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SUCCESSFUL FIELD-SCALE IN SITU THERMAL NAPL REMEDIATION AT THE YOUNG-RAINEY STAR CENTER

ABSTRACT: The U.S. Department of Energy (DOE) successfully completed a field-scale remediation to remove non-aqueous phase liquids (NAPLs) from the subsurface at a site on the Young-Rainey Science, Technology, and Research (STAR) Center, Largo, Florida. The STAR Center is a former DOE facility. The remediation project covered an area of 930 m^2 (10,000 ft^2) and depths extending to 10.5 m (35 ft) below ground surface.

In July 2001, DOE's contractor awarded a subcontract to SteamTech Environmental Services for removal of NAPLs from a portion of the Northeast Site. The technologies used for remediation were steam-enhanced extraction and Electro-Thermal Dynamic Stripping Process, an electrical resistive heating technology. McMillan-McGee Corporation implemented the process.

Construction of the remediation system was completed in September 2002. Operations began immediately after construction, and active heating ended in February 2003. After operations were completed, confirmatory sampling was conducted over a 6-month period to verify the level of cleanup achieved. Results of the sampling showed that NAPL concentrations were reduced significantly below the required cleanup goals and, in most cases, below the regulatory maximum contaminant levels. Lessons learned relative to the design, construction, operation, confirmatory sampling approach, and subcontracting could benefit managers of similar remediation projects.

INTRODUCTION

The former DOE facility (the Pinellas Plant) located in Largo, Florida, operated from the mid-1950s until 1995 when it was sold to Pinellas County. After the sale, DOE remained responsible for environmental restoration activities following historical DOE operations, which had resulted in NAPLs being left in the subsurface. The NAPLs were found in an area of the former facility, which is now called the Young-Rainey STAR Center, known as the Northeast Site. During a part of the former facility's operational period, the Northeast Site was used for waste solvent staging and storage and disposal of construction debris. In 1998, NAPL was detected at two areas on the Northeast Site. These areas were later referred to as Area A and Area B. In both areas, the NAPL was present in light (LNAPL) and dense (DNAPL) forms.

This paper provides an overview of the in situ thermal remediation of NAPLs at Area A on the Northeast Site, with emphasis on project management aspects. Another paper (Heron et al.) in these proceedings provides a more detailed description of the technologies used for the remediation at Area A. A paper by Tabor et al. provides a more detailed description of the NAPL characterization and confirmatory sampling methodology.

Site Description. The Northeast Site is an active Solid Waste Management Unit at the Young-Rainey STAR Center that is being remediated by DOE. Area A on the Northeast Site covered approximately 930 m^2 (10,000 ft^2) and extended from the surface to a depth of 10.5 m (35 ft) below ground surface, representing a total cleanup volume of 9,900 m^3 (13,000 yd^3).

Site hydrogeology at Area A consists of 9 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-grained sand with variable amounts of silt and clay. The horizontal hydraulic conductivity of the surficial aquifer (located between 1 and 9 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; water velocities range from 3 to 6 m (10 to 20 ft) per year.

Before remediation, the rough estimate of the mass of contaminants in the subsurface was 1,180 kg (2,600 lb) of volatile organic compounds and 1,360 kg (3,000 lb) of petroleum hydrocarbons. The primary volatile organic constituents included 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. Although there was no direct evidence, there was the potential that NAPLs could exist in the top 1.5 m (5 ft) of the underlying clay layer. Therefore, the top interval of the clay layer was included in the area to be remediated.

REMEDIATION APPROACH

Prior to the discovery of NAPLs at the Northeast Site, the remediation strategy for dissolved constituents previously detected in groundwater was to use a hydraulic barrier at the northern border of the site (upgradient) and a pump-and-treat remedy for containment and mass removal. After the discovery of NAPLs, a reevaluation of the remediation strategy (DOE 2000) 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 revised remediation plan also assumed that another technology, such as bioremediation, would be needed after completion of the thermal NAPL remediation as a polishing step.

In 2000, DOE's contractor sent to the prospective bidders a Request for Proposal that solicited remediation approaches using in situ thermal technologies. Four proposals were received and evaluated. The subcontract was awarded to SteamTech Environmental Services, who proposed using a combination of two technologies: steam-enhanced extraction and electrical resistive heating. A combination of technologies was chosen because of the clay layer, the presence of LNAPLs and DNAPLs in the alluvium, and the presence of oily NAPLs. Steam-enhanced extraction and electrical resistive heating would be used in the alluvium, and electrical resistive heating alone would be used in the clay layer. McMillan-McGee Corporation was the electrical resistive heating subcontractor. Their proprietary electrical resistive heating technology is called Electro-Thermal Dynamic Stripping Process (ET-DSP).

Remedial Objectives. The thermal remediation subcontractor, SteamTech Environmental Services, was required to meet all remedial objectives, including the cleanup goals presented in Table 1. If cleanup goals were not met, the subcontractor would be required to continue operations until the goals were met. The cleanup goals were applied to the entire area and depth of remediation for Area A. 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.

TABLE 1. Groundwater and soil remediation goals.

NAPL Component	Groundwater Remediation Goals (µg/L)	Soil Remediation Goals (µg/kg)
Trichloroethene	11,000	20,400
cis-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 following is a summary of the remedial objectives that were used for the project.

- Remove NAPLs and dissolved organic compounds from the subsurface within the remediation area to the cleanup levels shown in Table 1.
- Determine the cleanup levels achieved by taking confirmatory soil and groundwater samples. The 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 (EPA 1989). Another criterion was that soil sample concentrations 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.
- Operate the remediation system for a minimum of 15 weeks and use a minimum operating temperature of 84°C.
- Verify that contaminant levels in confirmatory groundwater samples remain below the cleanup goals for at least 24 weeks. If contaminant levels exceeded the cleanup goals within the 24-week period, the subcontractor was required to restart operations.
- Verify that contamination did not spread beyond the remediation area. If contamination had spread, the subcontractor was required to remediate the affected areas at their expense.
- Ensure that operation of the remediation system complied with applicable regulatory requirements at all times.

Remediation Strategy and Activities. The strategy for the remediation was to first establish hydraulic control, then heat the lower clay layer and perimeter, heat the entire area to the target temperature, conduct pressure cycling, and finally to cool the area to allow confirmatory sampling. Remediation operations started in late September 2002 and continued for approximately 5 months.

Hydraulic and pneumatic control was established by liquid and vapor extraction. This was 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. This was done using 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 in depth was generally above 100°C. Pressure cycling and mass removal optimization was 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. By that time, recovery of contaminants was minimal, and heating was stopped. Cooldown and polishing involved continued vapor and liquid extraction combined with air and cold water injection. Cooldown 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, sweep the oily areas, and control vapor. 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 additional energy applied. The temperature data were made available through a project website, where temporal trends and current temperature distributions could be viewed. During the entire operational period, vapor and liquid were extracted continuously from the surface. The extraction well field is shown on Figure 1.

Remediation Components. Construction of the remediation system was completed in late September 2002, and operations began immediately. The components used for in situ thermal remediation of Area A are listed below. The well-field layout was modified between December 2002 and February 2003 in response to high contamination levels that were found in a relatively cool area caused by a lens of resinous material. During that time, twelve additional shallow steam injection wells were installed in the east half of Area A. These were used to improve the steam delivery and heat distribution in this area.

- Fifteen steam injection wells around the perimeter of Area A, 28 extraction wells with ET-DSP electrode wells that were spaced throughout Area A, two deep ET-DSP electrodes located in the clay layer, and 21 combined steam injection and ET-DSP wells. The distribution of these wells is shown in Figure 2.
- Thirty-six temperature-monitoring arrays in boreholes distributed across Area A.
- Eight monitoring wells (in four well pairs) installed outside Area A.
- Five power delivery systems that provided power to the electrodes.

FIGURE 1. Area A remediation components.

- Well field piping for extracted vapors and liquid, and delivery of water for the electrodes and steam for the injection wells.
- An asphalt cap over the entire remediation area that extended 9 m (30 ft) out from the remediation area. The asphalt cap was used to control vapor emissions.
- Steam generation trailer with the capability to generate 6,000 lb per hour of steam.
- A treatment system for the extracted vapors and liquid. The extracted vapors were cooled in multiple knockout tanks before they were treated with granular activated carbon, then polished in another carbon vessel. The extracted liquid was treated in a clarifier, then an air stripper, and finally a series of granular activated carbon vessels.

OTHER PROJECT ASPECTS

Successful completion of the project required consideration of items other than the technical aspects of the remediation. These included interactions among the various parties involved (regulators, DOE, contractor, STAR Center subcontractor, and lower-tier subcontractors), health and safety performance, environmental compliance, waste management, and quality assurance. Roles and responsibilities for the all the parties involved in the project were defined in a management plan (DOE 2002). All major operational decisions were made by the Operations Oversight Team and approved by DOE as appropriate. Members of this team represented S.M. Stoller Corporation, SteamTech, and McMillan-McGee.

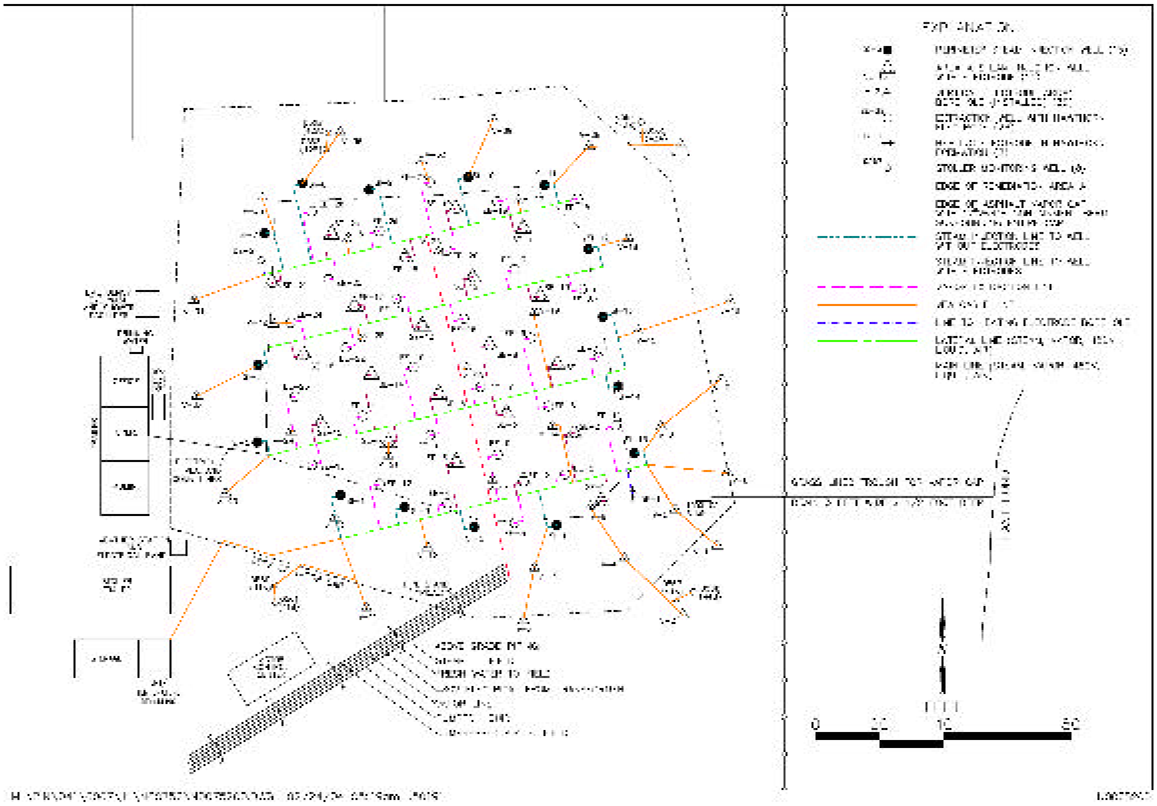

FIGURE 2. Area A site features.

During the project, the health and safety of the workers, the surrounding area, and the community was the primary focus. Ensuring adequate health and safety was a significant challenge because the project dealt with high energy electrical equipment, high temperature steam lines, high concentrations of vapor and liquid phase contaminants, collection of pure-phase chemicals, and operations that continued 24 hours per day, seven days per week. Health and safety procedures were defined in project-specific documents.

Environmental compliance was another critical aspect of the project. The requirements of several permits, such as air and water discharge permits and well permits, affected construction and operations. Management of wastes generated during the project was also a vital aspect. Wastes disposed of included drill cuttings, personal protective equipment, solid wastes, hazardous wastes, well development water, and spent activated carbon. Quality assurance and quality control were also integral to the project completion through the development of procedures and reporting.

RESULTS

The remediation proved to be very successful. There were no accidents or injuries during the remediation, and all 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 maximum contaminant levels (MCLs). Of the 48 groundwater samples collected during three rounds of post-operational sampling, only 10 had contaminant concentrations that exceeded MCLs. In addition, concentrations in groundwater sample did not increase over time after operations stopped. Post-operational soil samples showed similar results; concentrations in all samples were significantly less than cleanup goals. Table 2 compares the concentrations in the post-operational groundwater and soil samples with the groundwater and soil cleanup goals and the groundwater MCLs. Average groundwater and soil concentrations are generally an order of magnitude less than the highest concentrations.

TABLE 2. Comparison of cleanup levels achieved.

Contaminant	TCE	*cis*-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
Highest Groundwater Sample Concentration	29 µg/L	76 µg/L	13 µg/L	38 µg/L	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
Highest Soil Sample Concentration	110 µg/kg	120 µg/kg	8 µg/kg	420 µg/kg	550 mg/kg

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

Another remedial objective that was closely monitored was to evaluate remediation had spread contaminants 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.

LESSONS LEARNED

There were several lessons learned from the project. Some supported the approach that was taken, and some indicated areas where improvements could be made. The following are some of the most significant lessons learned.

- Pressure cycling was an effective technique for maximizing the mass of contaminants removed. During the initial pressure cycles, large spikes in the vapor phase concentrations were observed during the de-pressurization 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→cooldown) 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 at monitoring subsurface temperatures. High dissolved solids concentrations in the groundwater appeared to have made the resistivity effects from temperature not distinguishable.

CONCLUSIONS

This full-scale remediation of a NAPL site was successful from all aspects; outstanding health and safety record, exceeding remedial objectives, compliance with environmental requirements, and good quality. It was the first full-scale remediation of a NAPL site that used a combination of steam-enhanced extraction and electrical resistive heating. The two technologies worked well together in implementing the remediation strategy, as evidenced by cleanup levels attained that were generally 100 times lower than the cleanup goals.

ACKNOWLEDGMENTS

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