APPENDIX B

Case Studies

Presented herein are case studies, organized by the ISTR technology applied at each location. Some applications are better documented than others due to a lack of available information at the time this Appendix was compiled. Dynamic underground stripping case studies are included with SEE case studies. Case studies for Skokie, Illinois are presented under both SEE and ERH, since both technologies were applied sequentially at this site. The case studies do not cover every application of ISTR, but are provided to illustrate the variety of applications that have been undertaken.

B.1. Thermal Conductive Heating.

B.1.1. *Former Mare Island Naval Shipyard*.

Project Name:	Former Mare Island Naval Shipyard Bay Area Defense Conversion Action Team (BADCAT)
Location:	Vallejo, CA
Contaminants:	PCB – Aroclor 1254 and 1260 – maximum concentration of 2200 mg/kg
Regulatory Program:	Navy Environmental Quality R&D Requirement
Remediation Scale:	Demonstration Pilot Test
Site Owner:	U.S. Navy
Consultant:	Tetra Tech EM, Inc.
Project Duration:	September – December 1997

B.1.1.1. *Site Information.* The site was a 46.5 m^2 (500 ft^2) area adjacent to a former electric shop located within the Mare Island Naval Complex.

B.1.1.2. *Hydrogeology*. Fill and clay units overlying a siltstone/fine-grained sandstone. The Remedial Investigation report suggested that groundwater fluctuated seasonally from 4.57 to 7.62 m (15 to 25 ft) below ground surface (bgs), well below the target treatment zone (i.e., the fill unit).

B.1.1.3. *Remediation Objectives.* Demonstration of In Situ Thermal Desorption (ISTD) to remove and destroy PCBs from soils in situ. The cleanup goal was 2 ppm as prescribed by USEPA regulations at 40 CFR Part 761. Site-specific objectives were set in consultation with the Remediation Advisory Board (RAB) at less than 1.0 ppm. Target soil treatment temperatures were established of 316°C (600°F) at the centroids between the thermal wells (i.e., at the coldest regions). The particulate emissions rate could not exceed 2.83 grains/dry standard cubic meter (0.08 grains/dry standard cubic foot), corrected to 7% oxygen, using the procedure given in 40 CFR 264.343 (c). The HCl emissions could not exceed the greater quantity of 1.81 kg/hr (4.0 lb/hr).

B.1.1.4. *Approach*. The Thermal Well demonstration was conducted using a network of 12 heater-vacuum wells drilled to a depth of 4.27 m (14 ft). The Thermal Blanket test was conducted using two adjacent 2.44 by 6.1 m (8 by 20 ft) heating units, and treated soils to a depth of 30.48 cm (12 in.) over a period of 7 days.

B.1.1.5. *Operation*. Mobilization to the site in July 1997. Site construction was performed from July 1997 through September 1997. Thermal treatment was started in September 1997 and was completed in November 1997. Demobilization was completed by mid-December 1997.

B.1.1.6**.** *Results*. After reaching an in-situ soil temperature of at least 316°C (600°F) over a treatment period of 37 days, all post-treatment soil samples collected exhibited non-detectable Total PCB concentrations (less than 0.033 mg/kg). Prior to de-energizing the heater elements, the average soil temperature at the centroid of each thermal well pattern and at the base of each thermal blanket treatment cell exceeded 316°C (600°F). The emission rate limit of 1.81 kg/hr (4.0 lb/hr) was not exceeded during the demonstrations.

B.1.1.7. *Cost*. The total demonstration cost for design, permitting, operation, demobilization, and reporting was $912,500. Unit costs were not available.

B.1.1.8. *References*.

Conley, D.M., and K. Jenkins. 1998. "Application of ISTD to Remediate PCBs from Soil at the Former Mare Island Naval Shipyard, Vallejo, CA." Presented at the 3rd Annual Tri-Service Conference, San Diego, CA., August 15-17, 1998.

Naval Facilities Engineering Service Center. 1998. Tech Data Sheet: A Demonstration of In-Situ Thermal Desorption. TDS-2051-ENV, March 1998. Port Hueneme, CA.

TerraTherm Environmental Services Inc. and RT Environmental Services, Inc. 1998. Final Report for Environmental Technology Partnership (ETP) Demonstrations IN-SITU THERMAL DESORPTION. Prepared for U.S. Navy and Bay Area Defense Conversion Action Team (BADCAT). October.

B.1.2. *Naval Facility Centerville Beach.*

Project Name:	Naval Facility Centerville Beach
Location:	Ferndale, CA
Contaminants:	• PCB – Aroclor 1254 - contamination ranging from 0.15 ppm to 860 ppm; • PCDD/Fs – up to 3.2 ppb 2,3,7,8-TCDD Toxicity Equivalents (TEQ).
Regulatory Program:	RCRA Corrective Action
Remediation Scale:	Full Scale
Site Owner:	U.S. Navy
Consultant:	Tetra Tech EM, Inc.
Project Duration:	September 1998 – April 1999

B.1.2.1. *Site Information.* The site was located on a 12.1-hectare (30-acre) military base used for oceanographic research and undersea surveillance that was decommissioned in 1993. The site consisted of an area measuring 12.2 ×9.14 m (40 ×30 ft) x 4.57 m (15 ft) deep (for overall volume of 510 m^3 or 667 cy), with the contaminated soils under/adjacent to a former transformer/diesel generator building. The contamination under the building extended from 0.61 - 4.57 m (2.0 - 15 ft) below ground surface (bgs). PCBs outside the building occurred from 1.52 - 4.57 m (5 - 15 ft) bgs.

B.1.2.2. *Hydrogeology.* Unsaturated, silty and clayey colluvial soils. Groundwater was encountered at depths greater than 18.3 m (60 ft).

B.1.2.3. *Remediation Objectives.* Average PCB concentration of 1 ppm or lower; Dioxins and Furans (PCDD/Fs): Total 2,3,7,8-TCDD TEQ < 1.0 ppb.

B.1.2.4. *Approach.* Heat subsurface using a 3:1 ratio of heater-only to heater-vacuum thermal wells. Fifty-seven wells were installed using standard drilling techniques on a grid of equilateral triangles spaced 1.82 m (6 ft) apart forming a hexagonal pattern. The heater-vacuum wells were located at the center of each hexagonal pattern of heater-only wells, with a resulting spacing between heater-vacuum wells of approximately 3 m (10 ft). Target treatment temperatures at centroids between wells (coolest regions) were 450°C (840°F). Treatment gases removed from the subsurface by the heater-vacuum wells were treated using a flameless thermal oxidizer and granular activated carbon before being discharged to the atmosphere.

B.1.2.5. *Operations.* Mobilization to the site in September 1998. Construction September through October 1998. Treatment between November 1998 and January 1999. Interim soil sampling and shut down occurred in February 1999. Final Confirmation sampling was conducted in early April 1999.

B.1.2.6. *Results.* Target treatment area achieved the remedial objectives for all samples. The temperature in the center of the well patterns ranged from 357°C (2.1 m bgs) to 510°C (4.57 m bgs) (675 to 950°F). CO emissions were below 10 ppmV with a 3-minute lag throughout the soil treatment, and a mean concentration of approximately 2 ppmV. Carbon dioxide (CO_2) emissions were recorded by the CEM system and were observed generally at <2.0%. Total hydrocarbon (THC) readings observed during the treatment were generally below 10 ppmV or <0.0023 kg/hr (0.005 lb/hr) as CH_4. An in-situ destruction and removal efficiency (DRE) of two-nines (99%) plus the four-nines DRE of the air quality control unit resulted in a combined DRE of approximately six-nines (99.9999%),

B.1.2.7. *Cost.* The total turnkey cost for design, permitting, operation, demobilization, and reporting was $456,000 or approximately $890/$m^3$ ($680/cy).

B.1.2.8. *References.*

Conley, D.M., and C.M. Lonie. 2000. "Field Scale Implementation of In Situ Thermal Desorption Thermal Well Technology." pp. 175-182. In: G.D. Wickramanayake and A.R. Gavaskar (eds.) *Physical and Thermal Technologies: Remediation of Chlorinated and Recalcitrant Compounds*. Battelle Press, Columbus, OH.

TerraTherm Environmental Services. (November, 1999). *Naval Facility Centerville Beach, Technology Demonstration Report: In-Situ Thermal Desorption (ISTD)*, Prepared for U.S. Department of the Navy, Engineering Facility Activity – West, San Bruno, California.

B.1.3. *Former Shell Bulk Storage Terminal*.

Project Name:	Former Shell Bulk Storage Terminal
Location:	Eugene, OR
Contaminants:	• Benzene (1200 µg/L in groundwater) • Gasoline Range Organics (GRO; 3500 mg/kg in soil) • Diesel Range Organics (DRO; 9300 mg/kg in soil) • NAPL (Free Product): thickness ranged from trace to ~1 m
Regulatory Program:	Oregon Department of Environmental Quality
Remediation Scale:	Full Scale
Site Owner:	Shell Oil Products Company
Consultant:	Hart Crowser, Inc.
Project Duration:	June 1997 – September 1998

B.1.3.1. *Site Information*. The site was a 0.40-hectare (1-acre) site with buildings adjacent to railroad tracks in a residential and light commercial area of Eugene, Oregon. The site was a former bulk storage facility for middle and heavy hydrocarbon distillates. The remedial action was designed to enable closure under the Risk Based Corrective Action (RBCA) Underground Storage Tank (UST) program with the Oregon Dept. of Environmental Quality (ODEQ).

B.1.3.2. *Hydrogeology*. The geology consisted primarily of consolidated and semi-consolidated, marine and non-marine sediments overlain by unconsolidated alluvium. A gravel layer covers the surface of the site to a depth of 0.30 to 1.22 m bgs. A silt layer underlies the gravel and extends to approximately 3.35 to 4.88 m bgs. A second hydraulically permeable layer (4.76×10^{-2} cm/s) consisting of gravels in a sand to clay matrix was present beneath the impermeable (9.53×10^{-6} cm/s) silt layer. Two water-bearing zones are identified at the site. Perched groundwater was encountered in the unconfined top gravel and silt layers. A confined groundwater zone was present in the lower gravel layer.

B.1.3.3. *Remediation Objectives.* Remove free product (light non-aqueous phase liquid [LNAPL]) and smear zone hydrocarbons present in soils to a depth of 12 ft, attain groundwater cleanup standards in down-gradient areas, and enable closure of the site under RBCA UST program with ODEQ through the application of the thermal well technology.

B.1.3.4. *Approach.* Installation of 277 heater-vacuum wells and 484 heater-only wells to treat approximately 11,430 m^3 (14,950 cy). The thermal wells were spaced on 2.13 m (7.0 ft) centers and installed to a depth of 3.05 - 3.66 m (10.0 - 12.0 ft) bgs.

B.1.3.5. *Operations.* Site construction was performed from Sept 1997 through May 1998. Thermal treatment lasted 120 days from June through August 1998. Confirmatory soil samples were collected between September and October 1998. Demobilization was completed by early Oct. 1998. Post-remediation groundwater samples were collected quarterly between December 1998 and September 1999 from monitoring wells located within and down gradient of the treatment area. Site characterization efforts indicated that the treatment zone was below the water table. A two-phase approach was used to reduce the amount of water in the treatment zone at the start of thermal treatment, as well as to limit the influence of recharge both from the surface and from outside the treatment area. First, the heater-vacuum wells were equipped with ports at the top of the wells to allow for the removal of liquid before the commencement of thermal operation. This allowed for the removal of 970,000 L (257,000 gal.) from the treatment zone. Groundwater flow into the treatment area during operations was controlled through a set of 39 perimeter wells screened from 4.3 to 4.6 m (14 to 15 ft) bgs. The perimeter groundwater control system depressed the water level by an estimated 1.2 m (4 ft) during operation and removed approximately 5.7×10^6 liters (1.5×10^6 gallons) of water over a seven-month period (December 1997 - July 1998).

B.1.3.6. *Results.* The thermal well system achieved an average in-situ temperature of approximately 282°C (540°F). An estimated 200,000 lb of hydrocarbons were removed and treated during the 120-day heating cycle. The LNAPL was removed from the entire site. All confirmation (post-remediation) soil and groundwater samples were below the DEQ's Tier 1 Risk-Based Concentrations for both soil and groundwater exposure pathways. Benzene concentrations in groundwater within the treatment area were reduced from 1200 to 2.14 ug/L. All post-treatment off-site groundwater samples were below the analytical detection limit (i.e., <0.5 ug/L). The Oregon DEQ issued a "no further action" letter for the site in March 2000.

B.1.3.7. *Cost.* The total turnkey cost for design, permitting, operation, demobilization, and reporting was $2,971,000 or approximately $260/$m^3$ ($200/cy).

B.1.3.8. *References.*

Conley, D.M., K.S. Hansen, G.L. Stegemeier, H.J. Vinegar, F.R. Fossati, F.G. Carl, and H.F. Clough. 2000. "In Situ Thermal Desorption of Refined Petroleum Hydrocarbons from Saturated Soil." pp. 197-206. In: G.D. Wickramanayake and A.R. Gavaskar (eds.) *Physical and Thermal Technologies: Remediation of Chlorinated and Recalcitrant Compounds*. Battelle Press, Columbus, OH.

B.1.4. *Cholorinated Solvents - Manufacturing Facility.*

Project Name:	Chlorinated Solvents – Manufacturing Facility
Location:	Portland, Indiana
Contaminants: (pre-treatment concentrations)	• Tetrachloroethylene (3,500 mg/kg) • *cis*-1,2-Dichloroethylene (39 mg/kg) • Trichloroethylene (79 mg/kg)
Regulatory Program:	Indiana Department of Environmental Management, Voluntary Remedial Program
Remediation Scale:	Full Scale
Site Owner:	Private – Voluntary Cleanup
Consultant:	None
Project Duration:	July - December, 1997

B.1.4.1. *Site Information.* The site was an operating manufacturing facility with contaminants in two locations on the property, one of which ran alongside the building.

B.1.4.2. *Remediation Objectives.* 8 mg/kg for tetrachloroethylene; 25 mg/kg for trichloroethylene; and 0.08 mg/kg for *cis*-1,2-dichloroethylene.

B.1.4.3. *Hydrogeology.* There was wide variation in the permeabilities across the site, from tight clays to high permeability fill above the target zone. The fill was a combination of sand, clayey sand, gravel, and construction debris. The next layer was described as till, which consisted of moist to damp silty clay that ranged from brown to gray in color and extended down to depths of 5.5 to 5.8 m (18 to 19 ft) below ground surface (bgs). Running through some parts of the till were seams of sand that could become saturated during the wetter periods of the year. Below the tills was a sand and gravel layer, consisting of some sand ranging from fine to coarse, with some areas of gravel locally. Groundwater was encountered in the sand and gravel layer at depths of 6.7 - 7.6 m (22–25 ft). The groundwater was not impacted by the vadose-zone contamination.

B.1.4.4. *Approach.* Two areas were treated. The first area had 15 heater-vacuum wells that were each 3.66 m (12 ft) deep. The second are had 130 heater-vacuum wells that extended 5.8 m (19 ft) into the subsurface. Secondary and tertiary treatment was accomplished using a flameless thermal oxidizer and a carbon bed, both of which were situated on a process trailer.

B.1.4.5. *Operations.* The process was run for approximately nine weeks.

B.1.4.6. *Results.* The remediation goals were achieved for tetrachloroethylene, trichloroethylene, and *cis*-1,2-dichloroethylene. All soil samples were below 0.5 mg/kg, 0.057 mg/kg, and 0.2 mg/kg for PCE, *cis*-1,2-DCE, and TCE, respectively. The southern part of the well field reached 260^{o}C (500^{o}F), but influx of water in the northern part of the field limited the temperature to 100^{o}C (212^{o}F). Steam stripping, however, caused the removal of the

contaminants in the northern end and the remediation goals were met in spite of not superheating the soil in that area.

B.1.4.7. *Cost.* Not available.

B.1.4.8. *Reference.*

Vinegar, H.J., G.L. Stegemeier, F.G. Carl, J.D. Stevenson, and R.J. Dudley. 1999. "In Situ Thermal Desorption of Soils Impacted with Chlorinated Solvents." *Proceedings of the Annual Meetings of the Air and Waste Management Association*, Paper No. 99-450.

B.1.5. *Missouri Electric Works Site.*

Project Name:	Missouri Electric Works Site (MEW)
Location:	Cape Girardeau, MO
Contaminants:	PCB Aroclor 1260 – NAPL
Regulatory Program:	CERCLA
Remediation Scale:	Demonstration Pilot Scale
Site Owner:	MEW Site Trust Fund Donors
Consultant:	Sverdrup, Inc.
Project Duration:	March – June, 1997

B.1.5.1. *Site Information.* Missouri Electric Works previously sold, serviced, and remanufactured transformers, electric motors, and electrical equipment. The MEW site included all areas on and off the MEW property that had been impacted with PCBs above the action limits of 10 ppm from 0 to 1.22 m (0 to 4 ft) deep and 100 ppm below 1.22 m (4 ft) deep. It was located on a 2.59-hectare (6.4-acre) tract adjacent to Highway 61 in a commercial/light industrial area. Additional soil was contaminated in adjacent off site areas.

B.1.5.2. *Hydrogeology.* The MEW site is underlain by a weathered and unweathered loess that sits on Ordovician-aged sedimentary formations. The surficial loess deposits are typically brown, firm, silty clays. The shallow water-bearing zone occurs between 9.14 and 18.29 m (30 and 60 ft) below ground surface (bgs).

B.1.5.3. *Remediation Objectives.* Demonstration of TerraTherm's ISTD process through the application of thermal wells and blankets to achieve a clean-up goal for PCBs of 2 ppm.

B.1.5.4. *Approach.* Installation of 12 heater-vacuum wells in a triangular pattern spaced on 1.52-m (5-ft) centers. Wells were installed to a depth of 12 ft. To account for heat losses out of the top and the bottom of the system the bottom 0.61 m (2 ft) and top 0.3048 m (1 ft) of the heaters were run with a 57% higher power input. Application of two thermal blankets was used to treat contaminated soil to a depth of 45.7 cm (18 in.), and the demonstration of an ex-situ blanket application for stockpiled soil.

B.1.5.5. *Operations.* Mobilization to the site took place in March '97, with site construction beginning during the same month. Thermal treatment lasted from 10 - 45 days, depending on the

thermal configuration for the three different processes, and was completed in June '97. Demobilization from the site was in July '97.

B.1.5.6. *Results.* All clean-up goals were met for the thermal well and thermal blanket applications and pertinent information was produced for the continued development of the ISTD ex-situ operations. PCBs were reduced from a maximum concentration of about 20,000 ppm and a mean concentration of 782 ppm (n = 88) to less than 2 mg/kg in all 90 post-treatment samples within the treatment zone. PCB concentrations were non-detect (<0.033 ppm) in 84 of the post-treatment soil samples and less than 0.302 mg/kg in the 6 soil samples with detectable levels. Stack testing showed 99.9999998% Destruction and Removal Efficiency (DRE). Continuous emission monitoring (CEM) showed the average stack composition contained about 20,000 ppm CO_2, 2 ppm CO, and 1 ppm THC. The peak HCl concentration in the stack was 60 ppm from the decomposition of the PCBs. All emissions standards were met during the project. There was no evidence of horizontal or vertical contaminant migration. Dioxins in treated soil were below background level for North American soil (< 6 ppt). A soil temperature of 482°C (900°F) was reached in the center of all of the triangular patterns, with the very center of the entire pattern reaching a temperature of 593°C (1100°F). A comparison of pre- and post-treatment soil hydraulic characteristics indicated that the soil porosity increased from 30 to 40% and the horizontal and vertical hydraulic conductivities increased by over 4 orders of magnitude (e.g., 1×10^{-3} to 30 m/d) following treatment.

B.1.5.7. *Cost.* The total demonstration cost for design, permitting, operation, demobilization, and reporting was reported to be $2,038,000. Unit costs were not available.

B.1.5.8. *References.*

Vinegar, H.J., E.P. deRouffignac, R.L. Rosen, G.L Stegemeier, M.M. Bonn, D.M. Conley, S.H. Phillips, J.M Hirsch, F.G. Carl, J.R. Steed, D.H. Arrington, P.T. Brunette, W.M. Mueller, and T.E. Siedhoff. 1997. "In Situ Thermal Desorption (ISTD) of PCBs", *Proceedings of the HazWaste/World Superfund XVIII Conference*, Washington, DC, December 2, 1997.

Haley & Aldrich (Nov., 1997). *Demonstration Test Report-Thermal Wells, Missouri Electric Works Site, Cape Girardeau, Missouri*. Submitted to Mr. Hiroshi Dodohara, Permit Officer, USEPA Office of Pollution Prevention & Toxics (OPPT), Washington, D.C. Haley & Aldrich of New York, Inc.

Haley & Aldrich, Inc. (October, 1997). *Demonstration Test Report – Thermal Blanket. In-Situ Thermal Desorption Technology, Missouri Electric Works Site, Cape Girardeau, Missouri*, Prepared for TerraTherm Environmental Services, Inc.

France–Isetts, P. 1998. "In Situ Thermal Blankets and Wells for PCB Removal in Tight Clay Soils," *Tech Trends*, EPA Region 7. (February, 1998). Available at: http://clu-in.org/products/newsltrs/TTREND/tt0298.htm.

B.1.6. *Tanapag Village Site Remediation.*

Project Name:	Tanapag Village Site Remediation
Location:	Tanapag Village, Saipan, NMI (Western Pacific)
Contaminants:	Polychlorinated Biphenyls (PCBs) – Aroclors 1254 and 1260, average concentration 500 ppm, individual samples in excess of 10,000 ppm.
Regulatory Program:	
Remediation Scale:	Full Scale
Site Owner:	US Army Corps of Engineers
Consultant:	Environmental Chemicals Corporation
Project Duration:	July 1997 – August 1998

B.1.6.1. *Site Information.* A site with an area of approximately 1,858 m^2 (20,000 ft^2) was designated as the area for the staging of stockpiled soils, and the installation of TerraTherm's treatment cells and associated batch process equipment.

B.1.6.2. *Hydrogeology.* The treated soils were gathered from multiple sites on the island of Saipan. Soils consisted of silty sands and crushed coral. There was no groundwater impact during project duration. Stockpiled soils and treatment cell were subjected, however, to surface-level water saturation due to five typhoons and additional seasonal rainstorms.

B.1.6.3. *Remediation Objectives.* Ex-situ treatment of 765 m^3 (1000 cy) of PCB-contaminated soil through the application of thermal blankets to achieve cleanup criteria of 10 ppm.

B.1.6.4. *Approach.* Construction of four treatment cells to accommodate the placement of seven (7) thermal blankets each - soil was simultaneously placed in two (2) treatment cells and thermally treated. Each cell was sized to handle approximately 30.6 - 34.4 m^3 (40–45 cy) each. Treatment cells consisted of a thermal blanket beneath and another above each batch of soil.

B.1.6.5. *Operations.* Mobilization to the site occurred in July 1997. Site construction was performed from July 1997 through August 1997. Thermal treatment began in September 1997 and was completed in August 1998. Demobilization was complete by the end of September 1998.

B.1.6.6. *Results.* 765 m^3 (1000 cy) of PCB impacted soil was treated to 10 ppm or less. The project received a 1998 Merit Award from the US Army Corps of Engineers Chief of Engineers Design and Environmental Awards Program.

B.1.6.7. *Cost.* The total turnkey cost for design, permitting, operation, demobilization, and reporting was $2,805,000.

B.1.7. *Former Wood Treatment Area.*

Project Name:	Former Wood Treatment Area – AOC-2
Location:	Alhambra, CA
Contaminants:	• Polyaromatic hydrocarbons (PAHs) • Pentachlorophenol (PCP) • Dioxins and Furans • Petroleum Hydrocarbons
Regulatory Program:	California Department of Toxic Substances Control – Expedited Remedial Action Program
Remediation Scale:	Full Scale
Site Owner:	Southern California Edison
Consultant:	None
Project Duration:	Ongoing: May 2002 – March 2003

B.1.7.1. *Site Information.* Southern California Edison's (SCE) Alhambra Combined Facility occupies approximately 33 acres and is currently used for storage, maintenance, and employee training. The former wood treatment area (AOC-2) occupies a 0.81-hectare (2-acre) portion of the western third of the site. Wood treatment occurred at the area from approximately 1921 to 1957. The total treatment volume is approximately 11,500 m^3 (15,000 cy) of vadose zone soil. The treatment area includes a variety of buried subsurface features, including treatment tanks, the structural remains of the former boiler house and tank farm, and various buried utilities.

B.1.7.2. *Hydrogeology.* Soils within the treatment area are comprised of surficial fill and silty sands, inter-bedded with sands, silts, and clays. The average treatment depth is approximately 6.1 m (20 ft) below ground surface (bgs) and in some areas extends to 27.4 m (90 ft) bgs. The depth to the water table is 82.3 m (270 ft) bgs.

B.1.7.3. *Remediation Objectives.* The soil remediation standards for PAHs (expressed as Benzo(a)pyrene toxic equivalents), PCP, and dioxins (expressed as 2,3,7,8-tetrachloro-dibenzodioxin [TCDD] Toxic Equivalency [TEQ]), are 0.065 mg/kg, 2.5 mg/kg, and 1 µg/kg, respectively.

B.1.7.4. *Approach.* Using a 3:1 edge-centered hexagonal pattern with 2.13 m (7.0 ft) well spacing, a minimum target temperature of 325°C will be maintained for 3 days; 780 total wells will be used, with 128 of them being heater-vacuum wells, and the other 652 being heater-only wells. In-situ thermal oxidation and pyrolysis are predicted to result in an in-situ destruction efficiency of between 95 and 99%, with the remaining contamination being treated aboveground. The off-gas treatment will consist of a thermal oxidizer, heat exchanger, and granular activated carbon (GAC). The estimated dioxin emission rate calculated for the air discharge permit is 0.311 billionths of a kg (0.685 billionths of a lb) TCDD TEQ/hr. This is equal to 0.896

millionths of a kg (1.97 millionths of a lb) TCDD TEQ over the 120-day life of this project. This is a very low amount and less than one-thousandth of the annual TCDD TEQ emission from a typical hazardous waste incinerator. California's Department of Toxic Substances Control is overseeing the project, which is being conducted under California's Expedited Remedial Action Program (ERAP).

B.1.7.5. *Operations.* Two phases of operation. Simulation predicted 60 to 70-day heating time per phase; 90 days per phase allotted.

B.1.7.6. *Cost.* The total turnkey cost for design, permitting, operation, demobilization, and reporting is projected to be $5,343,500 or approximately $480/$m^3$ ($370/cy).

B.2. Electrical Resistivity Heating.

B.2.1. *Thermal Treatment of Viscous Specialty Fuel.*

Project Name:	Thermal treatment of viscous specialty fuel
Location:	Atlanta, Georgia
Contaminants:	Viscous specialty fuel comprised of jet and diesel fuels
Regulatory Program:	
Remediation Scale:	Full Scale
Site Owner:	
Consultant:	Brown & Caldwell
Project Duration:	December 1999 to November 2000

B.2.1.1. *Site Information.* Viscous specialty fuel released to soil and groundwater largely beneath a manufacturing facility.

B.2.1.2. *Hydrogeology.* Structural fill with moderate permeability beneath a large manufacturing building, underlain by candy clay saprolite with low permeability. Groundwater at 24 ft bgs.

B.2.1.3. *Remediation Objectives.* Reduce LNAPL thickness from 10 ft to less that $^1/_8$ inch on the water table.

B.2.1.4. *Approach.* ERH operating in a six phase mode was used to treat the soils at this site. Vapors recovered and treated by thermal oxidation.

B.2.1.5. *Operation.* 14 to 16 weeks

B.2.1.6. *Cost.* $223/ yd^3.

B.2.2. *Lucent Technologies.*

Project Name:	Lucent Technologies
Location:	Skokie, Illinois
Contaminants:	Trichloroethene, 1,1,1-trichloroethane and associated biodegradation and hydrolysis daughter compounds
Regulatory Program:	Illinois Site Remediation Program
Remediation Scale:	Full Scale
Site Owner:	Lucent Technologies
Consultant:	ENSR
Project Duration:	June 1998 to April 1999

B.2.2.1. *Site Information.* Site was a former Teletype manufacturing facility closed after the breakup of the Bell System in 1984. TCE and TCA were discovered beneath the plant floor with DNAPL measured as thick as 8 ft in several monitoring wells. A combination SEE and enhanced biodegradation system had been in operation from 1991 to 1998, and was successful in removing DNAPL and securing a no further remediation letter from Illinois EPA for a portion of the treatment area. The areas to be treated using ERH had limited success using SEE due to manmade subsurface features short-circuiting the steam injection.

B.2.2.2. *Hydrogeology.* Site lithology consists of heterogeneous silts to 18 ft bgs and a dense silty clay till from 18 - 25 feet bgs. The groundwater table was at 7 ft bgs and hydraulic conductivity through the remediation zone ranges from10^{-4} to 10^{-8} cm/s. At the start of SPH, most of the remaining solvent mass was pooled on top of the clay till at 18 - 20 feet bgs.

B.2.2.3. *Remediation Objectives.* Reduce concentrations of organic compounds below site specific Tier 3 criteria. Lucent modified this goal to treat to concentrations that after the system was turned off, and intrinsic biodegradation became the dominant fate of the residual organic compounds, rebound would not exceed levels of concern.

B.2.2.4. *Approach.* A network of 107 SPH electrodes was installed covering just over an acre. To treat directly beneath the plant, 85 of those electrodes were constructed directly through the floor of the building. The electrically conductive zone was from 11 - 21 ft bgs resulting in the ERH electrodes actively heated the depth interval from 5 - 24 ft bg. Once subsurface temperatures reach boiling, steam laden with chlorinated solvents was collected by 37 soil vapor extraction wells screened to 5 ft bgs. Full-scale operations of the system began on June 4, 1998. Initially operated in six phase mode. It was observed that previous treatment had elevated chloride levels in the water, resulting in lower applied voltages than anticipated. System was modified to operate in three-phase mode in August 1989.

B.2.2.4.1. Within 60 days, temperatures throughout the 24,000 cy of the first treatment volume had reached the boiling point of water. With another 70 days of heating, separate phase DNAPL in this area had been removed and groundwater concentrations of both TCE and TCA reduced to below the targeted TIER III risk based cleanup levels.

B.2.2.4.2. Due to the success of the first phase of SPH, a second 8500 cy treatment volume was cleaned to TIER I cleanup levels in 90 days using 85 new electrodes.

B.2.2.5. *Operation.* Project Timeline:

March 1998	Construction began.
June 1998	Startup of operations.
August 1998	Converted from six phase to three phase mode of operations
October 1998	Major system malfunction, operations down for the entire month.
December 1998	Construction of expanded treatment system.
January 1999	Treatment of expanded area brought on line, with phase out of treatment in initially treated area.
April 1999	Monitoring shows very low hydrocarbon removal rate and system shutdown.
May 1999	Post-treatment sampling shows soils at residential standards, 4 out of 13 monitoring wells below Tier 1 standards.
June 1999	System demob begins.
July 1999	Illinois EPA issues NFR for site.
August 1999	Site redevelopment begins.
December 1999	11 out of 13 wells below Tier 1 standards.
May 2000	Illinois EPA approves no further monitoring required, site redevelopment complete.

B.2.2.6. *Results.* Concentrations in groundwater were reduced from indications of residual DNAPL (the prior SEE applications had removed observable DNAPL in the wells) to less than Tier 3 criteria and through intrinsic biodegradation to less than Tier 1 standards.

B.2.2.7. *Cost.* Approximately $1.2 M.

B.2.3. *Avery-Dennison*.

Project Name:	Avery-Dennison
Location:	Waukegan, Illinois
Contaminants:	Methylene Chloride
Regulatory Program:	Illinois Site Remediation Program
Remediation Scale:	Full Scale
Site Owner:	Avery-Dennison
Consultant:	Clayton Environmental
Project Duration:	December 1999 to November 2000

B.2.3.1. *Site Information*. Methylene chloride was used in film coating operations from 1975 to 1992. In 1985, an inventory check indicated that 1585 gal. of methylene chloride were released from and underground pipe.

B.2.3.2. *Hydrogeology.* Silty clay glacial till to a depth of approximately 180 ft bgs. Discontinuous silty sand stringers also present. Water encountered at depths of 6 to 25 ft bgs.

B.2.3.3. *Remediation Objectives.* Reduce methylene chloride concentrations to less than 24 mg/kg.

B.2.3.4. *Approach.* ERH operating in a six phase mode was used to treat the soils at this site. An area of 17,000 ft^2 was treated to a depth of 25 ft. A total of 95 copper electrodes were installed with 34 wells for vapor and steam recovery. The goal of the remediation was to heat the sols to 75^oF.

B.2.3.5. *Operation.* Project Timeline:

December 1999 ERH treatment began.
November 2000 ERH treatment complete.

B.2.3.6. *Results.* Methylene chloride concentrations reduced from a maximum of 40,000 mg/kg and a mean of 1,400 mg/kg to a mean of 2.51 mg/kg.

B.2.3.7. *Cost.* Not Available.

B.2.4. *Area A, Young-Rainey STAR Center, Largo, Florida*.

Project Name:	Area A, Young-Rainey STAR Center, Largo, Florida (former DOE Facility)
Location:	Largo, Florida
Contaminants:	Trichloroethene, *cis*-1,2-dichloroethene, methylene chloride, toluene and petroleum hydrocarbon
Regulatory Program:	
Remediation Scale:	Full Scale
Site Owner:	DOE
Consultant:	
Project Duration:	October 1, 2002 to February 28, 2003

B.2.4.1. *Site Information.* Former DOE facility. Treatment area was approximately 10,000 ft^2.

B.2.4.2. *Hydrogeology.* Moderately permeable sand to 30 ft, underlain by a tight (Hawthorn) clay aquitard.

B.2.4.3. *Remediation Objectives.* Operational targets included achieving and maintaining a minimum temperature of 84^oC to the entire treatment volume, and to operate until NAPL was no longer observed to be recovered from the extraction wells. Numerical goals included:

Compound	Groundwater Goal (mg/L)	Soil Goal (mg/kg)
Trichloroethene	11	20.4
cis-1,2-dichloroethene	50	71
Methylene chloride	20	227
Toluene	3.3	15
TPH	50	2,500

B.2.4.4. *Approach.* A combination of steam and three phase ERH were used, consisting of 36 steam injection wells, 51 electrodes (21 in the upper sands, 30 in the Hawthorn clay) and 28 extraction wells. Well spacing was approximately 15 to 20 ft. Steam was injected at depths of 20 to 30 ft, near the base of the aquifer. ERH was conducted from depths of 10 to 15 ft and from 30 to 35 ft.

B.2.4.5. *Operation.* Hydraulic and pneumatic control was documented after one week of operation, and heating began of October 1, 2002 and was completed on February 28, 2003, after a cool-down mode beginning on February 17, 2003. The deep electrodes were activated first, forming a heated floor to the aquifer. After one week of heating the floor, stem injection was initiated in the perimeter wells. After this hot steam barrier was formed (after approximately 3 weeks) around the treatment zone, steam injection and ERH was begun in the central and upper portions of the treatment volume.

B.2.4.5.1. Once the desired temperature was reached, pressure cycling was induced for a period of approximately one month.

B.2.4.5.2. On January 13, 2003, an area containing sap-like resin was discovered, requiring a modification in the treatment involving additional injection and extraction wells.

B.2.4.6. *Results.* Screening and analytical sampling shows that after recovery of 5000 to 9000 lb of VOCs, an asymptotic level of 5 lb per day removal of VOCs was observed. Approximately 200 gal. of DNAPL were recovered. Groundwater concentrations were reduced by 3 to 4 orders of magnitude in most wells. Effluent vapor and water concentrations had been reduced to less than 0.5% of their peak values during treatment.

B.2.4.7. *Cost.* Turnkey remediation costs, including power were $1.3M or $118/cy. Contract includes a performance guarantee.

B.2.5. *Dry Cleaner Site.*

Project Name:	Dry Cleaner Site
Location:	Western Suburbs of Chicago, IL
Contaminants:	Perchloroethene (12,000mg/kg, average 1,400 mg/kg)
Regulatory Program:	Illinois Site Remediation Program
Remediation Scale:	Full Scale
Site Owner:	Privately Owned
Consultant:	Clayton Group
Project Duration:	November 2002 to March 2003

B.2.5.1. *Site Information.* Dry Cleaner site in western suburbs of Chicago. Ruptured sewer line release PCE 300' down gradient from dry cleaner. Soil contaminated from 4 to 20 ft deep.

B.2.5.2. *Hydrogeology.* Glacial silty clay.

B.2.5.3. *Remediation Objectives.* Remove DNAPL to 529 mg/kg.

B.2.5.4. *Approach.* Initially involved 70 4-inch diameter SVE wells that operated for 4 years.

B.2.5.5. *Operation.* Project Timeline:

November 19, 2002	Startup.
January 8, 2003	Interim Sampling (44 out of 58 samples below remediation objective).
March 21, 2003	Shutdown (Final mean concentration 50 mg/kg).

B.2.5.6. *Results.* 2,392 pounds of VOC removed.

B.2.5.7. *Cost.* $695,000 fixed price guaranteed remediation.

B.2.6. *Manufacturing Site.*

Project Name:	Manufacturing Site
Location:	Northwest Suburbs of Chicago, IL
Contaminants:	TCE (2,400mg/kg)
Regulatory Program:	Illinois Site Remediation Program
Remediation Scale:	Full Scale
Site Owner:	Privately Owned (confidential)
Consultant:	URS Corporation
Project Duration:	Two Phases: July 2002 to September 2002, and January 2003 to April 2003

B.2.6.1. *Site Information.* Manufacturer of computer-related equipment in northwest suburbs of Chicago, IL. Site had experienced releases of TCE from degreasing operations that were performed in a loading dock.

B.2.6.2. *Hydrogeology.* Glacial silty clay.

B.2.6.3. *Remediation Objectives.* Minimum Goal: remove TCE to less than C_{sat} concentration of 1200 mg/kg; revised goal (achieve IEPA Tier 1 residential soil ingestion criteria) of 5 mg/kg.

B.2.6.4. *Approach.* Initially involved 7 electrodes with horizontal vapor recovery system. Operated from 15 July to 21 September 2002. Confirmation sampling indicated that groundwater contaminated from previously undiscovered source north of treatment area was seeping into area already treated through granular sub-base. Second phase involved adding seven additional electrodes with integrated vapor recovery to treat previously undiscovered source and to re-treat the initial treatment area. TCE volatilized from soils beneath a catch basin re-condensed in soils immediately beneath catch basin as a result of catch basin receiving seepage through treatment; 7 cy of soil excavated from beneath the catch basin and disposed offsite to complete remediation.

B.2.6.5. *Operation.* Project Timeline:

July 15, 2002	Startup
September 21, 2002	Interim Shutdown
November 2002	Expand System
January 10, 2003	Re-start
April 8, 2003	Shutdown

B.2.6.6. *Results.* 292 pounds of VOC removed.

B.2.6.7. *Cost.* $919,000 (including electricity).

B.2.7. *Manufacturing Site*.

Project Name:	Manufacturing Site
Location:	Northwest Suburbs of Chicago, IL
Contaminants:	TCE (1,500mg/kg)
Regulatory Program:	Illinois Site Remediation Program
Remediation Scale:	Full Scale
Site Owner:	Privately Owned (confidential)
Consultant:	URS Corporation
Project Duration:	September 2002, to January 2003

B.2.7.1. *Site Information.* Manufacturer of computer-related equipment in northwest suburbs of Chicago, IL. Site had experienced releases of TCE from degreasing operations that were performed in a loading dock.

B.2.7.2. *Hydrogeology.* Glacial silty clay.

B.2.7.3. *Remediation Objectives.* Minimum Goal: remove TCE to less than C_{sat} concentration of 1200 mg/kg; revised goal (achieve IEPA Tier 1 residential soil ingestion criteria) of 5 mg/kg.

B.2.7.4. *Approach.* Involved nine electrodes with horizontal vapor recovery system. Operated from 2 September 2002 to 6 January 2003.

B.2.7.5. *Operation.* Project Timeline:

September 9, 2002	Startup
January 6, 2003	Shutdown

B.2.7.6. *Results.* 168 pounds of VOC removed.

B.2.7.7. *Cost.* $552,000 (including electricity).

B.2.8. *Ft. Richardson.*

Project Name:	Ft Richardson,
Location:	Anchorage, Alaska
Contaminants:	TCE, PCE, 1,1,22-tetrachloroethane
Regulatory Program:	
Remediation Scale:	Full Scale
Site Owner:	U.S. Army Corps of Engineers
Consultant:	URS Corporation
Project Duration:	December 1999 to November 2000

B.2.8.1. *Site Information.* Disposal pit for wastes from practice decontamination of chemical munition-exposed equipment.

B.2.8.2. *Hydrogeology.* Dense, relatively impermeable poorly sorted silty sandy gravel with some dense sand, silt or silty sand. Groundwater located at 8 ft bgs.

B.2.8.3. *Remediation Objectives.* Reduce LNAPL thickness from 10 ft to less that $^1/_8$-inch on the water table.

B.2.8.4. *Approach.* ERH operating in a six phase mode was used to treat the soils at this site. Heating extended from 8 to 40 ft bgs.

B.2.8.5. *Operation.* Three six phase arrays. Time to install and reach desired temperature was 3 weeks per array. Treatment time per array was 6 weeks, 18 weeks total.

B.2.8.6. *Results.* Initial and final concentrations (mg/kg):

Compound	Initial	Final
TCE	21.53	1.6
PCE	2.0	0.08
1,1,2,2-tetrchloroethane	82.34	1.17

B.2.8.7. *Cost.* $185/ yd^3.

B.2.9. *ICN Pharmaceuticals Incorporated.*

Project Name:	ICN Pharmaceuticals Incorporated
Location:	Portland, Oregon
Contaminants:	TCE (150 mg/l), DCE (370 mg/l) and vinyl chloride (24 mg/l)
Regulatory Program:	Unilateral Order, Oregon Department of Environmental Quality Oversight
Remediation Scale:	Full Scale
Site Owner:	
Consultant:	AMEC
Project Duration:	May 2000 to December 2001

B.2.9.1. *Site Information.* Wastes from laboratory operations were disposed in a 20 ft deep drywell. Concentrations of TCE in groundwater were indicative of the presence of DNAPL in an area southwest of the drywell. Groundwater plume size estimated at 120 ft by 80 ft.

B.2.9.2 *Hydrogeology.* Silt and sand in discontinuously interlayered in overbank deposits up to a thickness of 60 ft. The overbank deposits are underlain by the Troutdale Gravel Aquifer, measuring approximately 175 ft thick at the site. The water table is found at a depth of 8 ft bgs. The DNAPL appeared to have been restricted to the overbank deposits.

B.2.9.3. *Remediation Objectives.* There were no numerical goals for the pilot test. The following performance objectives were established:

a. Contaminants must be extracted from the target zone

b. The target zone must be heated to the applied boiling point

c. Air to support HPO must be injected into the treatment area.

B.2.9.4. *Approach.* Treatment was performed using ERH. Initially 60 electrodes were installed to a depth of 58 ft. in a six phase heating pattern. Each electrode was capable of directing power to three zones in the overbank: 20 to 30 ft bgs 34 to 44 ft bgs and 48 to 58 ft bgs.

Fifty electrode vents were installed along the perimeter and throughout the treatment area in December 2000 to help control migration of steam and hot water outside the treatment area. The system was expanded in May 2001 with the installation of 9 electrodes, four electrode vents, and 2 monitoring wells to address areas where contaminated steam appeared to have migrated beyond the treatment area.

B.2.9.5. *Operation.* Project Timeline:

May 2000	Startup
December 2000	System expanded with addition of 50 electrode vents
May 2001	System expanded with 13 electrodes and 19 electrode vents
December 2001	Shutdown

B.2.9.6. *Results.* As of June 2002, TCE concentrations reduced from 150 mg/l to 0.008 mg/l; DCE reduced from 370 mg/l to 1.3 mg/l; and vinyl chloride from 24 mg/l to 0.050 mg/l.

B.2.9.7. *Cost.* Not Available.

B.3. Steam Enhanced Extraction**.** At the time of preparation of this manual, individual write-ups were only available for the Visalia Pole Yard project. Table B.1 provides a summary of other SEE projects.

B**.**3.1. *Southern California Edison Company, Visalia Pole Yard NPL site, Visalia, California*

B.3.1.1. *Contaminants.* Polycyclic Aromatic Hydrocarbons (creosote), Diesel, Pentachlorophenol, Polychlorinated Dibenzo-p-Dioxins, and Polychlorinated Dibenzo-p-furans

B.3.1.2. *Technology.* In situ steam enhanced extraction with supplemental air injection to enhance in-situ chemical and metabolic oxidation.

B.3.1.3. *History.* The Southern California Edison Company operated a wood treating plant from 1925 to 1980 during which the subsurface soil and groundwater were infiltrated, to a depth of 120 ft. with polycyclic aromatic hydrocarbons (PAHs), pentachlorophenol (PCP), polychlorinated dibenzo-p-dioxins, polychlorinated dibenzo-p-furans ($TCDD_{eqv}$), and diesel (wood preservative chemicals). Since 1975, Edison has pumped and subsequently treated approximately 2.5 billion gallons of groundwater to control gradient and minimize plume volume of these dense non-aqueous phase liquids (DNAPLs) and the dissolved constituents.

B.3.1.4. *Project Goals.* The general project objective was to remove the source of contamination from the subsurface and allow “natural attenuation” to degrade the remaining aqueous-phase plume. Specific goals are listed in the following table.

Visalia Steam Remediation Project Groundwater Remediation Standards	
Parameter	Concentration
Pentachlorophenol	1 µg/L
Benzo(a)Pyrene	0.2 µg/L
Tetrachlorodibenzo-p-Dioxin$_{eqv}$	30 µg/L

B.3.1.5. *Engineered Systems.* SCE started with 11 steam injection wells, 7 liquid/vapor extraction wells, 4 steam boilers, a vacuum system, a two-staged heat exchange system, vapor treatment system, and a tertiary water treatment system. Electrical Resistance Tomography (ERT) and thermocouples were deployed via 29 wells to image the subsurface heated zone.

B.3.1.6. The steam generation system had the capability of 200,000 lb/hr, with nominal injection rates of 80,000 to 120,000 lb/hr. Recovery wells and treatment systems were capable of removing approximately 140,000 lb (H_2O/min.), maintaining overall hydraulic control of the site at nominal injection rates. Recovered liquids (groundwater and condensate) and vapors were separated and pumped to respective treatment systems. The non-condensable gases (vapors) were piped to the steam generators and thermally destroyed in the fire-box of the boiler. Groundwater and condensate were pumped to head-works of the tertiary water treatment system. This system consisted of serial separation (gravity and air-flotation), parallel dual media and polish filtration, and serial treatment by granular activated carbon. The treated effluent was discharge to the local sewer under an industrial waste discharge permit.

Major Design Parameters and Specifications	
Well Field Dimensions	145 ft. by 2 acres
Contaminated Material Volume	375,000 yd^3
Heated Material Volume	>1,000,000 yd^3
Water Treatment Plant Capacity	400 gpm
Vapor Extraction System Capacity	2500 scfm
Steam Injection System	120,000 lb/hr (+ 80% Reserve)

B.3.1.7. *Preliminary Results.* During May 1997 to June 2000, approximately 660 million pounds of steam were injected into the subsurface formation. Approximately 1.33 million pounds of wood preservative chemicals in the formation were mobilized and removed/destroyed. The following table depicts the wood treating chemical mass removed by free, aqueous, or vapor phase, and by chemical oxidation.

Removed Mass by Phase Category		
Phase	**Mass Removed (lb)**	**% Removed of Total**
Free	678,300	51
Vapor	239,400	18
In-situ Oxidation	212,800	16
Aqueous	199,500	15
Total	**1,330,000**	100

B.3.1.7.1. Southern California Edison designed and built a "carbon tracking" system, which on a real-time basis accounted for the mass removed in the aqueous and vapor phases. Oxidation in place was determined from the increase in CO_2 and dissolved carbonate over the native groundwater and injected steam, taking temperature/solubility relationships into account. Free-phase wood treating chemicals were measured daily from the skimmed volumes emanating from the gravity separators.

B.3.1.8. *Operational Considerations.* The system components must be robust and have inherent flexibility to maintain operational integrity. Strength and material compatibility if not addressed properly will result in many unforeseen events ranging from significant project delays to catastrophic failures. The Visalia design was robustly designed, constructed and maintained 96% operational capacity factor during 36 months of steaming operations.

B.3.1.8.1. The initial target of steam injection focused on the intermediate aquitard, which is a heterogeneous saturated zone typified by inter-bedded coarse sand and cobble sized material. This aquitard is about 80 to 100 ft below the ground level (bgl). The steam injection wells were installed in a circular array around the contaminant mass. The steam was injected to mobilize the wood preservative chemicals to centrally located liquid and vapor extraction wells. This operation scheme was a classic "steam flood" of the intermediated aquitard, which relies on the integrity of the confining formations (shallow and intermediate aquitards) to drive the "steam chest" horizontally across the intermediate aquifer. Under this scenario, the aquifer is primarily heated by convection. Portions of the confining shallow and intermediate aquitards would be conductively heat. Heat transfer modeling indicated that the first 15 ft of the intermediate aquitard would achieve the desired thermal treatment threshold of 100^{o}C if the leading surface of this confining layer were exposed to steam temperatures for 140 days.

B.3.1.8.2. This operational mode continued for approximately 10 months. The recovery rates of contaminants ranged from 2000 lb to a record high of about 14,000 lb in one day. The subsurface thermal signature resembled a "donut-shaped" plume of elevated temperatures approaching the apparent formation boiling point of water.

B.3.1.8.3. The original design called for three of the extraction wells to be adapted to inject steam. The second phase of steam injection, which was still based on aquifer steam flood was initiated to inject steam in the center of the contaminant mass. The electrical resistance tomography proved to be a valuable tool in managing the duration of steam injection from the center of the contaminant mass. The treatment of the intermediate aquitard based on steam flood techniques continued for an additional 8 months. The typical formation heat signature indicated temperatures approaching the apparent water boiling point from about 95 ft bgl virtually to the surface.

B.3.1.8.4. Steam flood techniques were not fully successful at conductively heating the intermediate aquitard. This method suffered from the persistent problem of "steam over-ride" which has been well documented by the enhanced oil recovery industry. There were two additional factors that added a cooling effect in the lower reaches of the intermediate aquifer. The material at 95 ft bgl is described as a 5 ft deposit of cobble size material with an estimated

horizontal groundwater velocity of greater than 3 ft per day. The second factor was a vertical connectivity of the "deep aquifer" into the intermediated aquifer. The vertical flux rate was measured at approximately 3 gpd/ft^2. The introduction of native groundwater at ambient temperature (~16^{o}C) both laterally and vertically imparted sufficient cooling capacity to prevent the desired heating of this part of the formation.

B.3.1.8.5. An alternative method relying on injecting steam below the intermediate aquitard was conceived and subsequently approved by the DTSC. This aquitard is about 100 ft to 125 ft bgl and is characterized as inter-bedding of sand, fine sand, and silts. This aquitard had been shown, during the 1991 Remedial Investigation, to have been significantly penetrated with the wood treating chemicals. It was also obvious that the intermediate aquitard was not impervious to permeation, based on the stated flux rates from the deep water bearing unit into the intermediate aquifer.

B.3.1.8.6. Three injection wells were drilled into the "deep" aquifer to a depth of 145 ft bgl. Heating the intermediate aquitard from below employed the natural physical character of the "buoyancy" of steam. Steam injected below this aquitard would take the "path of least resistance" and travel to the bottom edge of this formation and propagate in a radial fashion across the bottom of the aquitard. The steam would also take the same pathways through this aquitard that the native groundwater utilized in the vertical accent from the deeper unit into the intermediate aquifer. As the steam ascended, the contaminant mass was mobilized ahead of the steam front and delivered to the extraction wells in the intermediate formation. Steam injection cycles were virtually continuous to uniformly heat the intermediate aquitard and provide a thermal barrier for downward migration of the chemicals of concern. Additional extraction wells were installed into the deep aquifer as a precautionary measure.

B.3.1.8.7. An additional phenomenon was observed at Visalia that greatly reduced the possibility of downward migration of the wood treating chemicals. The specific gravity of the mixture of wood treating chemicals was measured at 1.11. Thus the free-phase mass within the formation was considered to be a DNAPL. The first 3500 gallons of recovered product resembled the original mixture, in terms of color, odor, and density. When the wood treating chemicals were exposed to temperatures in excess of 50^{o}C, and most probably in the presence of water, there was a dramatic change in the physical and chemical characters of this mixture. The original mixture was black in color and had a distinct coal-tar odor. After the thermal soak, the extracted mass, changed in appearance to a tight gray emulsion while retaining a coal-tar odor, albeit reduced in intensity. Of primary importance, the density of the recovered mass was lighter than water. Assays performed at LLNL indicate that the mixture of wood treating chemical was saponified, essentially changing a DNAPL into a Light Non-Aqueous Phase Liquid (LNAPL).

B.3.1.8.8. Injecting steam into the "deep" aquifer continued for 18 months with approximately an additional 440,000 lb of wood treating chemical recovered from the intermediate aquitard.

B.3.2. *Groundwater Quality.* Pentachlorophenol was considered as the target compound to be removed in the source area considering that it was the most soluble chemical in the suite of

wood preservative chemicals use at the Visalia facility. Historically, PCP was detected in monitoring wells located about 1000 yards from the VPY western property boundary. Through an aggressive pumping program from 1975 to 1990, the PCP aqueous phase plume was reduced to area roughly within the property boundary (Graph 1).

B.3.2.1 The following graphs (1, 3-6) describe the groundwater quality for the parameters listed in the above table. Graphs 1 and 3 present the analytical results in groundwater extracted from a well in the vicinity of the "point of compliance". Graphs 4-6 present similar groundwater assays from a production well in former free-phase hydrocarbon plume (source area). In general, the graphs for PCP and B(a)P contain approximately 150 data points, and, the $TCDD_{eqv}$ graphs contain about 20 data points. The data comprehensively describe the trend of improving groundwater quality from the initiation of steam injection to the present. Similar data sets exist for 12 additional production wells, all of which exhibit similar trends. The data selected for this appendix are representative of the improving groundwater quality at the Visalia Pole Yard.

B.3.2.2. The groundwater extracted from EW-4 has shown two orders of PCP mass reduction since May 1997, which was the on-set of steam injection activities. The May 2003 PCP assay is lower than the Remediation Standard of 1 µg/L. This trend is encouraging; however, the data may not be entirely representative in light of that these results are from an extraction well.

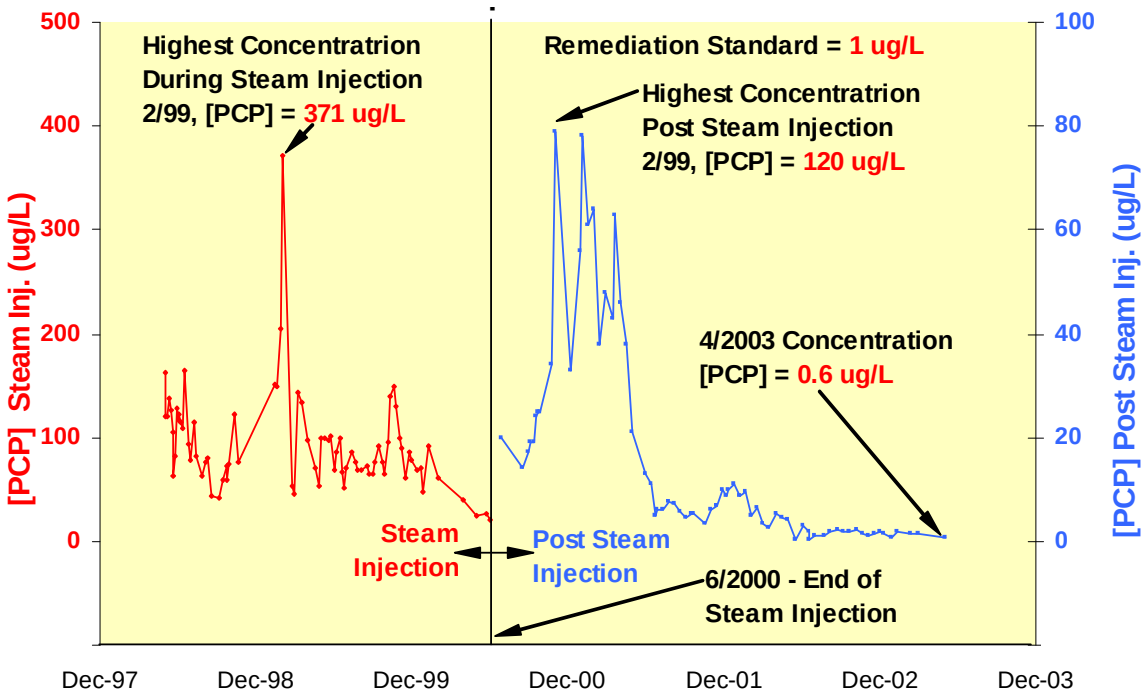

Figure B-1. EW-4 PCP in Groundwater.

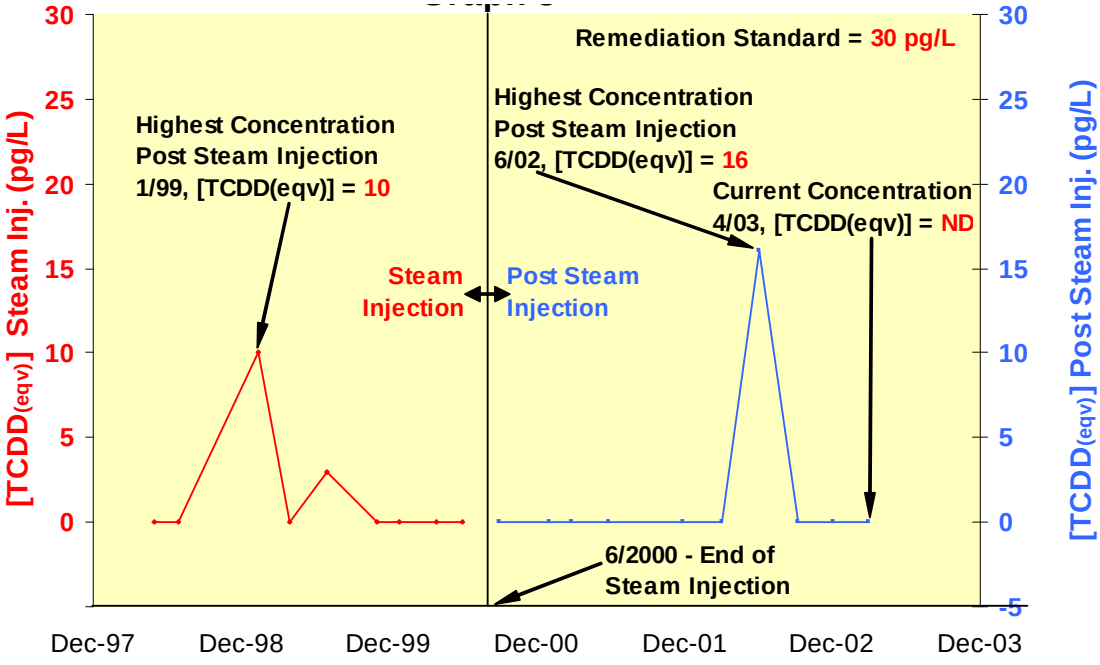

Figure B-2. EW-4 $TCDD_{(eqv)}$ in Groundwater.

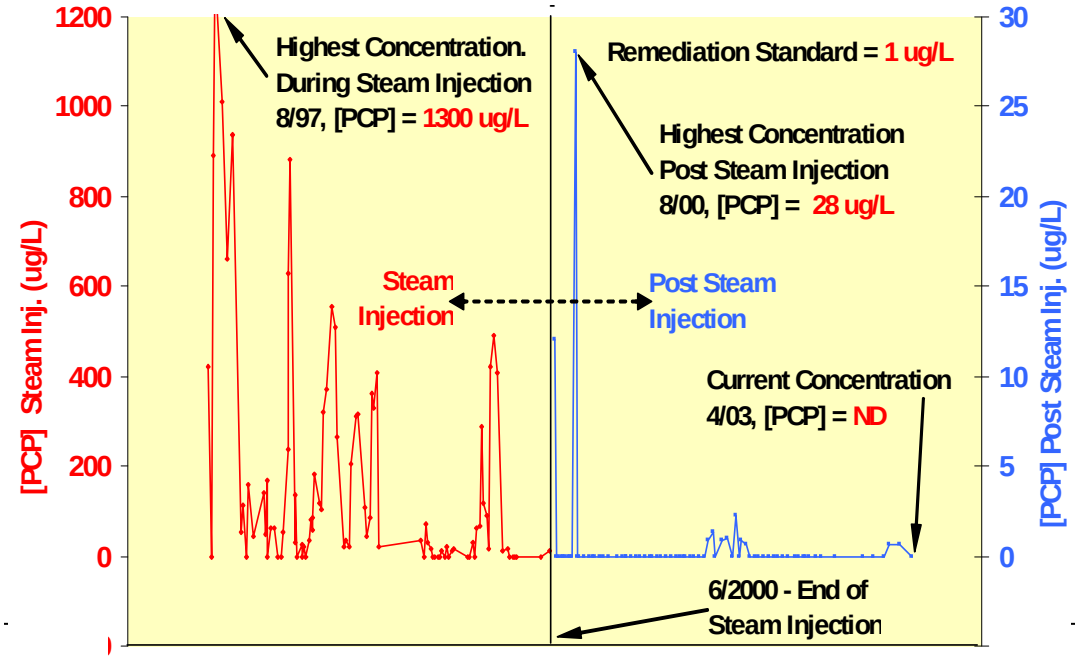

Figure B-3. S-14i, PCP in Groundwater.

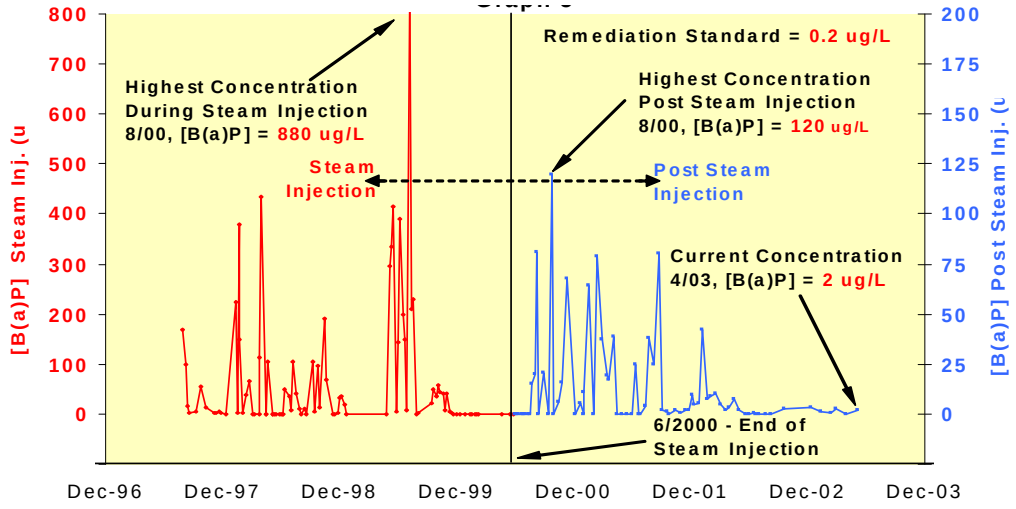

Figure B-4. S-14i B(a)P in Groundwater.

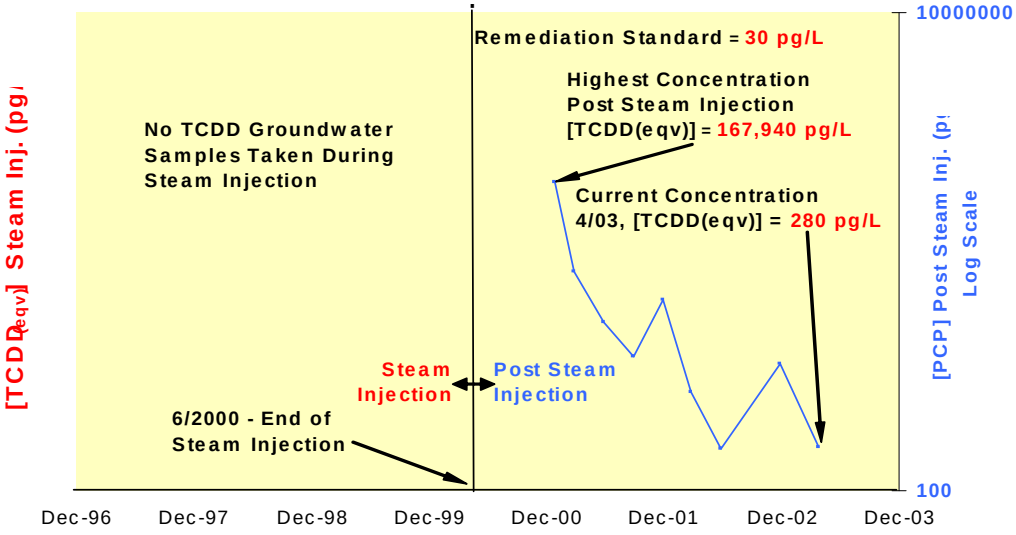

Figure B-5. S14i, $TCDD_{(eqv)}$ in Groundwater.

B.3.2.3. The B(a)P and dioxins data indicate that these parameters do not adversely impact the groundwater in the vicinity of the "compliance point." During 3 years of active steam injection cycles and the subsequent 3 years of post-steaming activities, these organic chemical species have not been detected at concentrations, which exceed the Remediation Standards.

B.3.2.4. In reviewing the quality of the groundwater pumped from the "source area" (see Figures B-3, B-4, and B-5), it becomes evident there was a considerable mobilization of PCP, B(a)P, and Dioxins occurred during steam injection cycles.

B.3.2.5. The highest recorded initial PCP concentration (1300 µg/L) in the groundwater has been reduced to a concentration below the method detection limit (ND @ < 1 µg/L). Since December 2000, there has been one time period in which the level of PCP in the groundwater was assayed in concentrations above the Remediation Standard. During this event (~ Dec. 2000), a cluster of assays recorded concentrations above the detection limit, however, only two the results were recorded above the remediation standard (1.3 µg/L and 2.1 µg/L, respectively). Since 12 December 2001 all assays results were reported at concentrations below the regulatory limit (1.0 µg/L). The two data points above the detection limit in early 2003 were measured at concentrations about 0.7 µg/L.

B.3.2.6. Pumping of S-14i still produces groundwater with B(a)P concentrations in excess of the regulatory limit of 0.2 µg/L. However, looking at the body of this data, it becomes clear that thermal treatment of the groundwater matrix in the vicinity of S-14 has resulted in a measurable improvement in quality in term of B(a)P. The B(a)P concentration has steady decreased from a maximum of 880 to 2 µg/L.

B.3.2.7. The same conclusion drawn for B(a)P concentrations in S-14i can be made for the Dioxins concentrations represented in Graph 6. The highest dioxin concentration was measured in excess of 160,000 µg/l. The groundwater dioxin content has progressively reduced in mass to the current measured amount of 280 pg/L.

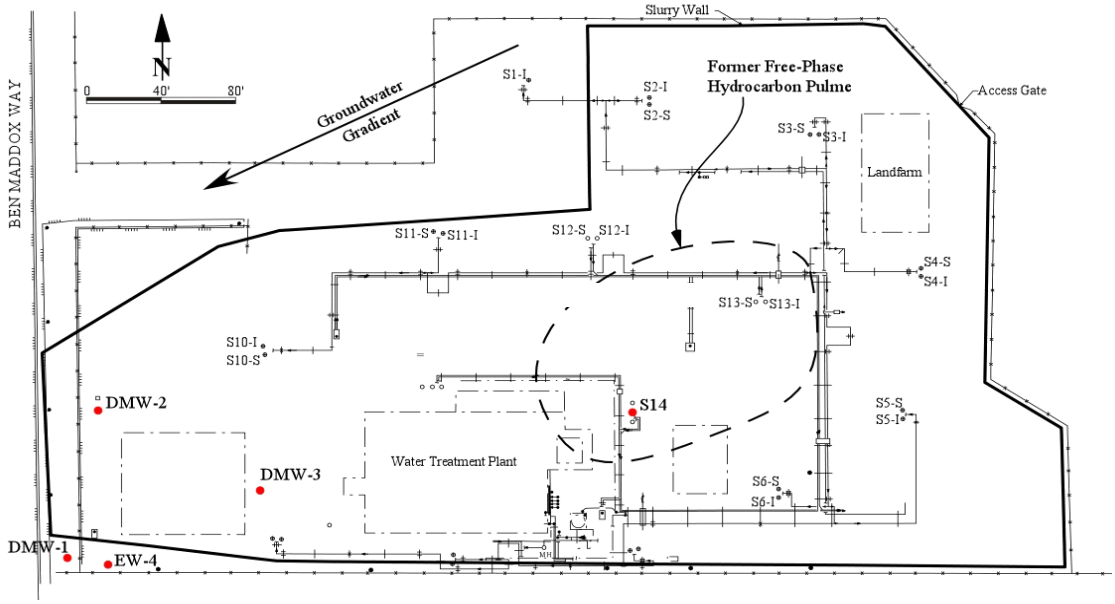

Figure B-6. Site Map

B.3.2.8. Observations over the past 60 months of the groundwater quality in other wells located at the site suggests B(a)P and Dioxins have not been mobilized to any degree beyond the original source area. The observations may not be entirely representative, however, the in the ensuing time period since the project initiation, the empirical observations of the groundwater quality have produced encouraging results and achieving the stated goals appears to be certain.

B.3.3. *Future Objectives.* The compliance plan negotiated with the California EPA - Department of Toxic Substances Control calls for the demonstration of compliance at a point along the western boundary of the Visalia Pole Yard property. The "compliance point" will be three dedicated monitoring wells, which are scheduled for completion by 3rd quarter of 2003. Upon completion of these wells, SCE will enter into a regulatory demonstration phase to show compliance with the remediation standards as listed above. The details of the monitoring program and data reduction methods have yet to be determined and subsequently approved by DTSC.

B.3.3.1. The EW-4 groundwater quality continues to improve, and as of May 2003, meets all of the regulatory objectives. Upon completion of the monitoring wells, SCE will continue with monthly assays of each of the wells. A representative data-base will be collected and a final decision will be made to discontinue the operation of the Visalia Water Treatment Plant. The water treatment plant will held in a "wet" standby status to insure a "back-up" remedy is available. The duration of the standby status of the water treatment plant has yet to be determined.

THIS SPACE INTENTIONALLY LEFT BLANK

Table B-1. Summary of Steam Injection Projects

Site	LLNL Gas Pad	Visalia Pole Yard	Lemoore NAS, CA	Alameda NAS, CA	DOE, Portsmouth, Ohio	Solvent Services, San Jose, CA	Lucent Technologies, Skokie, IL	AG Communication Systems, Northlake, IL	Amoco Minneapolis, MN
Status	complete	on-going full scale	full-scale cleanup completed	pilot project completed	pilot project completed	pilot project completed	Full scale cleanup completed	Full scale cleanup completed	Full scale cleanup completed
Target Chemicals	gasoline	creosote, PCP	JP-5	TCE, diesel, motor oil	TCE	chlorinated solvents	TCE, TCA	TCE, Mineral spirits	Fuel Oil
Geology	sand, gravel, silt and clay (K=2E-4 to 5E-2 cm/sec)	sand, silt and sand/silt mixture (high pumping rates suggest K approx. 1E-1 cm/sec	silt and clay (shallow); sand (deeper, K=4E-3 to 1E-2 cm/sec)	fill, silty sand and clay	sand, gravel (K=5E-3 cm/sec), and shale	silt and clay (K10^{-5} to 10^{-5} cm/s)	Fine sand, silt and clay (Clay Till – 10^{-9} cm/s; sand and Gravel 10^{-3} cm/s)	Clay till with sand and gravel seams	Sand
Treated Depth Interval (ft, BGS)	70 to 155	80 to 100	10 to 20	3 to 10	<20	0 to 5 (est.)	5 to 21 ft	5 to 80 ft	5 to 18 ft
Water Table Depth (ft, BGS)	100 to 120	35	16	5.5	12 to 15		7ft	12 ft	14 ft
Saturated Zone?	partial	yes	partial	yes	yes	no	Yes	Yes	Both vadose and saturated
Treated Area (acres)	0.3	3.6	0.2	0.08	0.5	0.002	3 acres	3 acres	3 acres
Treated Volume (cy)	45,333	115,000	6,296	933	<16,000	15	80,000	200,000	66,700
Duration	Nov. 1992-Dec. 1993	June 1997-June 2000	July 5-Sept 23, 1994	20 days in 1999	4 months in 1999	140 hours in Aug. 1988	7 years	5 years	1 year
Containment Mechanism	SVE	SVE, Pumping Wells	SVE	SVE	SVE	SVE	Well point system, SVE	vacuum-enhanced GW pumping/SVE	GW pumping/SVE
Pumping Rate (water/vapor steam)		350 to 400 gpm groundwater, 2500 scfm vapor	260 scfm for vapor, 9 gpm for liquid		8-15 gpm water, 100-500 scfm vapors		3-5 gpm/250cfm/300lb/hr	8-10gpm/350cfm/450lb/hr	
Number of Wells	23 (incl. 6 steam injection wells, 3 electrical heating wells, 3 extraction wells, 1 SVE well, and 10 MWs)	48 (11 injection, 8 extraction, 29 ERT and thermocouple)	31 (incl. 11 injection/extraction wells, 16 temperature monitoring wells, and 4 sample boreholes)	7 injection/extraction well clusters, 11 thermocouple wells, 11 sampling wells	24 wells + 23 sample boleholes	7	~115 well points, 15 thermistor, 96 steam inj., 115 vapor, 15 sampling wells	~120 gcombined vapor and GW recovery) 90 steam injection, 120 vapor, 8 thermocouple, gw extraction doubled as sampling	
Well Spacing (ft)	25	57	17	<11	22	3.4	22	22	

Site	LLNL Gas Pad	Visalia Pole Yard	Lemoore NAS, CA	Alameda NAS, CA	DOE, Portsmouth, Ohio	Solvent Services, San Jose, CA	Lucent Technologies, Skokie, IL	AG Communication Systems, Northlake, IL	Amoco Minneapolis, MN
# Wells per Acre	70	14	155	>362	94	3,860	70	70	
Mass Removed	115,000 lbs	1.3 million lb total -- 1 million lb in first 1.5 yr; 0.3 million lb in next 1.5 yr		>600 gals	est. as approx. 80% of initial mass; 828 lb.	>146 kg	>38,000 lbs	>33,000 lbs	
Volume Removed	7,600 gals gasoline		78,500 - 98,000 gal? (conflicting reports)		6.5 million liters of water extracted				
Groundwater Concentration (Initial)	several thousands ppb benzene		>20,000 ppm		<= 970 ppm TCE		up to 8 ft of DNAPL measured in wells	Up to 3 ft of DNAPL measured in wells	
Groundwater Concentration (Remediation Target)	CA MCLS: 1 ppb benzene; 680 ppb ethyl benzene; 1,750 total xylenes						IL Class II	IL Class II	
Groundwater Concentration (Final)	200-300 ppb benzene	<=2,300 ppb total creosote compounds	>20,000 ppm				IL Class II	IL Class II, one area exceeded	
Soil Concentration (Initial)	5,100 ppm		89,200 mg/kg max.		1,600 approx. max.	>1,000 ppm			
Soil Concentration (Remediation Target)									
Soil Concentration (Final)			20,000 mg/kg max.		450 mg/kg approx. max.		IL Residential Criteria		
Concentration In Extracted Vapor		1,100 ppm total organics			50-600 lbs/hr vapor per well giving a total average 2,500 lbs/hr				
Concentration In Extracted Condensate		10% of solubility	>7.8% JP5 (based on 0.76 gpm JP5 and 8.95 gpm water)						
Temperature Achieved	> 200 ^{o}F	280 ^{o} F max (avg. 140^{o}F)	100-140 ^{o}F in most extraction wells		max. approx. 107 ^{o}C		80 - 105^{o} C	Soil - 84 to 104^{o}F, Groundwater - 68 to 165^{o}F	

Site	LLNL Gas Pad	Visalia Pole Yard	Lemoore NAS, CA	Alameda NAS, CA	DOE, Portsmouth, Ohio	Solvent Services, San Jose, CA	Lucent Technologies, Skokie, IL	AG Communication Systems, Northlake, IL	Amoco Minneapolis, MN
Electrical Power Requirement									
Additional Findings	Dynamic Underground Stripping (DUS) =steam flushing+electric heating+electric resistance tomography (ERT)	Some soil still contaminated below treatment zone. Continuing to pump and treat and sparge without SVE.	No reduction in JP-5 conc. in sat'd. zone; vapor condensation incr. conc. in previously clean areas of unsat. zone.		4 co-located, pre- and post-treatment soil samples in "most contam. zone." results: 1 decr. by 60%, 2 incr., 1 NC.	Downward mobilization observed, post-treatment conc. in underlying low permeability zone higher than pre-treatment conc.	Enhanced bioactivity achieved	Enhanced bioactivity achieved	
Total Cost (U.S. dollar, Demonstrated)	$10.4 million	$22.5 million			$6.2 million		$8M	$4.9M	
Cost/Unit Volume (U.S. dollar/cubic yard, Demonstrated)	$230/cy	$197/cy			>$390/cy		$100/cy	$15/cy	
Total Cost (U.S. dollar, Vendor Estimate)	Est. future cost $6.4 million for "same site"								
Cost/Unit Volume (U.S. dollar/cubic yard, Vendor Estimate)	$140/cy								
Vendor	LLNL/UCB	Steam Tech Environmental Services	UCB/OHM	Steam Tech Environmental Services	Steam Tech Environmental Services	SIVE Services	ENSR	ENSR	SIVE
Vendor Comments/Status							Lucent Technologies/Bell Laboratories Patent	Lucent Technologies/Bell Laboratories Patent	
Owner	LLNL	Southern California Edison	U.S. Navy	U.S. Navy	DOE		Lucent Technologies	AG Communication Systems	

Site	LLNL Gas Pad	Visalia Pole Yard	Lemoore NAS, CA	Alameda NAS, CA	DOE, Portsmouth, Ohio	Solvent Services, San Jose, CA	Lucent Technologies, Skokie, IL	AG Communication Systems, Northlake, IL	Amoco Minneapolis, MN
Owner Comments		Craig Eaker (SCE): two of six monitoring wells remain above cleanup goal. Thinks two years of pump & treat plus sparging may clean them up "enough." Believes compliance point may be approx. 1/2 mile off site. Thinks K=1.0E-3 cm/sec would be lower limit of steam feasibility.					No Further Remediation Determination received from IEPA. Achieved Teir 1 Criteria - no rebound, no ongoing monitoring. Site has been redeveloped into movie cinema.	No Further Remediation Determination from IEPA. Achieved Tier 3 Criteria. Site redeveloped into warehouse distribution center with soft drink bottling operations. Ongoing monitoring	