Thermal-Enhanced Remediation of Residual LNAPL

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Topics

- Thermal Enhancements to Remedial Processes
  - Residual LNAPL remains after conventional recovery and depletion is the next step
  - Extraction (vapor and liquid)
  - In Situ Degradation (aerobic and anaerobic)
  - In Situ Destruction (oxidation)
- Cost Effective Additions of Energy
  - Energy Sources
  - Infrastructure
- Example Pilot Study Results

Thermal Enhancements

Remedial technologies benefitting from thermal additions include:

- Groundwater & NAPL Extraction
- Air Sparging
- Enhanced Microbiological Degradation
- Soil Vapor Extraction
- Bioventing
- ISCO by Persulfate

Thermal processes are additions to conventional remedial processes, not separate technologies

Mechanisms of SVE

(Change in Mass) = - (Extracted Mass) + (Mass Transfer from NAPL) - (Mass Degraded)

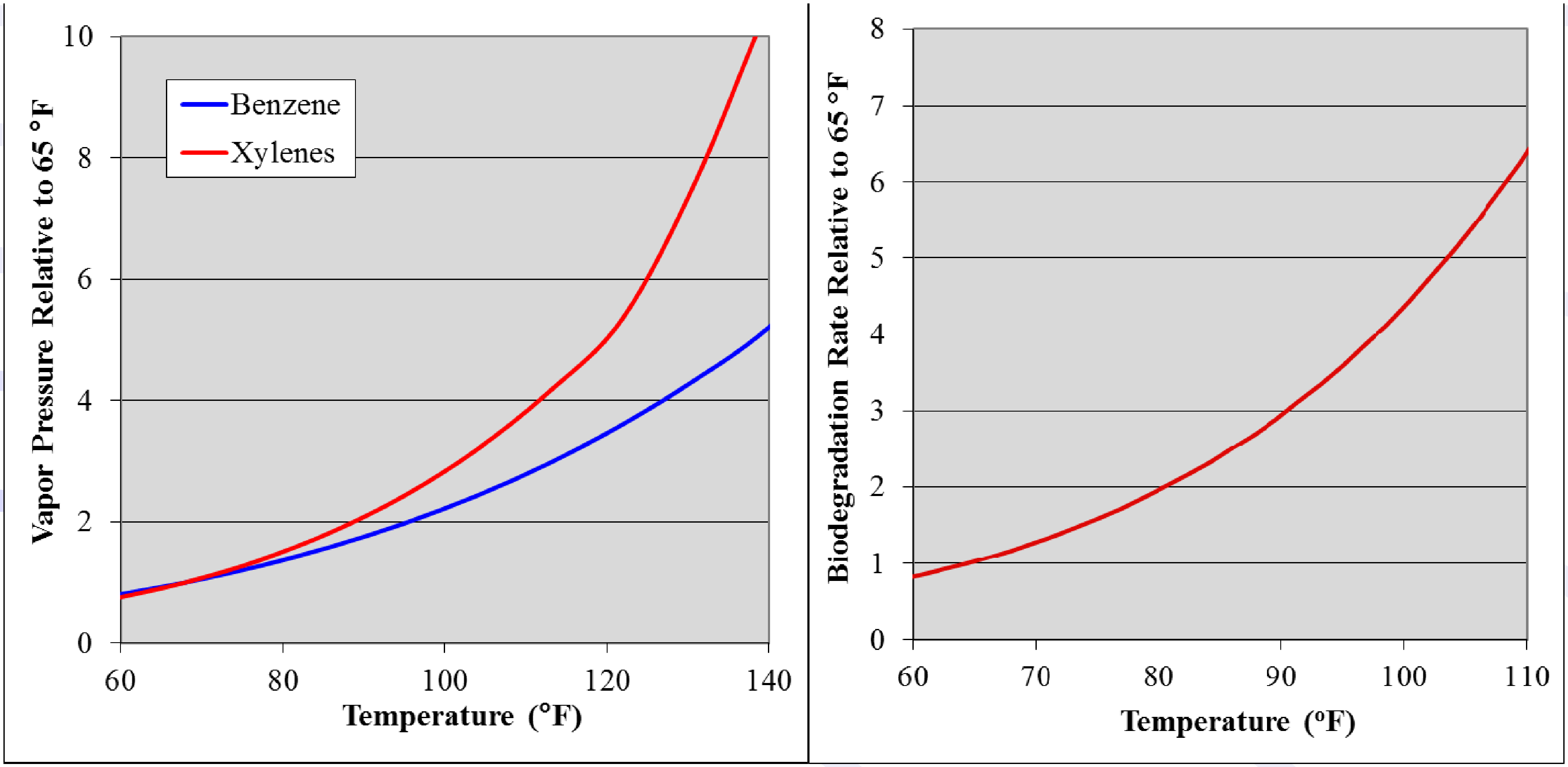
Extraction Rate — Vapor Pressure — Degradation Rate Constant

$$R_v dC_v/dt = -Q/V_t\, C_v + \alpha_d\,(\gamma C_{NAPL} - C_v) - \lambda_w C_{water}$$

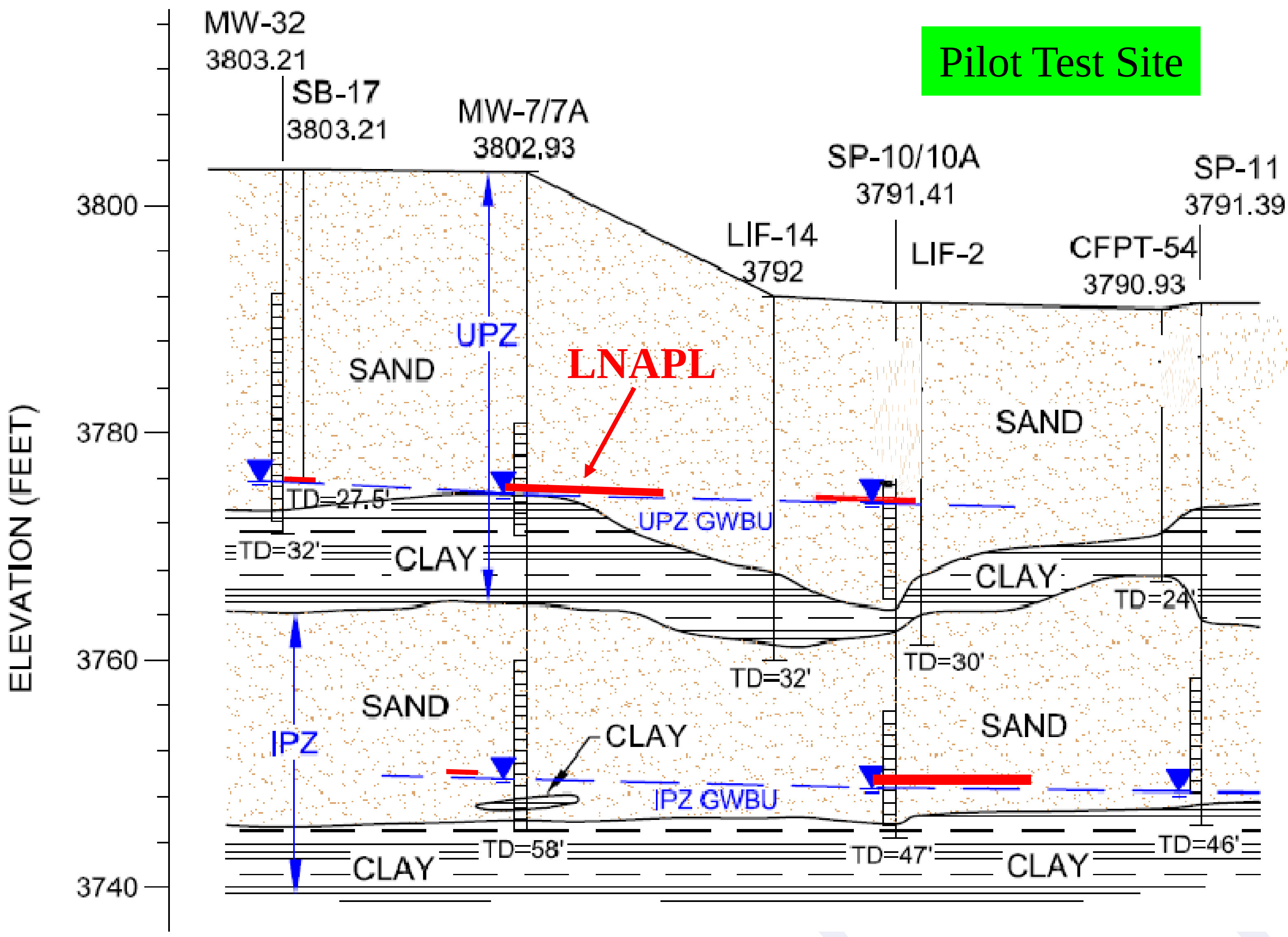
Engineers can specify or influence very few parameters:

- Vapor extraction rate (and location)
- Rate of mass transfer from NAPL
  - Vapor pressure by changing temperature
  - Mass transfer coefficient by changing temperature and flow dynamics
- Rate of In Situ Degradation
  - Temperature
  - Introduce electron acceptors (O_2) or nutrients

Property Enhancements



LNAPL in Perched Water Zones



Pilot Test Thermal Enhancement

Why add thermal enhancements?

- Soil vapor extraction is proceeding very slowly in "problem" areas
- Slurping of LNAPL is inefficient and/or ineffective
- Dissolved plume will remain off-site for decades

Accelerating cleanup is highly desirable:

- Increase subsurface temperature compatibly with existing system
- Introduce more flow across the vapor/NAPL interface
- Introduce oxygen, moisture to increase aerobic degradation and methanogenesis in fine-grained soil

Co-Air and Steam Injection meets these objectives

SVE Enhancement with Co-Air/Steam Injection

Co-air injection with steam has the following benefits:

- Distributes the energy laterally,
- Increases volatilization of compounds from the NAPL,
- Gradual heating and gradual increases in contaminant concentrations
- Vapor treatment system is conventional SVE (water knockout and simple air-to-air heat exchanger), and
- Operating temperatures are compatible with existing infrastructure.

Injecting steam alone has the following drawbacks:

- Limited control over direction of steam flow (e.g., applied vacuums at extraction wells have small influence on condensation)
- Treatment system is more complex (steam condensation, short peak contaminant concentrations require oversized treatment system, and
- Steam is incompatible with existing infrastructure

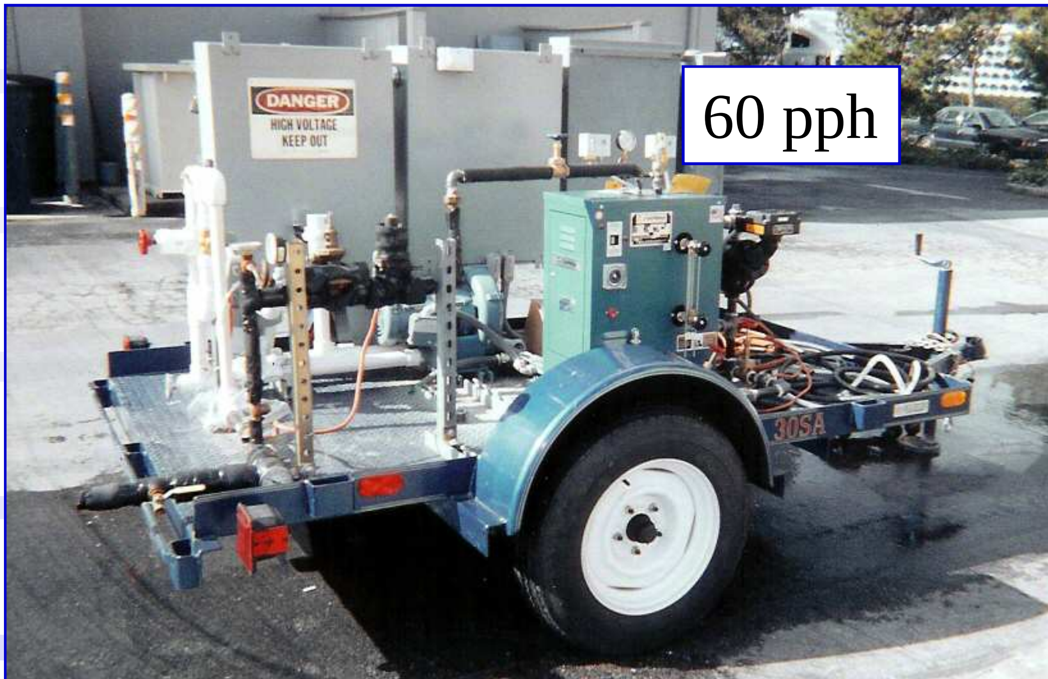
Energy Injection

- **Hot Air Injection**: 60 scfm (dry, 217 ° F)
  - Energy Rate = 2.7 kW = **9,600 BTU/hr**
- **Steam Injection**: 60 pounds per hour (**217 ° F**)
  - Volume Rate = 25 scfm
  - Energy Rate = 20 kW = **69,000 BTU/hr**
- **Air/Steam Co-Injection:** 60scfm + 60pph (**154 ° F**)
  - Volume Rate = 85 scfm
  - Energy Rate = 19 kW = **64,000 BTU/hr**

Incompatible with existing infrastructure

Compatible with existing infrastructure

Co-Air/Steam Injection System

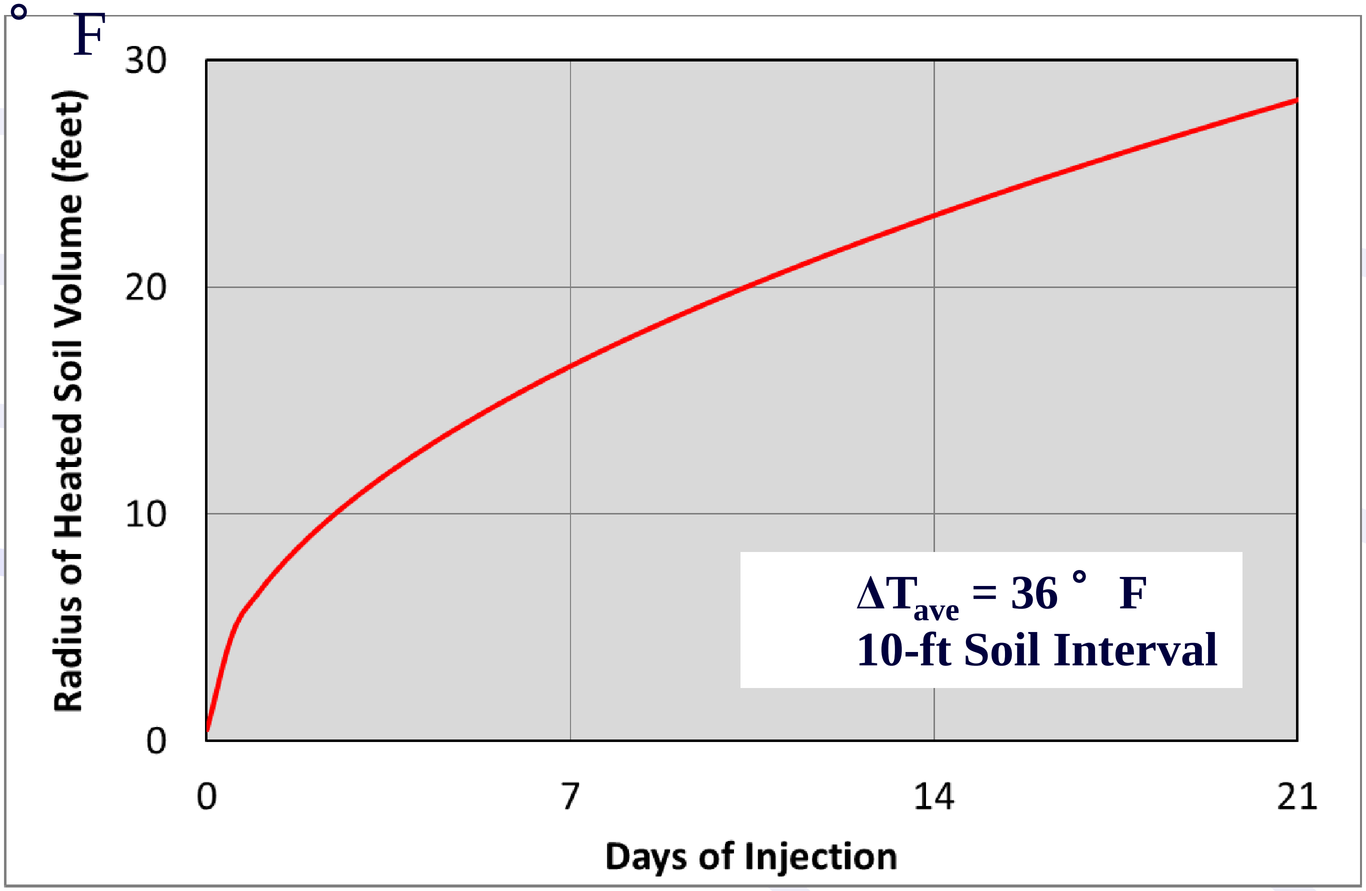


Soil Heating Rate

- **Soil Heat Capacity**:
  - Pore water saturation ~ 0.5 = **1,000 BTU/yd³/° F**
- **Soil Heating Rate**:
  - 60 scfm + 60 pph (Injection at **154 ° F**)
  - Air/Steam Energy Rate = 20 kW = **64,000 BTU/hr**
  - Increase average soil temperature, **ΔT = 36 ° F**
  - Average soil heating rate **= 1.8 yd³/hr**

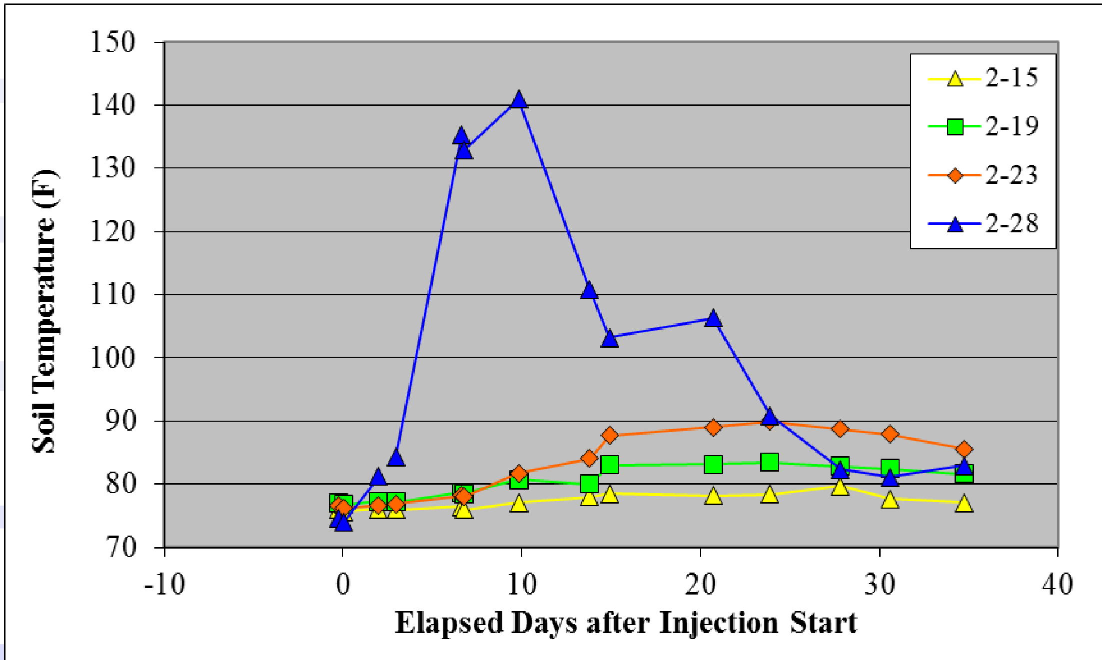
Soil Heating Rate

Co-Air/Steam Injection (60 scfm / 60 pph) at 154 ° F



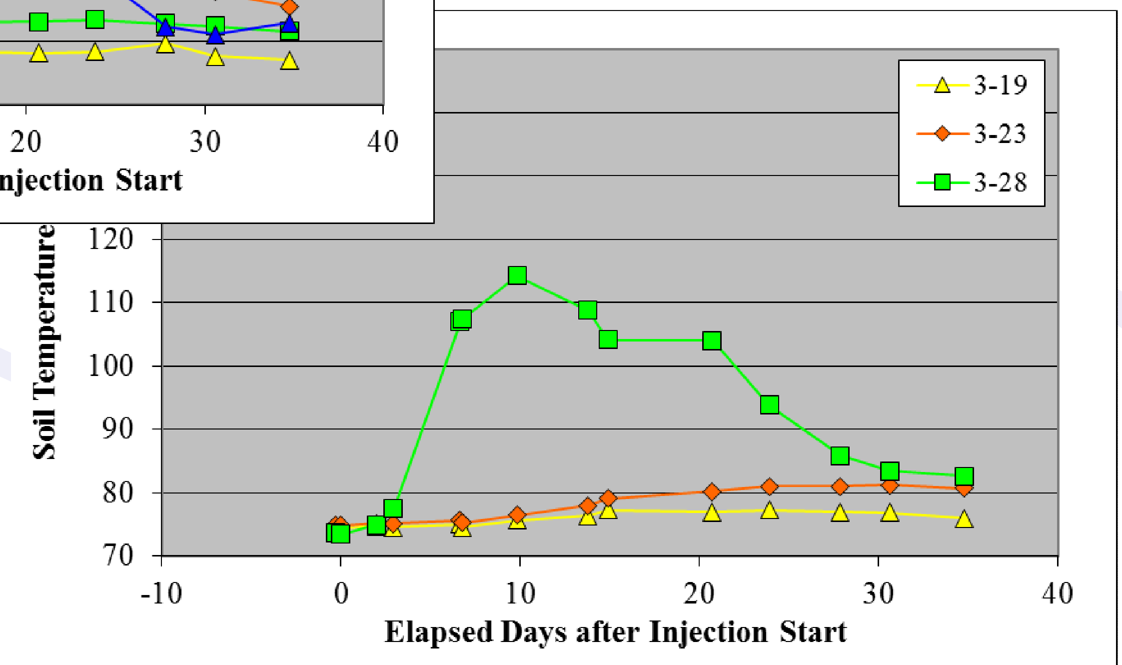
Pilot Test Setup

Pilot Test Heating Results

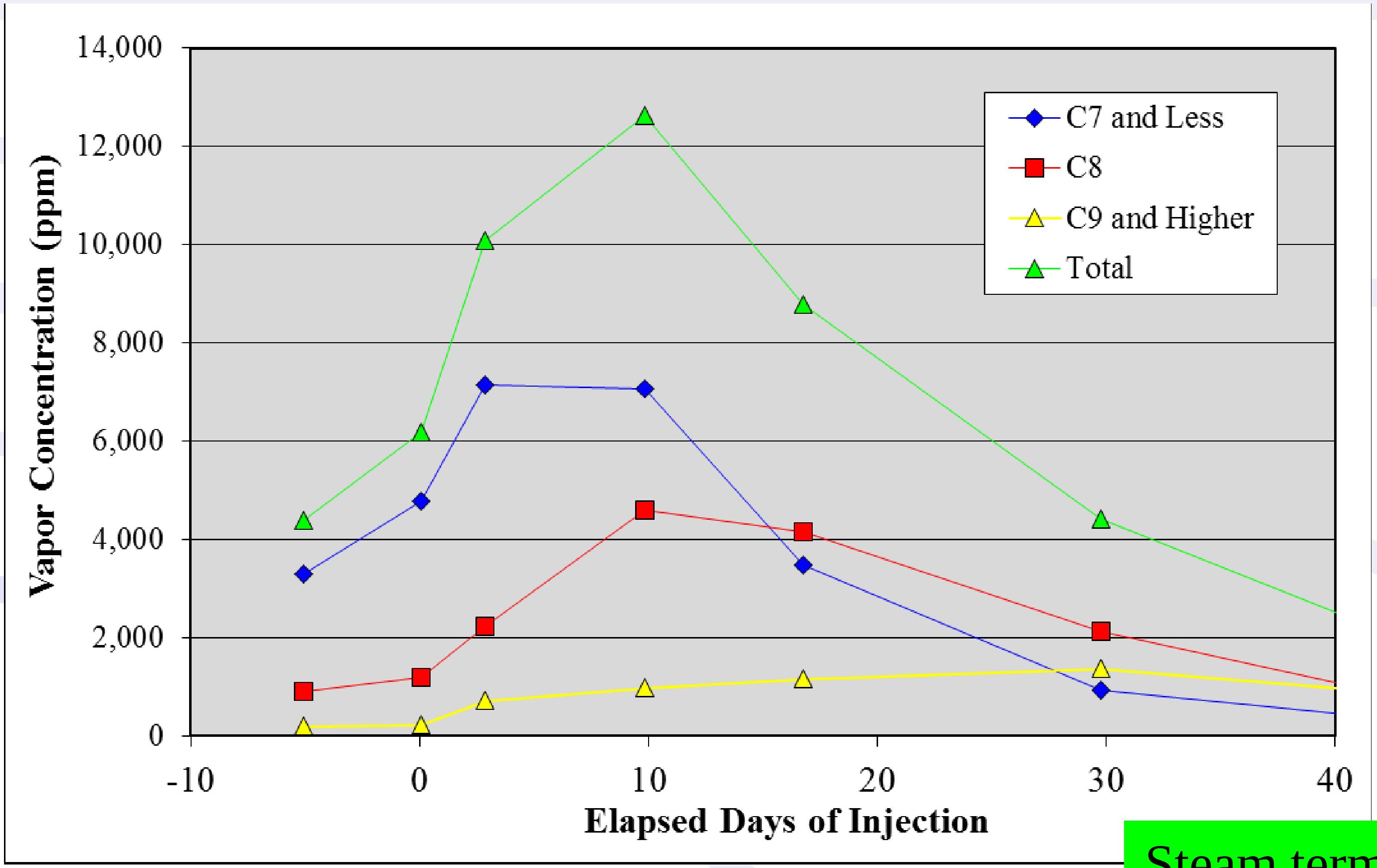


Steam terminated after 10 days

Monitoring well temperatures spaced 5 and 8 feet from injection well

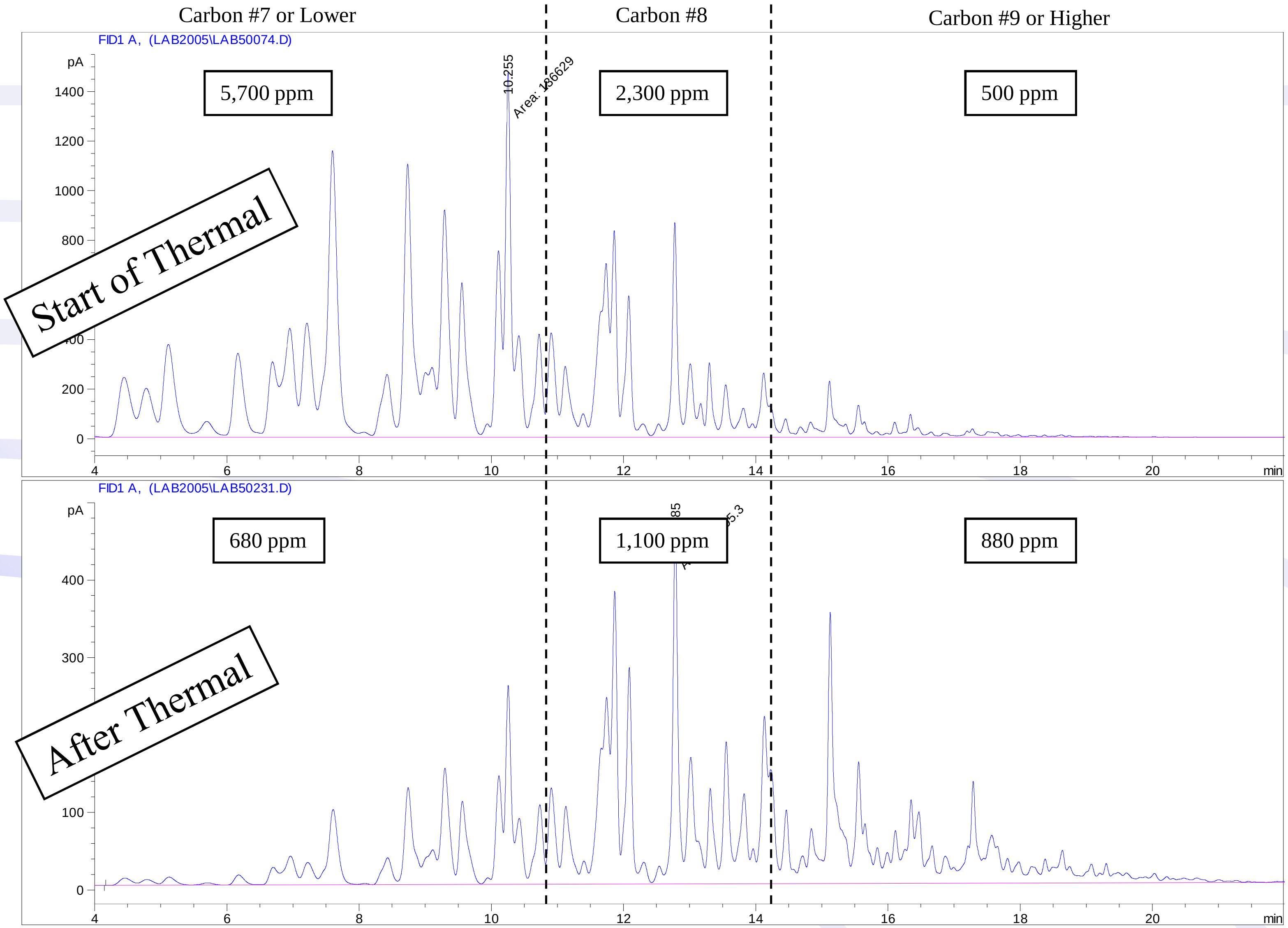


Pilot Test Volatilization Increases



Steam terminated after 10 days

Monitoring Well Concentrations



Conclusions

- Short test for proof-of-concept
- Implementation of heating was straightforward
- Soil temperatures increased to desired ranges
- Extracted TPH concentrations & mass removal increased
- CO_2 and methane concentrations increased
- Compatibility with PVC demonstrated
- Modeling indicates time to remediation decreased by factors of 5 to 8
- Scheduled for full-scale application in 2016