Simultaneous Thermal Treatment of Eight DNAPL Source Areas at Memphis Defense Depot

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E2S2
Denver, CO

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Overview

Introduction to In-Situ Thermal Remediation

- Usage
- Applicability

Representative Case Study: CVOCs at Memphis Depot

All Completed Projects have Met or Exceeded Goals
In-Situ Thermal Remediation (ISTR) is Mature and Widely Applied

- 182 ISTR Projects (ESTCP-funded study; Kingston, 2008)
- Accelerating trend
- Electrical Resistance and Thermal Conduction Heating are currently the most widely practiced
Reasons to Think Thermal

- Community friendly: Treats contaminated soils and groundwater in place
- Delivers robust and highly predictable results
  - Fast and final
- Meets needs of broad range of project sites and contaminants
- Provides potentially huge increases in property value
- Highly competitive costs – Often Thermal is the obvious choice
ISTR Technologies: How They Work

Thermal Conduction Heating (TCH) or In-Situ Thermal Desorption (ISTD)*

Electrical Resistance Heating (ERH) – Joule or Ohmic Heating, by means of the Electro-Thermal Dynamic Stripping Process (ET-DSP™)*

Steam Enhanced Extraction (SEE)* – Steam Injection

*Offered by TerraTherm, Inc.
**ISTR Applicability**

**TCH** - Heating governed by **thermal conductivity** \((f \approx 3)\);
Wide range of target temperatures; Low to moderate permeability settings

**ERH** - Heating governed by **electrical conductivity** \((f \approx 200)\);
\(\leq\) B.P. of water; Low to moderate permeability settings

**SEE** (SER) - Heating governed by **hydraulic conductivity** \((f \approx 10^6)\); \(\leq\) B.P. of water; High permeability settings

*Offered by TerraTherm, Inc.*
Vapor pressures increase exponentially during heating
# In Situ Thermal Remediation

Lower, Moderate and Higher Temperature Applications

<table>
<thead>
<tr>
<th>Temperature Range</th>
<th>Example Applications</th>
<th>Heating Methodology</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lower: Below 100°C</td>
<td>Free Product Recovery</td>
<td>Steam</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Electrical Resistance</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Thermal Conduction</td>
</tr>
<tr>
<td>Moderate: ~100°C</td>
<td>VOCs / CVOCs</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Higher: Above 100°C</td>
<td>SVOCs</td>
<td></td>
</tr>
</tbody>
</table>
Think Thermal When...

✓ You have a Source Zone, or Hot Spots
✓ Site is Heterogeneous and/or Low in Permeability
✓ Stringent Cleanup Levels Must be Achieved, Quickly (or you just need to remove a lot of mass)
✓ Excavation is Ruled Out or Impractical

Thermal is Especially Well Suited if:
✓ The Treatment Zone is Deep
✓ There’s a Mixture of Contaminants
Sustainability of Thermal

- Enables reutilization of idle Brownfields and/or restoration of groundwater resources.
- The energy cost to electrically heat a cy of contaminated soil is about the same as the cost of fuel to haul it away; meanwhile, in-situ treatment has a lower neighborhood impact, and is environmentally friendly.
- Verifiable carbon offsets can be obtained for <1% of project cost.

Achieving predictable and rapid site closure and reuse is environmentally and socially responsible.
In Situ Thermal Desorption (ISTD)

Simultaneous Application of
- Thermal Conduction Heating (TCH)
- Vapor Recovery

Power Supply

Power distribution system

Heater and vacuum wells

Heat exchanger

Knockout pot

Blower

Pump

Water treatment

Treated vapor to atmosphere

Vapor treatment

Discharge

Temperature and pressure monitoring holes (1 of many)

Treatment area foot-print
TerraTherm Heaters

Simple, Durable, Reliable, Reusable

U.S. Patent Nos. 5,190,405, 5,318,116, 6,485,232 and 6,632,047. International patents granted (e.g., EPC 1272290 + 10 countries) and pending.
Dunn Field, Memphis Depot, TN

- Former Defense Logistics Agency site, now under the Base Realignment and Closure (BRAC) Program
- 8 DNAPL source areas
- 49,800 cubic yards
- Target criteria below 0.1 mg/kg for CVOCs
- Funded by the U.S. Air Force Center for Engineering and the Environment (AFCEE)
Location of the Eight DNAPL Areas
Contaminants of Concern and Remedial Target Concentrations

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Remedial target concentration (mg/kg)</th>
</tr>
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<tbody>
<tr>
<td>Carbon Tetrachloride</td>
<td>0.2150</td>
</tr>
<tr>
<td>Chloroform</td>
<td>0.9170</td>
</tr>
<tr>
<td>Dichloroethane, 1,2-</td>
<td>0.0329</td>
</tr>
<tr>
<td>Dichloroethene, 1,1-</td>
<td>0.1500</td>
</tr>
<tr>
<td>Dichloroethene, cis-1,2-</td>
<td>0.7550</td>
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<tr>
<td>Dichloroethene, trans-1,2-</td>
<td>1.5200</td>
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<tr>
<td>Methylene Chloride</td>
<td>0.0305</td>
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<tr>
<td>Tetrachloroethane, 1,1,2,2-</td>
<td>0.0112</td>
</tr>
<tr>
<td>Tetrachloroethene</td>
<td>0.1806</td>
</tr>
<tr>
<td>Trichloroethane, 1,1,2</td>
<td>0.0627</td>
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<tr>
<td>Trichloroethene</td>
<td>0.1820</td>
</tr>
<tr>
<td>Vinyl Chloride</td>
<td>0.0294</td>
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</tbody>
</table>
Cross-section and Well Designs

Heater boring

Vapor extraction well

Temperature monitoring string

Pressure monitoring well

Heated section

Vapor cover

Thermo-couples

4” ID cased hole

Bottom of treatment – 30 ft bgs

High Temp Class G or H Grout

Cement Grout

Sand

Loess Clayey Silt

Loess Sandy Silt w/ Clay

Sandy Clay

Fluvial Sands
Well-Field Layout at Dunn Field

367 heaters
68 extraction wells
Aerial View of Memphis Site (During Demob)
Power Delivered and Steam Energy Extracted

- Injected power
- Steam condensate

Power and energy flux (kW) vs. Duration (days)
Temperatures Achieved in Each Area
Cumulative Energy Balance

- Injected
- Removed
- Net added

Duration (days)
Cumulative energy (kWh)

0 2,000,000 4,000,000 6,000,000 8,000,000 10,000,000 12,000,000
0 20 40 60 80 100 120 140 160 180

TERRATHERM®
Vapor Concentrations and Mass Removed

Graph showing the correlation between duration (days) and mass of VOC (kg) versus vapor PID reading (ppmv). The graph includes a line representing VOC mass and dots representing PID reading.
Treatment Mechanisms and Steam Flow Paths

Heater boring ~5 ft

High Temp Class G or H Grout 25 ft

Loess Clayey Silt

Loess Sandy Silt w/ Clay

Sandy Clay

Fluvial Sands

Heater boring

Vapor extraction well

Vapor cover

Steam and VOC vapors

DNAPL

Bottom of treatment 30 ft bgs

High Temp Class G or H Grout

Cement Grout

Sand
# Results - Eight DNAPL Source Areas

<table>
<thead>
<tr>
<th>DNAPL source area</th>
<th>Area (m²)</th>
<th>Treatment interval (m)</th>
<th>Volume (m³)</th>
<th># confirmatory samples</th>
<th>Governing contaminants</th>
<th>Max soil concentration before (mg/kg)</th>
<th>Max soil concentration after (mg/kg)</th>
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<tbody>
<tr>
<td>1A</td>
<td>345</td>
<td>1.5 to 6</td>
<td>1,578</td>
<td>3</td>
<td>Carbon tetrachloride</td>
<td>6.8</td>
<td>&lt;0.005</td>
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<td></td>
<td></td>
<td>Chloroform</td>
<td>14.0</td>
<td>0.053</td>
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<td>1B</td>
<td>117</td>
<td>1.5 to 9</td>
<td>890</td>
<td>1</td>
<td>cis-1,2-Dichloroethene</td>
<td>123.0</td>
<td>0.005</td>
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<td></td>
<td>Tetrachloroethene</td>
<td>20.8</td>
<td>0.010</td>
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<td>Trichloroethene</td>
<td>21.5</td>
<td>0.009</td>
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<td>1C</td>
<td>563</td>
<td>1.5 to 9</td>
<td>4,288</td>
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<td>1,1,2,2-Tetrachloroethane</td>
<td>2,850</td>
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<td>cis-1,2-Dichloroethene</td>
<td>199</td>
<td>0.132</td>
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<td>Trichloroethene</td>
<td>671</td>
<td>0.017</td>
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<td>1D</td>
<td>37</td>
<td>1.5 to 9</td>
<td>283</td>
<td>1</td>
<td>1,1,2,2-Tetrachloroethane</td>
<td>0.03</td>
<td>&lt;0.0027</td>
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<td>1E</td>
<td>861</td>
<td>1.5 to 9</td>
<td>6,560</td>
<td>6</td>
<td>1,2-Dichloroethane</td>
<td>17.0</td>
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<td>2</td>
<td>1,233</td>
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<td>Tetrachloroethene</td>
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<td>23.6</td>
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<td>3</td>
<td>631</td>
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<td>5</td>
<td>1,1,2,2-Tetrachloroethane</td>
<td>3.11</td>
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<td>cis-1,2-Dichloroethene</td>
<td>3.35</td>
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<td>1.56</td>
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<td>4</td>
<td>1,163</td>
<td>1.5 to 9</td>
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<td>7</td>
<td>Carbon tetrachloride</td>
<td>0.53</td>
<td>&lt;0.006</td>
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<td></td>
<td>Chloroform</td>
<td>2.18</td>
<td>0.005</td>
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<td>Trichloroethene</td>
<td>0.97</td>
<td>0.240</td>
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## Project Costs and Breakdown

<table>
<thead>
<tr>
<th>Category</th>
<th>Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>Design and permitting</td>
<td>$157,000</td>
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<tr>
<td>Drilling</td>
<td>$548,000</td>
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<tr>
<td>Construction</td>
<td>$1,230,000</td>
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<td>Operation – contractor</td>
<td>$906,000</td>
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<tr>
<td>Power</td>
<td>$1,010,000</td>
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<tr>
<td>Oversight and Sampling</td>
<td>$817,000</td>
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<tr>
<td>Other</td>
<td>$81,000</td>
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<tr>
<td><strong>Total</strong></td>
<td><strong>$4,749,000</strong></td>
</tr>
</tbody>
</table>

**Unit cost** $79/cy
Summary – Memphis Depot Case Study

- 8 DNAPL source areas treated simultaneously
- 49,800 cubic yards
- All areas met stringent target criteria
- 175 days of heating
- Turnkey cost: $79/cy
- Just Announced: Defense Depot Memphis, TN received the 2009 Secretary of Defense Environmental Award – the only one awarded in the Environmental Restoration category!
  - Our work was cited as “a key component of the program’s success”
  - “In addition to meeting the established goals ahead of schedule, the process saved taxpayers more than $2.5 million.”