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PROJECT OVERVIEW: SUCCESSFUL FIELD-SCALE IN SITU THERMAL NAPL REMEDIATION

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 the Northeast Site on the Young-Rainey Science, Technology, and Research (STAR) Center, Largo, Florida. The Young-Rainey STAR Center is a former DOE facility that was previously known as the Pinellas Plant and the Pinellas STAR Center. The remediation project encompassed an area of 10,000 ft^2 and depths extending to 35 ft below ground surface.

Prior to the remediation, DOE evaluated technologies that had the potential to remove NAPLs from the subsurface at the site. Because of site conditions (clay lenses and an underlying clay layer that were thought to be contaminated), steam injection and electrical heating were considered to be the only technologies that had the potential to remove these NAPLs. In July 2001, DOE's contractor awarded a subcontract for removal of NAPLs from a portion of the Northeast Site. The technologies used for remediation were a combination of steam-enhanced extraction and Electro-Thermal Dynamic Stripping Process, an electrical resistive heating technology.

Construction of the remediation system was completed in September 2002. Remedial operations began immediately after construction, and active heating ended in February 2003. After operations were completed, confirmatory sampling was conducted during a 6-month period to verify the level of cleanup achieved. Additional confirmatory sampling was conducted 18 months after operations ended. Analytical results of the confirmatory 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 Young-Rainey Science, Technology, and Research (STAR) Center, a former U.S. Department of Energy (DOE) facility 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 to address historical DOE operations. Parts of the site are contaminated with organic solvents and metals that were used during the manufacture of neutron generators and other devices. These operations resulted in non-aqueous phase liquids (NAPLs) left in the subsurface. The NAPLs were identified in an area of the former facility known as the Northeast Site. During part of the former facility's operational period, the Northeast Site was used for waste solvent staging and storage and for disposal of construction debris. In 1998, the presence of NAPL contamination was detected in samples collected from two areas at the Northeast Site that were later referred to as Area A and Area B. In both areas, the NAPL was present in light non-aqueous phase liquid (LNAPL) and dense non-aqueous phase liquid

(DNAPL) forms. Subsequently, in situ thermal remediation of NAPLs was conducted at Area A on the Northeast Site.

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 encompassed approximately 10,000 ft^2 and extended from the surface to a depth of 35 ft below ground surface, representing a total cleanup volume of 13,000 yd^3.

Site hydrogeology at Area A consists of 30 ft of alluvium with a surficial, unconfined aquifer underlain by clay of the Hawthorn Group that 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 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 10 to 20 ft per year.

Before remediation, the rough estimate of the mass of contaminants in the subsurface was 2,600 lb of volatile organic compounds and 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, NAPLS likely existed in the top 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 subsurface NAPL contamination at the Northeast Site, the remediation strategy for dissolved constituents 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. Following confirmation of the presence of NAPL contamination, a reevaluation of the remediation strategy (1) concluded that application of a thermal remediation technology, such as steam or electrical 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 to reach remediation standards.

In 2000, DOE’s contractor sent a Request for Proposal that solicited remediation approaches using in situ thermal technologies to prospective bidders. After evaluation of the proposals, a subcontract was awarded to SteamTech Environmental Services (SteamTech). SteamTech 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 both 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 underlying clay layer. McMillan-McGee Corporation was the electrical resistive heating subcontractor; its proprietary electrical resistive heating technology is called Electro-Thermal Dynamic Stripping Process (ET–DSP).

Remedial Objectives. The thermal remediation subcontractor 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

Table 1. Groundwater and Soil Remediation Goals

NAPL Component	Groundwater Remediation Goals (micrograms per liter)	Soil Remediation Goals (micrograms per kilogram)
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

goals were applied to the entire area and the 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. The following remedial objectives were used for the project:

- Remove NAPLs and dissolved organic compounds from the subsurface within the remediation area to the cleanup levels presented in Table 1.
- Determine achieved cleanup levels by confirmatory soil and groundwater samples. The confirmatory sampling was evaluated using a statistical approach that 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.(2) Another criterion was that contaminant concentrations in soil samples could not exceed the cleanup goals by more than 100 percent, and contaminant 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 the subcontractor's 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 controls werel was established by liquid and vapor extractions and were accomplished within a week after the start of operations. Once hydraulic controls were 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 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 approximately 10 feet in depth was generally above 100° C. Pressure cycling and mass removal optimization constituted the next phase. Pressure cycling was achieved by varying the steam injection rates and the ET−DSP power delivery. Mass recovery was highest during depressurization. Pressure cycling continued until mid-February 2003. By that time, recovery of contaminants was minimal, and heating was stopped. Cool down and polishing of the area involved continued vapor and liquid extractions, combined with air and cold water injection. Cool-down temperatures of less than 100^{o} C in all areas were reached in late March 2003, and 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 and heating the lower clay layer; preheating an area with ET−DSP provided a preferential path for steam to flow. An extensive subsurface-temperature monitoring network was used to determine which areas needed additional energy. Temperature data were available on 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 subsurface. Figure 1 shows the extraction well field.

Figure 1. Area A Extraction Well Field

Remediation Components. 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, caused by a lens of resinous material, that were identified in a relatively cool area. During that time, 12 additional shallow steam injection wells were installed in the east half of Area A 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, 2 deep ET–DSP electrodes located in the clay layer, and 21 combined steam injection and ET–DSP wells. Figure 2 presents the well distribution.
- 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.
- Well field piping for extracting vapors and liquid and for delivering water for the electrodes and steam for the injection wells.
- An asphalt cap over the entire remediation area that extended 30 ft beyond 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.

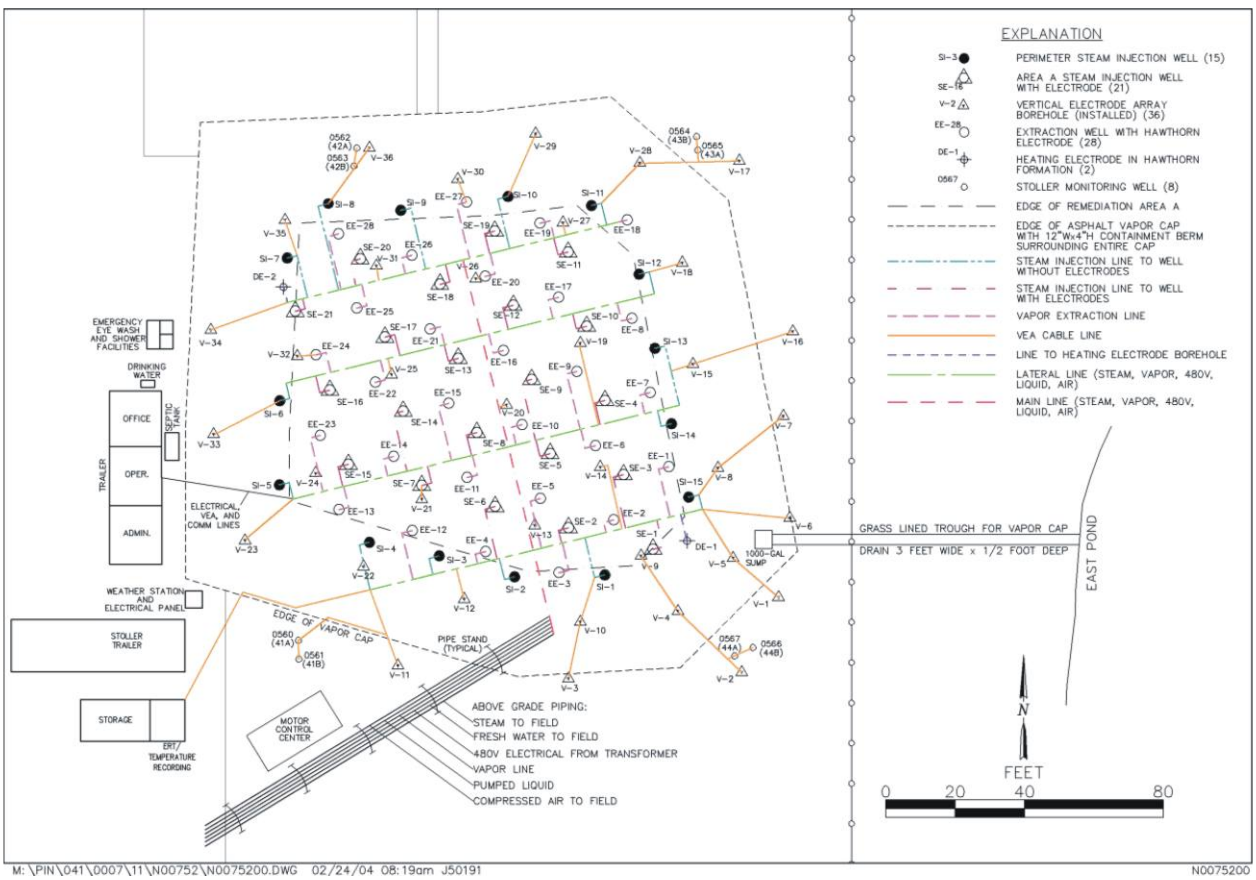

Figure 2. Area A Site Features

OTHER PROJECT ASPECTS

Successful completion of the project required consideration of factors 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 all the parties involved in the project were defined in a management plan.(3) 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 (DOE Technical Assistance Contract contractor), SteamTech, and McMillan-McGee Corporation.

Primary focus areas during the project were the health and safety of the workers, the surrounding area, and the community. 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, 7 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 was very successful. No accidents or injuries occurred 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 samples had contaminant concentrations that exceeded MCLs. In addition, concentrations in groundwater samples 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 presents a comparison of 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.

The mass of volatile contaminants remaining in the subsurface after treatment was estimated to be about 1 lb.(4) 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, which is a much lower treatment efficiency, but it still resulted in concentrations in all samples being significantly below cleanup levels.

Table 2. Comparison of Cleanup Levels Achieved[a]

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

[a]µg/L = micrograms per liter; µg/kg = micrograms per kilogram; mg/kg = milligrams per kilogram.

During operations, the potential spread of contaminants outside the remediation area was closely monitored. Sampling during and after remedial operations showed no evidence of either horizontal or vertical spreading of contaminants. 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.

The subcontract cost of the project was approximately \$3,800,000, or about \$290/yd^3. This cost encompasses all aspects of the project, including design, construction, operations, utilities, waste disposal, dismantlement of the system, and preparation of reports.

LESSONS LEARNED

Several lessons were learned during this project. Some supported the approach that was taken, and some indicated areas where improvements could be made:

- 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 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 at monitoring subsurface temperatures. High dissolved-solids concentrations in the groundwater appeared to have made the resistivity effects from temperature not distinguishable.

CONCLUSIONS

All aspects of this full-scale remediation of a NAPL site were successful: an outstanding health and safety record was established, remedial objectives were exceeded, compliance with environmental requirements was met, and a quality remediation project was achieved. Cleanup of the Northeast Site was the first full-scale remediation of a NAPL-contaminated 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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