THERMAL REMEDIATION services inc.

In-Situ Thermal Remediation of DNAPL using Six-Phase Heating

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Abstract: A demonstration of Six-Phase Heating (SPH) was conducted at Launch Complex 34 in Cape Canaveral, Florida in the Fall/Winter of 1999/2000. Personnel presently working for Thermal Remediation Services, Inc. (TRS) designed and managed the construction and operations of this demonstration while working for Current Environmental Solutions (CES). The purpose of the demonstration was to test the effectiveness of the technology at remediating trichloroethylene (TCE) as a dense non-aqueous phase liquid (DNAPL). The results of the SPH demonstration were a 90% reduction in the total TCE mass and a 97% reduction in the TCE DNAPL mass (Sixth Interim Report 2001).

SPH passes an electrical current through the soil and groundwater that requires treatment. The electrical current warms the soil and then boils a portion of the soil moisture (typically 10-20% by volume) into steam. This *in situ* steam generation occurs in all soil types, regardless of permeability. Electricity evaporates the target contaminant and provides steam as a carrier gas to sweep the volatile organic compounds (VOCs) to recovery wells (SVE wells). After the steam is condensed and the extracted air is cooled to ambient conditions, the vapors are treated using conventional methods. Because *in situ* steam generation is governed by the passage of electrical current - not the flow of a fluid - SPH remediation is not significantly effected by low permeability or heterogeneous soils. It is equally effective above or below the water table.

A series of site investigations between 1996-1999 identified TCE DNAPL in the groundwater, a part of which was underneath the Engineering Science Building (ESB), at Launch Complex 34, Cape Canaveral, Florida (LC34). This discovery led to the final selection of the LC34 site for a DNAPL remediation technology demonstration by the Interagency DNAPL Consortium (IDC). The member agencies of the IDC consisted of the Department of Energy, Department of Defense, NASA, Air Force, and the Environmental Protection Agency. Florida State University provided on-site coordination support.

A surficial aquifer exists at the LC34 site from 5 to 45 ft below ground surface (bgs). This aquifer consists of silt, sand, and shell material. The surficial aquifer is composed of three stratigraphic units: an upper sand unit (USU), a middle fine-grained unit (MFGU), and a lower sand unit (LSU). A lower clay unit (CU) acts as the aquitard that retards downward DNAPL migration. Another aquifer exists below the CU. Although water levels indicate the presence of a slight mound under the ESB, the hydraulic

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gradient is low in the demonstration area, suggesting slow groundwater flow. Infiltration of precipitation to the surficial aquifer is rapid. The groundwater has high salinity and total dissolved solids, which increase with depth. The aquifer in the DNAPL source area is mostly anaerobic. Microbiological conditions are poor in the source area, but improve toward the fringes of the source zone.

Setup for the SPH demonstration occurred between July 29 and August 18, 1999. SPH operations occurred between August 18, 1999 and July 12, 2000. Several interruptions occurred during operations including storm weather events and rocket launches. During startup and operations, the SPH system was monitored to ensure safe movement of personnel above ground; grounding of the electrodes was found to have successfully isolated the ground surface from the electrical voltage below.

The SPH design included preferentially heating the deep sections of the site (the MFGU and CU) first and then sweeping TCE upwards into the vadose zone. Once in the vadose zone, extraction wells captured the TCE vapors and routed them to the vapor treatment system. This sequence of site heating was selected as providing the greatest assurance that TCE would not migrate downward through the CU and into the underlying deep aquifer during heating. By October 1999, heating in the MFGU and CU had started volatilizing DNAPL and significant quantities of TCE had been lifted to the top of the water table.

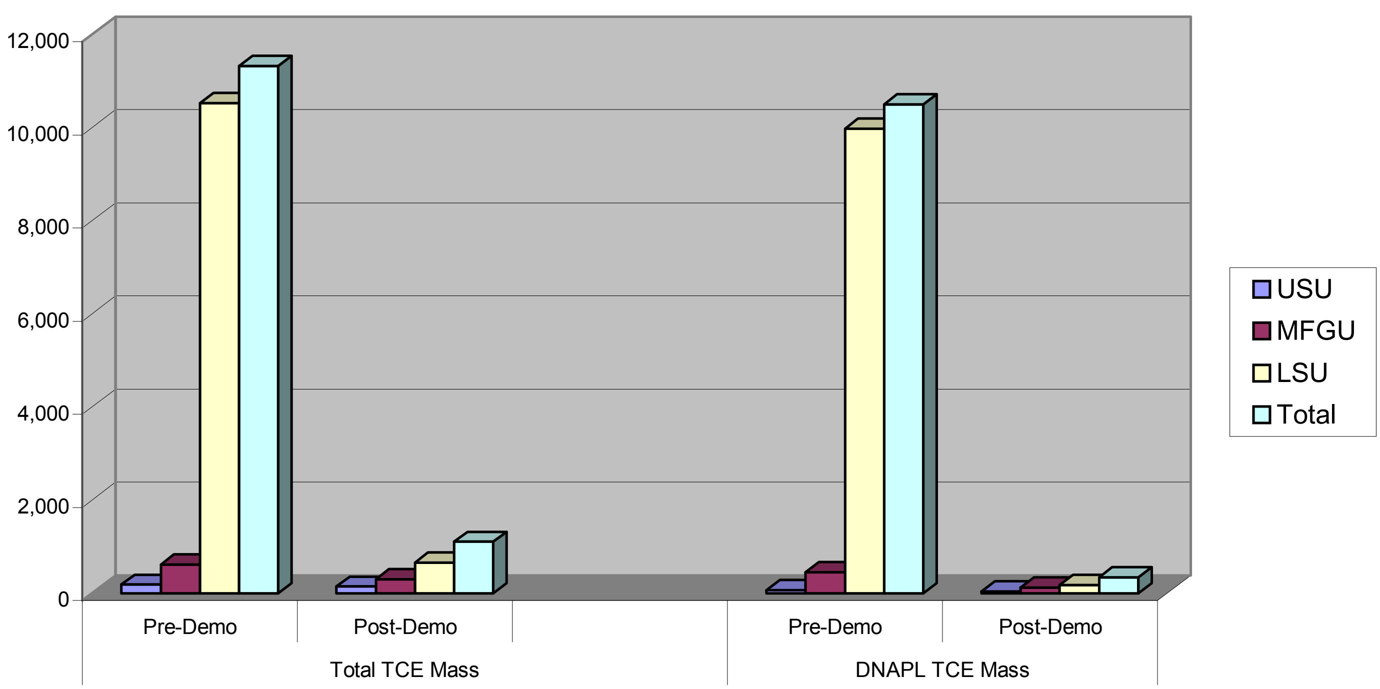
Two intense hurricanes led to the SPH power being turned off on September 30, 1999. At the time of the shut down, the aquifer had been heated to between 47°C on top (near the water table) and 92°C at the bottom (near the aquitard). Water levels throughout the site increased by almost 5 ft in less than two weeks, as indicated by continuous water level recorders installed for performance assessment in select monitoring wells at LC34.

An unanticipated consequence of the unusually high rainfall during the multiple hurricane and storm events was that the vadose zone virtually disappeared as water levels rose almost to the ground surface, especially near local topographic lows, such as near the SPH plot and the ditch on its west side. The SVE system in the vadose zone of the SPH plot was submerged. A surface plenum with vapor extraction points was installed to better capture CVOC vapors. SPH was restarted on December 16, 1999 and operated continuously until March 24, 2000. During this heat application period, temperatures rose from 39°C and 75°C at the top and bottom of the aquifer to 100°C and 124°C, respectively. At the depths and pressures involved, these are equivalent to boiling temperatures for water. Significant TCE mass (about 2,500 lbs) was recovered in the vapor extraction system during this period. The power transformer that had been procured for a specified period had to be returned and power was turned off on March 24, 2000 to replace the transformer. Rocket launch dates and transformer replacement delays resulted in power being shut down until May 11, 2000, when heat application was restarted.

The two monitoring well clusters inside the SPH plot were monitored until October 1999, after which debris was discovered in the wells and the screens could not be accessed. On May 10, 2000, the interruption in the SPH system operation allowed the wells to be flushed clean. Until the wells got clogged in October 1999, monitoring in the wells showed significant decline in TCE concentrations. Monitoring of TCE concentrations in the SPH vapor recovery system showed significant levels of TCE recovery aboveground, especially during the second heat application from December 1999 to March 2000.

Because of the relatively large mass and contiguous distribution of DNAPL at LC34 observed during the pre-demonstration characterization, soil sampling was used as the primary indicator of the degree of DNAPL removal from the SPH demonstration. Based on the pre-demonstration TCE concentrations in soil, there was 11,313,kg of TCE identified in the SPH plot, and 10,490 kg of this was DNAPL. Following SPH treatment, the soil data indicate that there was 1,101 kg of TCE remaining in the plot, and 338 kg of this was DNAPL. Table 1 represents total TCE Mass and DNAPL reductions of 90% and 97%, respectively (Sixth Interim Report 2001).

Table 1. SPH Demo Results: TCE Reduction (kg)



Reference

Sixth Interim Report (February 12, 2001), Battelle Columbus, Ohio, *IDC's Demonstration of Three Remediation Technologies at LC34, Cape Canaveral Air Station, FL*, p5.