EPA United States Environmental Protection Agency

Challenges in Thermal Remediation

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Thermal Remediation at Superfund Sites: Problem Statement

- Thermal remediation technologies are complex systems. It is an engineering feat to apply energy (electrical, thermal, and/or steam) to complex geologic & hydrogeologic settings to achieve uniform heating to achieve the target temperature & to recover what are often complex mixtures of contaminants.
- The recovered contaminants then must then be treated aboveground to separate them from the air & water that is then discharged.
- The contaminants can either be destroyed on site (for example, thermal oxidation), adsorbed onto activated carbon, or transported off site for disposal as a liquid.

Challenges at Thermal Remediation Sites

- Applying energy evenly to the subsurface
    - Complex geology/hydrogeology
    - Surface water
    - Low permeability soils
    - Deep contamination
    - Fractured rock
- Characterization – determining the area to be treated
    - delineation of NAPL horizontally & vertically
    - Differentiating between NAPL & dissolved phase
- Large amounts of contaminant mass to be recovered
- Separating contaminants that have been recovered from water & air
- Infrastructure
    - Buildings – often still in use
    - Railroad tracks
    - Abandoned subsurface structures
- Adverse weather conditions
- Power/energy availability

Four types of Thermal Remediation

- Electrical Resistance Heating (ERH) – electrodes constructed in subsurface, current flows through soils, dissipated as heat, contaminants volatilized & collected as vapors, for low permeability soils
- Thermal Conductive Heating (TCH) – heater wells constructed in subsurface, heat is conducted into soils, contaminants volatilized & collected as vapors, for low permeability soils
- Steam Enhanced Extraction (SEE) – steam injected into subsurface, multiphase extraction used to recover vapors, groundwater, NAPL, for permeable soils
- Emerging thermal technology – in situ smoldering combustion (STAR)

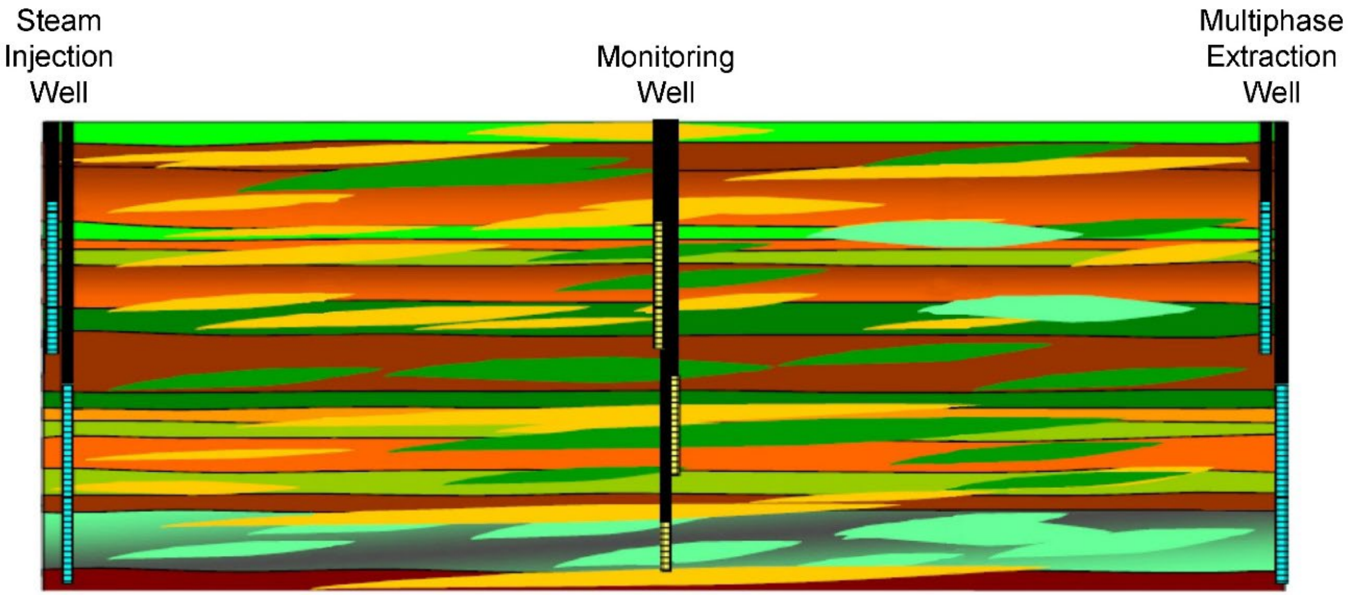
Challenge: Large site, LNAPL to 240 feet below ground surface

Former Williams Air Force Base, Mesa, AZ

- Jet Fuel spill, reached depths of 240 feet below ground surface
- ~410,000 yd^3 treatment area
    - 160 – 240 ft bgs
- >2.5 M lbs of petroleum hydrocarbons recovered, half as LNAPL, rest vapors
- Eductors to recover deep hot groundwater & fuel, thermal accelerators to destroy vapors, recovered fuel recycled

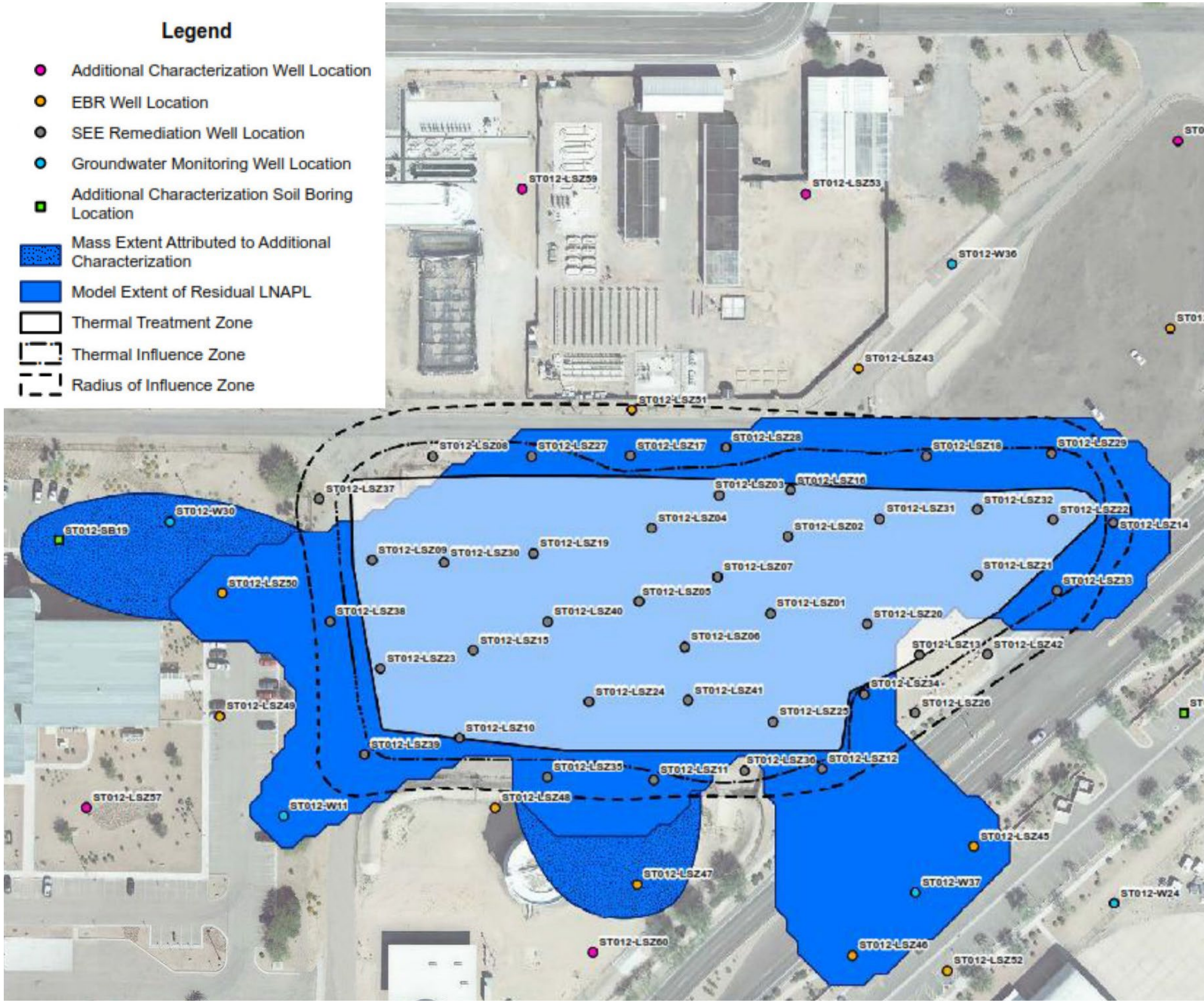
Challenge: complex geology, rising water table

- Highly heterogeneous soil strata did not stop downward migration of fuel, but low permeability zones trapped LNAPL below water table as the water table subsequently rose
- Effectively heated by steam injection into 3 vertical zones over 80 vertical feet



Challenge: Old/incomplete characterization of extent of LNAPL

- NAPL extended much further than known, especially in the lowest zone
- 2.5 million pounds recovered
- Estimated that as much remains in the ground



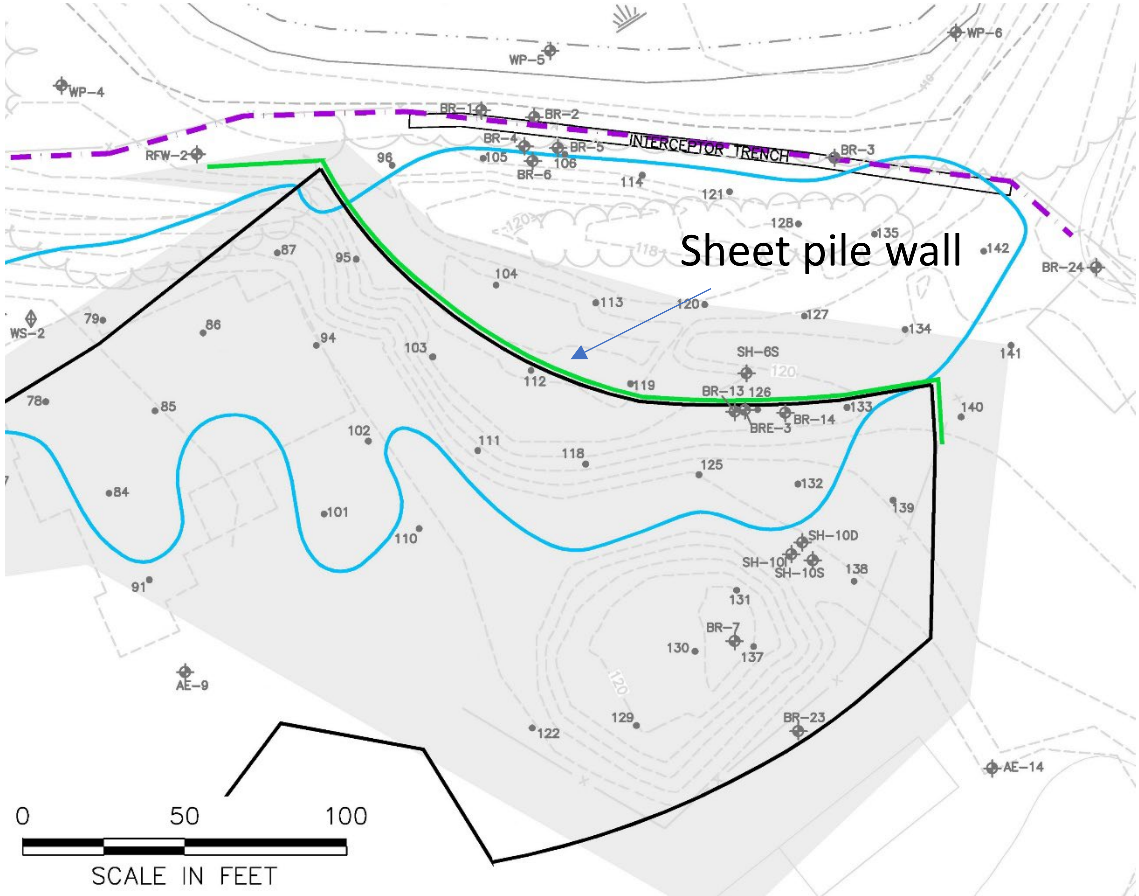
Beede Waste Oil Superfund Site

Plaistow, NH

- Operated from 1926 to 1994, blending oils
- Mostly petroleum hydrocarbons, mixed with chlorinated solvents
- LNAPL covered approximately 3 acres
- 90,000 gallons of LNAPL recovered by vacuum extraction from 2001 – 2005
- Steam Enhanced Extraction (SEE) chosen due to permeable sands, nearby surface water

Challenge: LNAPL extends to Surface Water

- Beede: Sheet pile wall constructed at northern end of thermal treatment area
- Extraction wells outside wall to aid in heat & NAPL recovery
- Eastern end of wall should have been extended
- Sheet pile joints should have been sealed


Sheet pile wall

Challenge: LNAPL Remained after Soil Criteria Met

- Positioning pump in MPE wells to provide drawdown & LNAPL recovery can be difficult
- A few MPE wells in Phase 1 at Beede still produce LNAPL (~ 80 gallons) after soil cleanup criteria met
- Solution: For Phase 2, ‘slurper’ system used to recover LNAPL not recovered by pumping

NAPL discharged to reinjection basin

- Caused in part by biological growth-generated LNAPL-water emulsion
- Solution:
  - Add biocides
  - Adjust pH, ferric chloride addition
  - Additional organoclay filters
  - Oily soils excavated from basin for proper disposal

Challenge: Separating NAPL from groundwater

- Jar tests to determine additives needed to separate NAPL from water

Challenge: Separating Recovered NAPL from Water

- NAPL was able to pass through the oil/water separator
- At Beede, additional ~40,000 lbs DNAPL was found in oil/water separator after project finished
- From the 2 areas treated separately ~400,000 lbs recovered

Solvent Recovery Services of New England

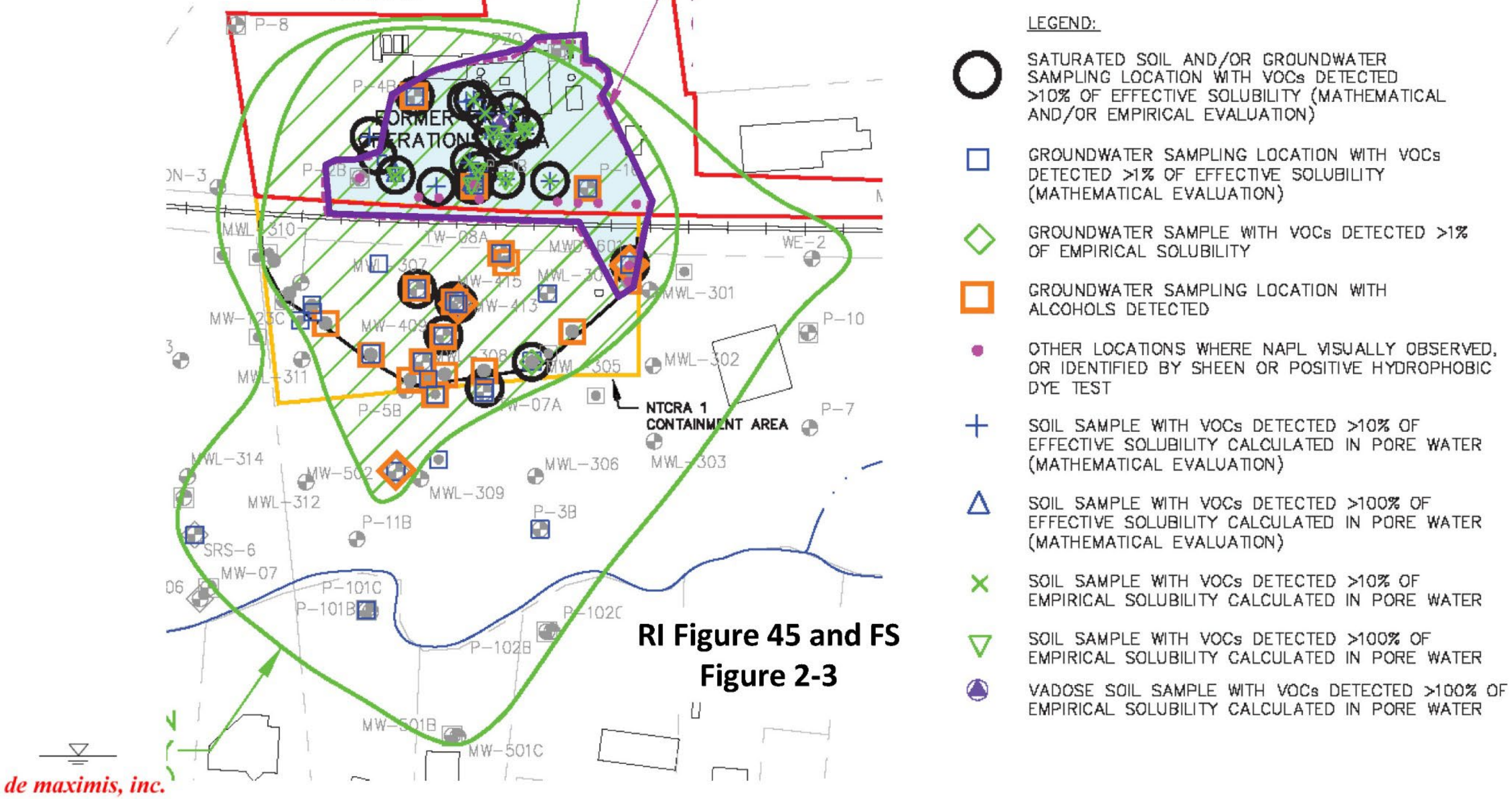
Southington, CT

- Operated from 1955 to 1991, redistilling ~100M gallons of solvents
- NAPL ~55% TCE by weight, other CVOCs, TPH, PCBs
- 2005 ROD selected In Situ Thermal Remediation (ISTR) to recover NAPL from the overburden, Thermal Conductive Heating (TCH) chosen due to low permeability soils
- Estimated 500,000 to 2,000,000 lbs of NAPL in thermal treatment area

Challenge: Delineating the NAPL Area

Potential & Probable NAPL Zones (RI/TI Eval.) & ISTR Zone (FS)

Potential: 12.4 acres
Probable: 4.9 acres
ISTR: 1.7 acres



LEGEND:

○	SATURATED SOIL AND/OR GROUNDWATER SAMPLING LOCATION WITH VOCs DETECTED >10% OF EFFECTIVE SOLUBILITY (MATHEMATICAL AND/OR EMPIRICAL EVALUATION)
□	GROUNDWATER SAMPLING LOCATION WITH VOCs DETECTED >1% OF EFFECTIVE SOLUBILITY (MATHEMATICAL EVALUATION)
◇	GROUNDWATER SAMPLE WITH VOCs DETECTED >1% OF EMPIRICAL SOLUBILITY
□	GROUNDWATER SAMPLING LOCATION WITH ALCOHOLS DETECTED
•	OTHER LOCATIONS WHERE NAPL VISUALLY OBSERVED, OR IDENTIFIED BY SHEEN OR POSITIVE HYDROPHOBIC DYE TEST
+	SOIL SAMPLE WITH VOCs DETECTED >10% OF EFFECTIVE SOLUBILITY CALCULATED IN PORE WATER (MATHEMATICAL EVALUATION)
△	SOIL SAMPLE WITH VOCs DETECTED >100% OF EFFECTIVE SOLUBILITY CALCULATED IN PORE WATER (MATHEMATICAL EVALUATION)
×	SOIL SAMPLE WITH VOCs DETECTED >10% OF EMPIRICAL SOLUBILITY CALCULATED IN PORE WATER
▽	SOIL SAMPLE WITH VOCs DETECTED >100% OF EMPIRICAL SOLUBILITY CALCULATED IN PORE WATER
▲	VADOSE SOIL SAMPLE WITH VOCs DETECTED >100% OF EMPIRICAL SOLUBILITY CALCULATED IN PORE WATER

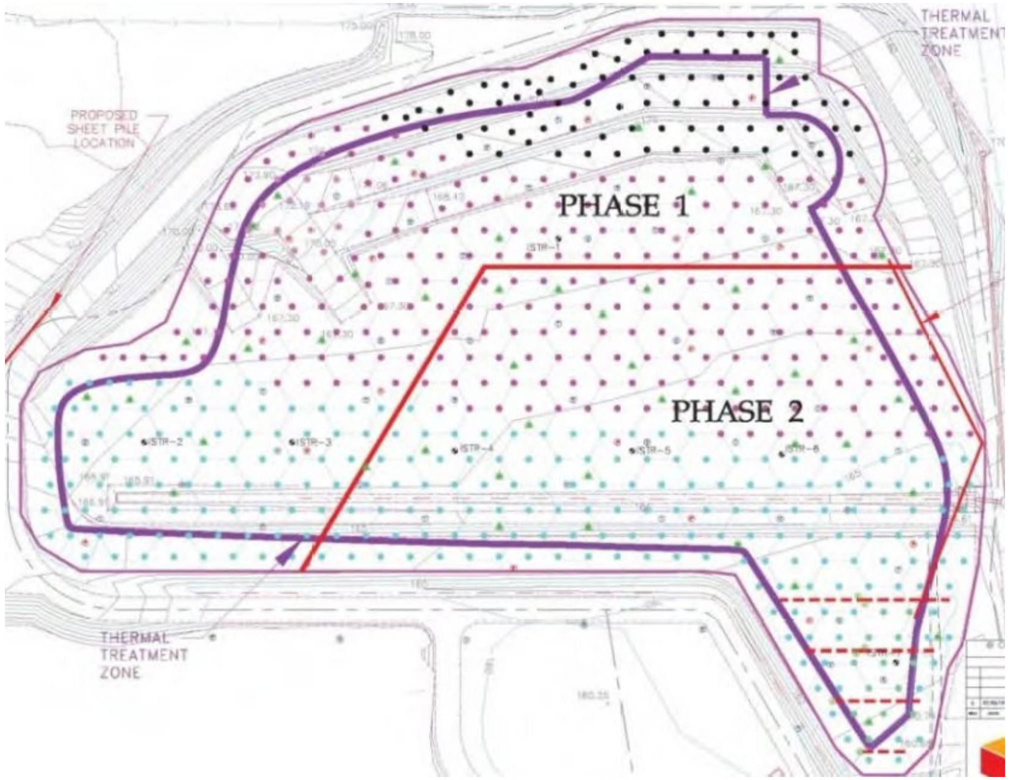
RI Figure 45 and FS Figure 2-3

de maximis, inc.

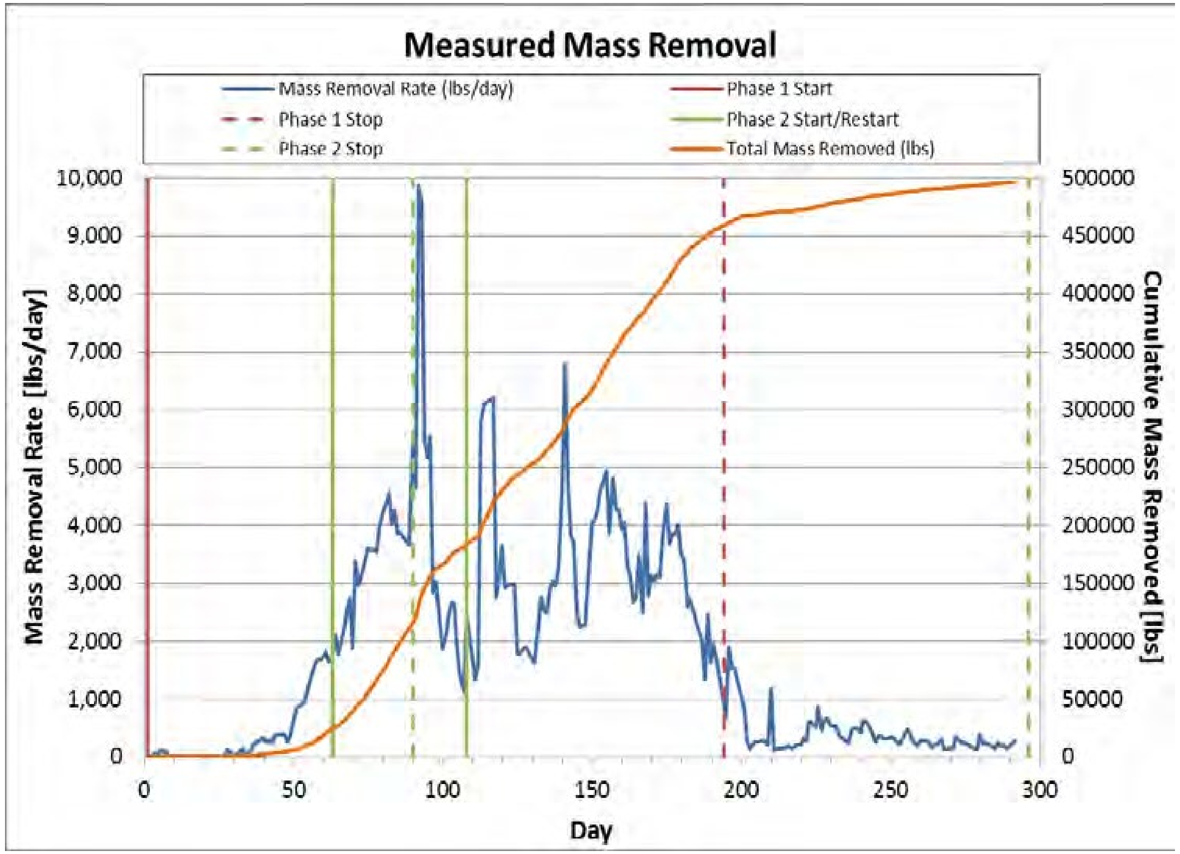
SRSNE DNAPL delineation – Visual observation, Oil Red O dye testing

Challenge: Large site, a lot of contaminant mass

Site divided into two phases



Initiate heating of second phase after the peak loading to the thermox from Phase 1 had passed



Challenge: Treating large quantity of contaminant above ground

- NAPL had high BTU value
- TCH heating system recovers contaminants as vapors
- Strategy was to maintain majority of contaminants in vapor phase & destroy in on site in thermal oxidizer

NAPL in pre-oxidizer heat exchanger

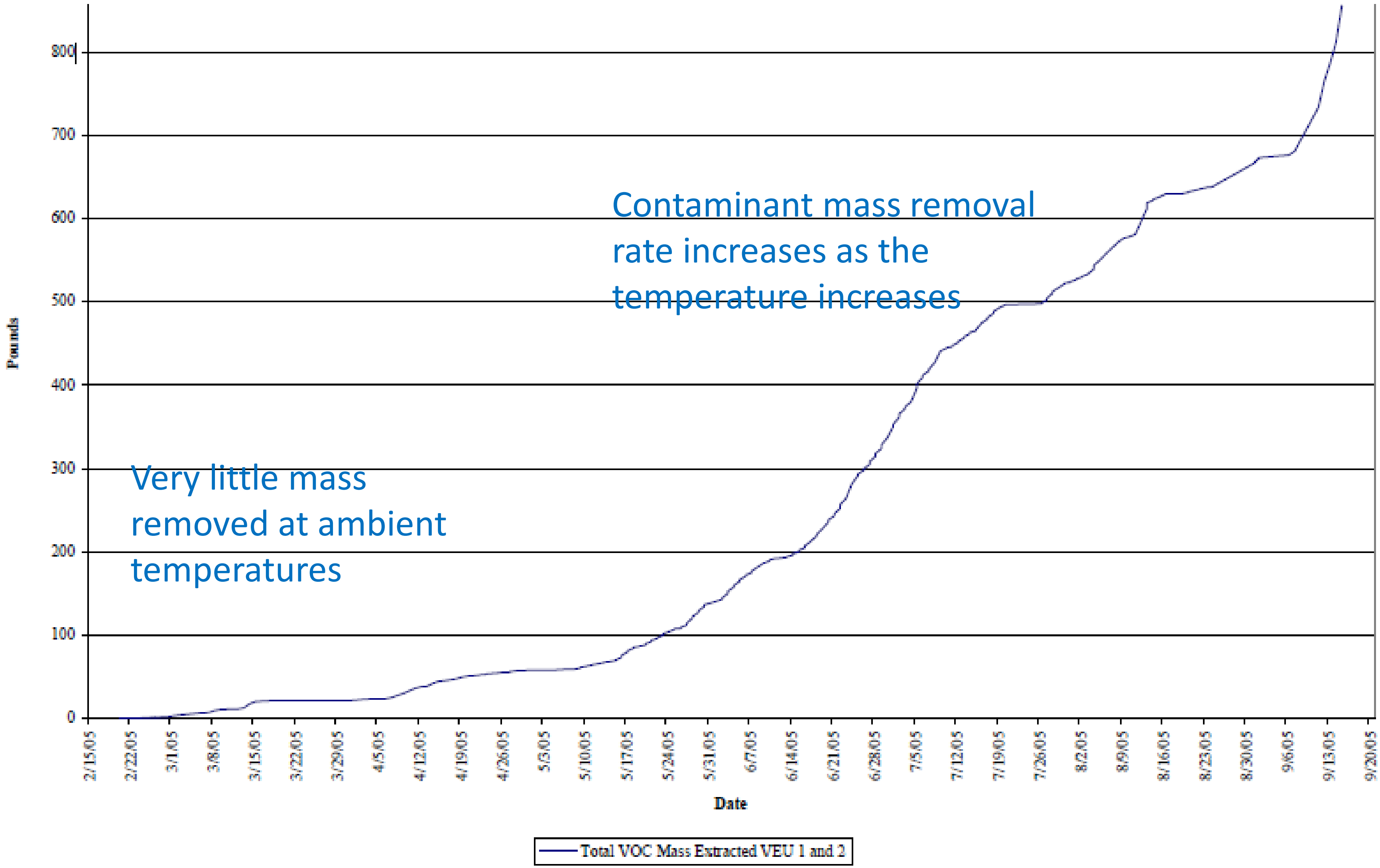
- NAPL re-vaporized in air stripper, caused combustion in pre-oxidizer heat exchanger, damaging ‘daisy wheel’ at oxidizer inlet
- Solution:
  - Added organoclay filter after oil-water separator
  - Added temperature sensor at oxidizer inlet
  - Reduced heat exchanger temperature set point
  - VGAC backup used for 5 weeks

Challenge: Low permeability soils

Camelot Cleaners, Fargo, ND

- Electrical Resistance Heating (ERH) & Thermal Conductive Heating (TCH) are both very effective in low permeability soils
- Tight, fat clay, little groundwater; threatened lower aquifer which provides Fargo's water supply
- Initial concentrations of PCE as high as 2200 mg/kg
- > 5,000 lbs of PCE recovered by ERH
- Of 80 confirmation samples, 57 were ND, 2 exceeded cleanup goal of 3 ppm

PCE mass recovery over time

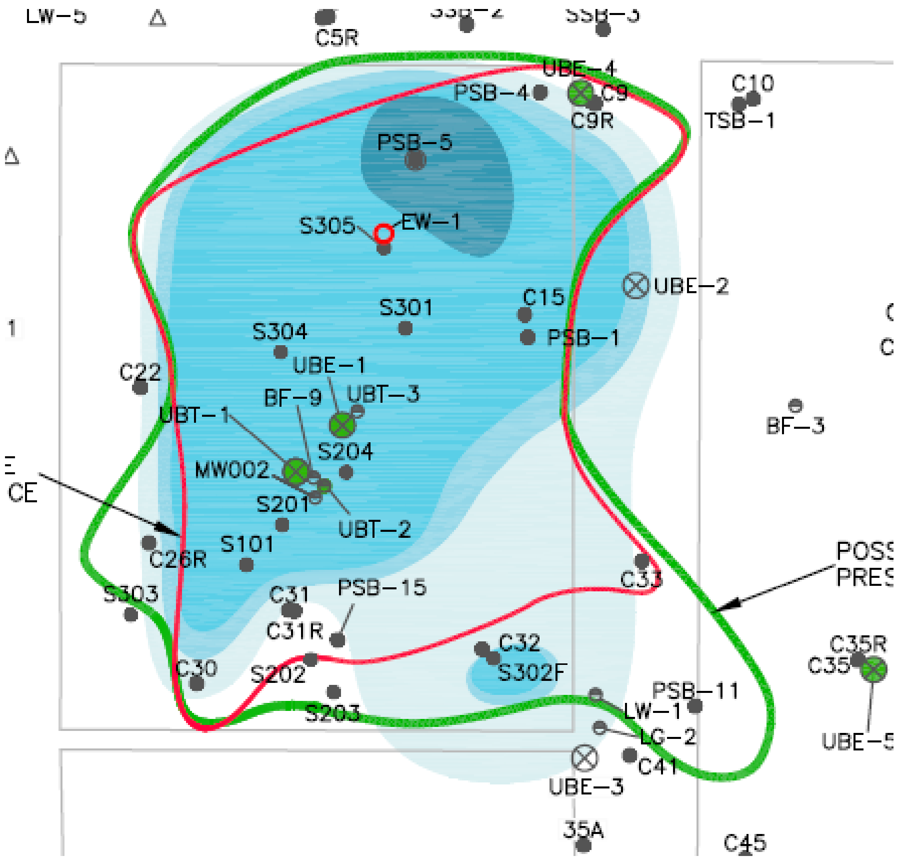


Contaminant mass removal rate increases as the temperature increases

Very little mass removed at ambient temperatures

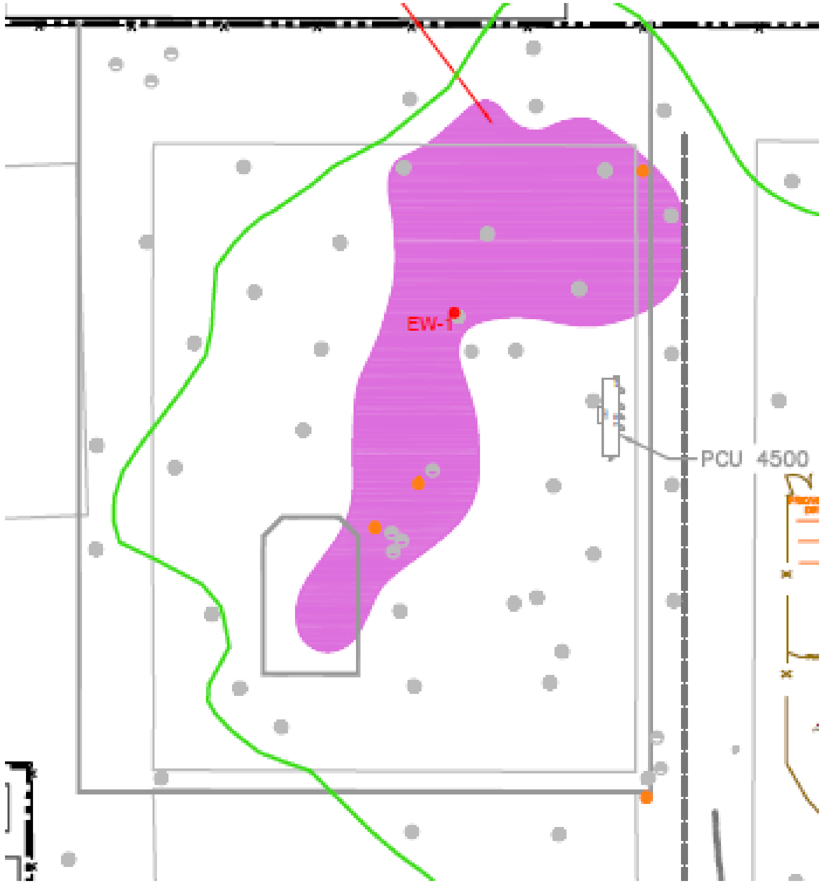
Montrose Chemical Superfund Site: Large contaminant mass

- Top 25 feet is tight soils, estimated 237,000 lbs chlorobenzene, not being addressed
- 25 – 65 feet unsaturated sands – estimated 261,000 lbs chlorobenzene



Challenge of Large Contaminant Mass

- 65 – 95 feet saturated lower permeability soils – estimated 473,000 – 780,000 lbs chlorobenzene to be recovered by Electrical Resistance Heating (ERH)
- Initiated SVE in the vadose zone to reduce the mass of contaminants that will be recovered during ERH
- To date, 423,000 lbs recovered from unsaturated zone, initially recovered 380 lb/day, currently recovering 185 lbs/day



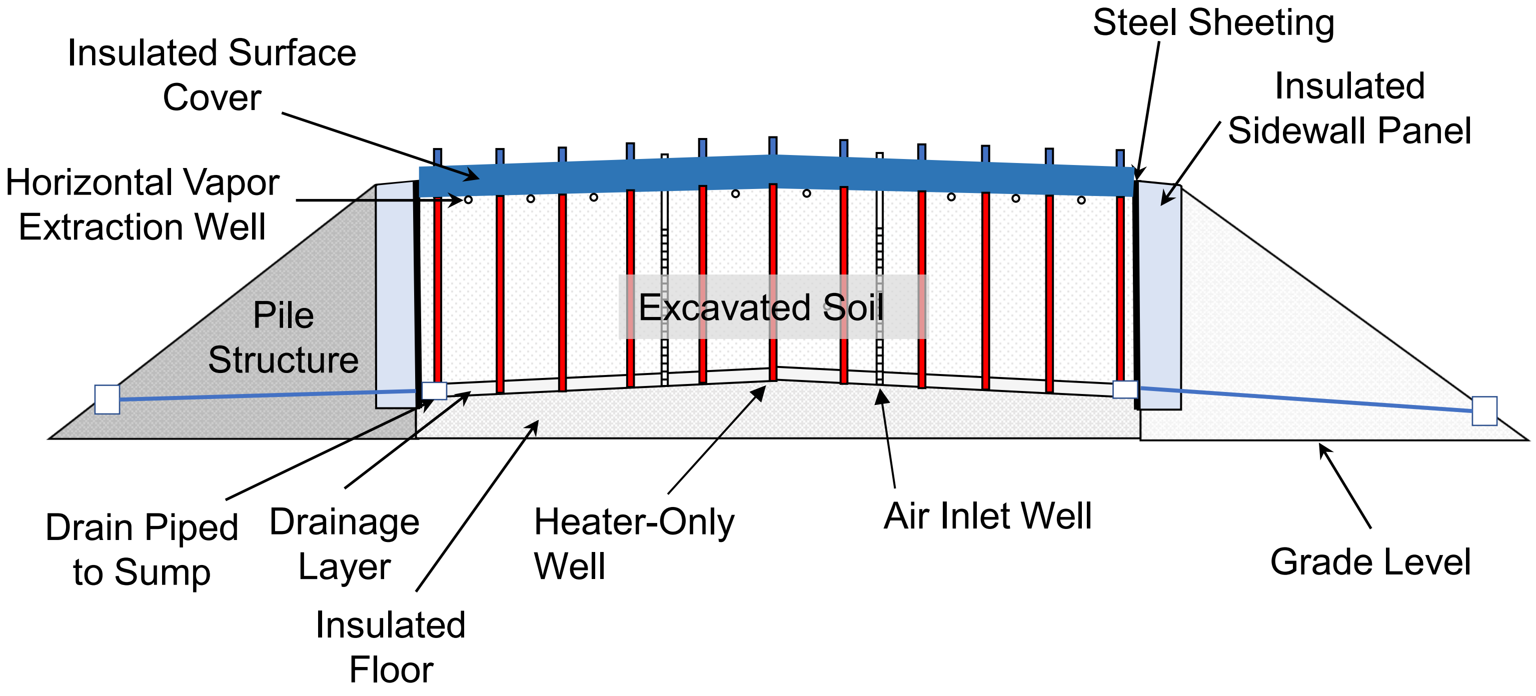
Challenges: Shallow soil contamination of high boiling compounds - Ex-Situ Thermal Desorption

Danang, Vietnam

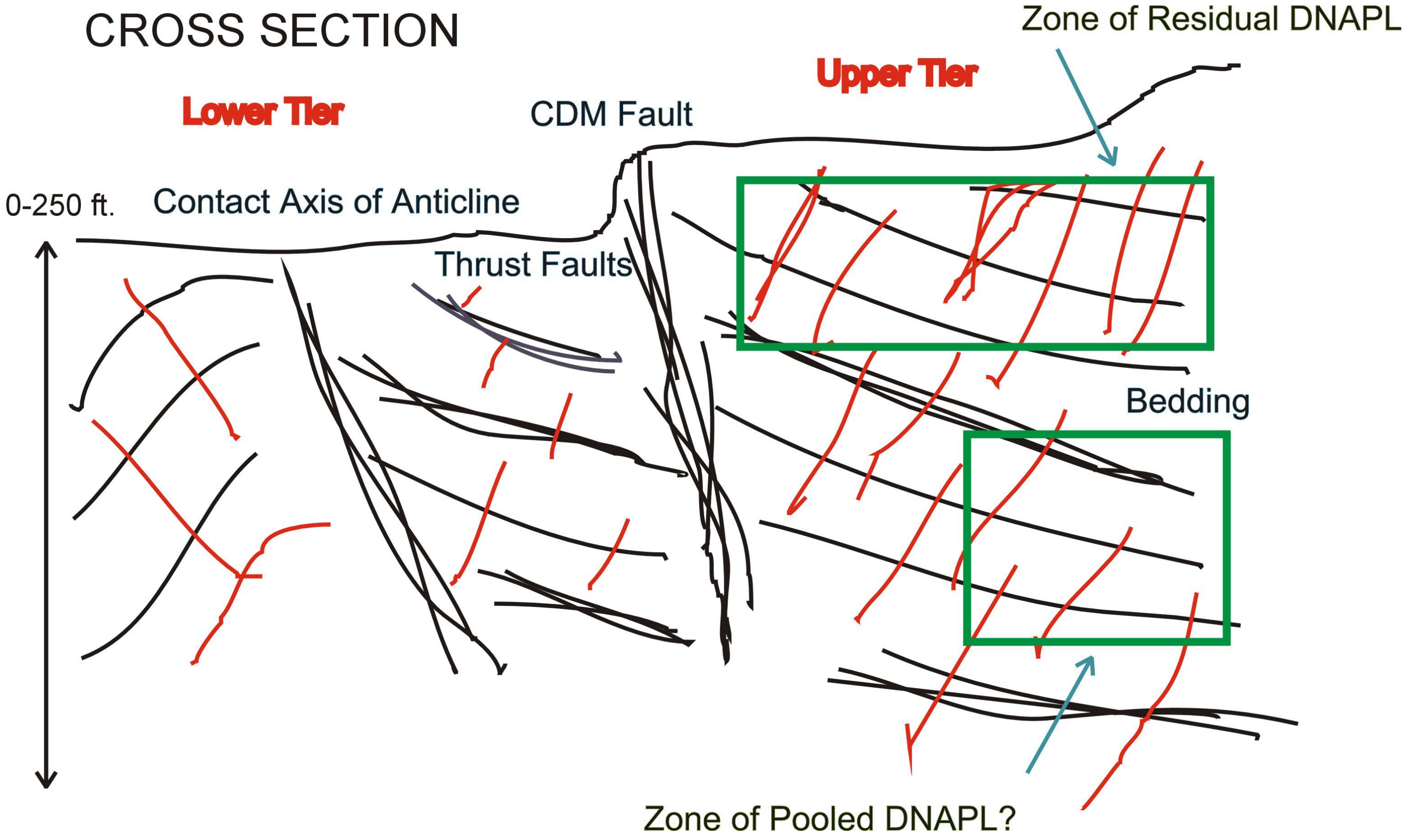
- Agent Orange, dioxin contamination
- Topsoil excavated, placed in concrete foundation
- Thermal Conductive Heating (TCH)

Challenge: Surface soil contamination over large area

Ex situ thermal remediation of excavated soils



Challenge – Fractured Bedrock



Loring Quarry: research on steam injection (SEE) in fracture rock

- Difficult to impossible to control vapors in a complex system
- Now generally TCH used for treating fractured rock, entire rock matrix is heated
- Where groundwater flow rates are high in fractures, SEE better to heat the zones where contaminants mass is the highest

Challenges of Fractured Rock

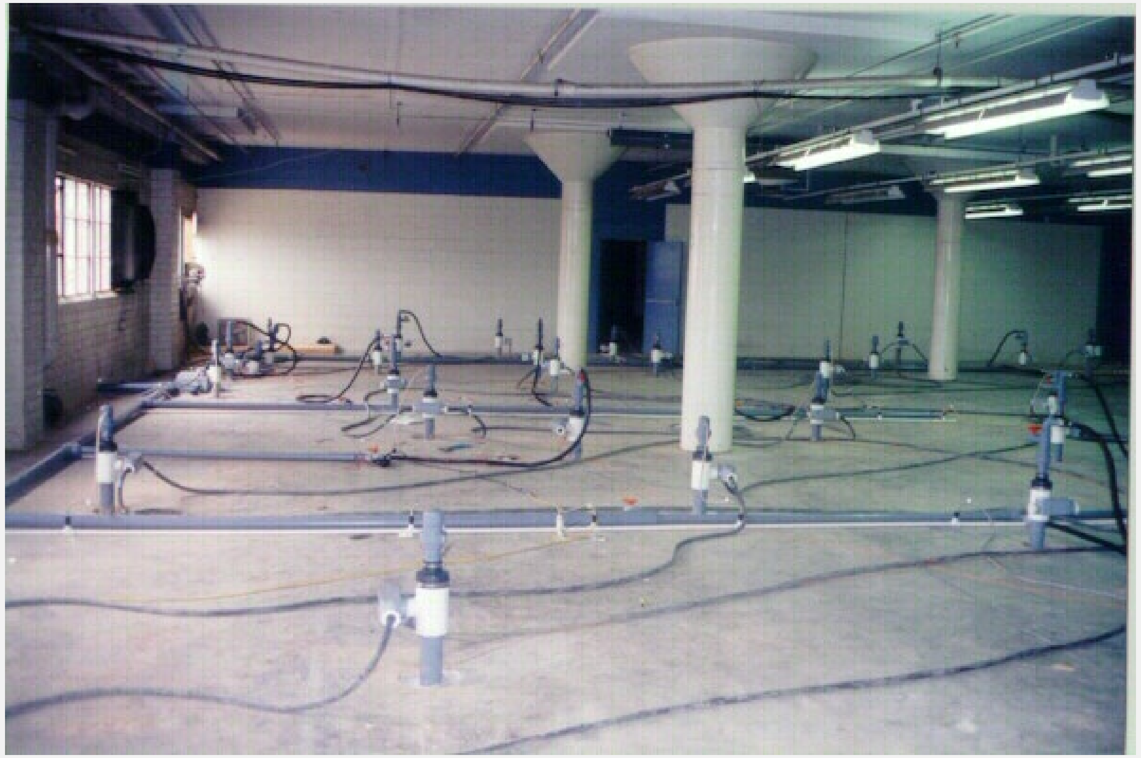
- Characterization of NAPL distribution and thus defining the area to be treated
- Moving contaminants out of low permeability matrix
  - During thermal remediation, pressure buildup due to vapor generation in low permeability matrix will force contaminants to higher permeability zones
- Low permeability matrix, low fracture frequency increases the boiling point of water/contaminants
- Ensuring capture of vapors and groundwater
- *These are also challenges in heterogeneous porous media*
- *The challenges are not insurmountable* – SEE, ERH and TCH have all been applied successfully to fractured rock – must match technology to specific site

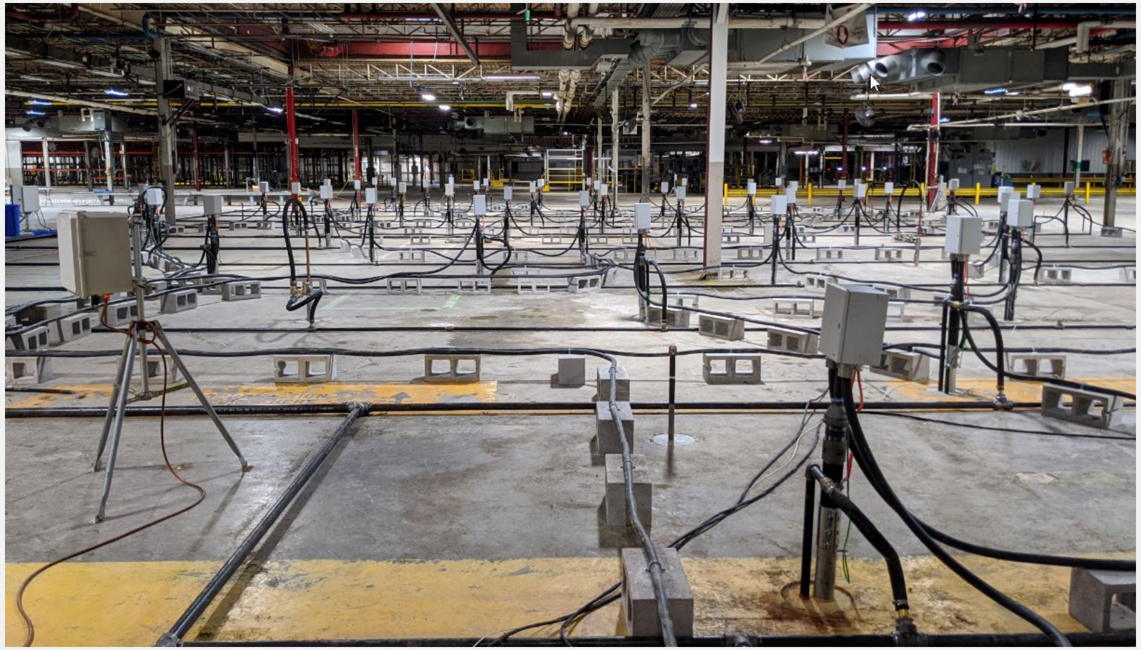
Challenge of Characterization – Defining the Area to be Treated

- Characterization is critical to the success of Remediation
- Treatment zone depends on objectives, defined by characterization
- NAPL – contaminated
- Soil concentration
- Groundwater concentration

Challenge: Operating under & adjacent to active manufacturing facility

Challenge: Infrastructure - ERH Under Building

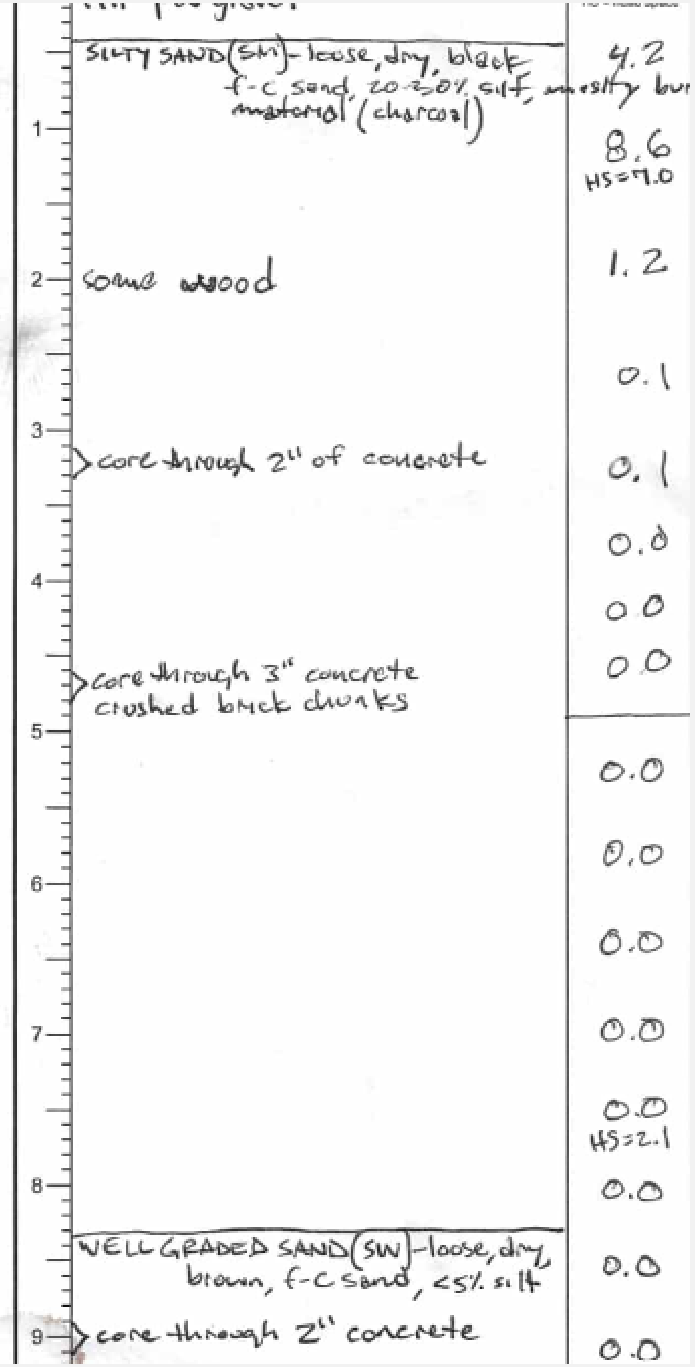




Treating next to occupied house & in operating business

Challenge : Concrete layers in the subsurface

- Old foundations at this former chemical plant
- Concrete slabs limited air flow, trapped contaminants
- Heating to the soil surface – even with surface cover – can be difficult



SILTY SAND (SM) - loose, dry, black f-c sand, 20-30% silt, mostly bur material (charcoal)

some wood

core through 2" of concrete

core through 3" concrete crushed brick chunks

WELL GRADED SAND (SW) - loose, dry, brown, f-c sand, <5% silt

core through 2" concrete

4.2
8.6
HS=7.0
1.2
0.1
0.1
0.0
0.0
0.0
0.0
0.0
0.0
0.0
0.0
HS=2.1
0.0
0.0
0.0

Subsidence at Thermal Remediation sites is not common, however -

- Subsidence did occur at Camelot Cleaners due to the tight, fat clay
- Subsidence has also occurred in peat soils
- Remediation done within tent-like structure due to cold climate

Challenge: Adjacent to or Under Railroad Tracks

- A few soil types can subside when heated for remediation: fat clays, peat soils
- Other soil types do not subside & thermal remediation can be used adjacent to & under railroad tracks
- Ground was monitored for movement during the remediation

Challenge: Winter Operation in New England

- Diaz: condensation in above ground lines
  - –Solution: wait for warmer weather to start system
- SRSNE: NAPL condensation under cap
  - –Solution: Increase insulation of cap, increase energy to upper part of formation
- Beede: Water lines froze/damaged
  - –Solution: heat tracing

Challenge: Energy Availability

Diaz Chemical Superfund Site, Holley, New York

- Insufficient natural gas available during the winter
- Semi trucks of compressed natural gas brought in to supply ~ 6 MMBTU/hr
- Each truck lasted ~ 1.5 days

Challenge: Working in Residential Areas

- Odor Monitoring
- Noise Monitoring
- Limit on working hours
- Site security
- Motion sensors

Groveland Wells Superfund Site

Successful Thermal Remediation requires:

- Good characterization to define the treatment zone, groundwater flow, existing infrastructure
- Heat to the boiling point of water throughout the treatment area, including low permeability zones
  - Use energy balance to ensure all areas are heated
- Collection of mobilized contaminants
- Separation of contaminants from air & water
- Proper disposal/destruction of contaminants