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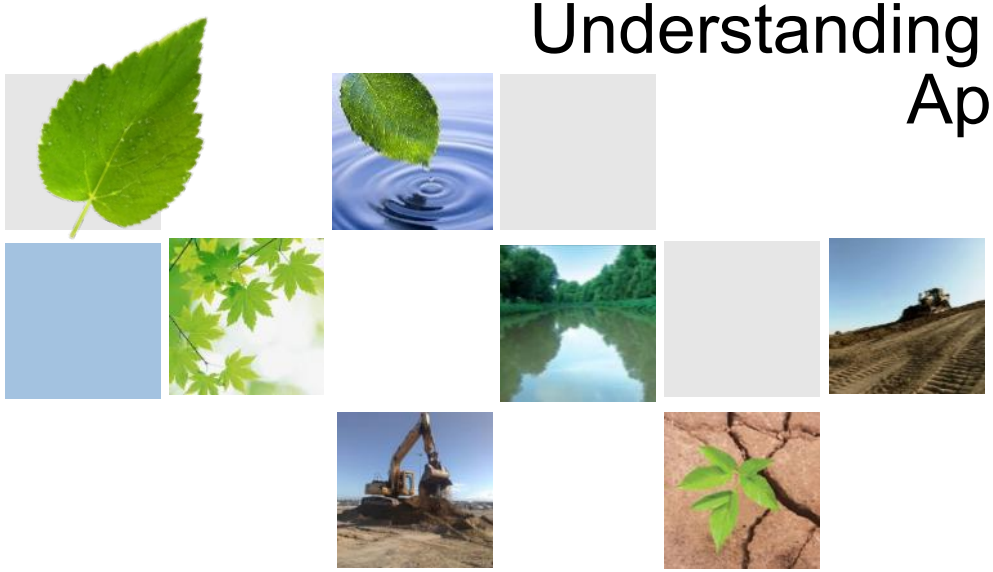
Understanding In-situ Thermal Treatment Application and Performance



Jason Cole, PhD, PE

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Agenda

- Source Treatment Continuum
- What is In-situ Thermal Treatment & What It Can Offer
- Technology Overview
- Performance Monitoring Concepts and Strategies
- Performance Examples Similar to Velsicol Site
  - Solvents
  - Pesticides
  - Combined Remedies
- Closing Thoughts

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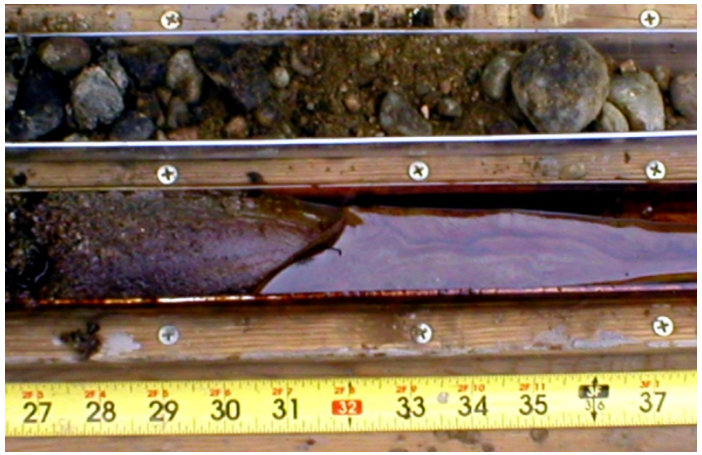
Source Treatment Continuum

Containment and long-term management	Partial source removal plus containment/long-term management	Complete or near complete source removal
Hydraulic containment (P&T) Physical Containment Plume Management (In-situ bio; PRBs) Timeframe: many decades to centuries	Hydraulic displacement, ISCO, ISSM, plus containment and long-term management options Timeframe: many decades to centuries	**In-situ Thermal Treatment** Excavation Plus polishing techniques **Timeframe: 1 to a few decades**



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What is Thermal Treatment?

- Subsurface heating for remediation of soil and groundwater
  - Optimal application is treatment of NAPL source zones
  - Three demonstrated methods; one additional considered emerging
  - Coupled with fluid extraction for contaminant source removal & recovery
- In-situ thermal treatment (ISTT) is a mature technology
  - Evolved to a group of powerful and robust remediation technologies
  - Applications number in the 100's; mainly for chlorinated solvents
- Coming Soon to St. Louis
  - Selected for NAPL/DBCP Area 1 and 2 on the former plant site
  - Proposed for use at the former burn pit area

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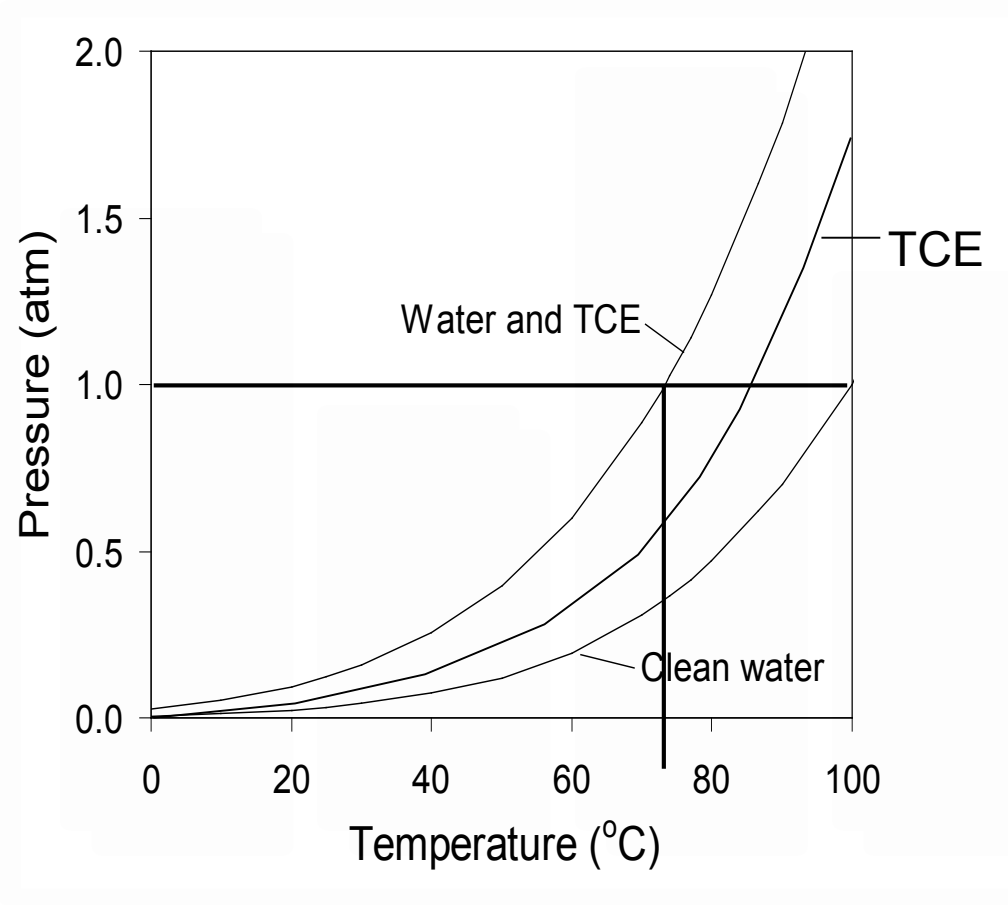
Subsurface Heating Effects

- Accelerate Mass Transfer
  - Vaporization
  - Increased solubility
  - Enhanced desorption
- Physical Removal
  - Stripping
  - Displacement
  - NAPL Viscosity reduction
- Secondary
  - Chemical destruction
    - Hydrolysis
    - Oxidation
  - Microbial degradation



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What Can Thermal Treatment Offer?

- Contaminant source removal
  - Minimum residual mobility
- Mass flux reduction
- Synergy with remedies
- Rapid implementation
- Lower sensitivity to
  - Contaminant mass
  - Subsurface conditions

Image by Terra Therm, Inc.

- Treatment in a variety of geologic settings
- Implementation around structures
  - Even ones that are occupied (with appropriate care)
- Controlled extraction and treatment of contaminants

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Some Disadvantages of In Situ Thermal

- High price point and cost variability
- Mechanically complex
- Limited commercial suppliers (and they are often busy)
- Typically area cannot be used during treatment
- Can be impacted by high permeability zones; cold water inflow
- Performance variability
- Energy availability

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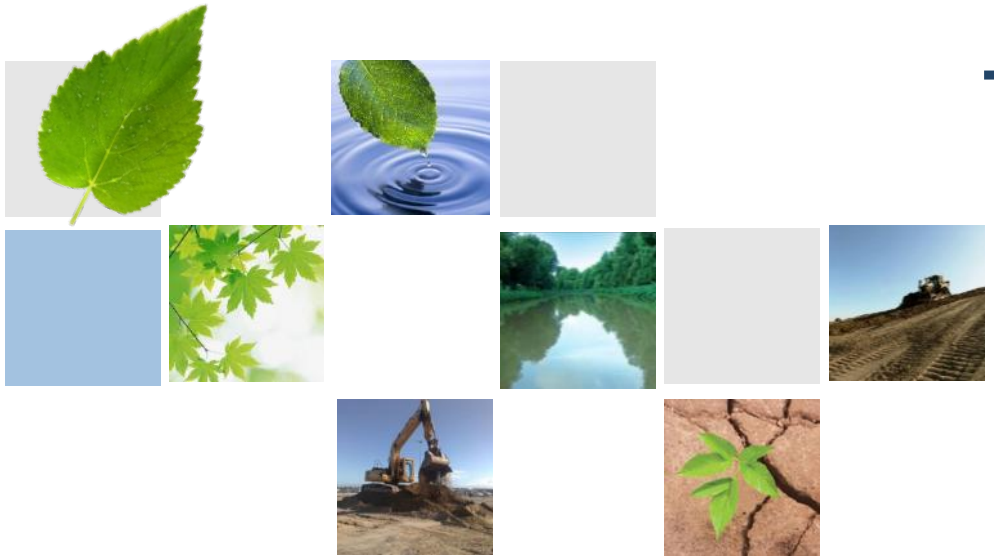
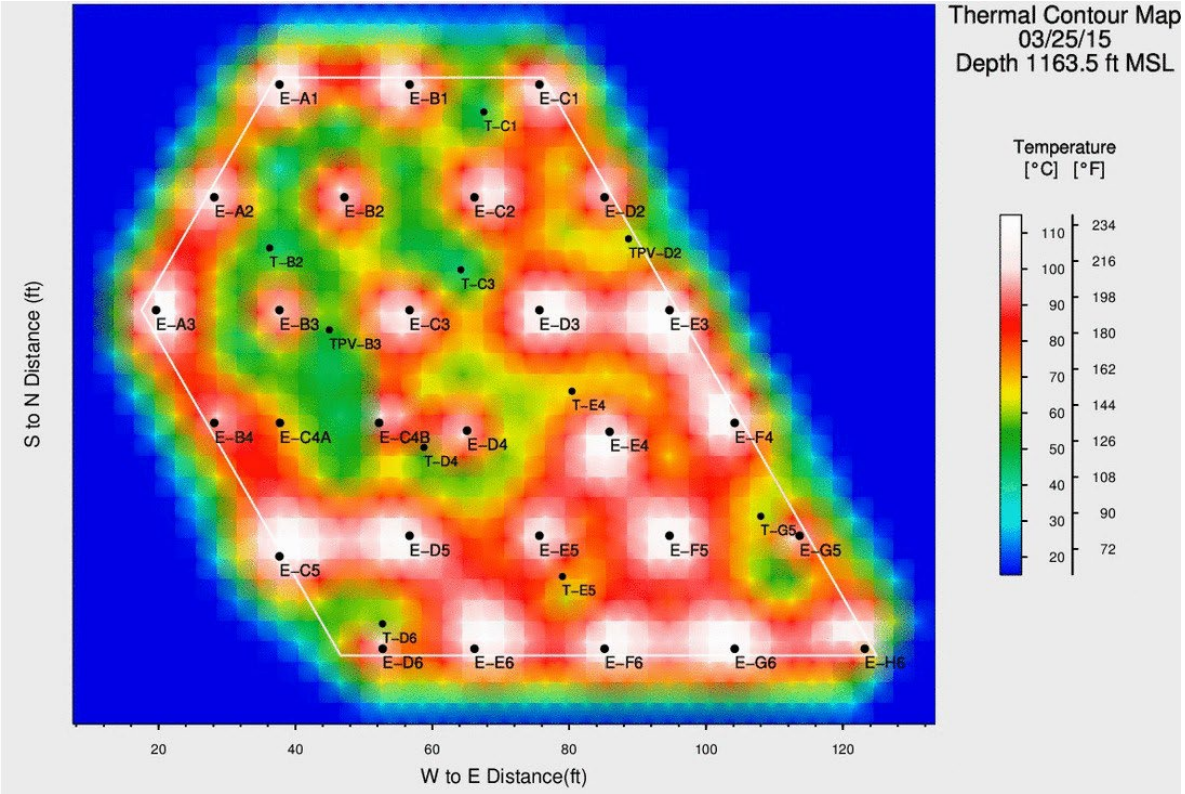


Technology Overview

Just the Facts

- In-situ Thermal Treatment Key Components:
  - Heat delivery technology
  - Fluid extraction for contaminant recovery from groundwater and vapor
  - Extracted fluid treatment equipment
  - In-situ temperature monitoring systems



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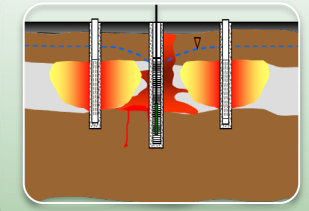
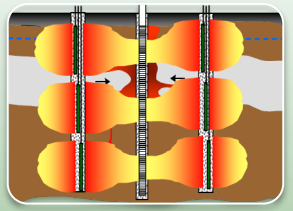
Many Process Options to Consider

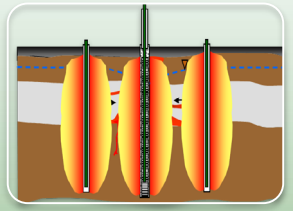


Steam Enhanced Extraction (SEE)



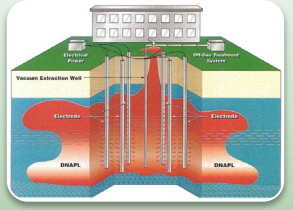
Electrical Resistance Heating (ERH)

- Electro-Thermal Dynamic Stripping (ET-DSP™)
- Six phase heating (SPH)



Thermal Conduction Heating (TCH)

- In-situ Thermal Desorption (ISTD)
- Gas Thermal Remediation (GTR)



Emerging Heating Approach

- Self-Sustaining Treatment for Active Remediation (STAR)

High Permeability Formations (10^{-2} cm/s)

- ~10^{-4} cm/s

(10^{-8} cm/s) Low Permeability Formations

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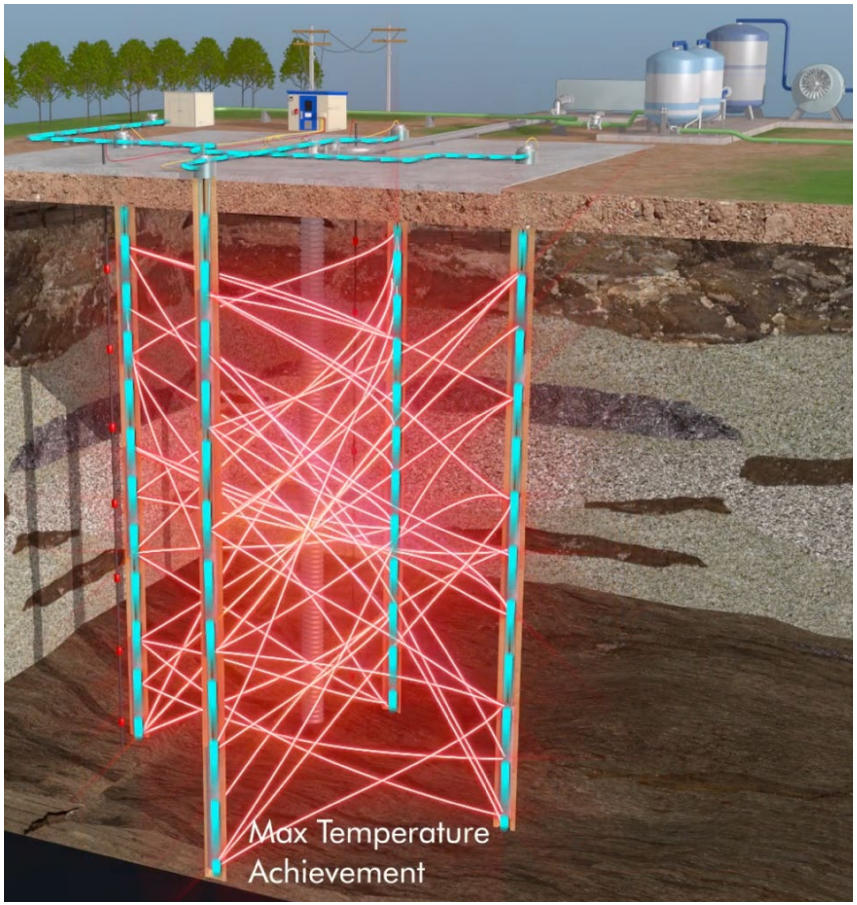
Electrical Resistance Heating

- Soil electrical conductivity and water boiling point govern heating
- Heating process
  - Alternating current supplied to subsurface electrodes
  - Electrical resistance of soil generates heat
- Temperature limited to boiling point of water at local pressure
- Specific heating approaches vary by technology provider



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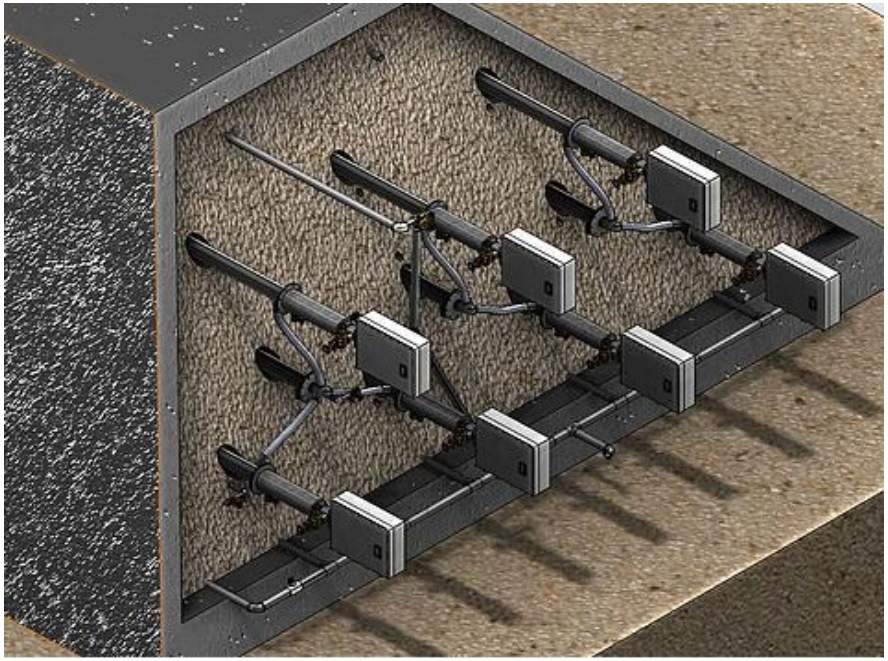
Thermal Conduction Heating

- Thermal conductivity governs subsurface heating
- Heating process
  - Accomplished using subsurface high temperature heaters.
  - Transfer heat by conduction to the surrounding formation
- Treatment temperatures > 100°C are readily attained
- Specific heating approaches vary by technology provider

- Ex-situ heating is also feasible
  - In constructed concrete cells
  - In covered soil piles



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TCH - In-situ Thermal Desorption

- Electrical heaters (~800°C) provide subsurface energy

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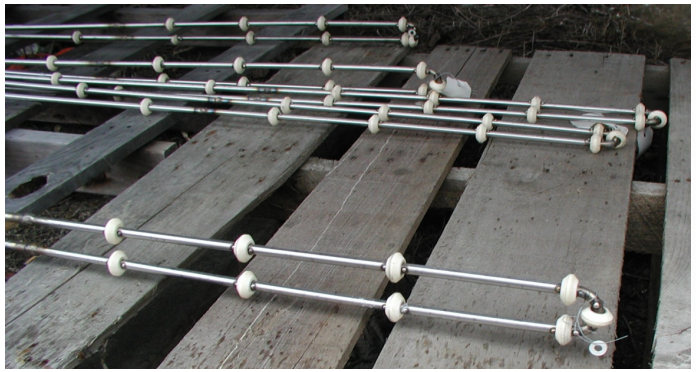

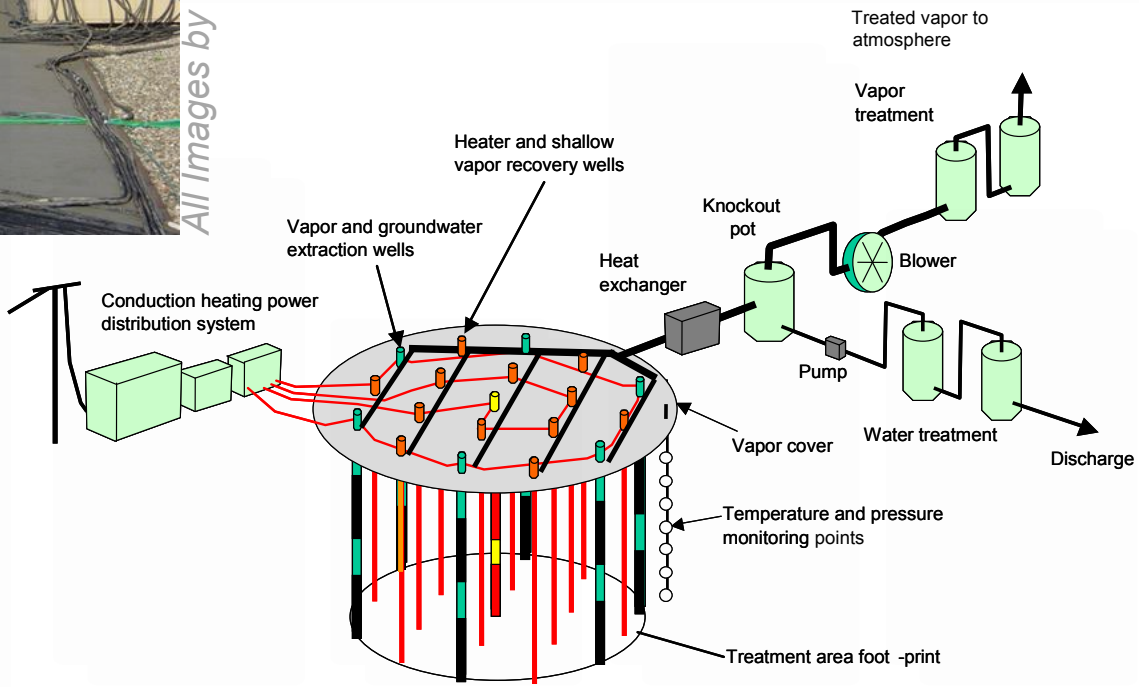

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TCH - Gas Thermal Remediation

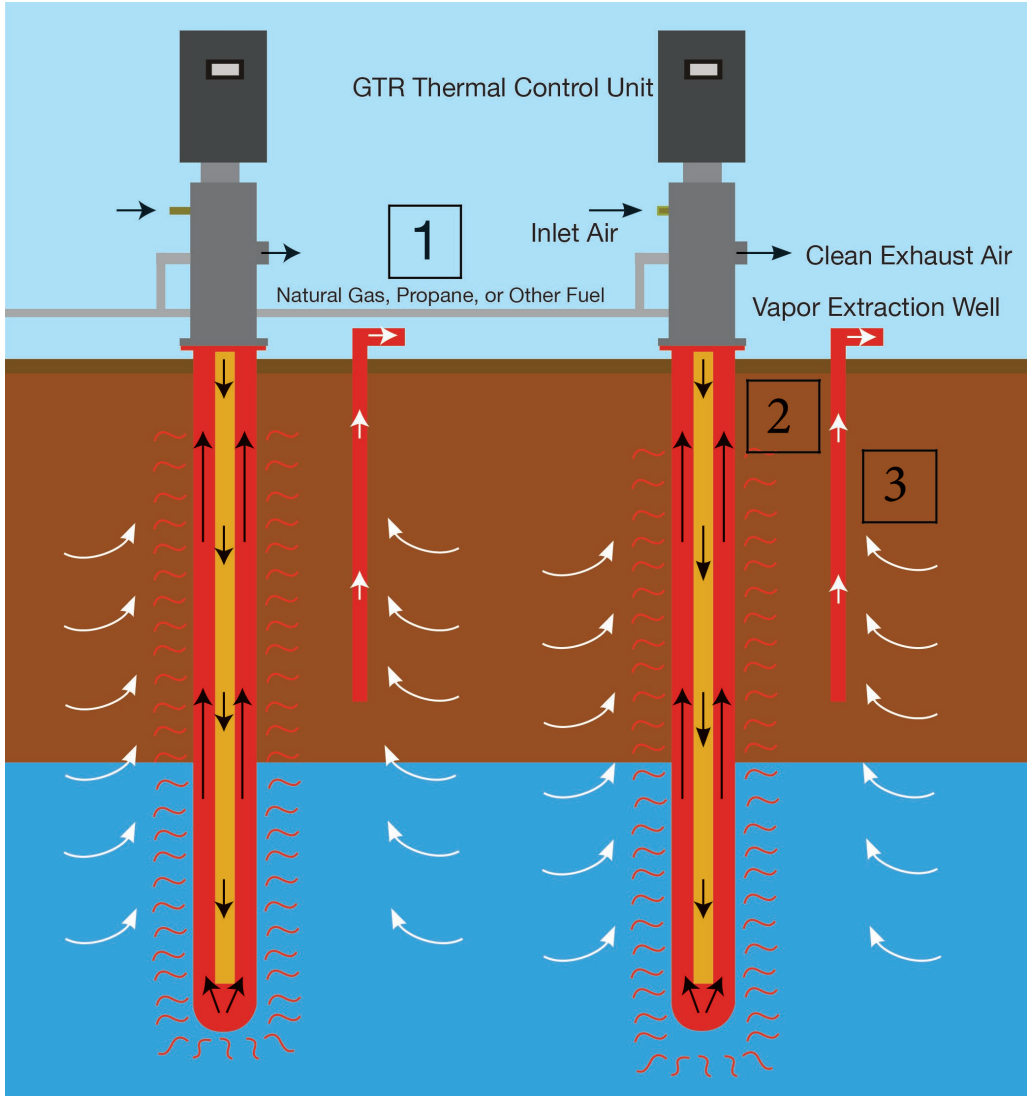

Image by GEO, Inc.

- Liquid or gaseous fuels provide subsurface thermal energy
- Soil and groundwater are heated to temperatures of 100-400°C by conduction
- Volatilized contaminants are collected by soil vapor extraction and treated ex-situ

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Vapor Extraction & Treatment is Required

- Primary condensation
- Low mass - GAC
- High mass
  - Thermal oxidation
  - GEO Compression/ Condensation

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So Which Technology Works Best?

- All heating technologies yield excellent results
  - With proper method selection and performance monitoring
  - All excel at source removal
- Design considerations
  - Contaminant characteristics
  - Remediation objectives
  - Treatment volume
  - Lithology
  - Site conditions
  - Treatment time
- Performance monitoring

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Subsurface Conditions Matter

ERH or TCH are likely candidates for these conditions

TCH may be the only viable candidate for sites with buried metal

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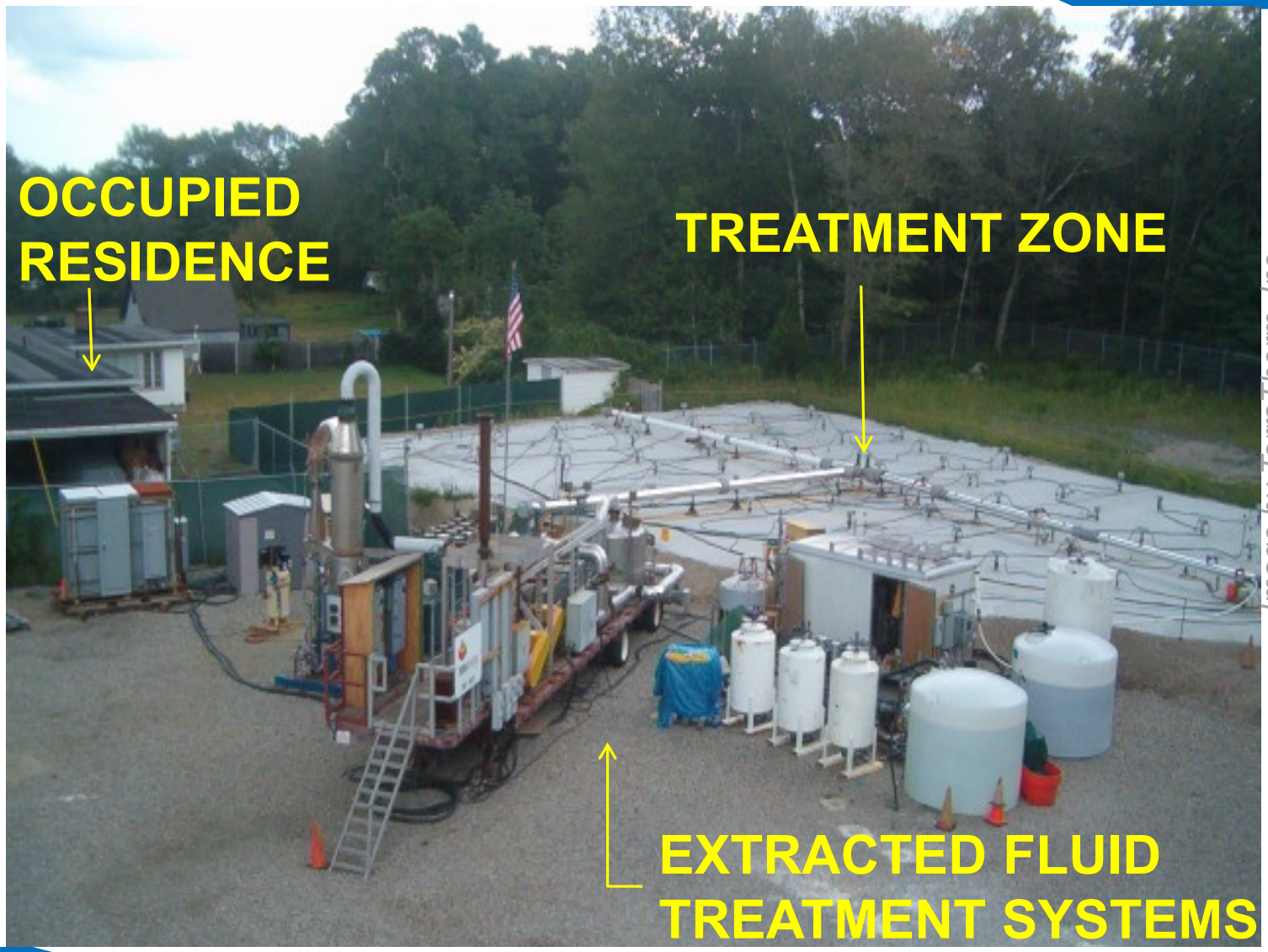
Thermal Treatment Systems are Readily Adapted to Site Conditions



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Privacy Screen to Minimize Visual Impacts of Treatment Area

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Urban Applications are Well Documented

- Thermal treatment in proximity to many residential receptors

- Cap, insulation and aggressive fluid extraction limit heating of exterior walls

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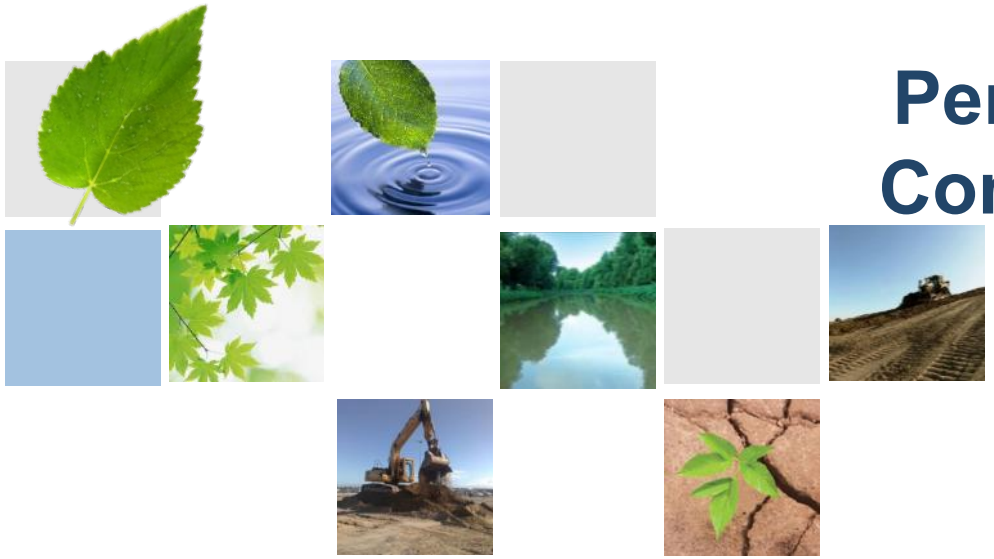

Performance Monitoring Concepts and Strategies

Monitoring Treatment Performance

- Subsurface temperature
  - Lateral and vertical measurement
  - Real time monitoring
- Temporal measurement
  - In-situ pressure
  - Groundwater elevation
  - Vapor concentration
  - Process parameters
    - Vapor, temperature, flow
- Discrete sampling
  - Extracted vapor concentration
  - Extracted liquid concentration
- Post treatment sampling
  - Soil and groundwater
- **<u>Contaminant removal is assessed in many ways using multiple lines of evidence</u>**

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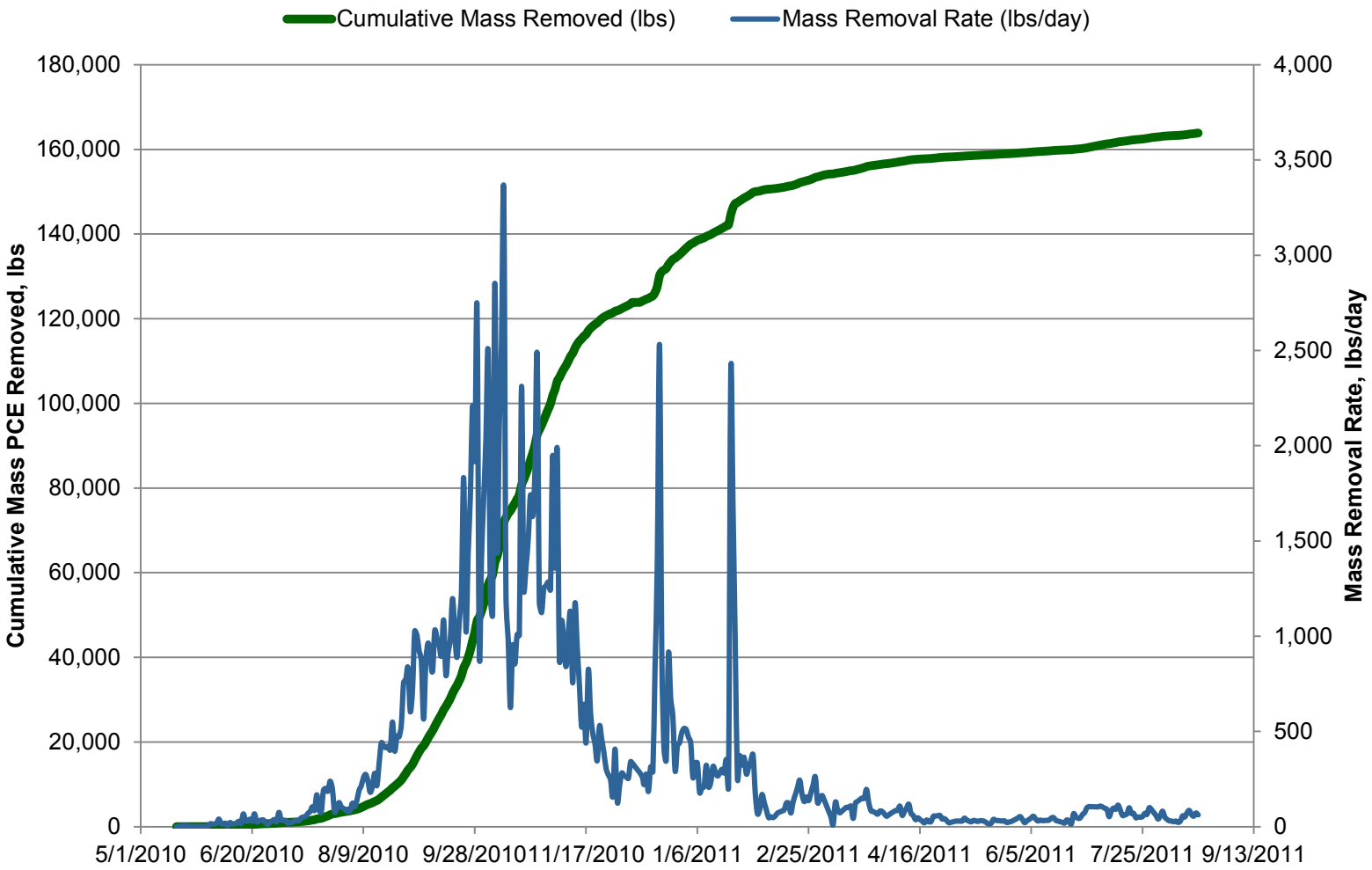
Process Monitoring Demonstrates Mass Removal



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Post-Treatment Sampling

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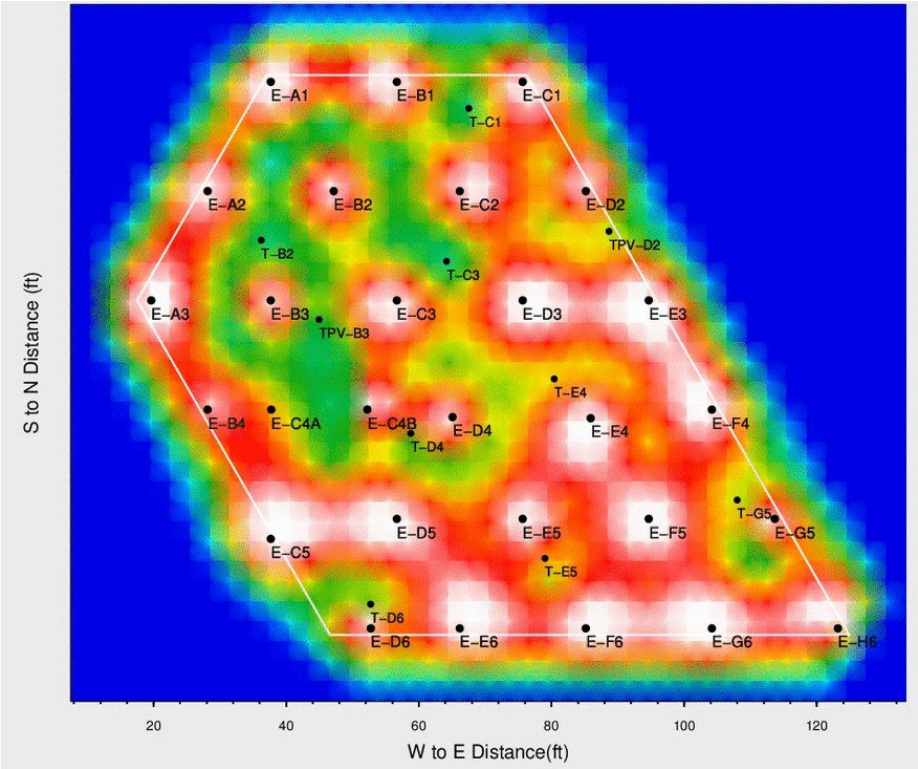
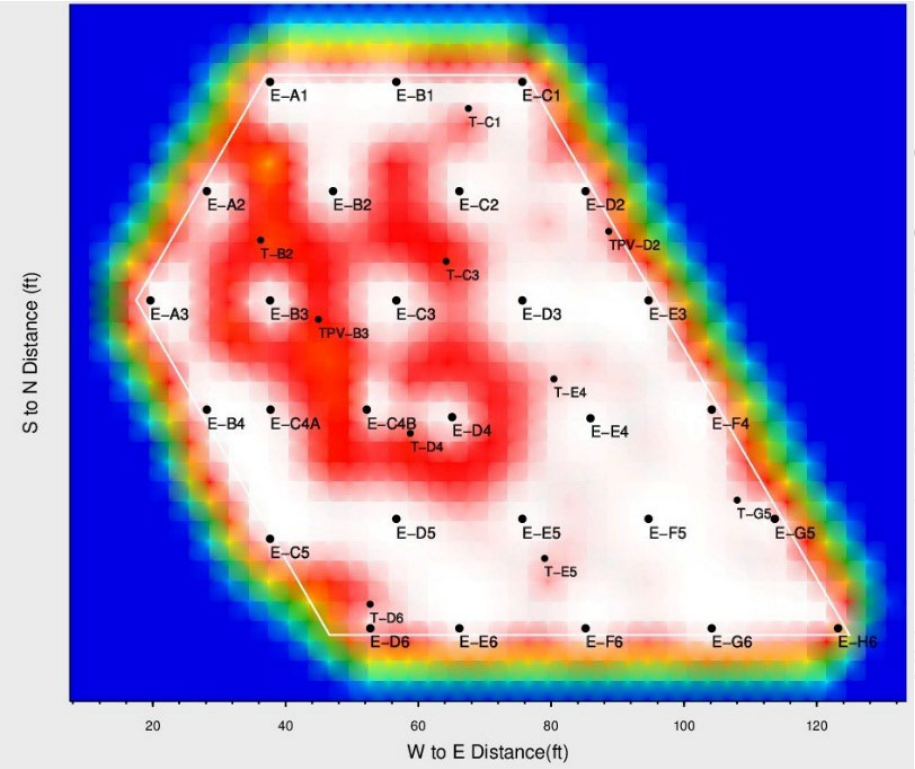
Thermal Monitoring Tells All



Temperature at Elevation 1163 ft MSL



Temperature at Elevation 1175 ft MSL

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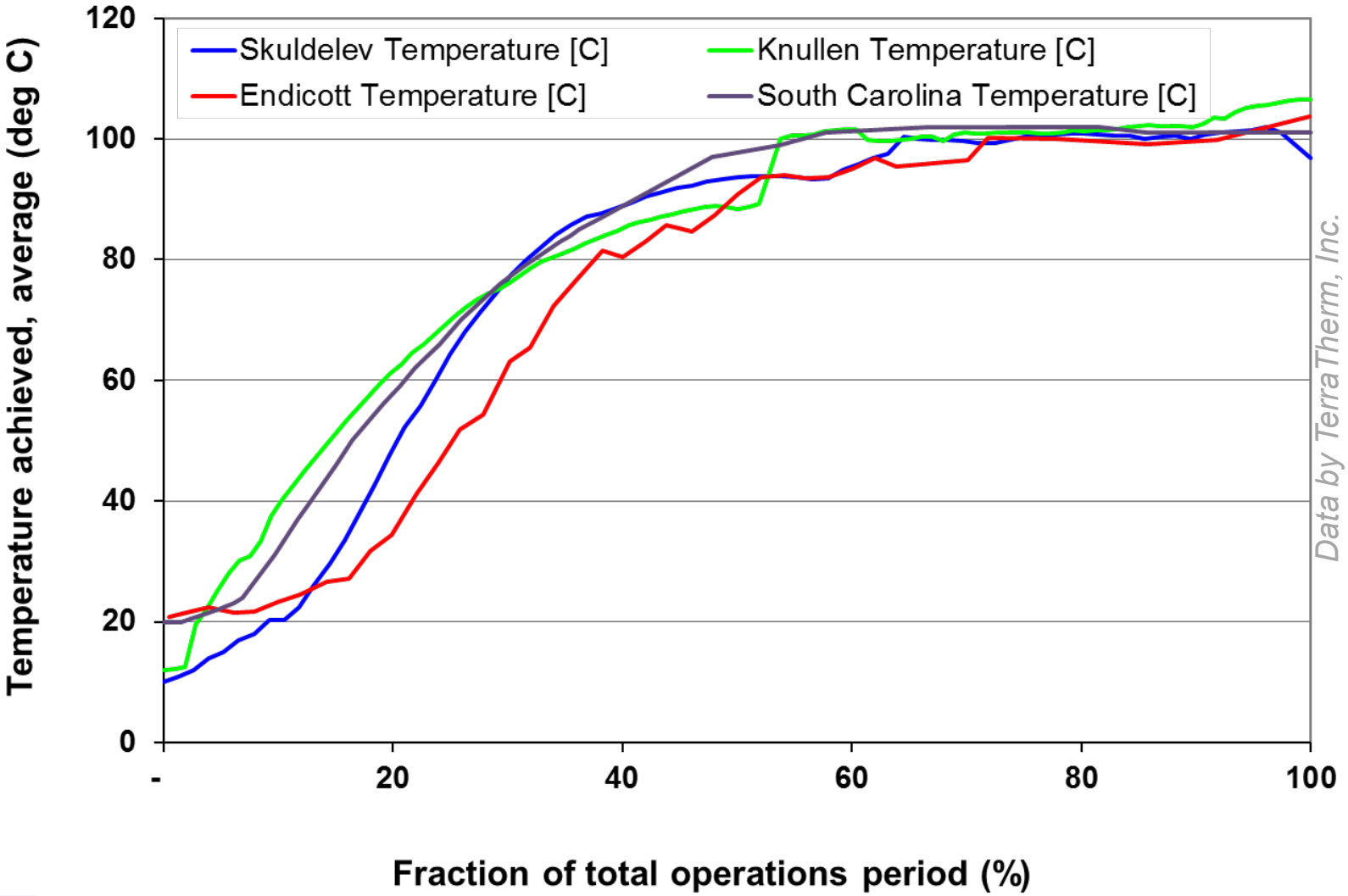
Temperature and Time Control Treatment Performance



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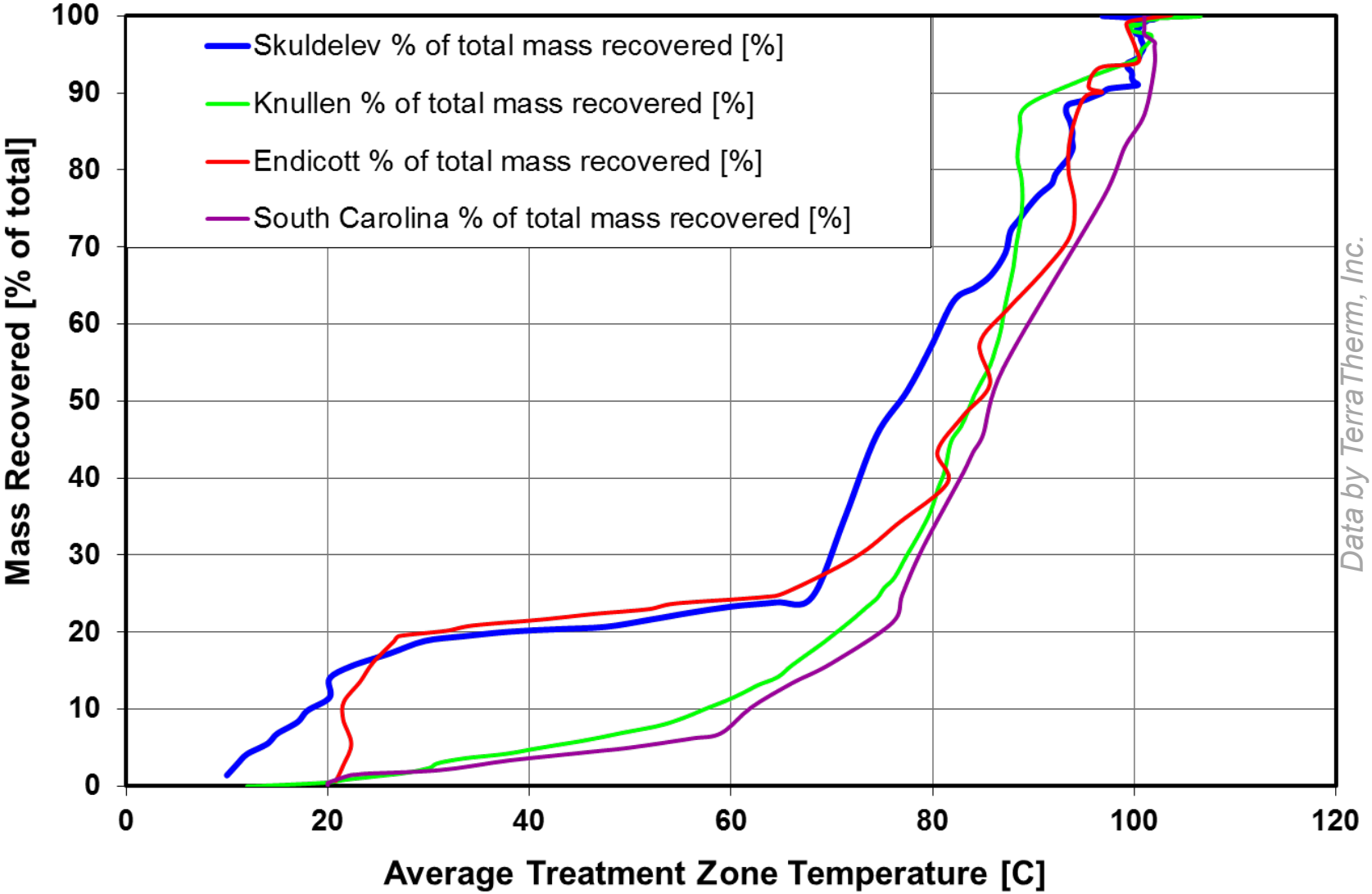
Treatment Temperature and Mass Removal are Directly Correlated



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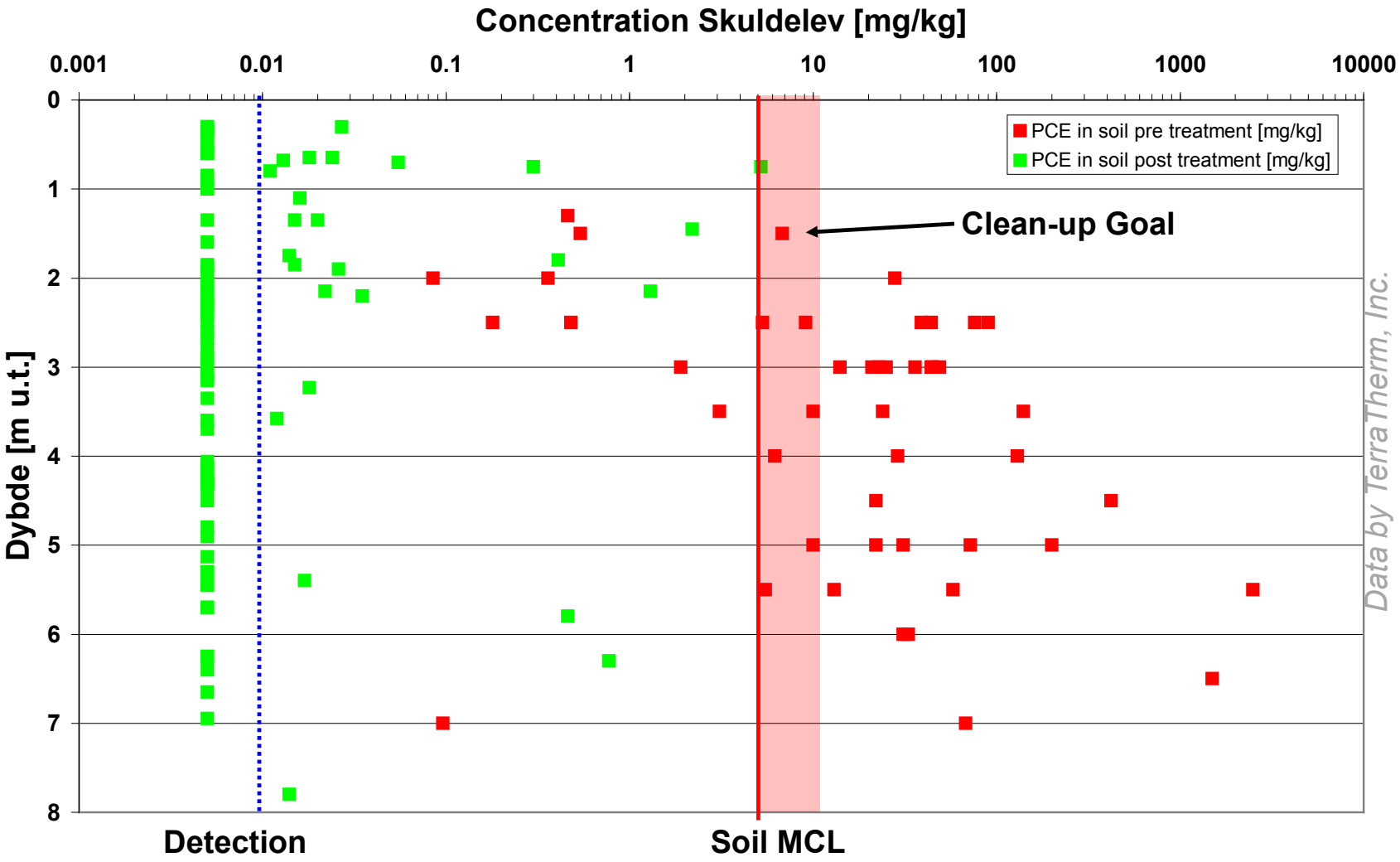
Soil Sampling Confirms Mass Removal Observations



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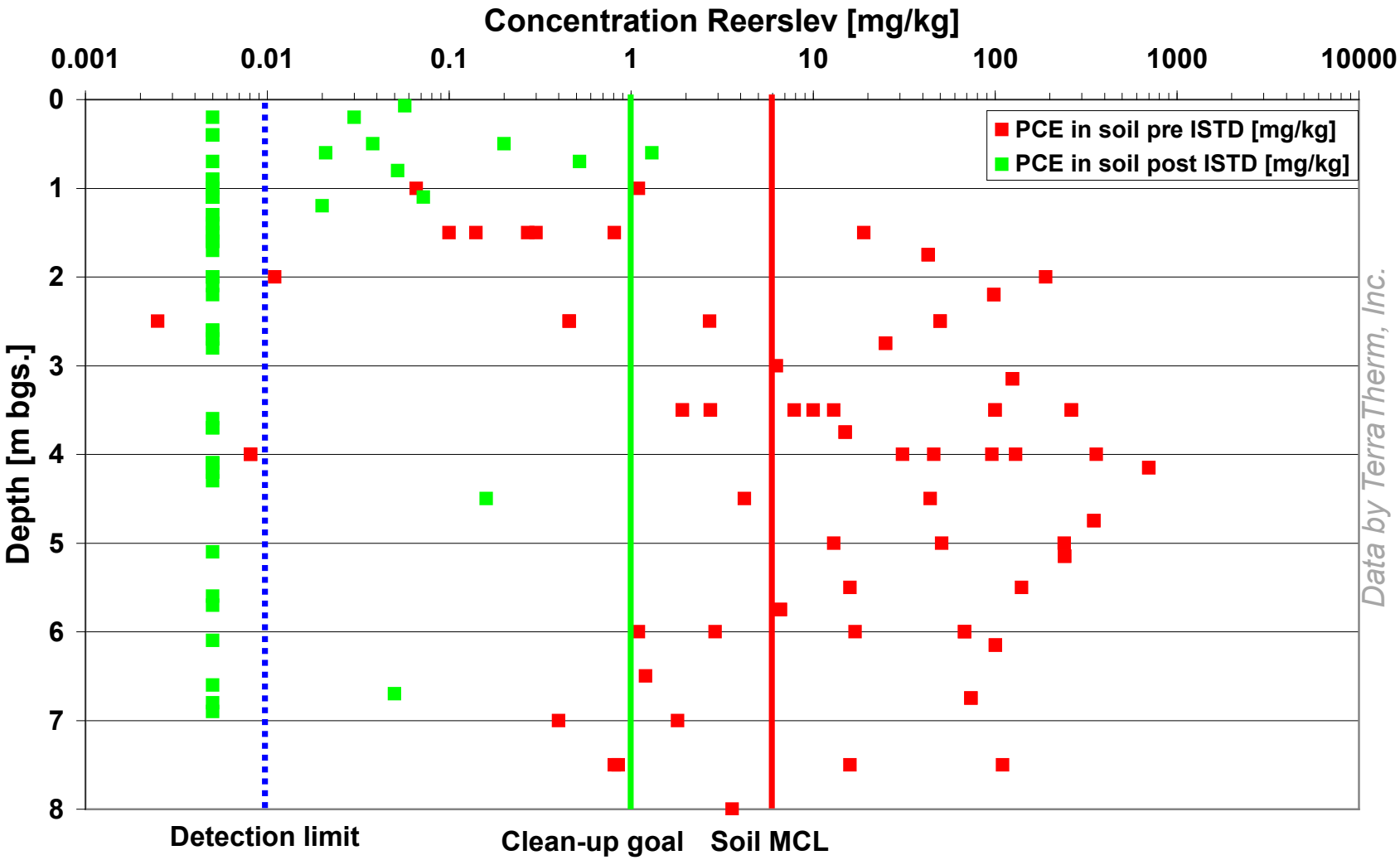
Different Site – Similar Results



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Analysis of Process Monitoring Data Determines Operation Endpoint

- Temperature and time control technology performance
  - Thermal monitoring data document target temperature achievement
  - Operation time at target temperature drives contaminant removal
- Instantaneous mass removal rate is measured with time
  - Mass removal typically peaks around co-boiling temperature
  - With increasing time and temperature removal rates decline
- Rate analysis yields cumulative contaminant mass removed
  - Total mass removed approaches asymptotic conditions with time

- The simultaneous evaluation of <u>temperature</u>, <u>time</u> and <u>contaminant mass removal</u> form the basis of the diminishing returns analysis
  - Results are the first line of evidence that treatment is complete

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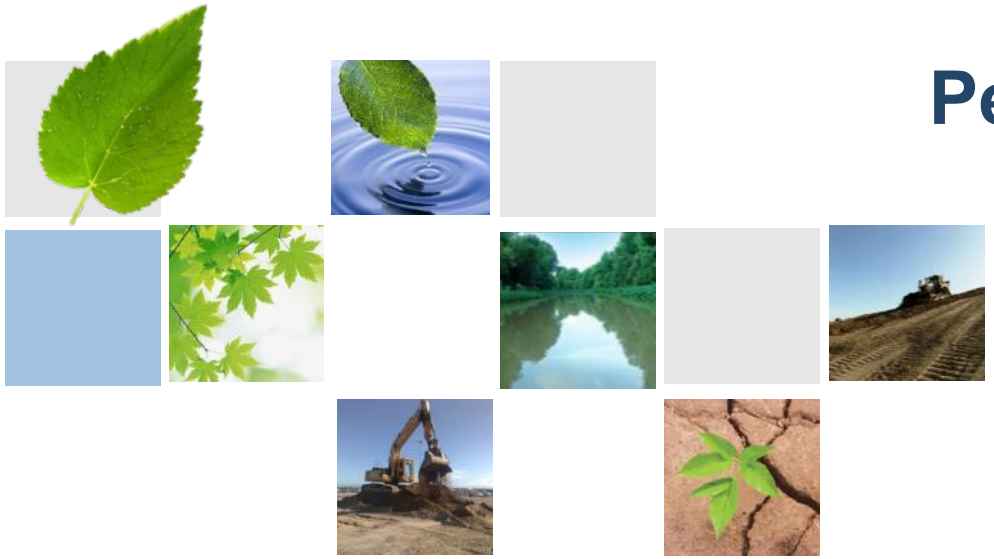
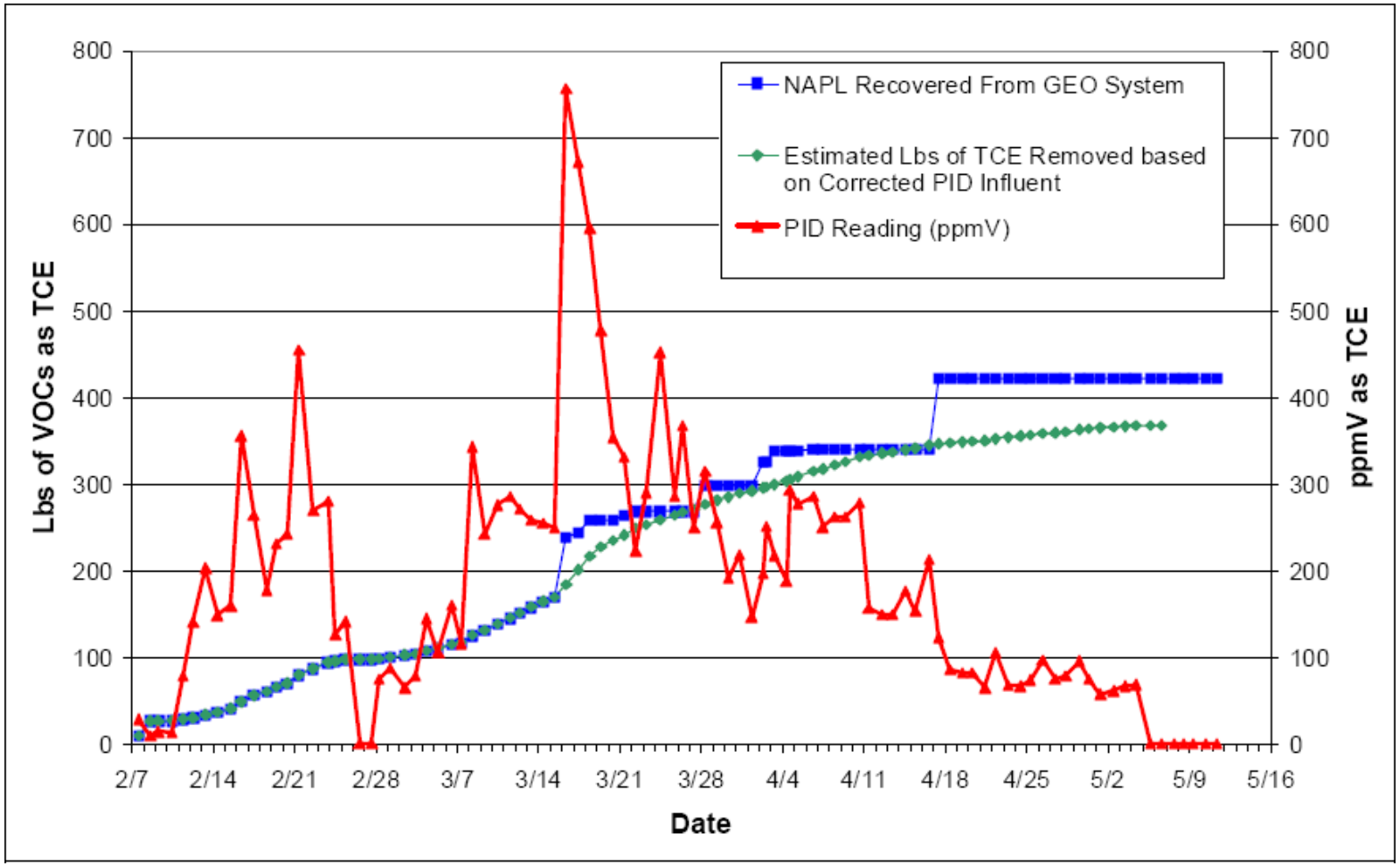


Performance Examples
Solvent Treatment

Performance Data Illustrates Thermal Treatment Endpoint



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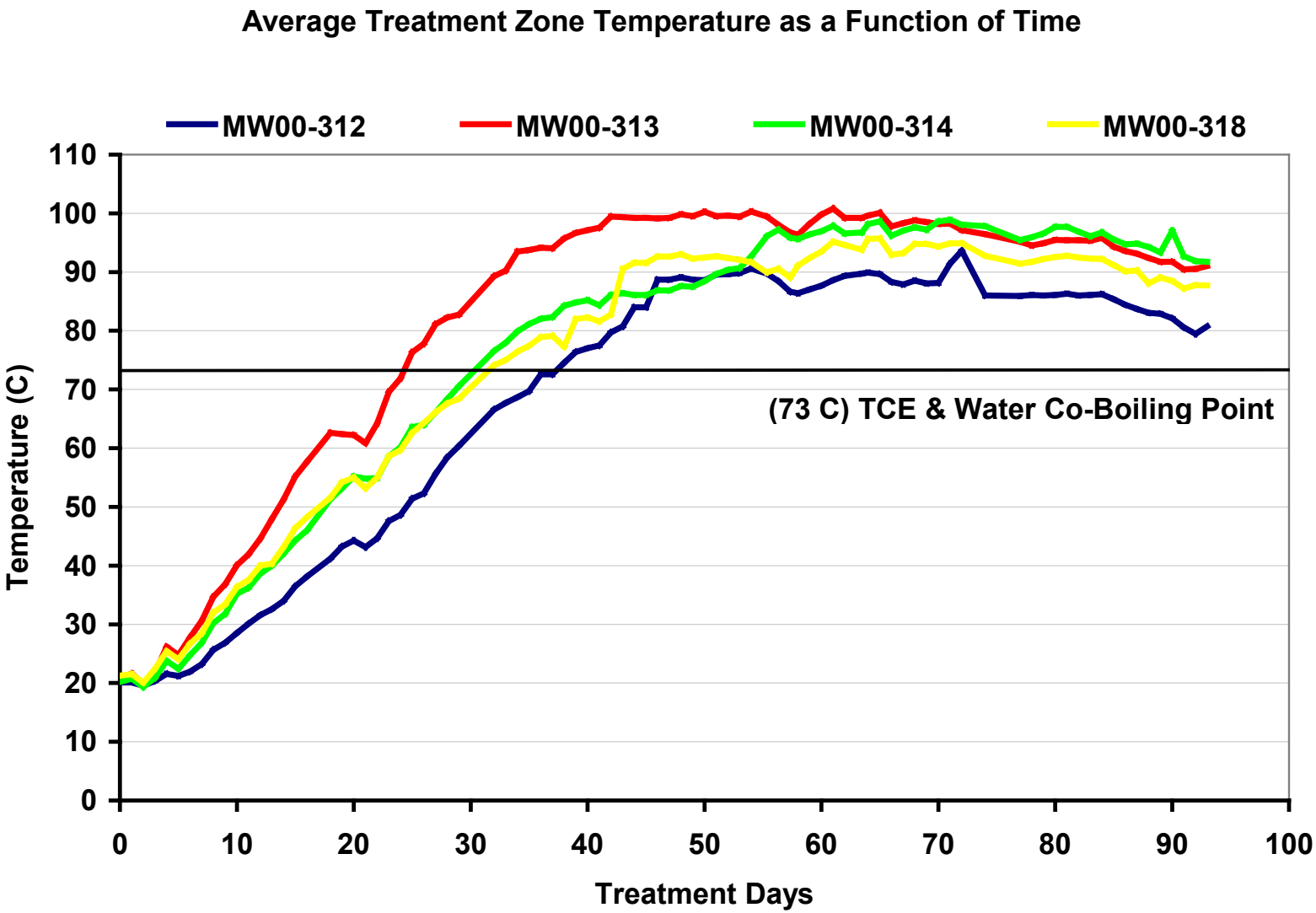
Treatment Zone Temperature



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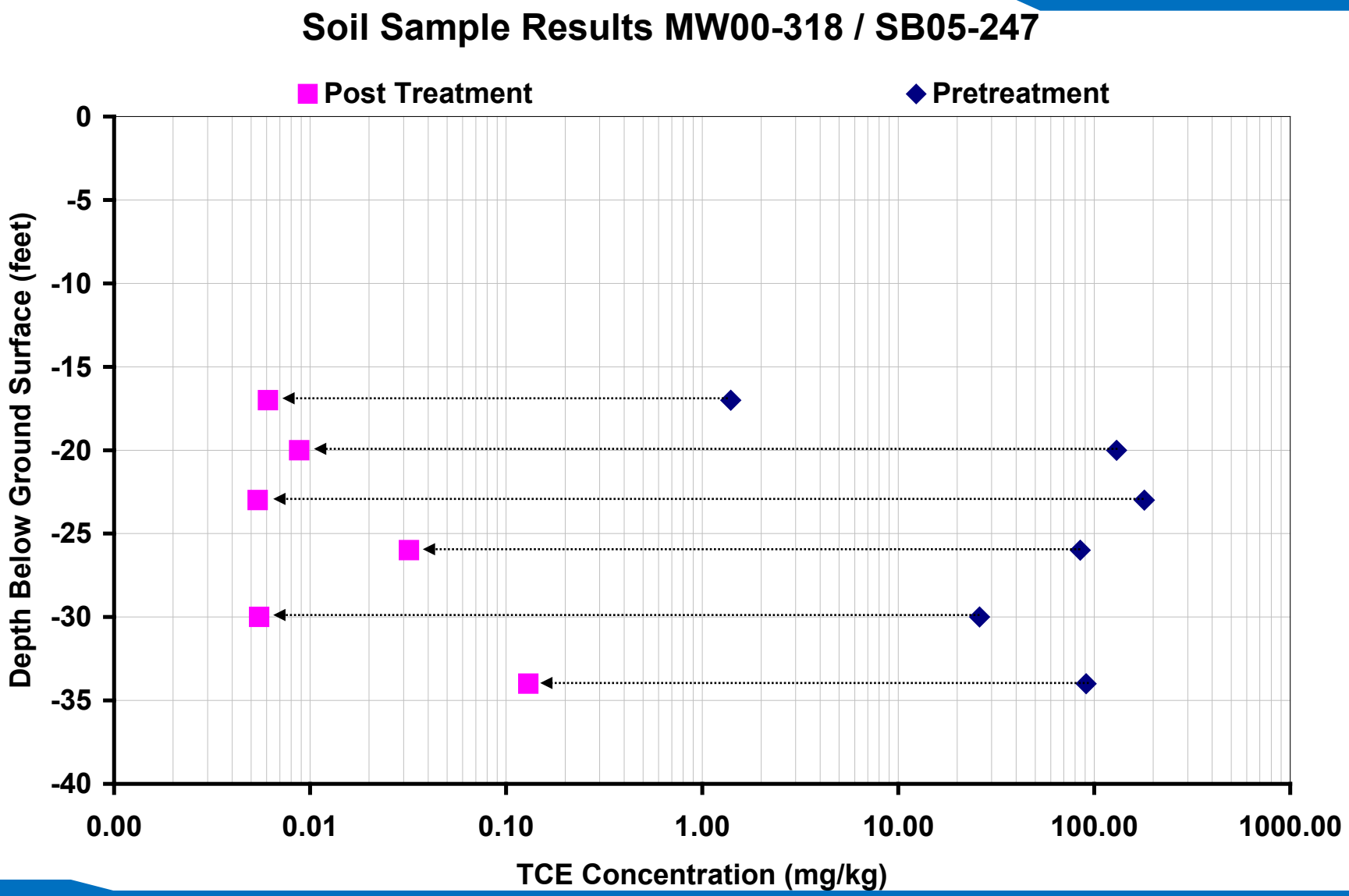
Soil Borings Confirm Performance



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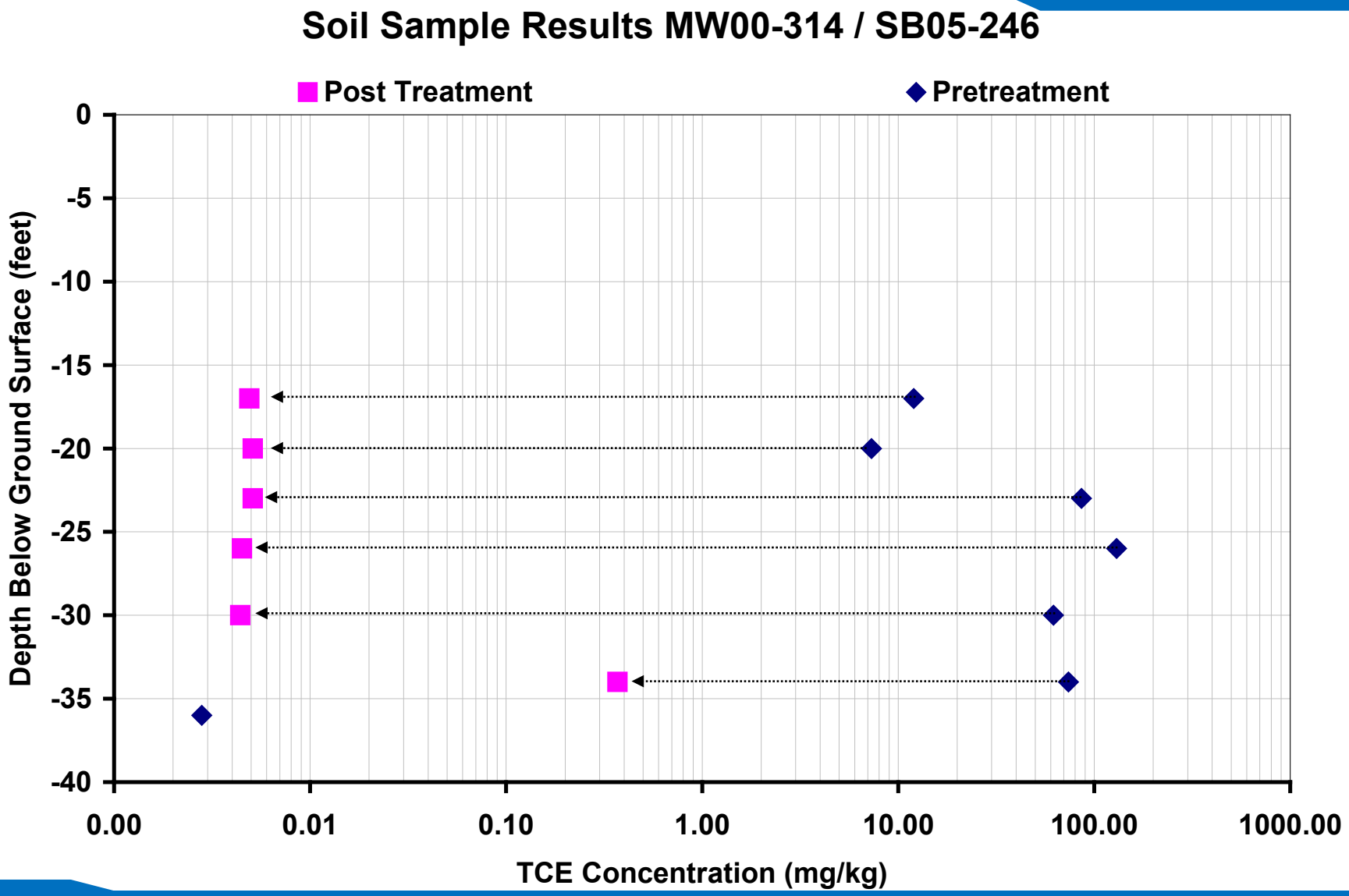
Results Are Spatially Consistent



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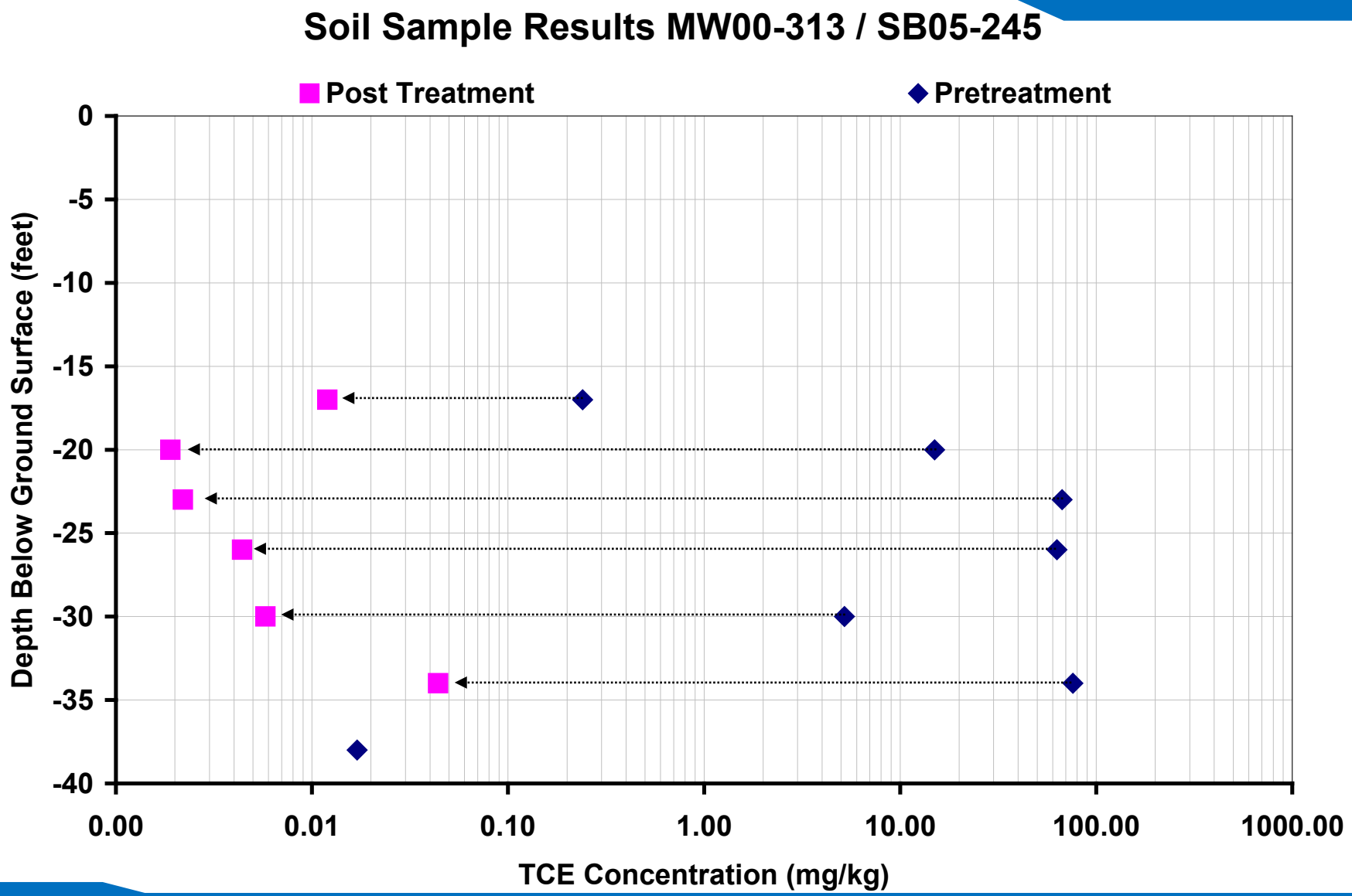
Concentration Reduction = Removal



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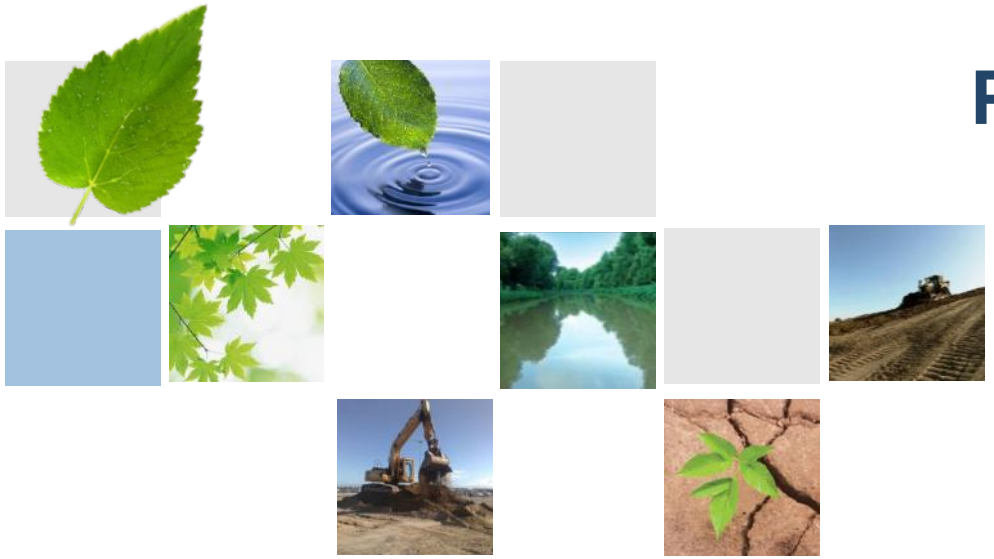
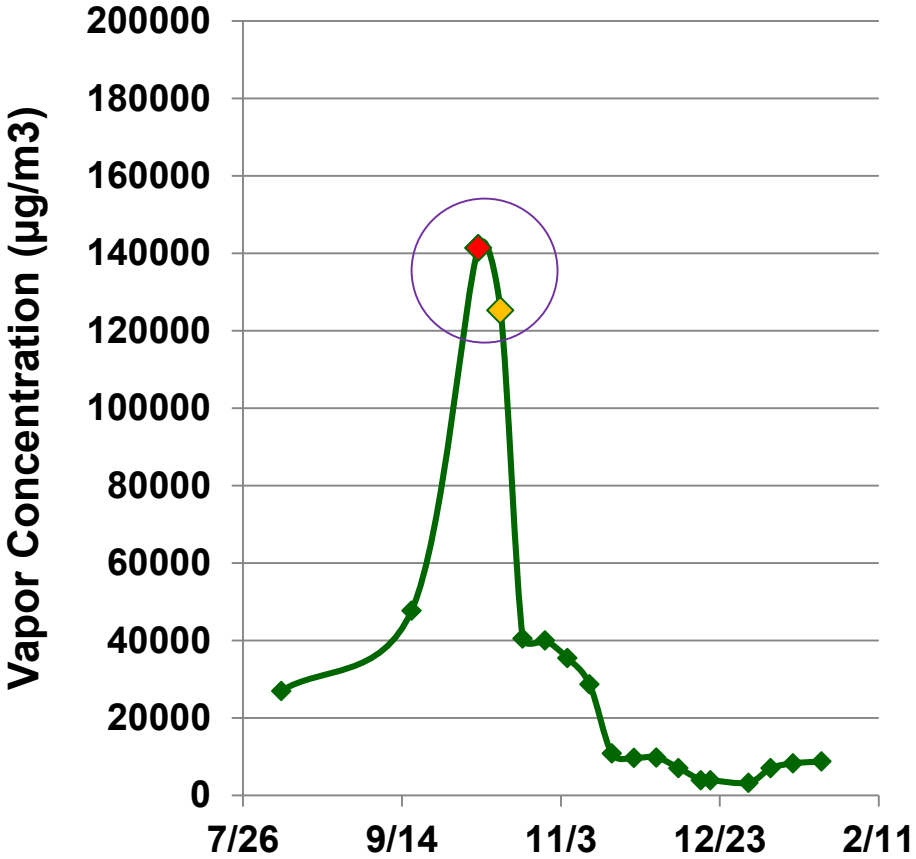
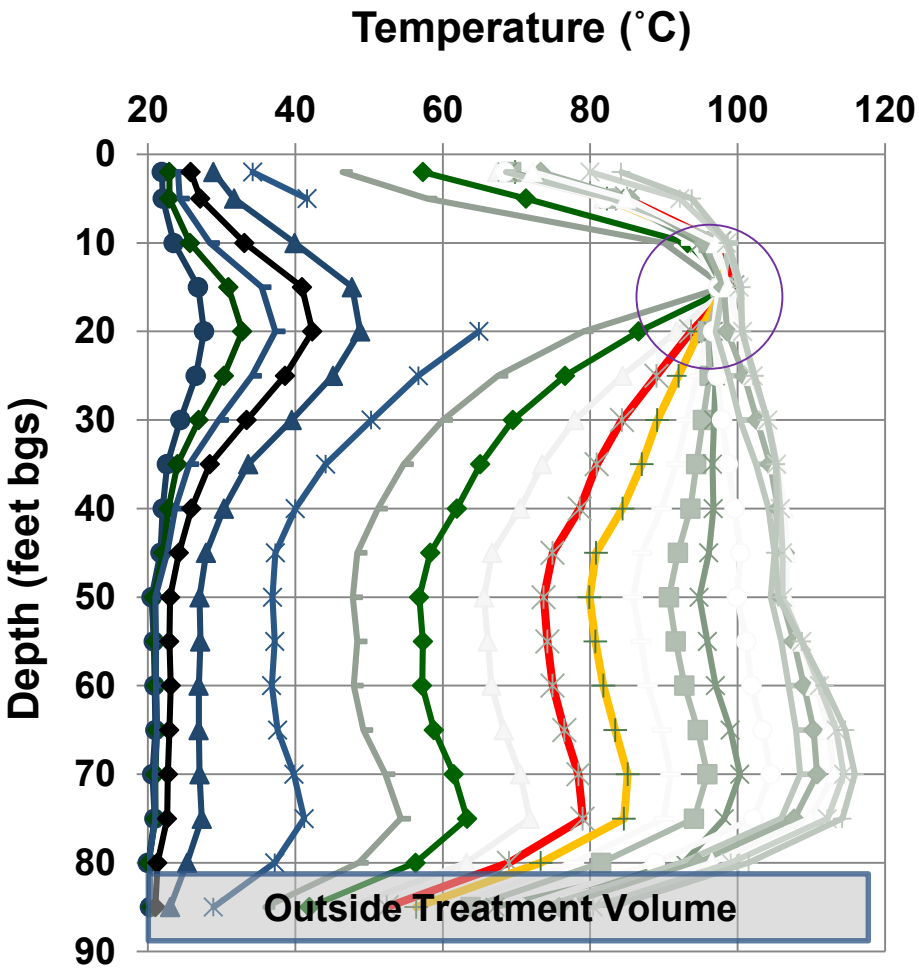


Performance Example
Pesticide Treatment

Mass Removal Follows Heating





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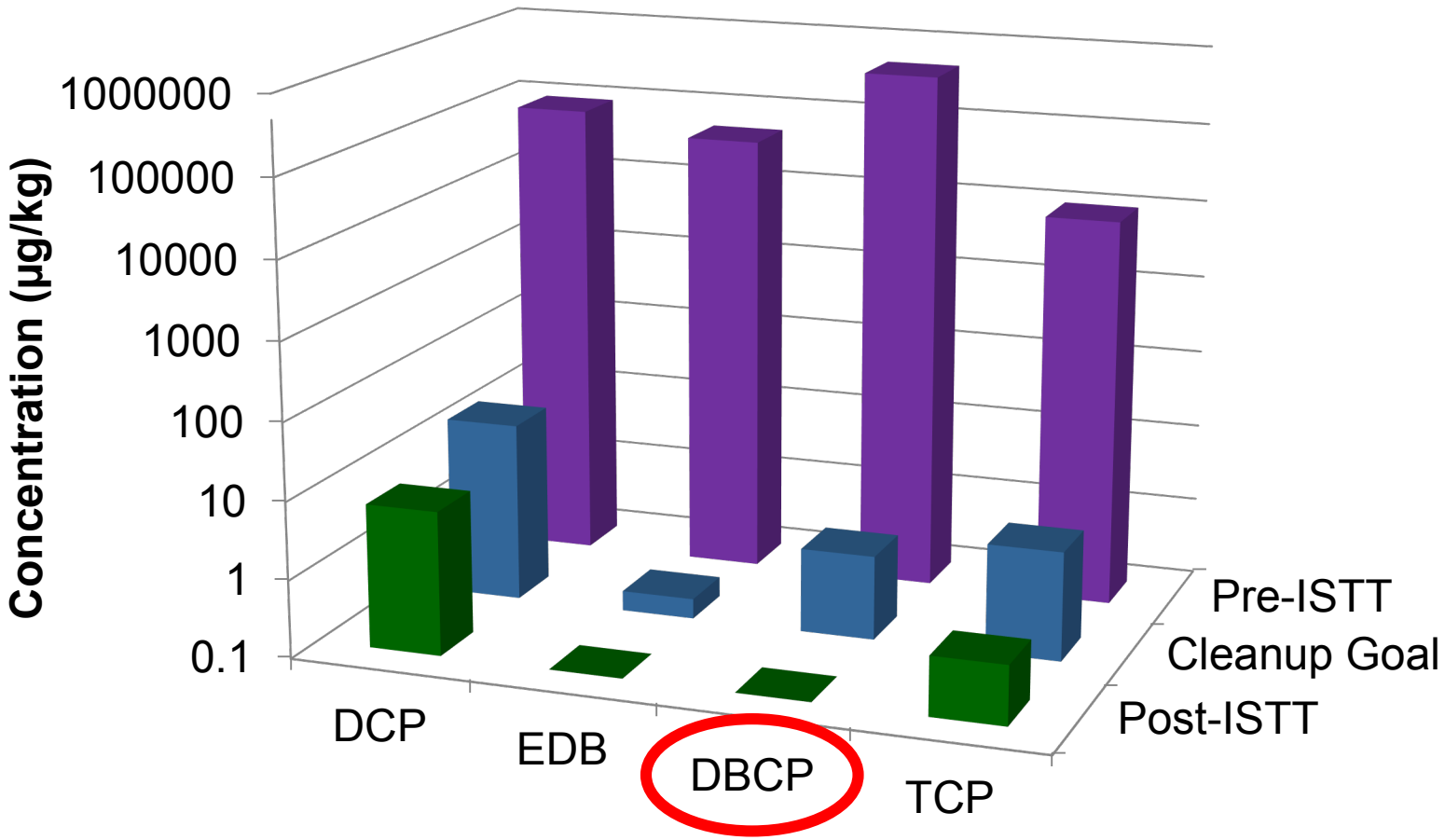
Soil Treatment Performance Summary



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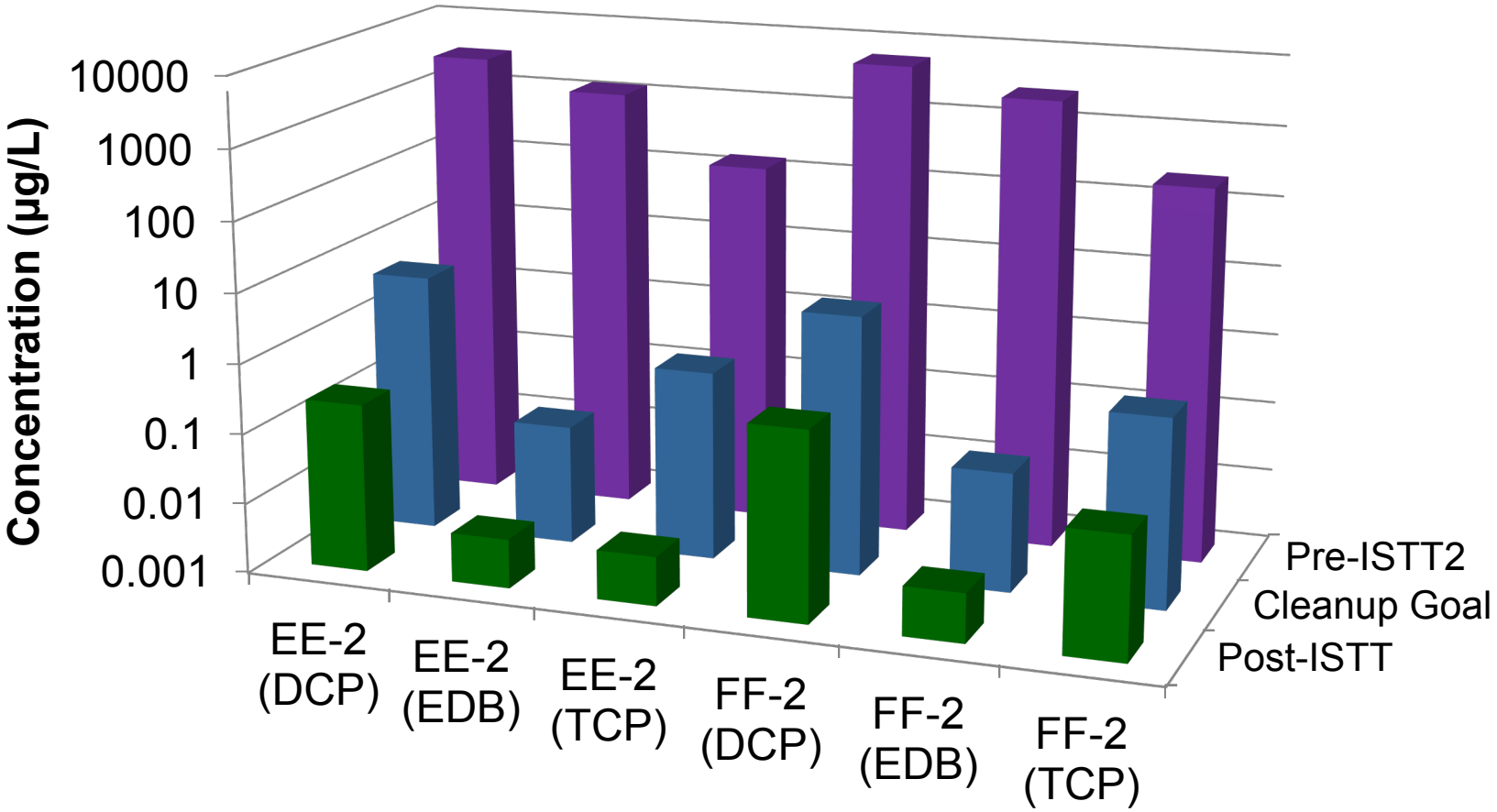
Performance - Groundwater



Post-ISTT: All Wells Below Cleanup Goals

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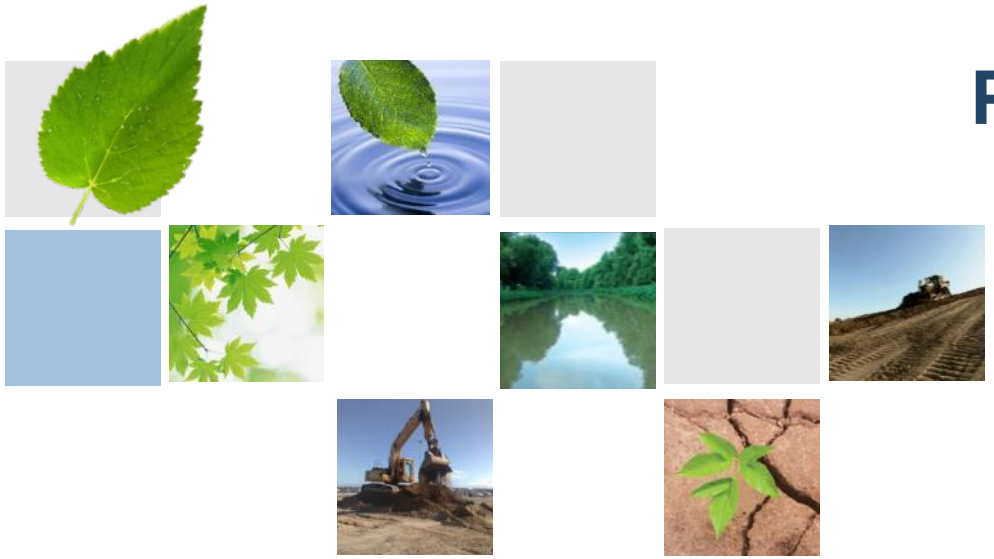

Performance Example
Combined Remedies

Oregon Solvent Site

- Voluntary cleanup of an active manufacturing site
- Solvent release to shallow groundwater
  - NAPL source contaminates groundwater
  - Dissolved contaminants migrate off site > 1000 feet
- In-situ thermal treatment selected for source removal
- Containment system installed for interim plume control
- Groundwater remedy deferred until ISTT was complete
  - Source removal by ISTT was successful
  - Removal immediately apparent on site groundwater
  - Containment no longer needed; Natural in-situ biological processes took over following contaminant source removal
- Combined remedy delivers No Further Action determination

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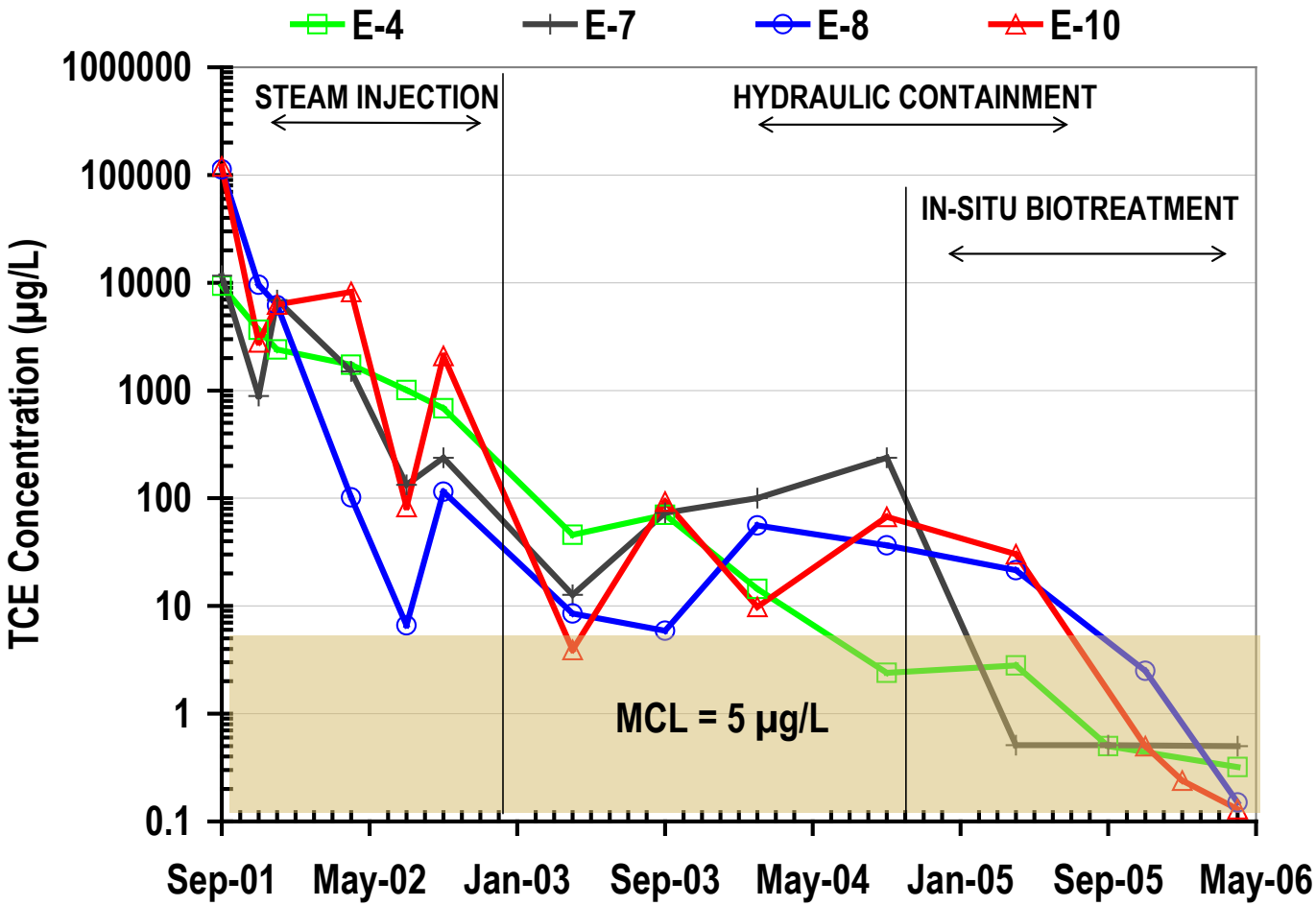
Combined Remedy Approach Example



Voluntary Cleanup Program – Private Industrial Site (Oregon)

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Closing Thoughts for In-situ Thermal Treatment

- Demonstrated and proven technology
  - Applications number in the 100s
  - Powerful treatment approach but highly site specific
  - Big hammer
  - Mechanically complex
  - Among the most effective strategies for controlled source removal
- Time and temperature control performance
  - Methods to reliably monitor spatial performance are well documented
- Discrete treatment footprint
  - Minimizes disruption to surrounding setting
  - Source removal occurs with the highest degree of control
- Source contaminants are removed and destroyed
  - Statutory preference for treatment is fulfilled

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Questions

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