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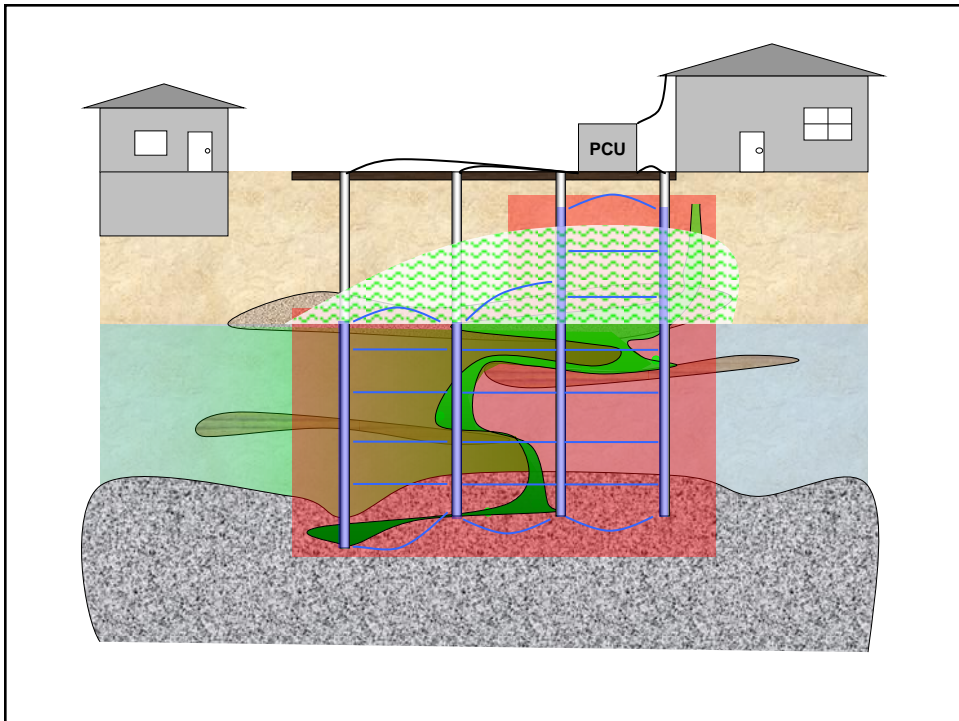
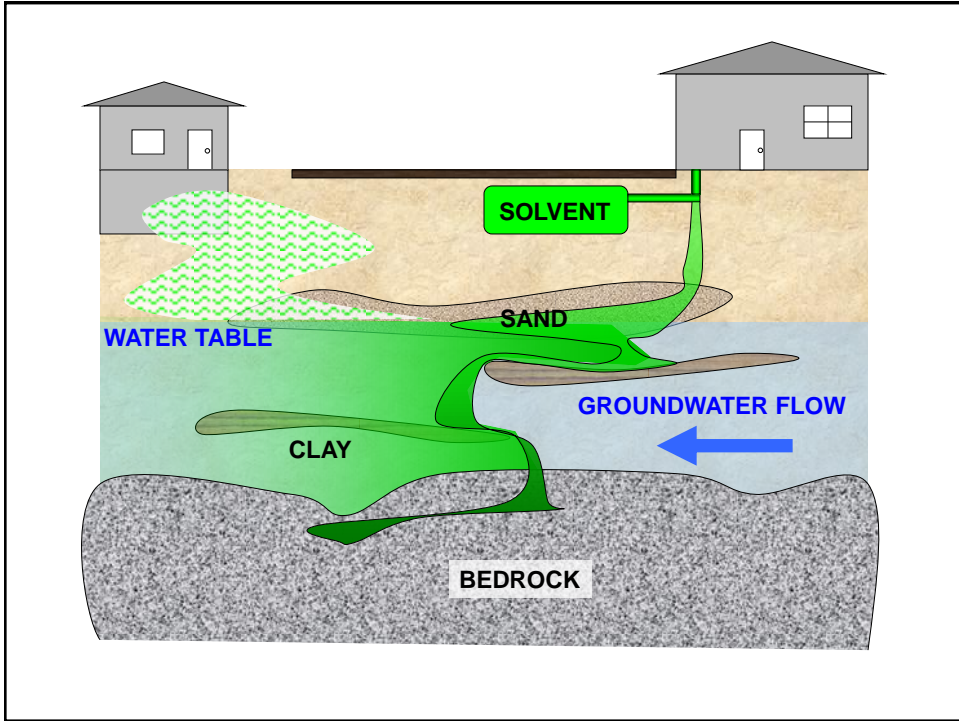
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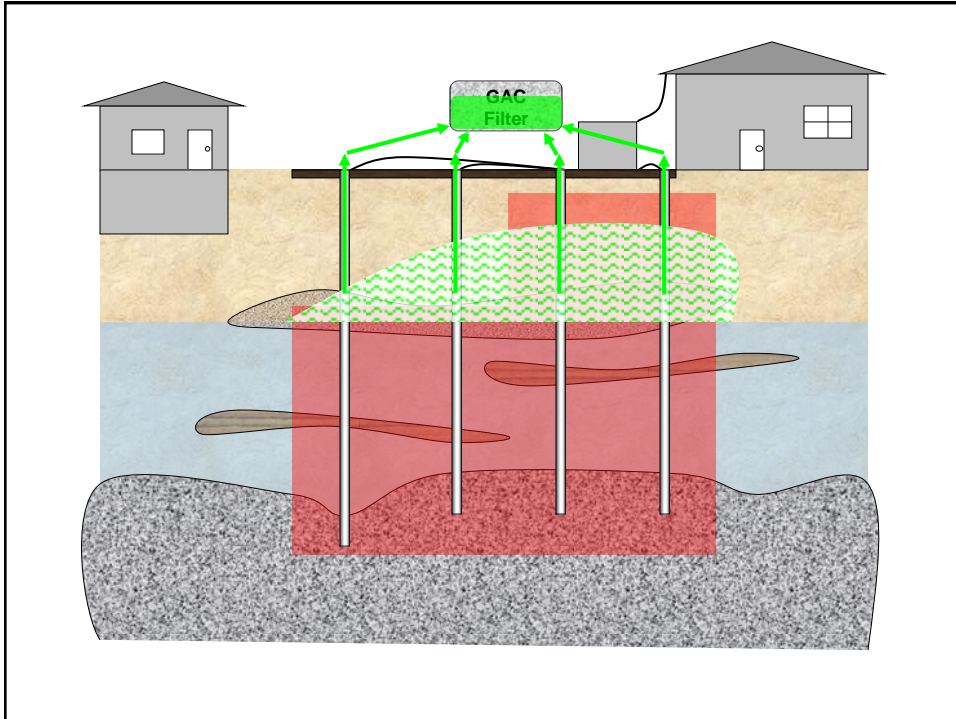


Electrical Resistance Heating

- Treatment of VOCs in groundwater, soil, and sedimentary bedrock.
- Concentration reductions of 95% to 99.9% are commonly achieved with four to eight months of operation, with no rebound.
- TRS offers guarantees of remediation effectiveness for soil, rock, and groundwater.

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Electrode Types

- Sheet piles
- Angled
- Horizontal





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ERH Surface Equipment




500 kW PCU

Steam Condenser

Operating Electrode

Photo
Courtesy of
Brown and
Caldwell

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Why Electrical Resistance Heating?

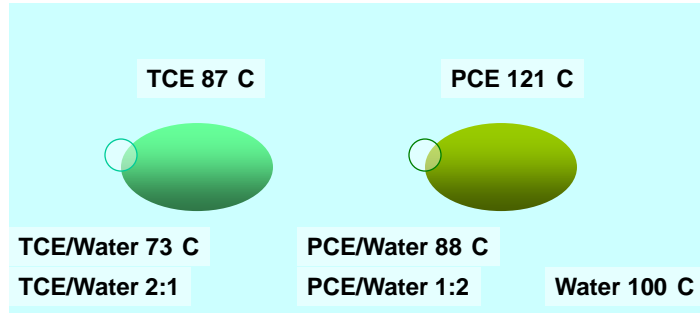
- Steam is produced *in-situ*
- Heating is uniform with no bypassed regions
- Equally effective in the vadose, saturated zone, and sedimentary bedrock
- Heating is rapid yet gentle
- No soil desiccation
- Preferentially heats tight soil lenses and DNAPL hot spots

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Boiling Temperature and Dalton's Law

- A substance boils when its vapor pressure is equal to the ambient pressure

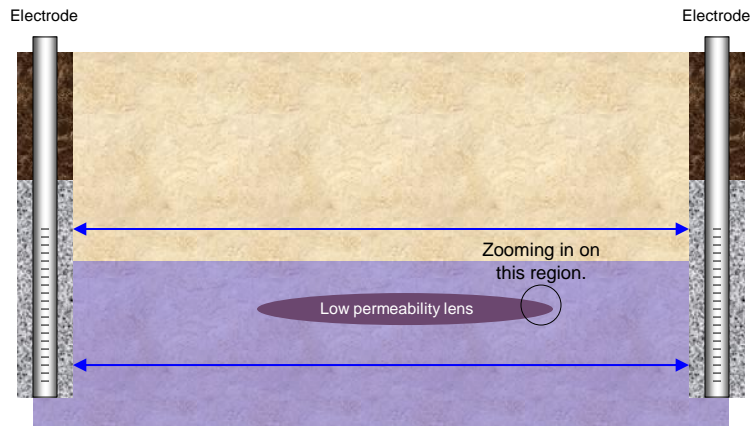


What about the vadose zone?

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In-Situ Steam Generation

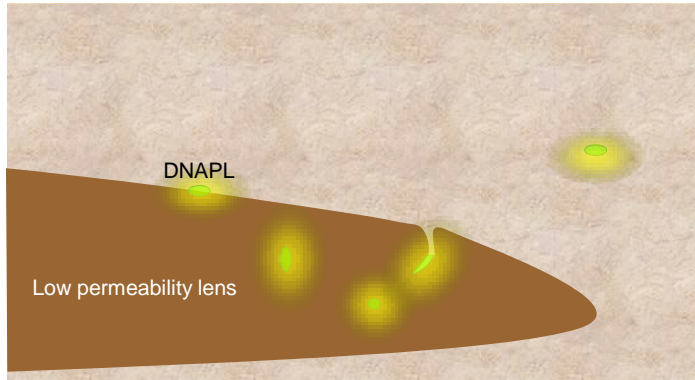


Current flowing between electrodes heats soil directly.

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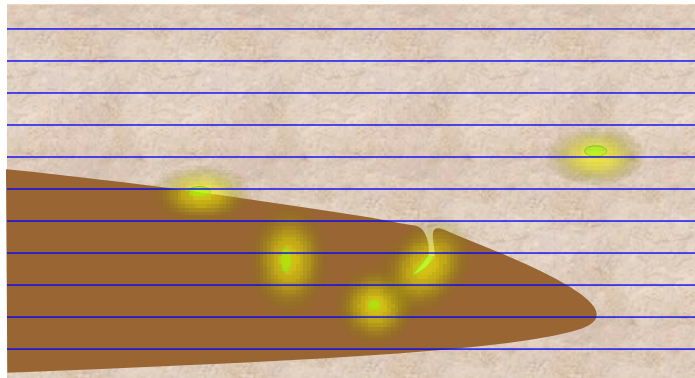
In-Situ Steam Generation



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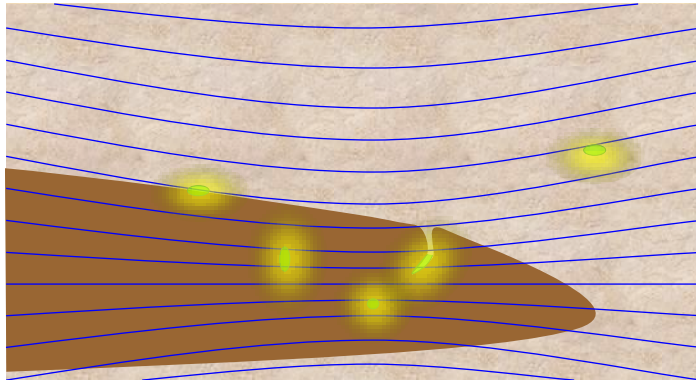
In-Situ Steam Generation



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In-Situ Steam Generation

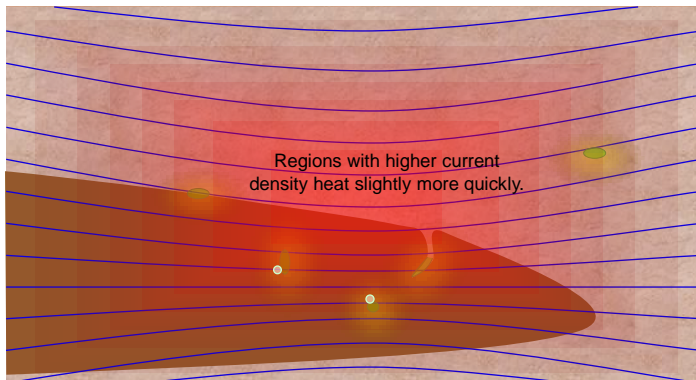


Low permeability lenses and CVOC hot spots attract current.

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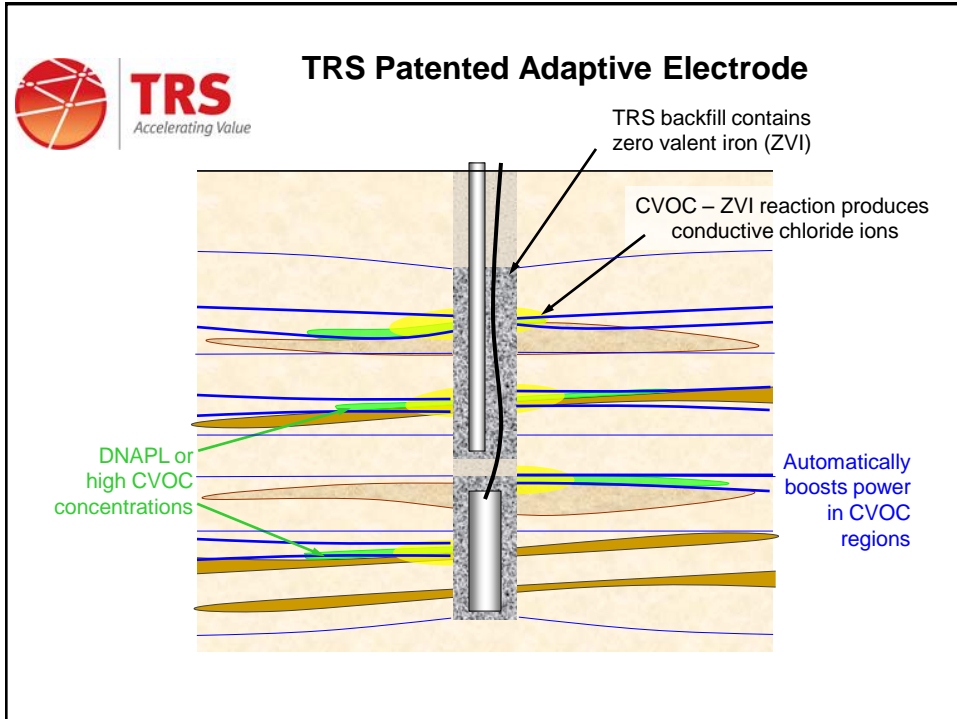
In-Situ Steam Generation




Regions with higher current density heat slightly more quickly.

Steam bubbles form more quickly at NAPL due to interfacial tension and reduced boiling temperatures. Typically form 500-1000 pore volumes of steam *in situ*.

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Why Electrical Resistance Heating?

- Because steam is produced *in-situ*, ERH is more tolerant of heterogeneity than any other remediation technology.
- It doesn't matter if:
 - The subsurface is clay
 - The subsurface is gravel
 - The subsurface is interbedded clay and gravel
 - The subsurface is vadose, perched water, or saturated

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Heating Weaknesses

- Peat or high organic carbon – granular activated carbon is used to adsorb VOCs because of the bonding between them*
- Oil or grease as a co-contaminant (Raoult's Law)*
- “Pancake sites” (big area, thin depth) – minimum 10ft treatment interval
- Fuel sites – other options and tend to be pancakes

ERH Weaknesses

- Landfills – ERH is more uniform in natural materials
- Fractured igneous rock – no experience yet
- ERH chases CVOC contamination (strength?)

* Weakness shared with other *in situ* technologies.

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Reasons to Heat Low Volatility NAPLs

- Reduce NAPL viscosity
- Reduce NAPL specific gravity – change DNAPL to LNAPL
- Steam bubble floatation
- Thermally enhanced bioremediation polish
- Strip out the more volatile and toxic components, leaving an inert and non-mobile soil particle stain

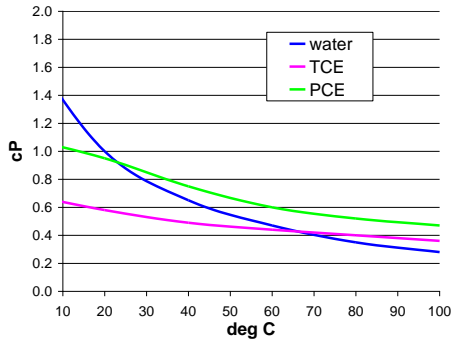
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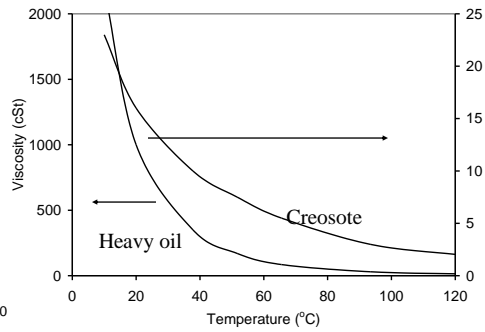
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NAPL Viscosity

Absolute Viscosity of VOCs



SVOC

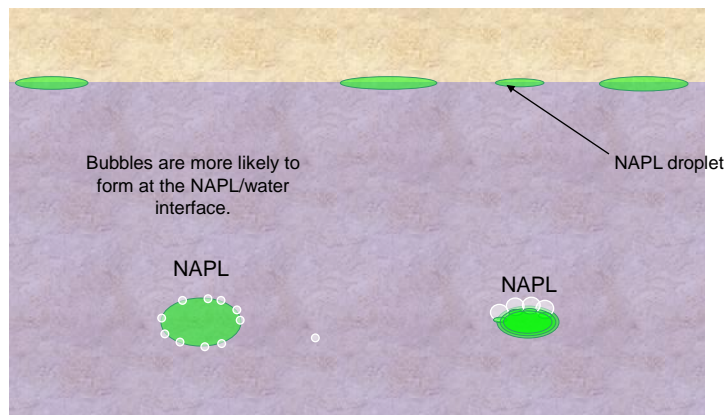


SVOC graph courtesy of Dr. Gorm Heron




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Steam Bubble Floatation



"Life preserver" of small bubbles lift NAPL to groundwater surface. Or small bubbles break away and lift NAPL droplets.


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 **Electrical Resistance Heating**

1. Soil particles act as electrical resistors

2. Steam generation is uniform through the heated zone

3. Discrete intervals can be heated

 **Applications**

- Low permeability & heterogeneous lithologies
- DNAPL & LNAPL cleanups by aquifer and smear zone heating
- Heavy hydrocarbon mobilization
- Degradation enhancement (hydrolysis, bio)
- Remediation underneath operating facilities, in the presence of buried utilities

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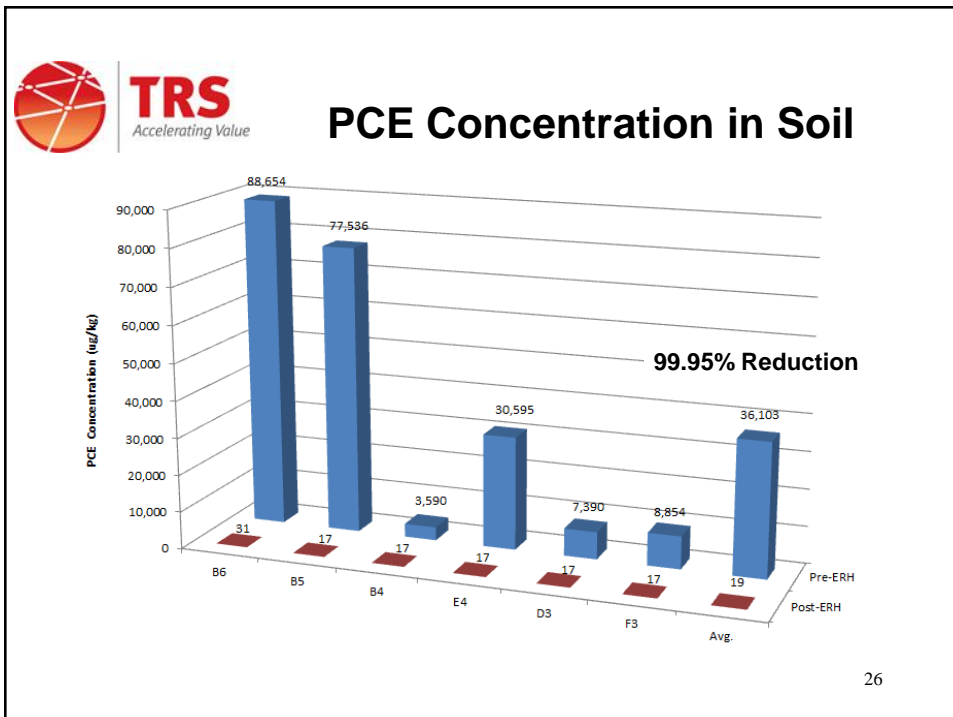
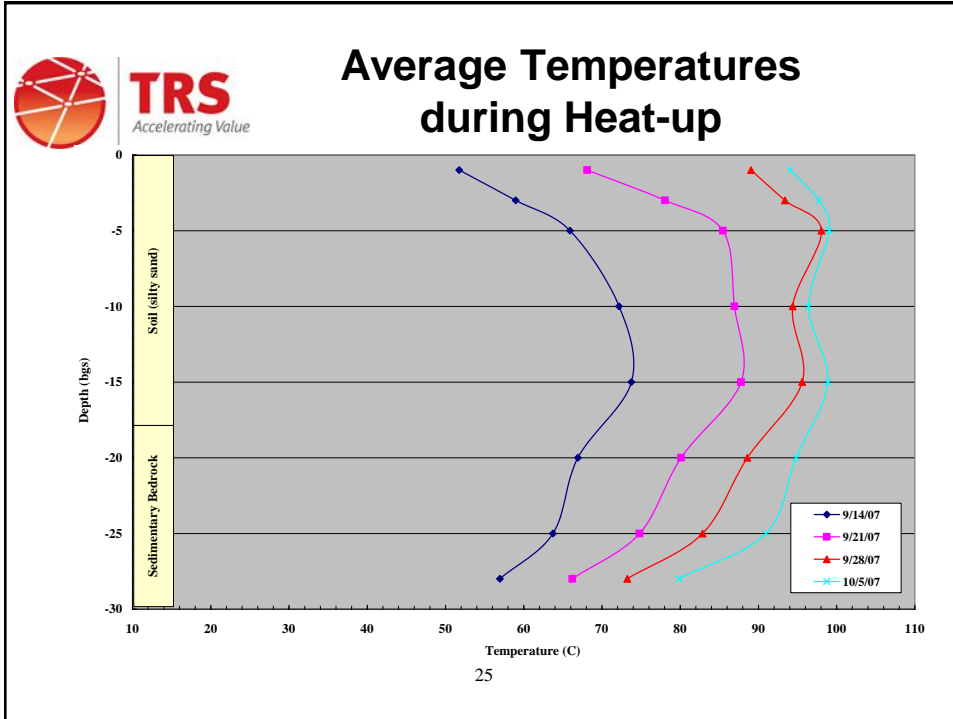
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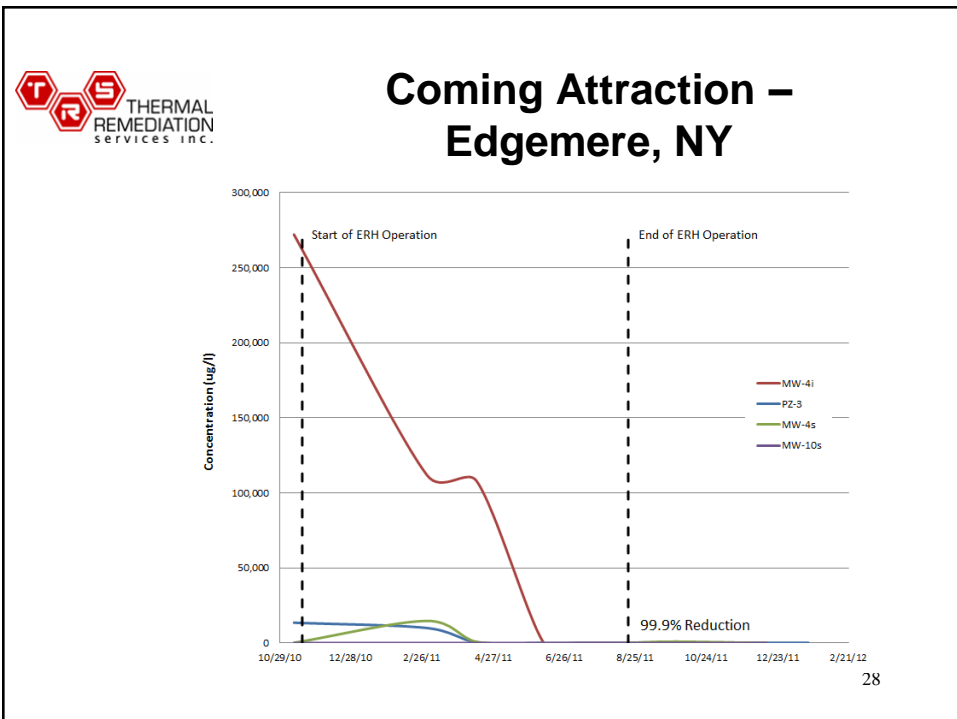
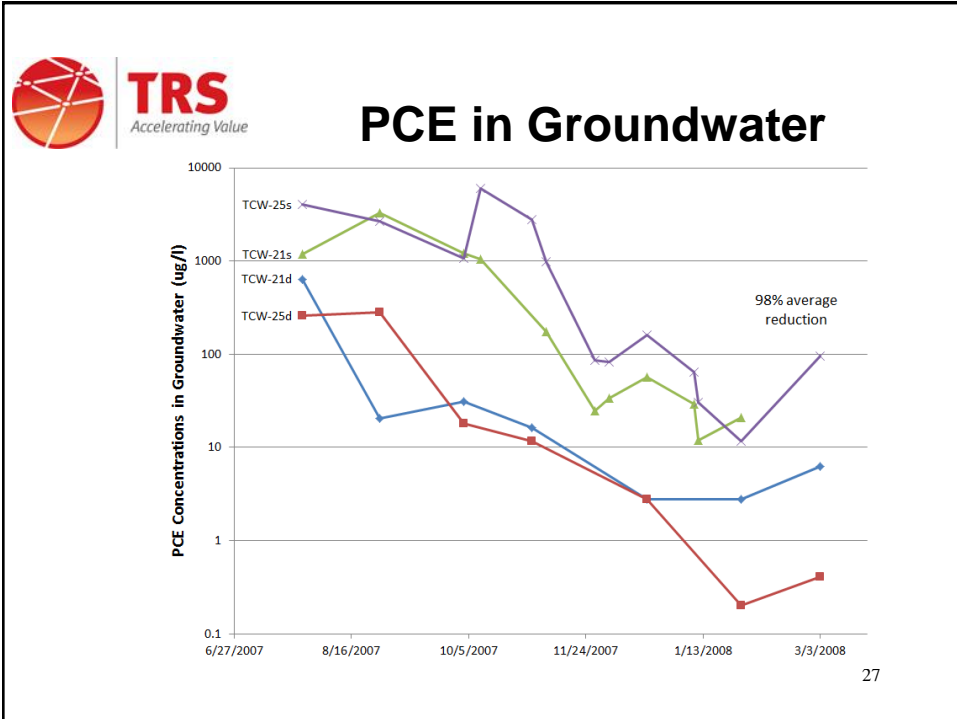
Dry Cleaner – Fair Lawn, NJ

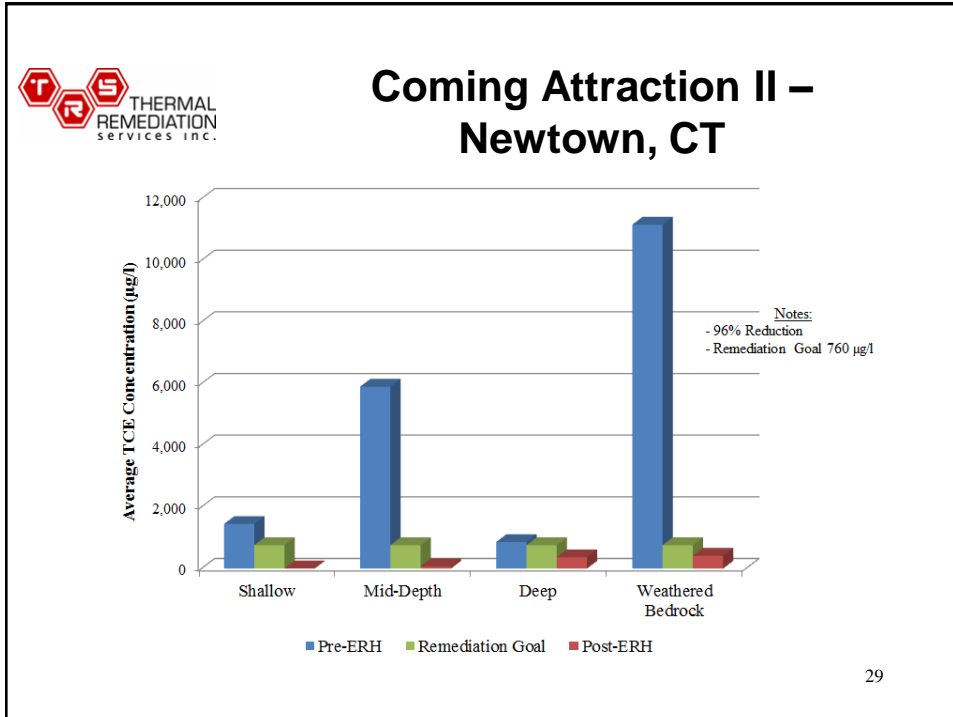
- PCE in Soil, Sandstone, and Groundwater
- Treatment area 6000 ft², depth 0.5 to 26-ft bgs, 5,000 yd³
- Glacial till with fractured sandstone bedrock at 16 ft bgs
- GAC for vapor treatment
- Baseline: Up to 288 mg/kg PCE in soil
- Remedial goal: PCE <1 mg/kg in soil


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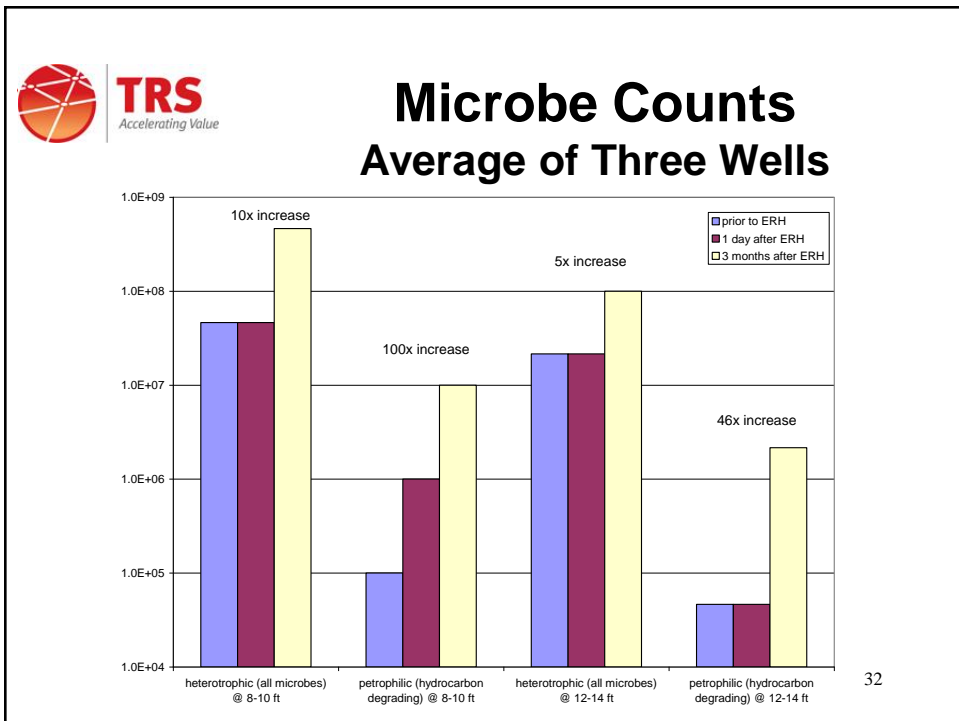
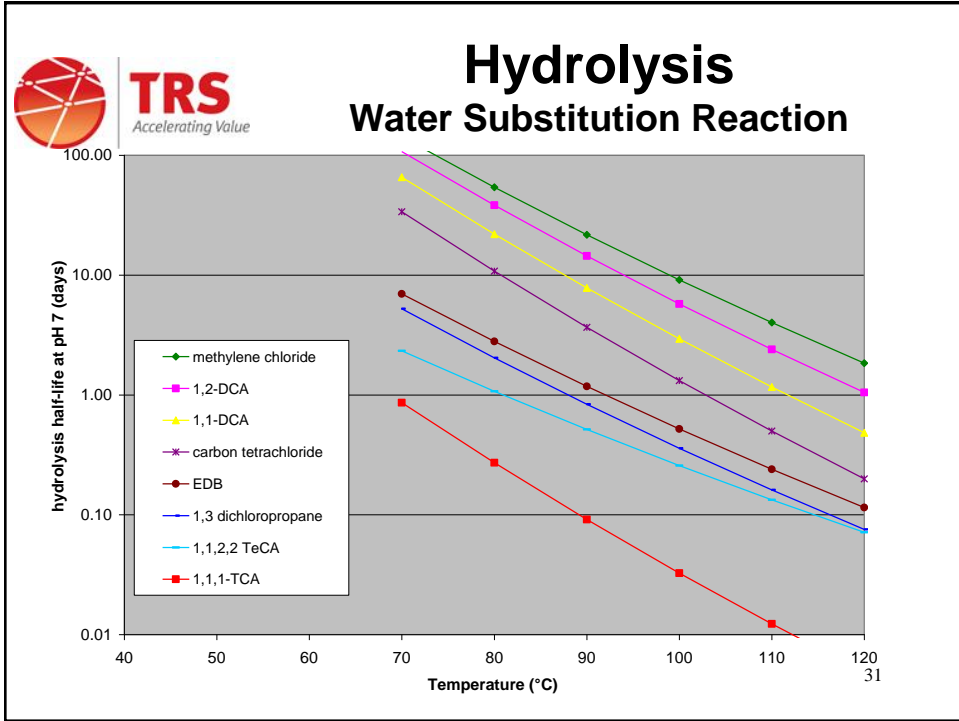


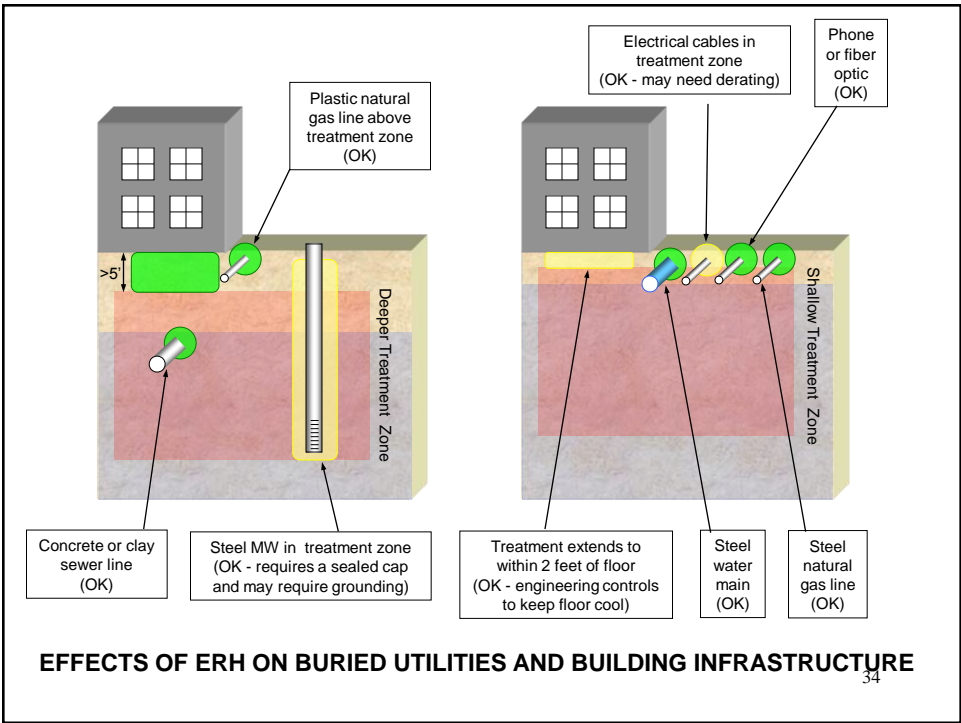
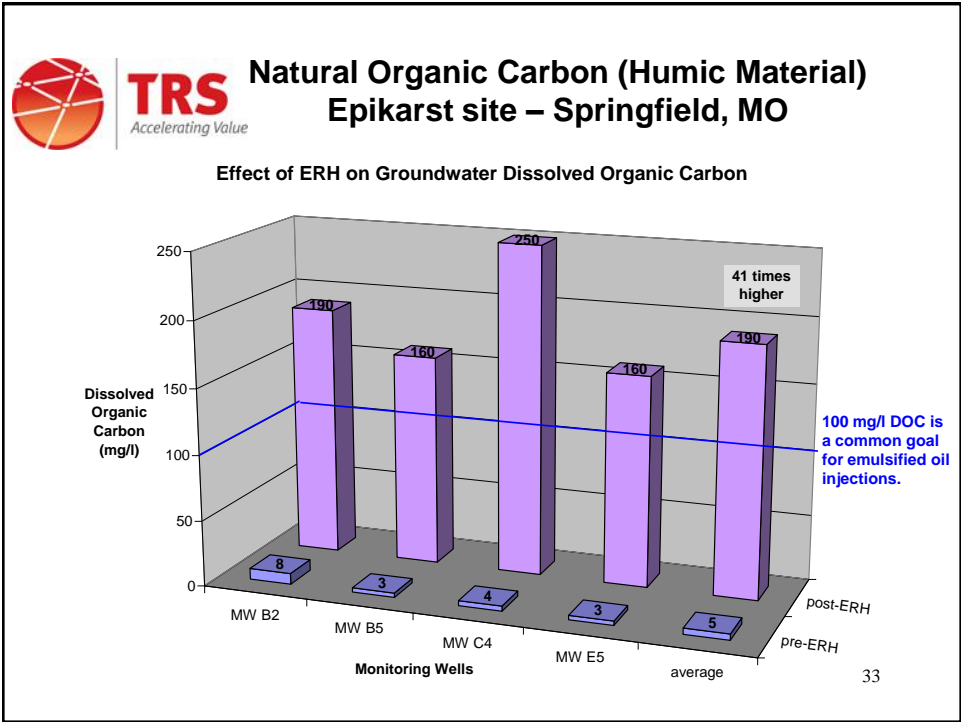


 **Polishing Mechanisms**

- Hydrolysis of Halogenated Alkanes
 - Compounds such as TCA have a hydrolysis half-life of less than one day at steam temperatures.
- Iron Reductive Dehalogenation
 - Steel shot used as electrode backfill provides an iron source for reductive dehalogenation (iron filing wall)
- Temperature Accelerates Reactions
 - The above reaction rates are increased by factor of thousands at 100°C (Arrhenius Equation)
- Bioremediation by Thermophiles
 - Dehalogenating bacteria *Dehalobacter*, *Desulfuromonas*, and *Desulfotomaculum* prefer 40-80°C
 - Dehalogenating bacteria *Dehalococcoides* prefer 30°C

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Electrical Resistance Heating uniformly heats the subsurface and removes VOCs from all soil types, both above and below the water table. Good for your “tough sites”.

Questions?

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