How can we be more successful at site cleanup?

Experience with pragmatic solutions for managing chlorinated solvents in subsurface environments.

Rob Hinchee

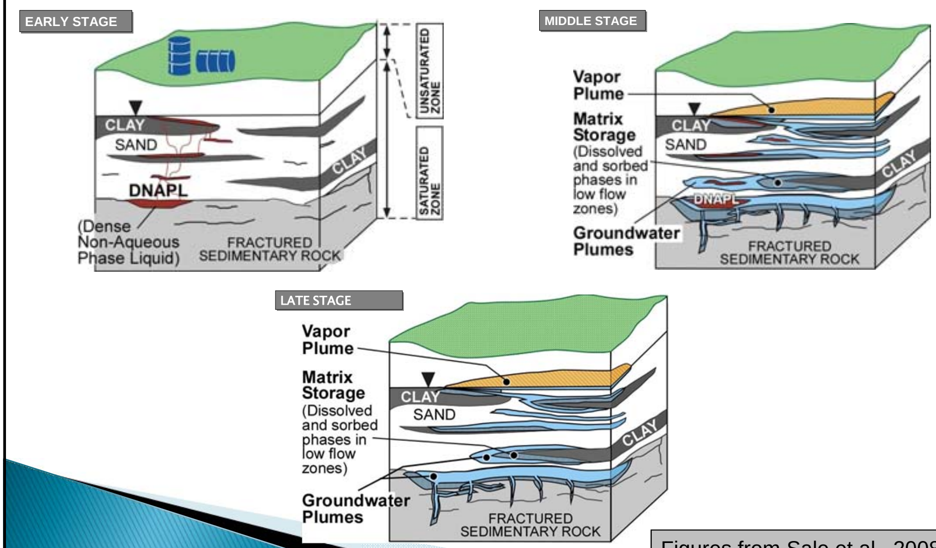
Chlorinated Solvent Remediation
30 years on – what have we learned?

- 30 years ago – pump and treat
- 20 years ago new technologies emerged
  - Bioremediation
  - In situ oxidation
  - Surfactant flushing
  - Thermal Treatment
  - Permeable Reactive Barriers
- We now have years of experience at thousands of sites in the US
  - Much has been learned
  - We still have no “silver bullets”
  - But we have made real progress

What Have We Learned?
Key Elements for Success

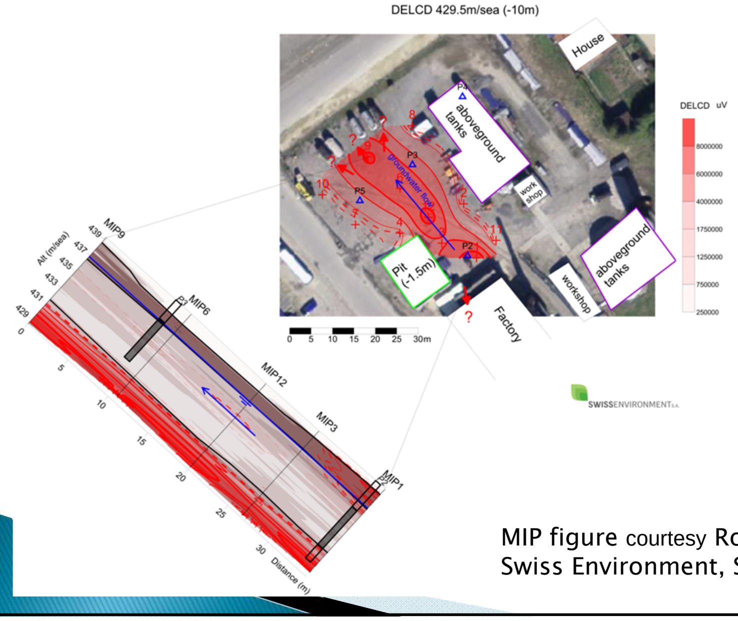
- Understand the site
  - Good characterization
  - Good conceptual site model
- Set realistic goals and objectives
  - Protect Human Health and the Environment
  - Comply with regulation and good practice
- Implement the right solution
  - Knowing what technology will and will not do
  - Proceed observationally pilot test and lessons learned

Understanding the Site
"Typical" DNAPL distribution



Figures from Sale et al., 2008

Good Characterization Requires New Tools



MIP figure courtesy Roland Mage, Swiss Environment, SA

Setting Realistic Goals and Objectives

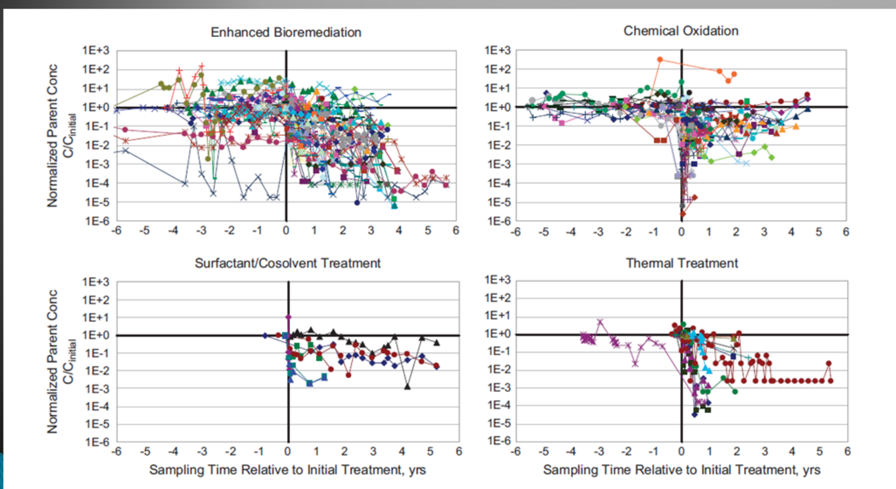
- Remedies must be protective
  - Understand the receptors and risks
  - Risk Assessment
- Understanding what technologies do
  - Treatment
    - Flux reduction
    - Mass reduction
    - Longevity reduction
  - Containment
    - Flux reduction
  - There is no 100% treatment
- Compliance with law and regulation

Should be BAV
- Beneficial
- Attainable
- Verifiable

Two Basic Classes of Technology

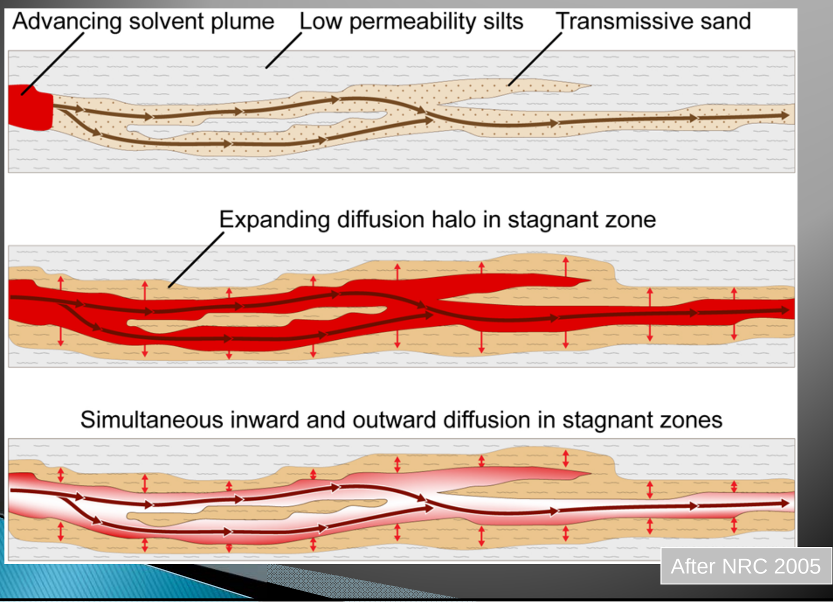
- Containment
  - Pump and Treat (Hydraulic Containment)
  - Permeable Reactive Barriers
  - In Situ Stabilization
- Treatment
  - Bioremediation
  - Chemical Oxidation
  - Thermal
  - Surfactant flush

Rebound – A Big Problem



McDade et al.

Matrix Diffusion and Storage in Dissolved Plumes

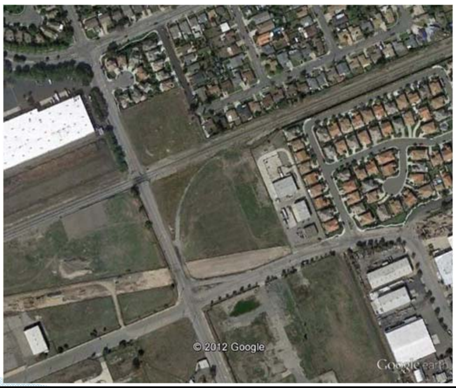


DNAPL Treatment Rules of Thumb

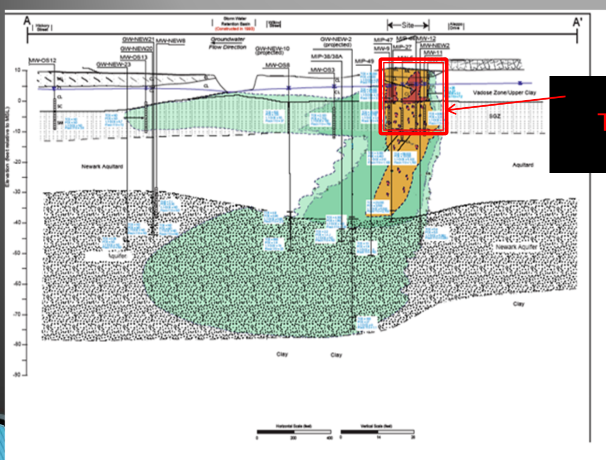
- Well implemented in-situ remediation remedies typically reduce source zone groundwater concentrations by about an order-of-magnitude (90%).
  - 90% source reduction gives 90% improvement downgradient water quality.
- Higher removal efficiencies are possible, up to 99% or 99.9%, for sites with
  - Fast groundwater flow,
  - Homogenous stratigraphs and/or,
  - Low mass storage, and/or high natural attenuation rates

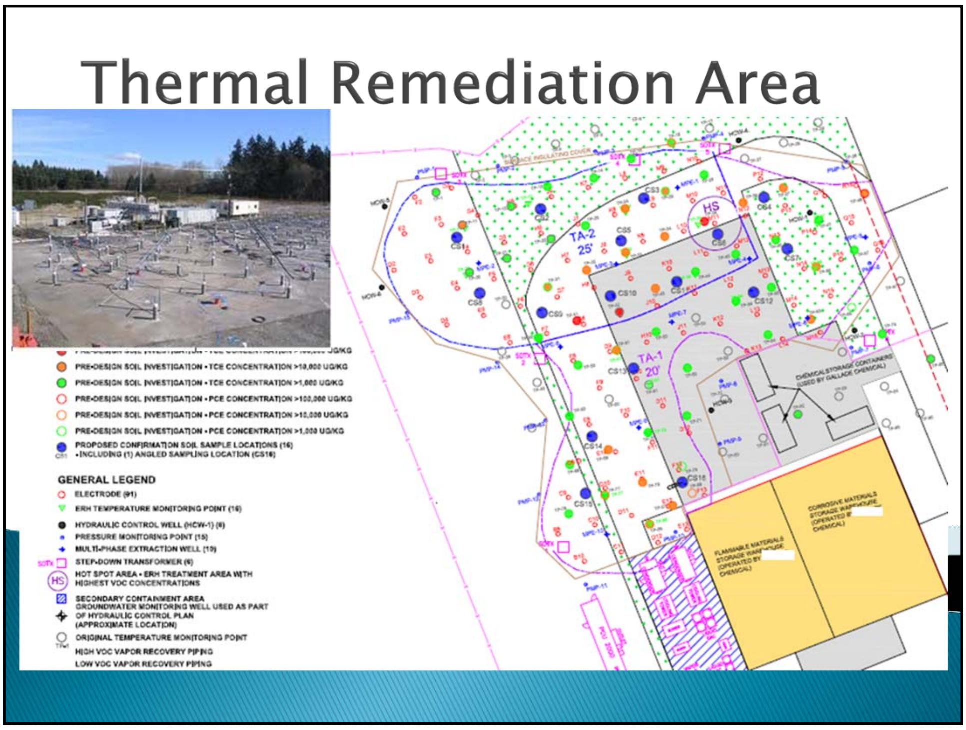
Thermal Treatment Example

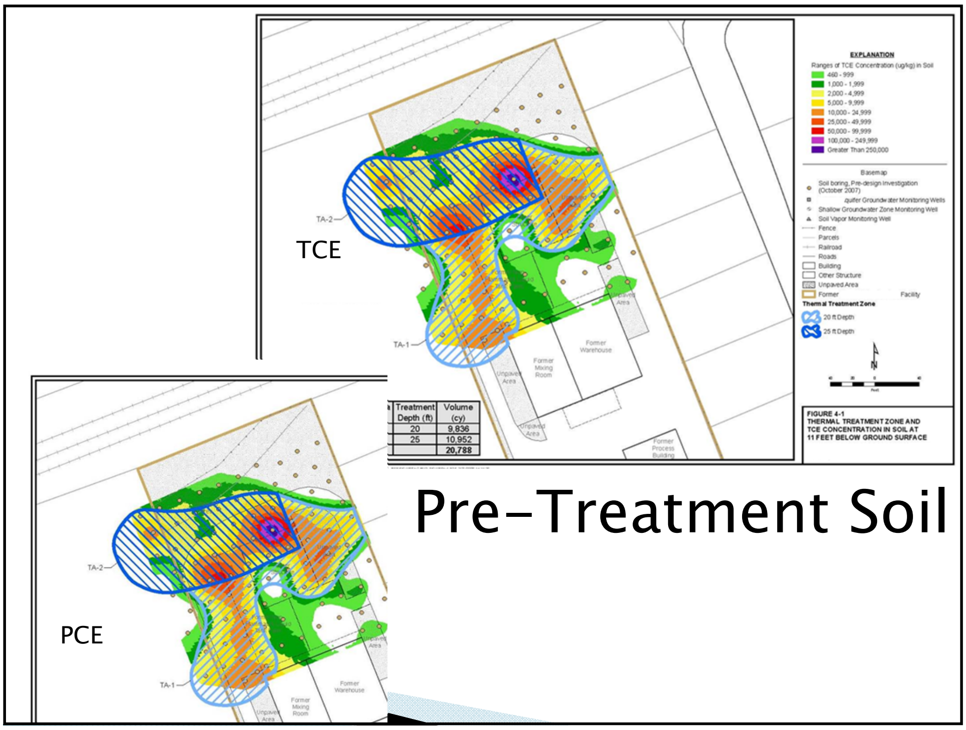
- DNAPL Source Zone
- Emissions Control
  - SVE & barrier for soil vapor
  - Hydraulic control – pump & treat
- Reasonable cleanup goals
  - 100's of ug/L



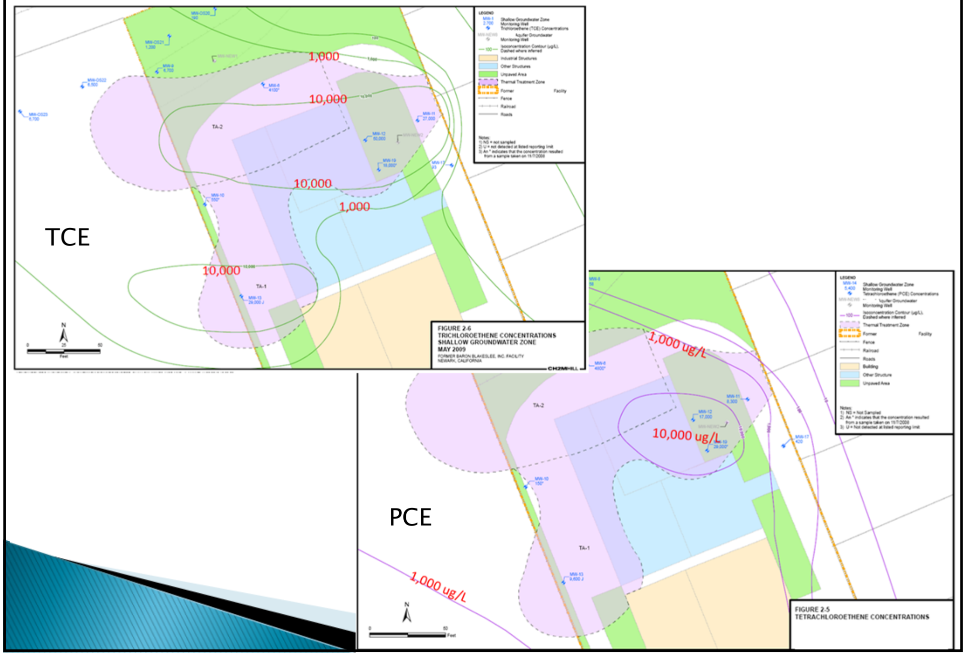
Thermal Treatment Example



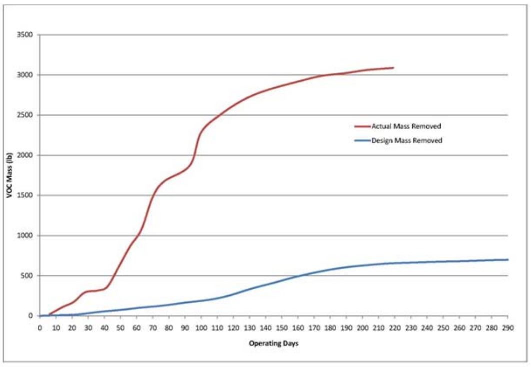

Thermal Remediation Area
PRE-DESIGN SOIL INVESTIGATION • TCE CONCENTRATION >10,000 UG/KG
PRE-DESIGN SOIL INVESTIGATION • TCE CONCENTRATION >1,000 UG/KG
PRE-DESIGN SOIL INVESTIGATION • PCE CONCENTRATION >100,000 UG/KG
PRE-DESIGN SOIL INVESTIGATION • PCE CONCENTRATION >10,000 UG/KG
PRE-DESIGN SOIL INVESTIGATION • PCE CONCENTRATION >1,000 UG/KG
PROPOSED CONFIRMATION SOIL SAMPLE LOCATIONS (16)
• INCLUDING (1) ANGLED SAMPLING LOCATION (CS16)
GENERAL LEGEND
ELECTRODE (91)
ERH TEMPERATURE MONITORING POINT (16)
HYDRAULIC CONTROL WELL (HCW-1) (8)
PRESSURE MONITORING POINT (15)
MULTI-PHASE EXTRACTION WELL (10)
STEP-DOWN TRANSFORMER (6)
HOT SPOT AREA • ERH TREATMENT AREA WITH HIGHEST VOC CONCENTRATIONS
SECONDARY CONTAINMENT AREA
GROUNDWATER MONITORING WELL USED AS PART OF HYDRAULIC CONTROL PLAN (APPROXIMATE LOCATION)
ORIGINAL TEMPERATURE MONITORING POINT
HIGH VOC VAPOR RECOVERY PIPING
LOW VOC VAPOR RECOVERY PIPING
TA-2
25'
TA-1
20'
HS


Pre-Treatment Soil
TCE
PCE
TA-2
TA-1
Treatment Depth (ft) | Volume (cy)
20 | 9,836
25 | 10,952
20,788
EXPLANATION
FIGURE 4-1
THERMAL TREATMENT ZONE AND TCE CONCENTRATION IN SOIL AT 11 FEET BELOW GROUND SURFACE

Pre-Treatment Groundwater



Thermal Remediation – Mass Removal Rate



Thermal Remediation – Temperatures

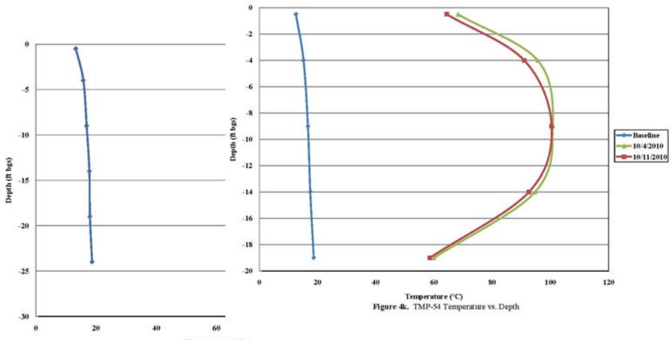
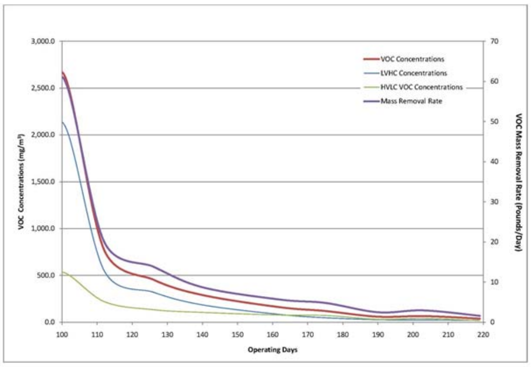


Figure 4a. TMP-11 Temperature vs. Depth

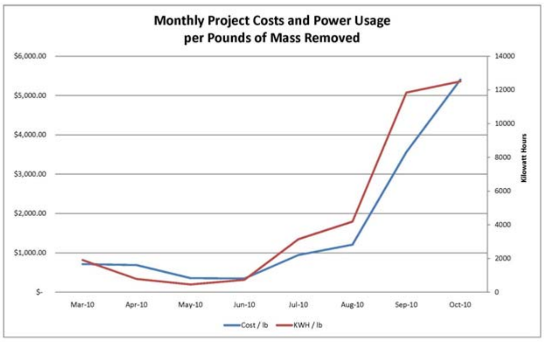
Figure 4k. TMP-54 Temperature vs. Depth

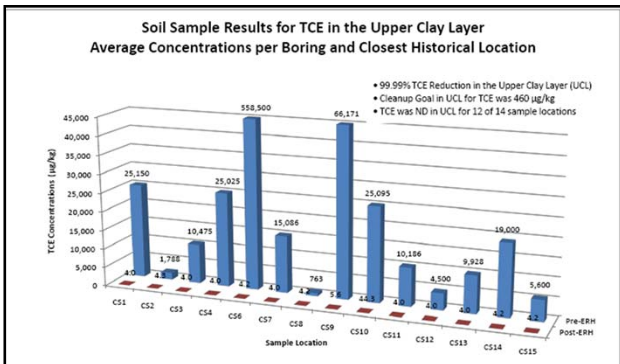
NEW09 WR 101510 acf

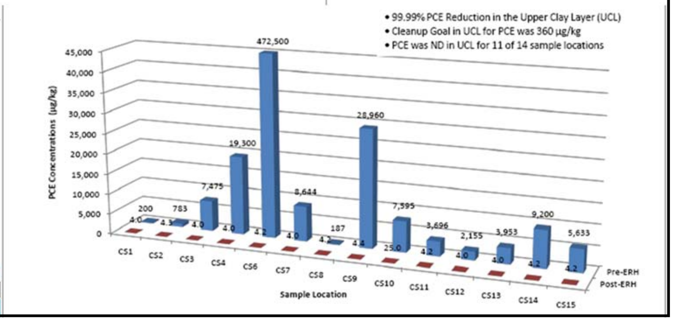
Thermal Remediation – VOC Concentrations



Thermal Remediation – Costs per Pound



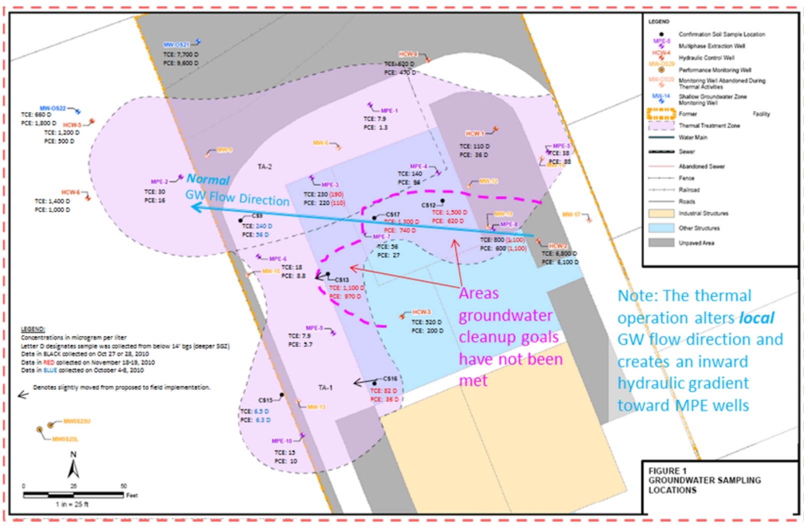




Groundwater

- **October 2010 Groundwater Data**
  - 2 grab groundwater samples collected the first week (drilling event)
  - 16 Extraction wells sampled third week of October
  - Based on results, 70% of treatment area completed and shut off.
- **November 2010 Groundwater Data**
  - 4 direct push grab groundwater samples in November (drilling event) in the remaining thermal treatment area (the 30%)
    - Repeated locations – CS12 and CS13
    - New locations – CS16 and CS17
  - Included sampling two extraction wells within remaining treatment area that had exceeded goals in October sampling
    - MPE-3 and MPE-8
- **Heating was stopped in December**
  - Contamination continued to enter from up gradiant
  - Cost of continued operation was not justifiable

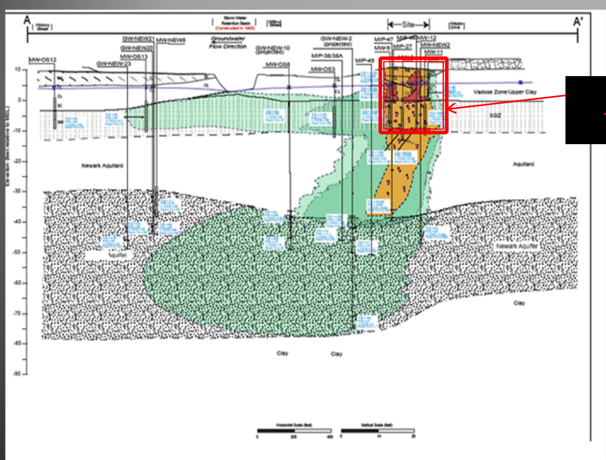
Groundwater Confirmation Sampling



Thermal Remediation Result

- Overview – More than 3,000 pounds of VOCs removed
  - ~99% reduction in TCE and PCE in the upper clay layer
  - Remedial Action Levels reached in upper clay layer
  - Remedial Action Levels met is most but not all source zone groundwater
  - Groundwater flux down gradient reduced ~90%
    - but not to goals
- The Details
  - ~16,000 m^3 treated at a cost of ~$2,000,000
  - ~$125/$m^3$
  - Plans for reactive permeable barrier downgradient

What Success Looks Like



~90%
Treatment

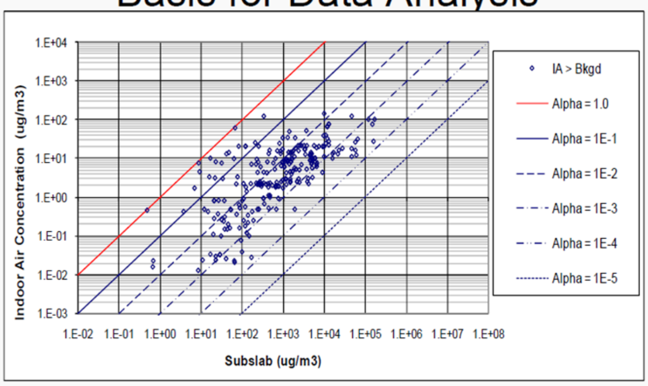
DNAPL Related Evolving Issues

- Vapor Intrusion
  - Understanding and standards still in flux
- Emerging Chemicals
  - 1,4-dioxane
    - found at ~20% of solvent sites
  - 1,2,3-trichloropropane
    - 0.005-µg/L California notification level
- Evolving understanding of Risk
  - Possible lowering of USEPA's 5 ug/L MCL

EPA VI Database

The Foundation for much of EPA's thinking to date

Empirical Attenuation Factors: Basis for Data Analysis



November 30, 2011 U.S. Environmental Protection Agency

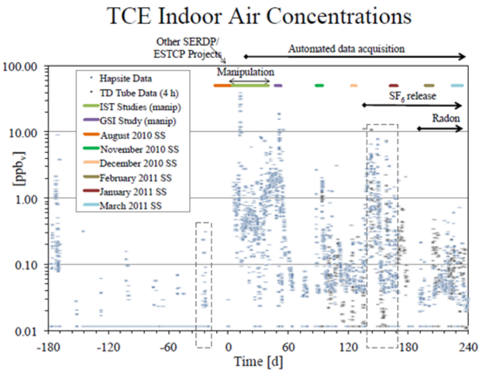
Based primarily on paired single event indoor air/sub-slab soil gas da

ASU's Hill AFB Study
Long-term intensive monitoring

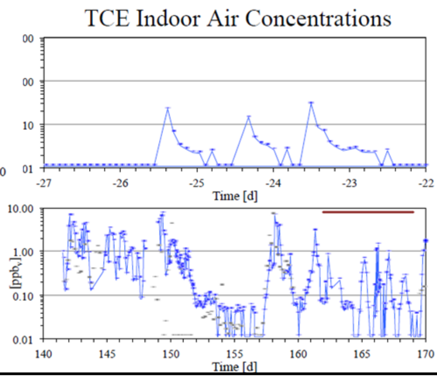
- Has the potential to impact VI sampling and assessment Paradigms
- Home over TCE plume intensively monitored for 2 yrs

- Indoor air sampled every 2 to 4 hours 24/7
- Frequent soil gas monitoring
  - Subslab
  - Deeper
- Groungwater monitoring
- 10,000+ samples

ASU's Preliminary Findings

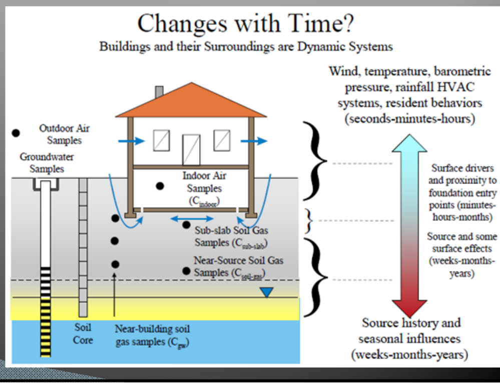


Blowup of shaded areas



ASU's Preliminary Findings

- Indoor air concentrations vary by orders of magnitude over relatively short time frames
- Subslab is less variable than indoor air
- Soil gas and groundwater less variable than subslab
- Tracer tests show indoor air sources can create subslab and soil gas contamination
  - Vapor goes both ways



1,4-Dioxane the newest DNAPL problem

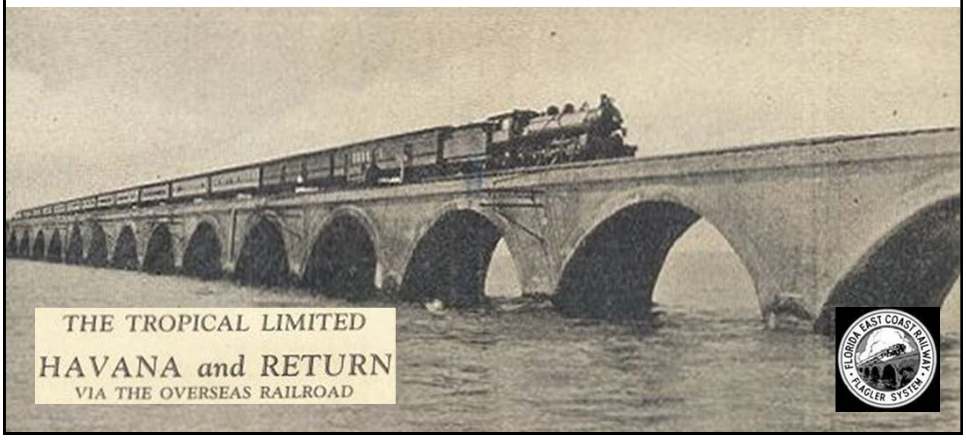
- Stabilizer additive found in most 1,1,1-TCA
- Problematic properties
  - Fully soluble in water
  - Not very biodegradable
  - Appears to be toxic
    - 1 ug/L California Notification Level
    - 0.35 µg/L EPA IRIS 10-6 DW risk level
    - 0.67 ug/L EPA Region 9 DW screening level
  - Not treatable using conventional DNAPL processes
    - Not removed by stripping, activated carbon or bioremediation
    - Only current treatment is pump and treat with AOP

	VP (mm Hg)	S (mg/L)
1,4-dioxane	38	Infinite
1,1,1-TCA	124	1,290
TCE	69	1,280
PCE	18	206

Solvent/DNAPL Remediation
Old Thinking

"DNAPL remediation is like building a bridge across a river but you can't see to the other side because it is too foggy. We are attempting to remediate DNAPLs anyway so that we can pass on a cleaner environment to the next generations. By the time our children are grown, they can continue building the DNAPL bridge to the other side of the river."

John Cherry 1998



Solvent/DNAPL Remediation
New Thinking

- We still have a few dragons to slay; but
- A new day is dawning:
  - Armed with the old generation's experience and
  - The new generation's innovations we are more effectively controlling the DNAPL dragon!