Enhancing Remediation in Low Permeability Soils

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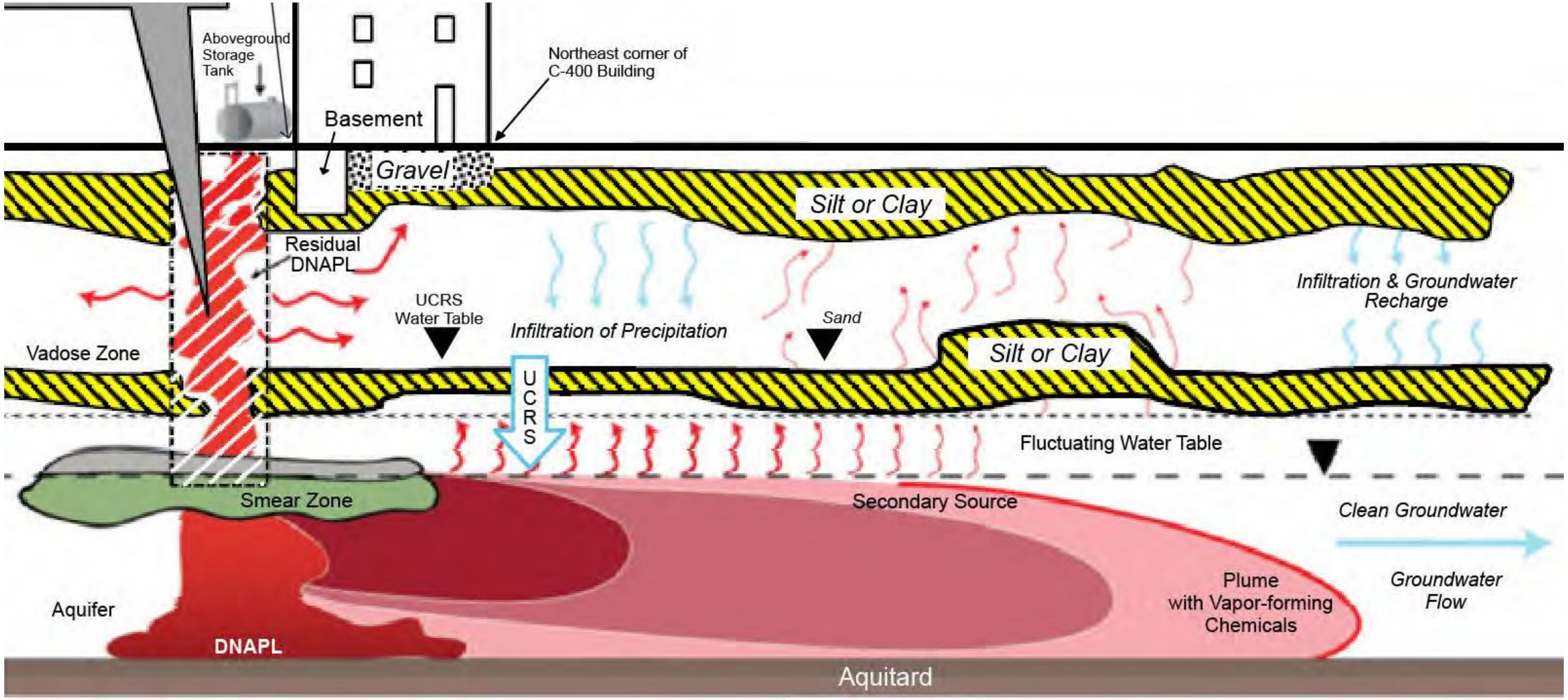
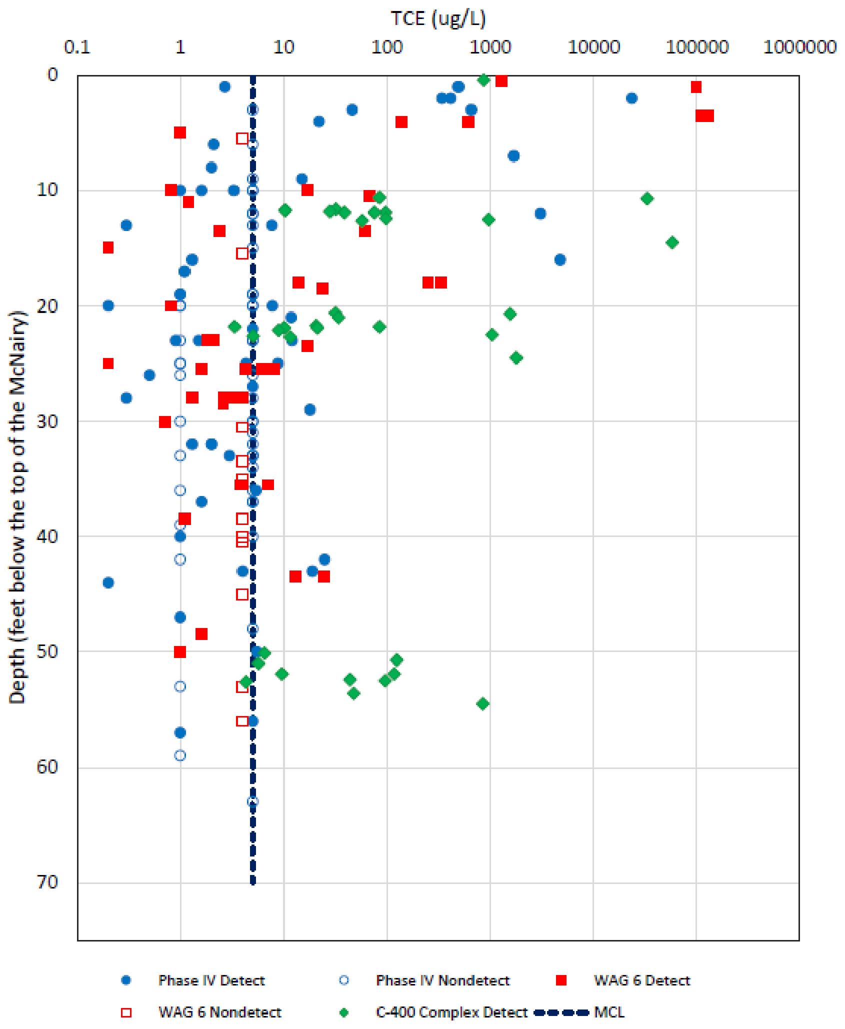
What reduces the effectiveness of remediation in low permeability soils?

- Difficult to extract groundwater for P&T or vapors for SVE
- Difficult to inject liquid reactants
- Difficult to inject air or other gases (ozone) for vaporization or to provide oxygen for biodegradation
- Presence of NAPLs

Typical Conceptual Site Model predicts DNAPL pooling on top of Low Permeability Soils

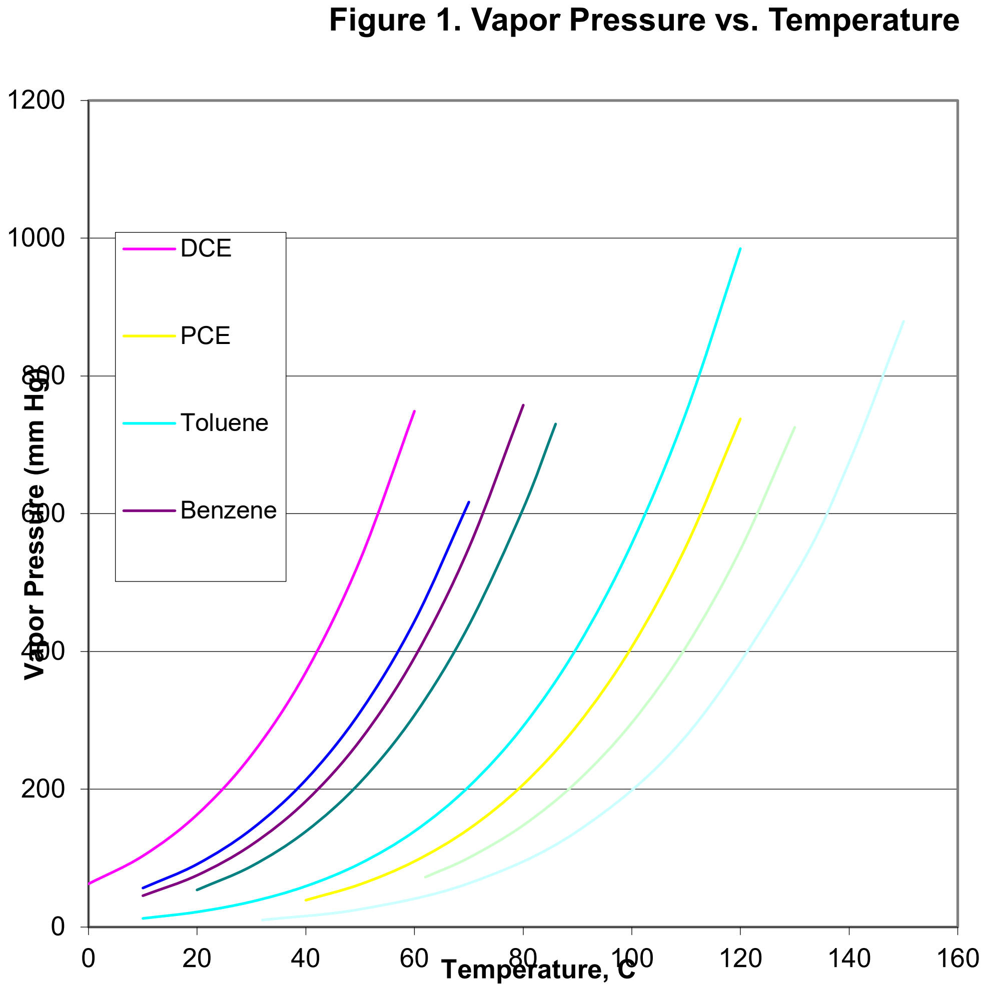


DNAPL & dissolved phase penetrated into the low permeability aquitard



- Concentration data from the 1990s (red squares) show DNAPL concentrations of TCE in the top 5 ft of the 'aquitard'
- 2020s concentration data (green diamonds) show DNAPL concentrations penetrating deeper into the 'aquitard'
- In 1990s, TCE exceeded MCL ~45 ft into 'aquitard'
- By 2020s, TCE exceeded MCL > 55 ft into 'aquitard'

What happens when energy is added to raise the temperature of low permeability soils?



- Increases vapor pressure exponentially
  - For VOCs, vapor pressure increases more than an order of magnitude going from ambient temperature to 100°C
- Decreases viscosity of water and NAPL
  - Most significant for viscous NAPLs such as creosote, coal tar
- Slightly increased solubility of contaminants
  - Increased rate of solubilization
- Decreases adsorption
  - May also increase desorption rate

Vapors generated as the temperature is increased can create enhanced permeability

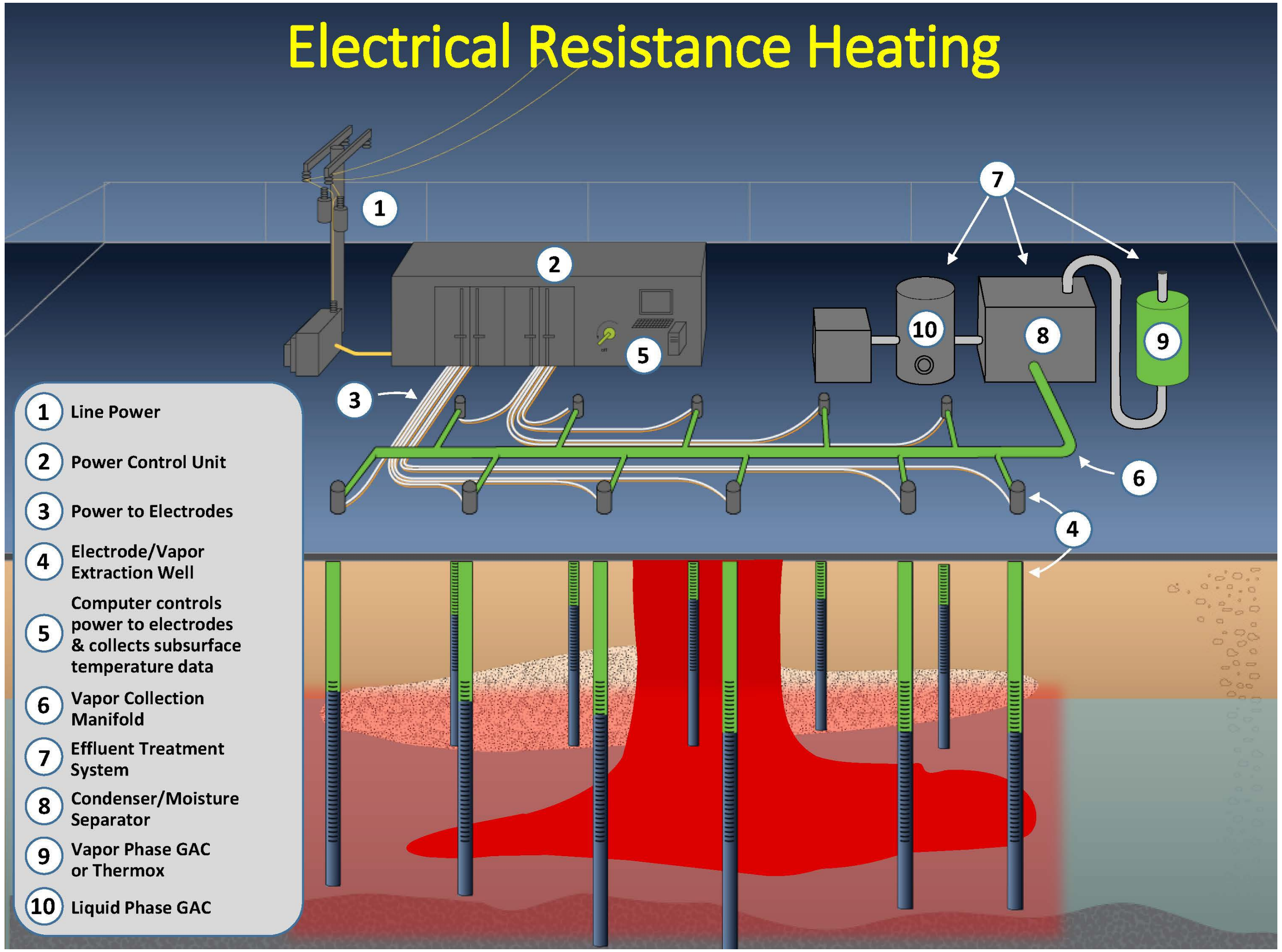
- "clay recovered from 25 feet below ground surface after 30 days of Electrical Resistance Heating (ERH). Steam bubble formation and escape created microfractures and vugular porosity. It was noted that the vacuum pressure on the subsurface decreased and the flow rate increased as heating of the clays progressed, with concurrent release of steam."

McGee et al., 2006

United States Environmental Protection Agency

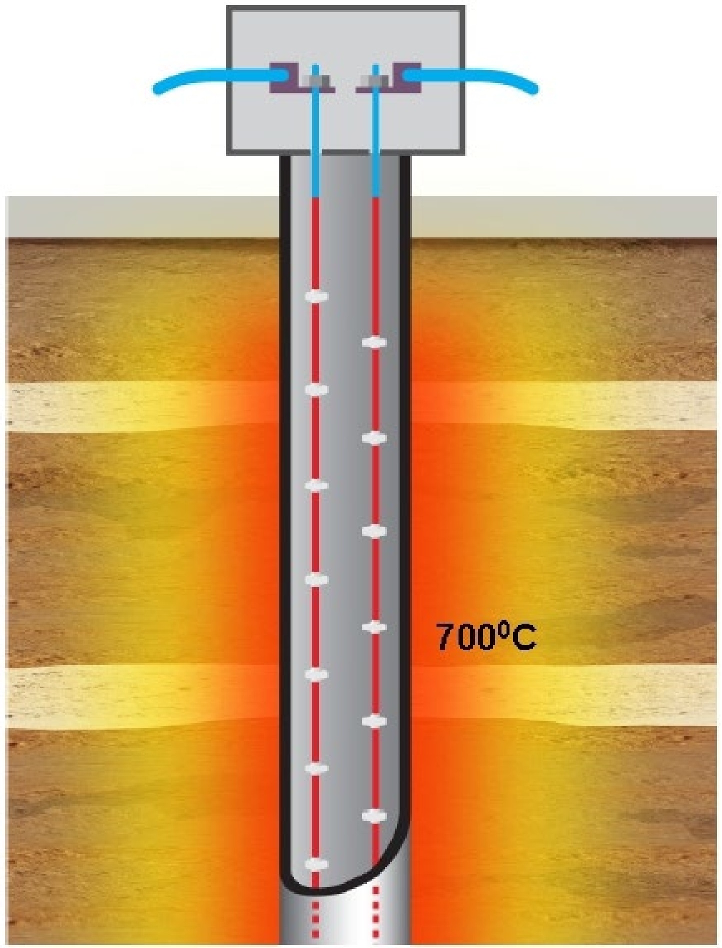
Electrical Resistance Heating

- Alternating current applied to electrodes in subsurface
- Current carried between electrodes by water in pore spaces – more current flow through low permeability soils
- Resistance of soils to current flow produces heat
- Full scale application uses 3 phase current

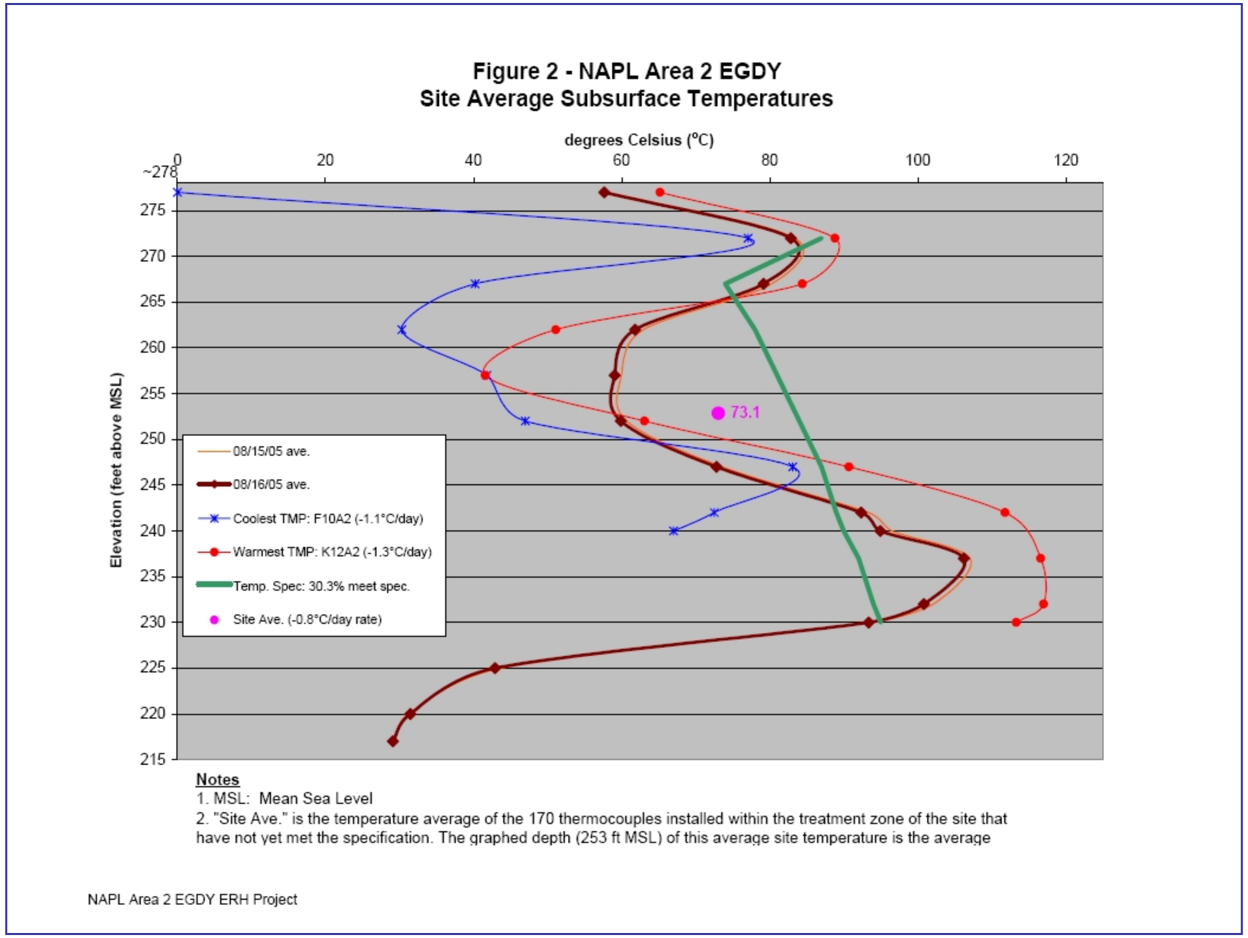


Thermal Conductive Heating

- Heat is conducted from the well into the soil, dependent on soil thermal conductivity
- Conductivity of soils various only by a factor of 2 – 4
- Heater wells with temperature of ~ 700°C installed in triangular pattern, 12 – 20 ft spacing
- Co-located or centrally located vapor extraction wells
- Can be electrical or gas combustion fueled



Energy added by ERH enhanced in low permeability soil lenses



- Temperature as a function of depth during ERH heating
- Highest temperatures (~ 118C) in low permeability lacustrine soils
- Lowest temperatures in highly permeable soils where groundwater flow removes energy

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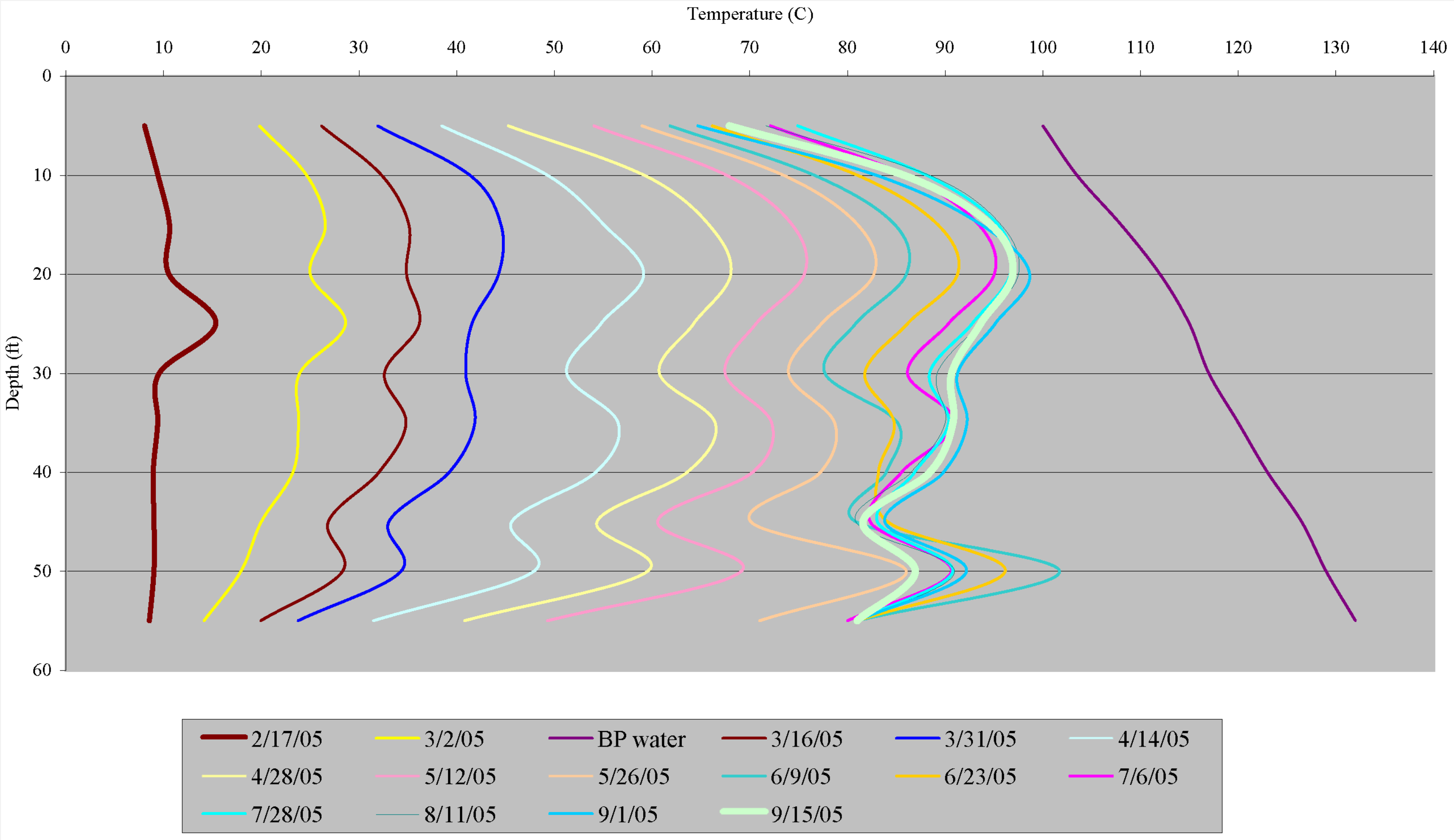
Case Study - Camelot Cleaners

Fargo, ND

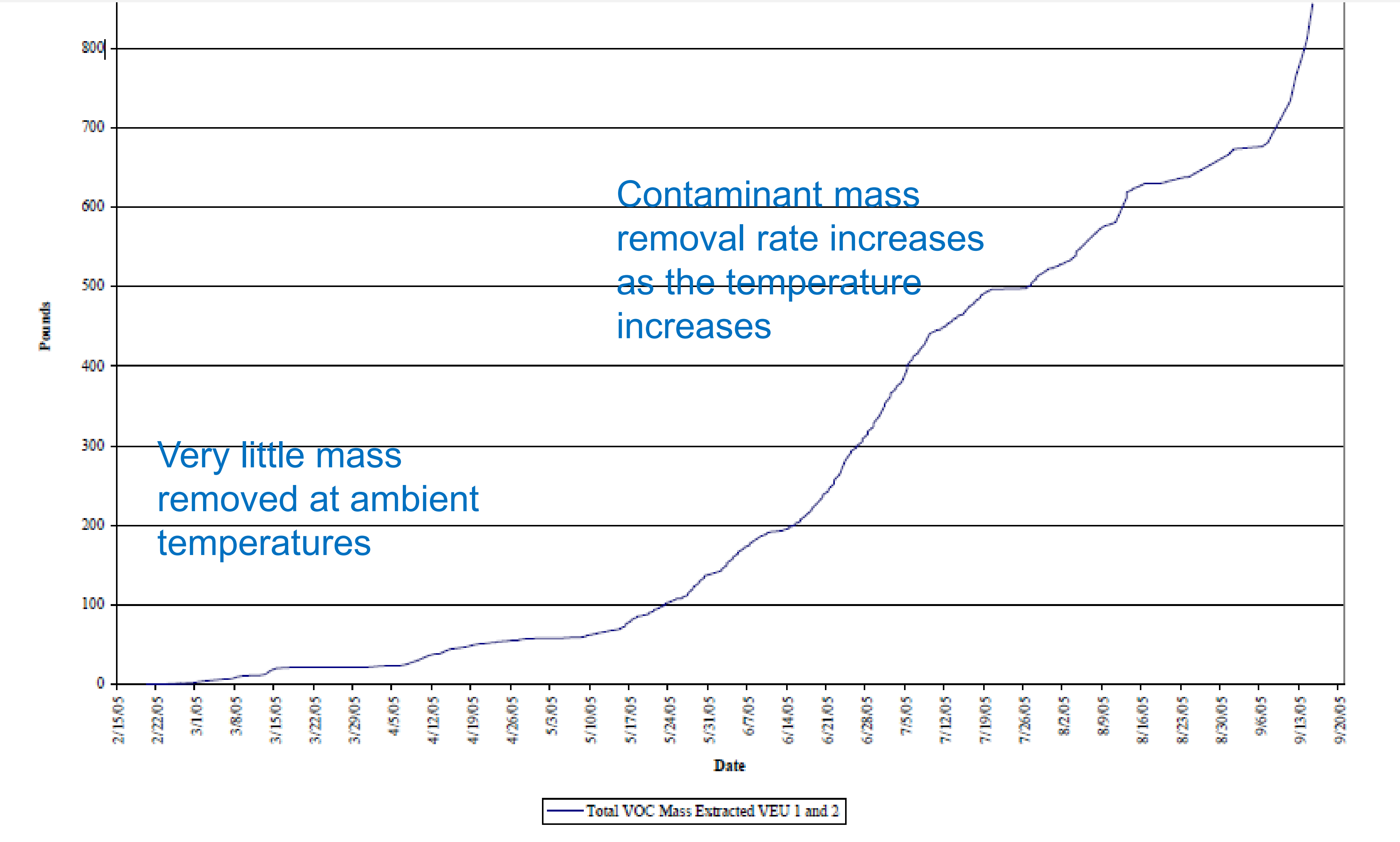
- Tight, fat clay, little groundwater; PCE dumped on ground threatened lower aquifer which provides Fargo's water supply
- Initial concentrations of PCE as high as 2200 mg/kg
- Of 80 confirmation samples, 57 were nondetect, only 2 exceeded cleanup goal of 3 mg/kg

Temperature vs Depth over time during ERH



- Fairly uniform soils made for fairly uniform temperature increase
- Line to the far right is boiling point of water vs depth below the water table

Camelot Cleaners PCE mass recovery over time



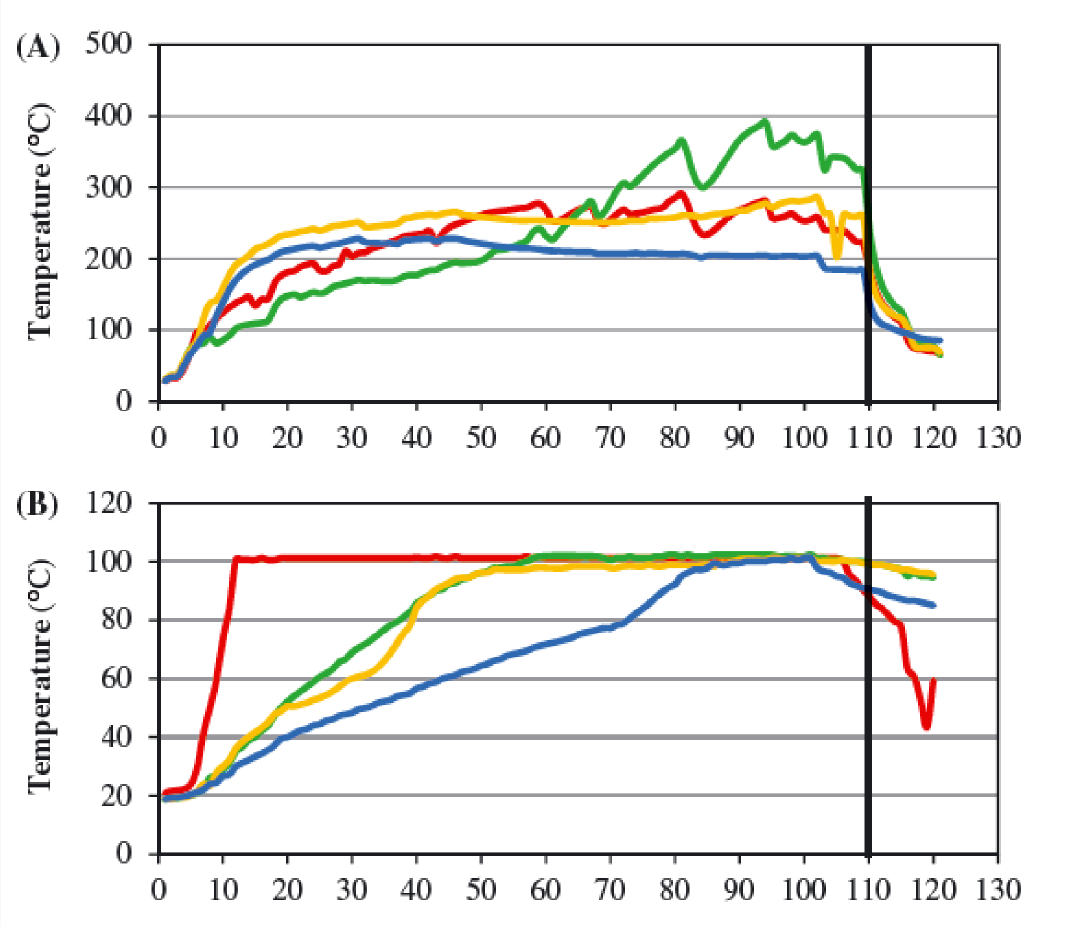
Case Study - Point Richmond, San Francisco Bay

- Bay Mud contaminated with chlorinated solvents
- Appeared that PCE DNAPL discharged to the ground, dichlorination occurring

- Gorm Heron, John Lachance, and Ralph Baker, **Removal of PCE DNAPL from Tight Clays Using In Situ Thermal Desorption,** Groundwater Monitoring & Remediation 33, no. 4: 31–43

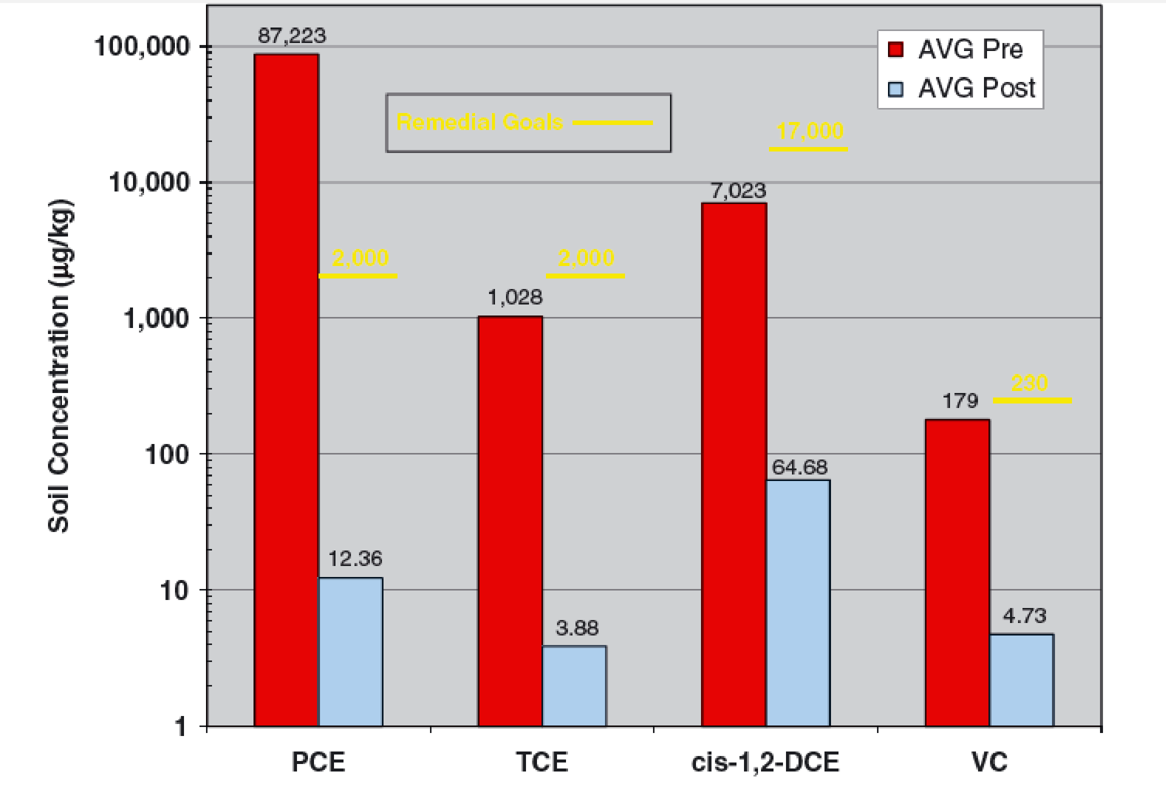
Point Richmond Energy Input and Temperatures

- Thermal Conduction Heating technology used
- Heater wells 12 feet apart
- Temperature at various depths vs heating time at ~ 1 foot from heater (A) graph and ~ 3 feet (B) from heater wells
- Energy input 327 kWh/yd3



Point Richmond Pre – and Post- remediation soil concentrations

- Pre- remediation PCE concentrations as high as 2,700 mg/kg, indicative of DNAPL
- Groundwater concentrations of PCE as high as 96,000 ug/L
- 5585 lb of VOCs removed in the vapor phase in 110 days of heating
- > 99% reductions in concentration of all VOCs



Solvent Recovery Services New England Superfund Site

Southington, CT

- Waste oil recycler
- Overburden was low permeability glacial till underlain by competent bedrock
- Thermal treatment area determined by extent of visible DNAPL in cores & pooled DNAPL on top of bedrock

Solvent Recovery Services New England Superfund Site

Southington, CT

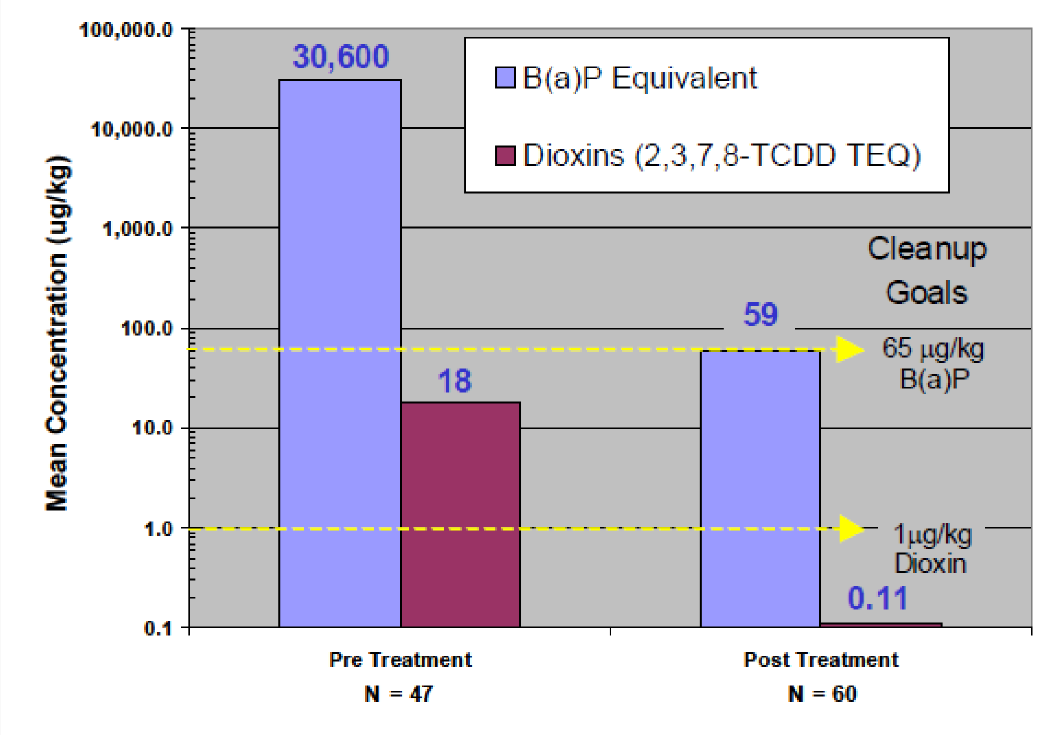
- Thermal Conductive Heating, > 700 heater wells
- Remedial objective was to eliminate NAPL, >500,000 lbs recovered
- Final soil concentrations were far below the cleanup criteria set in the ROD, many were nondetect

Southern California Edison's Alhambra Wood Preserving Site

Alhambra, CA

Creosote contamination to a depth of >100 feet

TCH remediated soils to stringent cleanup goals



Thermal Remediation in Low Permeability Soils

Conclusions

- NAPL does not just pool on top of low permeability soils but can migrate significant distances into ‘aquitards’
- Low permeability soils are readily heated by ERH and TCH
- Both VOCs & SVOCs can be recovered
- *The views expressed in this presentation are those of the author and do not necessarily represent the views or policies of the U.S. Environmental Protection Agency.*

Expected Outcomes

- Large percentage of mass recovered
- Orders of magnitude reductions in soil and groundwater concentrations
- Orders of magnitude reduction in mass flux to downgradient plume