SEALAND ENVIRO

THERMAL REMEDIATION GROUP

PREPARED BY:

SEALAND ENVIRO LLC
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CURRENT ENVIRONMENTAL SOLUTIONS
15399 CRANES MILL ROAD
CANYON LAKE, TX 78133

THERMAL REMEDIATION GROUP

Sealand Enviro's Thermal Remediation Group offers in-situ thermal remediation (ISTR) for properties and sites contaminated with Non-Aqueous Phase Liquids (NAPLs) and other volatile organic contaminants through an exclusive partnership with Current Environmental Solutions (CES) of Canyon Lake, TX. The partnership combines the large-scale environmental remediation experience of Sealand with the Electrical Resistance Heating (ERH) experience and development of CES to provide the evaluation, modeling, and implementation required to successfully meet project goals using the ERH technology. Services available through this partnership include:

Site Evaluations – CES has developed a proprietary site evaluation form that identifies the critical parameters required to quickly evaluate and predict the cost and performance of ERH for any particular site.

SETI™ Site Evaluation Testing – A comprehensive on-site electrical resistance evaluation that identifies critical site electrical characteristics and design parameters for ERH remediation and safety sub-systems.

Numerical Modeling – Some ERH applications benefit from numerical modeling to evaluate and optimize ERH, vapor extraction, or safety system designs. We offer several well-validated numeric codes capable of modeling vapor flows, vapor composition, electric power distribution, heat transfer, and other parameters.

Laboratory Testing – We perform a wide range of testing services to evaluate treatability, soil dynamic electrical properties, and in-situ degradation rates. We also have strategic alliances with some of the nations' leading universities to offer world class laboratory and experimental capabilities associated with DNAPL fate and transport.

Equipment Manufacture – CES designs and manufactures the specialty multi-phase subsurface heating equipment required to fully implement ERH technology, including systems for power delivery, steam and vapor recovery, and air/water treatment. CES has successfully designed and manufactured power supply units to both domestic and European electric code. The European unit(s) have been independently tested and certified by KEMA, the Dutch equivalent of UL Laboratories.

Full Scale/Turnkey ERH Operations – By combining the CES technology and services above with Sealand's civil site remediation expertise, and the backing of the O'Connell Companies, the Sealand/CES partnership provides our customers with total, ERH operations from a single source contractor. Our technical know-how and ability to enable clients to close difficult sites is unparalleled in the thermal remediation industry.

KEY PERSONNEL

Timothy Jones
Joseph Pezzullo
James J. Malot
Paul D. Armstrong
Robert A Dahl
Raymond V Duhem
William O. Heath
Michael W. O'Brien
Richard Somosky
Mathew Murray

KEY PROJECTS

LNAPL Remediation Gasoline and Dissolved Benzene

PCE/TCE Remediation From Impermeable Clay

Brownfields Redevelopment Using Six Phase Heating

Superfund DNAPL Remediation

TCE Remediation Camp Lejeune

DNAPL Technology Comparison

Residential DNAPL Remediation

Six Phase Heating Remediation Of TCE DNAPL

PCE Remediation

Low Temperature In-Situ Heating – An Option For MPG Sites

SEALAND ENVIRO

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Sealand Enviro is a national environmental services company providing management and construction services for the restoration of sites contaminated by hazardous, toxic and low-level radioactive waste. We provide a comprehensive range of services for site remediation, restoration and environmental response. Sealand Enviro is headquartered in Putnam Connecticut and is owned by Sealand Enviro management. Our customers include large industrial and real-estate companies, Federal and state agencies, and leading engineering and design firms. We are committed to assisting in the restoration of our natural environment and the protection of human health and safety.

OUR SERVICES

Sealand Enviro provides its management and construction services as a prime contractor or team participant on large scale and complex assignments involving the remediation and restoration of sites contaminated by hazardous, toxic or low-level radioactive waste. Our assignments range from Superfund, and Federal property restoration to large scale Brownfield redevelopment. Our projects may include some of the following remediation and restoration services. We do not own or license environmental technologies allowing us to select the most appropriate and cost effective solution for each specific project. Sealand Enviro qualifies as a small business under the Company's primary Federal NAICS code 562910 — Environmental Remediation Services (500 employees).

AREAS OF SPECIALIZATION

- Remedial construction and site closure
- Decontamination and decommissioning
- Demolition and beneficial reuse
- In situ and ex situ soil treatment
- Thermal desorption
- Soil vapor extraction
- Stabilization and fixation
- Contaminant containment
- Slurry walls and landfill capping
- Contaminated sediment dredging and handling
- Groundwater recovery and treatment
- Transportation and disposal of HTRW
- Volume reduction of LLRW
- Ecological restoration
- Natural disaster response
- Lead and PCB abatement
- Salvage and asset recovery

PROJECTS

Sealand Enviro is an accomplished environmental remediation contractor. We have completed complex restoration projects for government agencies and private sector clients nationwide. Our projects are performed in compliance with CERCLA, RCRA, SARA, HSWA, TSCA, CWA, CAA and other Federal and state regulations.

FEATURED PROJECTS

ENVIRONMENT

NYSDEC Former Paulsen Holbrook Site, NY
Under contract to the NYSDEC Sealand Enviro remediated the former wood treatment site utilizing in-situ groundwater and soil treatment technologies.

ENERGY

O'Connell Energy Group, Mansfield Hollow, CT
Under contract to O'Connell's Energy Group, Sealand Enviro constructed a 500 KW – Hydroelectric Project adjacent to the U.S. Army Corps of Engineers – Mansfield Hollow Dam.

FEDERAL

Small Business Teaming, Fort Peck, MT
Provided heavy civil construction services on this challenging project at FT Peck in the remote northeast corner of Montana.

SUPERFUND

Montclair West Orange and Glen Ridge Radium Sites, NJ, Excavation and disposal of 100,000 CY of low-level radioactive waste.

Salem Acres Superfund Site, MA
Remediation of 100,000 CY of hazardous sludge and soils from onsite lagoons.

McGillis & Gibbs Superfund Site, MN
Remediation of old pole wood treatment facility of hazardous waste.

North Lawrence Superfund Site, MA
Remediation of heavy metal contamination by stabilization/solidification and construction of onsite storage cell.

Li Tungsten Superfund Site, NY
Remediation of radioactive tungsten ore and debris from 26 acre site.

Sayerville Landfill Superfund Site, NJ
Remediation including removal of hundreds of 55 gallon drums of RCRA TSCA materials and construction of landfill containment cap.

BROWNFIELD

Worcester Medical City Site, MA
Remediation of 42 commercial and industrial properties on 25 acres resulting in model brownfields redevelopment.

Waterbury Scovill Brass Industrial Facility, CT
Remediation of 96 acre site including 150,000 CY of contaminated soils and onsite treatment.

Natick RUST Program, MA
Pilot residential underground storage tank removal and remediation project at 500 home sites.

FEDERAL, STATE & MUNICIPAL

DOD Loring Air Force Base, ME
Remediation of various operable units on 9,000 acre site over four year period as part of base closure.

DOD Fort Bliss Oil Pits, TX
Remediation of 30,000 CY of oil and pesticide contaminated soils using a transportable direct fired thermal desorption unit.

Airport Remediation, NY & NJ
Remediation of contaminated sites at LaGuardia, Kennedy and Newark airports including emergency response services.

DOE Brookhaven National Labs, NY
Excavation and onsite landfill capping of low-level radioactive waste.

Groundwater Removal and Treatment System, North Carver, MA Groundwater VOC remediation system for MA DEP.

Emergency Response TWA Flight 843, JFK International, NY Emergency response and remedial activities.

Section 1: CES Company Overview

Current Environmental Solutions (CES) was formed in 1997 under a license agreement with the Battelle Memorial Institute(BMI), the original developer of the Electric Resistance Heating (ERH) and Six Phase Heating (SPH) technology for the US Department of Energy. CES was the first licensee to all BMI polyphase subsurface heating patents in 1997. The only other licensee to the BMI patents has only had their license since January 2003, giving CES more than five (5) years experience than any other licensed competitor in applying the BMI patents. Since our formation, we have completed projects throughout the United States, and we have expanded our service internationally through a license agreement with Dura Vermeer in the Netherlands. Dura Vermeer now provides thermal treatment in the Benelux countries.

Global Engineering Solutions (GES) is the international operating affiliate of CES formed in 2004.

As the internationally recognized leader in the thermal treatment of soil and groundwater, our personnel include scientists, engineers, and technicians whose focus is to continue improving and adapting the ERH technology to meet difficult environmental challenges. Following are a selection of industry breakthroughs and successes achieved by CES/GES:

- **In 2003 the CES team who completed the Hunter Army Airfield SPH project were nominated by the US Army Corps of Engineers for the *Savannah District's Trainer's Award* for the "Project and Team of the Year" .**
- **CES ACHIEVED THE WORLDS FIRST DNAPL SITE CLOSURE in 1999 at a former manufacturing facility.**
- **CES ACHIEVED THE SECOND DNAPL SITE CLOSURE in 2000. The contamination extended under a building and under a public-access road. Methylene chloride was reduced to target concentrations by thermally accelerated hydrous-pyrolysis. These closures are unprecedented successes in the remediation industry.**
- **CES in 1999 ACHIEVED FIRST ERH CLEANUP OF PCE, TCE, and cis-1,2 DCE to EPA Maximum Contaminant Levels (MCLs). This was achieved under an operating strip mall where much of the remediation area was public access, and heating was in the presence of buried utilities. This achievement was another first for electrical resistance heating.**
- **CES DEMONSTRATED THE FIRST COMBINATION OF SIX-PHASE HEATING AND MULTI-PHASE EXTRACTION for LNAPL cleanup. The site contained as much as 10 ft of aviation fuel floating on the groundwater in a tight silty clay lithology, and the site treatment goal of less than 1/8 in. was achieved.**
- **CES' SIX-PHASE HEATING WAS SELECTED "BEST IN CLASS" for DNAPL remediation technologies in terms of cost, effectiveness, and speed by the Interagency DNAPL consortium (IDC) consisting of NASA, U.S. EPA, U.S. DOE, U.S. DOD, and the U.S. Air Force.**
- **CES SUCCESSFULLY DEPLOYED SIX-PHASE HEATING in a side by side technology demonstration of SPH, Steam Injection, and Permanganate Injection in 1999 at the Launch Complex 34, Cape Canaveral Florida. SPH was the fastest, most effective, and most cost-effective technology tested, and the only technology that met the 90% DNAPL removal goal.**

CES/GES...."***FIRST*** in Electric Resistance Heating"
"WORLDWIDE LEADERS IN ERH SINCE 1997"

Services

We believe that our success will only follow the success of our clients and licensees. We partner with our clients to provide creative and cost effective environmental solutions using unique electrical techniques. Our services range from turnkey remediation projects, to technology licensing, training, and equipment manufacture.

Today, CES/GES brings a wealth of experience and a track record of success to every site evaluation and remediation we perform. Our technical know-how and ability to enable clients to close difficult sites is unparalleled in the thermal remediation industry.

- **Site Evaluations -** a proprietary site evaluation form that identifies the critical parameters required to quickly evaluate and predict the cost and performance of SPH for any particular site.

- **SETI™ Site Evaluation Testing -** A comprehensive on-site electrical resistance evaluation that identifies critical site electrical characteristics and design parameters for SPH remediation and safety sub-systems.

- **Numerical Modeling -** Some SPH applications benefit from numerical modeling to evaluate and optimize SPH, vapor extraction, or safety system designs. We offer several well-validated numeric codes capable of modeling vapor flows, vapor composition, electric power distribution, heat transfer, and other parameters.

- **Laboratory Testing –** We perform a wide range of testing services to evaluate treatability, soil dynamic electrical properties, and in-situ degradation rates. We also have strategic alliances with some of the nations' leading universities to offer world class laboratory and experimental capabilities associated with DNAPL fate and transport.

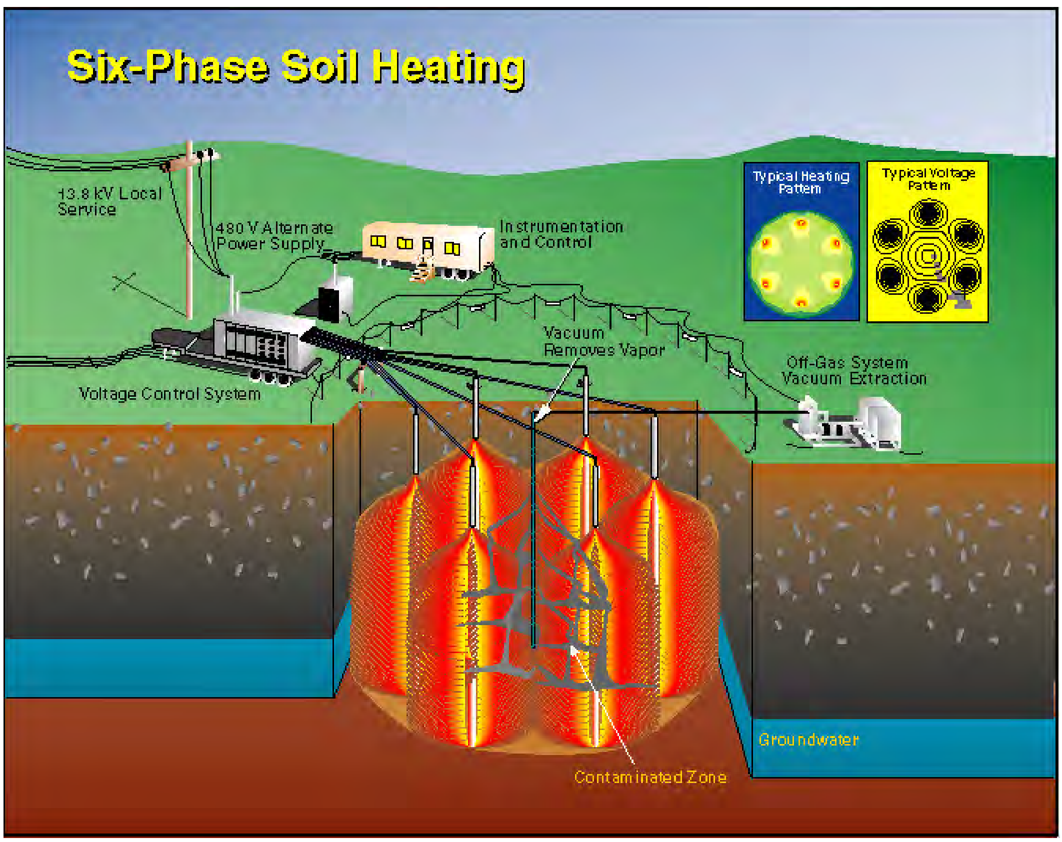
- **Equipment Manufacture -** We design, manufacture, and sell or lease the specialty poly-phase subsurface heating equipment including systems for power delivery, steam and vapor recovery, and air and water treatment. GES has successfully designed and manufactured power supply units to European electric code. These unit(s) have been independently tested and certified by KEMA, the Dutch equivalent of UL Laboratories.

- **Technology Partnerships -** Services range from turnkey remediation to licensing and overseeing the technology deployment. We can license the technology either on a site-by-site or permanent basis. CES/GES also provides specialized equipment and technical support to help our licensees achieve success.

Six-Phase Heating (SPH) Technology and Electric Resistance Heating (ERH)

SPH and ERH use polyphase electricity in either a three or six phase configuration to resistively heat the soil and groundwater to the boiling point of water. Heating increases the volatility of contaminants. Steam is generated, and acts as a carrier gas that strips out contaminants as it rises. The steam is collected from the subsurface by a soil vapor extraction process, and treated above ground by conventional means, including air stripping, activated carbon, and catalytic or thermal oxidization.

SPH provides an efficient and rapid means of remediating soil and groundwater that are contaminated by volatile and semi-volatile organic contaminants. Other applications for SPH include accelerating degradation and reducing viscosity for pumping. Both degradation and viscosity are dramatically affected by heat. CES has successfully degraded contaminants as a primary treatment mechanism on two sites and performed reduced-viscosity LNAPL extraction on two other sites.



SPH and ERH Licensing Status

CES was the FIRST exclusive licensee of the BMI patents in 1997 and currently maintains a worldwide license and sublicensing rights to the BMI poly-phase subsurface heating patents listed below. In 2002, CES and BMI reached an agreement to convert the exclusive license to a non-exclusive license, whereby CES gained significant financial incentives on all subsequent licenses granted by BMI for an undisclosed period of time. Beyond the patents, CES has invested over $2 million in further refinement of the technology, which has resulted in a suite of intellectual property owned exclusively by CES. We have the ability to sublicense the BMI patents, and we offer licensing of the patents as well as our own intellectual property.

The only licensed competitor to CES has only been licensed by BMI since January 2003, whereas CES has been actively deploying ERH since 1997. Hence, CES' actual field experience in applying ERH exceeds that of any other company by more than 5 years. Most importantly, CES' VP of technology, William Heath, was the PRIMARY INVENTOR of ERH during his previous employment with BMI, and he is the only one in the industry actually named on the BMI patents.

BMI Patents	
In-Situ Heating to Detoxify Organic Contaminated Soils United States Patent, 4,957,393 Buelt et al. (Sept. 18, 1990)	Heating of Solid Earthen Material, Measuring Moisture and Resistivity United States Patent, 5,330,291 **Heath**, et al. (July 19, 1994)
Heating to Detoxify Solid Earthen Material Having Contaminants International Patent, WO 93/09888 Heath et al. (May 27,1993)	Treating of Solid Earthen Material and a Method for Measuring Moisture Content and Resistivity of Solid Earthen Material United States Patent, 5,347,070 **Heath** et al., September 13, 1994
	Heating of Solid Earthen Material, Measuring Moisture and Resistivity United States Patent, 5,545,803 **Heath** et al., August 13, 1996

We have licensed the SPH technology in Belgium, Netherlands, and Luxembourg exclusively to Dura Vermeer, NL. Should you have interest regarding SPH in these areas, please contact at:

Duravermeer, NL.
Kruisweg 835
2131 N.G. Hoofddorp
The Netherlands

Tel: +(31) (0)23 569 25 78
Fax: +(31) (0)23 569 25 88

Registrations and Licenses

Members of CES/GES staff or affiliated companies hold Professional Engineering, Geologist or Electrician Licenses in the following states and US Territories

NY, NJ, CT, TX, NC, GA, CA, WA, FL, MI

Insurance

CES/GES maintains the following standard insurance:

Comprehensive General Liability and Pollution Liability	**$1,000,000** per occurrence **$2,000,000** aggregate
Professional Liability	**$1,000,000** claims made **$2,000,000** aggregate
Automobile Liability	**$1,000,000**
Workman’s Comp. & Employer’s Liability	**$1,000,000**
Excess Liability	**$5,000,000**

OSHA Training & Medical Monitoring

CES employees maintain OSHA 40 hr. initial Health & Safety training and 8hr. annual training in compliance with OSHA 1910.120. Also, CES employees undergo annual medical monitoring which exceeds OSHA requirements.

Section 2: CES/GES Experience

A History of Electric Resistance Heating

ERH and SPH were first conceived of in 1987 as a way of pre-drying soil for in-situ vitrification- an in-situ technology that converts soil into glass. Other in-situ thermal treatment technologies existed, such as steam injection, hot air injection, and radio frequency heating, but these technologies have difficulty in low permeability soils, and they do not transfer energy to the soil or groundwater as efficiently as SPH.

With potential applicability to decontamination of volatile organic contaminants (VOCs) from soil, the United States Department of Energy awarded funding to Battelle Memorial Institute (BMI) to develop SPH as a stand-alone technology. Several years of research and development led to the first field pilot study at a DOE site in Savannah River, GA. It took just 9 days to heat to 1000 cubic yards of soil to 100°C. An additional 17 days of boiling demonstrated the ability of SPH to remove VOCs from both clay and sand. This demonstration, along with further research and development led to three more BMI patents. These included an international patent (**Heath** et al., May 1993) for six-phases of electricity for heating (and hence, the name); A U.S. patent (**Heath** et al, Jul 1994) which specified six-phase electricity to achieve even heating patterns within the treatment region; and a U.S. patent (**Heath** et al, Sept 1994) which detailed variations of six–phase and three-phase heating schemes.

BMI performed a second field demonstration 1996 at a Niagara Falls Army Fire Training pit where BTEX and chlorinated VOCs were removed during the one-month remediation. A fifth BMI patent (**Heath** et al., Aug 1996) added a number variations of the poly-phase electrical heating scheme, including the now familiar ERH triangle pattern CES commonly uses for larger sites.

In February, 1997, a field study was conducted at Dover Air Force Base, Delaware, to determine whether or not SPH could heat an aquifer sufficiently to remove DNAPL contaminants. The 30-day test demonstrated the ability of SPH to heat rapidly heat a flowing aquifer and remove tracers mimicking DNAPLs.

Current Environmental Solutions (CES) was formed in April of 1997 by BMI to commercialize the poly-phase subsurface heating technology. In 2002, CES became an independent company.

From July through December 1997, CES performed a field verification study at Fort Richardson, Alaska that consisted of three sequential SPH arrays. In this study, CES succeeded in removing more than 99% of the DNAPL. Moreover, CES successfully demonstrated the effectiveness of larger electrode arrays (i.e. 40 ft spacing as opposed to the standard array of about 24-30 ft spacing). CES also began to develop new site surface grounding techniques for safety systems that led to the ability to heat in public-access areas such as roads, parking lots, and beneath occupied buildings. The demonstration was successful, and CES was contracted and completed the site remediation with three additional arrays during 1999.

Following the Fort Richardson success, the next SPH project was an experiment with heat-accelerated bioremedation followed by a test of steam stripping of benzene and diesel in a bake-off between SPH and radio-frequency (RF) heating at Ft. Wainwright, Alaska. The temperature was held at 35 °C for three months (April through June, 1998), then raised to 100 °C and held for another month. Microbial activity was significantly increased, and the diesel degradation rate was doubled. Then, continued subsurface heating up to 100°C resulted in much faster reduction of benzene and diesel concentrations. SPH was concluded to be more efficient and reliable than RF heating.

SPH was then deployed full-scale on a .86-acre commercial site in Skokie, IL. This project commenced in June 1998, and it was completed in April 1999. At this site, CES achieved the world's first regulatory site closure for a chlorinated DNAPL site with a letter of "No Further Action" (NFA) issued by the Illinois EPA on August 10, 1999.

Concurrently with the Skokie site, CES conducted a pilot study for a major oil company on a river island in Cincinnati, OH during October and November of 1998. Flood warnings resulted in a decision to shorten operating time, but the project goal of 98% reduction in benzene was accomplished as well as 80% removal of diesel components from the groundwater in silt and clay in just 31 days of heating.

From April through July of 1999, SPH was used to lower PCE levels to MCLs beneath an active shopping mall in Seattle, Washington. This was the first time subsurface electrical heating was safely performed in a public-access area and in the presence of buried utilities. The proprietary safety grounding techniques developed by CES to enable this were monumental developments for the technology.

Did You Know?

- **CES' Six-Phase Heating couples energy to soil with 97% efficiency.**
- **CES' Six-Phase Heating uses fewer electrodes to heat to higher temperatures than any other electrical heating technology for minimum installation cost.**
- **In 1995, Six-Phase Heating won the international R&D 100 award (similar to the Oscars for the technology industry) for being the one of the top 100 technologically significant inventions in 1990.**
- **SPH has been covered in business week, popular mechanics as well as numerous trade publications.**
- **In 1999, CES' SPH was selected as BEST IN CLASS for DNAPL technologies by an Interagency DNAPL Consortium (IDC) consisting of NASA, US EPA, US DOE, US DOD, and the US Air Force.**

Between May and December of 1999, CES deployed the SPH technology at a site where as much as 10 ft of kerosene and diesel were floating on the groundwater in a low permeability silty clay soil. The site to the treatment objective of <1/8-in. of NAPL was achieved.

The remediation of methylene chloride from tight silty clay began on a large industrial site from October of 1999 to November of 2000. This was the first in-situ degradation-based cleanup using SPH. The site received our second prized NFA letter from the Illinois EPA.

The famed "Cape Canaveral Demonstration" took place from August 1999 through July 2000. In side by side demonstrations, the three top-rated technologies for DNAPLs (i.e. SPH, Steam Injection, and Permanganate Injection) were compared for cost, effectiveness, and speed. SPH was the only technology to meet the DNAPL removal objectives within the specified treatment time. In fact, we achieved 99% removal of DNAPL while the treatment goal was set at 90%. SPH also proved to be half the cost of the other technologies tested.

In June and July of 2000, CES performed a pilot study at a site containing ethylene dibromide (EDB) in Newark, CA. Although complications existed because of the high conductivity of the brackish groundwater, and the site average temperature reached only 80 °C, the EDB was removed entirely from the groundwater due to heat-accelerated hydrolysis. This event of heat-accelerated degradation was another step forward in refining the applicability and cost effectiveness of SPH. A comprehensive R&D campaign including laboratory testing of modified electrodes and contaminant

APPENDIX A

Selected CES Project Summaries

LNAPL REMEDIATION

Gasoline LNAPL and Dissolved Benzene

Client: US ACE

Hunter Army Airfield
Georgia

In the summer of 2001 Current Environmental Solutions (CES) was contracted to design, build and operate a Six Phase Heating (SPH) system at the Hunter Army Airfield, GA.

SITE BACKGROUND

The site was a flat grassy area located between the main taxiway and the main runway on an airfield. The last of ten 25,000 gallon fuel tanks were removed in 1998 from a former fuel handling area. Soil samples were collected and monitoring wells were installed as part of the closure activities at the site. As a result of the sampling activities, light non aqueous phase liquid (LNAPL) consisting of a mixture of gasoline and diesel with a larger dissolved phase benzene plume was identified down gradient of the former buried tanks.

The estimated area affected by the benzene plume covered 30,000 s.f. The LNAPL layer was up to two feet thick over an area of approximately 10,000 s.f. The contamination extended from 8 feet below grade (bg) to 16 ft bgs, and the total volume of soil and groundwater requiring treatment was roughly 8,900 c.y. The subsurface soil mainly consisted of silty sand grading to sand with depth. Groundwater was encountered at about 10 ft bg.

The following objectives were established for the for the SPH remediation:

1) Remove the LNAPL, and
2) Reduce benzene concentrations in groundwater to regulatory predetermined alternate concentration limits (ACL) of 469 ug/L.

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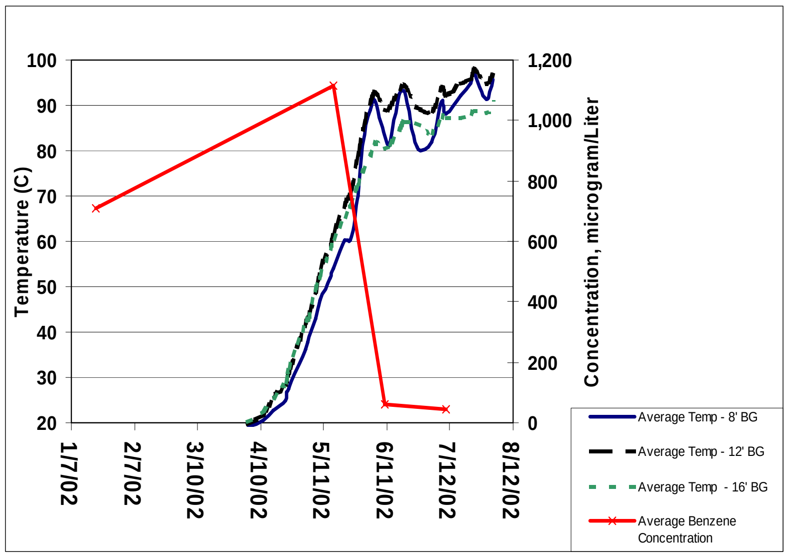
SIX PHASE HEATING SYSTEM

The SPH system consisted of 111 electrodes, 18 Soil Vacuum Extraction (SVE) wells and 5 Dual Vacuum Extraction (DVE) wells. Design, site preparation, and field construction took place between August 2001 and February 2002. Operations commenced in March 2002, and the system ran until early August 2002. Extracted vapors were discharged to the atmosphere within permitted limits, while the extracted groundwater was treated in an air-stripping tower, tested, and then discharged to an infiltration gallery.

RESULTS

Through four months of operation, nearly 1,678,000 kW-hrs of energy was input into the subsurface. Subsurface temperatures reached the boiling point 60 days after heating, exactly as predicted by CES' thermodynamic formation modeling. CES' proprietary electrodes operated to specification, and efficient power coupling between the electrodes and the formation was maintained throughout the remediation.



The SPH system proved extremely efficient, and contaminant mass was removed so quickly that careful management of the input power levels and extracted vapor concentrations was required to remain within a safe lower explosive limit (LEL) in the vacuum extraction system. An estimated 40,000 pounds of subsurface contamination was removed within twelve weeks of operation.

Overall, the SPH remediation was quite successful. CES was able to achieve 100 C evenly throughout the groundwater plume. All of the LNAPL was removed from the site, and the dissolved phase benzene concentrations were reduced to an average of 44 ug/L, far surpassing the regulatory guidelines, and thus achieving both treatment objectives.

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BROWNFIELDS REDEVELOPMENT USING SIX PHASE HEATING IN GLACIAL TILL SOILS

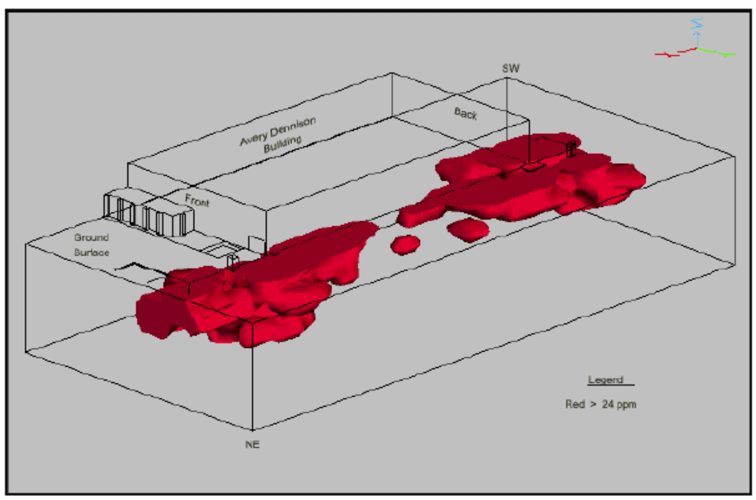
Client: Avery Dennison Company

Waukegan, IL

December 1999-November 2000

Current Environmental Solutions (CES) was contracted to provide Six Phase Heating (SPH) services at a former film coating operation in Waukegan, IL. Methylene chloride (MeCl) was used routinely at the facility as a solvent. In 1985, a fitting failed on a storage tank resulting the release of MeCl to surrounding soil. A consultant was hired to provide initial remediation services and to define the extent of contamination

Seven subsurface soil and groundwater investigations were subsequently performed between 1985 and 1997 in order to delineate the subsurface contamination. The investigations had shown that the subsurface consists of silty clay from grade to 22 feet below grade (bg). From 22 ft. bg to approximately 28 ft. bg was a flowing sand unit. Groundwater was typically found at 25 ft. bg. As typically found in glacial till, perched groundwater was detected as high as 6 ft. bg. All told, nearly 16,000 cubic yards of soil were contaminated with 15,000 pounds of MeCl. The highest soil concentration was identified at nearly 50,000 mg/kg.



The investigations also identified three MeCl source areas. The main contamination was identified in the soil surrounding the former tank storage area in the rear of the facility. The second contaminated area was found in the front of the facility in the soil surrounding the original MeCl off loading point. The third spot of soil contamination was found in an alley adjacent to the facility where the MeCl transfer lines were located.

Several remediation techniques have been implemented at the site to remove MeCl from the soil. Initially a grout curtain was installed surrounding the former tank area. A vacuum extraction system was installed and operated for three years in the former tank area. A pump and treat system was also installed and operated for two years. Finally, perched water sparging was performed with limited results.

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Excavation was considered, but not selected due to the risk of harming the structural integrity of the facility and the neighboring plant.

TECHNOLOGY

SPH has emerged as the leading technology to address difficult in-situ soil and groundwater remediation situations, specifically in low permeability stratigraphy. It has proved an efficient, rapid means of remediating soil contaminated by volatile and semi-volatile organic contaminants.

The technology was developed for the US Department of Energy at Pacific Northwest National Laboratories (PNNL) operated by the Battelle Memorial Institute (BMI). CES was the original licensee of this technology, and the original company formed by BMI to commercialize the technology.

SPH uses polyphase electricity to resistively heat the soil and groundwater to the boiling point of water. This increases the volatility of contaminants, which improves the effects of vacuum extraction. The heat also initiates VOC degradation through various pathways. Once steam is generated in situ, it acts as a carrier gas which strips out contaminants from the soil or groundwater. The steam is collected from the subsurface by a soil vapor extraction process, and treated aboveground by conventional means such as activated carbon and catalytic oxidization.

APPLICATION

The SPH system consisted of 95 electrodes, 34 vacuum extraction wells, five horizontal wells and 41 subsurface thermocouples. The site was heated using a 1,250 kW power supply capable of remote operation and monitoring. Remediation occurred both outside and inside the existing facility. Approximately 10 % of the treatment system was installed below grade because the contamination extended below a public access road.

RESULTS

After six months of operations, the site had been heated to an average temperature of 80°C, with central areas at boiling. Because, relatively little contamination had been extracted using vacuum extraction techniques, CES collected and analyze soil samples and vapor samples for sign of VOC degradation. Following an initial sampling in heavily treated areas, it was discovered that the MeCl had degraded to chloride ion. It is suspected that the degradation mechanism was hydrous pyrolysis oxidation (HPO), but this mechanism was never confirmed.

Once the final closure soil sampling was complete, it was determined that MeCl contamination that formerly exceeded 40,000 mg/kg, with an average concentration of 1,389 mg/kg and a 95th percentile of 2,453 mg/kg, had been reduced to below the Illinois EPA-approved soil remediation objective of 24 mg/kg. The average concentration of methylene chloride remaining in the soil after treatment with SPH was 2.51 mg/kg. The 95th percentile for the soil remaining beneath the identified area of soil contamination was 3.46 mg/kg. Having achieved the Illinois EPA's most stringent Tier 1 Soil Remediation Objective for Residential Properties (13 mg/kg), the State of Illinois issued a **"No Further Action"** letter to the owners, and the property was subsequently redeveloped into an office and warehouse park.

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Camp Lejeune, NC
Site 89
Sept ‘03 – Mar ‘04
U.S. Navy
Camp Lejeune, NC

SITE BACKGROUND

1,1,2,2 Tetrachloroethane (TECA) and Trichloroethene (TCE) were detected in monitoring wells at Site 89, Camp Lejeune, N.C. Investigations concluded that a separate-phase DNAPL was encountered between 5 and 19 ft bgs. It was assumed to be perched on discontinuous, lower permeability layers. The upper vadose zone was immediately treated with a separate technology; however a more sophisticated approach was required to address the DNAPL problem.

Site 89 was characterized by three hydro-stratigraphic units within the treatment interval of 5 to 26 ft bgs. 1) An undifferentiated formation from grade to around 8-15 ft bgs consisting of fine to medium sand with interbedded silt and clay layers. 2) The Belgrade formation, a discontinuous clay layer (perching layer) that was presumed to have retarded much of the downward migration of DNAPL. The discontinuous Belgrade formation occurs at depths from 8 to 18 ft bgs, and consists of clays, fine silty sand, or silt and was presumed to have retarded downward contaminant migration. 3) The River Bend formation begins at a depth of approximately 18 ft bgs and is distinguished by the presence of calcareous sands, shell fragments, and fossil fragments. The overall hydraulic conductivity of the Castle Hayne aquifer and Belgrade formation are 10^{-3} cm/sec and 10^{-6} cm/sec, respectively. Groundwater is typically found at 3 ft bgs.

APPLICATION

To meet the project objectives, CES deployed the Six Phase Heating™ technology using three-phase electricity delivered to an array of 91 vented electrodes to cover a total of 15,900 ft^2. System heating performance and contaminant migration detection was conducted by monitoring subsurface temperatures and pressures at 15 monitoring wells throughout the treatment area. Seventeen horizontal vapor extraction wells were installed under an impermeable and thermally insulated site cap. To ensure that the River Bend formation did not pressurize due to steam generation during heating, 25 deep vents were also installed to collect steam and hot water along the periphery of the heated volume. To further mitigate lateral and downward migration of DNAPL into the Castle Hayne aquifer, the electrodes were installed with the dual capability of extracting vapors and groundwater for hydraulic control. Therefore, active venting and moderate dual-phase extraction successfully managed subsurface pressures generated by heating.

A vacuum extraction system was used to capture steam and vapors. The contaminated steam was condensed in a heat exchanger and the condensate stored in a Baker tank for sampling and appropriate treatment or disposal.

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The non-condensed vapor, containing most of the contaminant mass, was then be treated by catalytic oxidation (CATOX) with an acid scrubber before discharge to the atmosphere.

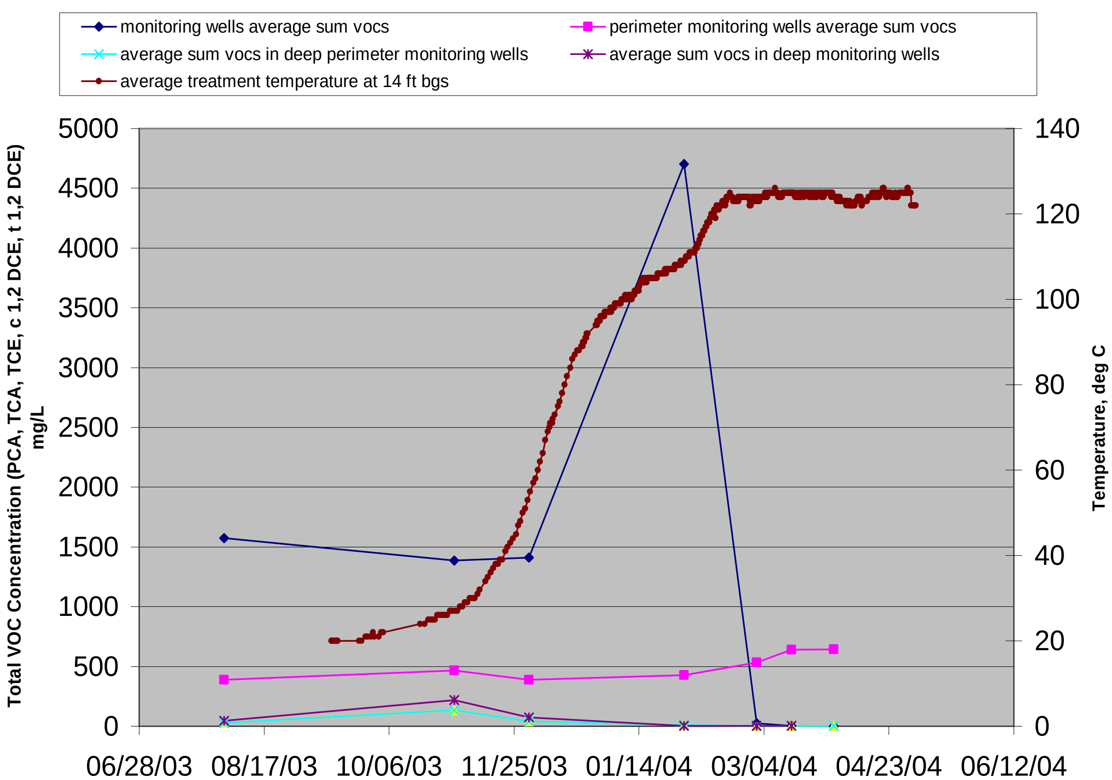
RESULTS

Operations began in Mid October, 2003 with targeted energy to the floor and walls of the site. Approximately two months later, active heating began at the core of the site. Energy was balanced to keep the floor and walls at a slightly higher temperature than the core until the bulk of the site reached active steaming temperatures in early February. Project performance data showed that the SPH Technology was able to increase subsurface temperatures in both the soil and groundwater to 100º C or greater and hold the temperatures to these levels until the desired remediation levels were reached. Active heating continued until April 30, 2004 at which time a review of operational data concluded that the objectives of the test had been achieved.

Heating served to dramatically increase the removal rate of VOCs. The contaminant extraction rate increased from an average of 2 lbs/day at the beginning to averages of 200-440 lbs/day in December and January. As heating continued, the concentrations gradually tailed off to a rate of about 10 lbs/day. It was concluded that DNAPL was no longer present and groundwater concentrations exceeded the treatment goals.

Groundwater monitoring throughout the project showed that the average total dissolved VOCs increased from about 1,500 mg/L to over 4,700 mg/L during heating. DNAPL was actually recovered from monitoring wells during sampling events during this period. Following the first 30 days of steaming, the dissolved total VOC concentrations were reduced to 24 mg/L, and at the conclusion of heating, the average total VOC concentrations were 4 mg/L throughout the site. TECA concentrations decreased by 99.99% after 6 months of operations; from an average of 992 mg/L to 0.9 mg/L.

The results of the technology exceeded the clients' expectations and were completed safely without a single health and safety incident.



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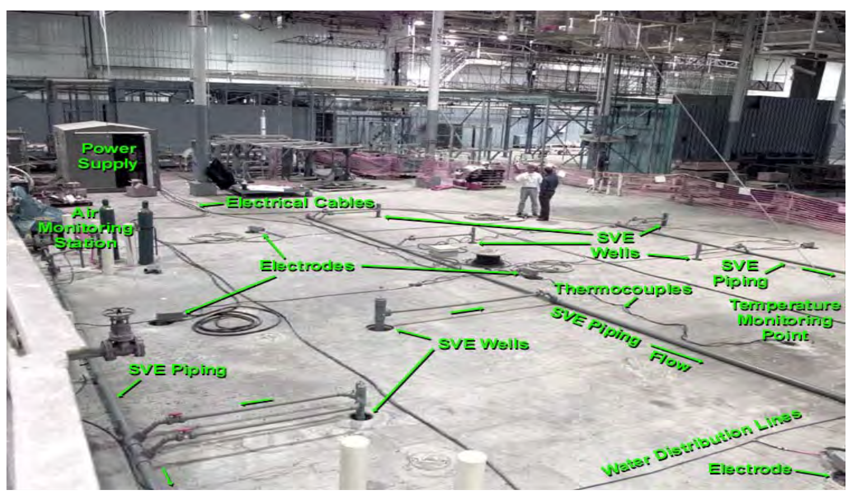
CURRENT ENVIRONMENTAL SOLUTIONS

Six Phase Heating Remediation of TCE DNAPL Under An Active Industrial Plant US Air Force, Plant 4 Ft. Worth, TX

SITE

Six Phase Heating was conducted by CES at Air Force Plant 4 Building 181 where F-16 fighter jets are manufactured. The test objectives were to evaluate the effectiveness and safety of Six-Phase Heating (SPH) beneath an existing structure a at this active military aircraft manufacturing facility. The primary source of subsurface TCE contamination was from leaking degreaser tanks had released a reported 20,000 gallons of the product. Site investigations found that the releases of TCE had resulted in contamination of the vadose zone and groundwater including DNAPL.

The lithology consisted of heterogeneous fine-grained alluvium with varying amounts of clay, sand, and silt underlain by a saturated silty clay unit. Beneath this formation was limestone and/or shale bedrock. Groundwater was encountered between 25-30 ft below grade (bg), and the bedrock was encountered at approximately 35 ft bg.



The peak TCE concentrations were >900 mg/L in the saturated zone and >2700 mg/kg in the vadose zone. Performance objectives were 11.5 mg/l in the groundwater and 11.5 mg/kg in the soil, representing >99% and >98% cleanup for groundwater and soil, respectively.

TECHNOLOGY

After reviewing the relative merits of SPH, steam injection, and radio frequency heating, SPH was the overwhelming choice by the USAF. SPH uses conventional polyphase electricity to resistively heat the soil and groundwater to the boiling point of water. This increases the volatility of contaminants, which improves the effects of vacuum extraction. The heat also initiates VOC degradation through various pathways. Once steam is generated in situ, it acts as a carrier gas which strips out contaminants from the soil or groundwater. The steam is collected from the subsurface by a soil vapor extraction process, and treated aboveground by conventional means such as activated carbon or catalytic oxidization.

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APPLICATION

The SPH System was designed to treat a circular area of 3,120 sq ft within the 35-ft interval between the building floor and the underlying limestone bedrock. Seven electrodes were used in a hexagonal pattern at 20 ft spacing. Steam, VOCs, and soil gas were collected through SVE wells installed within the array. Condensed steam was collected and treated with an air stripper. Non-condensed vapors were treated with an existing treatment system that included a catalytic oxidizer and scrubber.

RESULTS

The first 30 days of SPH operations resulted in a 40 fold increase in TCE vapor concentrations from a baseline of 40 mg/m^3 to 1,855 mg/m^3 on day 36. The maximum TCE extraction rate was 11.7 lb/day , and approximately 330 lb of TCE were extracted during the 88 day test.

Groundwater samples were collected before, during, and after the remediation from 10 DNAPL tracer test wells. Results proved that SPH had reduced TCE concentrations in the groundwater to below the 10 mg/l performance objective. The mean concentration in groundwater fell from 73.4 to 3.6 mg/l. Soil samples showed reduction to <1 mg/kg.

The mean chloride concentration in groundwater doubled during the heating with an average increase of 75 mg/l. The increase in chloride concentration was attributed to reductive dechlorination of the TCE, and this phenomena may have contributed significantly to the reduction of TCE concentrations at the site.

Because the technology met the treatment objectives in a safe manner and was cost-effective compared to other alternatives, the SPH coverage was enlarged to remediate the entire 0.5 acre source area.

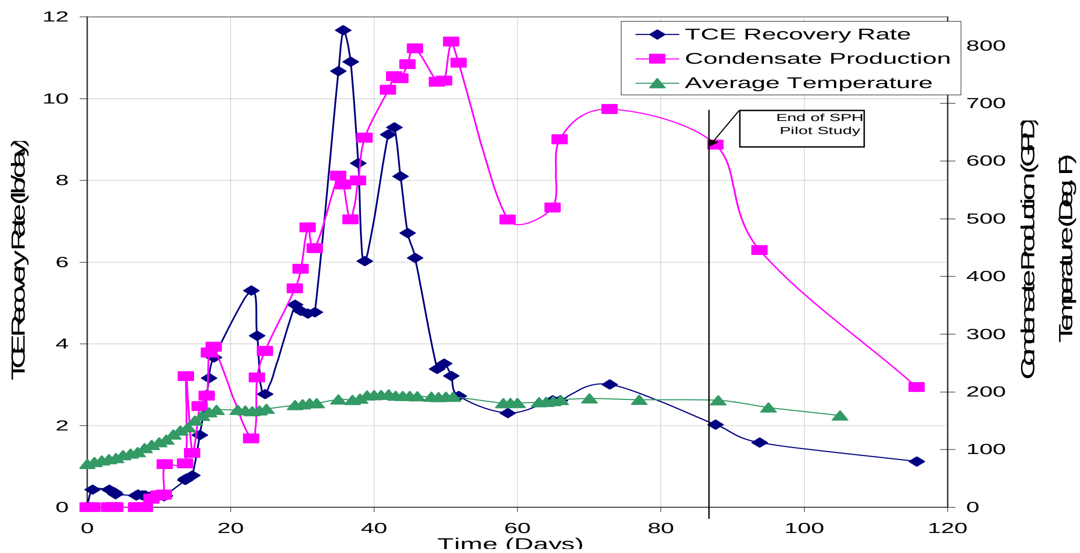

Figure 1. Site Operating Data

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Thermally Stimulated Degradation of Contaminants as an Emerging Application for Six-Phase Heating

William Heath, Chief Operating Officer
Current Environmental Solutions
www.cesiweb.com

Six Phase Heating is a thermally enhanced soil vapor extraction (SVE) technique that targets both contaminated soil and groundwater. It delivers conventional three-phase electricity to the subsurface through metal electrodes. Once in the subsurface, the electrical energy resistively heats soil and groundwater to generate steam. Contaminants are mobilized by direct volatilization and in situ steam stripping, removed by SVE, and treated before venting to the atmosphere. In parallel with steam assisted removal, subsurface heating has also proven effective in stimulating rapid in situ degradation.

Current Environmental Solutions (CES) is actively researching techniques for accomplishing in situ degradation of soil and groundwater contaminants, as a both a primary thermal treatment technique, and as a polishing step following steam induced separation. The potential for rapid in situ degradation of contaminants as observed at prior CES treatment operations and in the laboratory suggests a less energy and capital intensive method for treating contaminated sites at temperatures below boiling and the possibility of extending treatment to low-volatility contaminants.

In particular, low-temperature heating in the range of 50 to 80˚C has been shown effective in degrading a variety of dissolved-phase compounds. At these low temperatures, the need and costs for significant venting operations and above-surface treatment of soil off-gases can be avoided, and steam condensate requiring secondary treatment is not generated. Furthermore, significantly less electrical power and energy is required, enabling larger volumes to be treated with the same Six-Phase Heating™ equipment, using fewer electrodes at larger inter-electrode spacing, and a presenting a much smaller electricity bill on a per volume basis.

Contaminants that have been thermally degraded during Six Phase Heating operations include trichloroethylene (TCE), methylene chloride, cis 1,2 dichloroethane, 1,2 ethylene dibromide, 1,1,2,2 tetrachloroethane, and diesel range organics. We believe in situ degradation occurs as a result of the following mechanisms:

- thermally accelerated hydrolysis reactions,
- biodegradation by thermophilic consortia that are stimulated by heating,
- oxidation-reduction (redox) reactions driven by a shift in the thermo-chemical groundwater equilibrium,
- hydrous pyrolysis (under aerobic conditions) as reported by Knauss et al (1998).

Degradation of TCE during Pilot-Test at Cape Canaveral

During late 1999 through mid 2000, Six-Phase Heating was demonstrated at Launch Complex 34 at Cape Canaveral, Florida, as part of a multiple technology demonstration for the in situ remediation of dense DNAPL. The contaminant of concern was TCE, residing as a separate phase along the surface of a clay aquitard at a depth of 45 ft. A total of 6,250 yd^3 (4780 m^3) was treated at relatively low electrical power levels.

The contaminant impact at Launch Complex 34 was limited to a surficial aquifer overlying a confining clay unit located about 45 ft bgs. Across most of the site, groundwater was encountered at 4 to 7 ft bgs, with a typically flat groundwater gradient. The subsurface was divided into the following four distinct geologic units:

- The upper sand unit (USU)
- The middle fine-grained unit (MFGU)
- The lower sand unit (LSU)
- The lower clay unit (LCU)

The USU is a lens of uniform fine sand extending from grade surface to the top of the MFGU, which is at 20 to 23 ft bgs. The MFGU consists of silty and clayey fine–sands, with occasional thin sand lenses filled with shell fragments. The thickness and depth of the MFGU unit is irregular across the test site. Located beneath the MFGU, the LSU is a silty, fine sand lens that extends to the top of the LCU. The LSU typically extends from 30 to 45 ft bgs. The LCU is located at approximately 45 ft bgs, and acts as an aquitard.

Pre-demonstration sampling and monitoring within and adjacent to the test cells determined that the SPH test cell contained approximately 11,313 kg of TCE. Of this, 93 % was designated as a separate-phase DNAPL, based on the previously calculated maximum theoretical soil saturation concentrations equal to or greater than 300 mg/kg of TCE. Most of the DNAPL was located within the LSU above the LCU. As expected, the highest TCE soil concentrations were measured along the LCU aquitard at 45 ft bgs, ranging up to 42,405 mg/kg.

The Six Phase Heating demonstration system used 13 electrodes, each with two conductive intervals located at 23 to 30 ft bgs and 38 to 45 ft bgs. The lower heating interval was selected so that extra power could be directed into the most heavily impacted DNAPL region, within the LSU. To protect the thin aquitard, the electrodes were terminated at, or slightly above, the surface of the LCU. The upper heating zone was selected to decontaminate the lower-permeability MFGU formation, and to promote buoyant steam flow through that layer to the vadose zone above. In response to a rise in the water table caused by tropical storms that occurred during the demonstration, ground rods were inserted to extend the electrode heating to the 3 to 10 ft bgs interval.

The Six Phase Heating system was operated intermittently over an 11-month period, from August 18, 1999 through July 12, 2000. Subsurface temperatures ranged from 120˚C at the bottom of the treatment zone (45 ft bgs) to 100˚C in the vadose zone while power was applied.

However, the intermittent nature of the operation caused temperatures within the uppermost 10 ft of the treatment zone to average about 80˚C.

The demonstration was successful in that 97 % of the DNAPL mass was removed, based on analysis of soil cores taken before and after the demonstration. From data on the production of elevated levels of chloride ion and other degradation byproducts throughout the demonstration, it appeared that the majority of the TCE mass removal was via in situ degradation. **Figure 1** illustrates the production of organic daughter products at Cape Canaveral during the progressive reductive dechlorination of TCE. While the mechanism for the in situ degradation could not be identified, microbiological analysis of soil core samples showing not only viable but elevated microbial activity following heating.

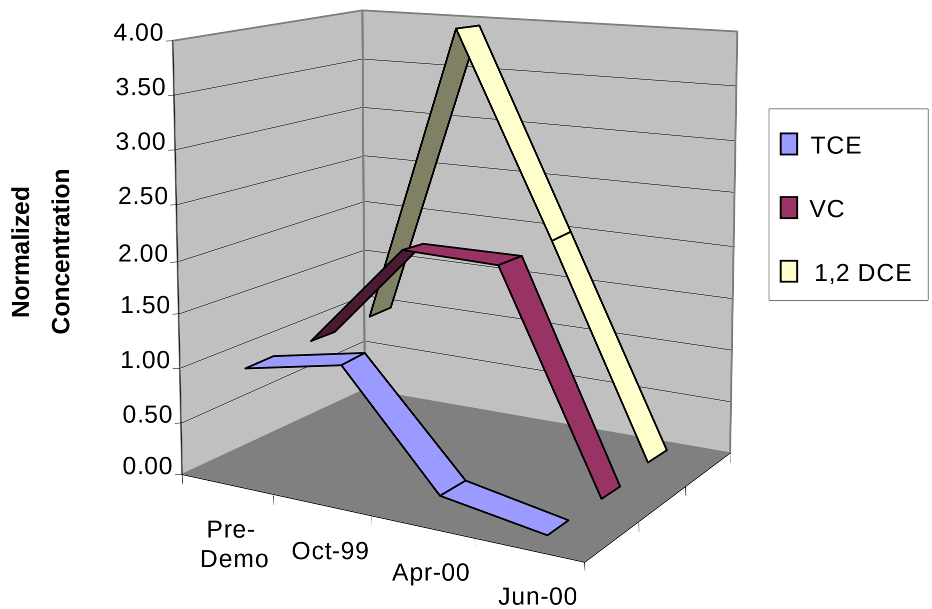

Figure 1. Normalized Concentration of TCE Daughter Products (Well PA-13S)

Figure 2 shows levels of chloride ion produced within and near the test volume. Based on the available characterization data, decontamination took place as follows:

- At least 44 % was removed via the primary route, an in situ degradation pathway
- 19 % was removed in the vapor phase by steam stripping
- Approximately 2 % was mobilized to the surrounding aquifer during a single flooding event, caused by a tropical storm that occurred early in the demonstration
- The remaining 33 % could not be accounted for, but is likely to have been degraded in place
- Sampling wells and soil borings beyond the perimeter of the treatment area revealed a net decrease in contaminant levels, indicating that treatment extended beyond the boundaries of the test cell

Data recently released by the demonstration program team appears to show the presence of an elevated concentration of chloride ions down-gradient of the Six Phase Heating test volume that may account for most of the missing 33% of TCE, suggesting it was indeed degraded in place. This data is, shown in **Figure 3**, is being further evaluated.

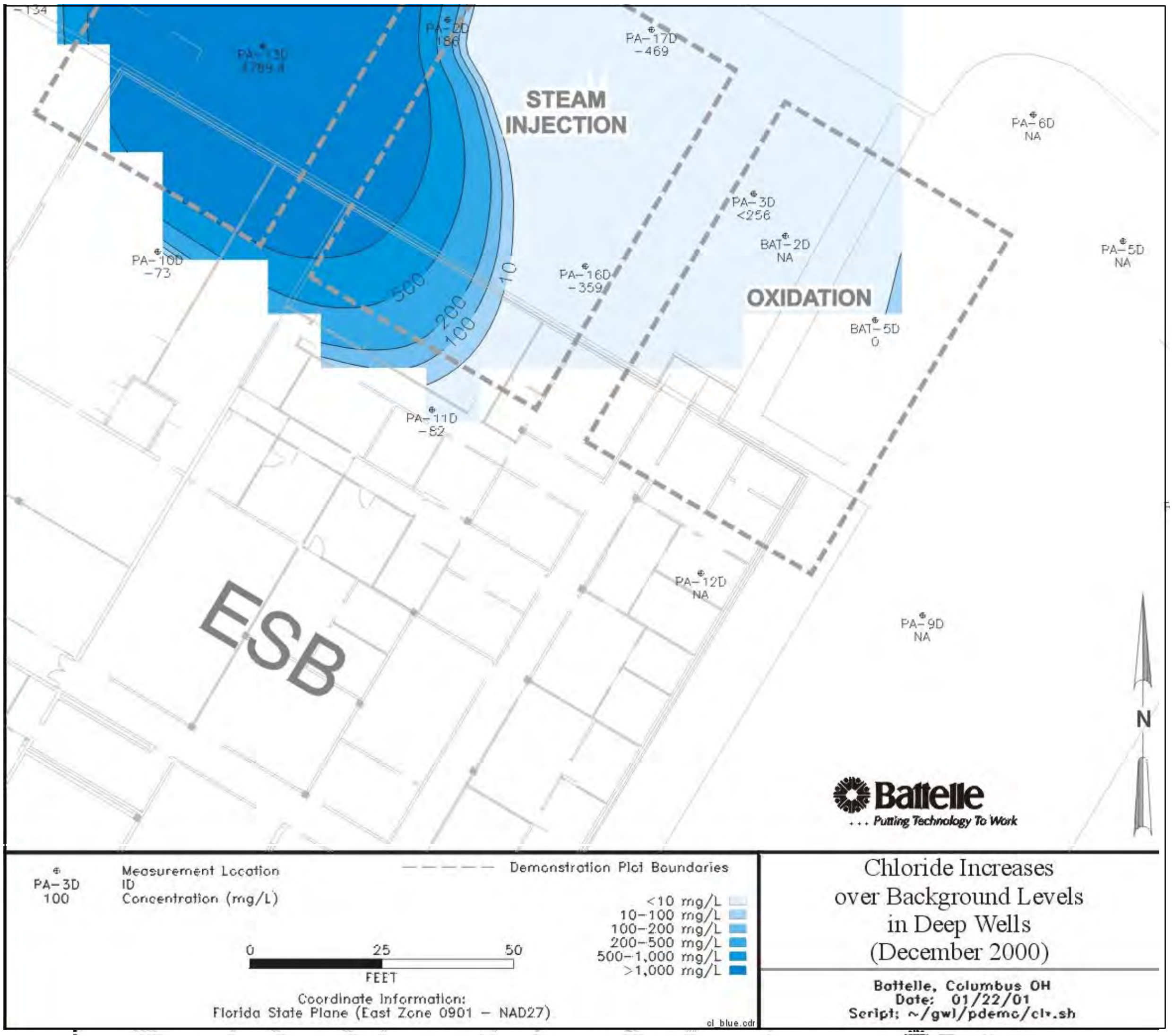

Figure 2. Deep Wells Chloride Concentrations (December 2000)

Subsequent laboratory experiments performed by Pacific Northwest National Laboratories (PNNL) confirmed the ability of indigenous microbial populations to degrade TCE at elevated temperatures (70˚C) and under anaerobic conditions similar to those during Six Phase Heating operations. Ongoing treatability tests initiated in November 2001 by CES for a commercial client are further demonstrating the ability of elevated temperatures (75˚C) to promote rapid in situ degradation of TCE, cis 1,2 DCE and vinyl chloride.

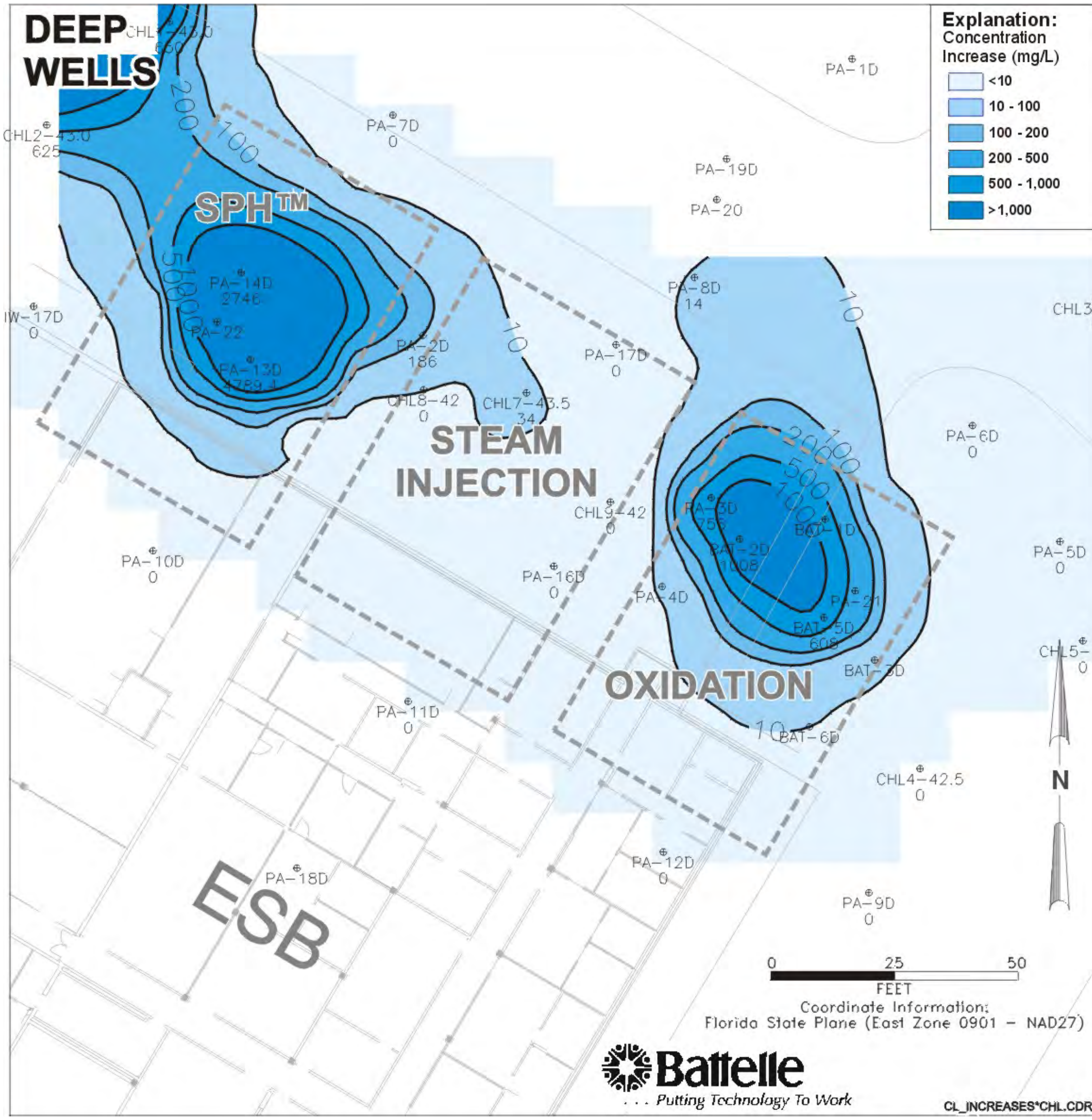

Figure 3. Deep Wells Chloride Concentrations (August 2001)

Degradation of TCE and 1,1,1 TCA at Manufacturing Plant

Six Phase Heating was applied at a former telecommunications manufacturing facility in Skokie, IL using a large-scale network of 107 electrodes to remediate DNAPL pools under a large building. The contaminants of concern were cis 1,2-DCE, TCE, and 1,1,1-trichloroethane (TCA). Initial concentrations in groundwater for cis 1,2-DCE were as high as 160,000 micrograms per liter (ug/L), for TCE up to 130,000 ug/L, and for TCA as high as 150,000 ug/L. The site lithology consisted of heterogeneous sandy silts to 18 feet below ground (bg) and a dense silty clay till from 18-25 feet bg. A shallow groundwater table was encountered at 7 feet bg and hydraulic conductivity through the remediation zone ranges from10^{-4} to 10^{-8} cm/sec. Most of the solvent mass was pooled on top of the clay till at 18-20 feet bg. Treatment was initiated in early June, 1998 and completed in April 1999. Temperatures averaged between 98 and 105˚C

Average groundwater concentration before, during and after remediation are summarized in **Figure 4**. Sampling results showed that all of the DNAPL had been removed and that groundwater concentrations were reduced by 97.9% DCE, 99.1 % for TCE, and 99.9% for TCA. The final groundwater concentrations were well below target cleanup levels given by the State of Illinois TIER III requirements. In fact, groundwater concentrations were approaching TIER I levels throughout the site at the end of treatment operations (< 350 ppb DCE, <25 ppb for TCE, and <1000 ppb for TCA.)

Two striking observations can be made from the data in **Figure 4**. First, increases in the concentration of cis-1,2 DCE during the later stages of treatment (shown in the data on DEC-'98) suggest its production as a result of TCE degradation. Second, the rapid decrease in 1,1,1 TCA is consistent with rapid hydrolysis. The hydrolysis half life of 1,1,1 TCA is 0.03 days at 100˚C.

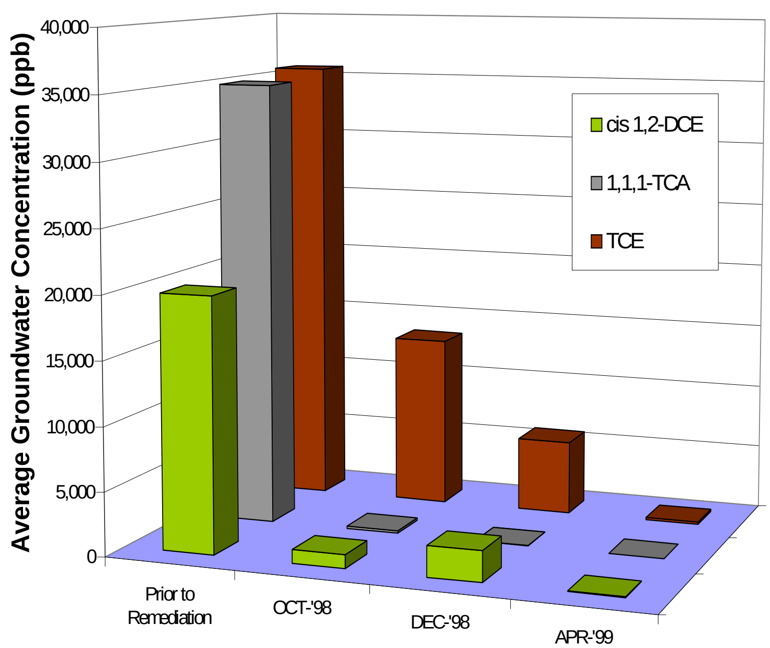

Figure 4. Contaminant Levels before, During and After DNAPL Remediation

Following treatment, groundwater sampling was continued for 12 months with no contaminant rebound. The site was then delisted by the State of Illinois EPA, and represents the first successful DNAPL remediation in U.S. history.

Degradation of Methylene Chloride at Plastics Manufacturing Plant

Six Phase Heating was deployed in 1999 and 2000 to treat a vadose zone contaminated with methylene chloride at the Avery Dennison commercial property located in Waukegan, Illinois.

A 3-D visualization of the extent of methylene chloride impacted soils is shown in **Figure 5**. Methylene chloride levels in the soil beneath the property were in excess of 40,000 mg/kg, with an average concentration of 1,389 mg/kg. The cleanup was conducted under the Illinois EPA Site Remediation Program, with a soil remediation objective of 24 mg/kg.

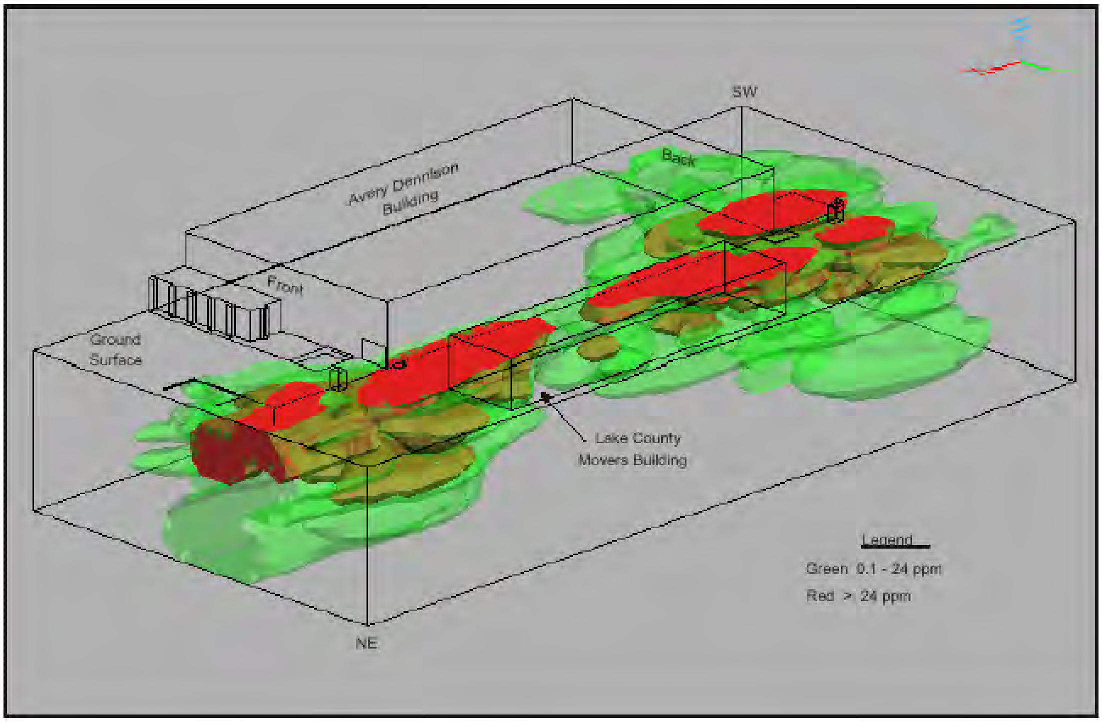

Figure 5. Methylene Chloride Impacted Soils at Avery Dennison Site

Roughly halfway through the 47-week treatment operation, the average temperature was 72°C, but the VOC extraction rates had declined to much lower than expected levels and the total mass extracted was a small fraction of the initial subsurface mass. Extraction rates were likewise lower than expected in the most heavily contaminated regions where subsurface temperatures were at or near 100°C. A decision was made to collect soil samples to determine the remaining methylene chloride concentrations, measure soluble chloride levels, and measure levels of any microbiological activity that may have been stimulating the in situ degradation of methylene chloride degradation. Samples were collected at the most heavily contaminated locations, where subsurface temperatures had reached 100°C, 70°C, and 30°C, along with background samples from untreated locations. Test results are summarized in **Table 1**.

At the 100°C location, the methylene chloride levels were well below the closure objective and six orders of a magnitude less than the original concentration. The samples at 70°C showed a 60% decreases in methylene chloride, and a 30% decrease at 30°C. Soluble chloride levels were found to be elevated by an order of magnitude or more in areas where treatment had occurred. These results suggested to CES that thermally enhanced degradation may be occurring, and may in fact be serving as the primary treatment pathway at the site. A cursory literature review identified the most likely pathways to be microbiological degradation, hydrous/pyrolysis oxidation (HPO), and reductive hydrolysis. However, biological testing on samples removed from the site indicated the biological activity was minimal at optimum temperatures (30°C) and nonexistent at greater than 70°C. Since degradation appeared to be active at temperatures in the 70-80°C range, CES tentatively concluded that either reductive hydrolysis or HPO was occurring at the elevated subsurface temperatures and apparently at sufficiently high rates that heating the subsurface to 100°C was not required to affect treatment.

Table 1. Interim Sampling Results

Sample Location	Initial [MeCl] mg/kg	May [MeCl] mg/kg	Temperature °C	Biological Activity	HPO/Hydrolysis Indicator as Cl-
Background	BDL	BDL	10	moderate	<50 mg/L
TMP 17	3,000	1,000	30	moderate	240
TMP2	40,000	0.07	100	none	445
TMP6	1100	450	70	none	340
EL2	~1,500	0.1	100	none	230

Additional research was performed by CES to determine whether HPO or hydrolysis was the most likely mechanism responsible for the in situ degradation of the methylene chloride. Vapor sampling was performed for methane and carbon dioxide to help differentiate which process was predominant. HPO typically produces carbon dioxide as an end product and hydrolysis liberates methane. The vapor samples indicated that there was a miniscule amount of methane, while carbon dioxide was at four times that of the background level. While hydrolysis and HPO may have been occurring simultaneously, the results were consistent with HPO as the primary thermal degradation mechanism. Further sampling during the remainder of the remedial operation confirmed that treatment to well below target cleanup levels occurred despite boiling conditions.

At the conclusion of treatment operations, the average concentration of methylene chloride remaining in the soil was 2.51 mg/kg, well below the treatment objective of 24 mg/kg. In fact, this is below Illinois EPA's most stringent ingestion/inhalation Tier 1 Soil Remediation Objective for Residential Properties (13 mg/kg). The success of the remediation was confirmed with the collection and analysis of one hundred and twenty-five (125) soil samples. Based on the results of the confirmatory samples, the remediation of the Avery Dennison property was complete and the Illinois EPA determined that no future remediation would be required.

Degradation of Ethylene Dibromide and DCA at Specialty Chemicals Manufacturing Plant

The Six Phase Heating technology was pilot tested at a former chemical manufacturing site in Newark, California from May through July, 2000. The subsurface was heated to between 70˚C and 90˚C over a 2-month period. Following heating operations, subsurface core samples showed high levels of EDB removal while the co-contaminant, DCA, was not removed to any extent. The mass of EDB recovered in soil off-gases and steam vented during the pilot test was insufficient to account for the apparent mass loss. The analytical results are summarized in **Table 2**.

Table 2. Contamination Levels in Soil Cores Before and After Pilot Test

sample depth (feet)	Pre-SPH EDB (mg/kg)	Post-SPH EDB (mg/kg)	Pre-SPH DCA (mg/kg)	Post-SPH DCA (mg/kg)
Boring:	**SPH-7**	**PSB-1**	**SPH-7**	**PSB-1**
3	210	1.9	0	2.4
7	15	1.3	14	2.9
13	180	47	0	99
18	53	180	45	93
Boring:	**SPH-4**	**PSB-2**	**SPH-4**	**PSB-2**
3	0	44	2	49
7	220	120	10	84
13	2,900	560	0	130
18	50,000	4.9	0	54

Immediately following the pilot test, the CES laboratory facility in Richland, Washington initiated a series of exploratory tests using samples of contaminated soil cores and groundwater obtained from the Newark subsurface. These included tests to evaluate the effect of elevated groundwater temperatures on degradation of dissolved contaminants.

Small (50 ml) samples of soil and groundwater obtained from the FMC Site were deoxygenated, and subjected to heating at controlled temperatures of 25˚C (baseline), 50˚C and 70˚C. After two weeks, the samples were analyzed to assess whether exposure to elevated temperatures alone could affect contaminant degradation. The primary contaminants of interest were ethylene dibromide (EDB) and 1,2 dichloroethane (DCA). Samples were analyzed by an independent testing laboratory using EPA Method 8260 for volatile organic compounds at an exposure duration of 2 weeks. The results are summarized in Table 3. Concentrations labeled ND refer to levels below the analytical detection limit. Further analysis of the laboratory samples is underway to detect changes in inorganic daughter products (bromide and chloride ions).

The results in **Table 3** indicate significant reduction in EDB and DCA concentrations in the heated samples compared to baseline. In particular, EDB was reduced by 28% and 99.9% in the samples held at 50˚C and 70˚C, respectively. Reduction of DCA was 0% and 54% over the same temperatures. The presence of known daughter products 1,2 dibromoethane, dibromomethane and vinyl chloride suggests that disappearance was caused by an in situ degradation pathway rather than by fugitive losses during sample handling. Fugitive losses were mitigated by carefully cooling the samples prior to opening the containers, and maintaining zero vapor headspace during heating. The results of the laboratory tests summarized in **Table 3** also tend to corroborate the dramatic decrease in EDB concentrations observed in soil cores obtained before and after the initial SPH pilot test at Newark. The most likely anaerobic degradation mechanisms active at Newark are hydrolysis, and abiotic reductive dehalogenation.

Table 3. Volatile Organic Compound Levels (in ppb) After Two Weeks

Analyte	Baseline	50 ˚C	70 ˚C
1,2 dibromoethane (EDB)	220,000	160,000	190
1,2 dichloroethane (DCA)	19,000	21,000	8,700
bromoform	75	ND	ND
dibromochloromethane	120	ND	ND
dibromomethane	ND	23	ND
Methylene chloride	160	140	270
Benzene	61	64	45
Vinyl chloride	ND	ND	93

Hydrocarbon Degradation at Commercial Fuel Storage Yard

In late 1998, CES performed a pilot treatment of a gasoline spill associated with a fuel storage facility for a major U.S. oil company. The remediation was conducted over the brief period of October 19, 1998 through November 30, 1998. During this time, the treatment was successful in that a targeted 98% removal of benzene was achieved, with post-treatment groundwater concentrations reduced to below a target level of 50 ppb. Surprisingly, the site was also found to be contaminated with kerosene although the source could not be identified. Dual-vapor extraction wells installed by CES to control the water table removed 51,000 gallons of groundwater and 4000 lb of free product. Even more surprisingly, post-test sampling indicated that total petroleum hydrocarbons, specifically diesel-range organics (TPH-DRO) were also reduced. The average reduction in TPH-DRO concentrations was only 7% in soil but 80% in groundwater. Further analysis of core samples was performed to assess whether biodegradation could have occurred as a cleanup mechanism. The results are summarized in **Figure 6**.

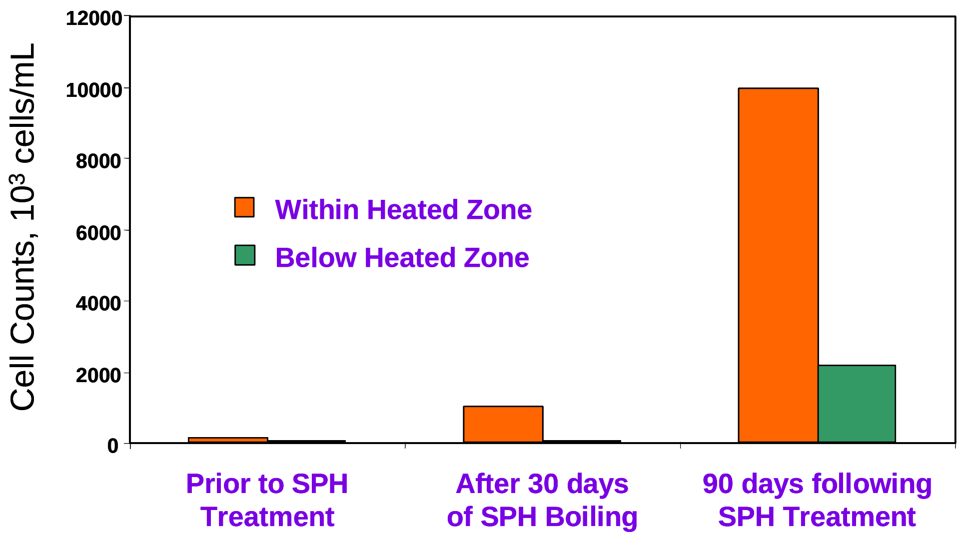

Figure 6. Petrophilic Microbial Activity Before, During and After Treatment

As shown, cell counts for microbes adapted to petroleum metabolism were found to increase dramatically during and following the treatment period even though the site was held at boiling conditions for 4 weeks. In fact, the largest increase was found within the heated area in comparison with samples taken in the cooler region directly below the electrode arrays.

Research and Laboratory Testing Capabilities

Further work is underway to assess which mechanisms are most important depending on the type of contaminants involved and depending on site conditions. To better understand and predict in situ degradation pathways, CES has teamed with Pacific Northwest National Laboratories (PNNL) and Portland State University (PSU). Researchers at PNNL are engaged in studies with the U.S. Department of Energy to measure byproduct distributions and mechanisms for thermally accelerated TCE degradation, degradation of low volatility diesel components, and phenanthrene and crysene, which are components of manufactured gas plant (MGP) sites. Portland State University is performing work to identify through DNA fingerprinting the thermophilic bacteria responsible for contaminant degradation at Six Phase Heating operations as an adjunct to their research on extremophilic biology at undersea thermal vents and hot springs.

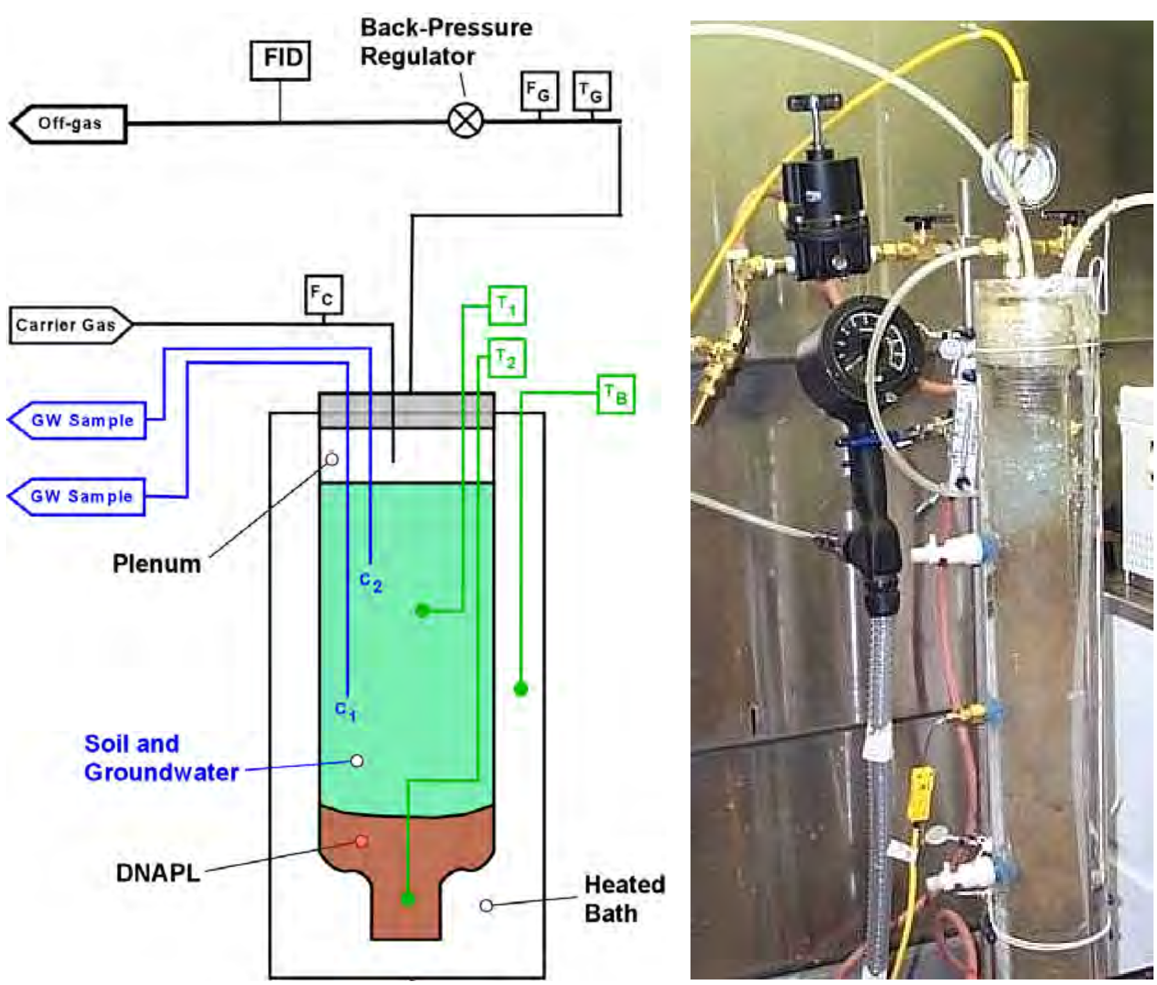

Figure 7. Bench-Scale Treatability Test System

To provide engineering data for Six Phase Heating applications, CES has developed its own laboratory capabilities to enable cost effective determination of degradation rates, byproducts, and achievable endpoints using field samples of contaminated soil and groundwater. Tests are now being performed to measure degradation rates of TCE, cis 1,2 DCE and vinyl chloride for a pharmaceutical site in Portland, OR where low-temperature heating will be used to attempt to reduce dissolved-phase concentrations to MCLs.

We have also developed laboratory techniques and apparatus for assessing the combined effects of multiphase transport with in situ degradation to track volatilization of pure-phase components, their dissolution, and degradation in a sediment column. This apparatus is depicted in **Figure 7**. It is being used to develop engineering design data for applying Six Phase Heating for treating a DNAPL at a former chemical manufacturing plant in the Bay Area of Northern California. Further tests are planned for an EPA Superfund site contaminated with chlorobenzene and DDT present as a DNAPL.

PCE REMEDIATION

Under Former Dry Cleaners Facility

Clients: Fortune 500 Company
Retail Facility
Western Washington
April-August 1999

In February 1999, Current Environmental Solutions (CES) was retained to remediate tetrachloroethylene (PCE) from beneath a former dry cleaners facility. The dry cleaner was in the corner storefront of a busy retail facility in Western Washington. The storefront shared common walls with other active retail businesses (see site map on next page).
Just prior to initiating remediation, additional site characterization disclosed that the PCE plume extended beyond the footprint of the dry cleaners and into the adjacent alley. Remediation efforts were immediately expanded to simultaneously treat both the interior and the exterior segments of the plume.

SITE

Site lithology consisted of sands to sandy-silts. An extremely shallow groundwater table was encountered at 2-4 feet below grade (bg) that rose to above the ground during part of the remediation. Initial PCE concentrations were 2,000 ug/kg in soil and 3,600 ug/l in groundwater. PCE Cleanup goals were 500 ug/kg in soil (75.0% removal) and 5 ug/l in groundwater (99.9% removal).

TECHNOLOGY

SPH is emerging as a leading technology in difficult in-situ soil and groundwater remediation. It has proved an efficient, rapid means of remediating soil contaminated by volatile and semi-volatile organic contaminants.

The *in situ* cleanup of DNAPL remains one of the toughest challenges facing the remediation industry. Traditional remediation technologies require years of continued application to produce even marginal results at DNAPL sites.

The technology was developed for the US Department of Energy at Pacific Northwest National Laboratories. CES was the first licensee of this technology, and we are the proprietor of sundry improvements. CES has been a licensee of this technology since 1997. The only other licensee has only had experience in applying these patents since January 2003, giving CES over five (5) years more experience than any other competitor.

SPH uses polyphase electricity to resistively heat the soil and groundwater to the boiling point of water. This increases the volatility of contaminants, which improves the effects of vacuum extraction. Once steam is generated in situ, it acts as a carrier gas which strips out contaminants from the soil or groundwater. The steam is collected from the subsurface by a soil vapor extraction process, and treated aboveground by conventional means such as activated carbon, and catalytic oxidization.

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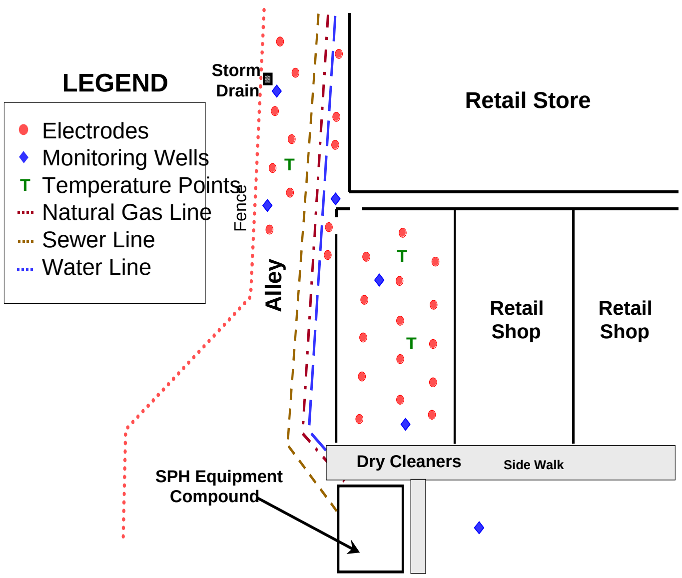
APPLICATION

Fifteen SPH electrodes were constructed inside the former dry cleaning store and 12 electrodes were installed in the alley. Electrodes extended to a depth of 20 feet bg and were electrically conductive from 12-20 feet bg. The groundwater was cleaned from 2-22 ft bg.

Inside the building the SPH system was installed through the concrete floor slab. Performing SPH in the alley however, represented a challenge. The alley contained buried utilities for sewer, electrical, water and natural gas. Additionally, it was a fire lane and could not be closed. CES developed a unique electrode design and installation process that allowed the alley to remain open to delivery truck and pedestrian traffic throughout the SPH operation.



Site Layout

The subsurface was heated using a 500kW-power supply. The steam created was collected in 4 horizontal Soil Vapor Extraction (SVE) wells, 2 in the building and 2 in the alley. The condensed steam was clean and could be discharged directly to a sanitary sewer while vapors were treated by activated carbon.

RESULTS

After 75 days of SPH operations, PCE, TCE, and cis-1-2 DCE levels had been lowered below the MCLs in groundwater, both beneath the building and in the alley.
The specialized grounding methods and electrode design enabled electrical resistance heating to operate in a public access road and directly adjacent to an operating retail facility.

The electrical heating did not cause danger to the public. The alleyway remained open to the public for the duration of the remediation and the adjacent retail shop was unaffected. There was no damage to the existing utilities.

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