

**In Situ Thermal NAPL Remediation at the Northeast Site
Pinellas Environmental Restoration Project**

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ABSTRACT

The U.S. Department of Energy (DOE) is conducting thermal remediation to remove non-aqueous phase liquids (NAPLs) from the subsurface at the Northeast Site that is part of the Pinellas Environmental Restoration Project. The Northeast Site is located on the Young – Rainey Science, Technology, and Research (STAR) Center in Largo, Florida. The STAR Center was formerly a DOE facility. The NAPL remediation was performed at Area A and is currently being performed at Area B at the Northeast Site. The remediation at Area A was completed in 2003 and covered an area of 900 m² (10,000 ft²) and a depth of remediation that extended to 10.7 m (35 ft) below ground surface. Cleanup levels achieved were at or below maximum contaminant levels in almost all locations.

The remediation project at Area B is ongoing and covers an area of 3,240 m² (36,000 ft²), a volume of 41,300 m³ (54,000 yd³), and a depth of remediation to 12 m (40 ft) below ground surface. In addition, a portion of the subsurface under an occupied building in Area B is included in the remediation. The cleanup levels achieved from this remediation will be available in the Area B Final Report that will be posted on the DOE Office of Legacy Management website (www.lm.doe.gov/land/sites/fl/pinellas/pinellas.htm) in January 2007. Electrical resistive heating and steam were the chosen remediation methods at both areas. Lessons learned from the Area A remediation were incorporated into the Area B remediation and could benefit managers of similar remediation projects.

INTRODUCTION

As part of the Pinellas Environmental Restoration Project, the U.S. Department of Energy (DOE) completed a thermal remediation project using steam and electrical resistive heating and is currently conducting another thermal remediation project. Both projects are located at the Northeast Site, which is located on the Young – Rainey Science, Technology, and Research (STAR) Center in Largo, Florida, formerly known as the Pinellas Plant. The Young-Rainey STAR Center is a former DOE facility that operated from the mid-1950s until 1995 when it was sold to Pinellas County. After the sale, DOE remained responsible for environmental restoration activities attributable to DOE operations. These operations resulted in non-aqueous phase liquids (NAPLs) being left in the subsurface. The presence of NAPLs was detected at two areas on the Northeast Site, referred to as Area A and Area B. In both areas, NAPLs were present as light NAPL (LNAPL) and dense NAPL (DNAPL). In situ thermal remediation of NAPLs has been completed at Area A and is ongoing at Area B.

Site Description

Hydrogeology at the Northeast Site consists of 9.14 m (30 ft) of alluvium with a surficial, unconfined aquifer underlain by clay of the Hawthorn Group. The clay acts as a local aquitard. The alluvium is composed of fine-grain sand with variable amounts of silt and clay. The horizontal hydraulic conductivity of the surficial aquifer (located from 0.9 to 9.14 m [3 to 30 ft] below ground surface) ranges from 3×10^{-4} to 2×10^{-3} cm/s. Vertical hydraulic conductivity ranges from 1×10^{-6} to 1×10^{-4} cm/s. The hydraulic gradient is relatively flat, and water velocities range from 3 to 6 m (10 to 20 ft) per year.

Area A covered approximately 900 m² (10,000 ft²) and extended from the surface to a depth of 10.7 m (35 ft) below ground surface, representing a total cleanup volume of 9,940 m³ (13,000 yd³). Area B covers approximately 3,240 m² (36,000 ft²), extends from the surface to 12 m (40 ft) below ground surface, and includes a volume of 41,300 m³ (54,000 yd³).

Before remediation, the estimate of the mass of contaminants in the subsurface at Area A was 1,170 kg (2,600 lb) of volatile organic compounds and 1,350 kg (3,000 lb) of petroleum hydrocarbons. The estimated mass of volatile organic compounds at Area B is approximately 6,750 kg (15,000 lb) with a minimal amount of petroleum hydrocarbons. In both areas, contamination consists of volatile organic constituents, primarily trichloroethene (TCE), *cis*-1,2-dichloroethene (DCE), methylene chloride, and toluene. NAPLs were suspected to exist at shallow locations in some areas and at deeper locations in other areas. There were indications that NAPLs existed in the top 1.5 m (5 ft) of the underlying clay layer at Area A and in the top 3 m (10 ft) at Area B. Therefore, this interval of the clay layer (the upper 1.5 m [5 ft] at Area A and 3 m [10 ft] at Area B) was included in the volume to be remediated.

Remediation Approach

After the discovery of NAPLs in 1998, an evaluation of the remediation strategies concluded that application of a thermal remediation technology, such as steam or electrical resistive heating, was the best approach to remove NAPLs from the subsurface. The remediation approach also assumed that the thermal remediation would not achieve the final cleanup goals, which were maximum contaminant levels (MCLs). It was assumed that another technology, such as bioremediation, would be needed after completion of the thermal NAPL remediation as a polishing step to achieve final cleanup goals.

Thermal remediation has several advantages when trying to remove NAPLs. Heating causes the vapor pressures of NAPLs to significantly increase, adsorption coefficients to decrease, viscosity to reduce, NAPL-water interfacial tensions to reduce, and the water solubility to increase. These effects enhance removal as a separate NAPL phase by extraction in the vapor phase, by volatilization and migration to the steam phase, and by dissolution in extracted groundwater.

AREA A REMEDIATION

The DOE contractor, S.M. Stoller Corporation, solicited remediation approaches using in situ thermal technologies. A remediation subcontract awarded to SteamTech Environmental Services

proposed using a combination of steam-enhanced extraction and electrical resistive heating. A combination of technologies was chosen because of the underlying clay layer, the presence of LNAPLs and DNAPLs in the alluvium, and the presence of oily NAPLs. Steam-enhanced extraction and electrical resistive heating were used in the alluvium, and electrical resistive heating alone was used in the clay layer. McMillan-McGee Corporation was the electrical resistive heating subcontractor. The company's proprietary electrical resistive heating technology is called Electro-Thermal Dynamic Stripping Process (ET-DSP).

Remedial Objectives

The thermal remediation subcontractor was required to meet the cleanup goals presented in Table I. If cleanup goals were not met, the subcontractor was required to continue operations until the goals were met. The cleanup goals were applied to the entire area and depth of remediation. It should be noted that the cleanup goals were based on levels that would indicate the absence of NAPLs and were not based on the final cleanup goals for the site. In addition, the subcontractor was required to obtain a minimum operating temperature of 84° C and ensure that operation of the remediation system complied with applicable regulatory requirements at all times. Groundwater concentrations were required to remain below standards for at least 24 weeks, and contamination could not spread outside the remediation area.

Table I. Groundwater and Soil Remediation Goals

NAPL Component	Groundwater Remediation Goals (µg/L)	Soil Remediation Goals (µg/kg)
Trichloroethene	11,000	20,400
<i>cis</i> -1,2-DCE	50,000	71,000
Methylene Chloride	20,000	227,000
Toluene	5,500	15,000
Total Petroleum Hydrocarbons	50,000	2,500,000

The cleanup levels achieved were determined by taking confirmatory soil and groundwater samples. S.M. Stoller Corporation, the DOE contractor, collected the samples. One set of soil samples was taken, and groundwater samples were obtained at 6 weeks, 12 weeks, and 24 weeks after remediation operations ceased. Confirmatory sampling was evaluated using a statistical approach, which was based on the goal of having a 90 percent certainty that contaminant levels at 90 percent of the site were at or below the cleanup levels. Another criterion was that concentrations in the soil samples could not exceed the cleanup goals by more than 100 percent, and concentrations in groundwater samples could not exceed a cleanup standard by more than 50 percent.

Remediation Strategy and Activities

The strategy for the remediation was to first establish hydraulic control, then heat the lower clay layer and perimeter. The next step was to heat the entire area to the target temperature and then

conduct pressure cycling. The final step was to cool the area to allow confirmatory sampling. Remediation operations started in late September 2002 and continued for approximately 5 months.

Hydraulic and pneumatic controls were established by liquid and vapor extraction and were accomplished within a week after the start of operations. Once hydraulic control was established, the lower clay layer and the perimeter of Area A were heated. ET-DSP was used to heat the clay layer, and both steam and ET-DSP were used to heat the perimeter. Heating to the target temperature around the perimeter and in the clay layer was achieved after approximately 1 month. The next phase was to heat all of Area A to the target temperature with steam injection and ET-DSP. By mid-November 2002, the average temperature inside Area A had reached about 84° C, and the zone below 3 m (9.8 ft) in depth was generally above 100° C.

Pressure cycling and optimization of mass removal constituted the next phase. Pressure cycling was achieved by varying the steam injection rates and the ET-DSP power delivery. Mass recovery was highest at times of depressurization. Pressure cycling continued until mid-February 2003, at which time recovery of contaminants was minimal and heating was stopped. Cool down and polishing involved continued vapor and liquid extraction combined with air and cold water injection. Cool-down target temperatures of less than 100° C in all areas were reached in late March 2003. Operations ended at that point.

During operations, steam-enhanced extraction was used primarily to heat the sands in the alluvium and sweep the oily areas. ET-DSP was used to assist in directing steam flow (preheating an area with ET-DSP provided a preferential path for steam to flow to an area) and heating the lower clay layer. An extensive subsurface temperature-monitoring network was used to determine which areas needed the application of additional energy. Temperature data were made available through a project website for viewing temporal trends and current temperature distributions. Vapor and liquid were extracted continuously from the subsurface during the entire operational period. Figure 1 shows the ET-DSP power deliver system and extraction well field.

Remediation Components

The well-field layout was modified between December 2002 and February 2003 in response to high contamination levels in a relatively cool area caused by a lens of resinous material. During that time, 12 additional shallow steam injection wells were installed in the east half of Area A. These wells were used to improve the steam delivery and heat distribution in this area. The components used for in situ thermal remediation of Area A were

- Fifteen steam injection wells around the perimeter of Area A, 28 extraction wells with ET-DSP electrode wells that were spaced throughout Area A, 2 deep ET-DSP electrodes located in the clay layer, and 21 combined steam injection and ET-DSP wells. Figure 2 shows the distribution and layout of these wells.
- Thirty-six temperature-monitoring arrays in boreholes distributed across Area A.



Fig. 1. Area A ET-DSP power delivery system and well field

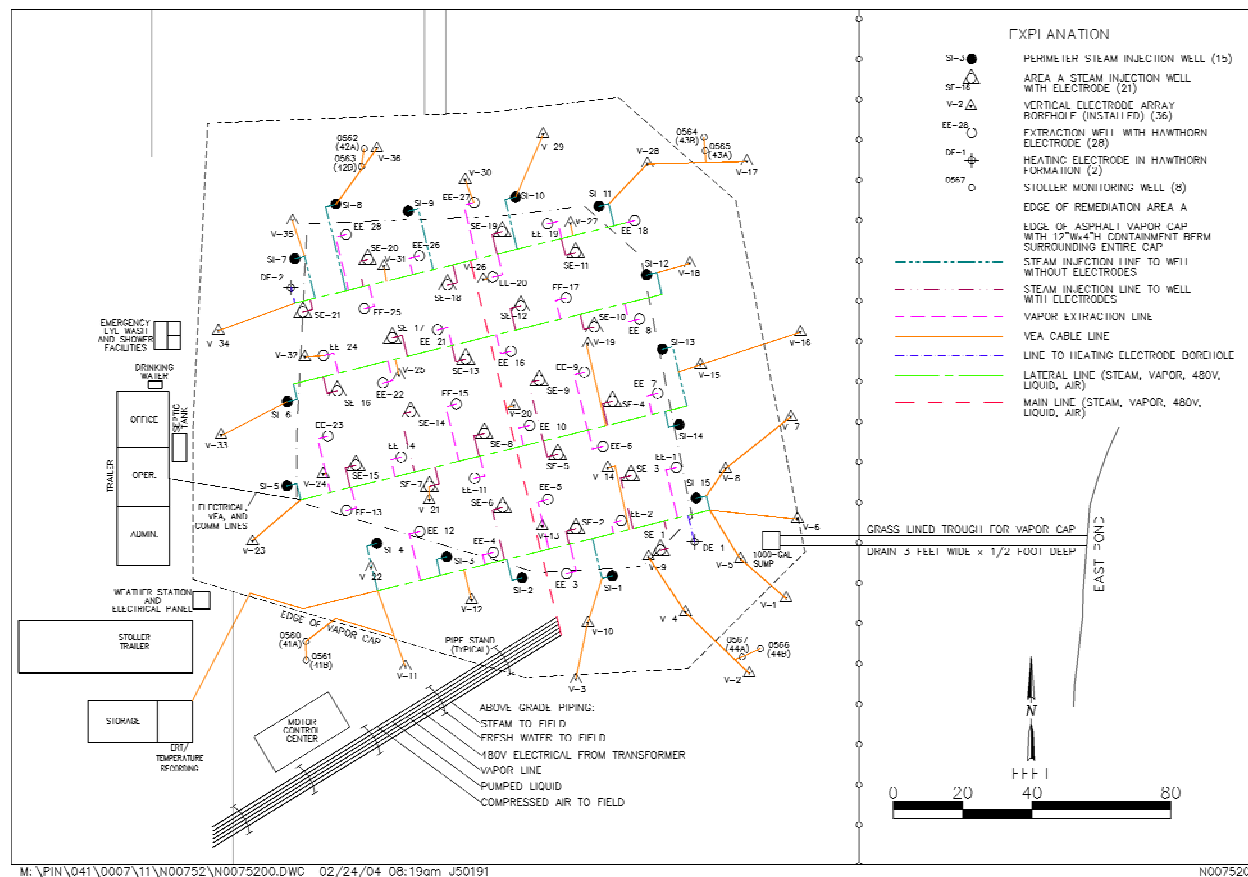


Fig. 2. Layout of remediation components for Area A

- Eight monitor wells (in four well pairs) installed outside Area A.
- Five power delivery systems that provided power to the electrodes.
- An asphalt cap over the remediation area.
- Steam generation trailer with the capability to generate 2,700 kg/h (6,000 lb/h) of steam.
- A treatment system for the extracted vapors and liquid. The extracted vapors were treated with granular activated carbon. The extracted liquid was treated with an air stripper and then with granular activated carbon before being discharged to a publicly owned treatment works.

Results

The remediation proved to be very successful. No accidents or injuries were incurred during the remediation, regulatory requirements were met, and remedial objectives were met or exceeded. All samples collected to determine the level of cleanup achieved had concentrations below the cleanup goals, and most of the groundwater samples had concentrations below MCLs. Of the 48 groundwater samples collected during three rounds of post-operational sampling, only 10 samples had contaminant concentrations that exceeded MCLs. In addition, concentrations in groundwater samples did not increase over time after operations ceased. Post-operational soil samples showed similar results; concentrations in all samples were significantly less than cleanup goals. Table II presents a comparison of the concentrations in the post-operational groundwater and soil samples with the groundwater and soil cleanup goals and groundwater MCLs. Average groundwater and soil concentrations are generally an order of magnitude less than the highest concentrations.

Table II. Comparison of Cleanup Levels Achieved

Contaminant	TCE	<i>cis</i> -1,2-DCE	Methylene Chloride	Toluene	Total Petroleum Hydrocarbons
Groundwater Cleanup Goals	11,000 µg/L	50,000 µg/L	20,000 µg/L	5,500 µg/L	50,000 µg/L
MCL	3 µg/L	70 µg/L	5 µg/L	1,000 µg/L	5,000 µg/L
Range of Groundwater Sample Concentrations	ND ^a - 29 µg/L	ND - 76 µg/L	ND - 13 µg/L	ND - 38 µg/L	ND - 9,500 µg/L
Soil Cleanup Goal	15,000 µg/kg	71,000 µg/kg	227,000 µg/kg	15,000 µg/kg	2,500 mg/kg
Range of Soil Sample Concentrations	ND - 10 µg/kg	ND - 120 µg/kg	ND - 8 µg/kg	ND - 420 µg/kg	ND - 550 mg/kg

^aND = nondetectable.

The mass of contaminants remaining in the subsurface after treatment was estimated to be about 0.45 kg (1 lb). This represents a 99.93-percent removal efficiency for all the volatile contaminants of concern. The treatment efficiency for total petroleum hydrocarbons was estimated to be 61 percent. This amount is a lower treatment efficiency, but it still resulted in contaminant concentrations in all samples being significantly below cleanup levels.

Another remedial objective that was closely monitored was whether contaminants spread outside the remediation area. Sampling during and after remedial operations showed no evidence of either horizontal or vertical spreading. The soil samples collected from the clay layer after remediation all showed very low contaminant concentrations, indicating that remediation in the clay layer had been successful and that contaminants had not spread downward. Sampling conducted at 1 year and 2 years after the remediation did not show any indication of rebound.

LESSONS LEARNED

Several lessons were learned from the Area A remediation. Some supported the approach that was taken, and some indicated areas where improvements could be made. Some of the most significant lessons learned are

- Cycling of the subsurface pressure proved to be an effective technique for maximizing the mass of contaminants removed. During the initial cycles, large spikes in the vapor phase concentrations were observed during the depressurization phase of a cycle.
- The strategy for remediation (establish hydraulic control→perimeter and bottom heating→heat the entire area to the target temperature→pressure cycling→cool down) proved to be effective at meeting the objectives and minimizing the risk of contaminants spreading.
- The combination of steam and electrical resistive heating proved beneficial. Steam would not have been as effective as electrical resistive heating at remediating the lower clay layer, and the combination of the technologies resulted in more uniform heating.
- Improvements to the treatment system efficiency need to be considered in future remedial activities. The air stripper, liquid-phase carbon, and regeneration of the vapor-phase carbon systems are the main areas where efficiency improvements are needed.
- The use of electrical resistive tomography was attempted at the site but was not effective for monitoring subsurface temperatures. High dissolved-solids concentrations in the groundwater appeared to have made the resistivity effects from temperature not distinguishable.

AREA B REMEDIATION

On the basis of the success of the remediation at Area A, a project to remove NAPLs from the subsurface at Area B was initiated. The remediation at Area B involved a significantly larger

area than the Area A remediation. Area B covered 3,240 m² (36,000 ft²), a depth of remediation to 12 m (40 ft), and an area of 41,2884 m³ (54,000 yd³) compared to a remediation area of 900 m² (10,000 ft²), depth of remediation to 10.7 m (35 ft), and a cleanup volume of 9,940 m³ (13,000 yd³) for Area A. To benefit from the successful remediation at Area A, the approach to Area B incorporated the lessons learned from Area A. The lessons learned included use of a similar remediation approach and strategy (i.e., using a combination of steam and electrical resistive heating, making improvements to the vapor and groundwater treatment systems, and not using electrical resistive tomography).

S.M. Stoller Corporation, the DOE contractor, is managing the remediation at Area B and selected a team lead by WRS Infrastructure and Environment. The WRS Infrastructure and Environment team also includes McMillan-McGee Corporation that provides its ET-DSP technology to heat the subsurface and PPM Consultants to provide engineering and aboveground treatment components. The design phase of the Area B remediation began in February 2004, construction started in July 2004, and operations started in August 2005. The construction period was extended across 2 fiscal years because of a limitation of funds.

Remedial Objectives

The remedial objectives for the Area B remediation were the same as for Area A with the addition of temperature limitations around and under Building 1400. The temperature limitation required that temperatures within a 1.8-m (6-ft) area under and adjacent to Building 1400, could not exceed 40° C.

Remediation Strategy and Activities

The strategy for the remediation at Area B is similar to the strategy used for Area A. Establishing hydraulic and pneumatic controls was the first activity, which was initiated in August 2005 and was completed within 2 weeks. Next, heating was focused on the lower clay layer and perimeter. After approximately 3 weeks of focusing energy to these areas, heating of the entire remediation volume began. The next step will be to heat the entire area to the target temperature and then conduct pulsing operations. Pulsing will involve varying heating rates and extraction rates to maximum vapor recovery. The final step will be to cool the area to allow confirmatory sampling. The operations started in August 2005 are continuing during December 2005.

Hydraulic and pneumatic controls were established and will be maintained at all time during operations by liquid and vapor extraction. Liquid extraction rates vary from 114 to 265 L/min (30 to 70 gal/min) but always exceed the injection rate into the electrodes by at least 25 percent. Vapor extraction rates average approximately 28 standard cubic meters per minute (1,000 standard cubic feet per minute). Heating of the subsurface is being accomplished with ET-DSP electrodes combined with the injection of hot water into the electrodes. Water is being heated aboveground to approximately 85° C before being injected into the electrodes to aid in convective heat transport. Injection of the hot water also allows in situ generation of steam. In addition, steam injection wells have been installed and will be used for spot heating, if necessary. The status of the Area B remediation at this time (December 2005) is that the target temperature

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has almost been achieved in all areas. The operational phase is expected to be complete by April 2006. Confirmatory sampling will be conducted from May 2006 to October 2006.

An extensive subsurface temperature-monitoring network of digital temperature sensors is being used to monitor and adjust the heating process. Temperature data are made available on a project website, where temperature trends and current temperature distributions can be viewed and evaluated.

Remediation Components

The components used for remediation of Area B are:

- A total of 187 ET-DSP electrodes were placed in 96 wells. Two electrodes were placed in each well except for the slant electrodes that were placed under Building 1400. The electrodes were placed at depths varying from 3 m (10 ft) into the Hawthorn to near the top of the Hawthorn.
- Twenty-nine shallow steam injection wells.
- Approximately 2,000 temperature sensors in 150 locations.
- Twelve monitoring wells (in six well pairs) installed outside Area B.
- Nine power delivery systems to provide power to the electrodes.
- Twenty-three vertical extraction wells and 3 horizontal extraction wells located under Building 1400.
- An asphalt cap over the remediation area.
- A treatment system for the extracted vapors and liquid. The vapors were extracted with two 100-horsepower vacuum pumps and treated with granular activated carbon. The extracted liquid was treated with an air stripper and then with granular activated carbon before being discharged to a publicly owned treatment works.

Results

Results of Area B remediation are not available at this time because the project is still in the operational phase. Results will be presented in the Area B Final Report that will be posted to the Office of Legacy Management website (www.lm.doe.gov/land/sites/fl/pinellas/pinellas.htm) in January 2007.

CONCLUSIONS

The NAPL remediation at Area A was successful from all aspects: outstanding health and safety record, remedial objectives exceeded, compliance with environmental requirements, and good quality. It was the first full-scale remediation of a site with NAPL contamination that employed a combination of steam-enhanced extraction and electrical resistive heating. The two technologies worked well together in implementing the remediation strategy, as evidenced by attained cleanup levels that were generally 100 times lower than the cleanup goals. On the basis of the success of remediation of Area A, similar remediation technologies were initiated at Area B. The Area B remediation incorporates resistive heating, steam-enhanced extraction, and the lessons learned from remediation of Area A. In December 2005, the Area B remediation was in the heat-up phase and preliminary results are not yet available.

ACKNOWLEDGMENTS

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