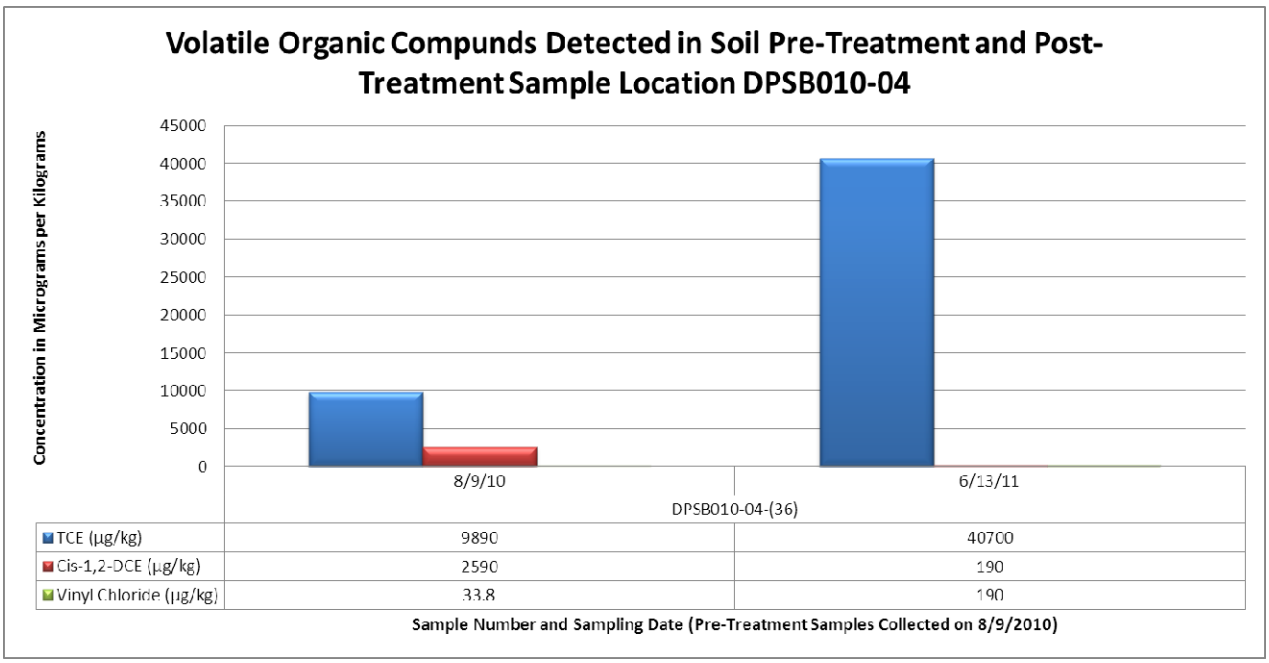
Soil samples were then collected from a total of six locations, DPSB010-01 through DPSB010-05 were sampled on June 13 and 14, 2011, approximately 1 month after completion of all treatment cells. DPSB010-67R was then sampled on July 8, 2011, approximately 2 months after completing all treatment activities and during the installation of replacement monitoring well SMW010-67R. The soil analytical results are illustrated on **Figure 5-1**, and summarized in **Table 5-1**. Soil analytical results were compared against EPA Region 9 Residential Regional Screening Levels (RSL), and NDEQ voluntary cleanup program (VCP) lookup table for all COCs. Prior to the treatment four locations DPSB010-67R(16), DPSB0101-02(20), DPSB010-03(15), and DPSB010-05 (12) exceeded the NDEQ residential standard for TCE of 80 µg/kg. No residential standards were exceeded for any COC in the vadose zone soil samples collected following treatment. The effectiveness of the treatment in soil was calculated for each location and COCs within the active treatment area. Half of the method detection limit was used as the value for all non-detect samples. The results were calculated by dividing the post-treatment concentrations by the pre-treatment concentrations for each contaminant. Graphs of the pre-treatment and post treatment analytical results for each sampling location are presented below:

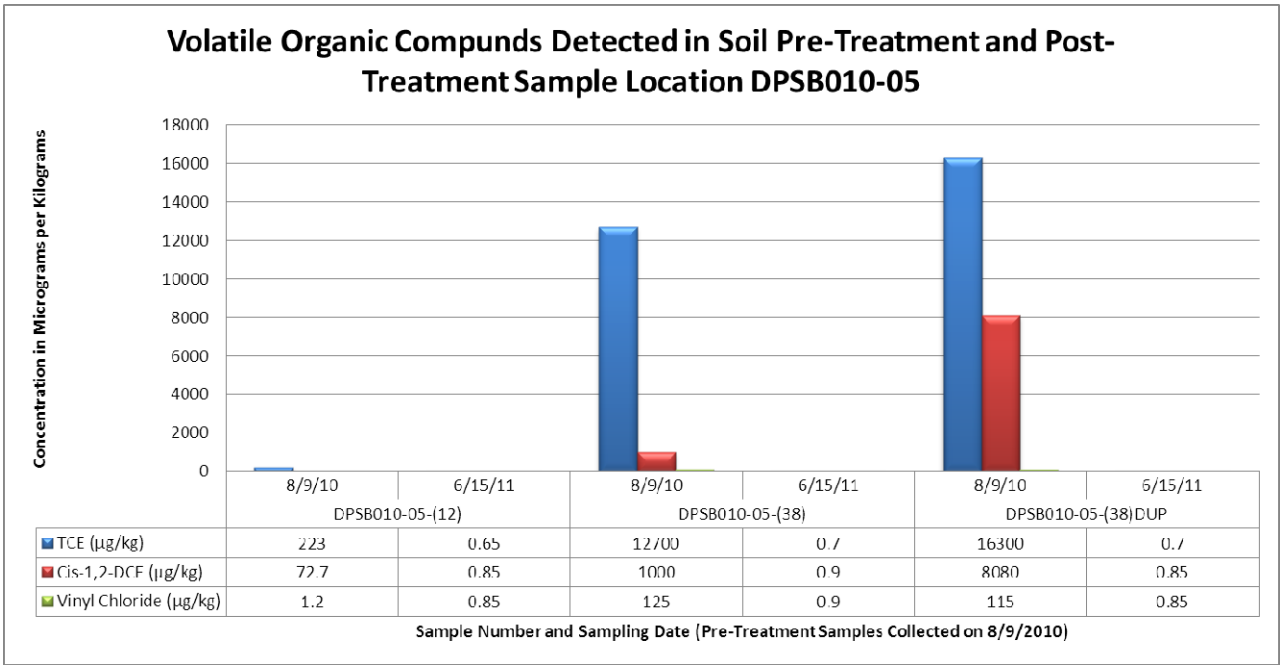



Volatile Organic Compunds Detected in Soil Pre-Treatment and Post-Treatment Sample Location DPSB010-01
Concentration in Micrograms per Kilograms
1000
900
800
700
600
500
400
300
200
100
0
8/9/10
6/13/11
8/9/10
6/13/11
8/9/10
6/13/11
DPSB010-01-(15)
DPSB010-01-(32)
DPSB010-01-(32)DUP
TCE (µg/kg) 0.9 2.3 24.8 2.2 26.2 0.7
Cis 1,2 DCE (µg/kg) 33.8 908 19 461 28.1 188
Vinyl Chloride (µg/kg) 1.15 14.5 1.1 24.6 1 36.2
Sample Number and Sampling Date (Pre-Treatment Samples Collected on 8/9/2010)


Volatile Organic Compunds Detected in Soil Pre-Treatment and Post-Treatment Sample Location DPSB010-02
Concentration in Micrograms per Kilograms
6000
5000
4000
3000
2000
1000
0
8/9/10
5/8/11
6/13/11
8/9/10
5/8/11
6/13/11
DPSB010-02 (20)
DPSB010-02 (32)
TCE (µg/kg) 5160 0.8 0.8 813 0.9 0.7
Cis-1,2-DCE (µg/kg) 3470 1.0 1.0 523 1.1 3.3
Vinyl Chloride (µg/kg) 47.3 1.0 1.0 3.5 1.0 2.7
Sample Number and Sampling Date (Pre-Treatment Samples Collected on 8/9/2010)


Volatile Organic Compunds Detected in Soil Pre-Treatment and Post-Treatment Sample Location DPSB010-03
Concentration in Micrograms per Kilograms
50000
45000
40000
35000
30000
25000
20000
15000
10000
5000
0
8/9/10
6/13/11
8/9/10
6/13/11
DPSB010-03-(15)
DPSB010-03-(34)
TCE (µg/kg) 200 0.7 49900 4.5
Cis-1,2-DCE (µg/kg) 52.9 38.1 659 10.7
Vinyl Chloride (µg/kg) 1.25 0.9 1.1 0.9
Sample Number and Sampling Date (Pre-Treatment Samples Collected on 8/9/2010)


Volatile Organic Compunds Detected in Soil Pre-Treatment and Post-Treatment Sample Location DPSB010-04
Concentration in Micrograms per Kilograms
45000
40000
35000
30000
25000
20000
15000
10000
5000
0
8/9/10
6/13/11
DPSB010-04-(36)
TCE (µg/kg) 9890 40700
Cis-1,2-DCE (µg/kg) 2590 190
Vinyl Chloride (µg/kg) 33.8 190
Sample Number and Sampling Date (Pre-Treatment Samples Collected on 8/9/2010)



The results within the treatment area are presented below in **Table 5-4**.

Table 5-4
Percent Contaminant Removal in Soil

Sample ID	TCE	Cis-1,2-DCE	Vinyl Chloride
Within Active Treatment Area			
DPSB010-67R	99.98%	88.14%	98.12%
DPSB010-02	99.97%	99.89%	92.72%
DPSB010-03	99.99%	93.15%	23.40%
DPSB010-05	99.99%	99.84%	98.61%
Total	99.98%	92.82%	97.70%

Sampling locations DPSB010-01 and DPSB010-04 were both located just outside the active thermal treatment area. DPSB010-01, while outside the active thermal treatment area, was still located within the perimeter ZVI barrier and was disturbed/mixed during the auguring process to place the ZVI. The difference in the pre and post-treatment soil concentrations (primarily in Cis-1,2-DCE and Vinyl Chroride) are likely a result of the soil mixing. The concentration of all three COCs in soil remained below the applicable RSLs and VCP remediation goals (**Table 5-1**) at this location. In addition, the post treatment GW results at this location (**Table 5-2**) indicate TCE and breakdown products are no longer observed in the groundwater along the south end of the treatment area following the treatment.

Analytical results collected at a depth of 36 feet and within the saturated zone at DPSB010-04 (approximately 10 ft northeast of the treatment area) showed an increase in TCE concentrations from 9,890 µg/kg to 40,700 µg/kg immediately following the treatment. This area was known to contain significant saturated zone contamination prior to treatment.

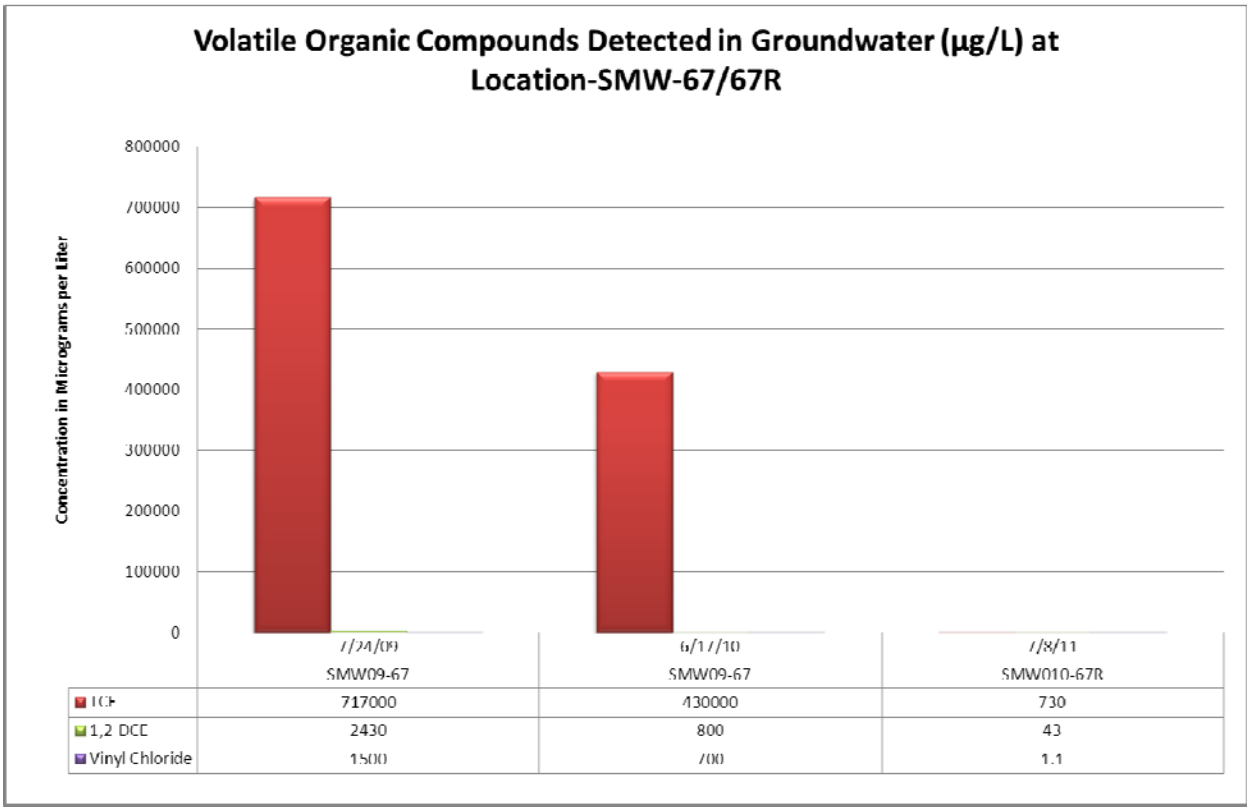
The increase in saturated zone and groundwater TCE concentrations at this location likely resulted from the radiant heating and desorption of contaminants within the already impacted area around the sample location. The saturated zone and groundwater located northeast of the thermal treatment area (including the area of DPSB010-04) were injected with an emulsified vegetable oil and ZVI substrate during pilot testing of the sitewide groundwater remedy. The overall sitewide remedy also includes additional emulsified vegetable oil injections on all sides of the thermal treatment area to address contaminants beyond the reaches of the thermal treatment activities.

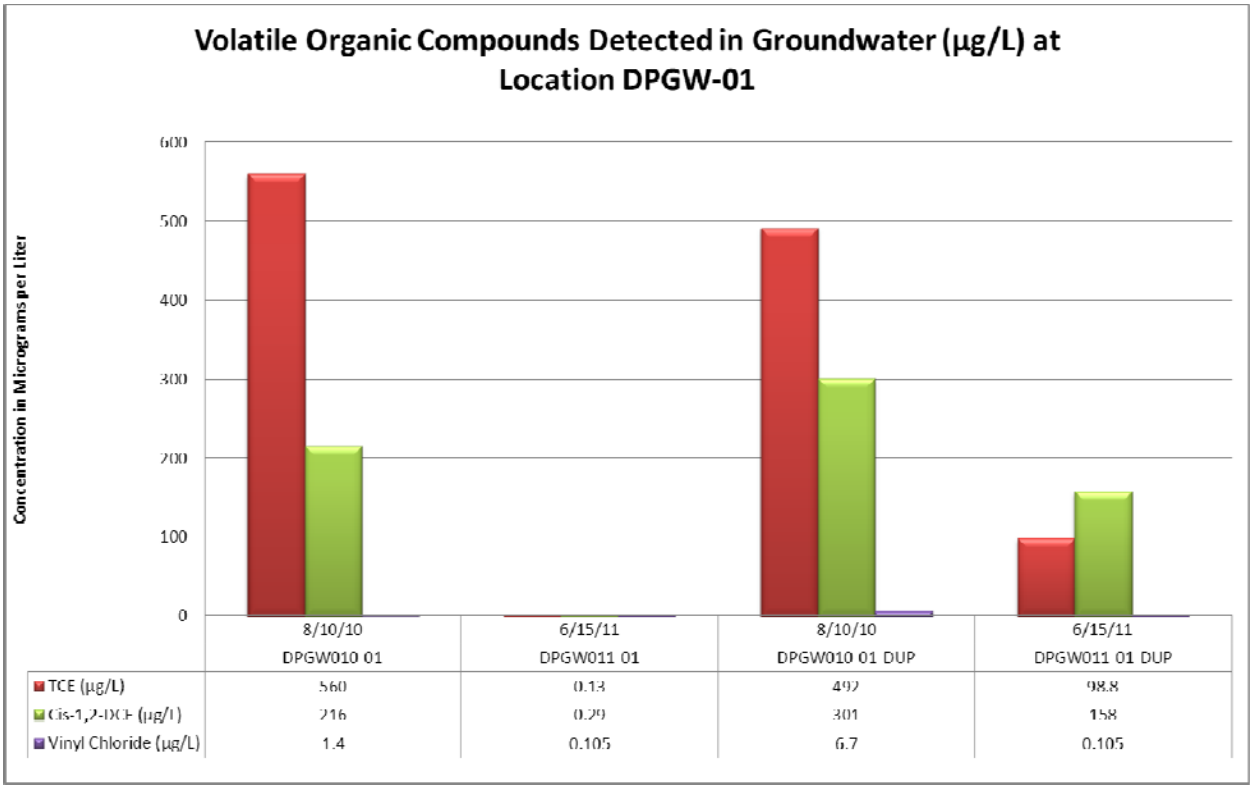
5.3 Post-Treatment Groundwater Conditions

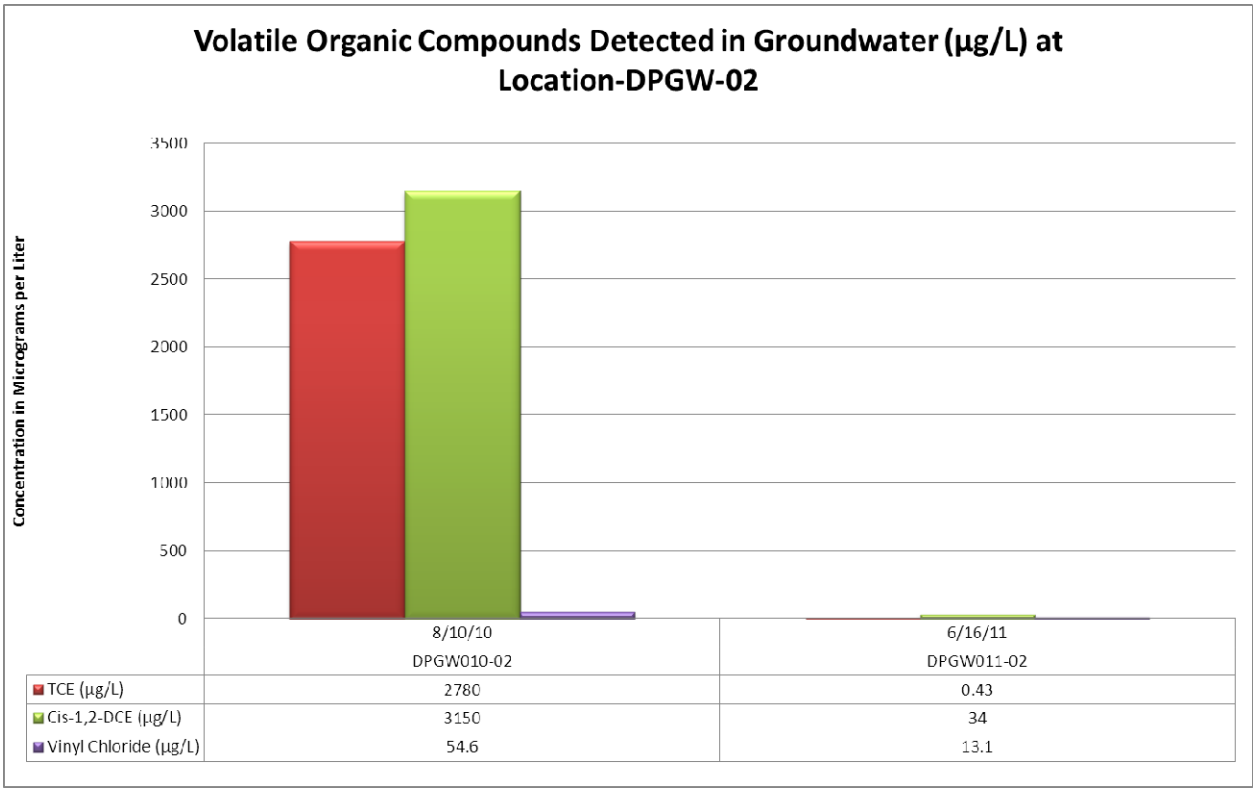
In order to determine the post-treatment groundwater conditions, well SMW010-67R was sampled on July 8, 2011. Groundwater samples were also collected on June 15/16, 2011from 3 direct push locations, DPGW010-02, DPGW010-03, DPGW010-05 within the treatment area and two locations DPGW010-01 and DPGW010-04 located outside the treatment area.

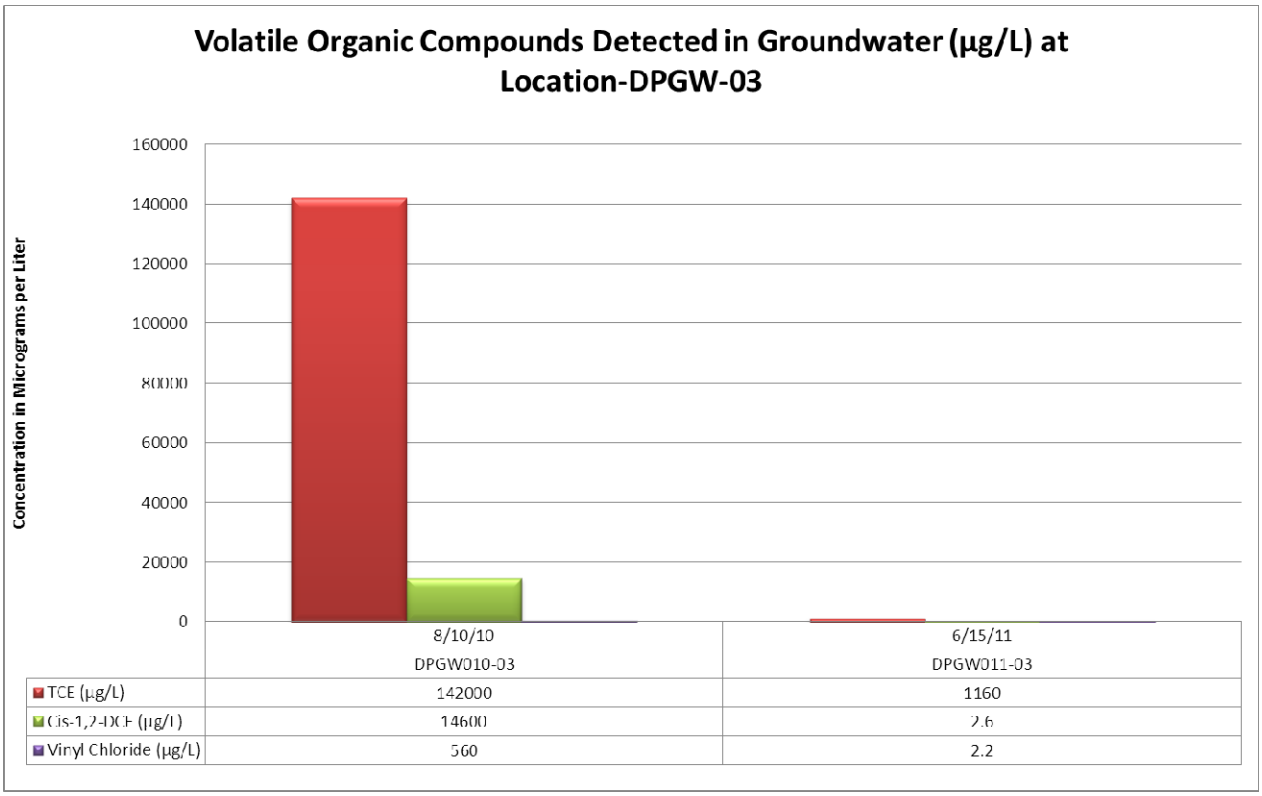
Groundwater samples were also collected as part of the sitewide remedy from eight permanent monitoring wells located downgradient of the treatment area.

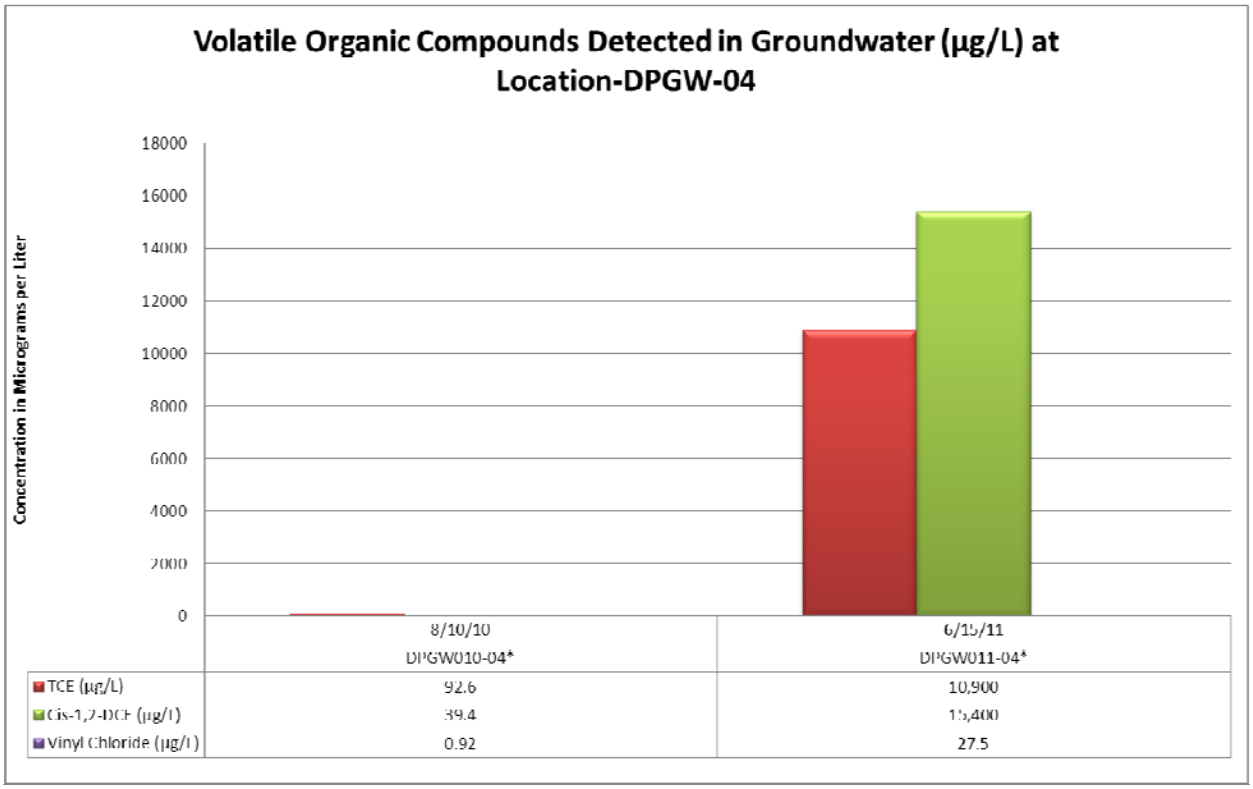
All samples were submitted for VOC analysis by EPA Method 8260B. TCE was detected in 5 of 6 groundwater samples at concentrations ranging from non-detect in sample DPGW011-01 to a maximum concentration of 10,900 µg/L in sample DPGW011-04. Post treatment groundwater sampling of well SMW010-67R showed a reduction in TCE concentration from 430,000 µg/L to 730 µg/L. **Figure 5-2** illustrates the groundwater sampling locations and analytical results. The analytical results are summarized in **Table 5-2**. Graphs of the pre-treatment and post-treatment analytical results for the direct push groundwater samples and monitoring wells SMW010-67R and IMW09-75 are presented below.

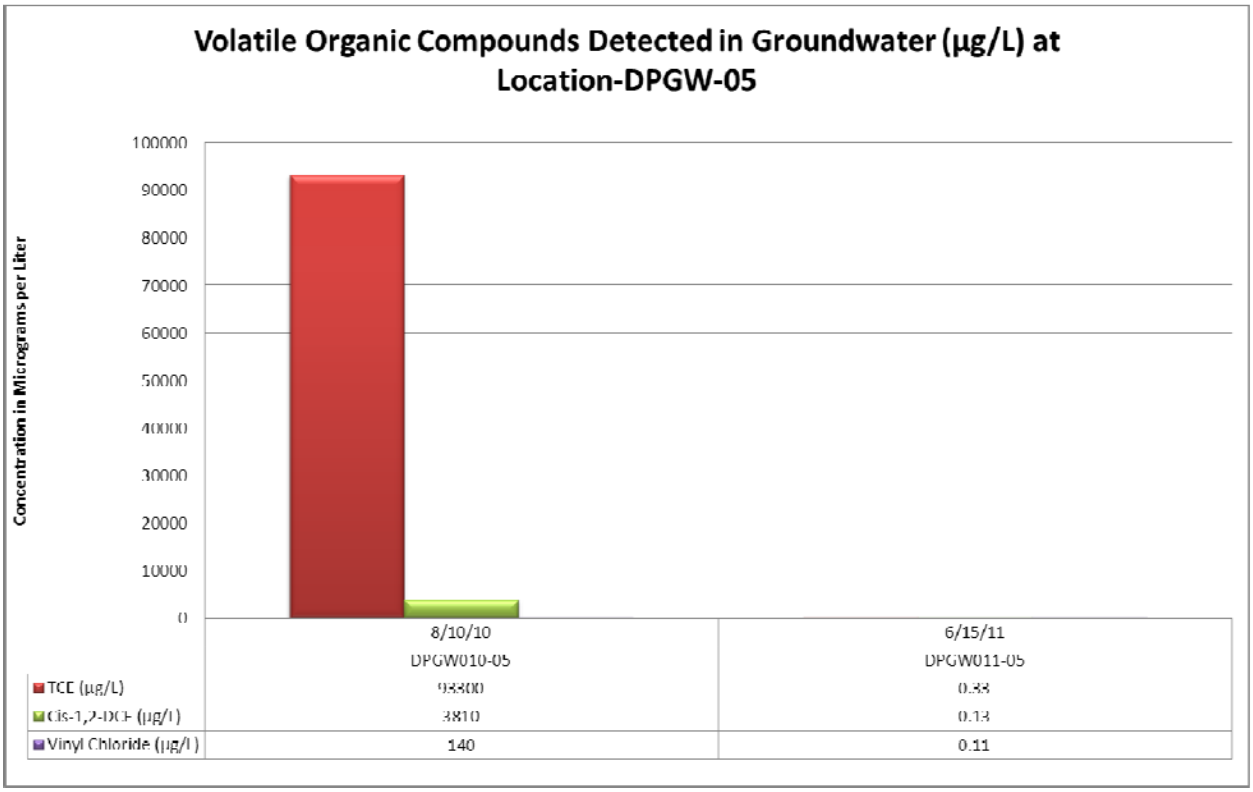

Volatile Organic Compounds Detected in Groundwater (µg/L) at Location-SMW-67/67R
Concentration in Micrograms per Liter
800000
700000
600000
500000
400000
300000
200000
100000
0
7/24/09
SMW09-67
6/17/10
SMW09-67
7/8/11
SMW010-67R
TCE
717000
430000
730
1,2 DCE
2430
800
43
Vinyl Chloride
1500
700
1.1

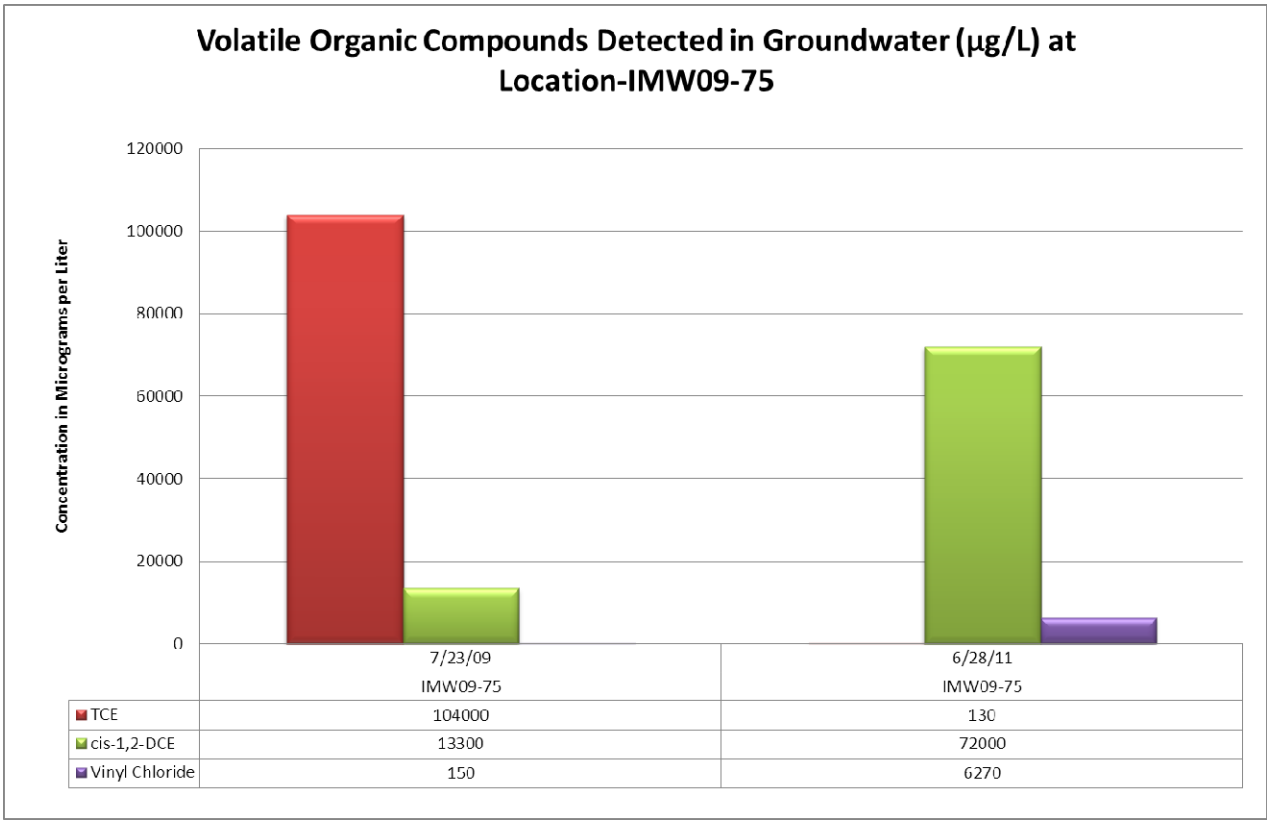

Volatile Organic Compounds Detected in Groundwater (µg/L) at Location DPGW-01
Concentration in Micrograms per Liter
600
500
400
300
200
100
0
8/10/10
DPGW010 01
6/15/11
DPGW011 01
8/10/10
DPGW010 01 DUP
6/15/11
DPGW011 01 DUP
TCE (µg/L)
560
0.13
492
98.8
Cis-1,2-DCE (µg/L)
216
0.29
301
158
Vinyl Chloride (µg/L)
1.4
0.105
6.7
0.105


Volatile Organic Compounds Detected in Groundwater (µg/L) at Location-DPGW-02
Concentration in Micrograms per Liter
3500
3000
2500
2000
1500
1000
500
0
8/10/10
DPGW010-02
6/16/11
DPGW011-02
TCE (µg/L)
2780
0.43
Cis-1,2-DCE (µg/L)
3150
34
Vinyl Chloride (µg/L)
54.6
13.1


Volatile Organic Compounds Detected in Groundwater (µg/L) at Location-DPGW-03
Concentration in Micrograms per Liter
160000
140000
120000
100000
80000
60000
40000
20000
0
8/10/10
DPGW010-03
6/15/11
DPGW011-03
TCE (µg/L)
142000
1160
Cis-1,2-DCE (µg/L)
14600
2.6
Vinyl Chloride (µg/L)
560
2.2


Volatile Organic Compounds Detected in Groundwater (µg/L) at Location-DPGW-04
Concentration in Micrograms per Liter
18000
16000
14000
12000
10000
8000
6000
4000
2000
0
8/10/10
DPGW010-04*
6/15/11
DPGW011-04*
TCE (µg/L)
92.6
10,900
Cis-1,2-DCE (µg/L)
39.4
15,400
Vinyl Chloride (µg/L)
0.92
27.5


Volatile Organic Compounds Detected in Groundwater (µg/L) at Location-DPGW-05
Concentration in Micrograms per Liter
100000
90000
80000
70000
60000
50000
40000
30000
20000
10000
0
8/10/10
DPGW010-05
6/15/11
DPGW011-05
TCE (µg/L)
93800
0.33
Cis-1,2-DCE (µg/L)
3810
0.13
Vinyl Chloride (µg/L)
140
0.11



Dissolved gases methane, ethane, and ethene were collected from all pre-treatment direct push groundwater sampling locations and post-treatment from monitoring well locations SMW010-67R and SMW96-04R. The summarized analytical results are presented in **Table 5-3**. The post-treatment methane and ethene concentrations within and outside the treatment area were similar to the pre-treatment levels. The mean ethane concentration from direct push groundwater samples DPGW010-01 through DPGW010-05 was 2.88 µg/L. The ethane concentration in the post-treatment sample collected from monitoring well SMW010-67R was 153 µg/L. The increase in ethane is an indicator of the dechlorination of TCE by ZVI.

The effectiveness of the treatment in groundwater was calculated for each sampling location and COC within the active treatment area. Half of the method detection limit was used as the value for all non-detect samples. The percent removal results within the treatment area are presented below in **Table 5-5**.

Table 5-5
Percent Contaminant Removal in Groundwater

Sample ID	TCE	Cis-1,2-DCE	Vinyl Chloride
Within Active Treatment Area			
SMW010-67R	99.83%	98.23%	99.93%
DPGW010-02	99.98%	98.92%	76.01%
DPGW010-03	99.18%	99.98%	99.61%
DPGW010-05	100.00%	100.00%	99.92%
Total	99.72%	99.63%	98.89%

Cell locations DPGW010-01 and DPGW010-04 were both located outside the active treatment area. Analytical results of groundwater samples collected from these locations indicate some mobilization of contamination occurred that was probably the result of desorption caused by the fluid injected and heating of the groundwater. Location DPGW010-04 showed the most significant increases with TCE concentrations increasing from 92.6 µg/L to 10,900 µg/L. However, groundwater samples collected from wells IMW09-94, IMW010-115, and IMW010-116 located downgradient of DPGW010-04 showed no increase in TCE concentrations following treatment indicating that the mobilization of TCE was limited to short distances adjacent to the treatment area. The groundwater analytical results for wells IMW09-94, IMW010-115, and IMW010-116 are presented on **Figure 5-2**.

As a point of clarification, prior groundwater remedial pilot testing at Site 2, including the injection of emulsified vegetable oil and ZVI, was conducted northeast of LSB2 (this area includes wells IMW09-94, IMW010-115, and IMW010-116). The reduction in TCE concentrations and subsequent increase in concentrations of breakdown products cis-1,2-DCE and vinyl chloride are likely the result of this previous testing more so than the In Situ thermal treatment process.

6.0 SUMMARY OF TREATMENT RESULTS AND LESSONS LEARNED

The thermal treatment using large-diameter auger soil mixing and placement of ZVI technology was effective in meeting the objectives outlined in **Section 1.1**. The post-treatment soil sampling data indicate that COC concentrations have been reduced below EPA Region 9 residential regional screening levels (RSLs) and NDEQ voluntary cleanup program (VCP) lookup tables. A post-treatment reduction in TCE concentrations of more than 99% was observed in both soil and groundwater samples collected within the treatment area. Cis-1,2-DCE concentrations were reduced by 92.8% in soil, and more than 99% in groundwater, and VC concentrations were reduced by 97.7% in soil and 98.9% in groundwater.

The site geology consisting of silty clay and glacial till, and the depth of the contamination posed challenges to traditional methods of remediation including soil vapor extraction. The Technical Evaluation and Cost Summary (ITSI, 2010a) prepared for this project evaluated excavation with off-site disposal, excavation with on-site treatment of soil, and in situ thermal treatment using large diameter auger soil mixing and ZVI. The LDA thermal technology was ultimately selected based on worker safety, the use of "green" technologies (elimination of the off-site disposal), depth of the impacted media, contaminant concentrations, treatment timeframe considerations, site-specific geologic and hydrogeologic conditions, cost, permitting considerations, and likelihood of success.

This treatment technology had previously been used most extensively in predominately sandy lithologies. One of the biggest concerns for this technology was the ability of the method to reach the required treatment depths given the geology at the site. Initial drilling times of 2 hours to 3 hours were common to reach a depth of 40 ft. Several modifications were implemented to improve the drilling rate. The auger bit was modified to add more aggressive teeth to the top and bottom of the auger bit. Starting on October 28, 2010 Baroid® EZ-MUD® was injected during drilling to help reduce swelling of the clays. Four pounds of EX-MUD® was mixed with 400 gallons of water and injected at a rate of 10 gallons per minute. The modifications and the addition of the steam during the thermal portion of the treatment improved drilling times to 30 minutes to 45 minutes to reach a depth of 40 ft.

The work plan called for conducting treatment around wells DMW09-08 and IMW09-75 to avoid replacing these wells, if possible. A buffer area of approximately ten feet was established around the two wells in which no thermal treatment was conducted. The intent of the buffer area was to reduce the risk of damaging the PVC wells during thermal treatment process. However, after treatment was complete it was determined that deep well DMW09-08 had still been destroyed and IMW09-75 partially damaged by the heating process. Future applications of this technology should likely include plans to abandon all PVC wells located within the treatment area with re-installation of the wells after treatment is complete or consider the use of stainless steel wells.

Weather conditions were also a factor for conducting the work. The process uses a significant amount of water primarily to generate the steam required, and piping to conduct the process. Temperatures below freezing were problematic for maintaining the operations.

Post-treatment groundwater sampling was conducted approximately one month after completion of all cells. Continued sampling of the permanent monitoring wells is recommended during routine groundwater sampling events to determine the long-term effectiveness of the technology.

7.0 REFERENCES

Innovative Technical Solutions, Inc. (ITSI), 2009. *Final Volume Refinement Work Plan,* Former Offutt AFB Atlas "D" Missile Site 2, Arlington, Nebraska. March.

ITSI 2010a. *Draft Technical Evaluation and Cost Summary LSB2.* January.

ITSI 2010b. *Final In-Situ Thermal Treatment with ZVI Pilot Study Work Plan.* September.

ITSI, 2011a. *Final Volume Refinement Report,* Former Offutt AFB Atlas "D" Missile Site 2, Arlington, Nebraska. June.

ITSI, 2011b. *Revised Final Investigation-Derived Waste Management Plan,* Former Offutt AFB Atlas "D" Missile Site 2, Arlington, Nebraska. May.

U.S. Environmental Protection Agency, 1992. *Estimating Potential for Occurrence of DNAPL at Superfund Sites,* EPA 9355.4-07FS.

FIGURES