ARCADIS
Infrastructure, environment, buildings

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ENVIRONMENT

Mr. Steve Scharf, P.E.
Project Manager
Bureau of Remedial Action
Division of Environmental Alternatives
New York State Department of Environmental Conservation – Central Office
625 Broadway
Albany, NY 12233-7015

Subject:
Additional Information on In-situ Thermal Desorption (ISTD)
Site Area Focused Feasibility Study (FFS)
Operable Unit 3 (Former Grumman Settling Ponds)
Bethpage, New York
NYSDEC Site # 1-30-003A

Date:
March 19, 2010

Contact:
William Wittek

Phone:
631-391-5270

Email:
william.wittek@arcadis-us.com

Our ref:
NY001496.0810.00007

Dear Mr. Scharf:

The subject information is being provided in response to your request for additional information on In-situ Thermal Desorption (ISTD). ISTD is an innovative remedial technology for Volatile Organic Compounds (VOCs) and Polychlorinated Biphenyls (PCBs) and is part of Northrop Grumman’s Recommended Remedy for the Operable Unit 3 (Former Grumman Settling Ponds) Site Area located in Bethpage, New York (NYSDEC Site # 1-30-003A). Specifically, Northrop Grumman recommends using ISTD to remediate the Source Area VOCs (Alternative SA-2 in the FFS) and potentially to remediate select soils impacted by PCBs (Alternative S-P3).

ISTD is a proven remedial technology to remove VOCs from soils, perched water, and, in some cases, groundwater. At the Bethpage Site, ISTD would be used to thermally desorb all the VOCs, including the chlorinated VOCs (CVOCs) from the impacted source areas (soils, low-permeability soils, perched water, and the upper seven (7) feet of the groundwater) where Total VOC (TVOC) concentrations exceed 10 parts-per-million (ppm). During the process, heat is added to these impacted media under controlled conditions in order to “volatilize” or desorb the VOCs from the soils, perched water, or groundwater. The volatized VOCs are then removed from the subsurface via a series of vapor extraction wells and treated by vapor phase granular activated carbon (VPGAC), potassium permanganate-impregnated zeolite (PPZ), and/or a catalytic oxidizer to reduce concentrations of VOCs to acceptable levels prior to discharge to the atmosphere.

ISTD can be used in much the same way to remediate PCB impacted soils. Two major differences are: a) the temperature needed to volatize the PCBs is much higher than it is for conventional VOCs, and b) the vapor treatment system can sometimes require additional treatment components. When ISTD is used to remediate soils impacted by both VOCs and PCBs, a two-step process is used. The temperature is initially raised only high enough to volatize the conventional VOCs. Once those VOCs have been volatilized, then the temperature is raised to remediate the PCBs.

Additional information, including a more detailed description of the ISTD and some selected case-studies from TerraTherm, Inc., the most experienced company that implements ISTD, is provided herein. In TerraTherm's information, they discuss various ISTD technology processes, including Thermal Conductive Heating (TCH) and Electrical Resistance Heating (ERH) processes, which are the only ISTD processes being considered for this project.

Please contact me or another member of the Northrop Grumman project team with any questions or comments.

Sincerely,

ARCADIS of New York, Inc.

William S. Wittek

William S. Wittek, P.E.
Senior Engineer

Copies:
Kent Smith, Northrop Grumman
John Cofman, Northrop Grumman
Carol Henry, Environmental Management & Global Innovations, Inc.
Michael Wolfert, ARCADIS
Carlo San Giovanni, ARCADIS

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ATTACHMENT
TerraTherm, Inc. ISTD Information Packet

STATEMENT OF QUALIFICATIONS

PCB CASE STUDIES

PCB Case Study #1

General Electric (GE) Dragstrip - Glens Falls, New York

PCB Case Study #2

Missouri Electric Works (MEW) - Cape Girardeau, Missouri

PCB Case Study #3

Former Naval Facility, Centerville Beach - Ferndale, California

PCB Case Study #4

Former Wood Treatment Facility - Southern California

High Temperature ISTD SVOC Treatability Summary - February 2010

High Temperature ISTD SVOC Cost and Performance Summary - February 2010

CVOC CASE STUDIES

CVOC Case Study #1

Pierce, Butler, & Pierce - Syracuse, New York - (Poster Only)

CVOC Case Study #2

Memphis Depot - Southeastern Memphis, Tennessee

CVOC Cost and Performance Summary Table - February 2010

TERRATHERM
Think Thermal

In Situ Thermal Remediation
from Concept to Closure Advise. Design. Build. Operate.

Statement of Qualifications (SOQ)
for
Designing, Building and Operating In Situ Thermal Remediation Projects

2008
BUSINESS
ACHIEVEMENT
AWARD
WINNER

TerraTherm, Inc.
10 Stevens Road
Fitchburg, MA 01420
Phone: (978) 343-0300
Fax: (978) 343-2727
www.terratherm.com

Section 1: TerraTherm Company Overview

About TerraTherm

TerraTherm is a worldwide leader in the development and implementation of in situ thermal remediation of hazardous waste. We advise on, design, build, and operate thermal remediation projects from concept to closure.

We offer the broadest array of thermal remediation technologies in the industry, allowing us to tailor project designs to specific site conditions, using the optimal combination of methods, without bias towards any single technology or approach.

TerraTherm partners with leading engineering firms, government agencies, corporations, and property owners in flexible, cooperative relationships to achieve cleanup goals. Our expertise, broad set of proven technologies, and seasoned staff combine to provide the most effective cleanup available for a broad array of contaminants within all soils and site conditions.

We deliver high return on investment, dramatically increase property value, and reduce liability. Our projects are neighborhood-friendly, producing minimal noise, dust and disruption. They achieve complete results within predictable timeframes, enable final site closure, optimize property value, and eliminate the risks of liability and long-term threats from contaminants.

History

TerraTherm was formed by a team of seasoned industry veterans with a passion for innovation and a dedication to making breakthroughs in the effectiveness of remediation technologies and processes. In 2000, a division of Royal Dutch Shell donated a cutting edge technology to the University of Texas at Austin, which in turn licensed it to TerraTherm's co-founders, making the formation of TerraTherm possible. Since that time, TerraTherm has broadened its capabilities, developed and patented new methods, added numerous partners, proven the applicability of thermal remediation, and completed numerous successful projects worldwide.

Here are some milestones:

- Late 1980s/early 1990s
    - Shell Exploration and Production (Shell E&P), a division of Royal Dutch Shell (Shell) develops the TerraTherm ISTD technology as part of its effort to enhance oil recovery.
- 1994 to 1998
    - Shell E&P recognizes the technology's potential to clean up contaminated soil

  - Shell Technology Ventures, Inc. (STVI), a wholly owned subsidiary of Shell E&P that held the ISTD patents, and TerraTherm Environmental Services Inc., an STVI spin-off, conduct seven ISTD demonstrations and projects.
- 1999-2000
  - Shell exits the remediation business and donates the ISTD rights to the University of Texas at Austin (UT).
- 2000 - 2001
  - Ralph Baker, Ph.D. and John Bierschenk, P.G. secure the exclusive license to commercialize ISTD within the United States from UT.
  - They co-found TerraTherm, LLC, assuming the roles of CEO and President, respectively.
  - Jim Galligan, P.E. joins the company as lead engineer. TerraTherm opens offices in Fitchburg, MA and equipment facilities in Houston, TX.
  - TerraTherm, LLC completes first round of funding, becomes TerraTherm, Inc.
- 2002
  - Industry veteran John LaChance joins the TerraTherm team.
  - TerraTherm secures the exclusive worldwide rights to commercialize ISTD
  - Partnership with SheGoTec Japan, Inc. is established.
- 2004
  - Six field projects underway.
  - Successful completion of the first ISTD CVOC project.
  - ISTR industry leader Dr. Gorm Heron joins TerraTherm.
- 2005
  - TerraTherm achieves another ISTD milestone with the successful completion of its first MGP project.
  - Successful completion of a fast turnaround Brownfield cleanup of CVOCs for the City of Richmond, CA.
- 2006
  - Successful completion of the pioneering Southern California Edison Alhambra ISTD project, achieving a No Further Action letter from the State of California.
  - Partnerships forged with Krüger A/S in Denmark and Sweden, and with AIGE, now Provectus Group, in the UK.
  - TerraTherm moves to larger facilities in W. Fitchburg, MA
- 2007
  - TerraTherm secures a license to practice Steam Enhanced Extraction (SEE) from the Univ. of California Berkeley.
  - TerraTherm begins its first SEE project.
  - Successful completion of the first ISTD project remediating DNAPL in fractured rock.
- 2008
  - TerraTherm utilizes ISTD to successfully treat 48,000 cy of CVOC-contaminated soil for the U.S. Air Force at Memphis Depot, TN.
  - TerraTherm adds ERH capability through partnership with McMillan-McGee Corporation.
  - Successful completion of first ISTD-SEE combination at an active dry cleaning facility in Odense, Denmark.
- 2009
  - TerraTherm is awarded the Gold Medal award for Business and Achievement in the Remediation Contracting category by the Environmental Business Journal.
  - 12 field projects underway, 22 field projects completed.

TerraTherm Leadership Team

Ralph S. Baker, Ph.D. is TerraTherm's CEO. Dr. Baker has overall responsibility for TerraTherm's application and development of the ISTD technology and leads the business development efforts. Dr. Baker is a soil physicist with over 30 years of experience, and has authored over 60 publications on in-situ remediation, including four books. Dr. Baker led the development of three comprehensive Engineer Manuals written for the U.S. Army Corps of Engineers on in-situ remediation: Soil Vapor Extraction (SVE) and Bioventing (1996); In Situ Air Sparging (1997); and Multiphase Extraction (1999). He served as technical advisor to government and industry on many remediation projects, and provided guidance for the U.S. EPA on the limitations and optimization of SVE, the most commonly used in-situ technology.

John M. Bierschenk, P.G. is TerraTherm's President and General Manager. Mr. Bierschenk has overall responsibility for general management of the company. In addition, he is the lead Project Manager for TerraTherm. Mr. Bierschenk is a registered Professional Geologist in Pennsylvania (USA), and holds a BS in Geology as well as an MBA. He has 23 years of technical and management experience in the environmental and energy businesses; working as an environmental consultant, general manager of a soil and groundwater remediation equipment company, and as an exploration geophysicist.

Gorm Heron, Ph.D. is TerraTherm's Vice President and Senior Scientist/Engineer. Dr. Heron has 14 years of experience in assessment, design and management of in-situ thermal remediation projects, focusing on the use of Steam-Enhanced Extraction (SEE) for treatment of CVOC DNAPL sites in soil and fractured rock. From 1997-2004, Dr. Heron served as Principal Environmental Engineer with SteamTech Environmental Services, Inc., where he designed, oversaw and operated six major steam projects. Based in TerraTherm's Bakersfield, CA office, Dr. Heron provides technical leadership and oversight in the design and application of ISTD and combined ISTD/SEE systems.

John C. LaChance is TerraTherm's Program Manager. Mr. LaChance has 19 years experience in assessment, design and management of in-situ remediation projects, focusing specifically on CVOC DNAPL sites. He is the project manager for several of TerraTherm's current ISTD remediation projects and provides technical leadership and oversight in the design and application of ISTD systems.

James P. Galligan, P.E. is TerraTherm's Principal Engineer. Mr. Galligan has 15 years experience in estimation, detailed design, procurement, installation and operation of in-situ remediation projects. He has been instrumental in each of the detailed ISTD remedial design and implementation efforts that TerraTherm has carried out. He also serves as TerraTherm's Health and Safety Officer.

Leadership Team Publication Examples

Members of TerraTherm's leadership team are frequently invited to serve on research advisory committees and have published dozens of papers, handbooks, and presentations including:

- Completion of In-situ Thermal Remediation of PAHs, PCP and Dioxins at a Former Wood Treatment Facility
- USEPA Technology News and Trends: In-Situ Thermal Remediation Completed on Wood-Treatment Waste
- DNAPL Removal From the Saturated Zone Using Thermal Wells
- Improved Approach for Implementing ISTD for Remediation of Chlorinated Solvents
- In-Pile Thermal Desorption of PAHs, PCBs and Dioxins/Furans in Soil and Sediment
- Demonstration of Three Levels of In-Situ Heating for Remediation of a Former MGP Site
- An Examination of Using ISTD to Remediate Mercury-Contaminated Soils
- In-Situ Thermal Remediation: Ecological and Economic Advantages of the TUBA and THERIS Methods
- In-Situ Delivery of Heat by Thermal Conduction and Steam Injection for Improved DNAPL Remediation
- Application of ISTD to the Remediation of CVOCs in Saturated and Unsaturated Settings
- In-Situ Thermal Destruction of MGP Waste in a Former Gasholder: Design and Installation
- Performance Relative to Dioxins of ISTD Soil Remediation Technology
- Remediating Subsurface Mercury Contamination using ISTD
- In Situ Thermal Desorption of Refined Petroleum Hydrocarbons from Saturated Soil
- In Situ Thermal Destruction Makes Stringent Soil & Sediment Cleanup Goals Attainable
- Heat from a horizontal wellbore, low cost, self-regulating heaters, and other methods and technologies that enhance thermal remediation.

TerraTherm R&D

TerraTherm's R&D efforts are focused on making our proven thermal technologies ever better; advancing the efficiency, applicability and cost-effectiveness of our solutions, and sharing our findings to advance the state of the art. Our internal R&D group works with leading research institutions to develop, test, and deploy new methodologies and materials. We have frequently been selected as a key contractor in important research projects to prove the reliability of thermal methods for various contaminants, soils, and site types such as fractured rock. Our principals are frequent contributors to the remediation community; providing papers, presentations, and insight in a wide variety of forums and publications.

- Selected as a key contractor in important research projects to prove the thermal methods.
- Partnerships and joint projects with leading institutions for advanced research in thermal remediation, including; the University of Texas, the University of Stuttgart, and Queens University.
- Frequent presentations and panel appearances at important industry events and government-sponsored conferences worldwide.
- In-house R&D and innovation to improve the reliability and cost-effectiveness of thermal solutions.
- Respected and recognized leadership staff with a history of leading publications and innovations in thermal technologies.

Research Partnerships and Joint Projects

We work closely with leading institutions such as the University of Texas and the University of Stuttgart to improve processes and tools. Shell Technology Ventures donated patents to UT, which in turn licensed them exclusively to TerraTherm. We fund and collaborate with UT Austin faculty and students in their research. This close relationship has led to many papers, graduate theses, and numerous research publications and papers.

Another example of research collaboration is the three-year SERDP-funded project featuring controlled release of DNAPL into a lower-permeability layer beneath the water table. This research is being conducted at the facilities of VEGAS - the Research Facility for Subsurface Remediation at the University of Stuttgart, Germany.

Intellectual Property Examples

Patented and Proprietary Materials and Methods

TerraTherm, its licensors, and its leadership team have over 24 patents on a wide range of issues. They include U.S. patents on:

- Vacuum methods for removing soil contamination.
- In situ decontamination by focused microwave/radio frequency heating.
- Thermal well designs.
- Heater blanket designs for in-situ soil heating.
- Enhanced deep soil vapor extraction processes for removing contaminants trapped in or below the water table.
- Radiant plate heaters for treatment of contaminated surfaces.
- Methods for treating DNAPL by applying heat.
- Electrical Resistance Heating (ERH).

Patent Examples

U.S. Patent Nos. 4,984,594; 5,076,727; 5,114,497; 5,190,405; 5,221,827; 5,229,583; 5,244,310; 5,271,693; 5,318,116; 5,553,189; 5,656,239; 5,660,500; 5,997,214; 6,102,622; 6,419,423; 6,485,232; 6,543,539; 6,632,047; 6,824,328; 6,854,929; 6,881,009; 6,951,436; 6,962,466; 7,004,678; and 7,534,926, and Pending; Australia Patent Nos. 720947 and 774595, and Pending; Austria Patent No. E222147; Belgium Patent Nos. 1011882, 1272290 and 1446239; Brazil Patent No. PI9809922-1, and Pending; Canada Patent No. 2289080, and Pending; China Patent Nos. 98805738.7 and 01809975.0; Czech Republic Patent No. 294883; Denmark Patent Nos. 1011882, 1467826, 1272290 and 1446239, and Pending; EPC Patent Nos. 1011882, 1467826, 1272290 and 1446239, and Pending; France Patent Nos. 1011882, 1467826, 1272290 and 1446239, and Pending; Germany Patent Nos. P69807238.3-08, P6020503803-08, P60110056.5-08 and P60215378.6-08, and Pending; Hungary Patent No. 224761; India Patents Pending; Indonesia Patent No. ID0008181; Ireland Patent No. 1011882; Italy Patent Nos. 1011882, 1467826, and 1446239, and Pending; Japan Patents Pending; Mexico Patent Nos. 216411 and 241679, and Pending; Netherlands Patent Nos. 1011882, 1467826, 1272290 and 1446239, and Pending; New Zealand Patent Nos. 500724 and 522078; PCT Patents Pending; Poland Patent No. 191230; Russia Patent No. 001706; Singapore Patent No. 68767; Slovakia Patent No. 283577; South Korea Patent No. 499762, and Pending; Spain Patent No. 1011882; Sweden Patent No. 98932146.8, 1467826 and 1446239, and Pending; Taiwan Patent No. 192090; United Kingdom Patent Nos. 1011882, 1467826, 1272290 and 1446239, and Pending; and Venezuela Patents Pending.

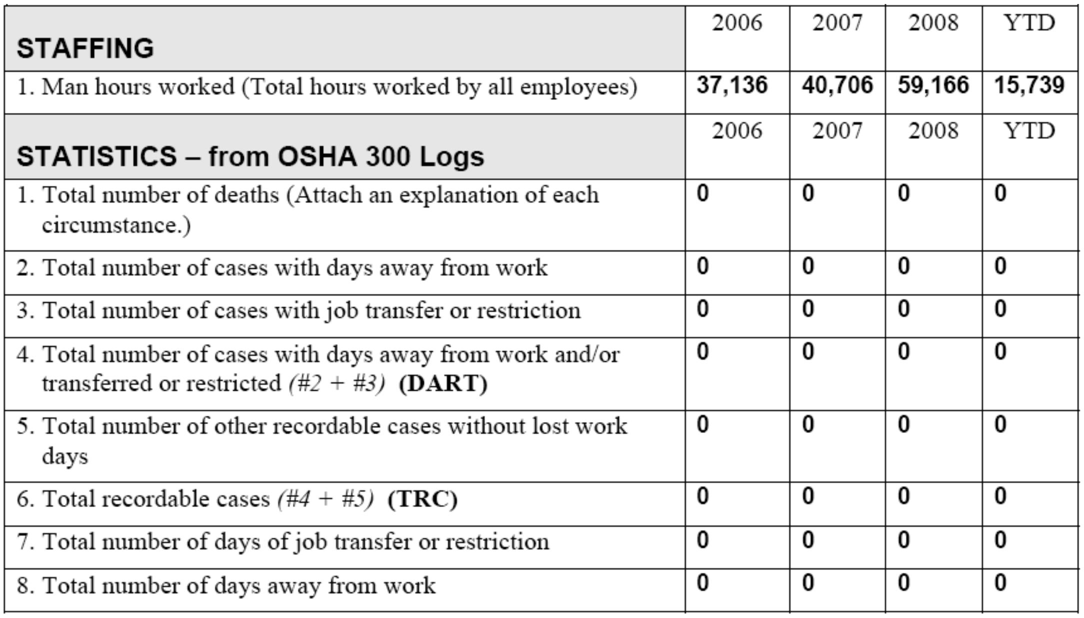
Commitment to Health and Safety

TerraTherm gives the utmost attention and priority to health and safety issues. We are driven to ensure that all of our procedures, processes, attitudes, and plans are highly safety-centric. This attention to detail is at the core of our company's culture, and has resulted in an impeccable safety record to date.

All of our field engineers, construction managers, craftsmen, and equipment operators are OSHA 40 Hour HAZWOPER trained. They also participate in training programs including:

- Electrical Safety
- Hazardous Energy Control
- Hazard Communication
- Respiratory Protection
- Powered Industrial Truck

A snapshot of statistics from recent OSAH 300 Logs tells our safety story.



STAFFING	2006	2007	2008	YTD
1. Man hours worked (Total hours worked by all employees)	**37,136**	**40,706**	**59,166**	**15,739**
STATISTICS – from OSHA 300 Logs	2006	2007	2008	YTD
1. Total number of deaths (Attach an explanation of each circumstance.)	**0**	**0**	**0**	**0**
2. Total number of cases with days away from work	**0**	**0**	**0**	**0**
3. Total number of cases with job transfer or restriction	**0**	**0**	**0**	**0**
4. Total number of cases with days away from work and/or transferred or restricted *(#2 + #3)* **(DART)**	**0**	**0**	**0**	**0**
5. Total number of other recordable cases without lost work days	**0**	**0**	**0**	**0**
6. Total recordable cases *(#4 + #5)* **(TRC)**	**0**	**0**	**0**	**0**
7. Total number of days of job transfer or restriction	**0**	**0**	**0**	**0**
8. Total number of days away from work	**0**	**0**	**0**	**0**

Locations

Headquarters:

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(678)858-4417

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Japan
www.shegotec.com

Section 2: In Situ Thermal Remediation Technologies

Introduction: In Situ Thermal Remediation

In Situ Thermal Remediation (ISTR) has become a "hot topic" for environmental consultants, regulators, developers, utilities, and other companies. Thermal remediation technologies have proven both capable and highly consistent in remediating essentially all hazardous organic compounds to levels at or below regulatory cleanup standards. As a result, the number of thermal projects has skyrocketed.

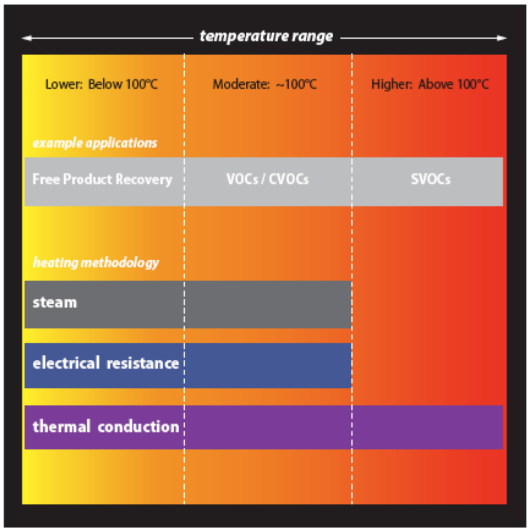
Why are so many people "thinking thermal?" The many advantages of thermal remediation include:

- Delivers robust, highly predictable results.
- Provides clean, quiet, dust free, and neighborhood friendly operations.
- Increases property values and reduces liability on the books.
- Treats inside buildings and near infrastructure.
- Eliminates contaminants in soil to non-detect levels, even to drinking water standards.
- Meets the needs of a broad range of project sites and contaminants.
- Achieves closure in short timeframes.
- Captures vapors and prevents unwanted contaminant mobilization.
- Provides cost effective remedies – often Thermal is the obvious choice.

In close cooperation with you, we design, build, and operate remediation projects from concept to closure. Our broad set of technologies and applications allow us to tailor an optimal design to your site's soil, permeability, contaminants, location and cleanup goals. We apply each technology to its best purpose, alone or in combinations, ensuring that no method is stretched or force-fit to purposes for which another might be more cost effective or efficient. No other thermal remediation company offers this full range of options.

In Situ Thermal Remediation

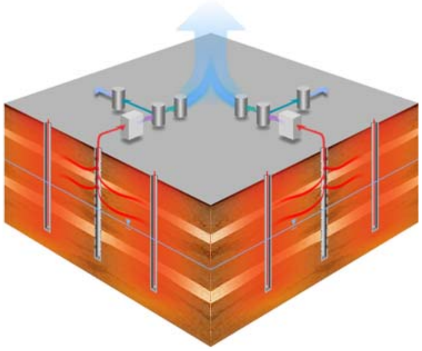
Lower, Moderate and Higher Temperature Applications

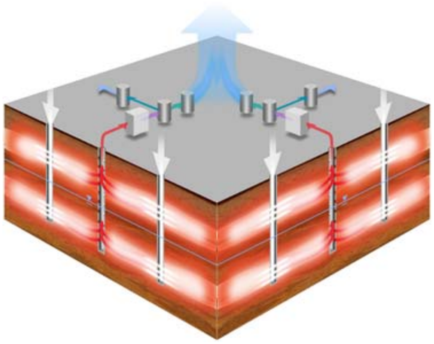


Thermal Remediation Technologies

TerraTherm performs screening and technology selection for all sites to determine and propose the optimal and most cost-effective heating technique or combinations.

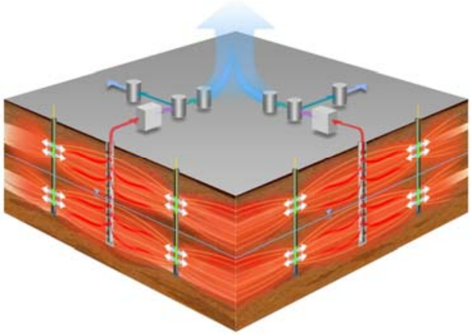
Thermal Conduction Heating (TCH) technologies including In-Situ Thermal Desorption (ISTD) for all sites with low to moderate groundwater flow rates and either VOCs or SVOCs.

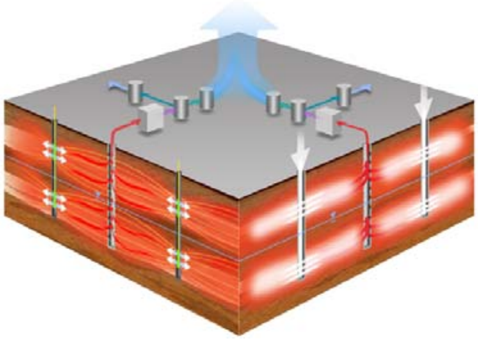




Steam Enhanced Extraction (SEE) is applicable in permeable sites with significant groundwater flow and for sites with volatile or moderately volatile contaminants.

Electrical Resistance Heating (ERH) in the form of Electrothermal Dynamic Stripping Process (ET-DSP™)* for sites with volatile or moderately volatile contaminants.



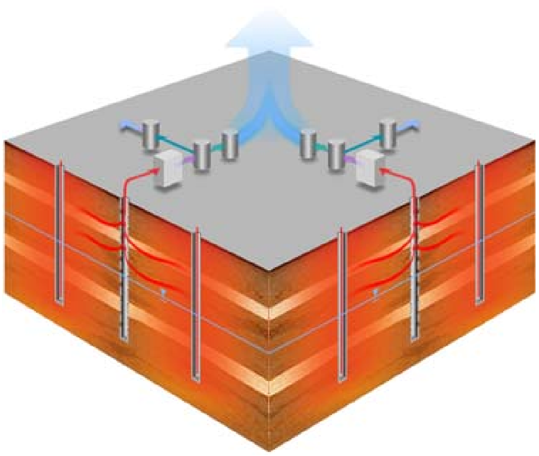


Combinations of these technologies to meet the specific conditions and requirements of a wide variety of sites.

*ET-DSP is a registered trademark of McMillan-McGee Corp.

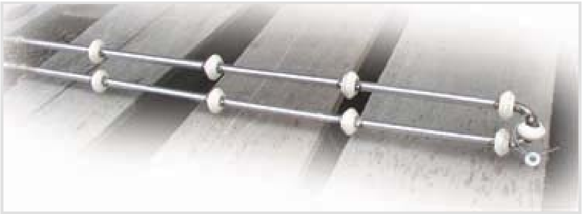
Thermal Conduction Heating

TerraTherm offers low, moderate, and higher temperature applications of Thermal Conduction Heating (TCH). TCH has been applied as a remedial technology to sites worldwide since 1995.



TCH Installation

TerraTherm uses the TCH technology by installing a series of patented electrically-powered heaters and vapor extraction points installed in situ, and operated to heat contaminated soil to target treatment temperatures. Target treatment temperatures are typically the boiling point of the contaminant of concern at the site.



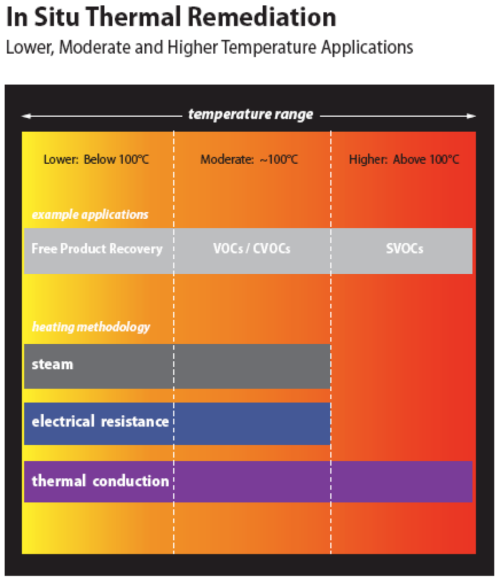
TerraTherm's Patented Electric Heater

What is Thermal Conduction?

Thermal conduction is the process of heat flowing from the hot end of a solid object (like an iron rod) to the cold end. In soil or rock, heat flows from TerraTherm's heater wells out into the formation by grain-to-grain contact (in soil) and across solid objects (rocks). The fluids (water, air, NAPL) in contact with the solids also heat up at the same time. The heat moves out radially from each thermal well until the heat fronts overlap. Due to the invariance of thermal conductivity, sands, silts, and clays conduct heat at nearly the same rate, leading to highly predictable in situ heating.

Benefits of TCH

Thermal conductivity values for the entire range of known soils vary by a factor of less than plus or minus three, while fluid conductivity of soils may vary by a factor of a million or more. Compared to fluid injection processes, the conductive heating process is uniform in its vertical and horizontal sweep. Transport of the vaporized contaminants is further improved by the creation of permeability, which results from drying (and, if clay is present, shrinking) of the soil close to the heaters. Preferential flow paths are created even in tight silt and clay layers, allowing escape and capture of the vaporized contaminants. TCH produces uniform heat transfer through thermal conduction and convection in the bulk of the soil volume. This allows the achievement of very high contaminant removal efficiency with a nearly 100% sweep efficiency, leaving no area untreated.



TCH can be applied at low (<100°C), moderate (~100°C), and higher (>100°C) temperature levels to accomplish the remediation of a wide variety of contaminants, both above and below the water table.

TCH is the only ISTR technology capable of achieving target treatment temperatures above the boiling point of water.

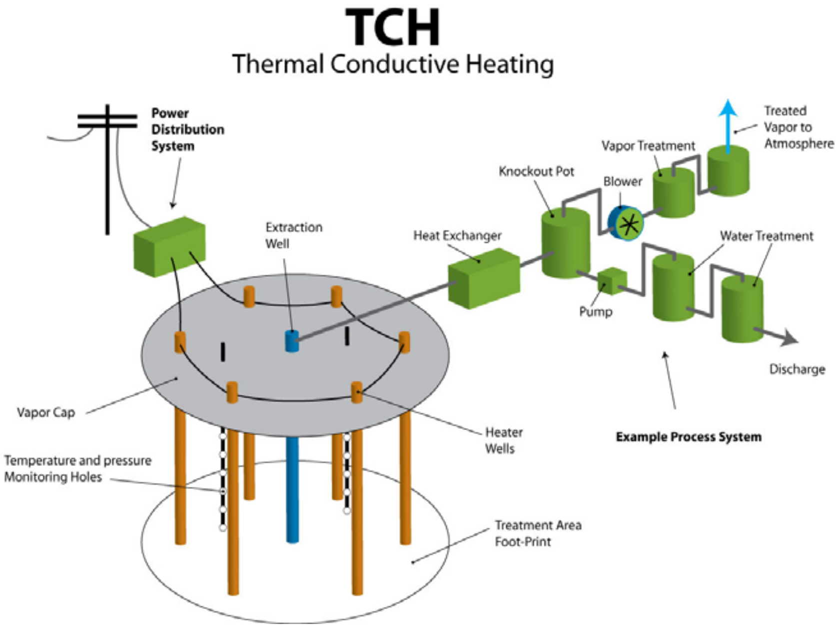
TCH is effective at virtually any depth in almost any media.

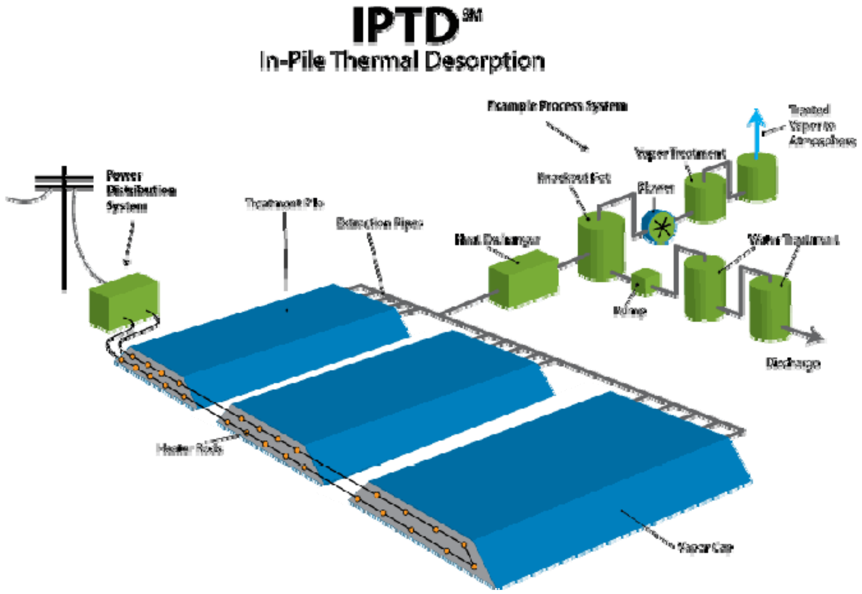
TCH works in tight soils, clay layers, and soils with wide heterogeneity in permeability or moisture content that are impacted by a broad range of volatile and semi-volatile contaminants such as:

- DNAPL
- LNAPL
- Tar
- PCBs
- Pesticides
- PAHs
- Dioxins
- Chlorinated Solvents
- Explosives Residue
- Heavy Hydrocarbons
- Mercury

TCH is Applicable to Both In Situ and Stockpiled Soils

TCH technology can be utilized both for in situ soils and stockpiled soils. The design of the treatment system for in situ soils typically includes vertically installed heaters whereas the design of the treatment system for the stockpiled soils typically incorporates horizontally installed heaters. Examples of the elements of each system are shown below.

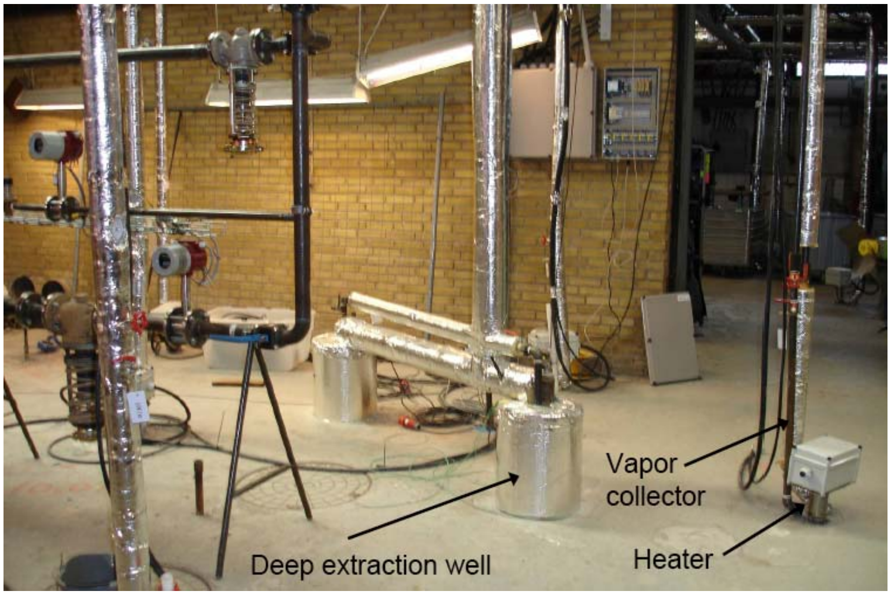




*IPTD and In-Pile Thermal Desorption are registered service marks of TerraTherm, Inc.

Works Inside Buildings and Near Structures

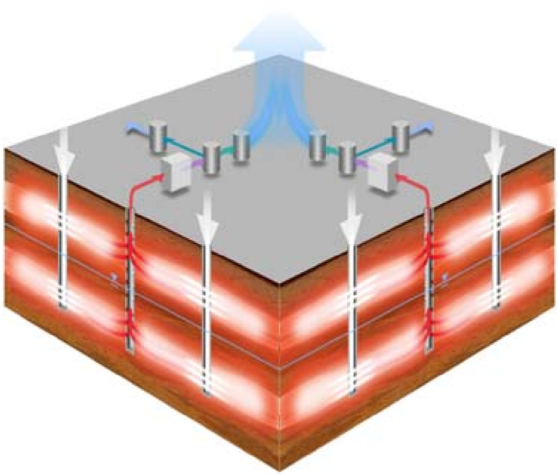
The TCH technology can operate inside and near buildings and infrastructure. This capability has been field proven in several projects. The photo below shows installation inside a working dry cleaning plant in Denmark.

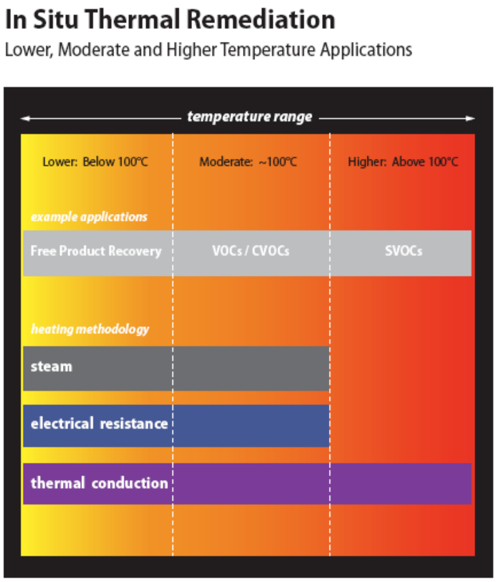


Applicable Above and Below the Water Table

The TCH technology can be applied to contaminants in soils both above and below the water table where the soils can be heated up to target treatment temperatures. Contaminants such as TCE, PCE, and other VOCs that do not require treatment temperatures higher than the boiling point of water, can be treated simply by steam distillation. Contaminants such as PAHs, dioxins, PCBs, and other SVOCs that require higher temperatures are treated by boiling off the water within the treatment zone, and then by heating the soil to the designated treatment temperatures. Where significant groundwater flow is present, additional measures such as groundwater management or a hydraulic barrier may be required.

Steam Enhanced Extraction (SEE)



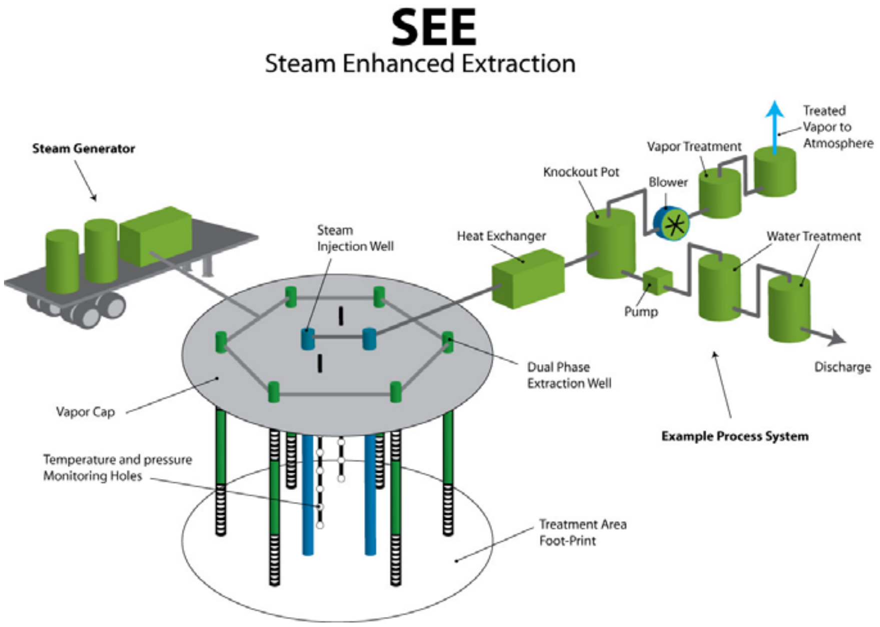


TerraTherm offers Steam Enhanced Extraction (SEE), a technology that has proven highly effective for the recovery of free product and the remediation of volatile organic compounds (VOCs).

TerraTherm uses SEE at low and moderate temperatures. It is applied through the installation of steam injection and extraction wells that are used to inject steam into the subsurface while simultaneously extracting steam, vapors, mobile non-aqueous phase liquid (NAPL), and groundwater. The injected steam is used to heat the subsurface to target treatment temperatures, typically the boiling point of the contaminant of concern at the site.

What is Steam Enhanced Extraction?

SEE achieves on-site separation and treatment through steam injection into wells and extraction of hot fluids. Steam propagation is a stable and predictable process, governed by heat transfer to the formation, and has been studied intensively for oil recovery and remediation of a wide range of contaminants.



SEE Contaminant Removal and Destruction Mechanisms:

- Displacement as a NAPL phase and extraction with the pumped groundwater.
- Vaporization in the steam zone.
- Accelerated vaporization and extraction is achieved in the vapor phase through pulsed pressurization and depressurization cycles.
- Dissolution, destruction, and removal with the extracted water.

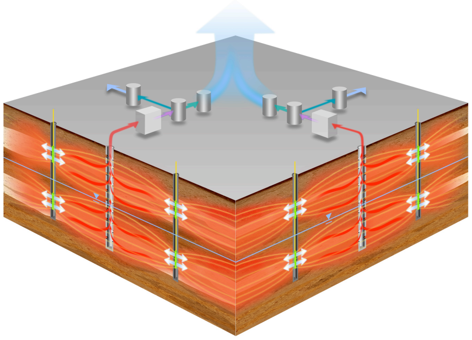
SEE is a Good Fit for Sites with Significant Groundwater Flow

SEE is a logical choice for large and deep sites with significant groundwater flow. The process allows for high net extraction of fluids and displaces large amounts of groundwater towards the extraction wells. As a result, less water has to be heated to allow the formation to reach target temperatures. In addition, this displacement facilitates hydraulic control of NAPL mobility. The steam sweeps through the formation and the accompanying pressure gradient displaces the mobile NAPL and vaporized components as an oil front, which is recovered when it reaches the extraction wells.

Pressure Cycling for Improved Contaminant Removal Rates

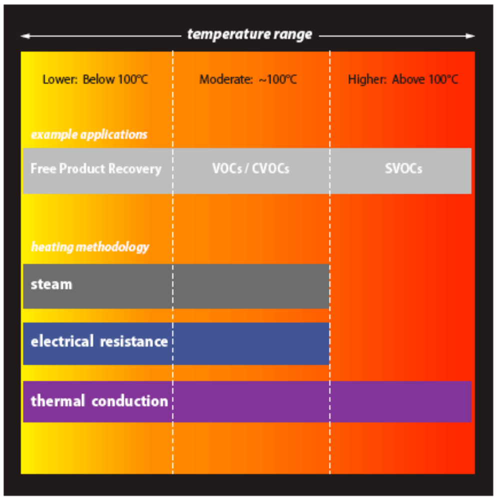
Another significant benefit of SEE is the ability to conduct pressure cycling to improve contaminant removal rates dramatically. After the target zone has been heated and the majority of the NAPL extracted as a liquid, pressure cycling is induced by varying the injection pressure and the applied vacuum. This has been demonstrated to achieve very low concentrations in the original source zone.

Electrothermal Dynamic Stripping Process (ET-DSP™), Electrical Resistance Heating (ERH)



In Situ Thermal Remediation

Lower, Moderate and Higher Temperature Applications



Electrical Resistance Heating (ERH) has been widely applied and proven effective for free product recovery and enhanced vapor extraction at sites with volatile contaminants such as VOCs, CVOCs, and NAPLs, and is applied at low and moderate temperatures. TerraTherm offers an ERH technology called Electro-Thermal Dynamic Stripping Process or ET-DSP™. ET-DSP™ has been field proven on over 30 successful projects by our technology partner, McMillan-McGee Corporation. (See our website http://www.terratherm.com to download a technical white paper on ET-DSP™.)

What is Electrical Resistance Heating (ERH)?

When electric current is passed through the soil, the resistance it encounters causes the soil and fluids to heat up, due to Ohmic (or Joule) heating. The current flows from one electrode to another, primarily through the soil water. Once the water boils off, electrical conductivity becomes negligible and heating ceases; thus, water is added at each electrode to keep them from drying out. Heat-up with ERH is limited to the boiling point of water. McMillan-McGee's ET-DSP™ is an advanced ERH technology.

ET-DSP™ Process

Electrodes are installed in wells throughout the contaminated soil and groundwater volume. The electrode array is connected to a Power Delivery System unit that uses standard, readily available three-phase power from the grid. The process begins by passing current between electrodes causing the soil temperature to rise. This increased temperature results in the volatilization of contaminant compounds into the vapor phase for removal with vapor extraction techniques.

Comprehensive computer controls are used to regulate and optimize the thermal response of the target formation.

ET-DSP™ Advantages

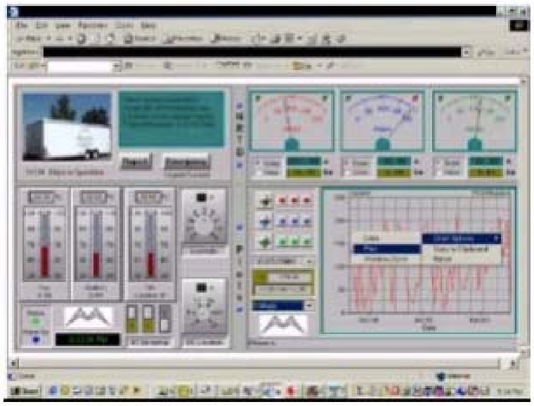
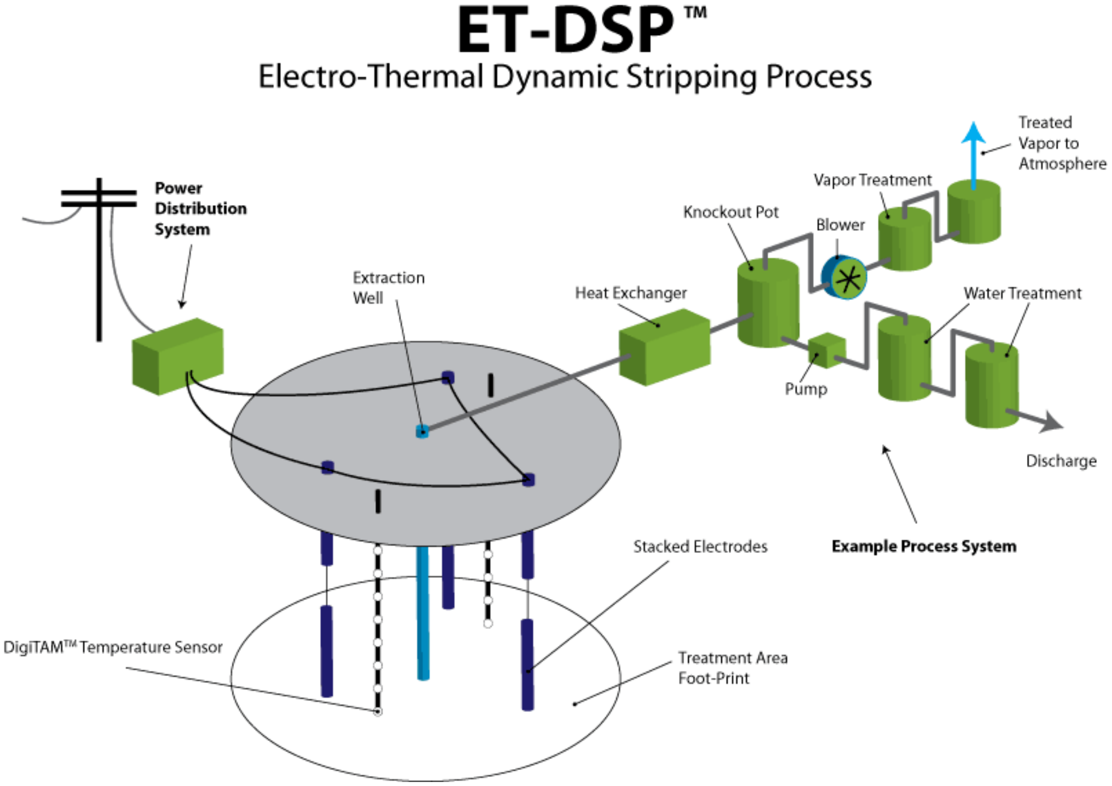


Figure 3 ET-DSP™ web-based control system

ET-DSP™ features efficient energy delivery, convective heat transfer in permeable settings, uniform temperature distribution, and digital real-time monitoring. These features are not found in other ERH technologies. ET-DSP™ project cycles are also shorter, because of its rapid installation process and quick achievement of target temperatures.

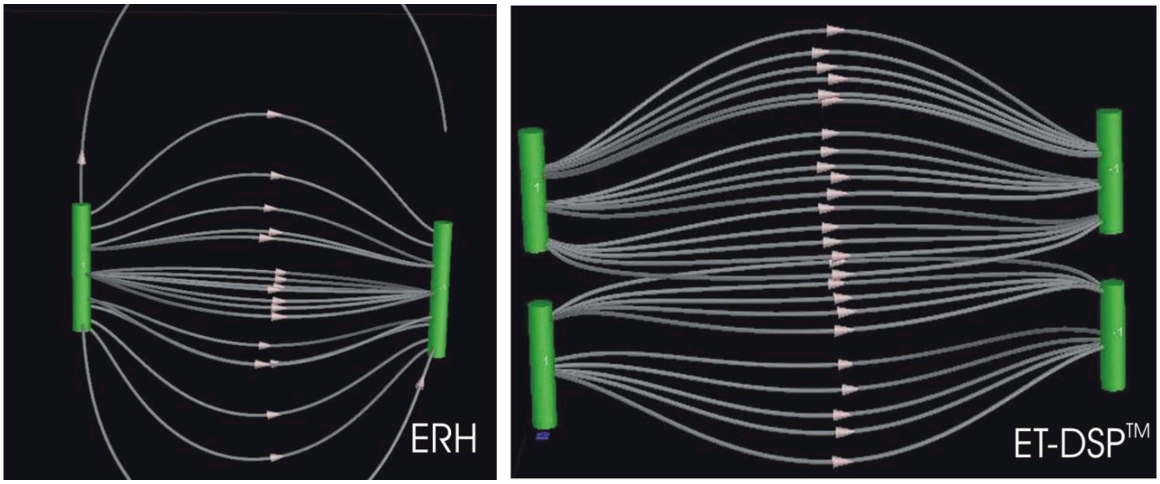
ET-DSP™ Process Description



Comparison of ET-DSP™ with 3-Phase and 6-Phase ERH Technologies

ET-DSP™ contrasts sharply with other ERH technologies on the market today, such as 3-phase and 6-phase heating. Advantages over other ERH technologies include:

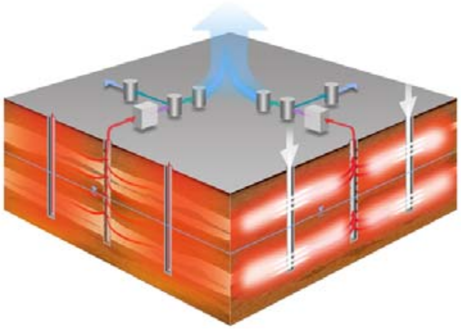
- Superior energy delivery and heat transfer achieved through custom-built electrodes that provide higher output and improved control.
- More effective energy delivery and subsurface heating provided by real-time computerized power controls for each electrode.
- Convective energy delivery is available in permeable settings, making it possible to generate and inject steam for additional heating and contaminant flushing.
- Safety and process transparency are enhanced for both the project team and the client with real-time Digital-at-the-source temperature and monitoring.



Comparison of Current Flow between Conventional ERH and ET-DSP™ Electrodes

Technology Combinations

Combining Thermal Conduction Technologies provides an optimal solution for many sites. TerraTherm has demonstrated that Steam Enhanced Extraction may be combined with either Electrical Resistance or Thermal Conduction methods for a glove-fit design for sites that include complex geology and layers with highly permeable materials (e.g., sandy or gravelly aquifers).



A combination of TCH or ERH and SEE often addresses the entire target treatment zone. At each well location, TCH or ERH is used along the entire depth interval, and steam is injected into the permeable zones.

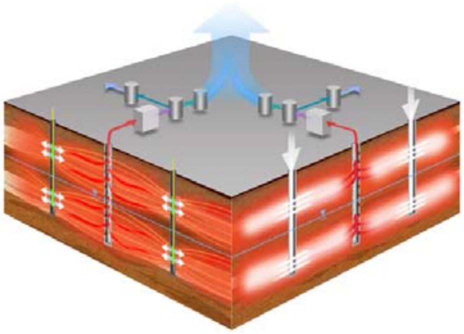
Each of the heating technologies is applied where it is most effective.

TCH or ERH

- Heats at all depths, including the bottom of the treatment zone, where it can form a "hot floor" that prevents downward migration of condensate and/or DNAPL.
- Heats the near-surface soils such that shallow NAPL condensation is prevented; and heats thick clay layers.
- ERH is applied at temperatures at or near the boiling point of water.
- TCH may be chosen at all temperatures, and is the logical choice for higher temperature applications where high boiling contaminants are targeted for removal.

Combined with SEE

- Heats the permeable zones and builds a high-pressure steam filled zone that reduces the water flow into the TTZ by reducing or negating the inward hydraulic gradient, and by reducing the relative permeability of water within the steam saturated porous media.



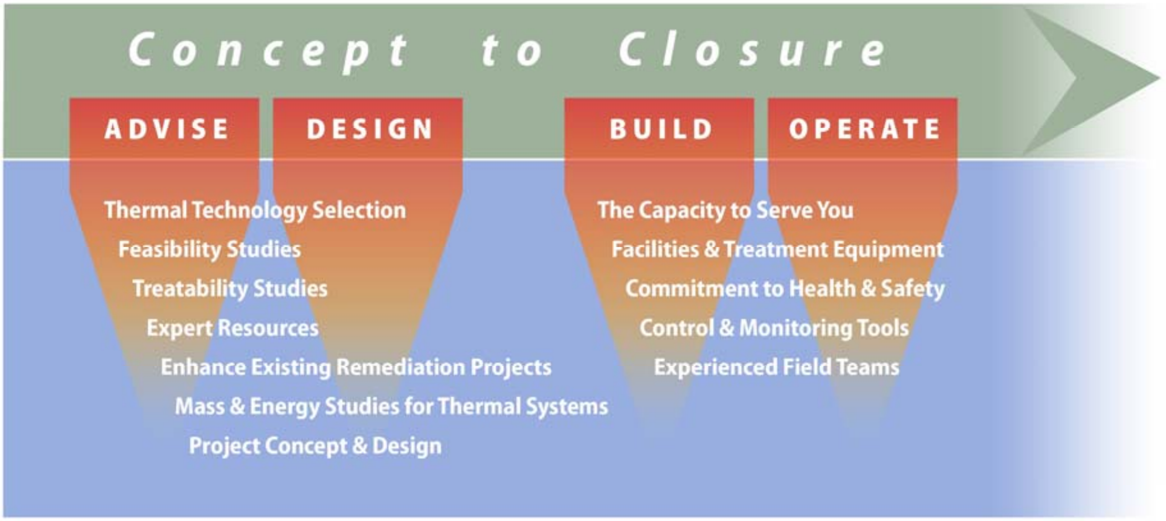
The combined technologies approach optimizes overall heating and treatment efficiency, often reducing both the operational period and the overall project cost.

Section 3: Services

TerraTherm advises on, designs, builds and operates In Situ Thermal Remediation (ISTR) projects from concept to closure.

Our breadth of technologies and field experience combine to maximize our ability to tailor solutions and provide creative problem solving. TerraTherm provides the people, equipment, project management, safety process, logistics, and regulatory understanding required for smooth and successful projects with positive, predictable outcomes.

At each phase of a project, we listen carefully and work as partners with our clients to create and execute the most cost-effective and timely path to your cleanup goals.



TerraTherm advises on, designs, builds and operates ISTR projects from concept to closure.

Advise, Design, Build, Operate

TerraTherm has the materials, facilities, equipment, personnel, project management skills, tools, and experience to design, build, operate, and complete your thermal remediation project. Our field construction and operations approach has been honed by extensive project experience in numerous locations and a wide variety of settings. TerraTherm's record of successful projects features efficient deployment of equipment, quality installation, smooth operation, timely completions, and an impeccable safety record.

Please visit our web site www.terratherm.com, where you will find more detailed descriptions of these services and topics:

Advise & Design Services

- Thermal Technology Selection
- Feasibility Studies
- Treatability Studies
- Expert Resources
- Enhancement of Existing Remediation Projects
- Mass & Energy Studies for Thermal Systems
- Project Concept & Design

Build & Operate Services

- The Capacity to Serve You
- Facilities & Treatment Equipment
- Commitment to Health & Safety
- Control & Monitoring Tools
- Experienced Field Teams

Section 4: Site Types, Applications and Projects

Get it right the first time

When it comes to remediation projects, getting it right the first time is the key to cost-effectiveness and value. To design the optimal solution and deliver on promised cleanup goals and timeframes, we work with you to gain a profound understanding of all aspects of the site including contaminants, geology, location, and potential complexities.

Permeability and Geology

Permeability and geology are key factors that guide the selection of the optimal Thermal Remediation Technology(ies) and remediation design for a given site. Our technologies have been proven effective across a wide range of site conditions.

Thermal Conduction Heating (TCH), Steam-Enhanced Extraction (SEE), and Electrical Resistance Heating (ERH), offer flexibility that can be matched to almost any site, both above and below the water table. Using each of these technologies alone or in combination, we are able to treat a wide variety of geologies including:

- Tight soils
- Clay layers
- Fractured rock
- Unconsolidated Soils
- Complex Stratigraphies
- Soils with wide heterogeneity in permeability or moisture content
- Above and below the water table
- Unsaturated Zone
- Saturated Zone
- Smear zones

Example Site Types and Applications

- Manufactured Gas Plants (MGP)
- Brownfields
- Railroad and Wood Treatment Sites
- Fractured Rock Sites
- Inside & Near Buildings & Infrastructure
- Rapid Site Cleanup, for Closure and Resale

Contaminants of Concern

- CVOC
- SVOC
- DNAPL

Our web site www.terratherm.com provides descriptions of selected projects and examples of applications for certain site types by industry, location, or contaminant. You may also wish to use the site search tool to locate the information you need on specific keywords, such as a contaminant or site geology; see the resources section for FAQs, white papers, and more.

Also, please feel free to contact us with any questions about your site, or about ISTR.

Appendix A: Project Case Study Examples

TerraTherm has completed numerous full-scale and pilot remediation projects at contaminated sites on five continents. Our technologies offer flexibility not only in the variety of contaminants that they can treat, but also in the applicability of the technologies to various site types.

TerraTherm's projects represent a wide variety of site applications including:

- Manufactured Gas Plant Sites
- Brownfields Redevelopment
- Fractured Rock Sites
- Inside and near Buildings and Infrastructure
- Rapid Site Cleanup for Closure and Resale

If you are interested in a site or project type not listed above, please contact us to discuss your site.

On the following pages, we provide some brief case study examples. For more examples, please visit www.terratherm.com.

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Active Manufacturing Facility ISTD Treatment in Saprolite and Fractured Rock

Bird's Eye View of ISTD Well Field

Project Location: Southeastern US

Owner: Confidential

Consultant: Rogers & Callcott Engineers, Inc.

Time Frame: 2006-2007

Site Information: Site is an active manufacturing facility. TCE is the primary contaminant of concern (COC) present in the subsurface and appears to have been released via a sump/catch basin system associated with an aboveground TCE storage tank and a TCE reclamation unit. The Target Treatment Zone (TTZ) or source area is associated with the former TCE storage and reclamation area and is approximately 33 ft x 76 ft (2,508 ft^2) extending from ground surface to approximately 10 feet below the typical bedrock surface or 85 feet below ground surface (bgs). The total volume encompassed by the TTZ is 7,900 cubic yards. The extended TTZ depth allowed for undulations in the bedrock surface and ensured treatment of all of the soil within the TTZ. The heated interval extended to approximately 90 ft bgs to ensure complete heating of the TTZ.

CoCs: Trichloroethene (TCE)

View of ISTD Well Field

Soil Characteristics: The source area targeted for treatment (i.e., TTZ) was underlain by 4 geologic units. The units are listed below in order from the ground surface down.

1) Fill (re-worked saprolite): 0-25 ft bgs

2) Saprolitic Soil (weathered granite): 25-55 ft bgs
3) Partially Weathered Bedrock: 55-75 ft bgs
4) Fractured Bedrock: The bedrock surface undulates with an average depth to the bedrock surface of approximately 75 ft.

The water table is at the bottom of the saprolitic soil at approximately 55 feet bgs, resulting in a total saturated thickness of approximately 20 feet of soil and partially weathered bedrock overlying the fractured bedrock.

Project Approach: ISTD remediation at the Southeastern US Active Manufacturing Facility Site included the following design features: a) minimum target temperature of 100°C; b) 15-ft spacing between thermal wells; c) 24 thermal wells; d) vapor barrier; e) heated interval extending from 1 ft to ~90 ft bgs (i.e., approximately 15 ft into the top of bedrock).

Project Results: The project was finished within the planned 120 day heating period and the treatment zone reached steam temperatures within 100 days. All remedial goals were reached. The ISTD heaters and vapor collection system operated continuously 100% of the time with no failures or downtime. Laboratory data from sampling showed that the 95% UCL of the TCE concentrations in soil above and below the water table was less than 0.02 mg/kg.

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ISTD Case Study: Dunn Field, Defense Depot (DLA), Memphis, TN

Project Information

At a former Defense Logistics Agency (DLA) site in Memphis, TN known as Dunn Field, which is part of the Memphis Defense Depot (a CERCLA NPL site), TerraTherm was selected by e^{2}M to design and implement In Situ Thermal Desorption (ISTD) for treatment of chlorinated solvents in soil. The Contaminants of Concern (COC) include TCE, PCE and Vinyl Chloride. The project was funded by the U.S. Air Force (USAF). Eight separate treatment areas covering a total of 53,000 square feet comprised a total target treatment zone (TTZ) volume of 48,000 cubic yards.

Subsurface Geology/Hydrogeology

The upper 30 ft (the TTZ) consisted of a loess deposit (silt, silty-clay and silty sand). Underlying the TTZ were fluvial sands/gravels to 100 ft bgs, over clay. Groundwater was at 75 ft bgs.

Project Goals

Soil remedial goals (RGs) for the primary COCs were as follows: 1,1,2,2-Tetrachloroethane (TCA), 0.0112 mg/kg; Tetrachloroethene (PCE), 0.1806 mg/kg; Trichloroethene (TCE), 0.1820 mg/kg; and Vinyl Chloride (VC), 0.0294 mg/kg. By contrast, the mean pre-treatment concentration of TCE was 73 mg/kg. Achievement of these remedial goals is equivalent to removing approximately 99.9% of the contaminant mass.

Project Approach

TerraTherm designed and installed 367 heaters wells and 68 vacuum extraction wells within the eight treatment areas, most at 17-ft spacing. The heater wells were designed to operate at temperatures of 1,000 to 1,100°F, to achieve Target Treatment Temperatures in the formation of 195 to 230°F. The extraction manifolds from each of the eight TTZs connected to a centralized AQC system.

Air Quality Control (AQC) System

Components included an influent heat exchanger, a moisture separator, positive displacement blowers, an air drier and vapor phase GAC vessels.

Performance and Cost

Remedial goals were achieved at all 8 treatment areas in November 2008. TCE concentrations in soil were reduced from a pre-treatment mean of 73 mg/kg to a post-treatment mean of 0.045 mg/kg, representing a removal of >99.9%. The estimated mass removed was in excess of 12,300 pounds. The overall turn-key cost of the project, including power, was $79/cy.

The site was awarded the ***2009 Secretary of Defense Environmental Award*** for Environmental Restoration on June 3, 2009. According to an April 21, 2009 press release from the DLA announcing the award, “A key component of the program's success is the use of thermally-enhanced soil vapor extraction, which removed more than 15,000 pounds of contaminants from the soils. In addition to meeting the established goals ahead of schedule, the process saved taxpayers more than $2.5 million.”

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Commercial Brownfields Project: Terminal One Tank Farm

Project Location: Richmond, California

Owner: Richmond Redevelopment Agency

Consultant: Geomatrix Consultants

Time Frame: 2005

Site Information: The City of Richmond's 14-acre site, known as the former Terminal One, was operated as a shipping and bulk storage terminal from about 1915 to the 1980s. The portion of the property being treated is known as the "Southwestern Tank Farm" where solvents and petroleum products were stored in above ground tanks. The total treatment volume is approximately 6,700 cy; of which, a small portion is under a warehouse that will be demolished after the thermal treatment is complete. The Southwestern Tank Farm is slated to become a recreational area as part of a 250 unit residential community after site cleanup is completed.

ISTD Well Field

CoCs: Contaminants of Concern are as follows: tetrachloroethene (PCE); trichloroethene (TCE); *cis*-1,2 dichloroethene (DCE); and vinyl chloride (VC).

Soil Characteristics: Soils within the thermal treatment area are composed of Bay Mud, a dark greenish gray lean clay with minor amounts (<5%) of sand. A 2-3' layer of fill exists above the Bay Mud. Thin interbedded layers with abundant shells (a few inches thick) have also been observed. The average thermal treatment depth was approximately 20 feet below ground surface (bgs).

Groundwater: Depth to water beneath the site is approximately 3 feet bgs.

Summary of Results:

		PCE	TCE	cis-1,2-DCE	VC
		ug/kg	ug/kg	ug/kg	ug/kg
Remedial Goals		**2,000**	**2,000**	**17,000**	**230**
AVG	**AVG Pre**	34,222	1,055	6,650	932
	AVG Post	12.36	< RL	64.68	4.73
	No. of Samples <RL (i.e., ND)	54	64	41	63
	% Reduction AVG Pre to Post	**99.96%**	**> 99.6%**	**99.03%**	**99.49%**
MAX	**Max Pre**	510,000	6,500	57,000	6,500
	Max Post	44	< RL	1,500	24
	% Reduction Max Pre to Post	**99.99%**	**> 99.2%**	**97.37%**	**99.63%**

RL = Laboratory Reporting Limit

AVG = Average - calculated using detected values and the RL/10 for non-detects.

Project Approach: In-Situ Thermal Desorption (ISTD) remediation at the Southwestern Tank Farm includes the following design features: a) minimum target temperature of 100°C; b) 12.0-ft spacing between thermal wells; c) 139 thermal wells; d) vapor barrier; e) granular activated carbon and potassium permanganate for off-gas treatment.

Project Staffing: As General Contractor, TerraTherm, Inc., has provided all project design, construction, operation,and equipment.

Subcontracting: TerraTherm subcontracted for construction labor, drilling, and electricians.

Project Summary: Site mobilization occured in late January 2005. Site construction was completed in May 2005. Startup of the ISTD system occured on schedule in early-June 2005 and treatment was completed ***on time*** (100 days) and ***on budget*** in September 2005. ***All remedial goals met*** (see table above). Demobilization from the site was completed in November 2005.

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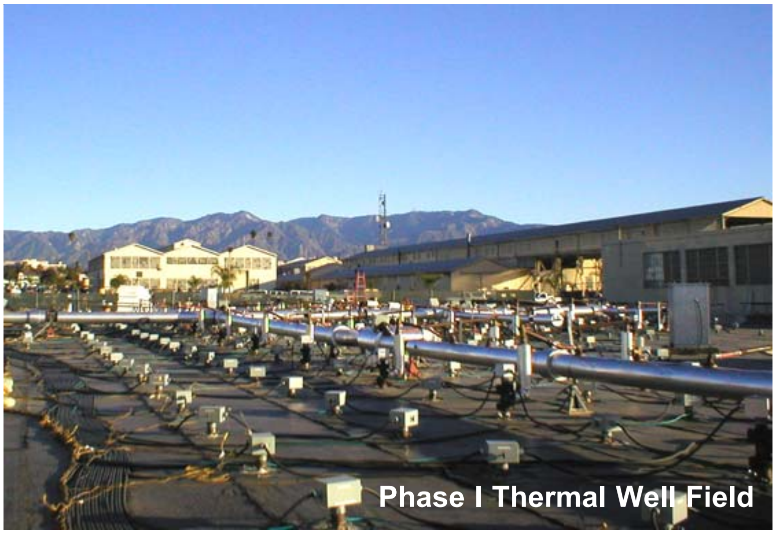
Commercial Project– California


Phase I Thermal Well Field

Project Name: Former Wood Treatment Area

Project Location: Alhambra, California

Owner: Southern California Edison (SCE)

Consultant: Shaw Group

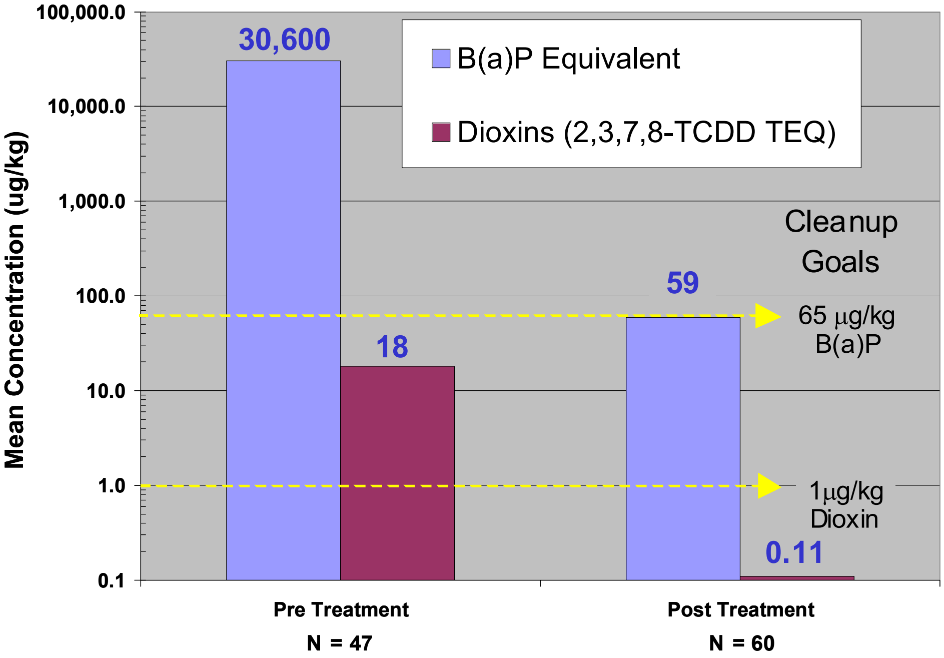
Time Frame: May 2002 - Early 2006

Site Information: SCE's 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 2-acre portion of the site. SCE carried out wood treatment at the area from approximately 1921 to 1957, by immersing utility poles in creosote. The total treatment volume is approximately 16,200 cy of vadose zone soil, and 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.

CoCs: Contaminants of Concern are as follows: polycyclic aromatic hydrocarbons (PAHs) are present in site soils to a maximum concentration of 35,000 mg/kg and mean concentration of 2,306 mg/kg Total PAHs; pentachlorophenol (PCP) to a maximum concentration of 58 mg/kg and mean concentration of <1 mg/kg; and dioxins (expressed as 2,3,7,8-tetrachlorodibenzodioxin [TCDD] Toxic Equivalency Quotient [TEQ]) to a maximum concentration of 0.194 mg/kg and mean concentration of 0.018 mg/kg.

Site Characteristics: Soils within the thermal treatment area are composed of fill and silty sands, inter-bedded with sands, silts, and clays. The average thermal treatment depth is approximately 20 feet below ground surface (bgs) and in some areas extends to over 100 feet bgs. The depth to the water table is greater than 240 feet bgs.

Project Goals: The soil remediation standard for PAHs (expressed as benzo(a)pyrene [B(a)P] toxic equivalents) is 0.065 mg/kg; for PCP, 2.5 mg/kg; and for dioxins (expressed as TEQ), 0.001 mg/kg.



Project Approach: In-Situ Thermal Destruction (ISTD) remediation at the Alhambra facility includes the following design features: a) minimum target temperature of 635°F (335°C), maintained for 3 days; b) 7.0-ft spacing between thermal wells; c) 785 thermal wells (131 heater-vacuum and 654 heater-only wells); d) insulated surface seal; and, e) thermal oxidizer, heat exchanger, and granular activated carbon (GAC) for off-gas treatment.

The measured dioxin emission rate for compliance with the air discharge permit is 0.036 billionths of a pound of TCDD TEQ/hr. This is equal to <1 millionth of a pound TCDD TEQ over the life of this project, a very low amount and less than one-thousandth of the annual TCDD TEQ emission from a typical hazardous waste treatment unit.

Project Staffing: As General Contractor, TerraTherm, Inc., has provided all project design, construction, operation, and equipment.

Subcontracting: TerraTherm subcontracted for construction labor, drilling, electricians, and source testing.

Project Time Line: ISTD Phase 2 treatment: July 2004- September 2005; Demobilization from the site was completed in March 2006.

Project Results: ***All remedial goals met*** (see figure above). Agency oversight provided by California's Department of Toxic Substances Control under California's Expedited Remedial Action Program (ERAP).

TERRATHERM®

Commercial Project – MGP Gasholder

Project Name: In-Situ Thermal Desorption (ISTD) of Former Manufactured Gas Plant (MGP) Gasholder

Project Location: North Adams, Massachusetts. Property adjacent to commercial, industrial, and residential areas. **Owner:** Massachusetts Electric Company (MEC), a subsidiary of National Grid

Consultant: Brown and Caldwell

Time Frame: August 2003 - June 2005

Site Information: MGP operations began in the 1860s and continued until 1952. Abandoned gasholder contains approximately 2,010 cubic yards (cy) (1,537 m^3) of soil and debris contaminated with coal tar. The 62 ft (19 m) diameter by 18 ft (5.5 m) deep gasholder has brick walls and a bottom believed to be constructed of concrete.

CoCs: Contaminants of Concern are as follows: Coal tar containing benzo(a)pyrene [B(a)P] concentrations as high as 650 mg/kg; napthalene 14,000 mg/kg; benzene 6,200 mg/kg; and Total Petroleum Hydrocarbons (TPH) 230,000 mg/kg.

Soil Characteristics: Mixture of sand, gravel, cobbles, bricks, concrete fragments, ash, and clinker.

Groundwater: Perched water was encountered within the gasholder at 5.5 ft (1.7 m) below ground surface (bgs). The regional groundwater table is beneath the holder.


Before Treatment


During Treatment


After Treatment

Contract Type, Project Goals: Guaranteed performance contract to achieve a Permanent Solution in accordance with the Massachusetts Contingency Plan (MCP), by eliminating DNAPL within the holder and reducing concentrations of VOCs, SVOCs, and TPH below MCP Upper Concentration Limits (UCLs), so that residual risk is minimized. ***Achieved all remedial goals*** (see table below).

Pre- and Post-Treatment Soil Concentrations Within the Construction Worker Exposure Depth

Sampling Depth: 6 - 14' **Average Concentrations**

Constituent	Pre-Treatment mg/kg	Post-Treatment mg/kg	Reduction %
Benzene	2068	0.35	99.98%
Anthracene	19	0.48	97.47%
Benzo(a)anthracene	20	0.51	97.45%
Benzo(a)pyrene	20	0.33	98.35%
Chrysene	20	0.71	96.45%
Fluoranthene	43	1.02	97.63%
Naphthalene	679	5.7	99.16%
Phenanthrene	107	3.82	96.43%
Pyrene	65	1.12	98.28%
C11-C22 Aromatics, unadj.	4000	43.15	98.92%

All below UCLs

Project Approach: Installation of 25 thermal wells spaced on ~12 ft (3.7 m) centers, to a depth of ~18 ft (5.5 m) bgs. Operate in three stages: 1) dewatering; 2) thermally-enhanced free-product recovery with gentle heating (produced > 16,000 gallons of coal tar); and, 3) ISTD to achieve target interwell temperatures of 617°F (325°C). Thermocouple arrays enable monitoring of subsurface temperatures. Water treatment by oil-water separator, clay-carbon media, liquid-phase granular activated carbon (GAC). Vapor treatment by regenerative thermal oxidizer with backup vapor-phase GAC.

Project Staffing: As General Contractor, TerraTherm, Inc., has provided all project design, construction, operation, and equipment.

Subcontracting: TerraTherm subcontracted for some labor, drilling, and electrical services.

Project Time Line: Mobilized to the site in November 2003, with site construction beginning the same month. Dewatering/tar recovery began in February 2004. Full power heating began in July 2004 and was completed in March 2005, with demobilization completed June 2005.

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Appendix B: Applicable Systems and Contracting Qualifications

Corporate Project Management and Financial Data Management Systems

TerraTherm maintains an integrated Project Management system and protocols designed to ensure consistency of project planning, execution, oversight, and accountability. Each TerraTherm Project Manager has many years of experience in project management. Weekly project review meetings with Senior Management facilitate timely communications and ensure each project stays on track. TerraTherm utilizes the Timberline Accounting System and makes use of many of its Project Management capabilities. Our accounting system has undergone a Defense Contract Auditing Agency (DCAA) assist audit.

Representations and Certifications (for Government Contracting)

TerraTherm, Inc. meets the definition of a Small Business for nearly all government procurements. Our Representations and Certifications are available online at www.bpn.gov (our D&B number is 00- 266-6522).

Navy BAA Eligibility

TerraTherm's ISTD technology has been determined to be زBA Eligible under the Naval Facilities Engineering Command Environmental Broad Agency Announcement (BAA) Program for Innovative Technologies and Methodologies Addressing Various Environmental Problems. DENIX users will find our listing by referencing TerraTherm's In Situ Thermal Desorption.

Corporate Quality Assurance/Quality Control (QA/QC) Program

TerraTherm is typically responsible for developing and implementing a Quality Assurance/Quality Control (QA/QC) program for each major project. As a component of such project-specific programs, a Quality Assurance Project Plan (QAPP) is developed, as well as a Sampling and Analysis Plan (SAP). It is the ultimate responsibility of the Corporate Officers to ensure that the plans meet both corporate and client requirements prior to their submittal, and that they are adhered to in all respects.

Major Elements of TerraTherm's Corporate QA/QC Program Include:

Maintenance of a Lessons Learned Process and Database: TerraTherm regularly convenes a Lessons Learned Committee comprised of engineering and field staff, which scrutinizes all significant design features, construction methods, and operational procedures. Decisions are made concerning needed changes, and a database is maintained and distributed to ensure that the resulting improvements are promulgated to all staff.

Standard Operating Procedures: TerraTherm has developed a series of Standard Operating Procedures (SOPs), including Engineering Review; Constructability Review; Hot Soil Sampling; Accident Reporting & Investigation; and Operations Data Management/Reporting.

Project Technical Reviews: Project Technical Reviews are carried out biweekly for most major projects. Such reviews include senior staff not involved in the day-to-day project or technical management of the projects. The purposes of such reviews are to review project progress against planned milestones; ensure that QA/QC requirements are being adhered to; and enable timely response to issues that may arise.

Appendix C: TerraTherm Sustainability Policy

TerraTherm is a Contributor to the Sustainable Remediation Forum (SuRF)

TerraTherm endorses and contributes to the efforts of the Sustainable Remediation Forum (SuRF) in working to define sustainability and social responsibility as they relate to site cleanup.

TerraTherm strives to establish and maintain a leadership role in the evolution of sustainable remediation through improvement in all operational aspects.

Ancillary Environmental Impacts from Cleanups

Our In Situ Thermal Remediation (ISTR) technologies prevent migration of contaminants from the site. In addition, since there is no excavation or transportation of materials, airborne contaminants, dust, and noise are virtually non-existent. Treatment of collected gases is thorough with odorless and clean vapor emissions. As a result, ISTR is a leading method in preventing ancillary environmental impacts.

Energy Consumption and Greenhouse Gas Emissions

TerraTherm's ISTR technologies employ electrical power. Since our project cycles are short and predicable, total energy use is well defined and the need for repeated applications or long-term O&M is eliminated; therefore, remediation is rapid and is inherently more sustainable than potential trial-and-error approaches that may use more resources, delay redevelopment, put Greenfields at risk of development, and create more emissions in the long run. In addition, TerraTherm is a USEPA Green Power Partner. We have contracted to purchase Renewable Energy Credits for 100% of our corporate office power usage, and we offer verifiable Carbon Offsets to our clients for TerraTherm field projects. Offsetting the carbon footprint of a typical ISTR project adds less than 1% to the project cost. Such initiatives have been successful in steadily increasing the energy efficiency of our technologies through R&D and innovation. The rapid and final site cleanup advantages, extremely high level of safety, cleanliness of our operations, and low community impact combine to make ISTR a logical and leading choice for sustainability. These factors greatly outweigh the slight carbon impact incurred in the use of electrical power.

Preservation of Natural Resources and Maximization of Land Reuse to Preserve Undeveloped Areas

Undeveloped lands play an important role in mitigating the effects of greenhouse gas emissions. In the effort to preserve such lands, time is of the essence. Among the most efficient ways to prevent undeveloped lands from being committed to industrial use is to revitalize and clean Brownfields for reuse in a timely and predictable manner. The rapid and predictable results of ISTR ensure the redevelopment of Brownfields on a fixed timeline, thereby preserving Greenfields. No other technology achieves this sustainability goal as quickly, or completely, as ISTR.

Permanent Elimination of Contamination

ISTR is proven uniquely effective in the elimination and stabilization of contaminants. Results consistently demonstrate the achievement of site cleanup goals, even to drinking water standards (where applicable). Through carefully engineered and controlled processes, permanent remediation is measurable and ensured through in situ destruction, desorption, stabilization, and/or extraction of offending materials. In addition, these processes prevent mobilization of contaminants, ensuring the safety of adjacent water supplies. No other remediation technology has proven more effective in the permanent elimination of contaminants.

Public and Contractor Safety and Health During and After the Project

TerraTherm has maintained an impeccable safety record throughout its history. Further, it can be said that in situ thermal remediation is inherently safer than other methods because little or no dust, heavy vehicle movement, chemical use, harmful emissions, or noise are consequential to the process. In this way, threats to public and contractor health that are common to excavation, chemical treatment, and some other purportedly “green” methods are eliminated or greatly reduced.

Recycling of Materials

TerraTherm endeavors to reuse, refurbish, and recycle materials to the fullest extent possible. We have found that refurbishing process equipment to fully restore it to useful life is both economical and safe. It also provides reductions in ancillary life cycle costs (resource extraction, manufacturing, shipping, etc.). Our aim is to exemplify the principal of “waste not, want not.”

PCB CASE STUDIES

PCB Case Study #1

General Electric (GE) Dragstrip
Glens Falls, New York

TERRATHERM
ENVIRONMENTAL SERVICES INC.

PROJECT PROFILE

December 1997

PROJECT:	Remediation of PCBs at State Superfund Site
LOCATION:	Glens Falls, New York
TIME OF OPERATIONS:	January, 1996 - March, 1996
REGULATORY AGENCY:	New York State Superfund Section and US EPA

SITE DESCRIPTION:

A portion of a former drag strip was contaminated with polychlorinated biphenyls (PCBs) from oils, which had been spread on the ground for dust suppression. The PCB contamination extended over an area of approximately 10 acres and was relatively shallow (less than 18 inches).

Tests showed PCB concentrations in some locations of more than 5,000 parts per million (ppm). The average PCB concentration in the upper six inches of soil was over 500 ppm.

The site had been designated as a State Superfund cleanup site. The U.S. Environmental Protection Agency requirement for PCB cleanups is less than 2 ppm, which was the target established for the cleanup operation.

A trailer park adjacent to the site did not require vacating during remediation operations.

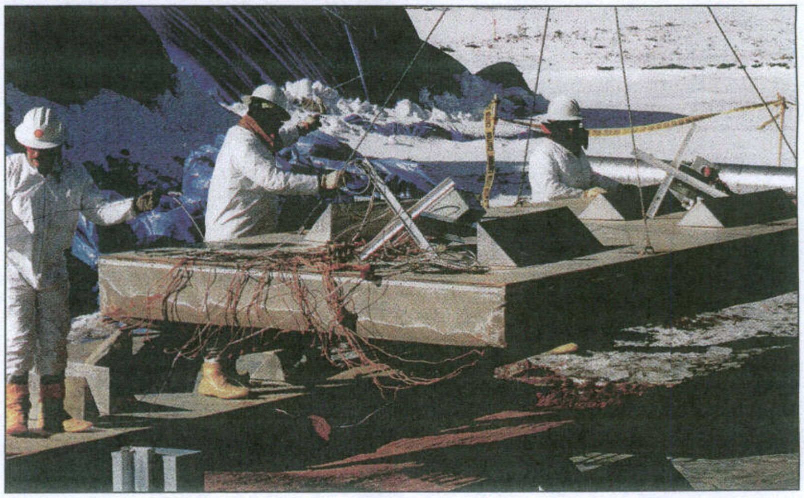
REMEDIATION OPERATIONS:

TerraTherm Environmental Services, Inc. performed a field demonstration of its new In Situ Thermal Desorption technology using Thermal Blankets at the upstate New York site in early 1996. The demonstration took place during one of the harshest winters experienced in the region in years, proving the ability of the TerraTherm equipment to perform in extreme conditions.

The demonstration was performed as part of the regulatory process to obtain a nationwide TSCA (Toxic Substances Control Act) permit for the TerraTherm technology covering the remediation of surficial soils containing PCBs in concentrations up to 5,000 ppm.

In addition, the demonstration had to meet New York State permit requirements for air emissions, as well as onsite and boundary dust emissions. A Continuous Emission Monitoring (CEM) system was used extensively on process equipment during the remediation operation to verify stack emissions from the Vapor Treatment System. Onsite and boundry surveys taken for dust emissions also indicated a contaminate free operation.

Because this is an in situ process in which heating elements in the Blankets heat the soil and vaporize contaminants, there are no material preprocessing or water pollution control requirements. Vapors (mainly CO_2 and water) from the Thermal Blankets are passed through a flameless thermal oxidizer and carbon beds on the process trailer.



Thermal Blanket being lowered into position

Treatment times for this project ranged from slightly more than 24 hours to treat the upper six inches of soil to approximately four days to treat the zone 12-18 inches deep.

REMEDIATION RESULTS:

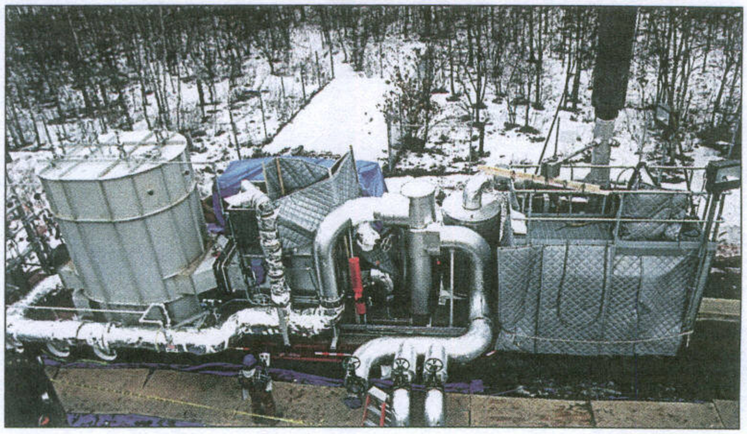
Post-treatment soil samples showed PCB concentrations had been reduced from as high as 5,200 ppm to less than 0.8 ppm. The field operation confirmed the ability of computer simulations to predict process timing, energy utilization and cleanup levels.

Discrete soil samples were analyzed at the request of the EPA to determine if lateral or vertical migration of contaminants occurred as a result of treatment with the In Situ Thermal Desorption technology. Post-treatment soil testing confirmed that PCBs did not migrate away from the Thermal Blanket during the treatment.

The operations met all ambient air quality standards for emission and worker exposure limits. Stack emission test results showed that more than 99.9999% of the PCBs removed from the soil had been successfully destroyed. In addition, worker exposure levels did not exceed existing or recommended levels.

Finally, this solution proved to be more cost-effective than other permanent treatment remedies, as well as less intrusive on the surrounding community.

Please contact TerraTherm for more information on In Situ Thermal Desorption technology and its applications.



Mobile Vapor Treatment System

Thermal Blankets in place and operating

PCB Case Study #2

Missouri Electric Works (MEW)

Cape Girardeau, Missouri

Cost and Performance Summary Report
In Situ Thermal Desorption at the Missouri Electric Works Superfund Site
Cape Girardeau, Missouri

Summary Information [1, 2, 4, 5, 6]

From 1953 until 1992, the Missouri Electric Works Inc. (MEW) operated a 6.4 acre site, located in an industrial area in Cape Girardeau, Missouri. MEW sold, serviced, and maintained electric motors, transformers, and transformer controls at this facility. More than 16,000 transformers have been repaired or scrapped at the facility. Historical operations included salvaging transformer oil and materials from old equipment; copper wire was sold and the transformer oil was filtered and reused. During the oil recovery process, approximately 90% of the oil was recovered while the remainder was spilled or leaked onto the ground. In addition, solvents were used to clean electrical equipment, and spills and disposal of solvents are believed to have occurred at the site.

In October 1984, the Missouri Department of Natural Resources (MDNR) inspected the site and discovered a number of 55-gallon drums of waste transformer oil. It was estimated that 28,000 gallons of oil were released at the site; about 5,000 gallons of drummed waste oil were removed from the site. In November 1984, EPA conducted a Toxic Substances Control Act (TSCA) inspection of the site and noted several violations for the storage of PCB waste oils. Two soil samples taken during the inspection showed PCB concentrations of 310 milligrams per kilogram (mg/kg) and 21,000 mg/kg. Further investigations performed by EPA between October 1985 and June 1987 confirmed PCB contamination in the surface and subsurface soils, and in the drainage pathways. The results of a Remedial Investigation (RI), conducted between September 1989 and March 1990, showed PCBs in the surface and subsurface soils (as high as 58,000 mg/kg in soils found on site and 2,030 mg/kg in off-site soils). Volatile organic compounds (VOCs) were detected in the groundwater (as high as 320 milligrams per liter); no PCBs were detected in the groundwater. The RI also indicated that PCBs had migrated off site through storm water drainage areas onto surrounding properties. The areal extent of PCB concentrations in the soil that were greater than 10 mg/kg was estimated to be 295,000 square feet (ft^2) or 6.8 acres.

A Record of Decision (ROD), signed in 1990, specified excavation of PCB-contaminated soil followed by incineration, and extraction and treatment of groundwater. In August 1994, a Consent Decree (CD) between EPA and the potentially responsible parties (PRPs) was approved by the federal district court to design the remedy and clean up the soil under EPA supervision. According to the RPM, a group of non-settling parties appealed the CD entry because they had not been allowed to intervene. The eighth circuit court of appeals agreed with the non-settling parties, vacated the CD entry and, after allowing the non-settling parties to intervene, approved the CD during August 1996. Although the non-settling parties again appealed entry of the CD, the eighth circuit court upheld the district courts decision and the consent decree became effective during March 1998. The MEW PRP Steering Committee proposed in situ thermal desorption of the soil. An Explanation of Significant Differences (ESD) was issued for this site in January 1995 which included thermal desorption as an acceptable process for treating site soils. In January 1997, EPA and MDNR accepted a Demonstration Test Plan for this technology.

The objectives of the demonstration were to clean soils to below cleanup levels and achieve a destruction and removal efficiency (DRE) of greater than 99.9999% for PCBs. The demonstration was conducted at a former PCB storage pad, where PCB concentrations were reported as high as 20,000 mg/kg. Soils in the demonstration area were analyzed to determine pre-test soil PCB concentrations. PCBs were found at depths of up to 10 feet (ft) below ground surface (bgs), with the highest concentrations found at 0 to 4 ft bgs. The results are presented in Table 1.

CERCLIS ID Number: MOD980965982
Lead: EPA Region 7

Timeline [1, 2]

October 1984 - June 1987	Site investigation performed
September 1989 - March 1990	RI performed
September 28, 1990	ROD signed
August 29, 1994 August 14, 1996 March 3, 1998	Consent Degree approved by Federal District Court
January 1995	ESD issued
January 1997	Demonstration Test Plan approved
April 21 - June 1, 1997	Demonstration performed

Table 1 - Soil Sample Results Summary, Cape Girardeau, MO [3]
(see Figure 1 for locations)

Pre-Demo Soil Sampling Results

Boring ID	Sample #	Depth (ft)	ATAS Lab Result PCB Concentration (mg/kg)
TW-1	S1-A	0.0-2.0	1590
	S1-B	2.0-3.4	357
	S2-A	3.4-5.4	<0.5
	S2-B	5.4-8.1	<0.5
	S5	8.2-10.0	NA
	S6	10.0-12.0	13.5*
TW-3	S1-A	0.2-2.2	2190
	S1-B	2.2-4.2	59.5
	S2-A	4.2-6.2	ND
	S2-B	6.2-8.2	ND
	S5	8.2-10.0	6.37*
	S6	10.0-12.0	4.34*
TW-3T	S1	0.0-0.5	614
	S2	0.5-1.0	2970
	S3	1.0-2.0	16.5
	S4	2.0-4.0	0.694
	S5	4.0-6.0	4.42
	S6	6.0-8.0	2.32
	S7	8.0-10.0	0.084
	S8	10.0-12.0	<0.033
	S9	12.0-14.0	<0.033
	S10	14.0-16.0	<0.033
TW-4	S1-A	0.2-2.2	3030/8030
	S1-B	2.2-4.2	NA
	S2-A	4.2-6.2	0.913
	S2-B	6.2-8.2	<0.50
	S5	8.2-10.0	0.418
	S6	10.0-12.0	3.63*
TW-6	S1-A	0.2-2.2	299
	S1-B	2.2-4.2	393
	S2-A	4.2-6.2	342
	S2-B	6.2-8.2	114
	S3-A	8.2-10.2	<0.50
	S3-B	10.2-12.2	0.973
TW-6T	S1	0.0-0.5	19900
	S2	0.5-1.0	2190
	S3	1.0-2.0	885
	S4	2.0-4.0	234
	S5	4.0-6.0	46.2
	S6	6.0-8.0	5.33
	S7	8.0-10.0	0.061
	S8	10.0-12.0	0.158
	S9	12.0-14.0	0.22
	S10	14.0-16.0	0.043
TW-7	S1-A	0.2-2.2	25.7
	S1-B	2.2-4.2	<0.50
	S2-A	4.2-6.2	11.4
	S2-B	6.2-8.2	<0.50
	S3-A	8.2-10.2	<0.50
	S3-B	10.2-12.2	<0.50
TW-10	S1-A	0.2-2.2	2.39
	S1-B	2.2-4.2	<0.50
	S2-A	4.2-6.2	<0.50
	S2-B	6.2-8.2	<0.50
	S5	8.2-10.0	0.475
	S6	10.0-12.0	<0.50

Boring ID	Sample #	Depth (ft)	AS Lab Result PCB Concentration (mg/kg)
TW-13	S1	0.2-2.2	253
	S2	2.2-4.2	2.23
	S3	4.2-6.2	0.099
	S4	6.2-8.2	NA
	S5	8.2-10.2	<0.50
	S6	10.2-12.2	<0.50
TW-14	S1	0.2-2.2	4100
	S2	2.2-4.2	1060
	S3	4.2-6.2	276
	S4	6.2-8.2	67.5
	S5	8.2-10.2	3.98
	S6	10.2-12.2	<0.50
TW-14T	S1	0.0-0.5	9210
	S2	0.5-1.0	1450
	S3	1.0-2.0	984
	S4	2.0-4.0	1470
	S5	4.0-6.0	134
	S6	6.0-8.0	11.8
	S7	8.0-10.0	<0.033
	S8	10.0-12.0	<0.033
	S9	12.0-14.0	<0.033
	S10	14.0-16.0	<0.033
TW-15	S1	0.2-2.2	93.8
	S2	2.2-4.2	5.3
	S3	4.2-6.2	NA
	S4	6.2-8.2	2.03
	S5	8.2-10.2	NA
	S6	10.2-12.2	8.35*
TW-16	S1	0.2-2.2	61.8
	S2	2.2-4.2	NA
	S3	4.2-6.2	1.14
	S4	6.2-8.2	NA
	S5	8.2-10.2	3.11
	S6	10.0-12.0	1.22(10.2)*
TW-17	S1	0.0-0.5	93.7
	S2	0.5-1.0	2530
	S3	1.0-2.0	<0.5
	S4	2.0-4.0	1.66
	S5	4.0-6.0	<0.50
	S6	6.0-8.0	<0.033
	S7	8.0-10.0	0.146
	S8	10.0-12.0	<0.033
	S9	12.0-14.0	1.27
	S10	14.0-16.0	0.395
TW-18	S1	0.0-0.5	9090
	S2	0.5-1.0	1690
	S3	1.0-2.0	762
	S4	2.0-4.0	450
	S5	4.0-6.0	293
	S6	6.0-8.0	1.53
	S7	8.0-10.0	0.421
	S8	10.0-12.0	0.136
	S9	12.0-14.0	0.051
	S10	14.0-16.0	<0.033

Post-Demo Soil Sampling Results

Boring ID	Sample #	Depth (ft)	ATAS Lab Result PCB Concentration (ppm)
PTW-1	S1	0.0-0.5	<0.033
	S2	0.5-1.0	<0.033
	S3	1.0-1.5	<0.033
	S4	1.5-2.0	<0.033
	S5	2.0-2.5	<0.033
PTW-2	S1	0.0-0.5	<0.033
	S2	0.5-1.0	<0.033
	S3	1.0-2.0	<0.033
	S4	2.0-4.0	<0.033
	S5	4.0-6.0	<0.033
	S6	6.0-8.0	<0.033
	S7	8.0-9.9	<0.033
PTW-3	S1	0.0-0.5	<0.033
	S2	0.5-1.0	<0.033
	S3	1.0-2.0	<0.033
	S4	2.0-4.0	<0.033
	S5	4.0-6.0	<0.033
	S6	6.0-8.0	<0.033
	S7	8.0-9.9	<0.033
PTW-4	S1	0.0-0.5	<0.033
	S2	0.5-1.0	<0.033
	S3	1.0-2.0	<0.033
	S4	2.0-4.0	NS
PTW-6	S1	0.0-0.	<0.033
	S2	0.5-1.0	<0.033
	S3	1.0-2.0	<0.033
	S3 DUP	1.0-2.0	<0.033
	S4	2.0-4.0	<0.033
	S5	4.0-6.0	<0.033
	S6	6.0-8.0	<0.033
	S7	8.0-10.0	<0.033
	S8	10.0-12.0	<0.033
	S9	12.0-13.5	<0.033
	S10	13.5-14.0	0.072
	S11	14.0-15.5	<0.033
PTW-7	S1	0.0-0.5	<0.033
	S2	0.5-1.0	<0.033
	S3	1.0-2.0	<0.033
	S4	2.0-4.0	<0.033
	S5	4.0-6.0	<0.033
	S6	6.0-8.0	<0.033
	S7	8.0-9.9	0.168

Boring ID	Sample #	Depth (ft)	ATAS Lab Result PCB Concentration (ppm)
PTW-8	S1	0.0-0.5	<0.033
	S2	0.5-1.0	<0.033
	S3	1.0-2.0	<0.033
	S4	2.0-4.0	<0.033
	S5	4.0-6.0	0.036
PTW-9	S1	0.0-0.5	<0.033
	S2	0.5-1.0	<0.033
	S3	1.0-2.0	<0.033
	S4	2.0-4.0	<0.033
	S5	4.0-6.0	<0.033
	S6	6.0-8.0	<0.033
	S7	8.0-9.9	<0.033
PTW-10	S1	0.0-0.5	<0.033
	S2	0.5-1.0	<0.033
	S3	1.0-2.0	<0.033
	S4	1.0-2.0	<0.033
	S5	2.0-4.0	<0.033
	S6	4.0-4.0	<0.033
	S7	6.0-8.0	<0.033
	S8	8.0-9.9	0.302
PTW-11	S1	0.0-0.5	<0.033
	S2	0.5-1.0	<0.033
	S3	1.0-2.0	<0.033
	S4	1.0-2.0	<0.033
	S5	2.0-4.0	<0.033
	S6	4.0-6.0	<0.033
	S7	6.0-8.0	<0.033
	S8	8.0-9.0	<0.033
	S9	9.0-9.9	<0.033
TW-12	S1	0.0-0.5	<0.033
	S2	0.5-1.0	<0.033
	S3	1.0-2.0	<0.033
	S4	1.0-2.0	<0.033
	S5	2.0-4.0	<0.033
	S6	4.0-6.0	<0.033
	S7	6.0-8.0	<0.033
	S8	8.0-9.9	<0.033
TW-13	S1	0.0-0.5	0.045
	S2	0.5-1.0	0.045
	S3	1.0-2.0	0.042
	S4	2.0-4.0	<0.033
	S5	4.0-6.0	<0.033
	S6	6.0-8.0	<0.033
	S7	8.0-9.9	<0.033
PTW-14	S1	0.0-0.5	<0.033
	S2	0.5-1.0	<0.033
	S3	1.0-2.0	<0.033
	S4	1.0-2.0	<0.033
	S5	2.0-4.0	<0.033
	S6	4.0-6.0	<0.033
	S7	6.0-8.0	<0.033
	S8	8.0-9.9	<0.033

NOTES:

1. NA denotes that sample analysis results are not available at this time.
2. NS indicates no sample was collected.
3. Samples taken at locations of thermal wells, e.g, TW-1 as shown on Figure 1.
4. "T" denotes twinned geoprobe location.
5. * Split spoon sample, possible contamination from shallow cavings
6. PTW-8 samples were collected adjacent to the PTW-1 location.

This report covers the results of the in situ thermal desorption demonstration for PCB-contaminated soils conducted April 21 - June 1, 1997. A total of 52 cubic yards (yd^3) of soil was treated during this demonstration.

Factors that Affected Cost or Performance of Treatment [1, 6]

Listed below are the key matrix characteristics for this technology and the values measured for each.

Matrix Characteristics

Parameter	Value
Soil Classification:	Brown clay with traces of silt, overlain by a thin layer of top soil
Clay Content and/or Particle Size Distribution:	2-9% sand, 68-81% silt, 17-23% clay
Moisture Content:	12-28%
pH:	5.3-8.0
Oil and Grease:	Soil soaked with oil in transformer storage areas
Bulk Density:	115-125 pcf
Lower Explosive Limit:	N/A

Treatment Technology Description [1]

In situ thermal desorption (ISTD) simultaneously applies heat and vacuum to soils to extract vapors which are collected and sent to a mobile processing unit for further treatment prior to release to the atmosphere. According to the vendor (TerraTherm), a typical ISTD process uses thermal blankets (modular blankets that are 8 ft x 20 ft) placed on the soil surface to treat shallow contamination and thermal wells (heater/vacuum wells) placed in the ground in triangular patterns to treat deeper contamination (>3 ft bgs). The thermal well process was demonstrated at MEW to treat subsurface soil contamination in an area near a former PCB storage pad.

Figure 1 shows the layout of the thermal heater wells used at MEW. As shown in Figure 1, twelve heater/vacuum wells were installed in a triangular pattern, spaced 5 ft apart. Each well included 12-ft long nichrome wire heating element threaded through ceramic insulation. The insulated heating element was placed within a 2.5-inch (in) diameter stainless steel pipe and sealed at both ends to create a “heater can” (to isolate the heating elements from fluids and vapors during operation). The heater can, in turn, was enclosed with a 4-in diameter stainless steel slotted liner. Each well was completed to a depth of 12 ft in a sand-filled annulus designed to improve the inflow of vapors from the soil to the well. Heat from the thermal wells was transferred to the soil by radiation and thermal conduction. According to the vendor, thermal conduction is estimated to account for 80% of the heat transfer. Vacuum was applied to the wells to remove soil vapors from the subsurface.

To compensate for heat losses to the lower soils and the atmosphere, the thermal wells were designed such that the lower 2 ft of the well and the upper 1 ft of the well delivered more power (57% more) than the middle portion of the well. Each well had the capacity to inject 350 to 700 watts/ft^2 at heater temperatures of 1600 to 1800°F. Surface heating pads (18 in^2) were placed at the center of each triangle to assist in treating the soils between the wells and operated at 500 watts/ft^2.

A vapor seal was constructed over the entire test area to insulate and reduce heat loss, and to seal the surface of the test area against vapor emissions. A vacuum frame structure was constructed around the well area. Rectangular pieces of steel shim stock (4 ft x 20 ft) were fitted together to cover the test area and were welded to the wells at the point of penetration. A 16-in thick layer of vermiculite insulation was placed over the steel plate and covered with an impermeable silicone tarpaulin, which extended 5 ft beyond the edges of the treatment area.

To monitor temperatures during operation, fifteen thermocouple tubes were installed at locations roughly in the center of each of the 13 triangular areas between the thermal wells and at two central locations within the treatment area (see Figure 1). Each 1-in steel tube was installed to a depth of 7 ft and was sealed at the bottom.

Two pressure monitoring wells (PW-1 and PW-2), located near the center of the treatment area (see Figure 1), were used to monitor the subsurface vacuum. Each well was perforated pipe completed with 1 ft of sand at a depth of 6 ft and sealed to the surface with bentonite grout.

To control surface run-off, a 1-ft deep trench was dug around the perimeter of the test area and equipped with a sump pump.

The MU-125 mobile process unit was equipped with a particulate cyclone, a Thermatrix ES-125 flameless thermal oxidizer, and two carbon canisters in series. Auxiliary equipment included the control room housing, a programmable logic control system, heater controllers, and a PC-based data acquisition system.

Operation [1, 3]

On April 21, 1997, the well heaters were energized by increasing power to the 12 injectors over a three-hour period to an initial rate of 500 watts/ft^2. Power was then increased in all injectors until the maximum operating temperature (as measured by the

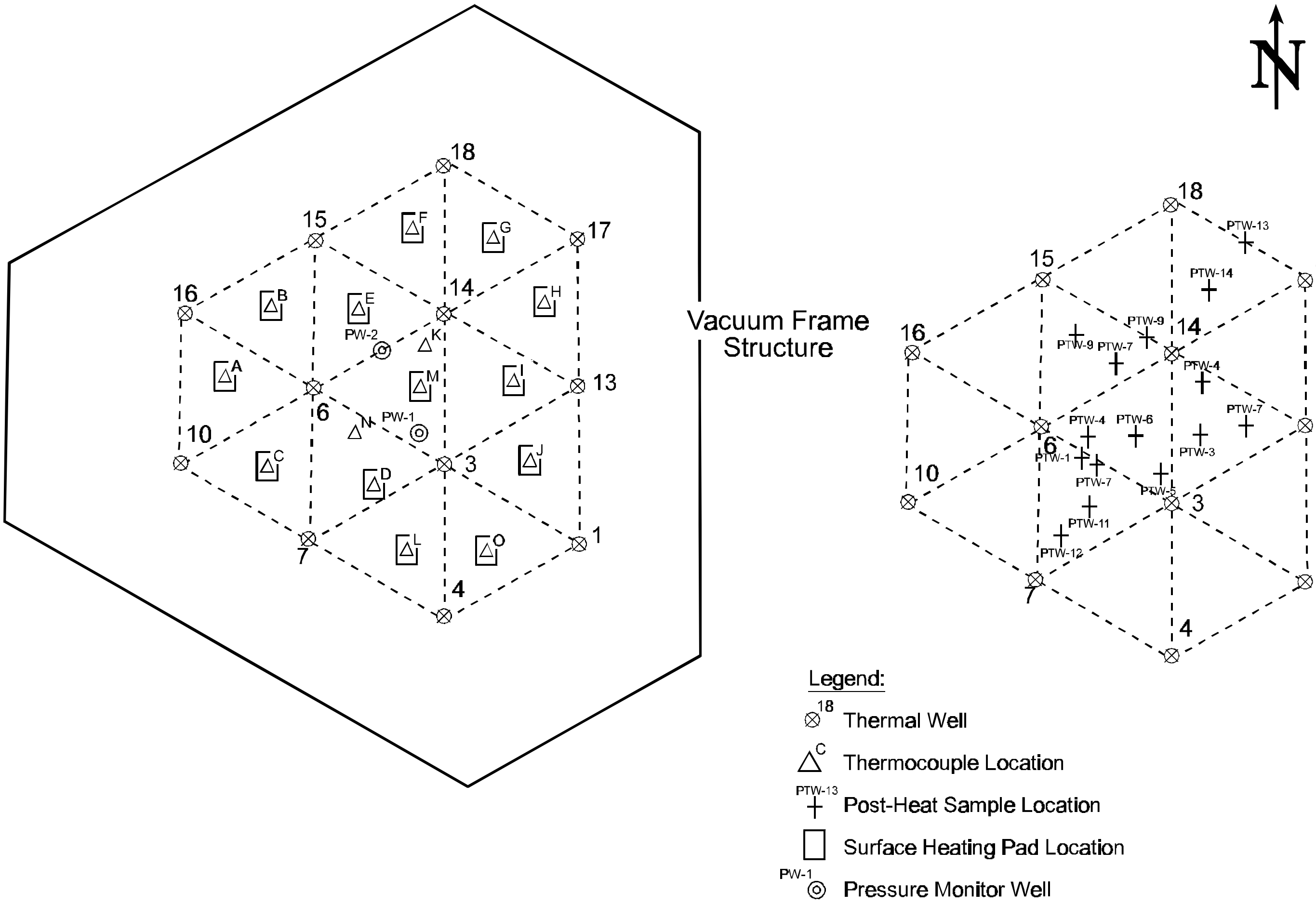


Figure 1: Left, position of thermal heater wells and thermocouples. Right, post-heat sample locations. Well spacing = 5 ft [3]

thermocouples) reached 1600°F. Within 48 hours of the start of the demonstration, two changes in operating conditions were observed that indicated that the soil permeability had increased as a result of the heating process: 1) the vacuum at the heater wells decreased from 25 to 5 in of water; and 2) the vacuum at the pressure monitoring wells increased from 1 to 4.5 in of water. Following the increase in soil permeability, the surface heating pads were energized at 500 watts/ft^2. During the 42-day demonstration period, the flow rate was maintained between 50 and 70 standard cubic feet per minute (scfm) with a well vacuum of 3 to 5 in of water.

Temperature was measured every 12 hours during the test. When the upper 1 ft of soil reached 900°F, the power to the surface heating pads was reduced to avoid excessive corrosion of the vapor seal.

Three distinct temperature phases were recorded during the heating process. During the first phase (250 hrs of operation), soil temperatures rose to the boiling point of water (212°F). During the second phase, water boiling occurred and the temperature remained near 212°F. During the third phase, also called the superheating phase (630 hours to end of operation), soil temperatures rose to over 1000°F. A soil temperature of 900°F was measured at the center of all triangles and a temperature of 1100°F was measured at the center of the treatment area (thermocouple K); the vendor used this data to estimate that about 50% of the total soil volume reached a temperature of over 1100°F.

Listed below are the key operating parameters for this technology and the values measured for each.

Operating Parameters

Parameter	Value
Vacuum:	3-5 in of water
Air Flow:	50-70 scfm
Heating Power:	350-500 watts/ft^2
Soil Temperature:	212°F to > 1100°F

Performance Information [1, 2, 6]

The site cleanup level identified in the ROD was 2 mg/kg. Site soils contaminated with PCBs at concentrations greater than or equal to 10 mg/kg at depths from 0 to 4 feet below ground surface, and at concentrations greater than 100 mg/kg at depths greater than 4 feet below ground surface, were to be treated using thermal treatment. The PCB concentrations at which treatment was to occur was variable because the greatest risk to human health is due to direct contact. A DRE of greater than 99.9999% for PCBS was specified for stack emissions. The PCB cleanup goals represent a lifetime cancer risk of 2 x 10^{-5}.

Following the completion of the 42-day demonstration, 94 samples were collected from 13 core boring locations as shown on Figure 1 (depths of about 10 ft except in the center, PTW-6, which was 16 ft deep). Samples were analyzed for PCBs, porosity, permeability, and soil texture. The results of the PCB analyses are presented in Table 1.

As shown in Table 1, the concentration of PCBs in all samples was below the 2 mg/kg cleanup goal. PCB concentrations were below the detection limit of 0.33 mg/kg in 83 of the 94 samples. For the remaining samples, PCB concentrations ranged from 0.036 mg/kg to 0.302 mg/kg. According to the RPM, a lateral migration demonstration test was conducted adjacent to an area previously treated by thermal blankets. The test areas were overlapped 6 inches. Pre-test sampling typically indicated PCB concentrations less than 33 micrograms per kilogram; two samples indicated PCB concentrations of approximately 2 mg/kg. Post-test sampling indicated no significant increase in PCB concentrations in the area which had been non-detect prior to the test and a reduction in the PCB concentrations in those areas which had detectable concentrations prior to the test.

In addition, four composite samples were collected and analyzed for PCDD and PCDF. The “vertical” composite sample consisted of soil from 0-8 ft at the center of the treatment area. Three “areal” composite samples were collected: 0-2 ft; 2-4 ft; and 4-6 ft (from the locations of PTW-3, 4, 5, 6, 7, 8 and 10). PCDD and PCDF were not detected in analyses for the vertical composite samples. [illegible] areal composites were 0.00284 mg/kg toxic equivalent (TEQ) for 0-2 ft; 0.00684 mg/kg TEQ for 2-4 ft; and 0.0033 mg/kg TEQ for 4-6 ft.

Results of stack testing showed that the DRE for PCBs was 99.9999998%, exceeding the goal of 99.9999%. According to the vendor, a total of 0.10 mg of PCB was emitted from the stack (from an estimated 40 kg of PCB in the treated area). Details of the DRE calculation are presented in Appendix A.

Porosity in post-heat soil samples was reported to have increased from approximately 30% of pore volume to 40%. The horizontal air permeability increased from 3 x 10^{-3} millidarcies (md) to 50 md; vertical air permeability increased from 1 x 10^{-3} md to 30 md. According to the vendor, reasons for increased porosity and permeability included fracturing, clay desiccation, removal of organics from the soil, and evaporation of in situ soil moisture.

Changes in soil textures also were observed. In areas exposed to temperatures of at least 1100° F, the soil solidified (siltstone) and an iron oxide coating was observed. According to the vendor, the solidification may have occurred by sintering silicate materials, particularly clay materials.

Performance Data Quality [1, 6]

PCB soil samples were analyzed using EPA Method 8080. PCB concentrations in stack emissions were analyzed using EPA Method 680. PCDD and PCDF samples were analyzed using EPA Method 8280. Each analytical procedure was performed in compliance with applicable EPA protocols. Each data package contained chain-of-custody documents, analytical report forms, site-specific quality assurance/quality control, sample preparation chronologies and raw material data. Data validation reports reviewed each sample analysis for compliance with method-specific and project-specific QA/QC requirements in accordance with the “Functional Guidelines for Evaluating Organic Analyses”, EPA 1988. Based on the review of the data packages, the analytical data were judged to be representative of site conditions at the time the samples were obtained.

Cost Information [1, 6]

TerraTherm used the results of the demonstration to project the cost for a full-scale application. TerraTherm estimated that the cost for a full-scale application is between $120 to $200 per cubic yard for “most standard sites.” According to the RPM, factors that could affect actual costs include the moisture content of the soil, the cost of electricity required to operate the system, and the extent and depth of the contamination which affects the number of wells required and the depth of the wells.

Observations and Lessons Learned

In situ thermal desorption reduced PCB concentrations in soils at the MEW site from levels as high as 20,000 mg/kg to below the cleanup level of 2 mg/kg. PCB concentrations were reduced to below detection limits (0.33 mg/kg) in 83 of the 94 post-treatment samples.

The in situ thermal desorption technology achieved a PCB DRE of 99.9999998%, exceeding the goal of 99.9999%.

The heating process increased both soil porosity and permeability. Soil porosity increased from 30% of pore volume to 40%; permeability increased from 1 x 10^{-3} to 30 md. According to the vendor, the mechanisms for increases in these parameters included fracturing, clay desiccation, removal of organic content, and evaporation of in situ moisture.

Requests for proposals (RFPs) for the soil remediation activities at the Missouri Electric Works Site were issued during April 1998. Terra Therm submitted a proposal for the work. However, according to the RPM, the cost associated with their proposal was not the lowest and the Missouri Electric Works Steering Committee has retained another experienced vendor whose cost proposal for the remediation effort was less to perform the work at the Missouri Electric Works site.

According to the RPM, demonstration tests should not be conducted during the winter months. In addition, the results of such tests should be viewed as the final arm of research and development. The RPM noted that full-scale applications often identify problems not considered or confronted in a laboratory or pilot-scale test.

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The following references were used in the preparation of this report.

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Acknowledgments

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APPENDIX A

DRE CALCULATION FOR THE ISTD DEMONSTRATION AT MEW

The following was excerpted from the TerraTherm Report (Ref 1.)

DESTRUCTION/REMOVAL EFFICIENCY

The overall effectiveness of the ISTD remediation process can be evaluated from the destruction and removal efficiency (DRE) of the treatment system. The components used to calculate the PCB destruction and removal efficiency for the thermal well demonstration at Cape Girardeau were as follows:

1. The pre-treatment and post-treatment calculations for the mass of PCBs in soil was calculated based on the arithmetic mean of the pre-treatment soil concentration in the 0-4 ft depth range within the well array area;

2. The mass of PCBs removed was calculated by subtracting the post-treatment PCB mass (essentially zero) from the pre-treatment PCB mass;

3. The mass of PCBs emitted from the treatment process was calculated from the stack test results, including the emission rate and stack-test duration to arrive at a flow-weighted total mass;

4. PCB destruction and removal efficiency (%) for the system operation was calculated as follows:

$$DRE=\frac{PCB_{removed}-PCB_{emitted}*100}{PCB_{removed}}$$

Where DRE is the destruction and removal efficiency percentage, $PCB_{removed}$ is the mass of PCBs treated, and $PCB_{emitted}$ is the mass of PCBs discharged.

Soil Sampling & Air Monitoring Data for DRE Calculation

Pre-treatment and post-treatment soil samples were collected to determine the quantity of PCBs extracted from the soil during Thermal Well heating and to demonstrate effective removal of PCBs from soils at a depth up to 10 ft below the original surface grade. Pre- and post-treatment soil analytical results were reported directly by the designated laboratory and are summarized in Table 1 and Figure 1. Soil concentration summaries were produced directly from the laboratory report data to illustrate PCB profiles before and after treatment.

A stack test for PCBs and breakdown products was conducted during 28 hours of system operation on May 11-12, 1997. Stack sampling for PCBs, PCDDs, and PCDFs was conducted in accordance with procedures provided in EPA Method 23. Stack sample analyses were conducted as prescribed by EPA method 23 for PCDDs/PCDFs and modified EPA Method 680 for PCB homologues.

Thermal Well Demonstration DRE Calculation

Maximum detected concentration in the upper 4 ft of the central triangle was 19,900 mg/kg, and the arithmetic mean was 4,600 mg/kg. All post-treatment soil samples collected in this interval were determined to contain less than 0.033 mg/kg, which is the low level detection limit reported for EPA Method 8080A by the laboratory. Therefore, the pre-treatment soil mass is the $PCB_{removed}$.

Based on a mean PCB concentration in the upper 4 ft of the treated area (4,600 mg/kg), a soil density of 43.2 kg/ft^3 (RI Report, Earth Technologies Corp, July 1990), and a conservative treated soil volume of 200 ft^3 (approximately 4.6 triangular patterns to a depth of 4 ft) the mass of PCBs treated was determined to be at least 40 kg.

The total PCB detected in the stack sample was 400 nanograms. The total volume of effluent passed through the XAD resin during the test was 24.5 cubic meters (m^3). The flow determined by EPA Method 2C within the stack during sampling was 123 standard cubic feet per minute (SCFM). The total mass of $PCB_{emitted}$ during the 28-hour stack test was calculated to be 0.0955 mg.

The DRE, as presented above, was calculated by subtracting 0.0000955 grams (g) $PCB_{emitted}$ from 40,000 g $PCB_{removed}$, divided by $PCB_{removed}$, and multiplied by 100% for a DRE of 99.9999998% for the thermal well demonstration at the Cape Girardeau Site.

PCB Case Study #3

Former Naval Facility
Centerville Beach
Ferndale, California

__Physical and Thermal Technologies__: Remediation of Chlorinated and Recalcitrant Compounds. G.B. Wickramanayake and A.R. Gavaskar (eds.) Battelle Press, Columbus, OH. 2000, pp. 175-182.

FIELD SCALE IMPLEMENTATION OF IN SITU THERMAL DESORPTION THERMAL WELL TECHNOLOGY

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Abstract: In Situ Thermal Desorption (ISTD) technology using Thermal Wells was implemented at the former Naval Facility Centerville Beach (NFCB), Ferndale, CA. The project was conducted from September 1998 through February 1999 by TerraTherm Environmental Services as part of the facility restoration program managed by the U.S. Navy Engineering Field Activity West (EFA-West), San Bruno, CA. The ISTD Thermal Well technology deployed at the site used electrical heating elements suspended within stainless steel well casings to raise the temperature of soils in situ and remove targeted contaminants by volatilization and/or in situ destruction reactions. Process gases and contaminant vapors created during heating were drawn through the hot soil to an array of soil vapor extraction wells. The extracted contaminant vapors received secondary and tertiary treatment within a flameless thermal oxidizer (FTO) and/or adsorbed by vapor phase granulated activated carbon (GAC). Subsurface soils at the NFCB were impacted with polychlorinated biphenyls (PCBs) identified as Aroclor 1254 by USEPA Method 8080. A network of 57 Thermal Wells was installed to a depth of 17 feet (5.2 m) within and around the area of known contamination. After achieving an in situ soil temperature of >600°F, the treatment system was shutdown and soils were allowed to cool prior to confirmation sampling activities. The results of post treatment soil sampling indicated that the target treatment zone contaminant concentrations were reduced to <1.0 mg/kg total PCBs and exhibited a 2,3,7,8 TCDD toxicity equivalent quotient (TEQ) of <0.1 µg/kg.

INTRODUCTION

The Naval Facility Centerville Beach (NFCB) is located on County Road 100, in Ferndale, Humboldt County, California. The NFCB was operated as a research facility by the Department of the Navy, West Division, from 1956 to 1993. Naval operations at the facility included oceanographic research of the northern Pacific coastline. As a contingency to local shore power, the facility was equipped with a back-up diesel powered generator and 1,000 KVA electrical transformer station.

Contaminants of Concern: Environment contaminants of concern detected within overburden soils at NFCB included polychlorinated biphenyls (PCBs) from an apparent release of electrical transformer fluids, and petroleum hydrocarbons from underground storage tank releases. The former transformer area had undergone significant investigative and remedial activities. The

<u>Physical and Thermal Technologies</u>: Remediation of Chlorinated and Recalcitrant Compounds. G.B. Wickramanayake and A.R. Gavaskar (eds.) Battelle Press, Columbus, OH. 2000, pp. 175-182.

sampling and analysis performed during the investigative activities indicated that elevated levels (>500 mg/kg) of PCBs (Aroclor 1254) were present in the soil beneath the building foundation (Radian 1997). Data also indicated that PCB concentrations >2.0 mg/kg extended to depths of approximately 15 feet (5 m) beneath the former transformer pad location (Leedshill-Herkenhoff, 1991).

Site Geology: Overburden soils at the NFCB consist of terraced silty and clayey collovial materials that vary in thickness across the site. The terraced deposit resides above the Pleistocene Hookton formation which is comprised of indurated sand, gravel with minor silt and clay layers. The Hookton formation is orange and yellow in color and is greater than 100 feet (33 m) in thickness (Dames & Moore, 1985).

Site Hydrogeology: Depth to groundwater in the vicinity of former transformer pad location had been measured from 99 to 145 feet (33 to 48 m) below ground surface (bgs) while perched water had been detected as shallow as 6 feet (2 m) bgs (Radian, 1997).

MATERIALS AND METHODS

Thermal Well System: The ISTD Thermal well system was designed based on the geophysical properties of the site soils, and the physical properties of the contaminants present. The thermal vapor extraction well casings and thermal well heaters were constructed of corrosion resistant metallurgy. Stainless steel wire wrapped extraction well screens were installed from 2 feet to 15 feet (0.6 to 5 m) bgs to promote efficient recovery of process gases during heating. Thermal Wells were installed using standard drilling techniques on a grid of equilateral triangles spaced 6 feet (2 m) apart forming a hexagonal pattern. The thermal vapor extraction wells were located at the center of each hexagonal pattern of heater wells. The spacing between each extraction well was approximately 10 feet (3 m). Surface completions of the thermal wells used an assembly constructed of carbon steel that was mechanically attached to a vapor barrier consisting of a high temperature resistant coated fabric. Insulated manifold piping was installed and connected to the thermal vapor extraction wells using brass sealed flanges. Inconel sheathed Type K thermocouples were placed within the heaters to monitor the temperature of the heating elements. Thermocouple arrays were also installed at numerous locations between wells within the treatment zone to record in situ soil temperatures. The vapor extraction manifolds were interfaced with a common header leading to the process and control system for secondary and tertiary treatment prior to atmospheric discharge. The manifold piping and common header were equipped with magnehelic gauges to monitor applied vacuum. The integrated process and control system, constructed on a 40 foot (13 m) flatbed trailer, was delivered to the site by a commercial tractor trailer rig.

The process and control system connected to the Thermal Well system was designed to control electrical energy applied to the heating elements; monitor contaminant vapor and process gas concentrations; collect and treat vapors extracted from the treatment area; and to provide emergency power in case of loss of shore power.

Control System: The thermal well and Air Quality Control (AQC) systems were monitored by a programmable logic controller (PLC) located within the control room of the process trailer. The PLC displayed the operating status of each thermal well heating element and the AQC system components through a personal computer. The personal computer provided data logging and graphing capabilities for trend analysis and assisted in scheduling of preventative maintenance on system components.

Process Vapor Extraction & Treatment: Two (2) sealed vacuum blowers, configured in parallel, were used to maintain negative pressure on the soils and the AQC system components. The vacuum blower system pulled the process gas stream through the secondary and tertiary treatment processes to prevent uncontrolled fugitive emissions. Secondary treatment was provided by a flameless thermal oxidizer (FTO) with a demonstrated treatment efficiency of <99.99%. Two (2) granulated activated carbon (GAC) beds, configured in series, provided tertiary treatment.

Air Emissions Monitoring: The process effluent was monitored using a calibrated continuous emission monitoring (CEM) system manufactured by Rosemount Analytical. The CEM utilized an extractive sample probe and conditioning system. The sample stream was introduced to a non-destructive infrared analyzer for the quantification of carbon monoxide (CO) and carbon dioxide (CO_2) prior to the analysis of oxygen (O_2) using a zirconium oxide detector, and total hydrocarbons (THC) using a flame ionization detector. The data was stored using computer software designed for the project and could be retrieved remotely. Stack emissions were sampled following EPA Methods and analyzed to demonstrate compliance with local air permit criteria. Emission samples were collected from sample ports located in the stack and were representative of the final atmospheric discharge.

Electrical Power Generator: In the event of an interruption of shore power, an emergency generator was available to operate the vacuum blowers and FTO to assure that vapors were processed through the secondary and tertiary treatment.

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RESULTS AND DISCUSSION

Final approval of the project work plan by the Regional Water Quality Control Board, California EPA, and Humboldt County Dept. of Health was received in late July and early August 1998. Prior to the installation of the Thermal Well system, pre-treatment soil sampling was conducted in early September, 1998 by TetraTech EMI. In mid September, TerraTherm installed the ISTD thermal well system utilizing local skilled labor for site construction. By early October, TerraTherm installed the process and control system for remedial phase activities. The integrated system shakedown was conducted from 10-16 October 1998 by performing Thermal Well system control checks, CEM calibration, and establishing daily system operations procedures. The soil heating was conducted from November 1998 through January 1999. Interim soil sampling was conducted in early February with the system shutdown on February 26, 1999.

Project Performance Data: Performance data collected and analyzed during the project consisted of soil sampling and analysis data; process monitoring information including in situ and process vapor temperatures; emissions monitoring information including stack testing results, and CEM system data; and ambient air monitoring data.

Soil Data: Soil samples were analyzed for total PCBs using EPA Method 8082, and PCDD/Fs by EPA Method 8290 (USEPA, 1986). Pre-treatment analyses indicated the presence of PCB Aroclor 1254 at a concentration of >500 mg/kg. Pre-treatment concentrations of polychlorinated dibenzodioxins/furans (PCDD/Fs) indicated a 2,3,7,8–TCDD Toxicity Equivalent Quotient (TEQ) of >1.0 ug/kg for the PCB impacted soils under the building foundation (TTEMi, 1998). Post-treatment soil sampling was conducted by TetraTech EMI in early April 1999. Discreet soil samples were collected using a hydraulic drive rig equipped with a stainless steel macro-core (3.0 inch; 7.6 cm interior diameter) soil sampler. Post-treatment soil analysis data indicate that the total PCB detected was <1.0 mg/kg, and the total PCDD/Fs detected was <0.10 ug/kg 2,3,7,8 TCDD TEQ within the target treatment zone. (TTEMi, 1999)

In Situ Temperature Monitoring Data: The boiling point of soil pore water (212°F) was reached at 15 feet (5 m) bgs in approximately 7 days of heating. The average soil temperature at the center of each triangle of thermal wells exceeded 212°F at approximately 25 days from the application of full power to the thermal wells. The soil temperature increased at a rate of approximately 20°F per day. When heating ceased, soil temperatures ranged from 675°F (7 feet; 2.1 m bgs) to 950°F (15 feet; 5 m bgs) at the thermocouple array placed in the center of the target treatment area (TC-6).

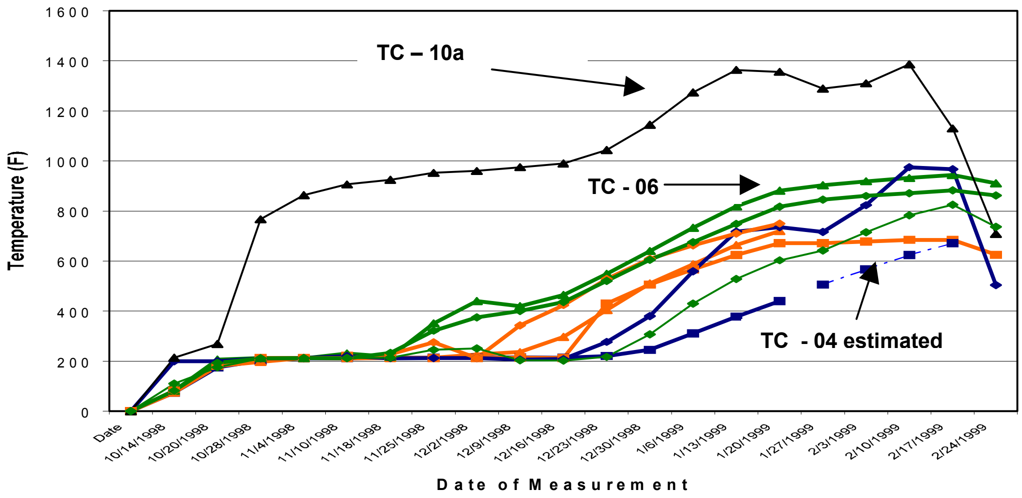

Figure 1. Thermocouple Measurements – NFCB ISTD Demonstration

Emissions Data: Emissions data collected during the execution of the project included: effluent CO, CO_2, O_2, THC concentrations, and source testing for total PCBs, PCDD/Fs, hydrogen chloride, & total particulates. Carbon monoxide (CO) emissions were monitored by the CEM system. Generally, CO emissions were below 10 ppmV with a 3 minute lag throughout the soil treatment. The mean concentration was approximately 2 ppmV. Carbon dioxide (CO_2) emissions were recorded by the CEM system and were observed generally at <2.0%. The concentration was generally higher during the initial heating of the soil with a gradual decrease as the target treatment temperature (600 °F) was achieved. Excess oxygen (O_2) as indicated by the percent of oxygen in the system emission measured on a wet basis was at or above 7%. Relative humidity (RH) of the process vapor stream peaked of approximately 45%. The RH dropped to a low of approximately 15% as the in situ soil thermocouples achieved the target treatment temperature of >600 °F. Total hydrocarbon (THC) emissions were monitored continuously by the CEM system using a flame ionization detector (FID) calibrated to methane (CH_4). THC readings observed during the treatment were generally below 10 ppmV or <0.005 lb/hr as CH_4. Exhaust temperature was monitored by a thermocouple placed in the CEM sample port and recorded by the PLC. The temperature was maintained at approximately 200 °F through adjustment of the heat exchanger flow. The GAC beds were maintained at >220 °F to minimize the formation of condensation within the vessels. Source testing was performed by an approved California Air Resources Board independent contractor following USEPA sampling procedures.

TABLE 1. Independent Stack Testing Results – NFCB ISTD Demonstration

Parameter	**Run#1**	**Run#2**	**Run#3**	**Average**
PCBs	**(ng/dscm)**	**(ng/dscm)**	**(ng/dscm)**	**(ng/dscm)**
Dichlorobiphenyl	8.74E-04	3.52E-03	4.90E-03	3.10E-03
Trichlorobiphenyl	6.01E-04	<5.42E-04	<5.44E-04	5.62E-04
Pentachlorobiphenyl	2.13E-03	<5.42E-04	<1.14E-03	1.27E-03
PCDD/Fs (TEQ)	**(ng/dscm)**	**(ng/dscm)**	**(ng/dscm)**	**Average (ng/dscm)**
Total 2,3,7,8 Dioxin	2.96E-03	2.88E-03	2.88E-03	2.89E-03
Total 2,3,7,8 Furans	2.50E-03	2.58E-03	2.61E-03	2.56E-03
Total 2,3,7,8-TCDD Equivalents (TEQ)	5.47E-03	5.46E-03	5.44E-03	5.46E-03
Particulates	**(gr/dscf)**	**(gr/dscf)**	**(gr/dscf)**	**Average (gr/dscf)**
Total PM 10	1.72E-03	2.15E-03	2.16E-03	2.01E-03
Hydrogen Chloride	**(lb/hr)**	**(lb/hr)**	**(lb/hr)**	**Average (lb/hr)**
HCl Vapor	5.8E-03	2.18E-03	6.31E-03	4.76E-03

Sampling methods included Methods 1, 2C, 3 & 4 for the determination of stack gas velocity, flow, temperature, molecular weight and moisture content (USEPA, 1988) respectively. Isokinetic sampling using an EPA Method 005 sampling train was conducted for the measurement of particulate matter, hydrogen chloride, total PCBs, and PCDD/Fs isomers. Samples were shipped under chain of custody for off-site analyses conducted by a CalEPA certified air testing laboratory. The PCB and PCDD/Fs isomers were collected upon an XAD-2 sorbent trap in accordance with EPA Method 23. Aqueous condensate was collected within glass impingers prior to the sorbent trap. The sorbent trap and impinger condensate samples were submitted for analysis by High Resolution combined Gas Chromatograph /Mass Spectrometer (HR GC/MS) in accordance with EPA Method 8290.

Ambient Air Monitoring: Two ambient air monitoring procedures were conducted throughout the project to ensure protection of on-site worker health and safety, and the environment. Initial survey monitoring was conducted using a handheld Model 503B Organic Vapor Monitor (OVM) manufactured by Thermo Instruments. Surveys were conducted approximately every four (4) hours by site workers in and around the treatment system. No measurement of volatile organic compounds (VOCs) above background (>1.0 ppmV) were noted. Ambient air samples were collected periodically using calibrated personal air sampling pumps manufactured by MSA to confirm these observations. The pumps were fitted with polyurethane foam tube samplers in accordance with EPA Method 0010 and attached to the treatment area exclusion zone fencing in up wind and downwind locations. Samples were collected for 24 hours at a sampling rate sufficient to filter approximately 5.0 cubic meters of ambient air. Samples were submitted under chain of custody to an off-site CalEPA certified air testing laboratory for the analysis of Total PCBs by EPA Method 8082. All samples were below the NIOSH Recommended Exposure Limit (REL) of 1.0 microgram per cubic meter (ug/M^3).

CONCLUSIONS

Confirmatory soil sampling data indicate that the Total PCB concentration within the target treatment area was reduced from greater than 500 to below 1.0 mg/kg dry weight of soil. Total 2,3,7,8 - TCDD toxicity equivalents were reduced from greater than 1.0 to less than 0.100 ug/kg dry weight of soil. The ISTD system delivered sufficient thermal energy to raise the in-situ soil temperature to >900°F. Sampling and analysis data from source testing, emissions monitoring, and ambient air testing indicate that the soil remediation was completed without exposure of on-site personnel or the environment to the contaminants of concern and/or oxidation by products. These measurements indicate that the combined Thermal Well and AQC system operated at greater than 99.9999% destruction/removal efficiency (DRE) and treated the PCB contaminants to acceptable discharge levels for Total PCBs, hydrogen chloride, and total particulates. The calculated discharge of PCDD/Fs isomers as 2,3,7,8,-TCDD TEQ was approximately 100 times less than the Maximum Acceptable Control Technology standard of 0.2 ng/dscm established by the USEPA for the treatment of dioxin-like substances.

ACKNOWLEDGEMENTS

The author would like to thank the dedicated personnel at TerraTherm Environmental Services for their commitment to the completion of this project, and Drs. George Stegemeier and Harold J. Vinegar for their encouragement, guidance, and for their courage in the development of this valuable technology.

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PCB Case Study #4

Former Wood Treatment Facility
Southern California

IT3'07 Conference, May 14-18, 2007, Phoenix, AZ

COMPLETION OF IN-SITU THERMAL REMEDIATION OF PAHs, PCP AND DIOXINS AT A FORMER WOOD TREATMENT FACILITY

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TerraTherm, Inc.

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Lopez and Associates Engineers

ABSTRACT

The largest in-situ thermal conduction heating project ever undertaken at a wood treatment site was completed in March 2006. The site was a former utility pole treatment facility that Southern California Edison (SCE) operated from 1922 to 1957. The subsurface soils were contaminated primarily with polycyclic aromatic hydrocarbons (PAHs), pentachlorophenol (PCP), and polychlorinated dibenzodioxins and furans (PCDD/Fs), with soil treatment standards of 0.065 mg/kg Benzo(a)Pyrene Equivalents (B(a)P-E), 2.5 mg/kg PCP, and 1.0 µg/kg PCDD/Fs, expressed as 2,3,7,8-Tetrachlorodibenzodioxin (TCDD) Toxic Equivalents (TEQ), respectively. A feasibility study led to the selection of TerraTherm's patented In-Situ Thermal Destruction (ISTD) technology, also known as In-Situ Thermal Desorption, which utilizes simultaneous application of thermal conduction heating and vacuum to treat contaminated soil without excavation. The applied heat volatilizes organic contaminants within the soil, enabling them to be carried in the vapor stream toward heater-vacuum wells.

Approximately 12,385 m^3 (16,200 cubic yards [CY]) of predominantly silty soil was treated to a maximum depth of 32 m (105 ft). TerraTherm installed 785 thermal wells, including 654 heater-only and 131 heater-vacuum wells, in a hexagonal pattern at 2.1-m (7.0-foot) spacing. Subsurface temperature monitoring tracked the progress of heating. The heating goal for inter-well temperatures was 335°C (635°F) for three days, or 300°C (570°F) sustained for thirty days.

Gases emerging from the heated soil were collected under vacuum and conveyed to an Air Quality Control (AQC) system, permitted by the South Coast Air Quality Management District. The AQC system consisted of a thermal oxidizer, heat exchanger to cool the gases, and serial vessels of granular activated carbon. AQC system performance was gauged by a Continuous Emissions Monitoring (CEM) system operated by TerraTherm, vapor sampling, and four source tests conducted by an independent stack testing firm.

Over the course of the project, TerraTherm reduced mean B(a)P-E and TEQ concentrations in soil from 30.6 mg/kg and 0.018 mg/kg (pre-treatment) to 0.059 mg/kg and 0.00011 mg/kg (post-treatment), respectively; thereby meeting the remedial goals, and resulting in a No Further Action letter from the Department of Toxic Substances Control. Attainment of such stringent soil treatment goals with an in-situ technology is unprecedented. Dioxin (PCDD/F) emissions based on four source tests averaged 0.0071 ng TEQ/dsm^3, compared to the standard of 0.2 ng TEQ/dsm^3. Averaged over the life of the project, this is equal to 0.00023 g TCDD, one-quarter of the projected (design) amount. Furthermore, this stack emission rate is equivalent to a TCDD TEQ concentration in the air of less than 2 parts per quadrillion, an extremely low emission rate for any remediation off-gas treatment system.

INTRODUCTION

The TerraTherm ISTD process utilizes conductive heating and vacuum to remediate soils contaminated with a wide range of organic compounds. Heat and vacuum are applied simultaneously to the soil with an array of vertical heaters. Heat flows through the soil primarily by thermal conduction from electrically powered heating elements. Because their temperature can be easily controlled, like the burners on an electric range, they can be operated at any desired temperature from ambient to about 870ºC (1600ºF), allowing the heating process to be tailored to the needs of a particular project.

ISTD remediation uses a network of thermal wells to achieve the soil clean-up standards within the target treatment zone (TTZ). At the Alhambra site, one-fifth of the thermal wells within the limits of the TTZ (Fig. 1) were configured as heater-vacuum wells to allow collection of the volatilized contaminants, and the remaining wells functioned as heater-only wells, delivering heat only. Electrical heating elements placed in all the thermal wells were designed to reach temperatures of approximately 700-870ºC (1300-1600ºF), resulting in an extremely hot zone surrounding each heater well. With ISTD, as the thermal heat front advances radially outward from each of the heater wells through the surrounding soils, most of the heat transfer occurs via thermal conduction (1).

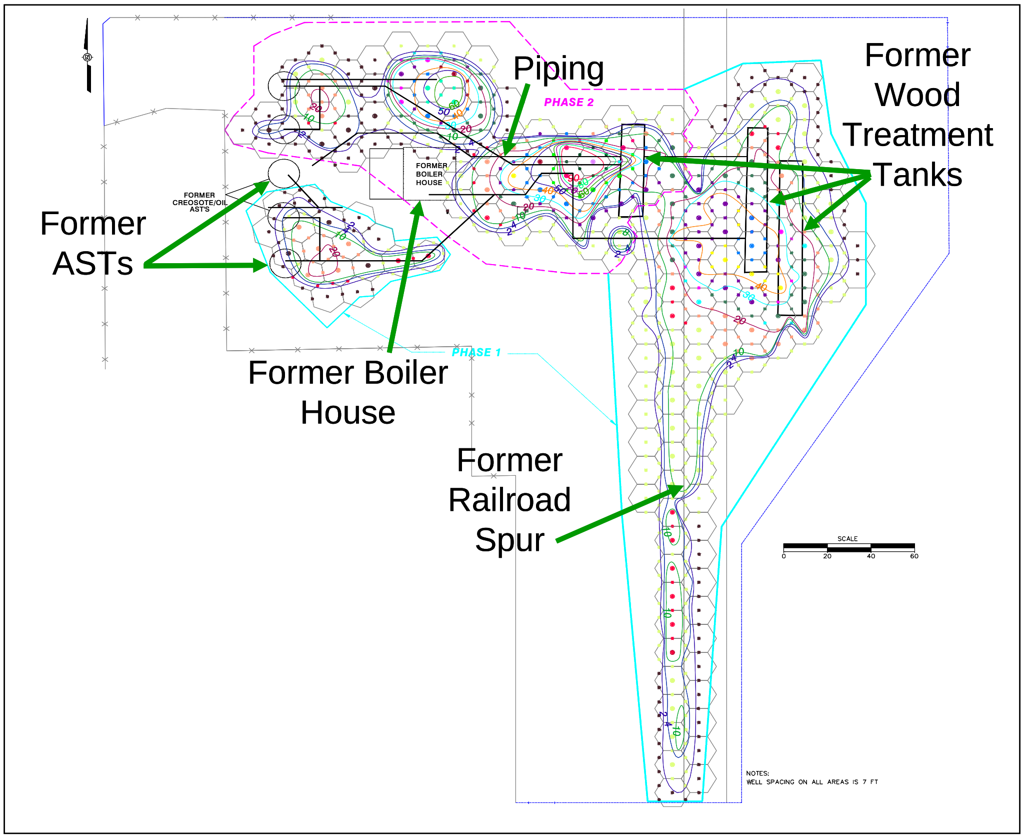

Fig. 1. Former Wood Treatment Facilities and ISTD Wellfield Layout. Colored contour lines indicate depth of contamination.

SITE HISTORY

The former wood treating facilities (AOC-2) were constructed in 1922-1923 for chemical treatment of utility poles by immersion in creosote. The facilities consisted of two full-length tanks (~3 m (10 ft) wide x 21.3 m (70 ft) long x 1.7 m (5.5 ft) deep), two butt-dip tanks (~3 m (10 ft) wide x 13.7 m (45 ft) long x 4 m (13 ft) deep), a boiler house, an aboveground storage tank farm, buried pipe lines and railroad spurs. Wood treatment operations continued until 1957.

PCP was employed briefly prior to shutdown of wood treatment operations, and is believed to be the source of the dioxins. Since then, the site has been used by SCE as a maintenance facility. SCE and their consulting engineer, IT Corporation performed a treatability study and selected ISTD in 2000. TerraTherm mobilized to the site in 2002 and implemented ISTD as a Voluntary Action under the Expedited Remedial Action Program administered by the California Department of Toxic Substances Control (DTSC).

SOIL TREATMENT STANDARDS

Maximum and average pre-treatment concentrations of the contaminants of concern (COCs) are displayed in Table I, along with the soil cleanup standards.

Table I. Soil Contaminant Concentrations and Cleanup Standards (2)

Constituent	Max. Conc. (mg/kg)	Mean Conc. (mg/kg)	Cleanup Standard (mg/kg)
TPH	50,000	2,730	N/A
Total PAH	35,000	2,306	0.065 [B(a)P-E]
Creosote	61,000	4,505	N/A
PCP	58	2.94*	2.5
Dioxins (2,3,7,8-TCDD TEQ)	0.194	0.018	0.001

* Average of 15 detected samples; PCP was not detected in the other 231 samples collected.

DESIGN CONCEPT

TerraTherm developed its design concept for the site using data from a treatability test that was performed on site soil, numerical simulation modeling, electrical power supply limitations, and air emission standards. An extensive community involvement program was undertaken by SCE and TerraTherm, and in response to community concerns additional contingencies were included in the system design, including redundant air treatment equipment, process blowers, stack testing events and longer operator hours.

Target Treatment Temperature. Laboratory treatability testing on site soils showed total contaminant mass removal of more than 99.96% when heating was applied to temperatures of 371ºC (700ºF) and 427ºC (800ºF) for 24 hours. Thermal desorption research shows that time, in addition to temperature, is a key factor in determining treatment effectiveness (3). For example, treatability testing (4) has shown that PAH-contaminated soils treated at 300ºC (592ºF) for three days achieved much lower residual contaminant concentrations than soils treated at 400ºC (752ºF) for just one day. The ability to effect treatment of these high-boiling point compounds at temperatures well below their boiling points is largely due to the significant increase in vapor pressure that accompanies the elevated subsurface temperatures created by ISTD, and the relatively long contaminant residence times in the hot subsurface during ISTD remediation.

TerraTherm also performed simulation modeling to evaluate the duration of treatment given the selected target temperature. Based on the treatability testing, simulation modeling, and previous experience with high-boiling point compounds, TerraTherm selected a target temperature of 335ºC (635ºF). The target temperature was defined as the temperature to be achieved within the coolest points in the wellfield (centroids midway between wells) and maintained for a period of 3 days.

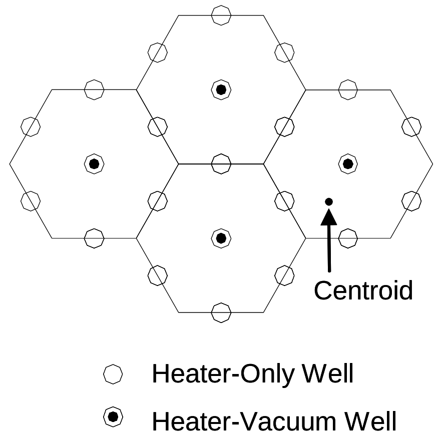

Fig. 2 – Hexagonal Grid Pattern Wellfield Layout (2).

Well Layout. TerraTherm installed a total of 785 thermal wells (131 heater-vacuum wells and 654 heater-only wells) within the 2,920 m^2 (31,430 ft^2) area of the TTZ. The thermal wells were arrayed in a hexagonal grid pattern (Fig. 2) at a spacing interval of 2.1 m (7.0 ft) on center. TerraTherm positioned heater-only wells at the center of each side of each hexagon and a heater-vacuum well at the center of each hexagon. Thermal wells ranged in depth from 2.1 m (7.0 ft) to 31.1 m (102 ft), and averaged 6.1 m (20 ft).

Vapor Seal. Due to electrical power constraints (discussed in more detail below), operation of the ISTD process proceeded using a phased approach. For Phase 1, TerraTherm poured a light aggregate cement surface cover over the wellfield to insulate the surface, preventing excessive heat loss from the soil, and providing a vapor seal that prevented steam and vapors from escaping to the atmosphere through the surface. To improve the insulation, TerraTherm poured a similar light aggregate, high insulating value cement above and below a layer of insulation board prior to Phase 2.

Electrical and Mechanical Systems. Two 2,500-kVA transformers were installed to provide power to the heater circuits, AQC system components, and trailers. The large power demand necessitated that the project proceed in two separate phases to avoid exceeding the capacity of the local power supply. Phase 1 utilized four distribution panels fed from the main switchgear that connected to the secondary side of the main transformers. The thermal well circuits were powered off the distribution panels and controlled by silicon controlled rectifiers (SCRs), which governed the duty cycle of the heaters based on representative in-well temperatures. A total of 16 circuits powered approximately 2,650 m (8,700 ft) of heaters operated at approximately 984 W/m (300 W/ft) for a total heater power demand of approximately 2,600 kW. Licensed electricians performed the electrical work and all electrical and mechanical equipment was bonded and grounded to ensure safety.

Insulated manifold piping connected the lateral piping from each heater-vacuum well to the main piping trunk line that led to the inlet of the AQC system. TerraTherm installed insertion heaters inside the manifold piping to keep the vapor stream warm and minimize condensation within the piping. Per City of Alhambra requirements, TerraTherm installed seismic bracing to secure the manifold piping and the AQC system components. Fig. 3 is an aerial view of the wellfield and immediate surroundings in December 2004, during operation of Phase 1.

AQC System and Emission Standards. The South Coast Air Quality Management District (SCAQMD) permitted the AQC system, which consisted of the following: three cyclone separators plumbed in parallel for particulate removal, a regenerative thermal oxidizer (RTO) with 99% Destruction and Removal Efficiency (DRE) for contaminant removal, a heat exchanger to cool the RTO exhaust, and two 2,268-kg (5,000-lb) granular activated carbon (GAC) vessels (plus an installed 1,361-kg (3,000-lb) spare) piped in series for additional contaminant removal. Vapors were pulled through the AQC system by two blowers, operated by variable frequency drives to apply a consistent vacuum on the wellfield, and then emitted via a discharge stack. A third blower was also installed as a spare. The AQC system was operated using a programmable logic controller (PLC) and operations staff were on site 24 hours/day, 7 days/week, as required by SCAQMD permit. A photograph of the AQC system and related equipment is presented in Fig. 4.

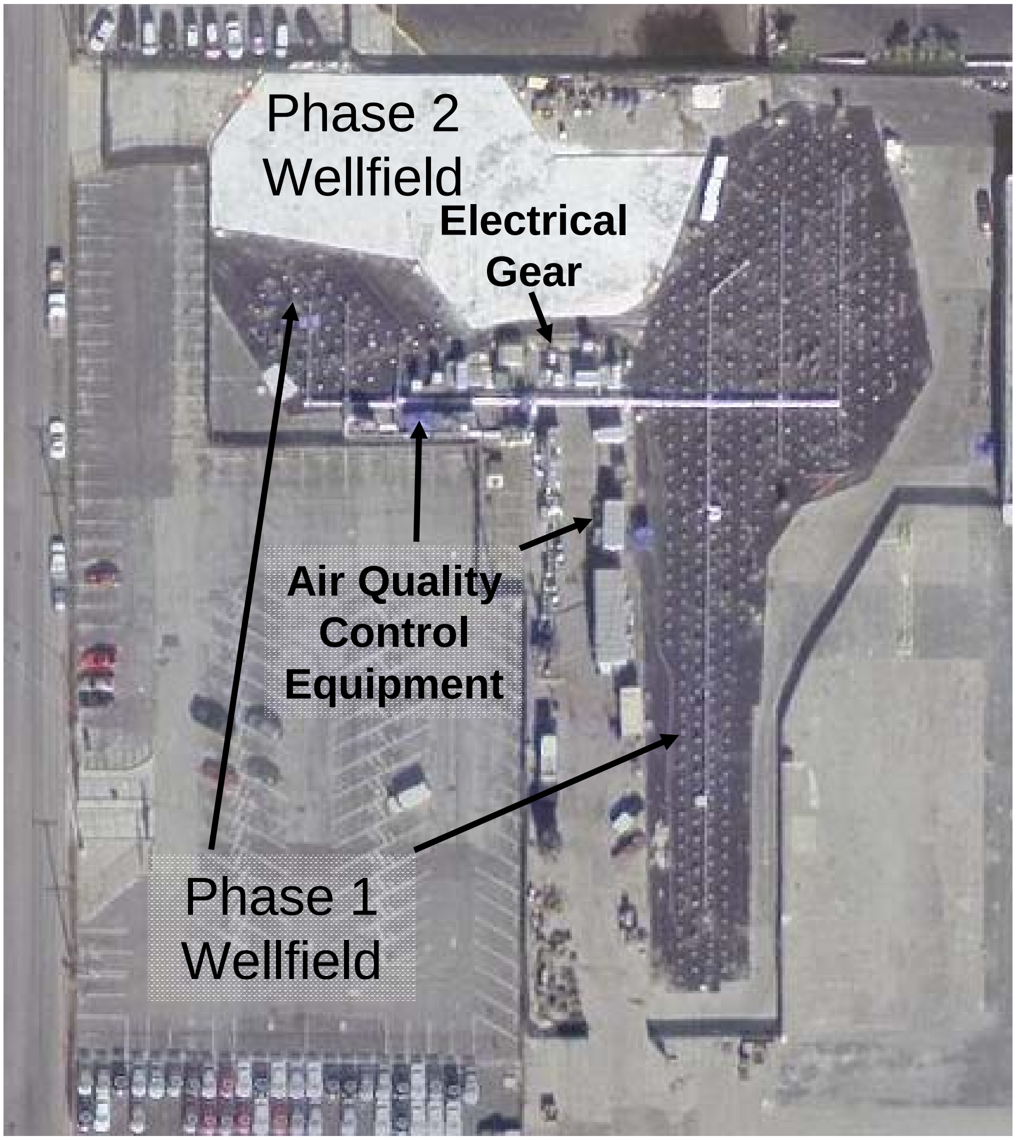

Fig. 3. Aerial View of Phase 1 ISTD under Operation, December 2004.

Air monitoring requirements included a Continuous Emissions Monitoring (CEM) system installed on the discharge stack, which measured carbon monoxide (CO), carbon dioxide (CO_2), wet and dry oxygen (O_2), and total hydrocarbons (THC). Volatile organic compound (VOC) samples were collected monthly from several locations in the AQC stream and analyzed by SCAQMD Method 25.1. An independent firm conducted source testing, including VOCs, PAHs, particulate matter (PM), hydrochloric acid (HCl), and PCDD/F, three times during Phase 1 of operations, and once during Phase 2.

ISTD OPERATIONS PROGRESS MONITORING

To evaluate the progress of in-situ heating and the performance of the AQC system, TerraTherm collected operational data frequently. The most pertinent data used for this evaluation were in-situ soil temperatures and pressures, AQC system source testing results, and soil sampling results.

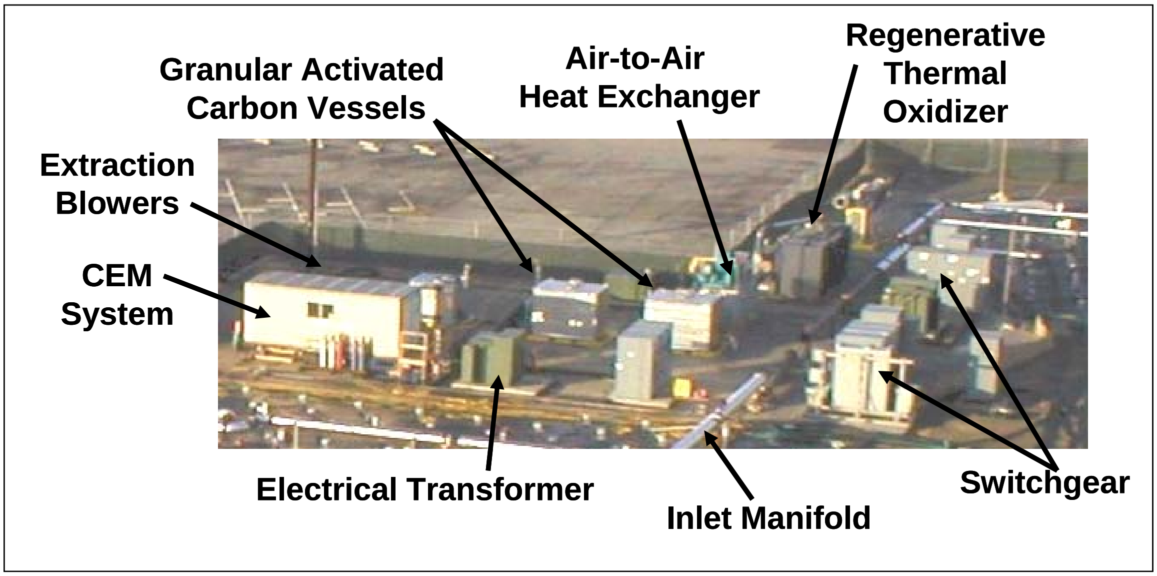

Fig. 4. AQC System and ISTD Mechanical and Electrical Equipment. A portion of the Phase 1 wellfield is evident in the foreground.

Wellfield Temperatures and Pressures. Thermocouples were installed inside temperature monitoring points at varying depths and locations throughout the wellfield to monitor soil temperature. The range of temperatures varied depending on the depth of the thermocouple and its proximity to thermal wells. The coolest point in each well pattern is always the centroid of the equilateral triangle formed by any three adjacent thermal wells (Fig. 2). The shallowest thermocouple in these centroid locations was generally the coolest due to heat loss through the surface cover. Temperature data for a representative centroid thermocouple in Phase 1 is presented in Fig. 5, showing the succession of rising temperatures up to attainment of the target temperature of 335°C (635°F).

In-situ pressures were monitored at eight locations around the perimeter of the wellfield to ensure that sufficient vacuum was being applied to the boundaries of the TTZ to prevent migration of steam and contaminants. Pressure data indicated that a negative pressure gradient was maintained on the boundaries of the wellfield throughout ISTD operation.

CEM and AQC Source Testing Results. CEM system measurements of THC and CO were monitored by the PLC. An alarm condition was defined to exist if the levels approached TerraTherm's self-imposed limits of 100 ppm_v for CO and 100 ppm_v as hexane for THC.

Three separate source-testing events were performed during Phase 1 of operations. Samples were collected from the RTO inlet and discharge stack and analyzed for HCl, PM, THC, chlorophenols, PAHs, polychlorinated biphenyls (PCBs), and PCDD/Fs. The three source-testing events within Phase 1 were conducted: (a) within the first five days of ISTD operation, and subsequently when the average of all centroid thermocouple temperatures reached (b) 100ºC (212ºF) and (c) 282ºC (540ºF), respectively. A single representative source testing event within Phase 2 was conducted within the first 60 days of Phase 2 ISTD operation. Tables II and III present data from all four events, along with associated emission standards (5). SCAQMD performed a detailed health risk assessment based on the data, which indicated full compliance with their Rule 1401.

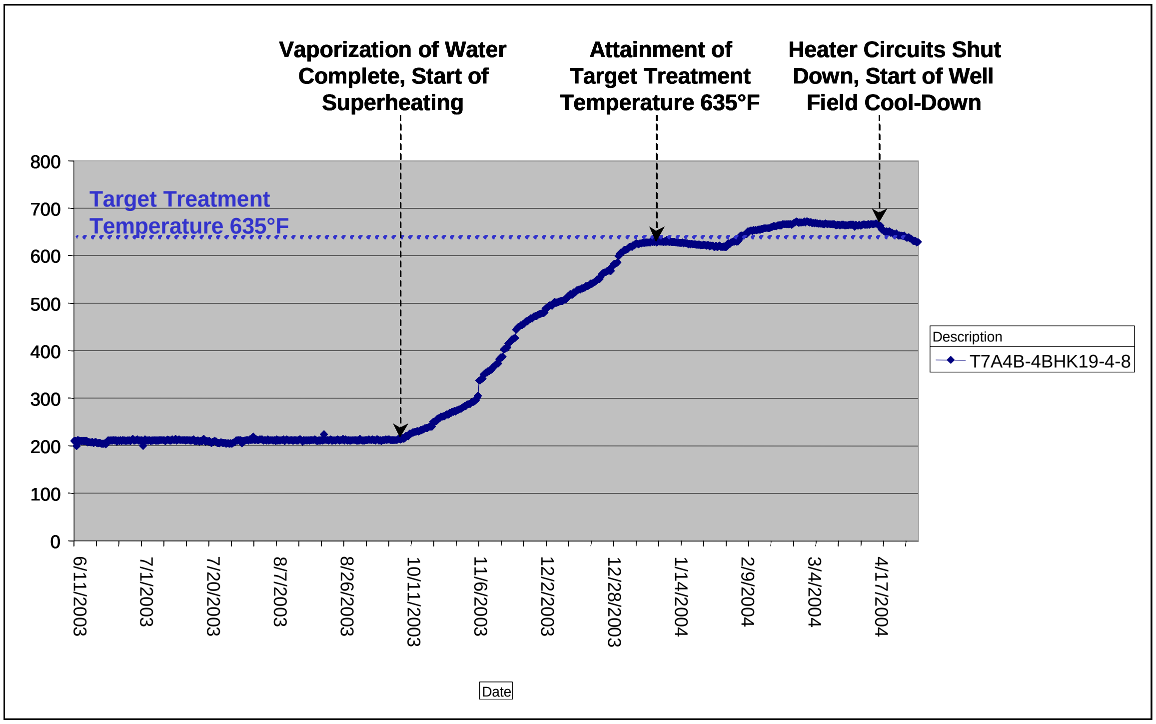

Fig. 5. Phase 1 Temperatures, Degrees Fahrenheit at a Representative Centroid Location.

VOC emission standards are listed in Table II as "varied" because emission limits corresponding to a maximum individual cancer risk (MICR) of 10^{-6} (i.e., one per million) varied depending on the chemical constituent. For all source-testing events, concentrations of VOC were ≤ 4.5% and of PAHs ≤ 4.1% of the MICR of 1×10^{-6} in all cases.

During the four source-testing events, DREs calculated by comparing mass emission rates from the RTO inlet and stack were > 99.7% for PAHs, PCBs, and PCDD/PCDF. The slight particulate matter exceedance (0.0021 vs. 0.002 gr/dscf in Phase 1, Event 2) may have been due to some fine carbon dust carried into the piping from the GAC.

Dioxin (PCDD/F) emissions based on four source tests averaged 0.0071 ng TEQ/dsm^3, compared to the standard of 0.2 ng TEQ/dsm^3. Averaged over the life of the project, this is equal to 0.00023 g TCDD, one-quarter of the projected (design) amount of 0.0009 g TCDD (6, 7). This value is much less than one hundredth of the TCDD emission from a typical oxidizer unit (8). Furthermore, this stack emission rate is equivalent to a TCDD TEQ concentration in the air of 1.8 parts per quadrillion[i], an extremely low emission rate, for any remediation off-gas treatment system.

Table II. Phase 1 and 2 Source Testing Results (5)

Compound	Units	Emission Limit	Phase 1 Event 1	Phase 1 Event 2	Phase 1 Event 3	Phase 2 Event 1
THC (a)	ppm_v as Hexane	100	1.23	0.71	1.65	1.92
PCDD/ PCDF (b)	ng/dscm	0.2	1.61×10^{-2}	6.53×10^{-3}	3.53×10^{-3}	2.4×10^{-3}
PCP	µg/dscm	1,630	< 9.31	< 8.68	< 23.7	< 19.03
HCl (c)	µg/dscm	N/A	1,434	171	< 169	1,273
PM	gr/dscf	0.002	4.25×10^{-4}	2.10×10^{-3}	7.98×10^{-4}	9.49×10^{-4}
PCBs (d)	µg/dscm	2.44	5.94×10^{-3}	7.54×10^{-3}	0.0121	2.59×10^{-4}
VOC (e)	ppb_v (f)	Varied	None Detected	3.7	None Detected	323.3

(a) Total hydrocarbons (b) Expressed as 2,3,7,8-TCDD TEQ; (c) Hydrochloric Acid (d) Polychlorinated Biphenyls; (e) The emission limit for VOCs varied depending upon the specific contaminant; (f) Sum of all VOCs analyzed.

Table III. Summary of Source Testing Results (µg/M^3 Discharge Concentrations) for PAHs (5)

Compound	MICR Limit	Phase 1 Event 1	Phase 1 Event 2	Phase 1 Event 3	Phase 2 Event 1
Benzo(a)anthracene	23.9	0.869	0.610	1.00	0.946
Chrysene	239	1.27	1.34	1.83	2.89
Benzo(b)fluoranthene	23.9	0.341	0.172	0.898	0.686
Benzo(k)fluoranthene	23.9	0.149	0.0894	0.317	0.252
Benzo(a)pyrene	2.39	0.0954	0.0378	0.0839	0.1150
Indenopyrene	23.9	0.0793	0.0099	0.0681	0.0750
Dibenz(a,h)anthracene	6.74	0.0371	0.0069	0.0391	0.0400

Soil Sampling Results. Soil samples were collected in accordance with the prescribed sampling and analysis plan at 20 locations within the TTZ where the highest pre-treatment concentrations had been found. At each such location, a sample was collected from 0 to 0.30 m (2.0 ft) from the top, 0.30 m (2.0 ft) from the bottom, and at the midway point within the vertical limits of the TTZ. The site-wide mean for carcinogenic PAHs (cPAHs), expressed as B(a)P Toxicity Equivalents was 0.059 mg/kg as compared to the cleanup standard of 0.065 mg/kg. EPA Method 8270C-SIM (low detection limit) was used to analyze PAHs. The site-wide mean for dioxins and furans, expressed as 2,3,7,8-TCDD TEQ was 0.11 µg/kg compared to the remediation goal of 1 µg/kg. EPA Method 8290 was used to analyze dioxin and furan samples. Finally, PCP was not detected in any of the soil samples at or above the remediation goal of 2.5 mg/kg (EPA 8270C). For those samples whose analytical result were below the laboratory detection limit, the PAH, PCDD/F, and PCP soil concentrations were each calculated by taking 1/2 the respective detection limit. Using this method, the mean PCP soil concentration was 1.25 mg/kg. These results are summarized in Table IV.

Table IV. Summary of Soil Sampling Results

Contaminant	Clean-up Standard (µg/kg)	Mean Soil Concentration (µg/kg)	
		Pre-Treatment	Post-Treatment
B(a)P-E	< 65	30,600 (n = 47)	59 (n = 60)
PCP	< 2,500	2,940 (n = 15*)	1,250 (n = 60)
TCDD TEQ	< 1	18	0.11 (n = 18)

*See Table I. n indicates the number of samples

CONCLUSIONS

On Feb. 8, 2007, DTSC certified that "the AOC-2 portion of the site has been remediated to allow for unrestricted land use, and that no further action is required" (9). To the authors' knowledge, achievement of unrestricted/residential land use at a facility of this type has never before been accomplished with an in-situ remediation method. In fact, during project planning, the only other remediation alternative deemed capable of achieving the unrestricted land use goal was soil excavation followed by off-site incineration. Although ISTD remediation costs exceeded the originally estimated cost, the all-in project cost was still approximately 40% lower than the excavation/incineration alternative for this F-listed waste. The ISTD project was completed without the complications and inherent risks associated with excavation projects, such as: strong odors, potential for chemical exposure, transportation of waste through city streets/communities, and the potential for other environmental impacts on the community.

Based on the completion of this project, and the lessons learned, TerraTherm prepared a cost estimate for a similar sized wood treatment site. The estimate assumed ISTD treatment in one operational phase lasting 130 days. The turnkey project cost is estimated to be \$500/m^3 (\$383/cy), broken into the following cost elements:

- Design/Installation/Commissioning – capital cost: \$3.9M
- Operation – includes electricity, source and confirmation sampling: \$2.2M
- Demobilization/Reporting/License Fee: \$0.23M

Based on these results, ISTD deserves consideration for treatment of sites contaminated with Persistant Organic Pollutants (POPs) such as those that were addressed at this site (10).

ACKNOWLEDGEMENT

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[i] Calculated as follows: (2.65 x 10E-10 lb TCDD/hr)*(1hr/60 min)*(1 lbmole TCDD/308 lb TCDD)*(1 min/3000 cfm air)*(379 ft^3 air/1 lbmole air) =1.8E-15 parts TCDD/parts air, or 1.8 parts per quadrillion (wt/wt).

High Temperature ISTD
SVOC Treatability Summary

February 2010

TERRATHERM®

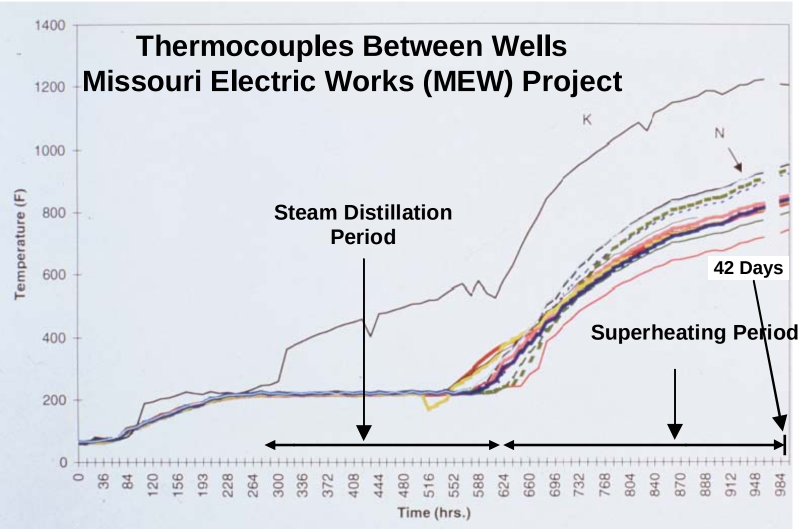
High Temperature ISTD Application: Semi-Volatile Organic Compounds (SVOCs)

Applicable Contaminants:

- ***Polyaromatic Hydrocarbons (PAHs)***
- ***Polychlorinated Biphenyls (PCBs)***
- ***Chlorobenzenes***
- ***Napthalenes***
- ***Chlorinated Pesticides***
- ***Pentachlorophenol (PCP)***
- ***Dioxins***
- ***Creosote/Coal Tar***
- ***Other SVOCs***

Applicable Geologic Settings:

- ***Unsaturated Zone:***
  - ➢ High to low permeability settings (e.g., sands and gravels to clays)
  - ➢ High to low soil moisture (may need to control perched water, if present)
- ***Saturated Zone:***
  - ➢ Low permeability settings ($<10^{-6}$ cm/s)
  - ➢ Moderate to high permeability settings with groundwater control



Summary: Completed ISTD Projects for PCB-Contaminated Soils			
LOCATION	**PCB**	**INITIAL CONC. (ppm)**	**FINAL CONC. (ppm)**
S. Glens Falls, NY	1248/1254	5,000	< 0.8
Cape Girardeau, MO (MEW)	1260	500	< 1
	1260	20,000	< 0.033
Vallejo, CA	1254/1260	2,200	< 0.033
Tanapag, Saipan	1254/1260	10,000	< 1
Ferndale, CA	1254	800	< 0.17

Concept:

- Thermal well spacing typically ranges from 6-10 ft (2-3 m) with a 3:1 ratio of heater-only wells to heater-vacuum wells.
- Thermal wells extend several feet below and around the perimeter of the treatment zone to ensure adequate heating and to minimize risk of vertical and lateral mobilization.
- Creation of a “hot-floor” (TerraTherm patents: U.S. 5,997,214 and 6,102,622 and Int’l Patent WO9855240) and upward vertical gradients if there is a risk of vertical DNAPL mobilization.
- Target treatment temperature of 150 to 450°C at centroids between wells (coolest regions), depending on molecular weights/boiling points of contaminants.
- Vapors are pulled from regions undergoing heat-up through very hot regions (>500°C) surrounding heater vacuum wells, resulting in significant (>95%) in-situ destruction of the contaminants.
- High temperatures around heater-vacuum wells desiccates soil resulting in significant improvements in air permeability and ensuring effective vapor capture (steam and contaminants).
- Effective capture of vapors eliminates risk of lateral contaminant migration due to condensation.

Removal/Destruction Mechanisms:

- Vaporization, steam distillation/stripping in cooler regions (100°C or less).
- In-situ destruction (oxidation and pyrolysis) in hot regions around thermal wells.
- Proven to achieve 95%-99% destruction in-situ and very low remedial standards (e.g. <0.033 mg/kg).

Costs:

- Unit treatment costs are dependent on the scale and configuration of the treatment volume (e.g., unit costs decrease as treatment volume increases and the ratio of surface area to volume decreases) and off-gas treatment requirements.
- General ranges in turnkey costs for SVOC sites are as follows:
  - ➢ 5,000 -10,000 cy - $300-$450/cy
  - ➢ 10,000 – 20,000 cy - $200-$300/cy
  - ➢ >20,000 cy - <$200/cy

High Temperature ISTD SVOC
Cost and Performance Summary

February 2010

Summary of ISTD Performance Data for SVOC Sites - TerraTherm, Inc., Feb. 2010

Site Name	Location	Date Completed	Volume	Depth Treated (Well Spacing)	Major Contaminant(s) of Concern	Type(s) of Soil (thickness, ft); Water Table	Target Temperature	Maximum and/or Mean Pretreatment Concentration	Remedial Goal	Mean Post-treatment Concentration	Comments
			cy	ft		ft	°C	mg/kg	mg/kg	mg/kg	
GE Test 3B	S. Glens Falls, NY	Mar-96	16	0.5 (thermal blanket)	PCB 1248/1254	sand; vadose zone	~370	Max.: 5,212 Mean: 509	2	< 0.033	Avg. temperature achieved = 424°C Heating duration 1.5 days
Missouri Electric Works	Cape Girardeau, MO	May-97	61	12 (5)	PCB 1260	silty clay; water table at 40 ft depth	~370	Max.: 19,900 Mean: 649	2	< 0.033	Avg. temperature achieved = 427°C Heating duration 42 days
US Navy Former Mare Is. Naval Shipyard	Vallejo, CA	Dec-97	175	14 (5)	PCB 1254/1260	silt/clay; water table at ~20 ft depth	~370	Max.: 2,200 Mean: 53.5	2	< 0.033	Avg. temperature achieved = 410°C Heating duration 37 days
Tanapag Village Site Remediation	Saipan, NMI	Aug-98	1000	N/A (IPTD)	PCB 1254/1260	silty sands and crushed coral vadose zone	~370	Max: 10,000 Mean: 500	10	< 10	Batches averaged 40-45 cy each.
US Navy Centerville Beach	Ferndale, CA	Dec-98	530	17 (6)	PCB 1254/1260	silty and clayey colluvium	316	Max: 860 Mean: 302	1	< 0.17	Avg. temperature achieved = 427°C Heating duration 90 days
Southern California Edison AOC-2	Alhambra, CA	Jan-06	16,200	0 to 105 (7.0)	PAHs, PCP and PCDD/Fs	Silty sand; vadose zone	335	Max.: Total PAHs: 35,000 PCP: 58 PCDD/Fs: 0.194 (TEQ) Mean: Total PAHs: 2,306 PCP: 2.94 PCDD/Fs: 0.018 (TEQ)	PAHs [B(a)P-Eq]: 0.065 PCP: 2.5 PCDD/Fs: 0.001 (TEQ)	PAHs [B(a)P-Eq]: 0.059 PCP: 1.25 PCDD/Fs: 0.00011 (TEQ)	2 treatment areas, treated as successive phases Many buried utility lines and tanks. Treatment temperatures achieved in ~ 1 yr (each phase) At least 1,000,000 lb of contaminant (expressed as naphthalene) removed in total. Air emissions were well below compliance requirements. No Further Action letter (February 7, 2007) from California Department of Toxic Substances Control to Southern California Edison allows unrestricted land use.

Summary of ISTD Performance Data for SVOC Sites - TerraTherm, Inc., Feb. 2010

Site Name	Location	Date Completed	Volume	Depth Treated (Well Spacing)	Major Contaminant(s) of Concern	Type(s) of Soil (thickness, ft); Water Table	Target Temperature	Maximum and/or Mean Pretreatment Concentration	Remedial Goal	Mean Post-treatment Concentration	Comments
			cy	ft		ft	°C	mg/kg	mg/kg	mg/kg	
National Grid Former MGP Site	North Adams, MA	Mar-05	2,010	6 to 18 (12.5)	Benzene, PAHs, Coal Tar	Fill and debris inside gasholder; perched water initially filled gasholder; water table below bottom of gasholder	Mid-portion of gasholder: 325 Bottom of gasholder: 120	Mean: Mid-portion: Benzene: 2,068 Naphthalene: 679 Benzo(a)pyrene: 20 TPH: 4,000 Bottom of gasholder: Coal Tar DNAPL	Mid-portion: Benzene: 2,000 Naphthalene: 10,000 Benzo(a)pyrene: 100 TPH: 10,000 Bottom of gasholder: No DNAPL	Mid-portion: Benzene: 0.35 Naphthalene: 5.7 Benzo(a)pyrene: 0.33 TPH: 43.15 Bottom of gasholder: No DNAPL present	Max. pre-treatment concentrations in mid-portion of gasholder were significantly above remedial goals. Over 16,000 gal of coal tar / emulsion recovered as NAPL. At least 300,000 lb of contaminant (expressed as naphthalene) removed in total. Fixed price plus performance guarantee Completed after about 1 year of heating
Rt. 44 Drum Site	Taunton, MA	Mar-07	5,300	0 to 14 (12)	Chlorobenzenes, Naphthalene, Toluene	Sandy fill and sand; water table at 12 to 16.5 ft depth	Unsaturated Zone: 150 Saturated Zone: 100	Max.: Total TCB: 4000 Total DCB: 450 Naphthalene: 2500 Toluene: 350 (max conc./history indicate DNAPL likely present)	No Strict Goals; Reduce COPC mass to accelerate attainment of water quality goals. For reference, the S2-GW3 Standard is: 1,2,4-TCB: 890 1,2-DCB: 290 Naphthalene: 990 Toluene: 990	Unsaturated Zone: Total TCB: 10.1 Total DCB: 0.65 Naphthalene: 19 Toluene: 0.58 Saturated Zone: Total TCB: 310 Total DCB: 4 Naphthalene: 120 Toluene: 30	Avg. temperature achieved in unsaturated zone = 153 °C; Avg. temperature achieved in capillary fringe = 101°C; Avg. temperature achieved in saturated zone = 87 °C. Multiphase extraction system operated in parallel with ISTD. 14,700 lb of contaminant mass (VOCs) removed. No evidence of vertical mobilization of NAPL. 140 days of heating planned; 200 days of heating (extended due to client request).
Japan Ministry of Environment IPTD Dioxin Demo	Yamaguchi, Shimonoseki Prefecture, Japan	Feb-09	4	0 to 4.9 (3.6)	Dioxins	Silty sand; vadose zone	325	1,800 pg-TEQ/g	1,000 pg-TEQ/g	67.75 pg-TEQ/g	Avg. temperature achieved in unsaturated zone = 325 °C; heating period = 22 days. All emissions standards met. The exhaust gas from the stack showed a concentration of 0.0000012 ng-TEQ/m3N to 0.000083 ng-TEQ/m3N - below the Japanese emission standard for dioxins in the exhaust gas (0.1 ng-TEQ/m3N)

Other completed ISTD SVOC projects include:

- 2 Field-Scale Demonstrations
- Several Drum-Scale Tests
- ~20 Laboratory Treatability Studies

ISTD SVOC projects currently under contract include:

- 2 Field-Scale Demonstrations

For more information, please visit www.terratherm.com, or call 978-343-0300.

CVOC CASE STUDIES

CVOC Case Study #1

Pierce, Butler, & Pierce

Syracuse, New York

(Poster Only)

In Situ Thermal Desorption Enabled Rapid Redevelopment of Pioneer-Midler Ave. Syracuse, NY Project

Ralph S. Baker, Ph.D., John M. Bierschenk, P.G., Ken Parker, Devon Phelan, John LaChance and Gorm Heron, Ph.D., TerraTherm, Inc. contact: rbaker@terratherm.com, (978) 343-0300, Fitchburg, MA;
Steven M. Vinci, CPG, Thomas Barba, Rory Woodmansee and Tom Wirickx, C&S Engineers, Inc., contact: svinci@cscos.com, (315) 703-4294, Syracuse, NY
Jed S. Schneider, Pioneer Companies, contact: jschneider@pioneercos.com, (315) 471-2181, Syracuse, NY

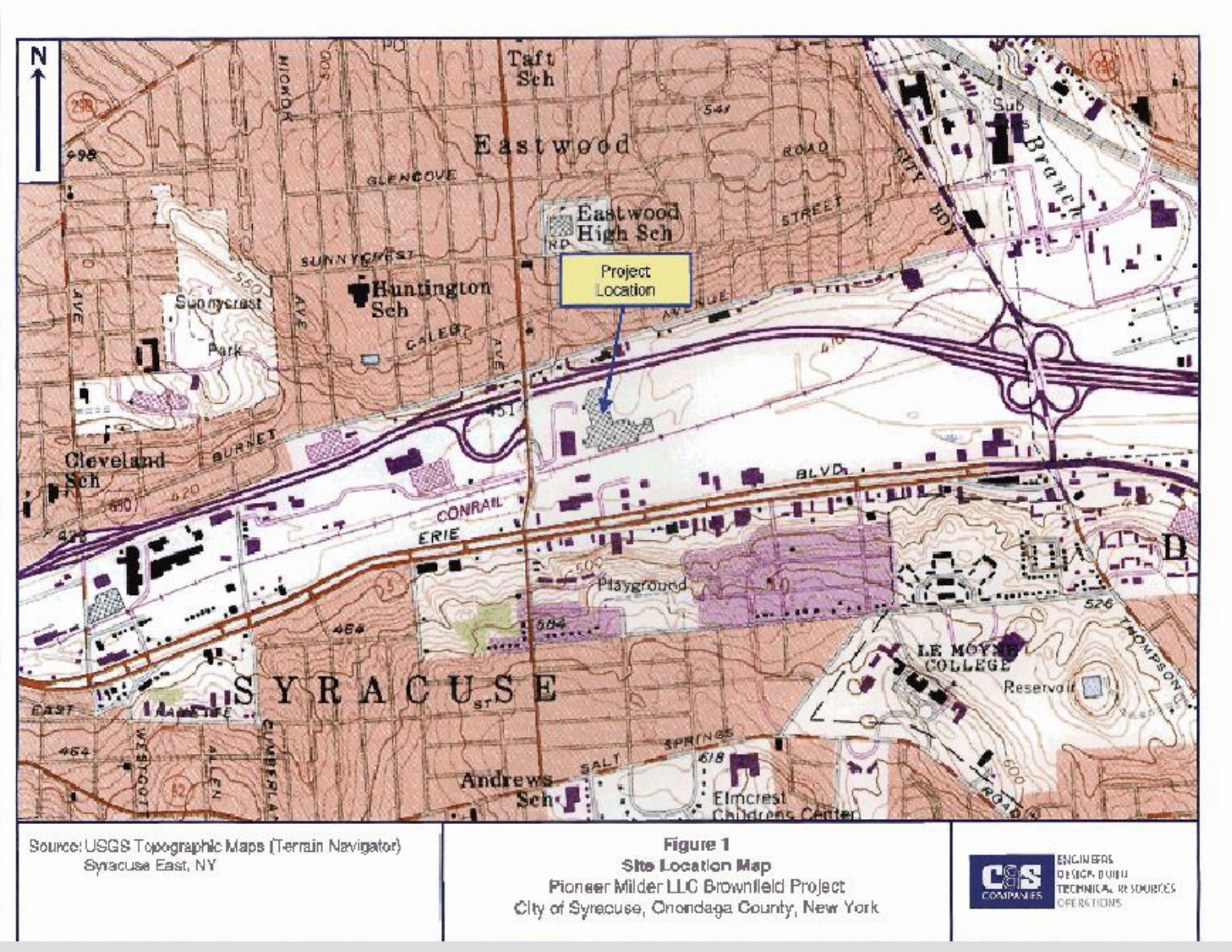
Site History:


Operated as a warehouse since 1961.
(Midler Ave. is behind viewer, I-690 to left)

As early as 1866, Pierce, Butler & Pierce manufactured boilers and radiators here.

From the 1920s-1950s, the Prosperity Co. manufactured industrial laundry and dry cleaning equipment on the site, becoming a world leader in that industry, a major exporter in Syracuse, and employed 600 people.


Interior of factory



26-acre Midler Crossing site, Interstate 690, Syracuse, NY

Environmental Restoration Program:

1994 – Prospective purchaser walks away from the site based on Phase I ESA by C&S.

2004 – After 10 years of abandonment, Pioneer Midler Avenue, LLC "Steps Up to the Plate" to take on the site and applies to NYSDEC Brownfield Cleanup Program.

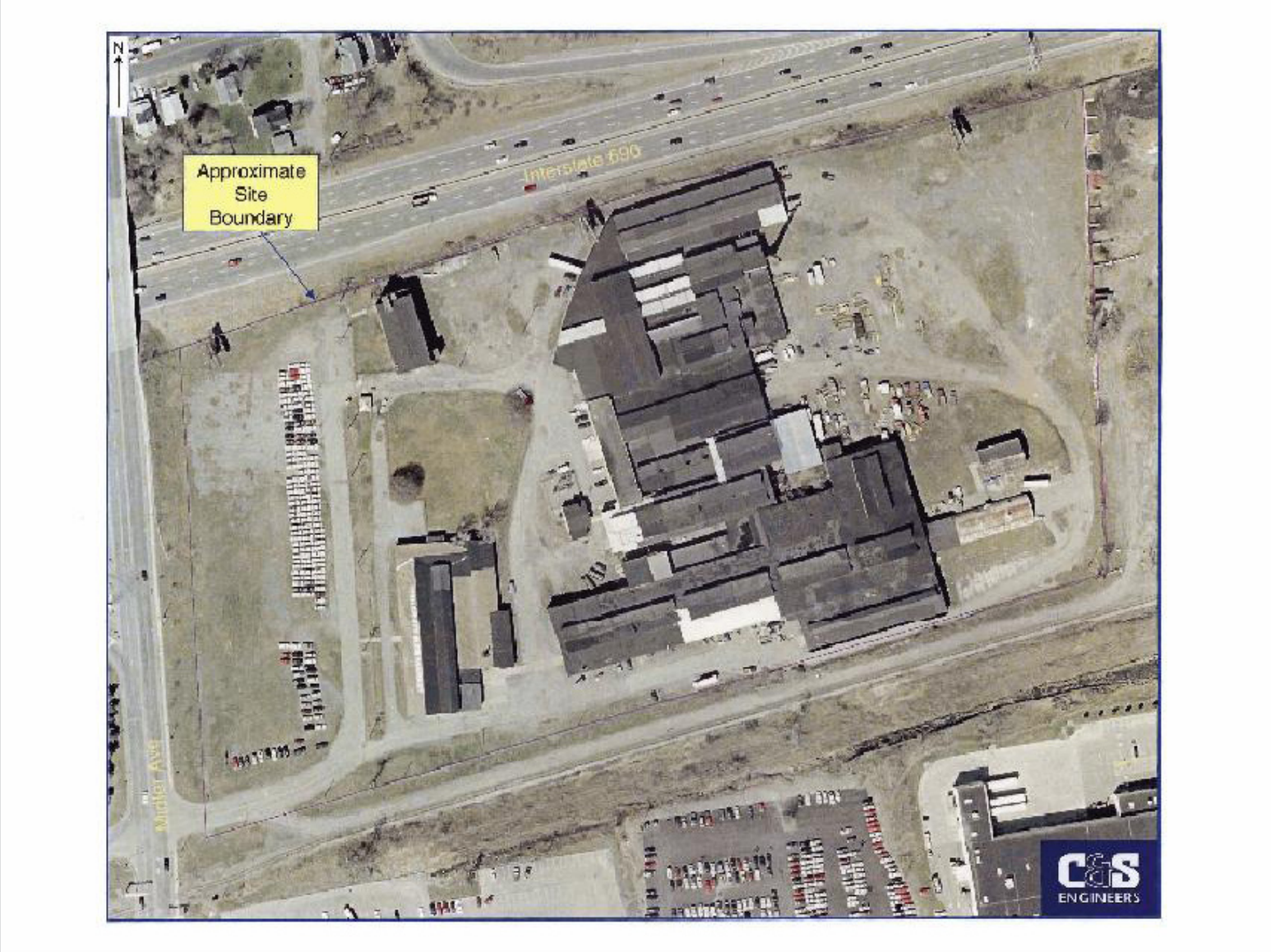
11/04 – Draft Remedial Investigation (RI) begins.

02/05 – Brownfield Cleanup Agreement Executed.

09/05 – NYDEC approval of RI Work Plan.

Building Demolition 11/05 thru 01/06.

07/06 – Interim Remedial Measure (IRM) Work Plan selected **In-Situ Thermal Desorption (ISTD)**.



Former Prosperity Co. plant.


Building demolition

Site Setting and Challenges:

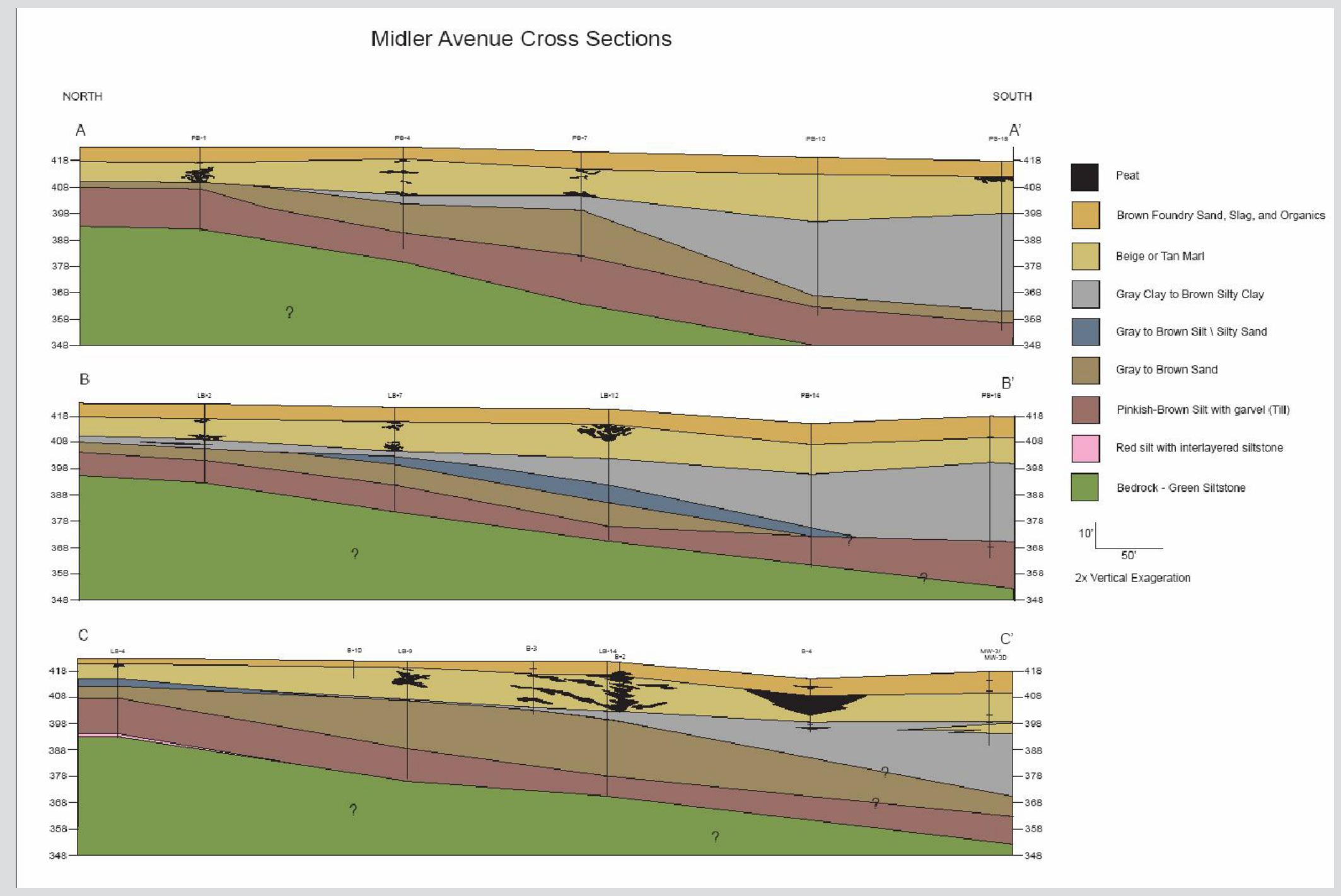
Large mass of CVOCs resided in the Peat/Marl layers, underlain by clayey soils.

Soil has a high Total Organic Carbon (TOC) content, averaging 10.8%.

Water table was shallow, 2 to 4 ft below grade. Nearly the entire interval of the treated zone was saturated.

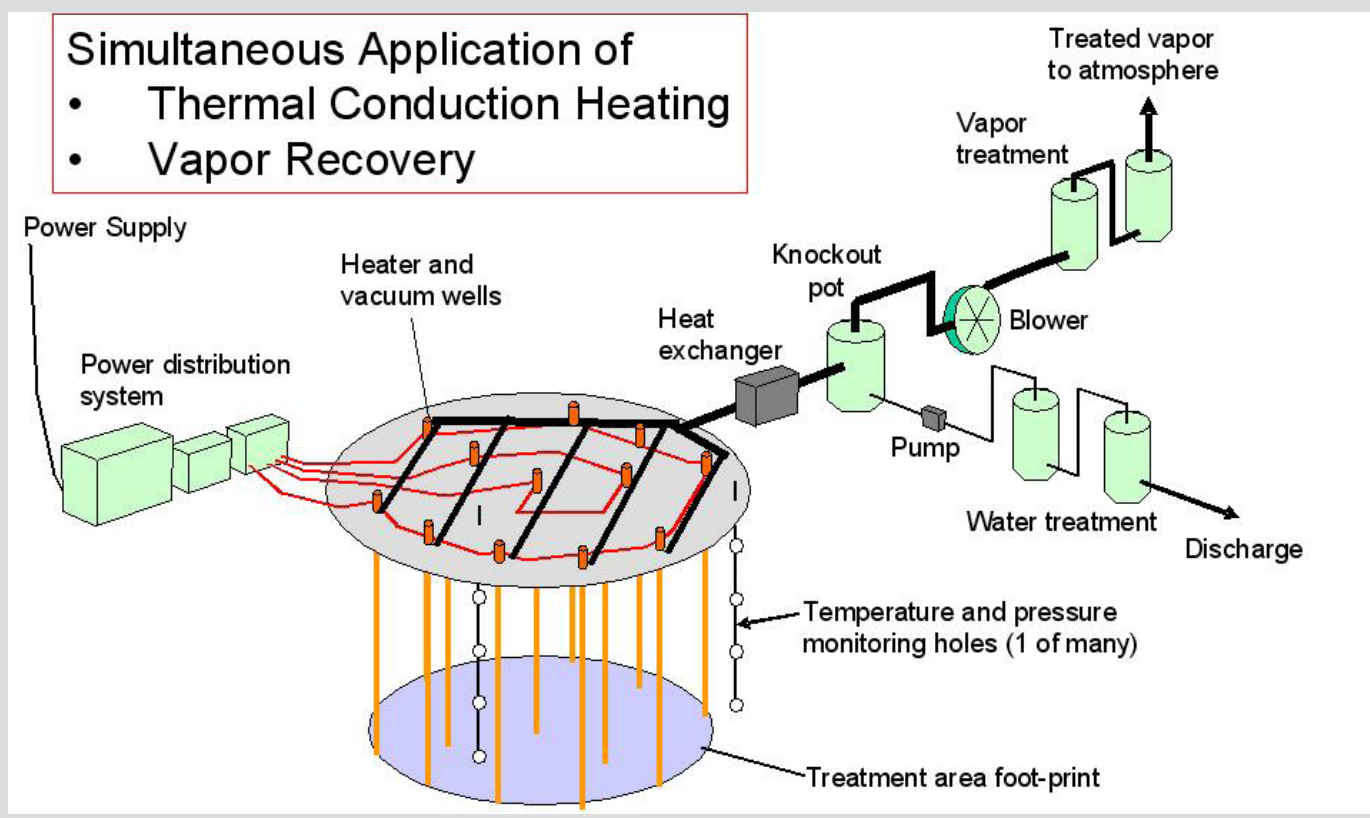
Contaminant	Mean Pre-Treatment Concentration (mg/kg)	Site Specific Cleanup Objective (mg/kg)
PCE	3,630	5.60
TCE	57.9	2.80
VC	0.96	0.80
t-1,2-DCE	0.29	1.20
c-1,2-DCE	11.7	NA
TVOC	3,700	10.40

Soil Contaminants and Goals



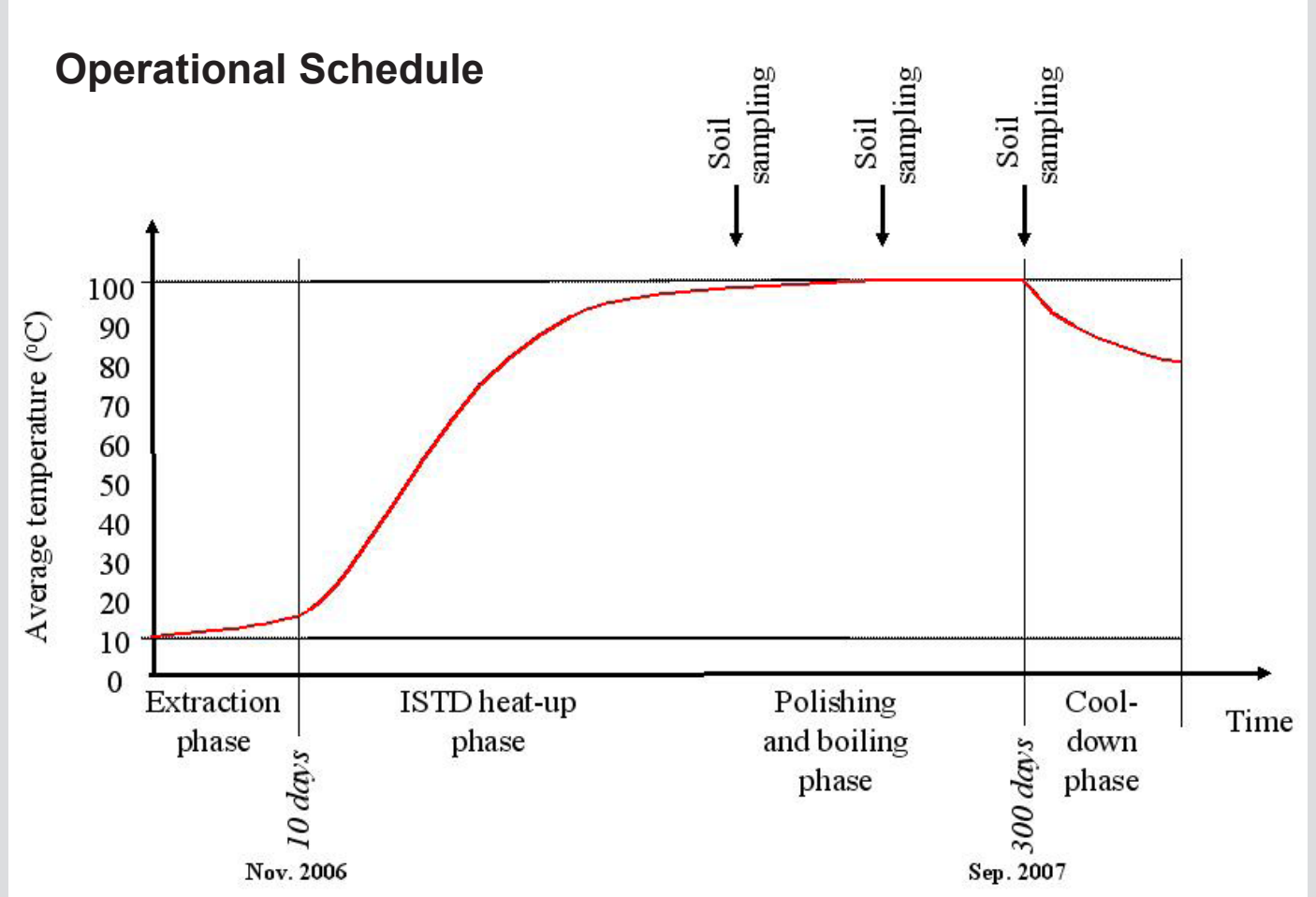
Treatment zone included foundry sand over saturated silty clay, marl, sand and peat deposits.

ISTD Design and Implementation:

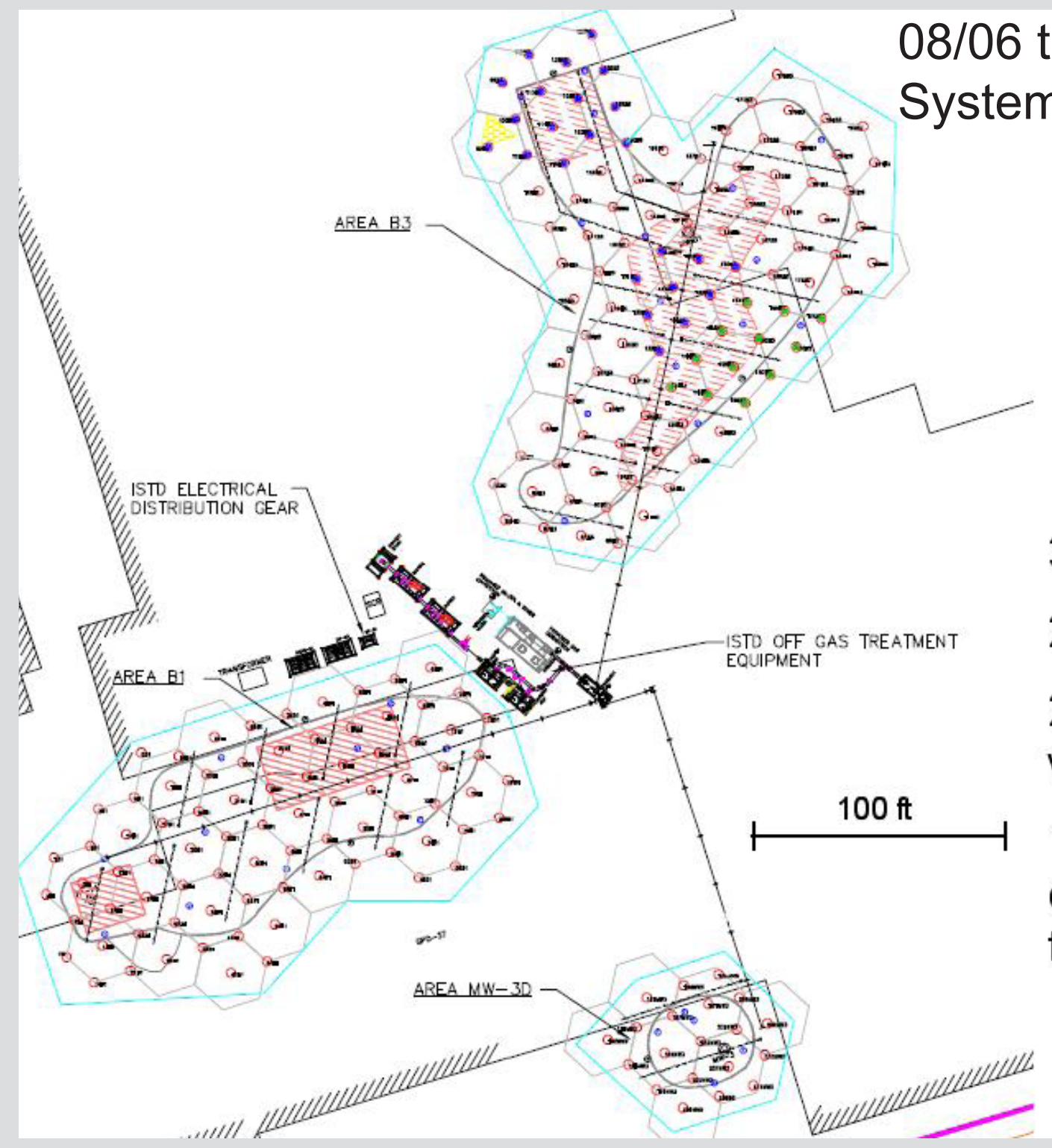

Simultaneous Application of
- Thermal Conduction Heating
- Vapor Recovery

In Situ Thermal Desorption (ISTD)


July 2006: B-5 Area Soil Excavation (after which soil was placed within one of the thermal treatment zones).



08/06 thru 10/06 – ISTD System Installation



3 treatment areas

288 heater wells

25 horizontal vapor wells

18-25 ft maximum depth of thermal treatment

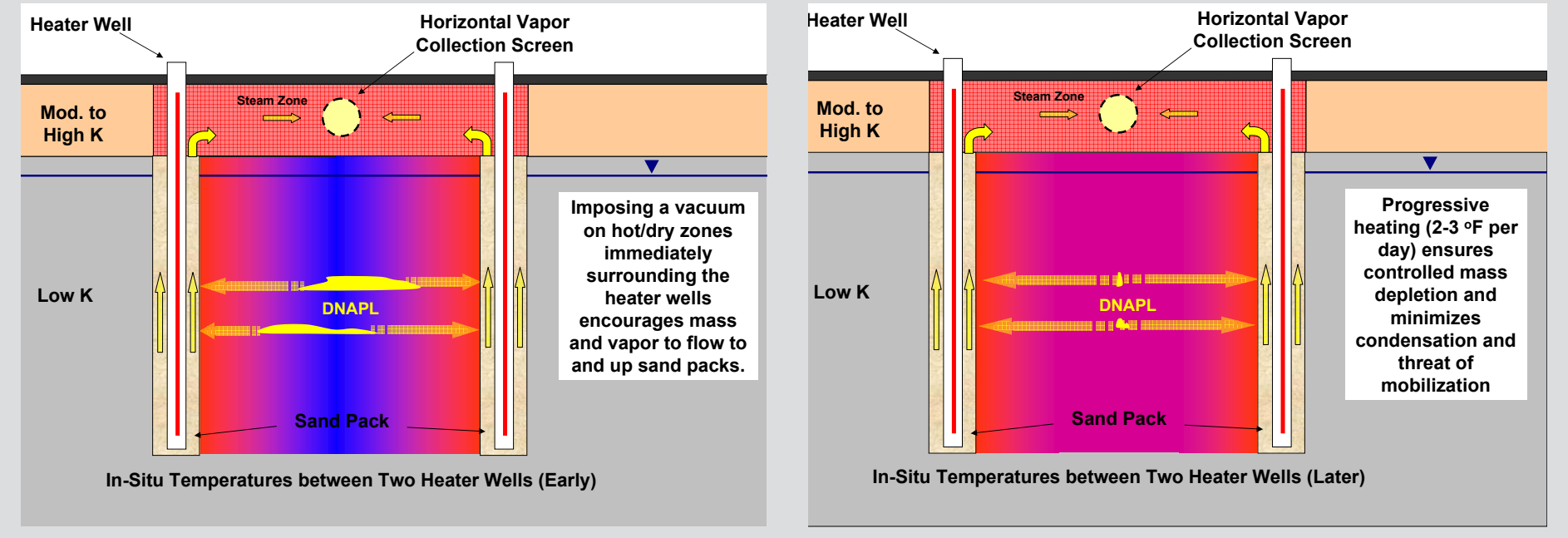
ISTD System Layout


ISTD Wellfield during Operation


ISTD System during Operation

ISTD Results:

Optimized Approach for Vapor Collection



Phased treatment and shutdown of areas coordinated with phased construction of retail development.

211 heater wells planned, 77 heater wells added to off-set greater than expected heat losses.

Over 86,000 pounds of PCE/TCE were removed from the site.

All ISTD remedial goals achieved under a Guaranteed Fixed Price Contract.

Certificate of Completion for the source areas issued by NYSDEC on 31 Dec 2007.

Conditions included implementation of the MNA program for groundwater, installation of soil vapor control systems for each building constructed at the site, and other institutional/engineering controls.

ISTD used to heat 3 separate source areas and treat a total of 16,210 cy.

210 to 240 days of heating planned; 300 days of heating required to meet remediation goals.


Confirmatory Soil Sampling

Summary of Confirmatory Soil Sampling Results
Mean Concentrations

	Midler Ave. SSCOs µg/kg	B3 Area µg/kg n = 26	B1 Area µg/kg n = 20	MW-3D Area µg/kg n = 5
PCE	5,600	5,322	3,379	2,845
TCE	2,800	1,148	918	450
VC	800	663	329	577
trans-1,2-DCE	1,200	741	360	458

SSCO = Site Specific Cleanup Objective

Redevelopment Status:


Completed Project

Midler Crossing is within three miles of a population of 190,000 and a 20 minute drive for any of the 450,000 residents of Onondaga County.

Anchor tenants of the project include a 165,000 s/f Lowe's home improvement store and the Central New York flagship branch of the State Employees Federal Credit Union.

The $30 million project was over two years in the planning and right-to-build process and represents one of the largest private cleanups of a contaminated site in upstate New York.

Groundwater Status

Groundwater adjacent to the thermal treatment area contained a high population of dehalococcoides with vinyl chloride reductase.

Further groundwater analysis consistent with USEPA evaluation protocol is being used to support Monitored Natural Attenuation as the final site remedy.

Groundwater concentrations have been declining steadily over seven quarterly rounds of sampling.

Acknowledgements:

The authors are grateful for the contributions of project team members:

TerraTherm - Glenn Anderson, Gregg Crisp, Dave Brogan, Dennis Rentschler, Dennis Callahan, Nick LaChance, and Peter Quintin.

Pioneer Co - Brian Maher.

We would also like to acknowledge the role that NYSDEC played on the project: Karen Cahill, Mary Jane Peachey.

CVOC Case Study #2

Memphis Depot

Southeastern Memphis, Tennessee

Ground Water

Monitoring & Remediation

Summer 2009

A National Ground Water Association Publication

$32.00

Ground Water Monitoring & Remediation

Thermal Treatment of Eight CVOC Source Zones to Near Nondetect Concentrations

by Gorm Heron, Ken Parker, Jim Galligan, and Thomas C. Holmes

Abstract

In situ thermal desorption (ISTD) was used for the treatment of eight separate source zones containing chlorinated solvents in a tight loess (silt/clay) above the water table. The source areas were as much as 365 m (1200 feet) apart. A target volume of 38,200 m^3 (49,950 cubic yards) of subsurface material to a depth of 9.1 m (30 feet) was treated in a period of 177 days. Energy was delivered through 367 thermal conduction heater borings, and vapors were extracted from 68 vertical vacuum wells. A vapor extraction and capture system, including a surface cover and vertical vacuum wells next to heater borings, provided for effective pneumatic control and capture of the chlorinated volatile organic compound (CVOC) vapors. A central treatment system, based on condensation and granular activated carbon filtration, was used to treat the vapors. Approximately 5675 kg (12,500 pounds) of contaminants was recovered in the extracted vapors. Forty-seven soil samples were used to document remedial performance. Based on these, the concentrations of the target contaminants were reduced to below the target remedial goals in all eight areas, typically with concentrations below 0.01 mg/kg in locations that had had CVOC concentrations higher than 1000 mg/kg. Turn-key costs for the thermal remediation were \$3.9 million, and the unit treatment cost, including all utilities, was \$103 per cubic meter treated (\$79 per cubic yard).

Introduction

The release of man-made chemicals in the form of dense nonaqueous phase liquids (DNAPL) to the subsurface has created great environmental concerns. Soil and ground water contaminated with DNAPL are relatively slow to remediate naturally, with typical plume life expected to be hundreds or thousands of years. The longevity of DNAPL source zones is primarily caused by the environmental stability of the DNAPL, its immobility in the subsurface, low dissolution rate into moving ground water, and its low vaporization rate when located below the ground water table (Hunt et al. 1988; Mercer and Cohen 1990; Pankow and Cherry 1996).

Conventional in situ remediation techniques have used fluid injection and extraction at ambient temperature, and therefore often suffer from mass-transfer limitations (Hunt et al. 1988). Flushing with water and air has limited effect, because the DNAPL is relatively immobile, and the constituents dissolve and vaporize slowly at ambient temperature.

Thermal conduction heating, also named in situ thermal desorption (ISTD), uses simple heater elements hung in vertical borings to heat the subsurface by thermal conduction, while generated vapors are extracted under vacuum (Stegemeier and Vinegar 2001). Heating the subsurface to temperatures around the boiling point of water leads to dramatic changes in the thermodynamic conditions and makes the DNAPL much more mobile. The vapor pressure of the DNAPL increases markedly with temperature. As the subsurface is heated from 20°C to an average temperature of 100°C, the vapor pressure of the contaminants will increase by between 10-fold and 30-fold (Udell 1996). The Henry's law constant also increases dramatically during heating (Heron et al. 1998a). For chlorinated solvents such as trichloroethene (TCE) and tetrachloroethene (PCE), vaporization is therefore the dominant removal mechanism during thermal remediation (Hunt et al. 1988; Davis 1997; Imhoff et al. 1997; Heron et al. 1998c; Sleep and Ma 1997). Contaminants such as 1,1,2,2-tetrachloroethane (PCA), which are also subject to hydrolysis, can be completely removed at lower temperatures, as they mineralize (Jeffers et al. 1989). Figure 1 shows the half-life of PCA in aqueous solution as a function of temperature, based on Arrhenius' equation with an activation energy of 92 kJ/mol and a half-life at 25°C of 0.4 years (Jeffers et al. 1989). At temperatures above 70°C, the half-life is on the order of days or less.

The effectiveness of ISTD for site restoration of CVOC DNAPL sources to acceptable levels has been documented for several sites (Vinegar et al. 1999; LaChance et al. 2004, 2006; Heron et al. 2008). At these sites, typical target concentrations were in the range of 1 to 5 mg/kg for contaminants such as TCE and PCE, but the soil concentrations

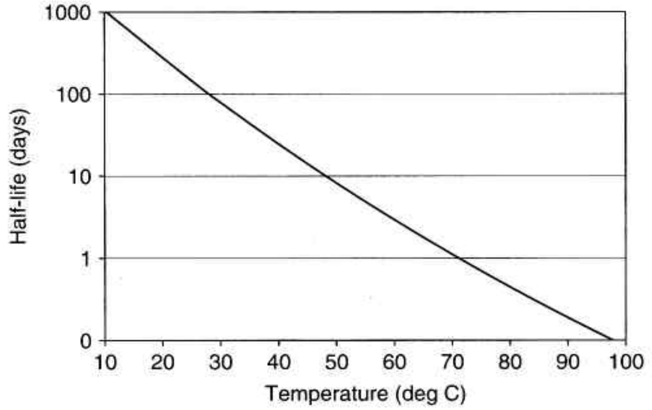


Figure 1. Theoretical temperature dependency of the half-life of PCA in solution and subject to hydrolysis (Arrhenius' equation used with an activation energy of 92 kJ/mol and a half-life at 25°C of 0.4 years).

achieved, based on confirmatory sampling, were in the range of 0.1 mg/kg or lower. Such results led to expectations that even lower CVOC goals can be met using ISTD.

At the Memphis Depot, eight CVOC source areas, extending to depths between 6 and 9 m, with starting concentrations in the range of 100 to 2850 mg/kg of CVOCs, had to be reduced to concentrations around 0.01 mg/kg (PCA) to 0.18 mg/kg (TCE and PCE). The reduction in soil concentration at several locations needed to be better than 99.99% to achieve the remedial goals and site closure. Thermal treatment was identified as the prime candidate technology. Among the options, ISTD was selected based on the high level of confidence in the results and the moderate treatment costs.

This paper presents the results of a full-scale ISTD remediation of eight CVOC-impacted source areas with stringent treatment goals. A mixture of CVOC contaminants was present in the different areas, but the extracted vapors were treated simultaneously using one process system, resulting in complete site restoration and favorable treatment costs.

Memphis Depot Site Description

The Memphis Depot is located in southeastern Memphis, Tennessee. The depot originated as a military facility in the early 1940s. Its initial mission and function was to provide stock control, materiel storage, and maintenance services for the U.S. Army. In 1995, the depot was placed on the list of Department of Defense (DoD) facilities to be closed under the Base Reenactment and Closure (BRAC) program. Storage and distribution of materiel for all U.S. military services and some civil agencies continued until the depot closed in September 1997. Dunn Field is approximately 64 acres of undeveloped land, previously used for storage and stockpiling of materials, including hazardous chemicals. Approximately two-thirds of Dunn Field is covered with grass, and the remaining area is covered with crushed rock and paved surfaces. All of Dunn Field is zoned for light industrial (I-L) use.

Figure 2 presents a schematic cross section of the site. The impacted vadose zone at Dunn Field consists of two distinct geological units: (1) a shallow, relatively low-permeability loess, and (2) a deep, relatively high-permeability alluvium composed of sands, sands and gravels, and discontinuous layers of silt and clay that collectively have been referred to as the fluvial deposits. The loess, a semicohesive aeolian deposit composed of silt, silty clay, silty fine sand, and mixtures thereof, extends from the ground surface to a

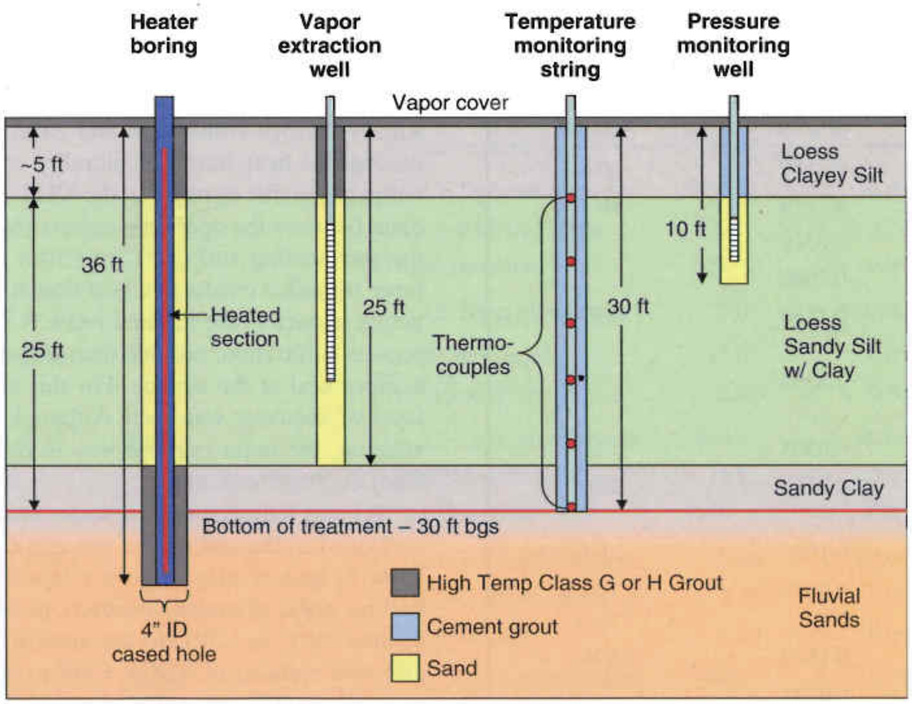


Figure 2. Schematic cross section showing stratigraphy and ISTD borings and wells for an area treated to 30 feet depth.

depth of about 30 feet below ground surface (bgs). Underlying the loess are several feet of sandy clay, followed by 30 to 75 feet of the fluvial sands, silt, and gravel. The upper 10 feet of the fluvial deposits represents a transition zone between the silt-dominated loess and the sand and gravel of the fluvial deposits. The ground water table is found in the fluvial deposits at approximately 23 m (75 feet) below grade, deeper than the CVOC impacts addressed by the ISTD remedy. The shallow ground water is not used as a source of drinking water.

Subsurface soil samples collected at Dunn Field have shown significant levels of CVOCs, including PCA; 1,2-dichloroethane (DCA); 1,2-dichloroethene (1,2-DCE); carbon tetrachloride (CT); chloroform (CF); methylene chloride; PCE; TCE; and vinyl chloride. The highest CVOC concentrations were detected in the northwest corner of Dunn Field: PCA at 2850 mg/kg; TCE at 671 mg/kg, *cis*-DCE at 199 mg/kg, and PCE at 35.7 mg/kg. The contaminants of concern (COCs) and remedial goals are listed in Table 1 along with the maximum concentrations detected.

Several source areas were identified for remediation of subsurface soil. A remedial design investigation (RDI) was performed in 2005 and 2006 to increase soil data density in the four soil treatment areas to delineate CVOC soil contamination laterally and down to a depth of approximately 30 feet, where the loess deposits transitions to the fluvial sands. The RDI included a membrane interface probe (MIP) investigation to characterize the magnitude and extent of elevated CVOCs in the loess using a 40-foot × 40-foot grid. Soil samples were collected from select MIP locations for laboratory analysis to correlate the data sets and adequately delineate the areas with CVOC concentrations below the MIP detection limit but above the established Dunn Field remedial goals (RGs). More than 160 locations were investigated with the MIP and more than 80 soil samples were collected. The collective interpretation of available data led to identification of the eight source areas shown in Figure 3. The MIP and soil sample data clearly delineated the areas requiring treatment; each treatment area was surrounded by MIP or sample locations below RGs. Table 2 shows the surface area, depth, and volume of each of the eight treatment areas. The total surface area is 4950 m^2 (1.25 acres), and the total treatment volume is 38,200 m^3 (49,900 cubic yards).

Table 1

Contaminants of Concern and Remedial Target Concentrations

Parameter	Remedial Target Concentration (mg/kg)	Maximum Starting Concentration (mg/kg)
Carbon tetrachloride	0.2150	6.8
Chloroform	0.9170	96.2
Dichloroethane, 1,2-	0.0329	
Dichloroethene, 1,1-	0.1500	
Dichloroethene, *cis*-1,2-	0.7550	199
Dichloroethene, *trans*-1,2-	1.5200	
Methylene chloride	0.0305	
Tetrachloroethane, 1,1,2,2-	0.0112	2850
Tetrachloroethene	0.1806	21.1
Trichloroethane, 1,1,2-	0.0627	
Trichloroethene	0.1820	671
Vinyl chloride	0.0294	

For the contaminants that exceeded the remedial goals before treatment, the maximum concentration is shown.

Description of Field Implementation

ISTD is the simultaneous application of heat by thermal conduction and vacuum to contaminated soil. Soil is heated using a network of thermal wells installed throughout and immediately surrounding the target treatment zone (TTZ). Figure 4 shows the layout of heater and extraction wells for one of the treatment areas. The heaters were spaced between 15 and 18 feet apart in the different treatment areas, customized based on the presence of contaminants, their boiling point and hydrolysis rates, and the shape of each area. Areas such as Area 3, which has relatively modest starting concentrations, have heater wells spaced the farthest apart, whereas small areas such as Area 1B with high concentrations of PCE and TCE have closer well spacing. Areas dominated by PCA had a larger spacing, because hydrolysis facilitates degradation of PCA at temperatures below the boiling point of water, such that heating to around 90°C is sufficient for effective treatment. Because the potential by-products of the hydrolysis include TCE, the area was heated and treated such that TCE also would be effectively removed.

Figure 2 contains a schematic of the borings and well installed. Electrically powered heating elements suspended vertically within the thermal borings deliver 1.15 kW/m (0.35 kW/feet) over their entire length, when at full power. The heat front moves away from the heaters through the soil by thermal conduction and convection, and the superposition of heat from the plurality of heaters results in a temperature rise throughout the TTZ. The high thermal gradient between the operating heaters (600°C and 800°C) and the surrounding soil (10°C to 15°C) serves as the driving force for radial conductive heat flow to occur over the entire length of each of the thermal wells. A vapor cover is used to prevent infiltration, provide thermal insulation, and provide a vapor seal at the surface. For this site, a simple sprayed layer of shotcrete was used. Although it provided some insulation, the main purpose was to divert rain water away from the treatment areas.

As soil temperatures increase, contaminants and water contained in the soil matrix are vaporized. While locations close to heaters may achieve temperatures well above the boiling point of water, locations in between heaters must achieve 90°C to 100°C to accomplish steam distillation for effective removal of VOCs. Concurrently, hydrolysis leads to mineralization of contaminants such as PCA.

The vacuum applied to the extraction wells from the process system draws vapors through the hot soil around

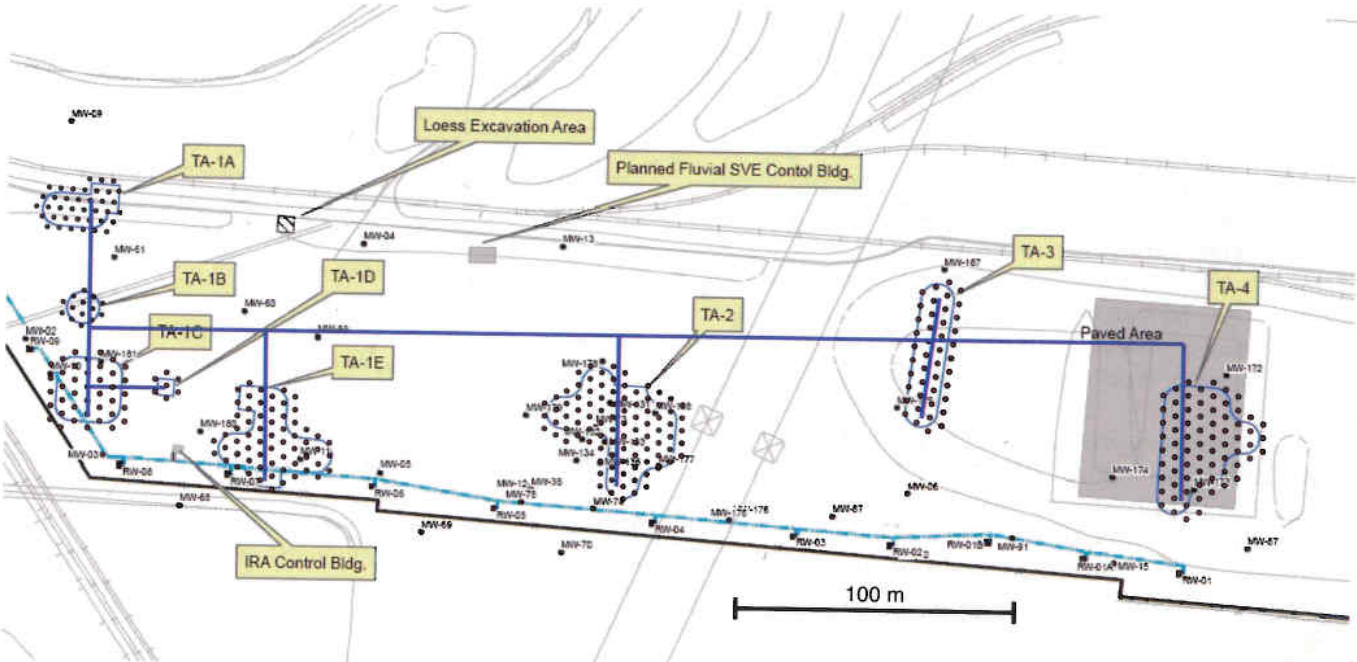


Figure 3. Location of the eight source areas at Dunn Field in Memphis, Tennessee. ISTD heaters are shown as red dots; conveyance piping for extracted vapors is shown in blue.

Table 2
Areas, Depths, and Treatment Volumes for the Eight Source Areas, with Primary Contaminants and Maximum Concentrations before and after Treatment, and Percent Reduction

Source Area	Area (m^2)	Treatment Interval (m)	Volume (m^3)	Number of Confirmatory Samples	Primary Contaminants	Max Soil Concentration Before (mg/kg)	Max Soil Concentration After (mg/kg)	Percent Reduction (%)
1A	345	1.5–6.1	1578	3	Carbon tetrachloride	6.8	<0.005	>99.93
					Chloroform	14.0	0.053	99.62
1B	117	1.5–9	890	1	cis-1,2-Dichloroethene	123.0	0.005	100.00
					Tetrachloroethene	20.8	0.010	99.95
					Trichloroethene	21.5	0.009	99.96
1C	563	1.5–9.1	4288	4	1,1,2,2-Tetrachloroethane	2850	0.005	100.00
					cis-1,2-Dichloroethene	199	0.132	99.93
					Trichloroethene	671	0.044	99.99
1D	37	1.5–9.1	283	1	1,1,2,2-Tetrachloroethane	0.03	<0.0027	>91.56
1E	861	1.5–9.1	6560	6	1,2-Dichloroethene	17.0	0.017	99.90
					Trichloroethene	2.42	0.031	98.72
2	1233	1.5–10.7	10899	8	1,1,2,2-Tetrachloroethane	1850	<0.003	>99.99
					Tetrachloroethene	21.1	<0.005	>99.98
					Trichloroethene	170	0.417	99.75
3	631	1.5–9.1	4805	5	1,1,2,2-Tetrachloroethane	3.11	<0.003	>99.90
					cis-1,2-Dichloroethene	3.35	0.006	99.82
					Trichloroethene	1.56	0.041	97.37
4	1163	1.5–9.1	8864	7	1,1,2,2-Tetrachloroethane	190	<0.016	>99.99
					Chloroform	96.2	0.929	99.03
					Trichloroethene	4.28	0.082	98.08

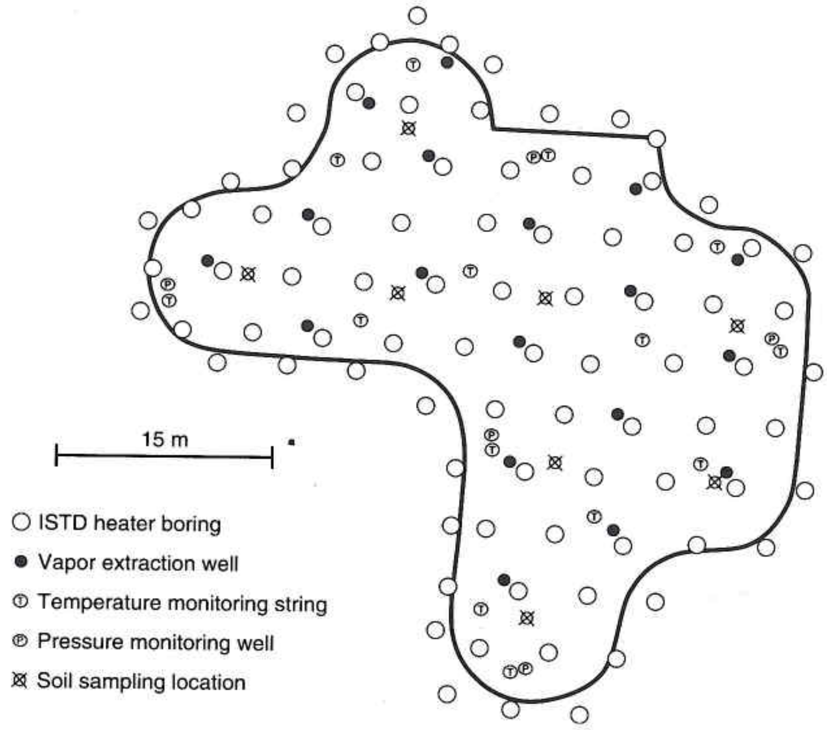


Figure 4. Detailed well-field layout for treatment Area 2. Locations for temperature and pressure monitoring, as well as performance sampling, are also shown.

a subset of the thermal borings (68 locations out of 367 heaters). Vapor treatment is completed within an off-gas treatment unit. The unit consisted of cooling, condensation, phase separation, and granular activated carbon (GAC) filtration. Emissions and discharges met all local and regional requirements as specified in the proper permits.

The heater-only wells are 7.6-cm (3-inch) diameter steel-cased wells housing thermal conduction heaters. Each of these contains a stainless steel heater that is controlled using thermocouples and a silicon controlled rectifier (SCR), allowing the power delivered to the heating elements to be adjusted as needed. The vacuum wells are 5-cm (2-inch) diameter screened wells, set in a sand pack.

The TCH heating system consisted of step-down transformers, energy distribution gear, and the SCR controllers that regulate power to each heater circuit. A total of 4500 kW of power could be delivered to the 367 heater borings (between 9 and 12 kW per heater well).

Heating progress was measured using 63 temperature monitoring strings, each with electronic temperature sensors located at 1.5-m (5-foot) intervals from depths from 1.5 m (5 feet) to the total treatment depth (typically 9 m [30 feet]). In addition, 26 shallow pressure monitoring wells were used to document negative pressure in the formation during heating. Subsurface pressures were recorded using pressure gauges installed at the top of the steel risers connected to a buried screen.

The remedial action objective (RAO) for thermal treatment of the loess required that the average concentration for each CVOC in each treatment area (defined as TA-1 areas combined, TA-2, TA-3, and TA-4) be below the remediation goal, and that no individual sample result exceeds the remediation goal by a factor of 10 or more. For samples that were nondetect, the average was calculated using one-half the laboratory reporting limit.

Soil confirmation samples were collected in a phased approach. The sample locations were selected based on previous sample results and included the locations with the highest reported CVOC concentrations. Samples were planned at multiple depths from several locations with a total of 47 samples from 35 borings. The initial confirmation samples were collected when soil temperatures in the treatment areas approached 90°C on Days 83 to 85 of treatment operations. Round 2 soil samples were collected at the completion of the planned treatment period on Days 106 to 108. After Round 2, sample results demonstrated that CVOC concentrations were below remediation goals at 33 of the 47 locations. Treatment operations were focused in the recalcitrant areas, and locations were resampled at 2- to 3-week intervals until the final sample was collected on Day 174 and the RAO was met in all areas.

Soil samples were collected by direct-push sampling with a Geoprobe 6620DT. Soil cores were collected in a 24-inch steel sampling tool with a Teflon disposable sleeve. The Teflon sleeve was removed from the sampling tool, capped at both ends, placed in a shallow basin containing ice, and cooled until the sample reached ambient temperature as determined by an infrared thermometer. At each sample depth, three EnCore® samples were collected for analysis of volatile organic compounds by EPA Method 8260. Borings for repeat samples were located 1 to 3 feet from the previous location(s).

Vapor monitoring of the thermal treatment system included field measurements and laboratory analyses. Photo-ionization detector (PID) readings were collected 6 days/week at the vapor treatment area. Measurements were made at four locations: the well field influent prior to any treatment; the influent to the granular activated carbon (GAC) treatment vessels; between the two operating carbon treatment vessels; and at the vapor discharge. PID readings were also collected at the vapor extraction header pipe from each treatment area; the frequency was increased from every two weeks to every other day on Day 108.

At the well-field influent and the loess treatment area headers, a vacuum pump was used to overcome the vacuum of the soil vapor extraction (SVE) system. The vacuum pump was connected to the individual sampling ports with short Teflon tubing and allowed to purge for 2 to 3 min; the sample was then collected from the outflow of the vacuum pump. At the three locations in the vapor treatment system, a vacuum pump was not required. A short piece of Teflon tubing was connected to the sampling port and allowed to purge for 2 to 3 min. The samples for PID readings were collected in a 1-L dedicated Tedlar sample bag. After filling, the bag was connected directly to the PID through a moisture trap and the peak value was recorded. The PID was calibrated daily to a 100 ppmv isobutylene standard.

Vapor samples were collected monthly at the influent to the GAC treatment vessels and at the vapor discharge. Samples were collected in 6-L Summa canisters and submitted for VOC analysis using EPA Method TO-15. The results were used with the daily PID readings to estimated CVOC mass removed in the vapor stream.

Energy balance calculations were based on simple heat transfer equations and enthalpy of vaporization for water at 100°C. Energy flux in the extracted steam was calculated as the mass of condensate produced in the condenser times a unit energy content of 2230 kJ/kg (1050 BTU/pounds). The number of pore volumes of steam generated and extracted was estimated from the condensate totals, converted to a steam volume at 100°C using steam table values for steam density (0.60 kg/L), a porosity of 30%, and volume (38,200 m^3 = 49,950 cubic yards) of the treatment zones. The average temperature achieved was estimated from simple averaging of all the thermocouple measurements in each treatment area. It should be noted that this created a bias toward lower numbers, because the majority of the temperature monitoring locations were at the coldest locations in the center of the equilateral triangle formed by three heaters (centroid locations), and the fact that hot zones around each heater well were not accounted for. This provided a safety margin during operations—ensuring that all locations are properly heated before operations were ended in an area.

Mass removal estimates were derived from vapor flow rate data and measured vapor concentrations. Daily fluctuations were recorded using a PID. The PID data were calibrated to the laboratory sampling results, with response factors adjusted over time as the vapor composition would change.

Results

Extraction of vapor began on May 27, 2008. The ISTD heating was started and slowly ramped up to the design power input of between 3500 and 4500 kW over a period of 5 days. The power delivered to the eight treatment areas is shown in Figure 5. The ISTD system operated continuously with minimal downtime, and the treatment areas heated to the target temperature over a period of between 95 and 120 days, with substantial variation from area to area. The calculated average temperatures in each of the eight areas are shown in Figure 6. Interim and confirmatory soil samples were collected on six occasions during treatment to track the progress, until the last area had met the cleanup criteria after 174 days of heating. A period of controlled cool-down followed in each area, with vapor extraction continuing for a minimum of 10 days, until all operation was completed by December 4, 2008. All ISTD equipment was demobilized by February 2009.

Electrical energy delivered and energy removed as steam is shown in Figure 5, and a cumulative energy balance is shown in Figure 7. The power input reached a level between 3000 and 4500 kW after 10 days of operation, and steam extraction became significant after 4 weeks of heating, before peaking between days 90 and 150 at a rate corresponding to 1500 kW, or approximately 50% of the power injection at that time. By the end of operation, 10.6 million kWh of

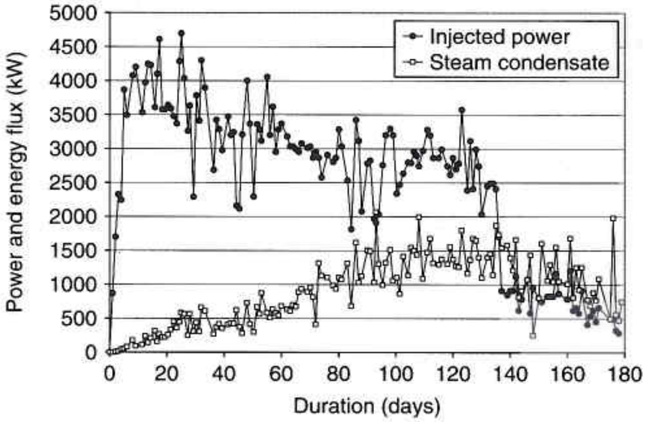


Figure 5. Electrical energy delivered to and energy removed as steam from the eight treatment areas. Note the drop in power supply on Day 135 when two large areas had met the cleanup criteria and were de-energized.

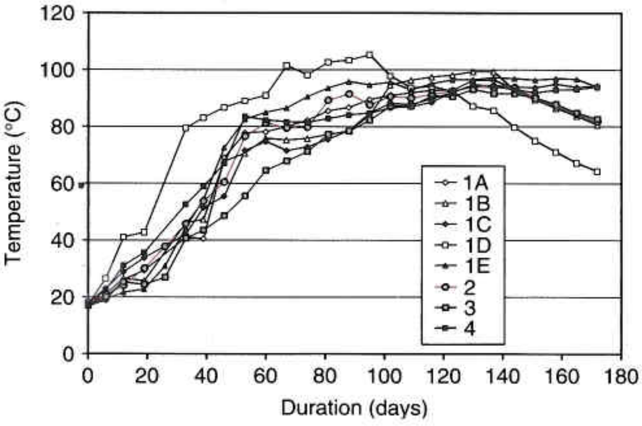


Figure 6. Calculated average subsurface temperature for the eight source areas. After reaching the remedial standards, heating was suspended in each area and cooling started (note the different heating shutdown times).

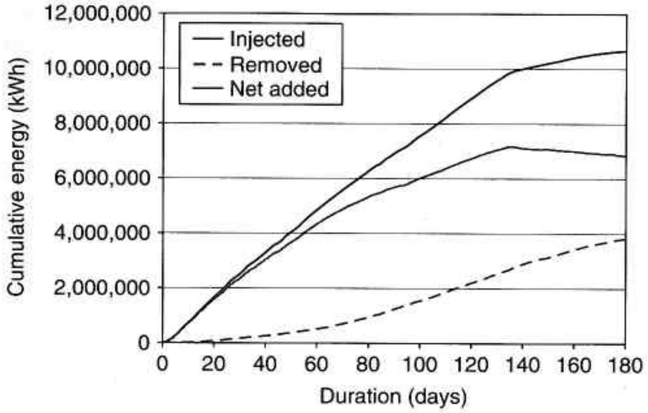


Figure 7. Cumulative energy balance for the ISTD operation.

electric power had been delivered, and 3.8 million kWh of energy in the form of steam had been removed, corresponding to 36% of the injected energy. The energy delivered corresponded to 289 kWh/m^3 (221 kWh per cubic yard) of soil and sediment within the treatment zone.

The vapor extraction system removed approximately 1350 Nm^3/h (800 scfm) of air and steam during operations. When the system was shut down after 180 days of operation, a total of 3.0 million L (793,000 gallons) of steam condensate had been recovered. Based on an average porosity of 30%, the pore volume of the treatment zones is 11,010 m^3 (14,400 cubic yards). With a steam density of 0.62 g/L at atmospheric pressure, the steam removed from the subsurface corresponds to 4.8 million m^3 (6.3 million cubic yards), which is equal to approximately 436 pore volumes of steam generated and extracted from the TTZ. This steam generation, sweep through the subsurface, and extraction is the main mechanism for the physical removal of contaminants.

Contaminant concentrations in the extracted vapors started increasing immediately after start of operations (Figure 8). The concentrations peaked after 90 days of heating and remained high until Day 130, and then declined steadily as the depleted treatment areas were shut down. At the end of ISTD operation, concentrations in the extracted vapors were below 20 ppmv, and an estimated total of 5675 kg (12,500 pounds) of VOCs had been removed in the vapor phase.

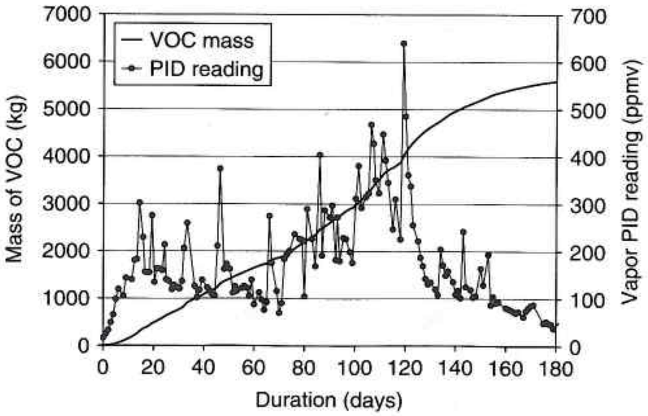


Figure 8. PID readings of extracted vapors and cumulative mass removed in the vapor phase.

Interim soil sampling was conducted on six occasions, with repeat sampling of locations that exceeded the target criteria during the previous sampling round. Forty-seven confirmation soil samples were collected from 35 sample locations and depths. Locations were added to improve spatial distribution within the treatment areas and vertical distribution within the treatment interval. Although the target treatment interval was typically from about 1.6 m to either 6 or 9 m bgs (depending on the source area), three of the confirmation samples were collected from shallower depths of 0.6 and 0.9 m bgs because CVOC concentrations were above RGs at these locations before thermal treatment. The selected sample locations included the locations with the highest CVOC concentrations based on analytical or MIP results. The confirmation sampling program was reviewed and approved by EPA and Tennessee Department of Environmental Control (TDEC) before implementation.

Table 2 summarizes the treatment results, as well as peak concentrations at the sampling locations measured before thermal treatment. At the end of thermal treatment, all CVOC remedial goals were met.

The maximum soil concentration of any of the contaminants after ISTD treatment was 0.93 mg/kg for chloroform and 0.42 mg/kg for TCE, both in Area 4. These values were both flagged by a "J" by the analytical laboratory, meaning that these are estimated values. These results were from samples collected before treatment was completed. The locations were not resampled because the concentrations were only slightly above the remediation goals and did not prevent meeting the remedial action objective.

Table 2 shows the percent reduction in the peak concentrations. Generally, the reduction in concentration was on the order of 99.99% for CVOCs that were present in high concentrations before the thermal treatment. Approximately 5675 kg (12,500 pounds) of contaminants were removed in the vapor stream. An additional quantity was likely degraded by hydrolysis. This dramatic reduction in contaminant mass, and the reductions in soil concentrations at the site facilitated successful closure of the eight source areas.

The project costs are summarized in Table 3. Terra-Therm was hired by engineering-environmental Management (e^{2}M) as the sole contractor, after the successful response to a request for proposal in early 2007. The total thermal treatment cost was $3.9 million, which corresponds to a unit cost of $103/m^3 ($79/cubic yard). This cost is inclusive of all project expenses, including design, utility line protection, power drop, and electricity. The unit costs do no include e^{2}M's oversight and interim/confirmatory sampling.

Discussion

Figure 9 shows a conceptual model of the ISTD process as the heat spreads between two heaters by thermal conduction. Close to the heaters (within 1 m [3 feet]) the pore water is evaporated and the soil dries and heats to above 100°C. The hot and dry conditions provide a zone of elevated gas permeability. As the heating progresses, boiling temperatures are achieved at larger distances from the heaters, and steam

Table 3
Project Costs and Breakdown

Workplan	$25,399
Design & permitting	$131,331
Drilling	$548,003
Construction	$1,230,162
Operations	$660,497
Transformer installation and power usage	$1,009,736
Activated charcoal usage w/disposal	$103,891
Demobilization	$142,795
License fee	$80,582
Total thermal treatment cost	$3,932,396
Oversight, sampling, and utility protection	$816,547
Total project cost	$4,748,943
Treated volume, cubic meters	$38,167
Unit thermal treatment cost, per cubic meter	$103
Unit thermal treatment cost, per cubic yard	$79

is generated deeper into the soil matrix. The generation of steam leads to a 1600-fold expansion of the water (based on water and steam densities at 100°C and 1 atm pressure of 970 and 0.62 g/L). The steam generation at the pore scale is believed to be the major removal mechanism for contaminants during thermal remediation (Udell 1983; Yuan and Udell 1993). It was also the major mechanism identified during a laboratory-scale demonstration of thermal treatment of a silt layer contaminated with TCE (Heron et al. 1998b). After heating of the zone between heater borings, gas-phase permeability allows for a sweep of steam toward the extraction wells, effectively connecting all the boiling zones via heated pathways, through which the steam can migrate and be captured. For thermal remediation, it is crucial to understand not only how the site is heated, but also how the generated vapors migrate and are captured by the extraction system. At this site, the vapor cover assisted in the capture of the contaminants, preventing rain infiltration, and by providing thermal insulation so the upper few meters of the site could be heated effectively, enabling the steam to sweep through instead of condensing.

Toward the end of the projected duration of the thermal treatment, interim sampling indicated a small subset of locations where the VOC concentrations remained above the remediation criteria. This occurred mainly in the most low-lying areas, where precipitation caused a high water content of the soils prior to and during thermal operations. Treatment of these areas was accelerated by the installation of additional vapor extraction wells around these recalcitrant areas. These wells were alternated between air injection and vapor extraction during the final weeks of operation to increase the flow and exchange of vapors in these areas, and resulted in the remedial goals being met. Similar modifications were used previously at the Young-Rainey STAR Center, where thermal remediation was challenged by the presence of a low-permeability layer (Heron et al. 2005).

At every site, the number of samples and the resolution of the sampling grid will limit the certainty with which conclusions can be drawn. Confirmatory sampling was biased high at this site by selection of the locations that had the

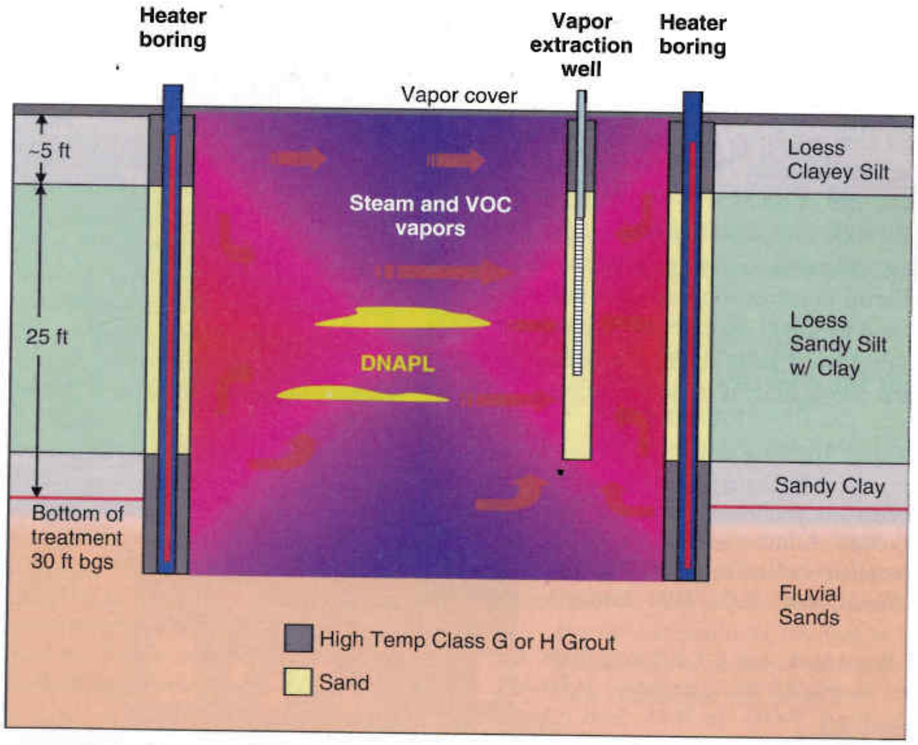


Figure 9. Conceptual model showing heating, migration, and capture of steam and VOC vapors. Note that the upper part of the unsaturated zone was heated to near steam temperatures, allowing steam to flow through to extraction wells without condensing.

highest pretreatment concentrations. The ISTD treatment was applied uniformly across all eight source areas with the same level of treatment. The 47 soil samples collected for confirmatory sampling all showed concentrations of the target contaminants below the RGs. This data indicates that final concentrations in areas with less contamination would have been even lower. However, few samples were collected outside and above or below the target treatment volumes, where the concentrations were below RGs to begin with. The nature of the thermal technology applied here, combined with experience from other similar CVOC sites treated using ISTD, suggested to the authors that low concentrations would have been measured if more sampled had been collected in such areas. The combined evidence of the substantial hotspot reductions in concentration and the mass recovery curves indicating that the sites were depleted in COCs at the end of thermal treatment was taken as an indication that all areas had met the remedial standards at this site.

Conclusions

In situ thermal desorption was shown to be highly effective for treatment of chlorinated solvents in eight CVOC source zones. The eight areas were heated in a period of 177 days, and 5675 kg (12,500 pounds) of CVOC contaminants were recovered. Soil concentrations of all contaminants were reduced from concentrations over 1000 mg/kg (indicating the presence of DNAPL) to below 1 mg/kg in all 47 confirmatory soil samples, with all remedial goals met. This was accomplished by the use of 289 kWh/m^3 (221 kWh/cubic yard), and a unit treatment cost of \$103/m^3 (\$79/cubic yard).

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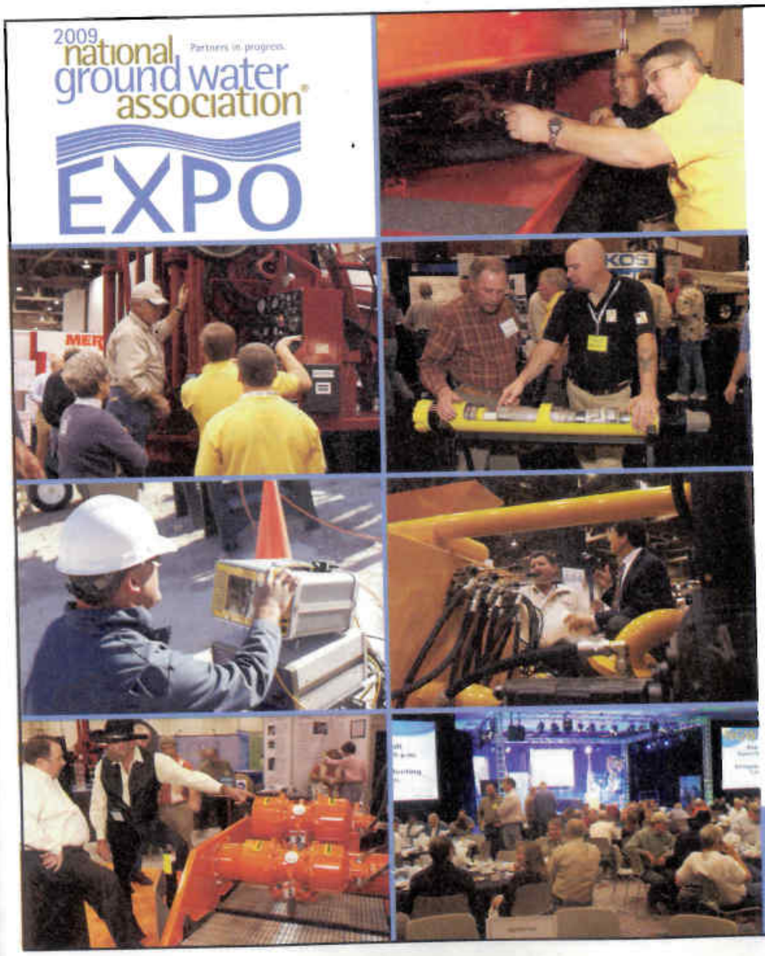

CVOC Cost and Performance Summary Table

February 2010

Summary of ISTR Performance and Cost Data for CVOC Sites - TerraTherm, Inc., Feb. 2010

Site Name	Location	Date Completed	Volume	Depth Treated (Well Spacing)	Major COC	Type(s) of Soil (thickness, ft) Water Table	Target Temperature	Mean Pretreatment Concentration	Remedial Goal	Mean Post-treatment Concentration	Total Cost	Unit Cost	Comments
			cy	ft		ft	°C	mg/kg	mg/kg	mg/kg	$	$ / cy	
Confidential Midwest Site	-	Feb-04	11,500	0 to 15 (14.1)	TCE	Silty clay (fractured clay till); perched water table at 3'	100	99.7 (max conc./history indicate DNAPL likely present)	1.0	0.070	$1,429,385	$124	3 separate treatment areas Heated around a buried utility line and adjacent to a operating mfg. facility. Main wellfield area: 150 days of heating 2 yr following completion of ISTD, client sampled for rebound and found none.
Terminal One	Richmond, CA	Nov-05	7,000	0 to 20 (12.1)	PCE	Sandy fill (3') over Bay Mud (17'); water table at 3' depth	100	34.2 (max conc./history indicate DNAPL likely present)	2.0	0.012	$1,961,444	$280	Partly underneath a building Fixed price plus performance guarantee Completed on schedule. 100 days of heating
SMC Facility	Carson, CA	Dec-05	6,700	20 to 35 (22)	1,2-DCA	Silty clay (35') over A-Zone sands; water table at 20' depth	100	903 (max conc./history indicate DNAPL likely present)	[Pilot Test]	0.23	$1,001,892	$150	420 days of heating (extended due to client request).
Confidential SE Site	-	May-06	9,000	0 to 87 (15)	TCE	Fill (25') over saprolite (30'), over partially weathered rock (20'), over fractured rock; water table at 55' depth	100	DNAPL	In Vadose Zone: 0.060; In GW: Reduction in source concentration	0.017	$1,277,000 - TT +$120,900 - Power	$155	Heated/treated upper 15 to 20 ft of fractured rock Fixed price plus performance guarantee Completed on schedule, 100 days of heating to achieve boiling point of water.
Pioneer Midler Ave.	Syracuse, NY	Oct-07	16,200	0 to 25 (15)	PCE	Fill over peat and marl, over clay; water table 2 to 4' depth	100	2,864 (max conc./history indicate DNAPL likely present)	5.6	3.8	$3,801,031	$235	Estimated power costs are included in prices. 180 days of heating to achieve boiling point of water in most areas

Summary of ISTR Performance and Cost Data for CVOC Sites - TerraTherm, Inc., Feb. 2010

Site Name	Location	Date Completed	Volume	Depth Treated (Well Spacing)	Major COC	Type(s) of Soil (thickness, ft) Water Table	Target Temperature	Mean Pretreatment Concentration	Remedial Goal	Mean Post-treatment Concentration	Total Cost	Unit Cost	Comments
			cy	ft		ft	°C	mg/kg	mg/kg	mg/kg	$	$ / cy	
NASA Marshall Space Flight Center	Huntsville, AL	May-07	1,000 (pilot test)	15 to 37 (10)	TCE	Clay over rubble zone over limestone; water table at 32' depth	100	47.65 (max conc./history indicate DNAPL likely present)	1.0	0.060	$992,024	Does not apply for pilot test	Estimated power costs are included in prices. Pilot test 90 days of heating
Memphis Depot	Memphis, TN	Nov-08	49,950	5 to 30 (16)	CVOC	Silty clay and loess; water table below bottom of treatment zone	100	73 (max conc./history indicate DNAPL likely present)	0.34	0.045	$3,932,396	$79	Price includes estimated power cost 100 days to achieve boiling point of water in most locations
Northrop-Grumman	Danville, PA	May-09	68,000	0 to 42 (31.25)	LNAPL and CVOC	Heterogeneous and layered; water table at 30' depth	>95	5,168 (max conc./history indicate DNAPL likely present)	Reduce residual LNAPL and corresponding CVOC concentrations in soil to further minimize future impact to underlying groundwater quality	N/A All remedial goals were achieved. Permission received from PADER to shut down pump-and-treat system that had operated for 15 years.	$2,690,306	$40 Partner provided drilling and was responsible for portions of the project	Steam-Enhanced Extraction project. 150 days of heating to achieve boiling point of water in formation. Client elected to expand project to adjacent areas.

For more information, please visit www.terratherm.com, or call 978-343-0300.