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Greg Beyke

Thermal Remediation Services

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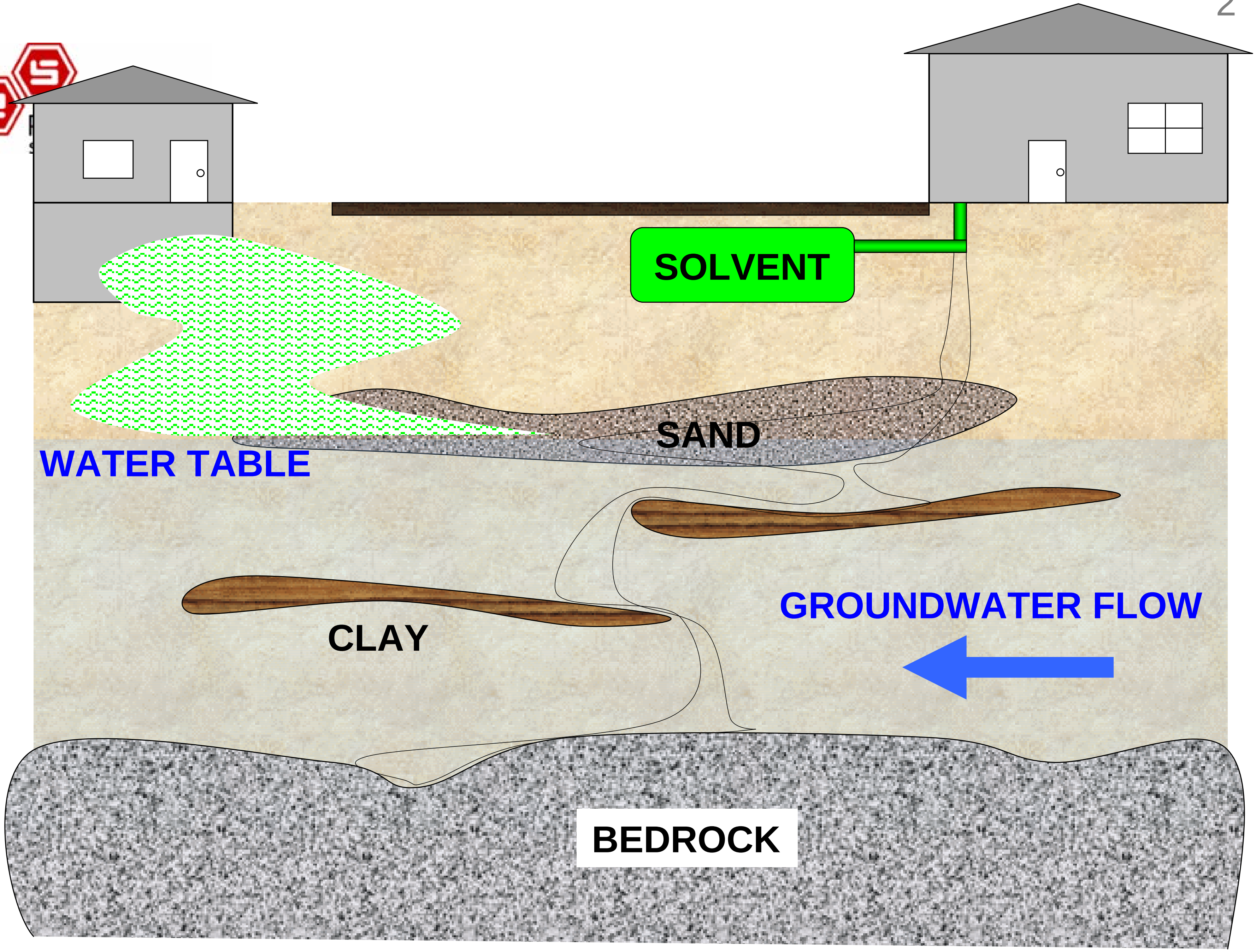
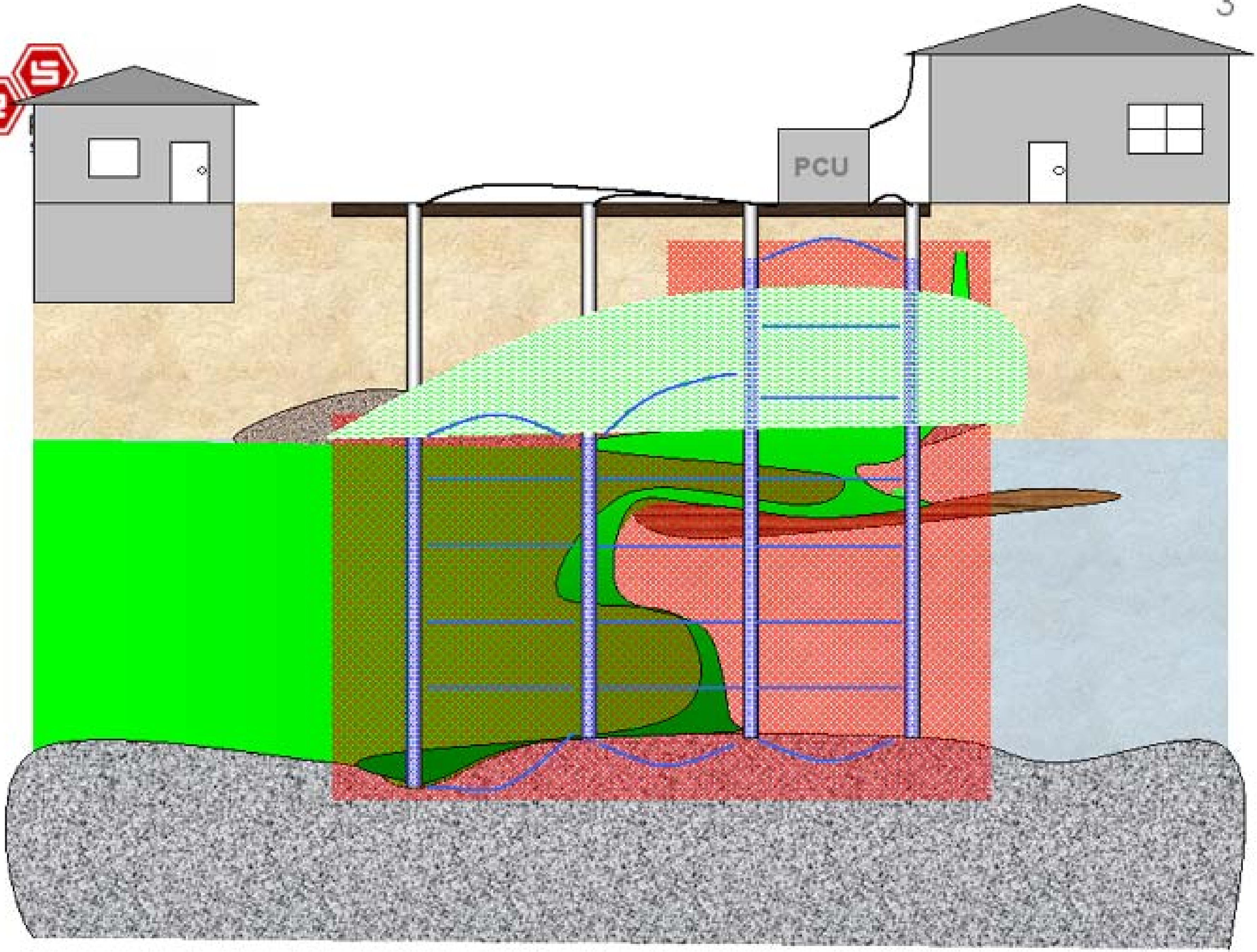
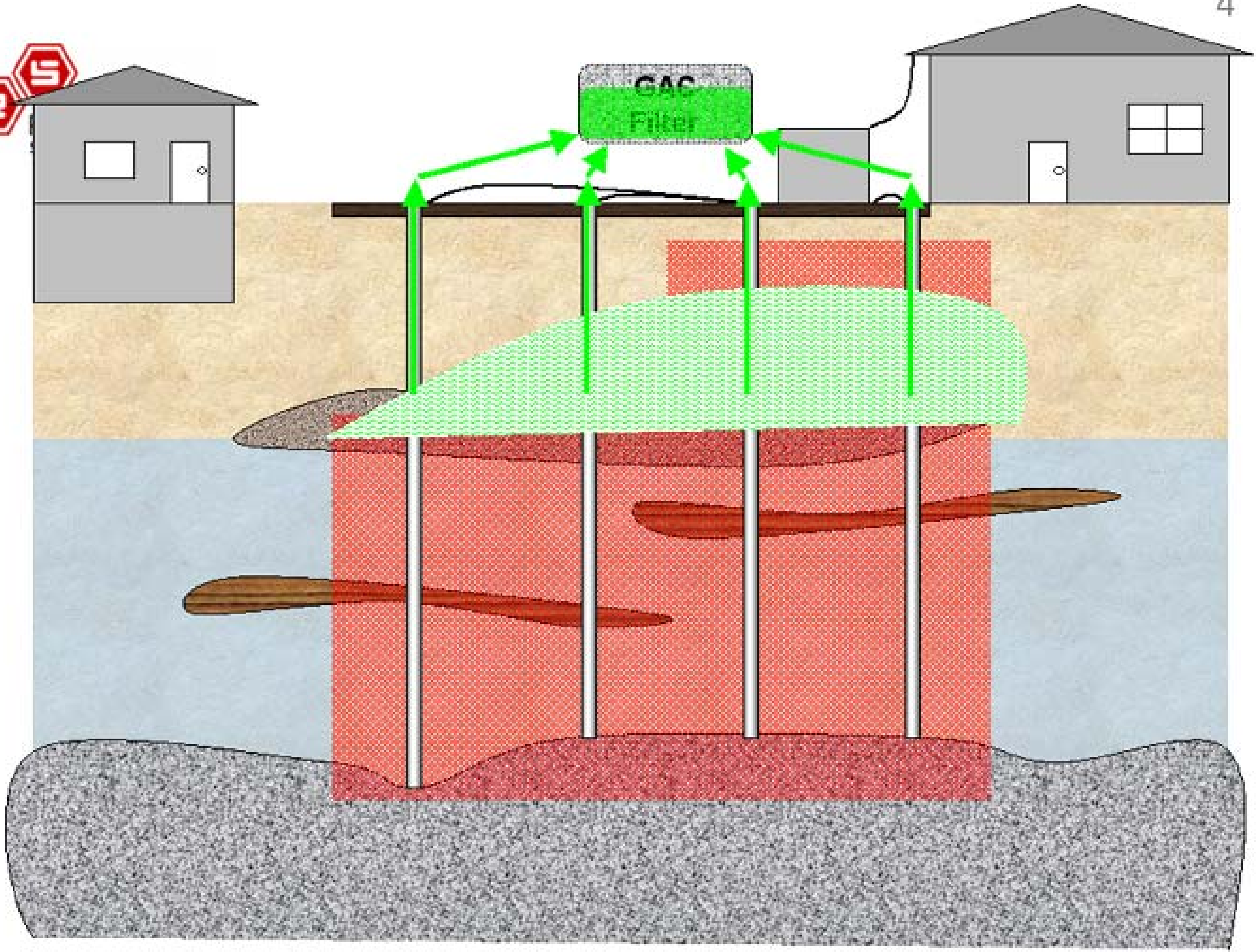

SOLVENT
SAND
WATER TABLE
GROUNDWATER FLOW
CLAY
BEDROCK

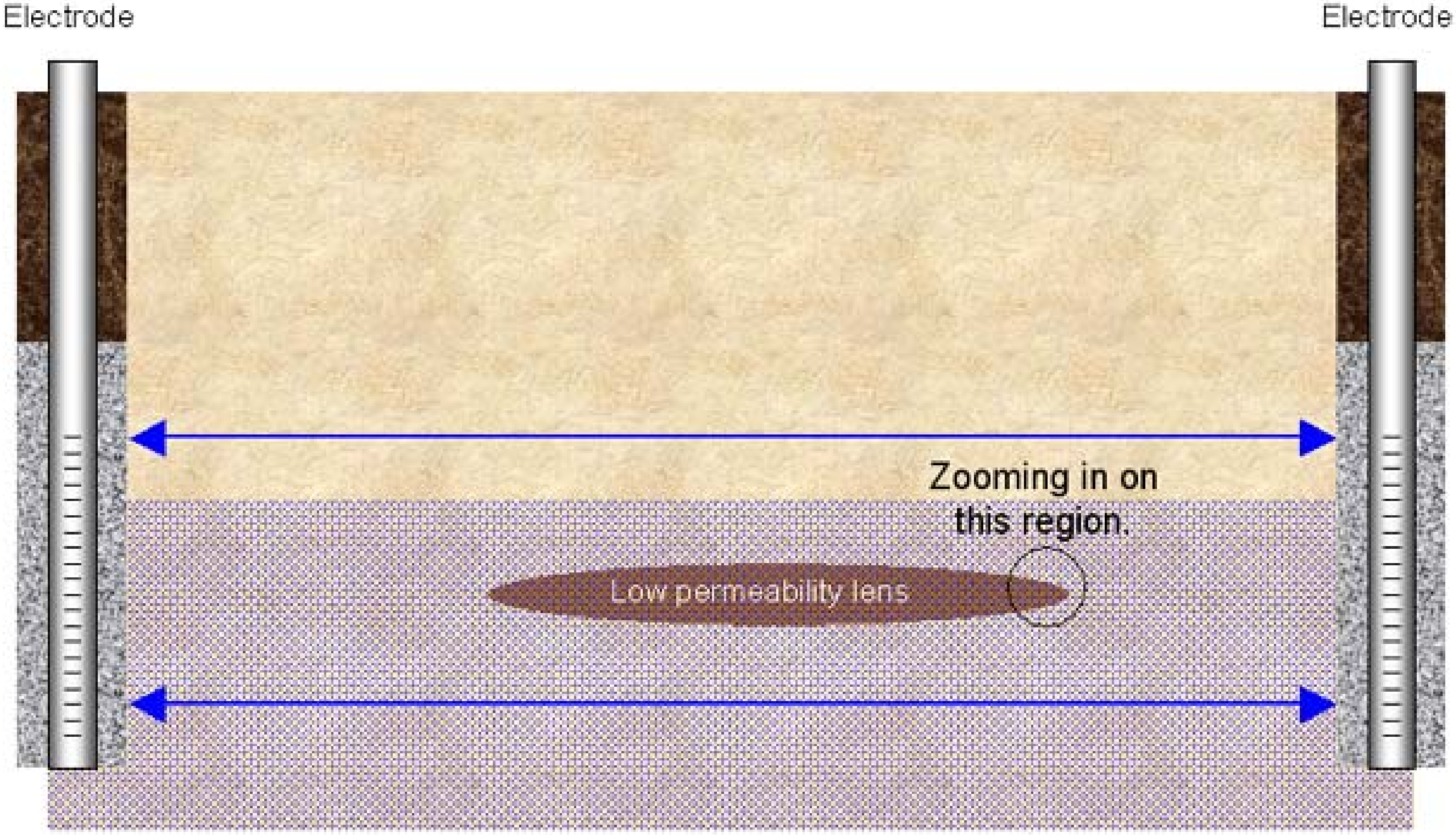

PCU



Why Electrical Resistance Heating?

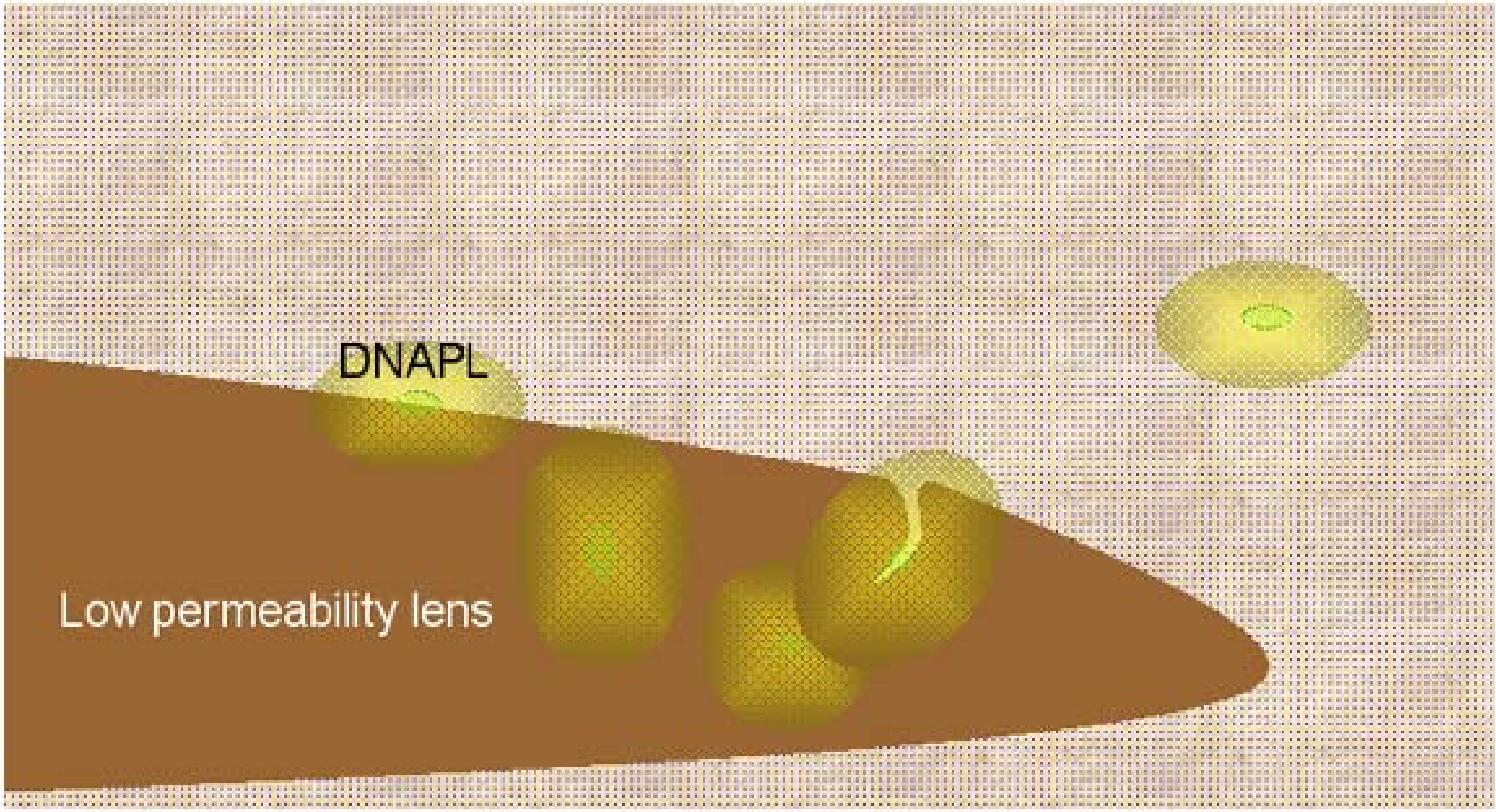
- Steam is produced *in-situ*
- Heating is uniform with no bypassed regions
- Heating is rapid yet gentle
- No soil desiccation
- Preferentially heats tight soil lenses and DNAPL hot spots
- Cost effective: most commercial, full-scale sites range from \$40-\$100 per yd^3

In-Situ Steam Generation



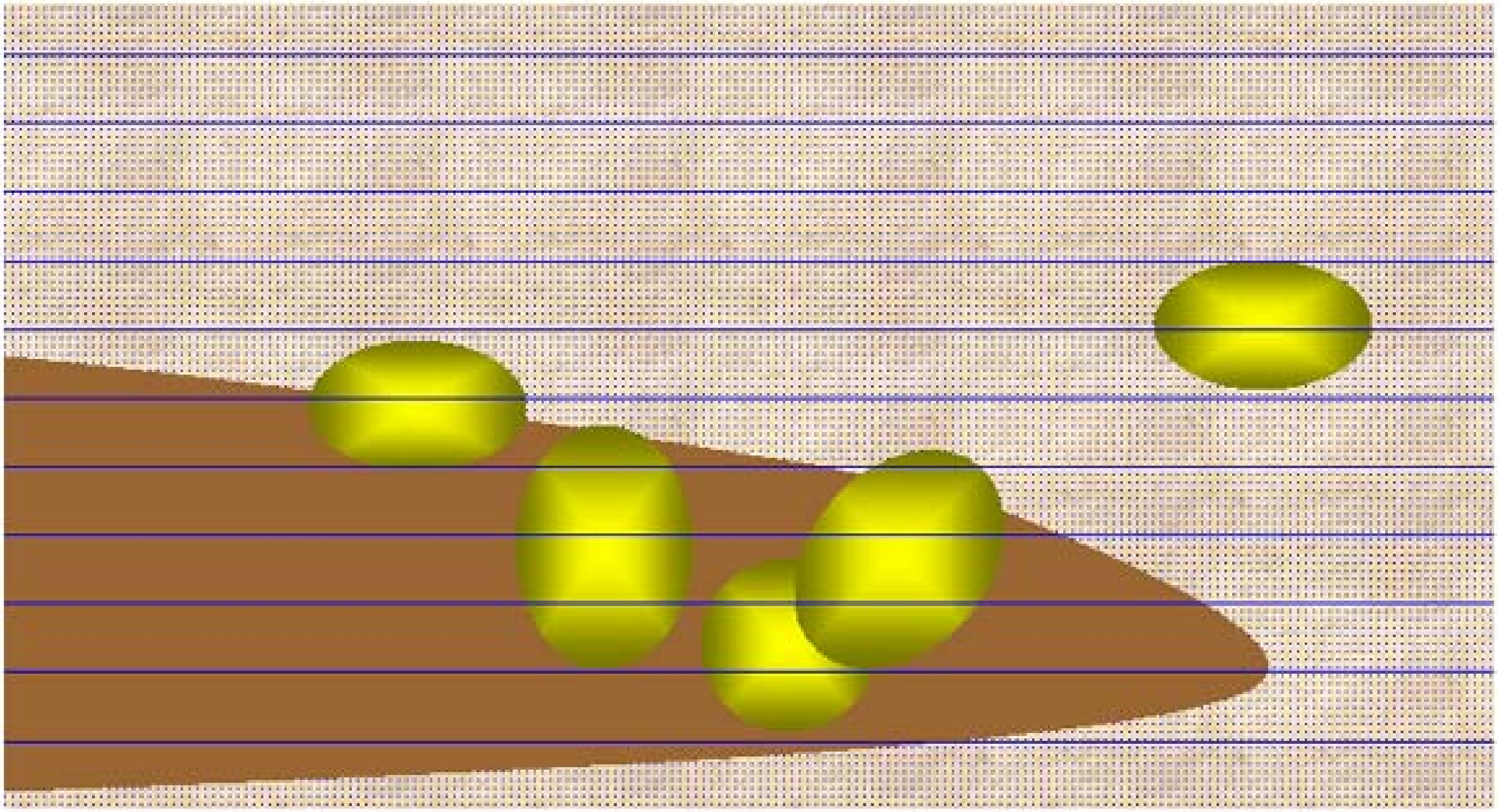
Current flowing between electrodes heats soil directly.

In-Situ Steam Generation



Reductive dehalogenation creates “halo” of chloride ions in CVOC hot spots

In-Situ Steam Generation



If the subsurface were perfectly uniform, current would flow in straight lines, as shown above.

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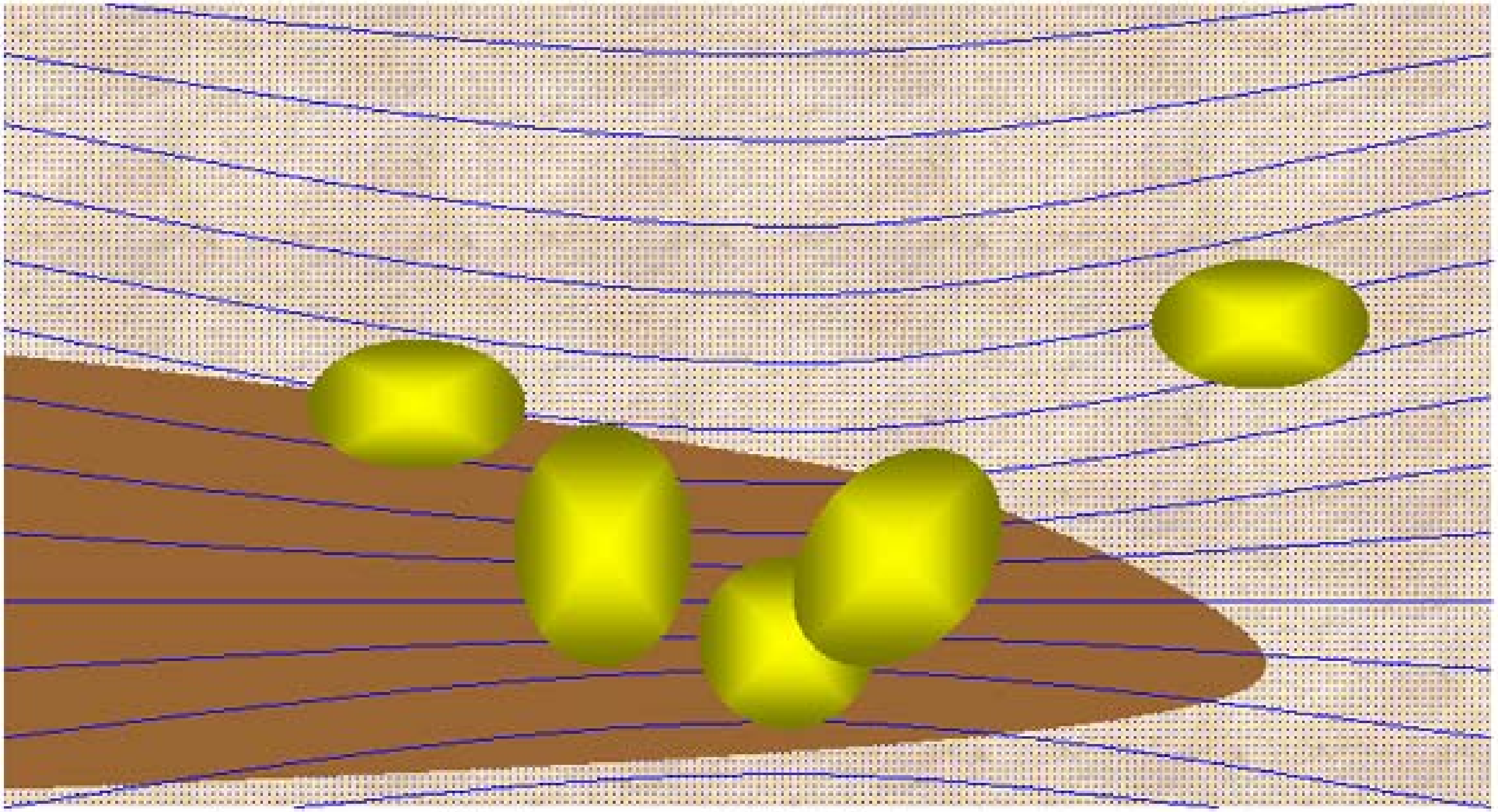
In-Situ Steam Generation



Low permeability lenses and CVOC hot spots attract current.

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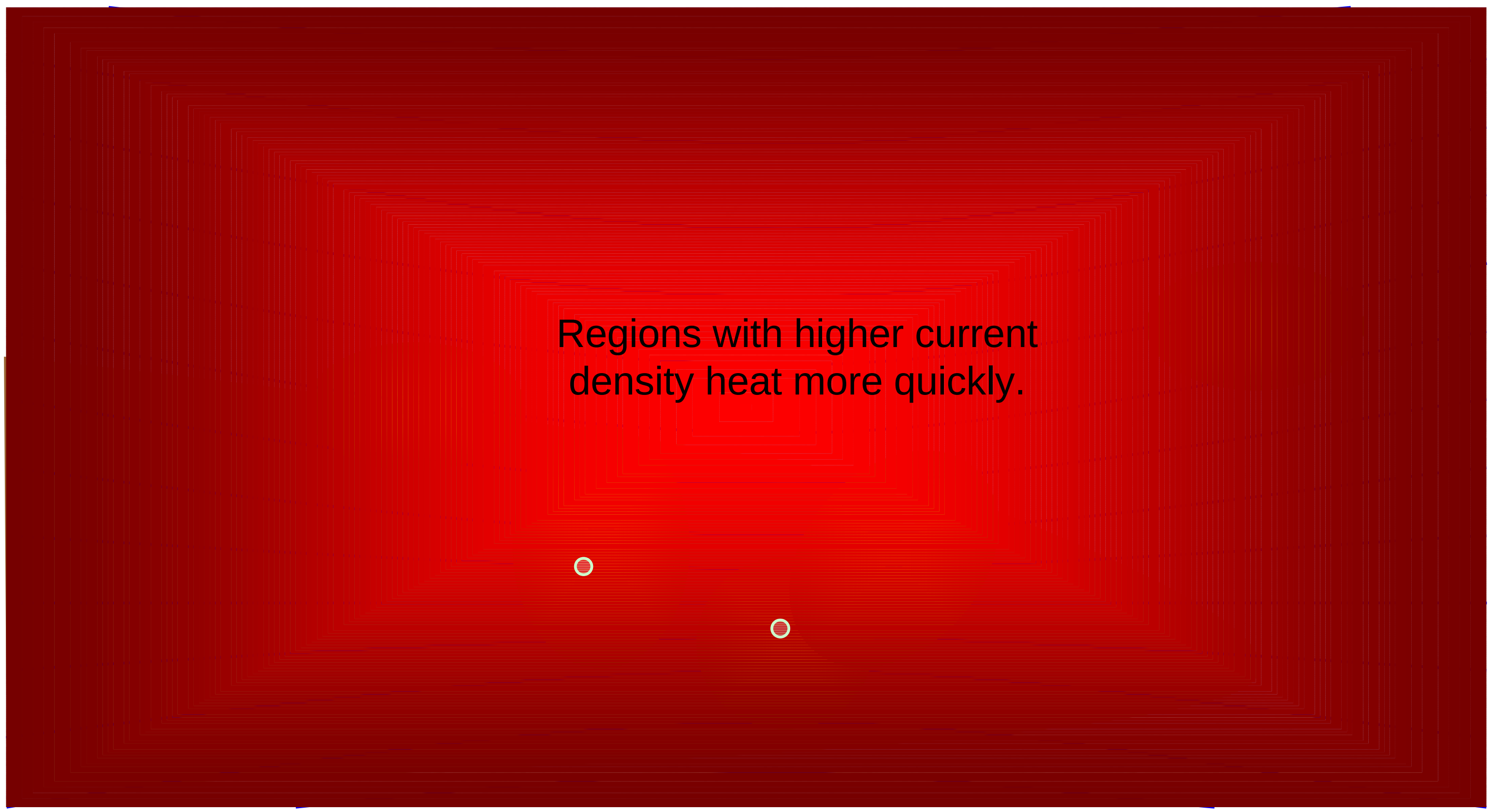
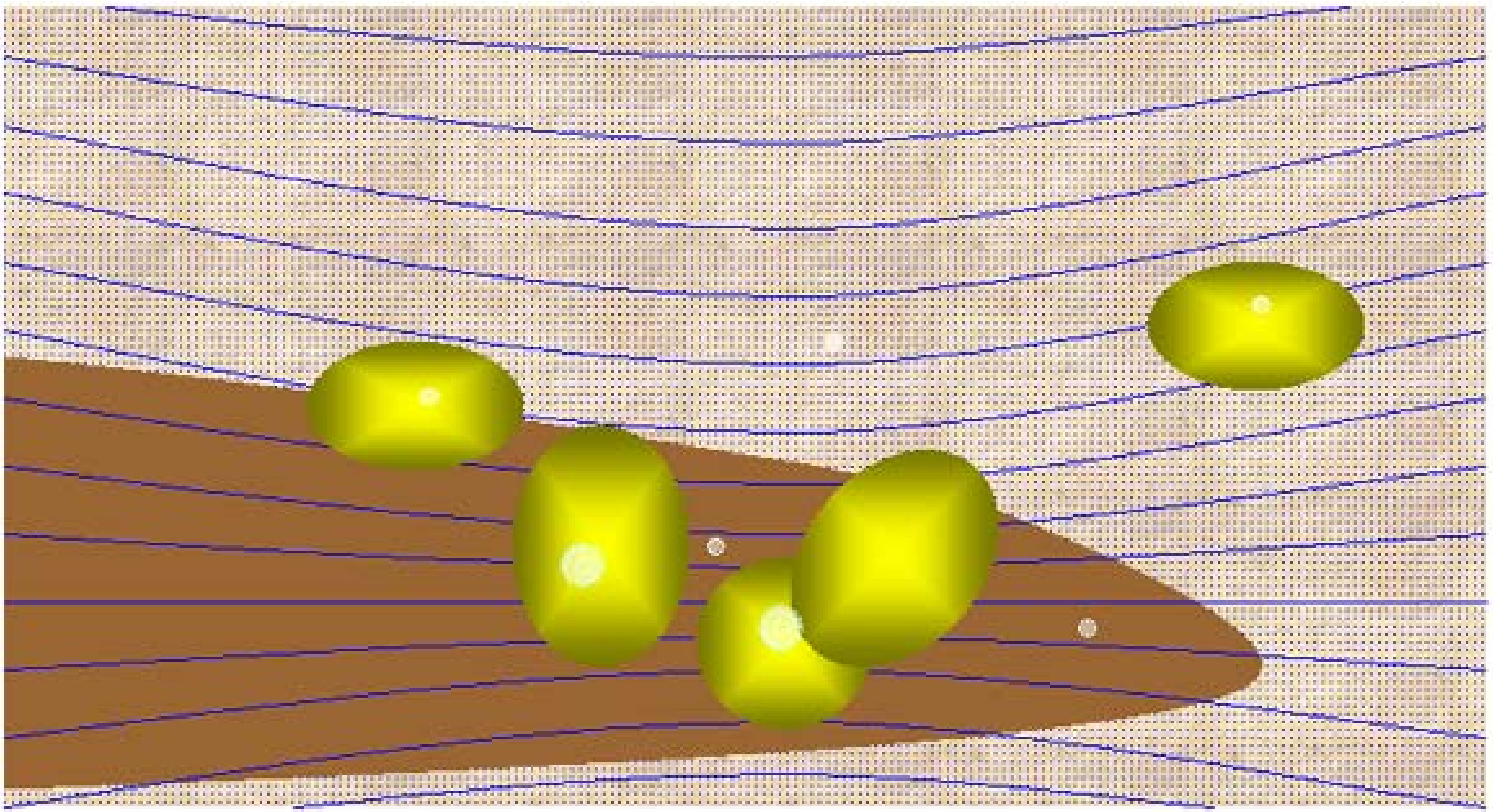
In-Situ Steam Generation

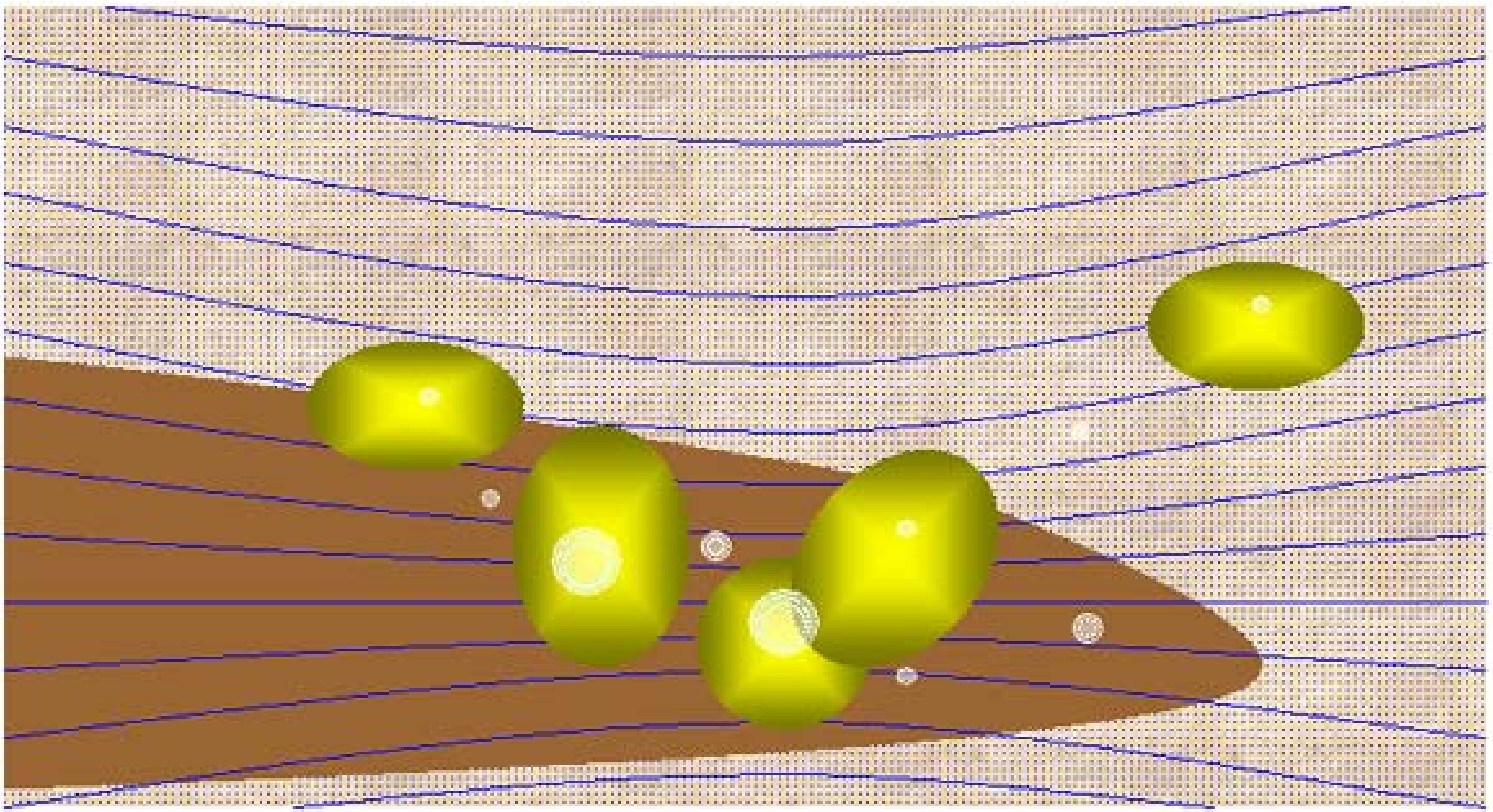


Steam bubbles form more quickly at DNAPL due to interfacial tension and reduced boiling temperatures.

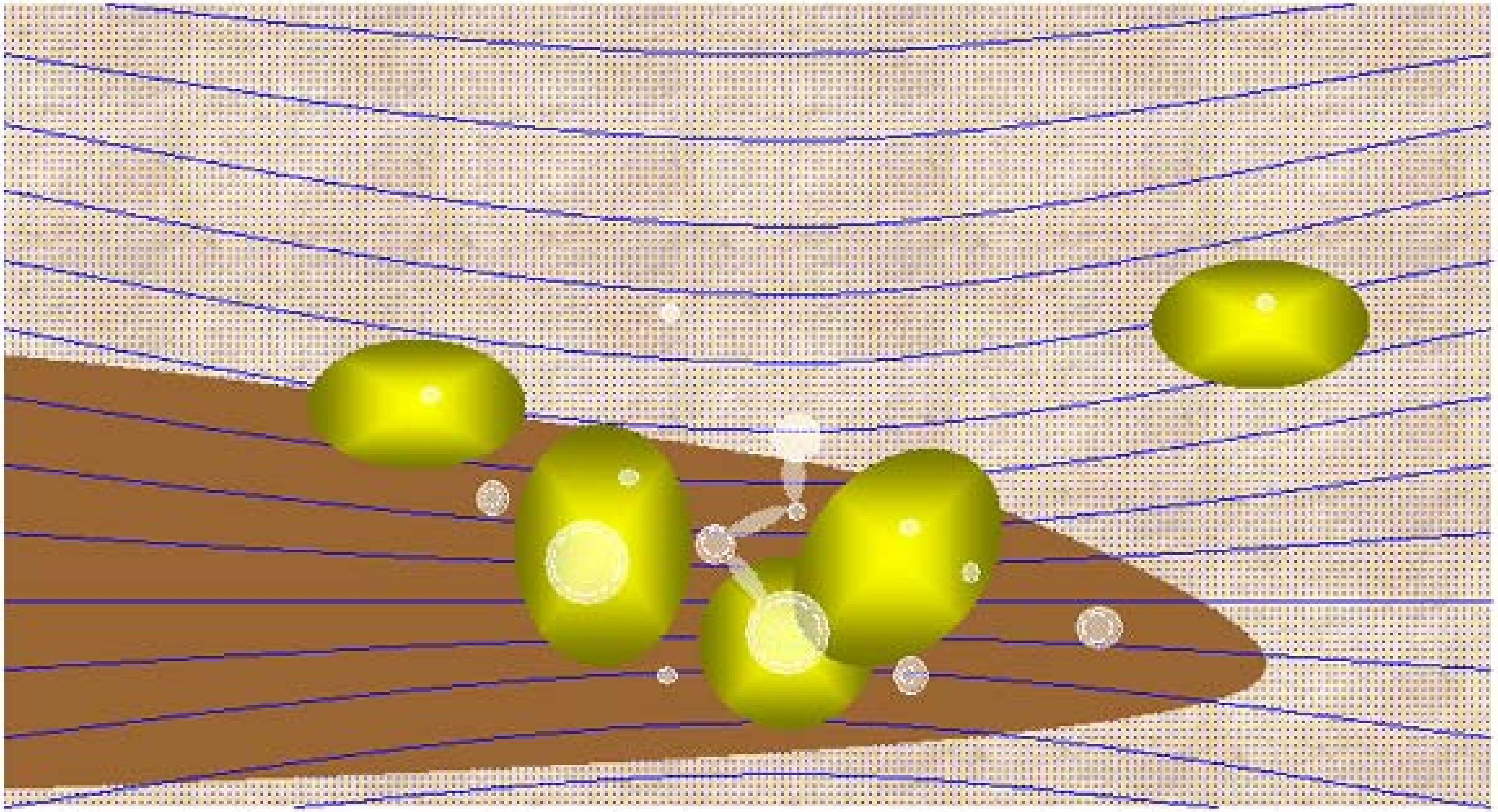
In-Situ Steam Generation



In-Situ Steam Generation



In-Situ Steam Generation

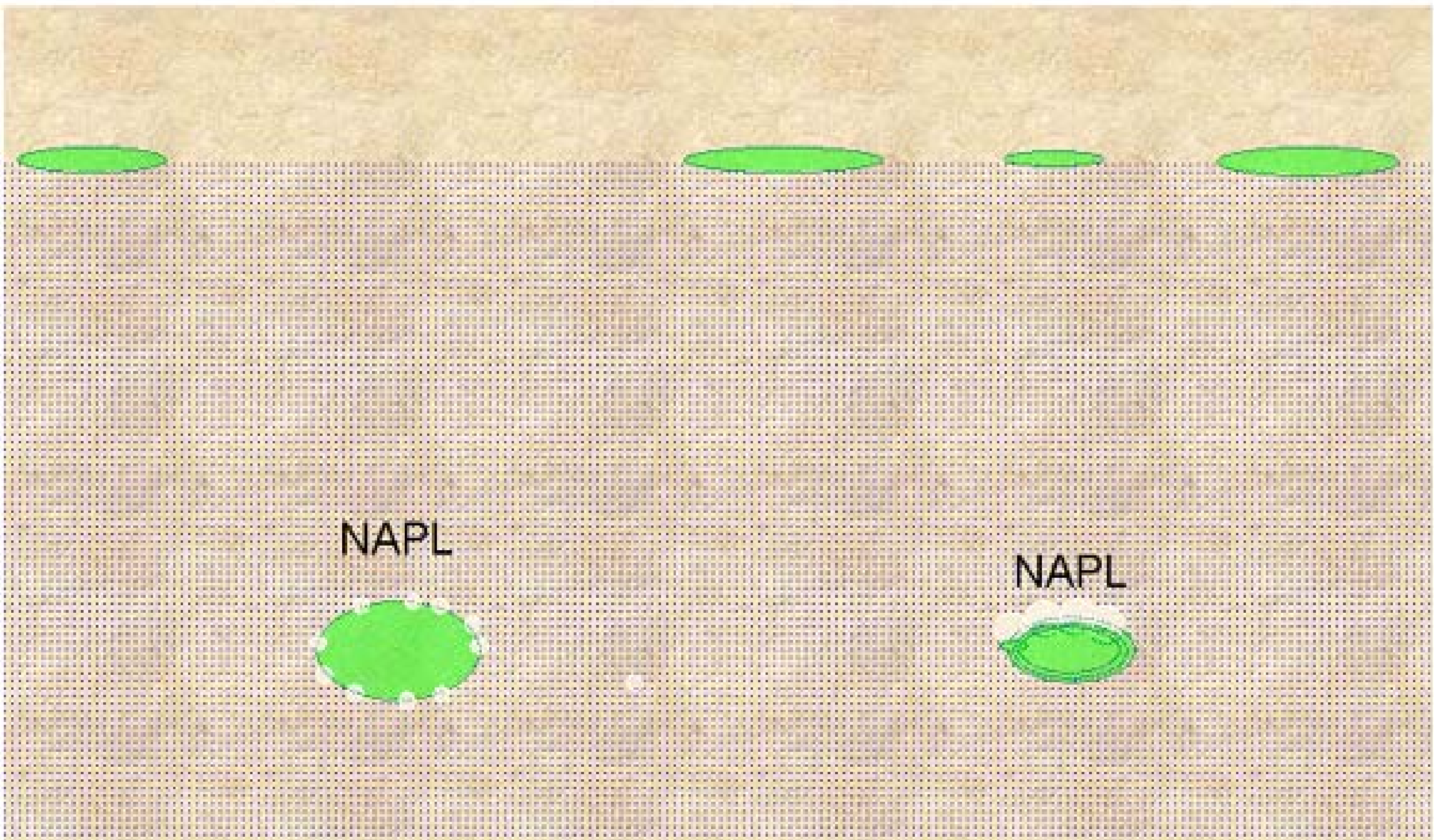


Steam bubbles can vent via soil fractures or by bridging from bubble to bubble.

Reasons to Heat Low Volatility NAPLs

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

Steam Bubble Floatation

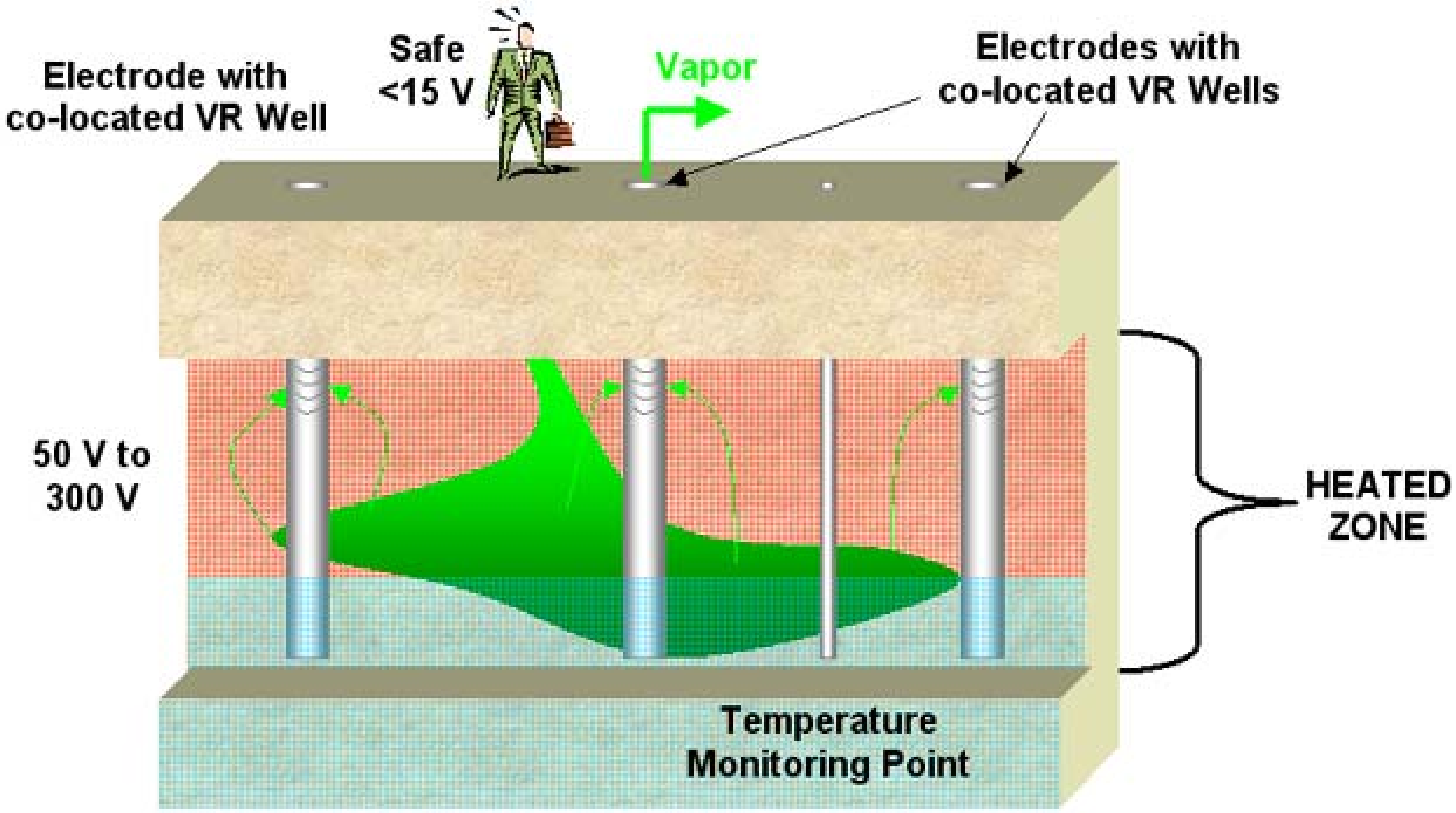


"Life preserver" of small bubbles lift NAPL to groundwater surface.
Or small bubbles break away and lift NAPL droplets.

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

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

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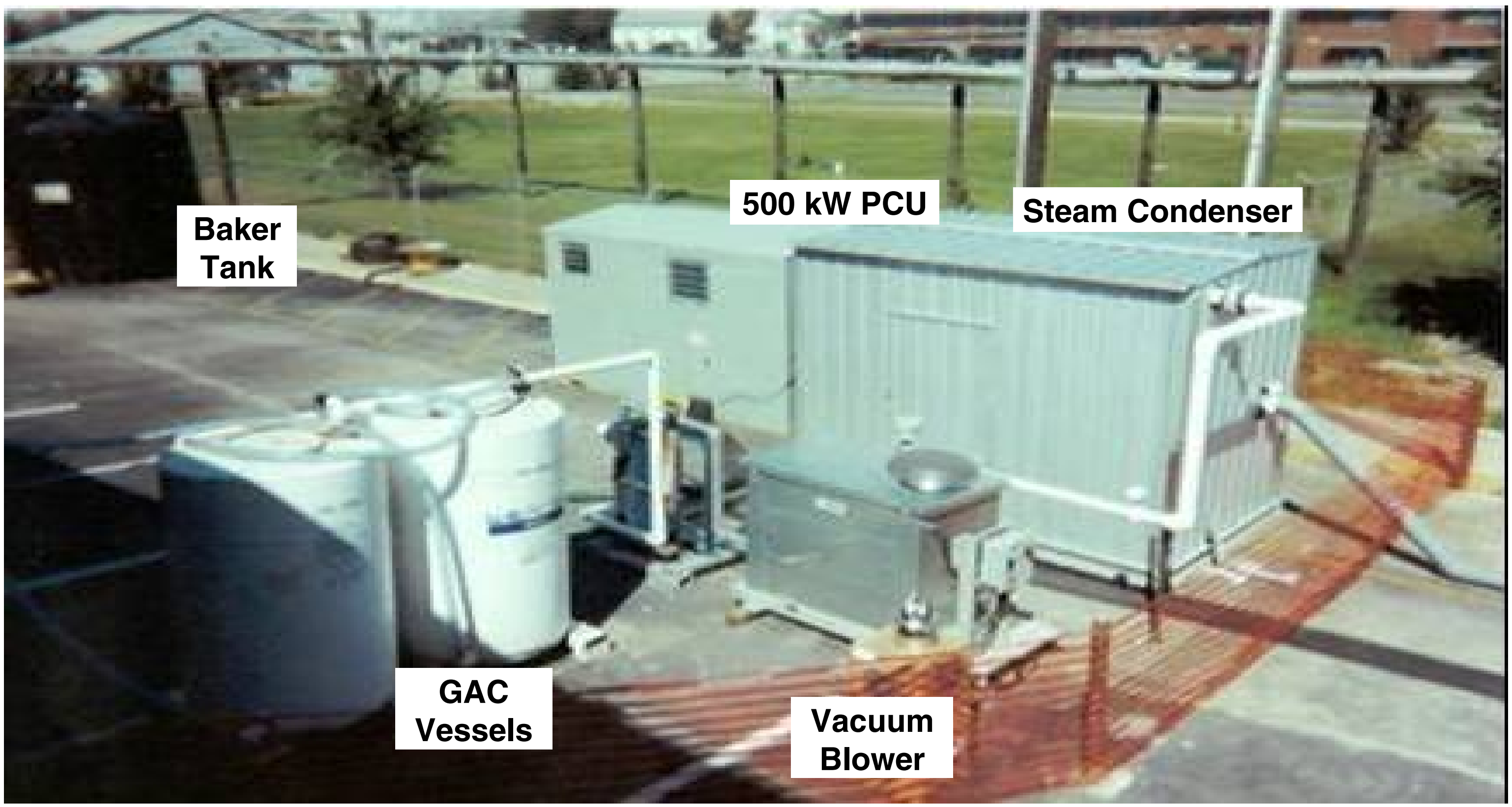
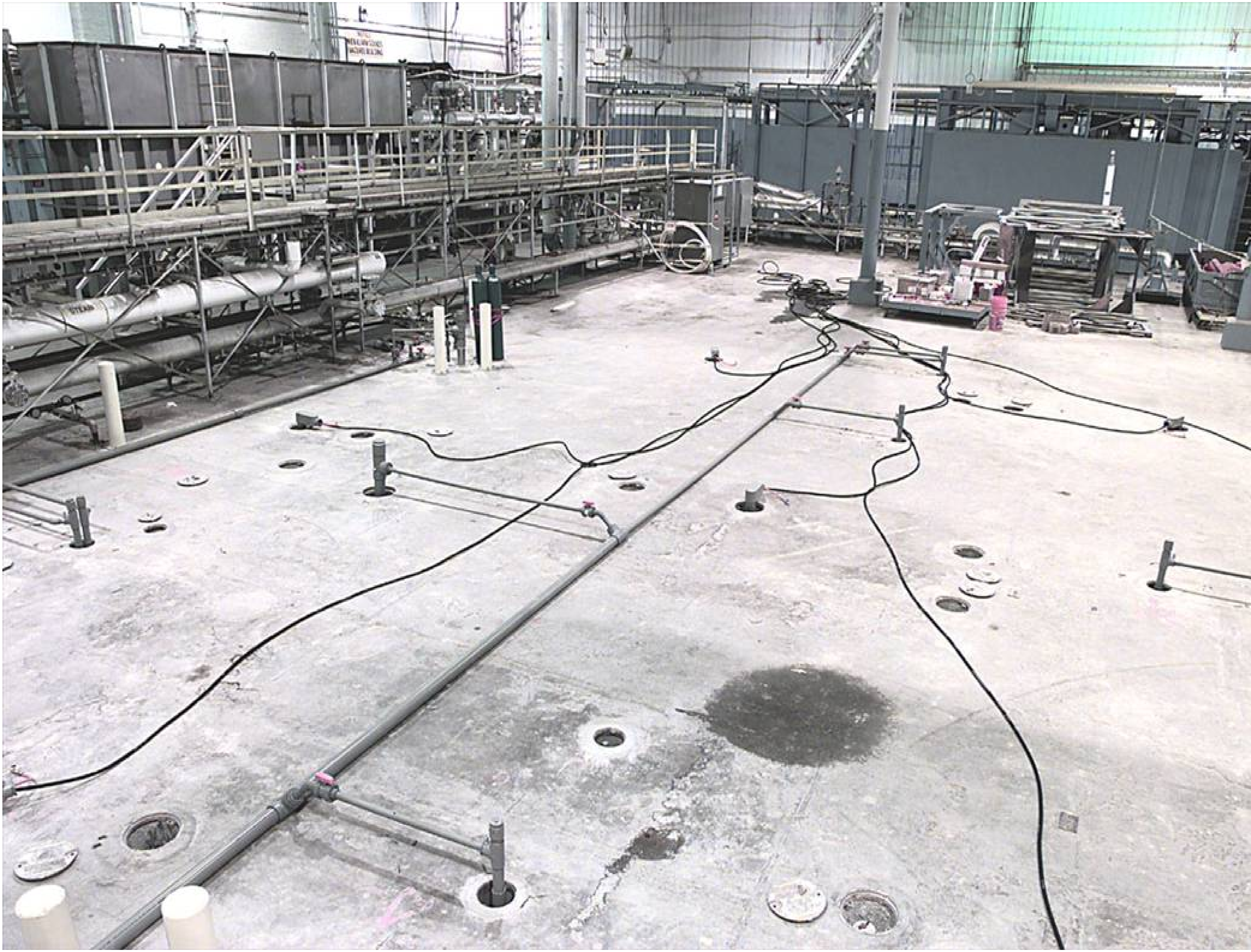
Applications

- 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 and hazardous waste drums

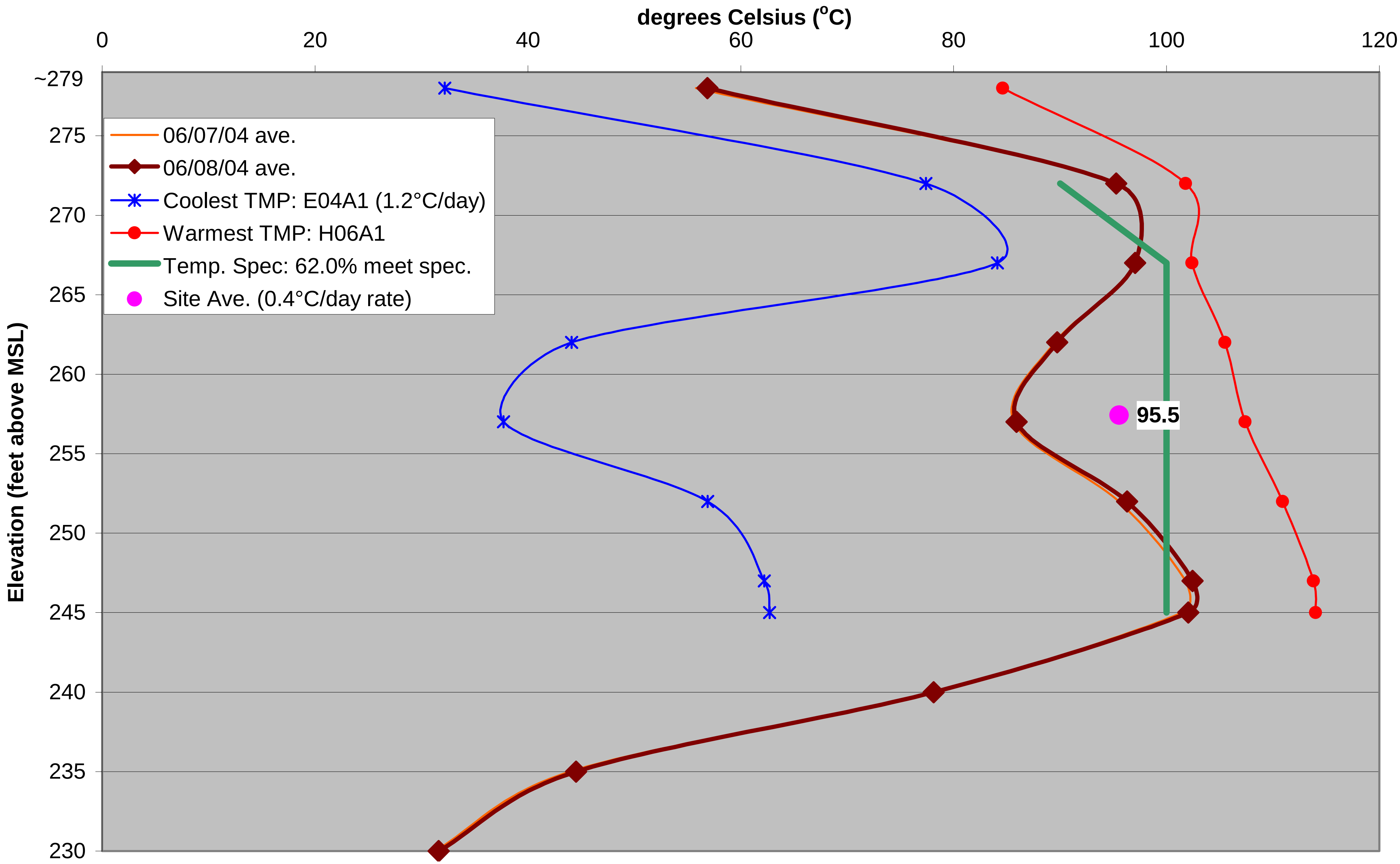
ERH Equipment Staging



CPVC pipe from wells



Fort Lewis Temperatures



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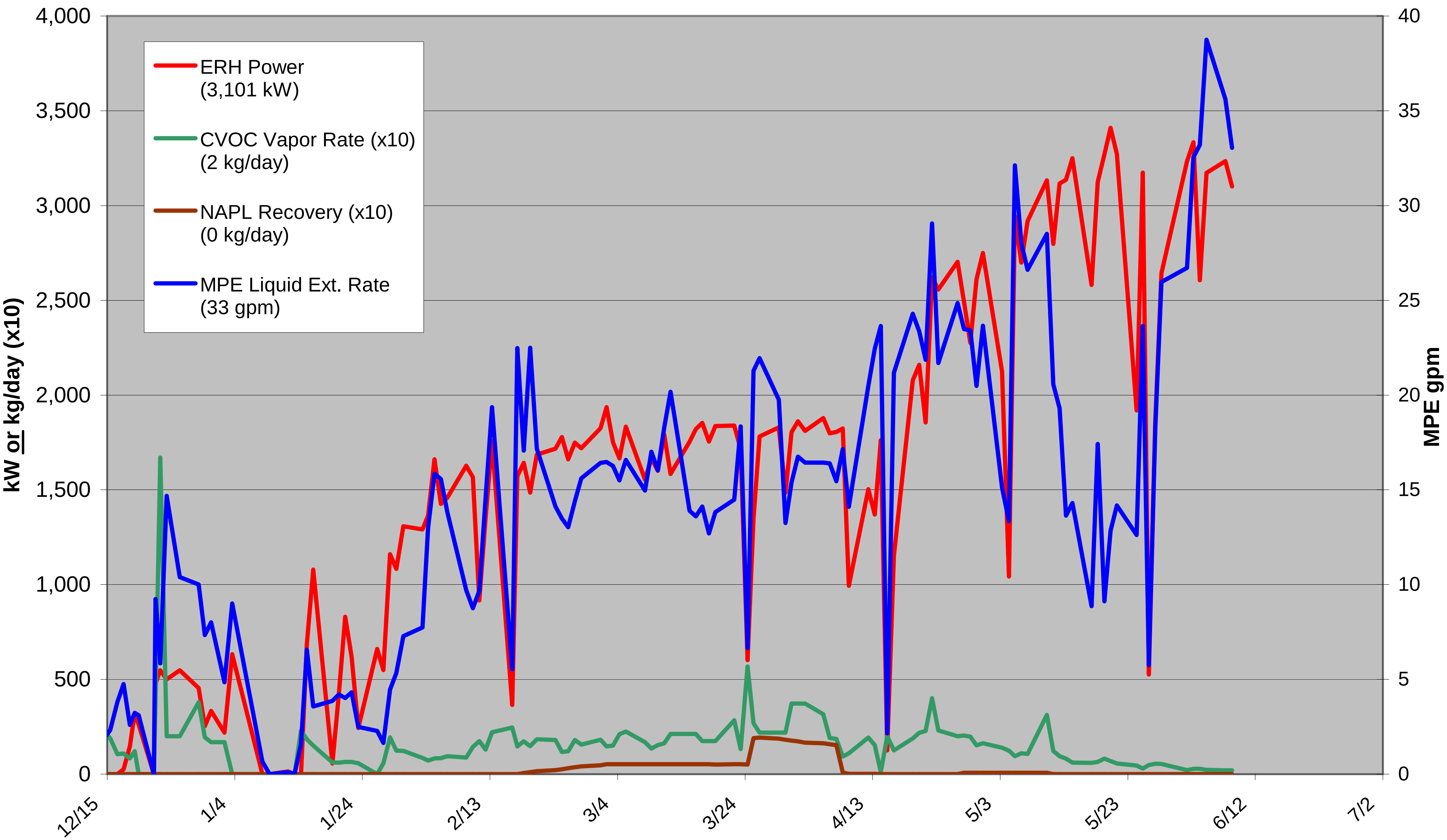
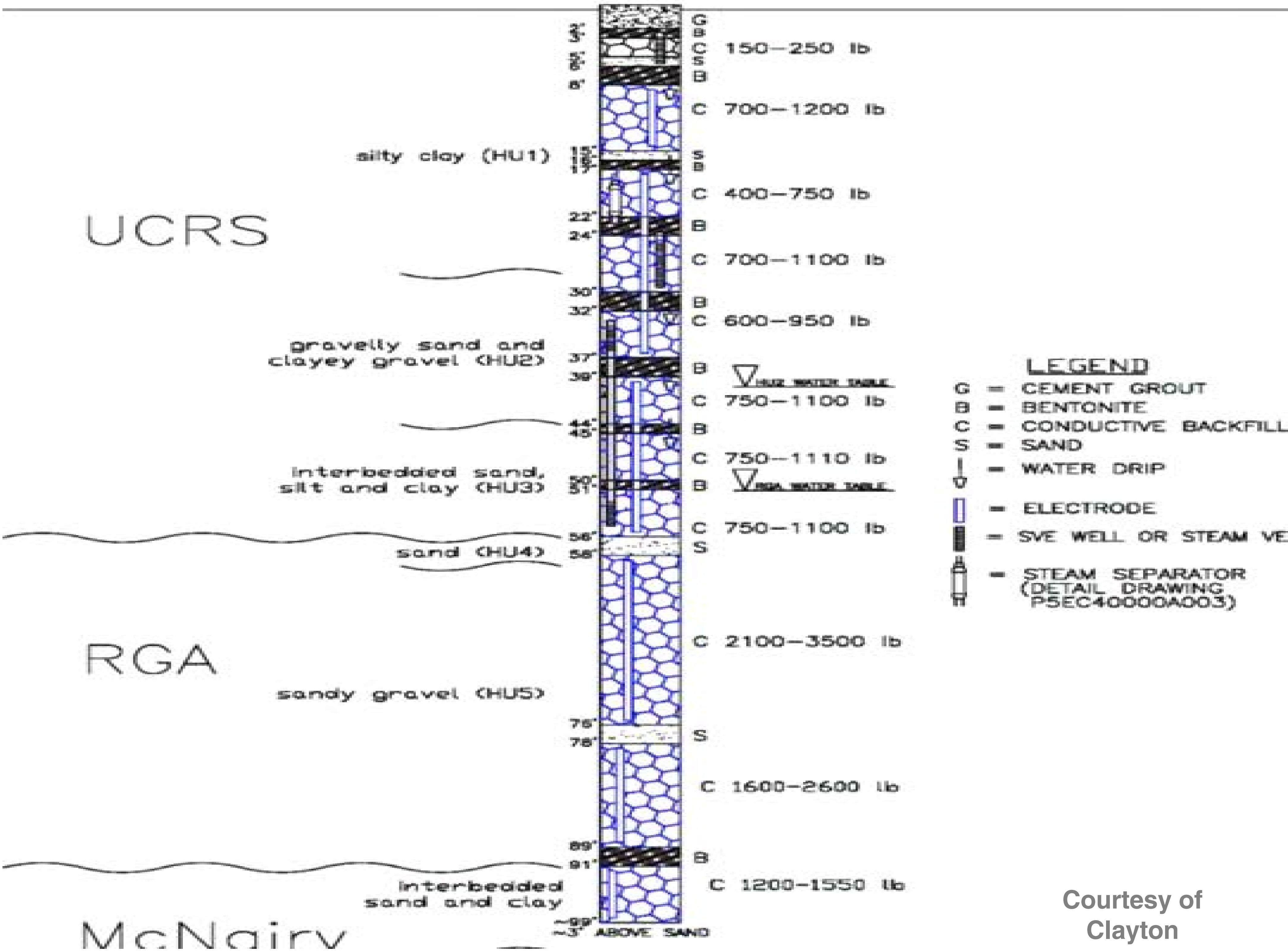
Fort Lewis

Remediation Rates Daily Averages through 06/08/04



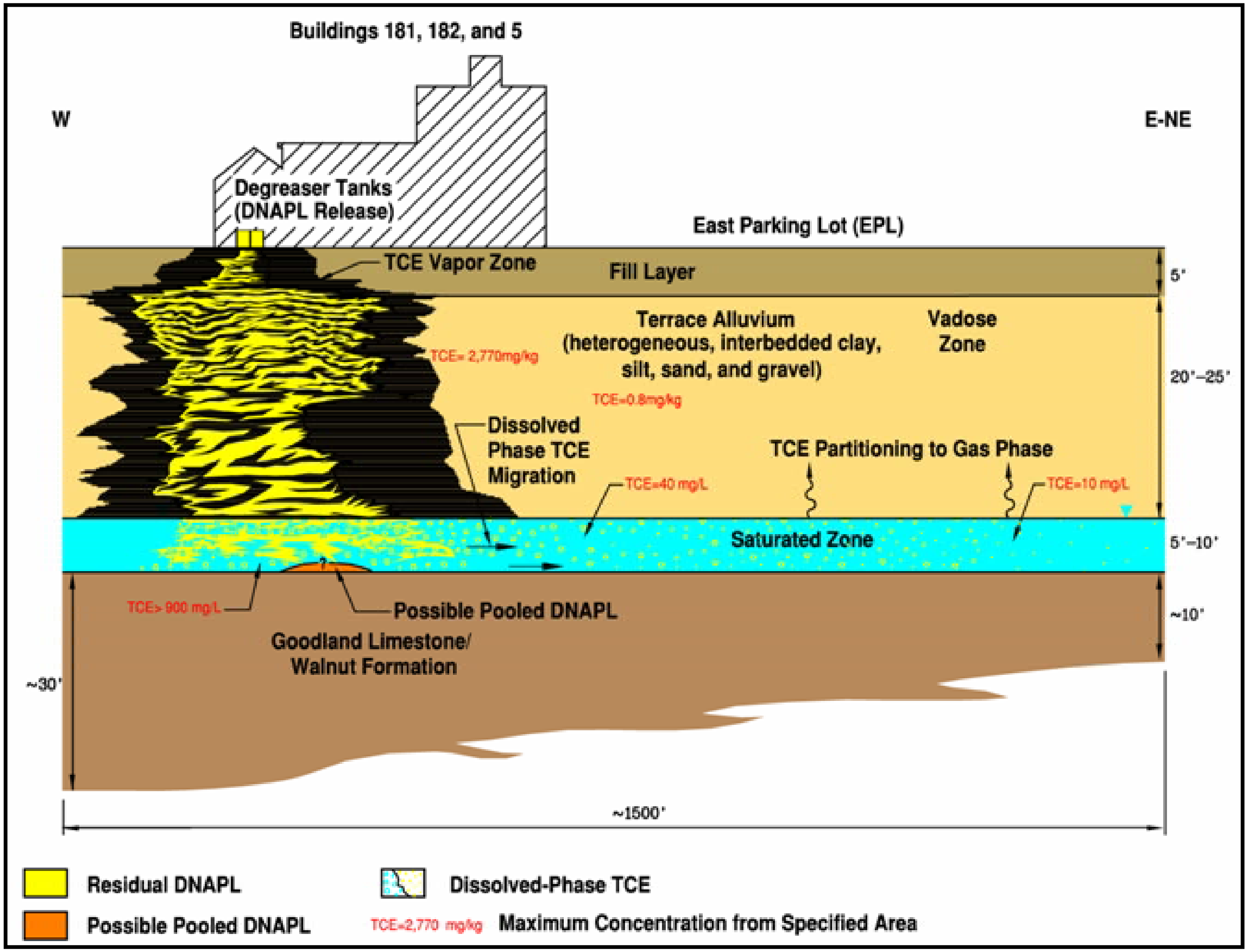


Courtesy of Clayton

Site Background

- Air Force Plant 4 (AFP4) is an active military aircraft manufacturing facility in Fort Worth, Texas
- Releases from degreaser tanks are the source of the groundwater plume
- Site evidence of DNAPL
- Source Area defined as:
  - >10 mg/L TCE in groundwater
  - >11.5 mg/Kg TCE in soil

Building 181 and EPL Conceptual Site Model



Areas of Soil and Groundwater Contamination

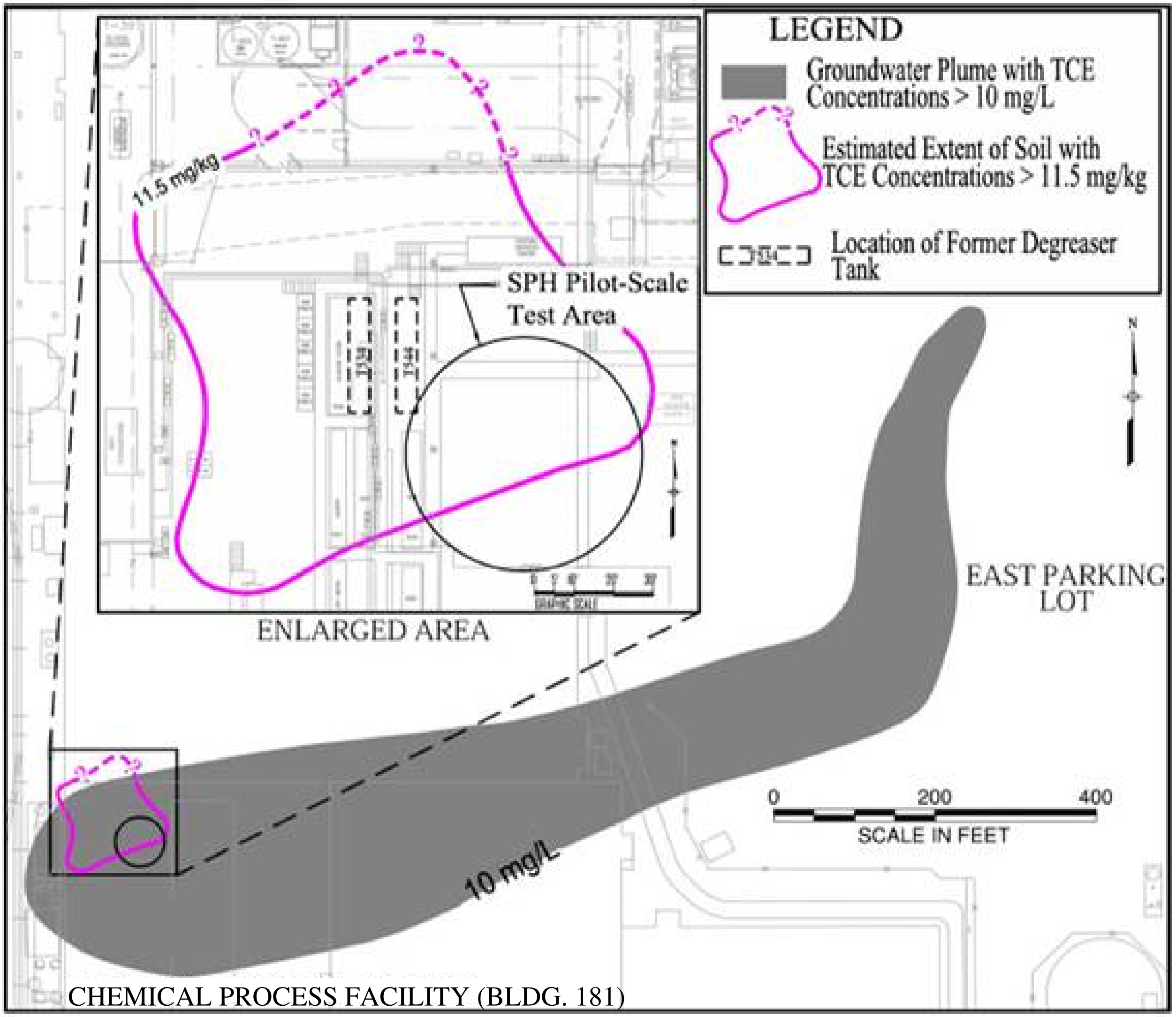
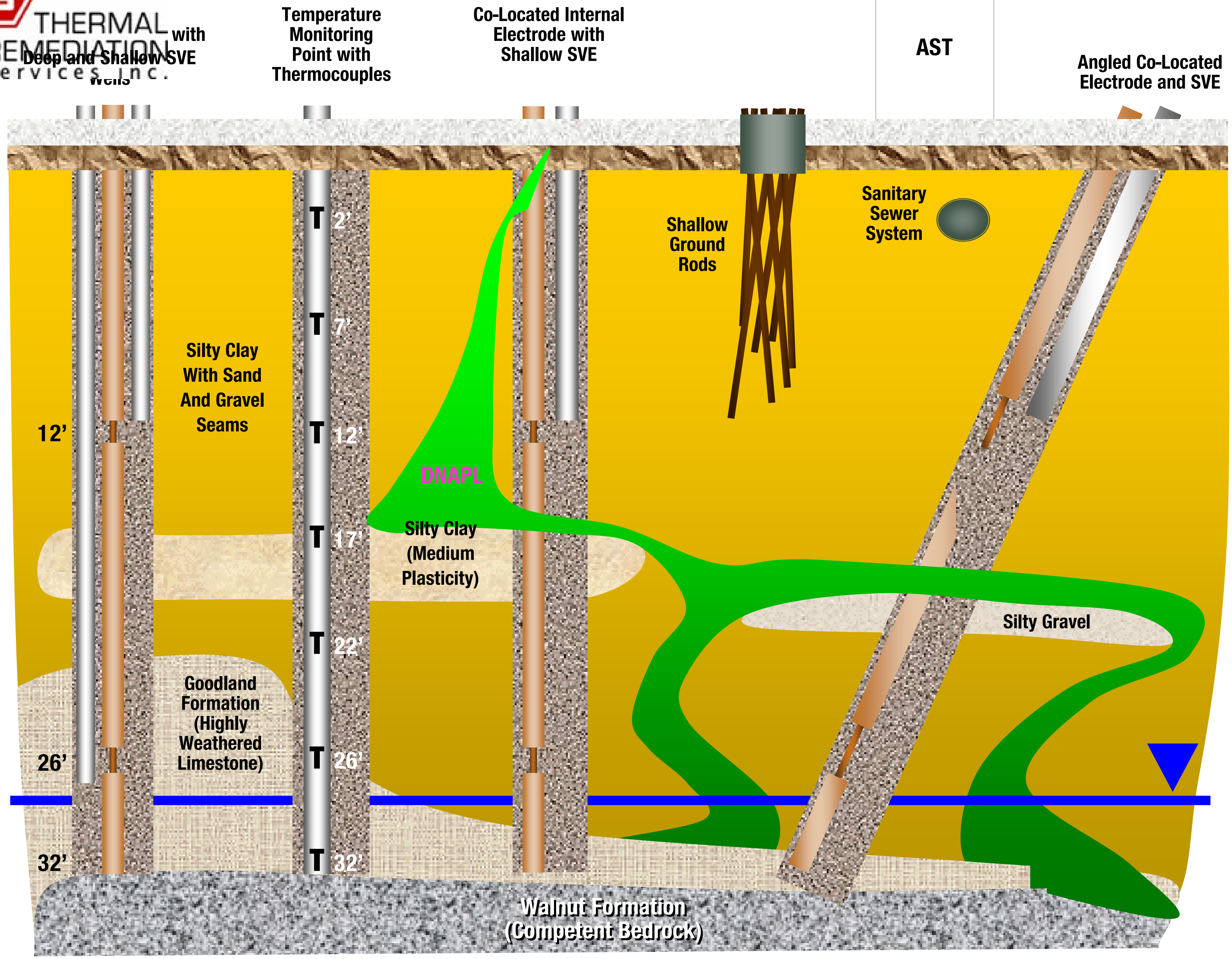



Photo
Courtesy of
URS

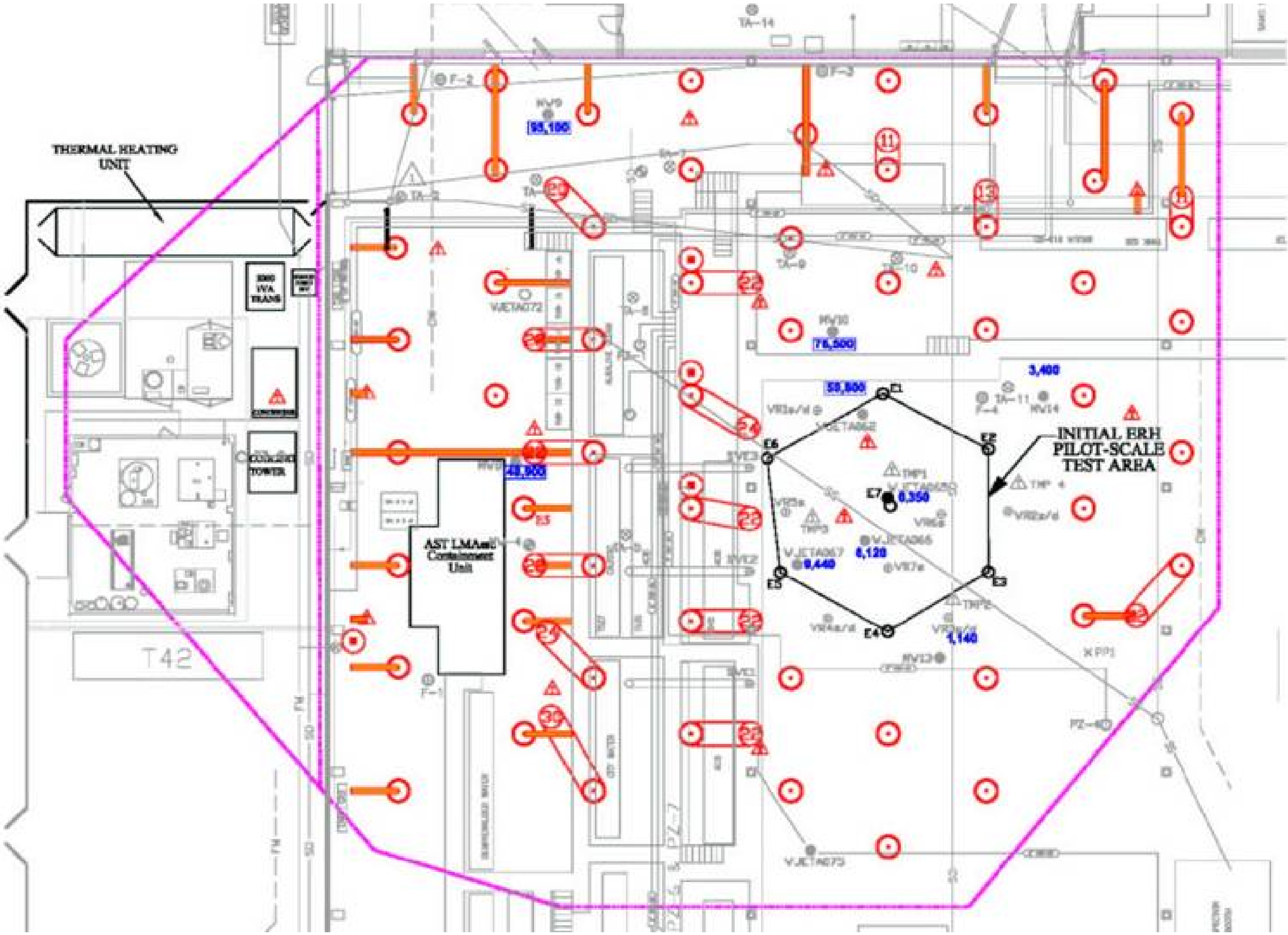
Expanded ERH Application

– 63 electrodes w/ 92 SVE wells
– Covers a 1/2 acre area inside Building 181
– Above and below grade piping network conveys soil vapor and steam to water cooled condenser
– Condensate sent to existing air stripper for treatment and discharge to POTW

ERH Subsurface Cross Section

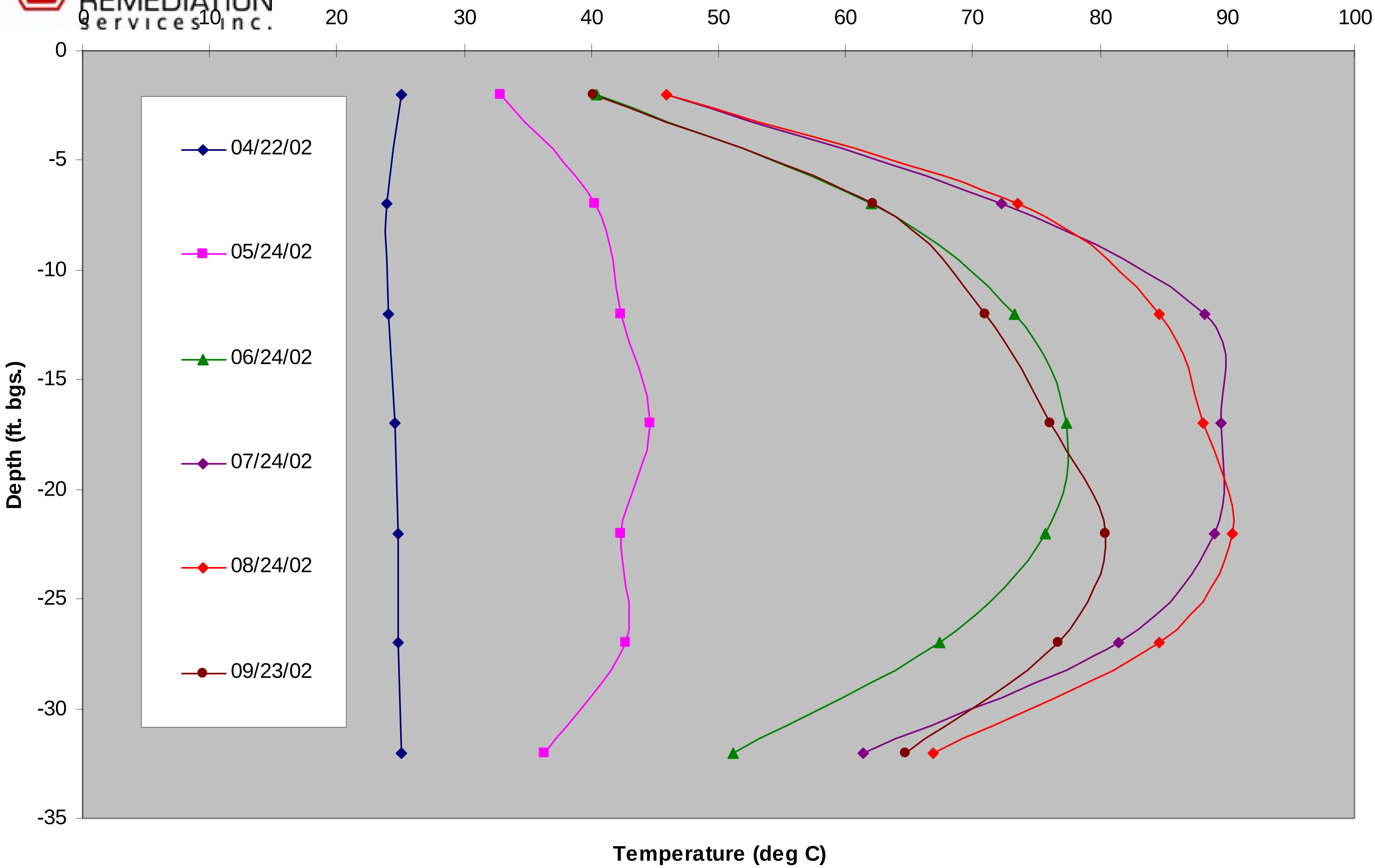


ERH Application

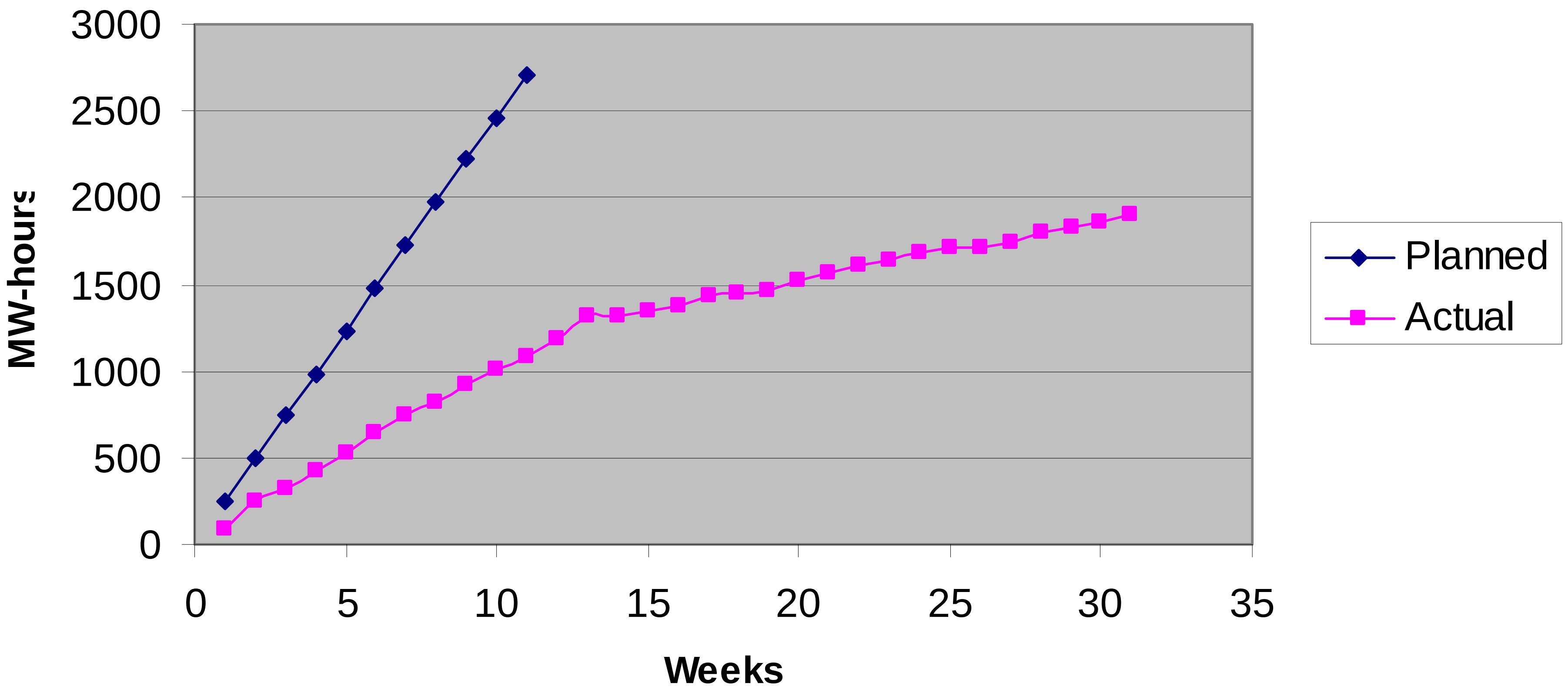


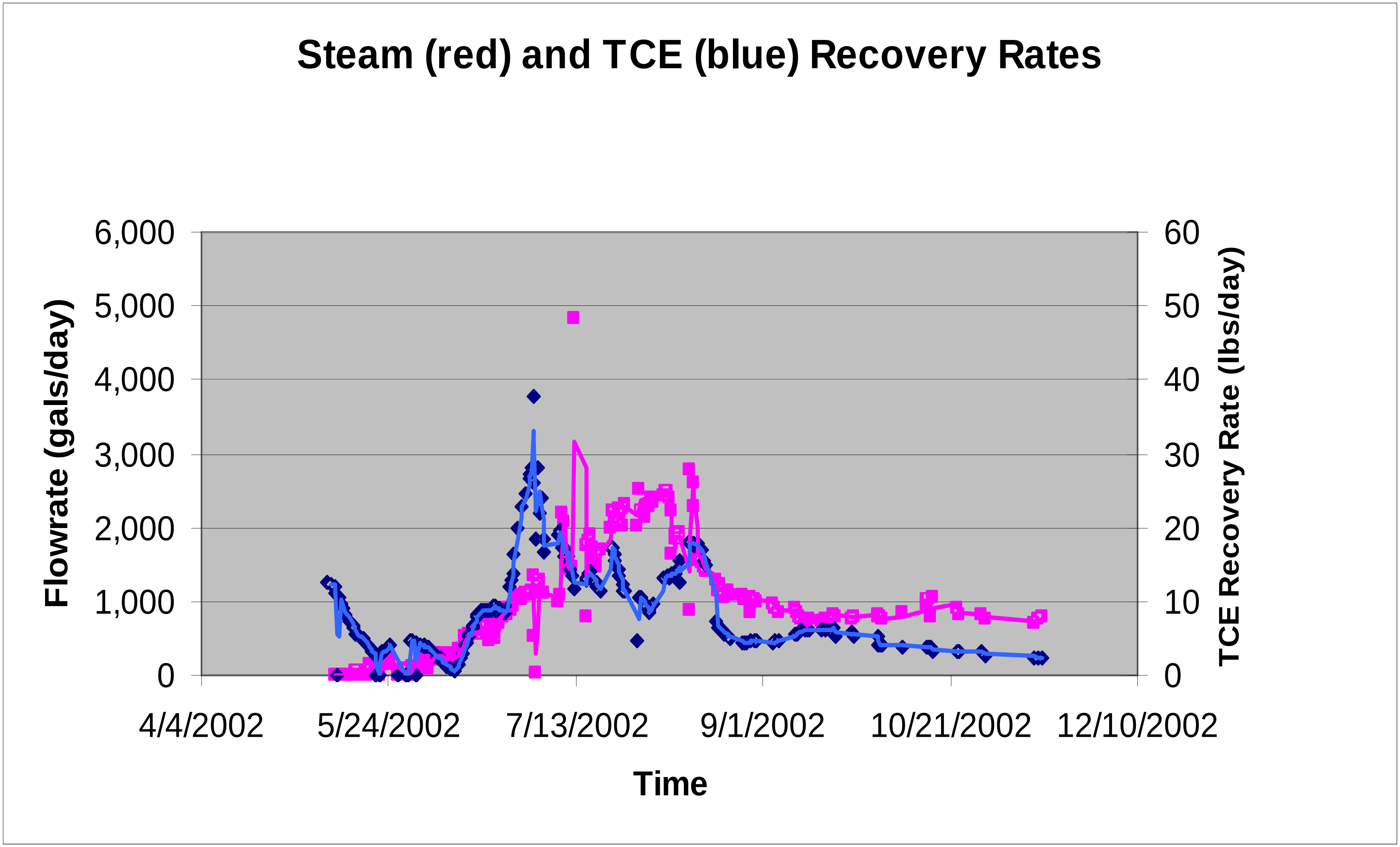
ERH Application
Angle Drilling

Monthly Average
Temperature vs. Depth

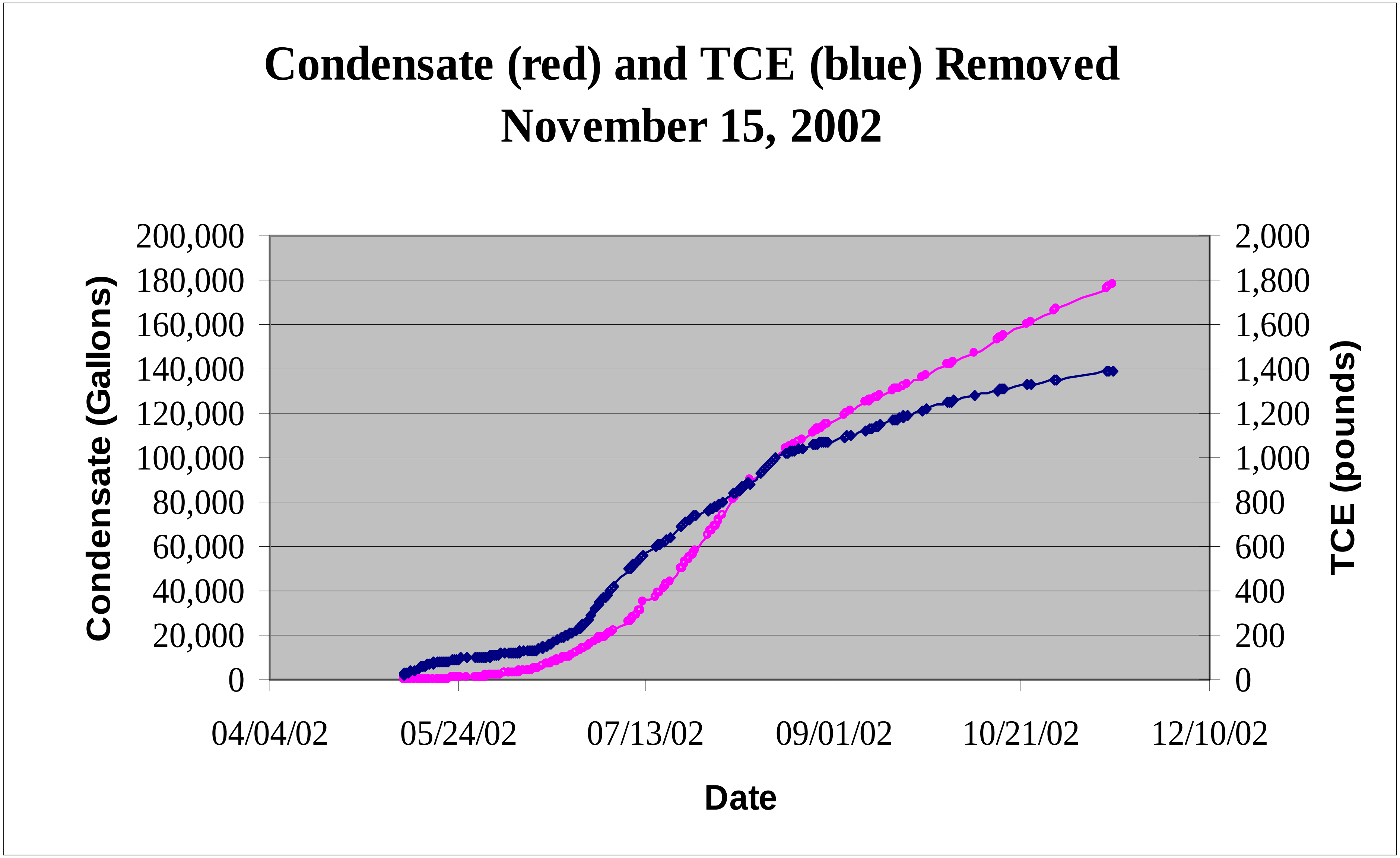


Input Power Planned vs Actual

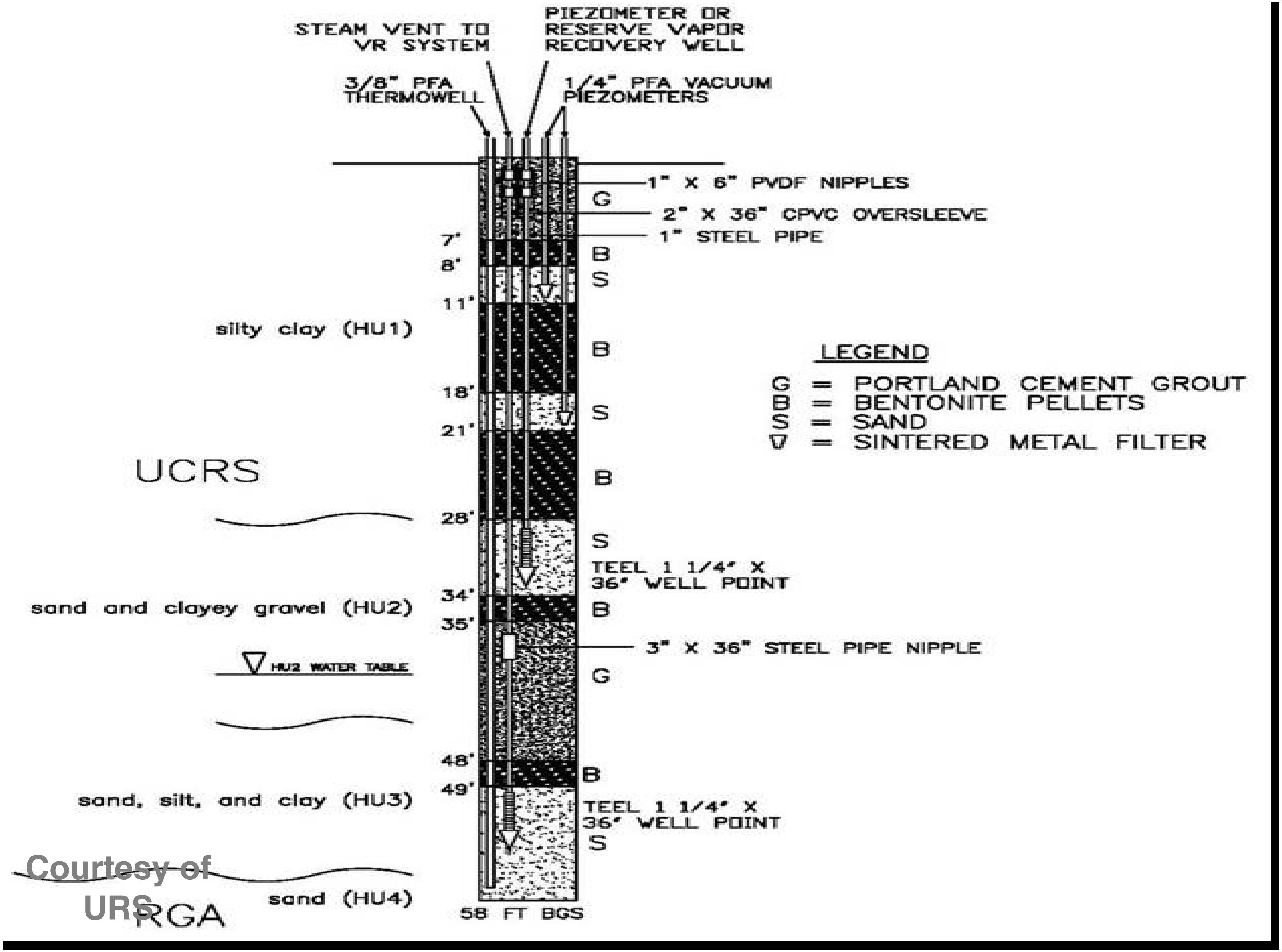




Steam (red) and TCE (blue) Recovery Rates
6,000
5,000
4,000
3,000
2,000
1,000
0
60
50
40
30
20
10
0
Flowrate (gals/day)
TCE Recovery Rate (lbs/day)
4/4/2002
5/24/2002
7/13/2002
9/1/2002
10/21/2002
12/10/2002
Time



Condensate (red) and TCE (blue) Removed
November 15, 2002
Condensate (Gallons)
200,000
180,000
160,000
140,000
120,000
100,000
80,000
60,000
40,000
20,000
0
TCE (pounds)
2,000
1,800
1,600
1,400
1,200
1,000
800
600
400
200
0
04/04/02
05/24/02
07/13/02
09/01/02
10/21/02
12/10/02
Date

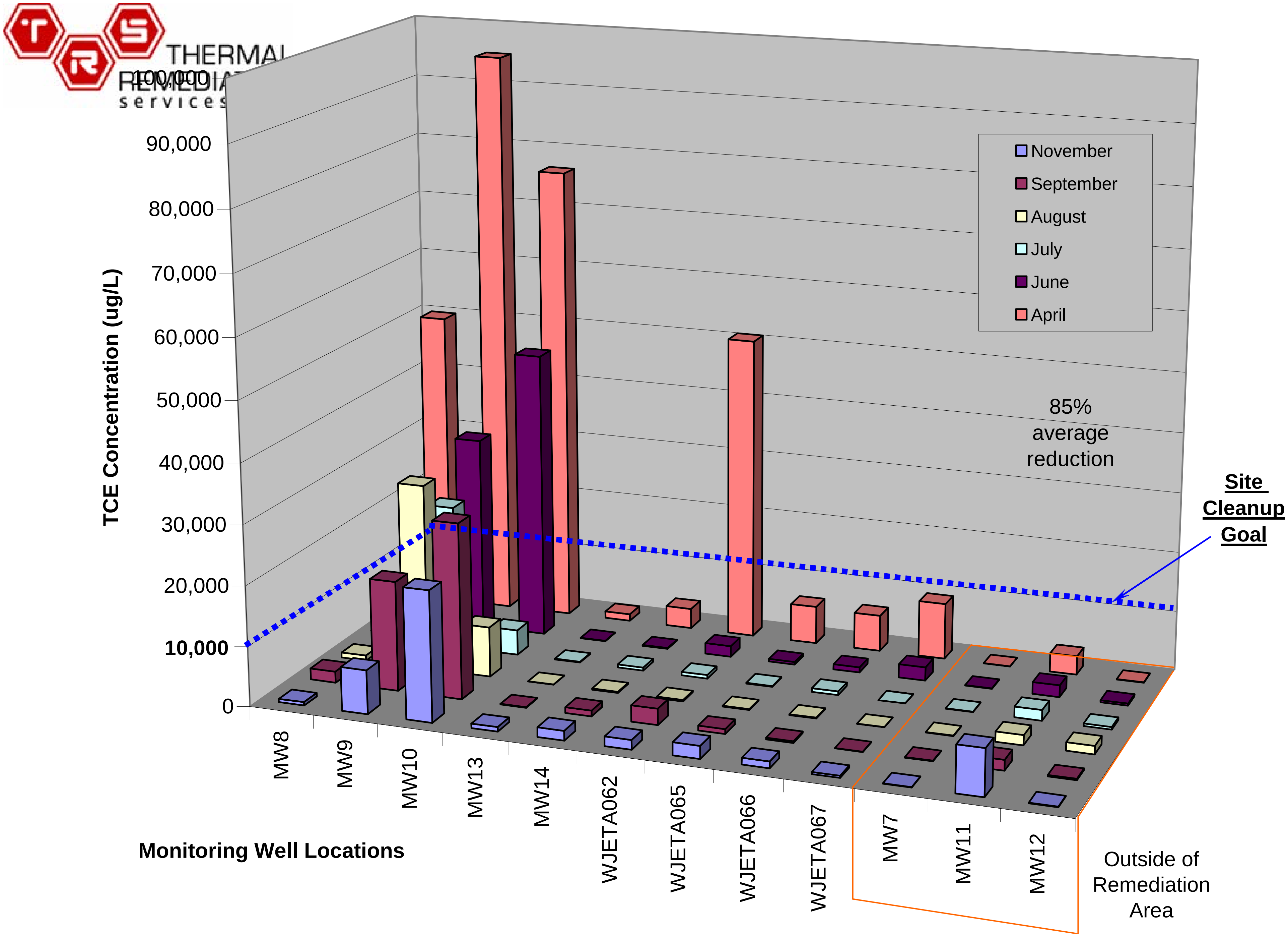


Courtesy of URS

Test Results
Groundwater

- Groundwater samples collected from 10 wells before, during, and after heating
  - Mean TCE concentration reduced by 95% (73.4 to 3.6 mg/L)
  - 95% UCL TCE concentration reduced by 96% (129 to 5.7 mg/L)
- Final 95% UCL TCE concentration in groundwater < 10 mg/L
- Increase in chloride concentrations indicate enhanced biodegradation of TCE

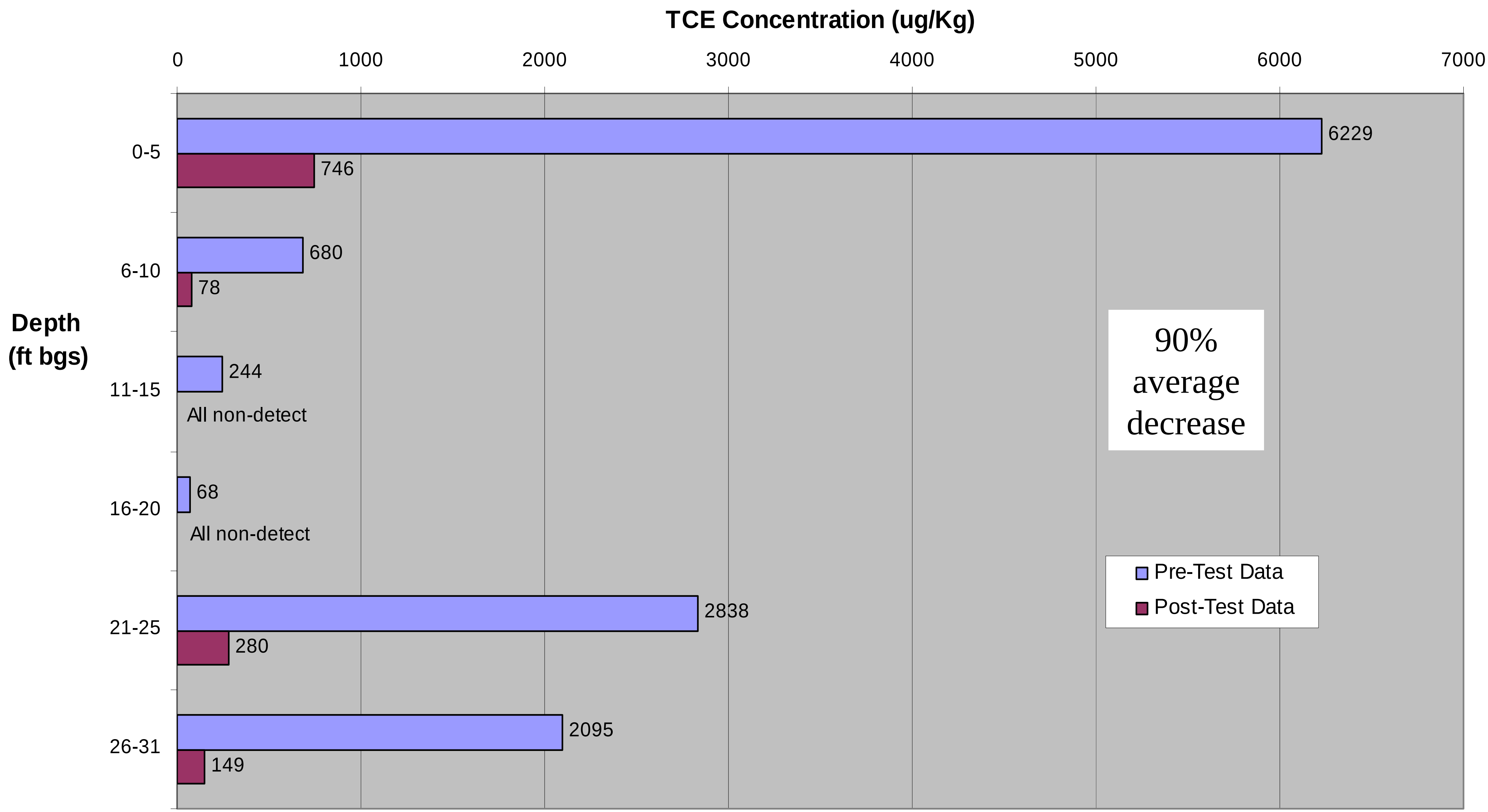
April – Nov. 2002



Test Results
Soils

- Soil samples collected before and after heating using Encore method
  - Paired sampling from 52 intervals (5 or 6 depths at 10 locations)
  - Mean TCE concentration reduced by 91% (2.2 to 0.17 mg/kg)
- Soil concentrations at the 95% UCL were reduced to 0.28 mg/kg, far under the goal of 11.1 mg/kg

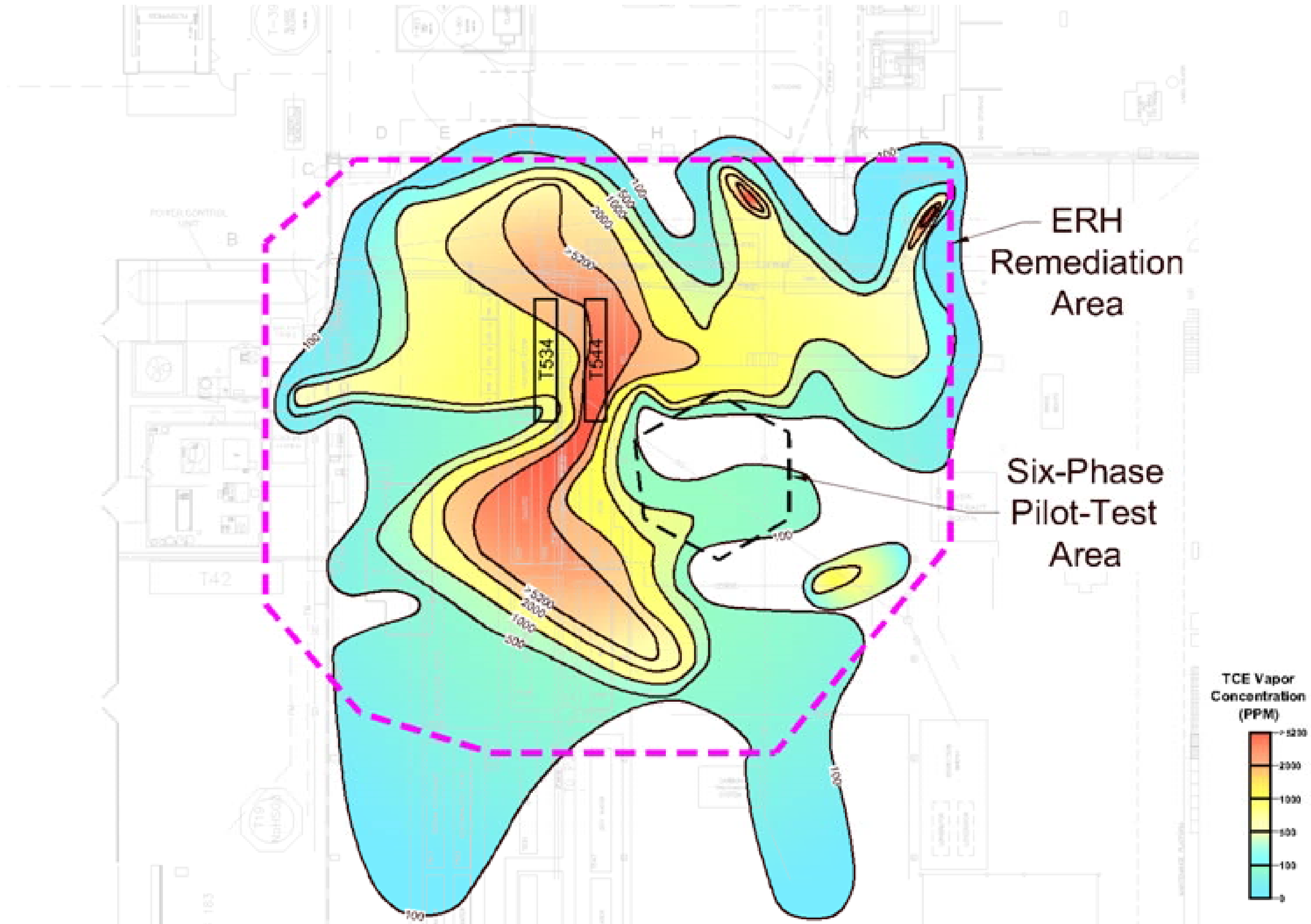
Average Soil Concentration With Depth



Test Results
Soil Vapor

- Soil vapor samples were collected before and after heating:
  - Mean TCE concentration reduced by 93% (1049 to 73.4 ppm)
  - Marked reduction in the area of vapor plume greater than 100 ppm
  - Maximum result decreased from >5200 to 1358 ppm

Pre-Test
Soil Vapor Results



Post-Test
Soil Vapor Results

Conclusions

- Total power input into the subsurface - 1.899 MWh (about $95,000 for electricity)
- Total condensate removed from the subsurface – 177,711 gals
- Total TCE removed from the subsurface – 1391 lbs
- Total soil borings that achieved cleanup goals – 10 of 10
- Total monitoring wells that achieved cleanup goals - 8 of 9
- 95% UCL for groundwater met goal in difficult bedrock environment

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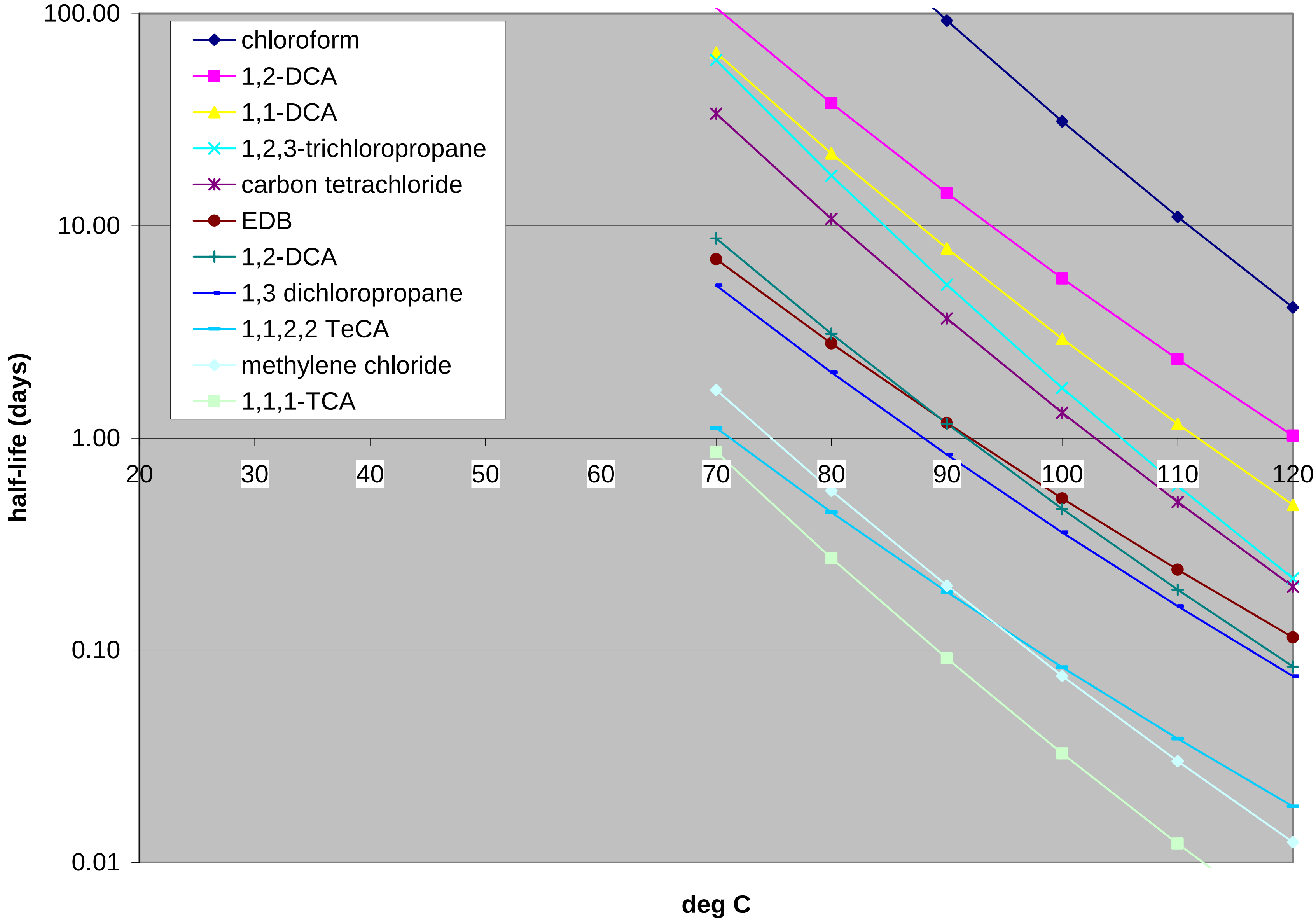
Polishing Mechanisms

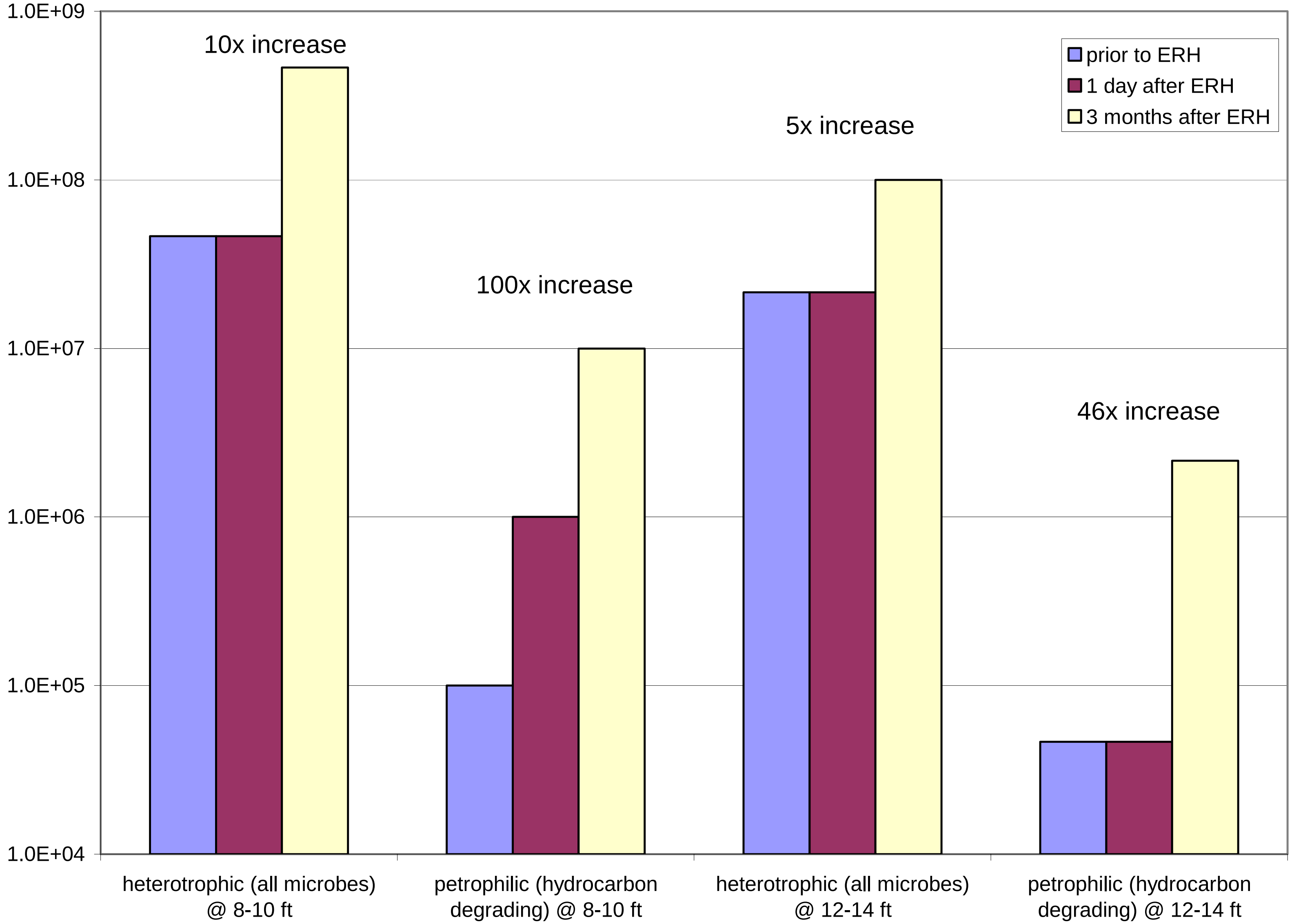
- Hydrolysis of Halogenated Alkanes
  - Compounds such as TCA have a hydrolysis half-life of less than one day at steam temperatures.
- Iron Reductive Dehalogenation
  - Steel shot used as electrode backfill provides an iron source for reductive dehalogenation (iron filing wall)
- Temperature Accelerates Reactions
  - The above reaction rates are increased by factor of thousands at 100°C (Arrhenius Equation)
- Bioremediation Enhancement
  - Heating makes hydrocarbons more bioavailable and most degraders prefer 35-70°C

Hydrolysis

Water Substitution Reaction



Microbe Counts
Average of Three Wells



LNAPL Remediation Initial Conditions

- Up to 10 feet of viscous LNAPL, most wells had 2-3 feet
- LNAPL was a specialty fuel
  - volatility - between kerosene and diesel
  - viscosity - similar to diesel fuel
- Very heterogeneous, low permeability saprolite soil
- Water table at 25 feet below grade

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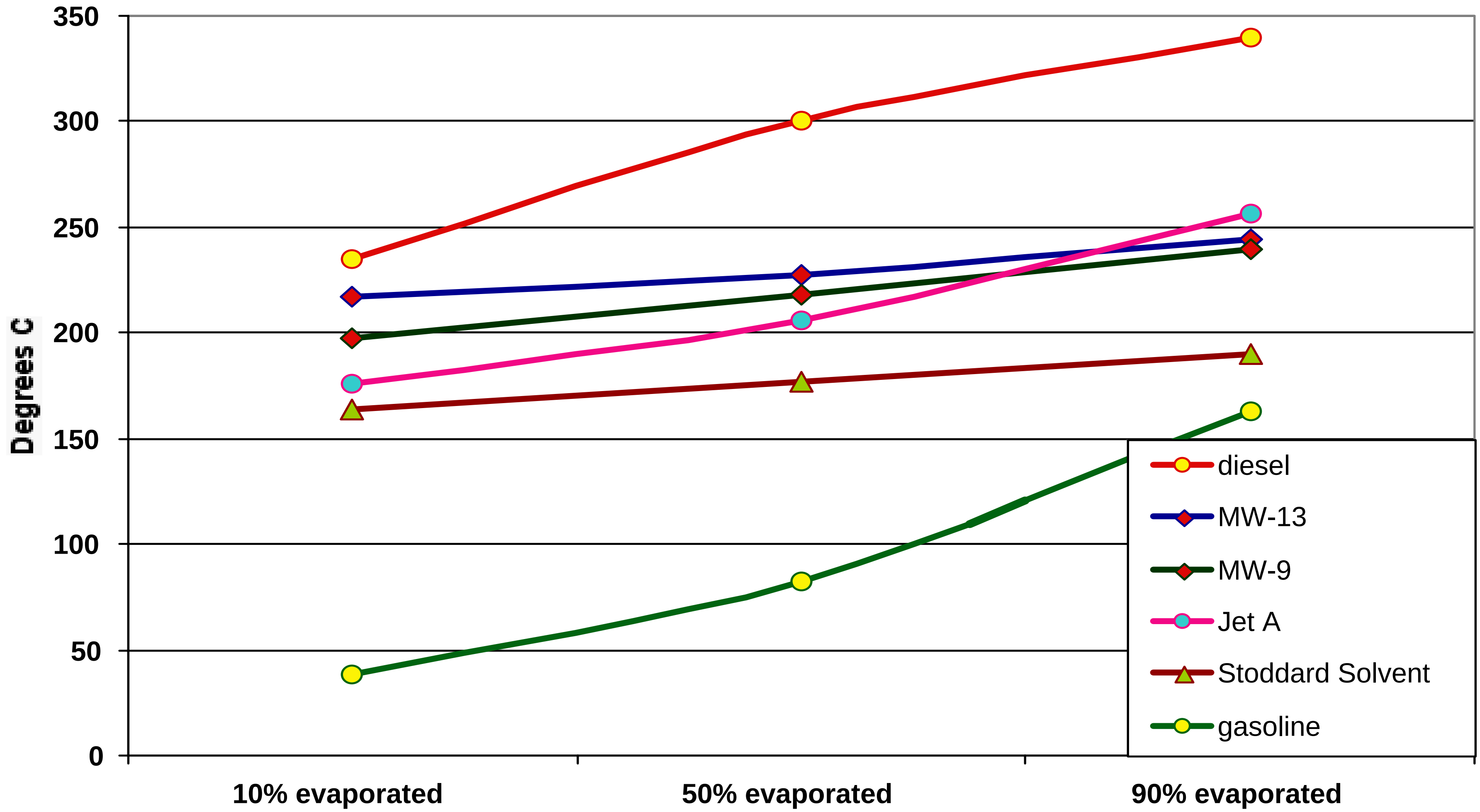
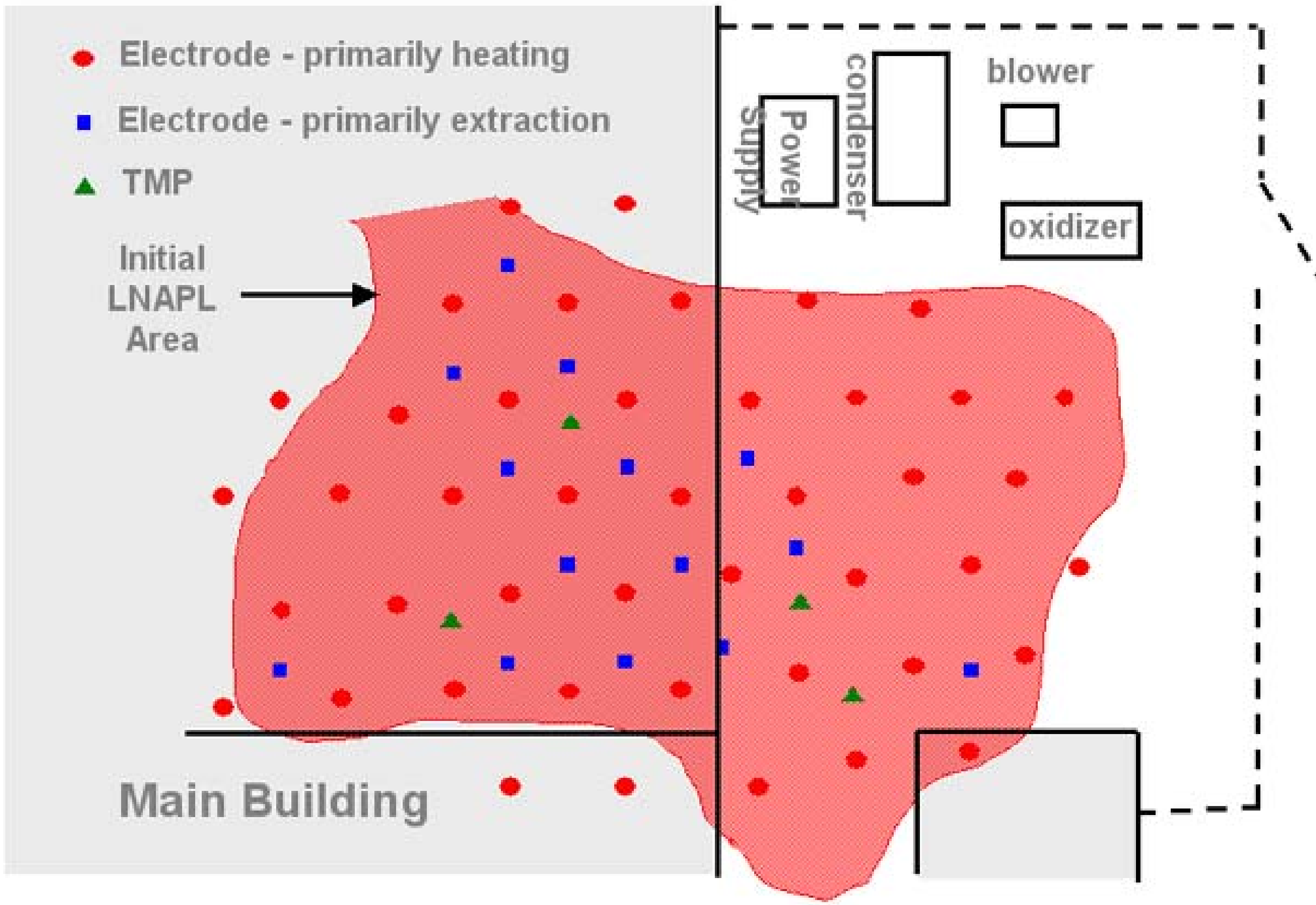
Initial Conditions

- Goals
  - Reduce thickness to less than 1/8” in all wells
  - GW remediation a side benefit
  - Short time frame
  - Minimize rebound

Boiling Point Distribution



Atlanta - Viscous LNAPL Remediation



Typical Electrode Head

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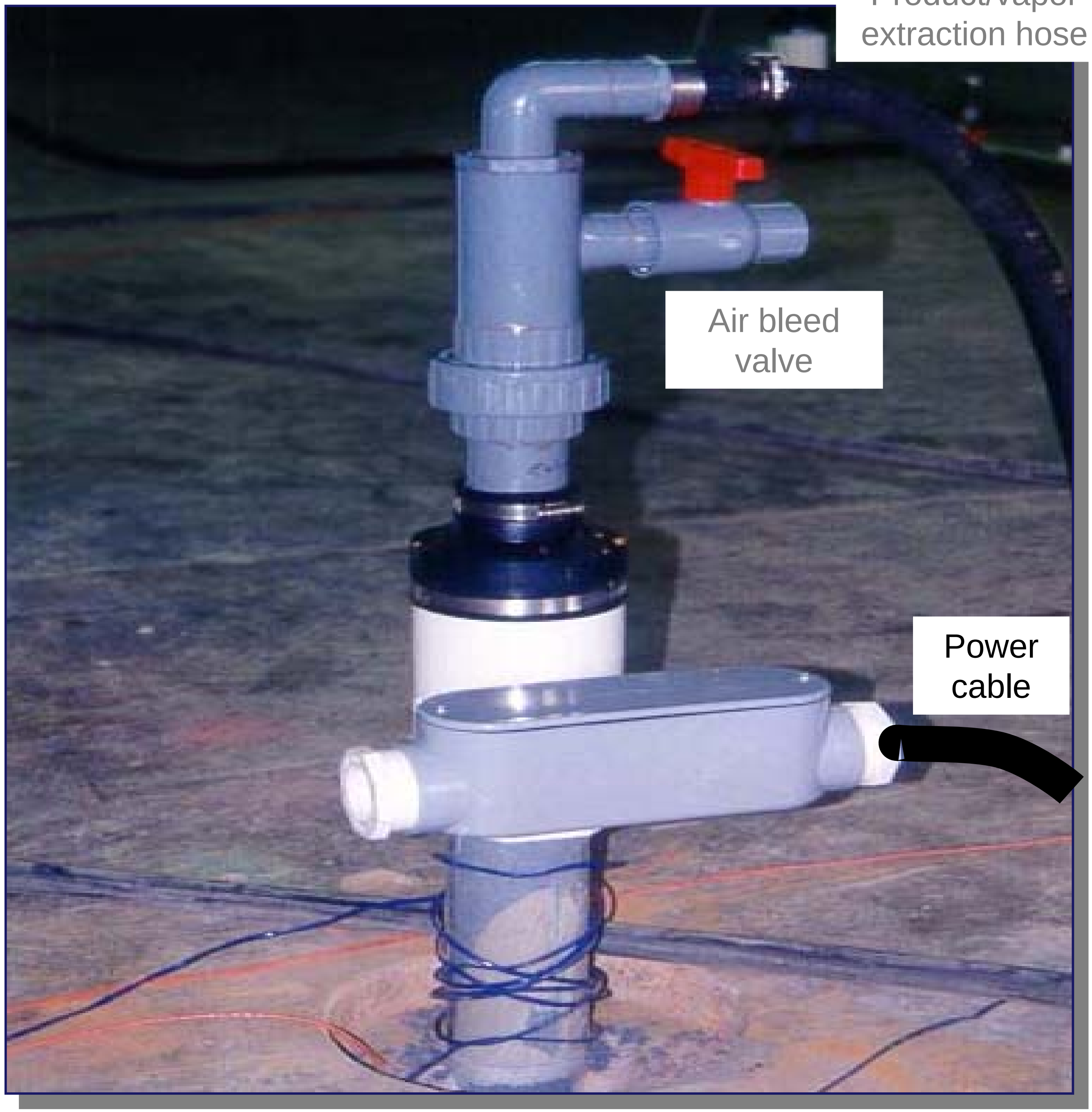
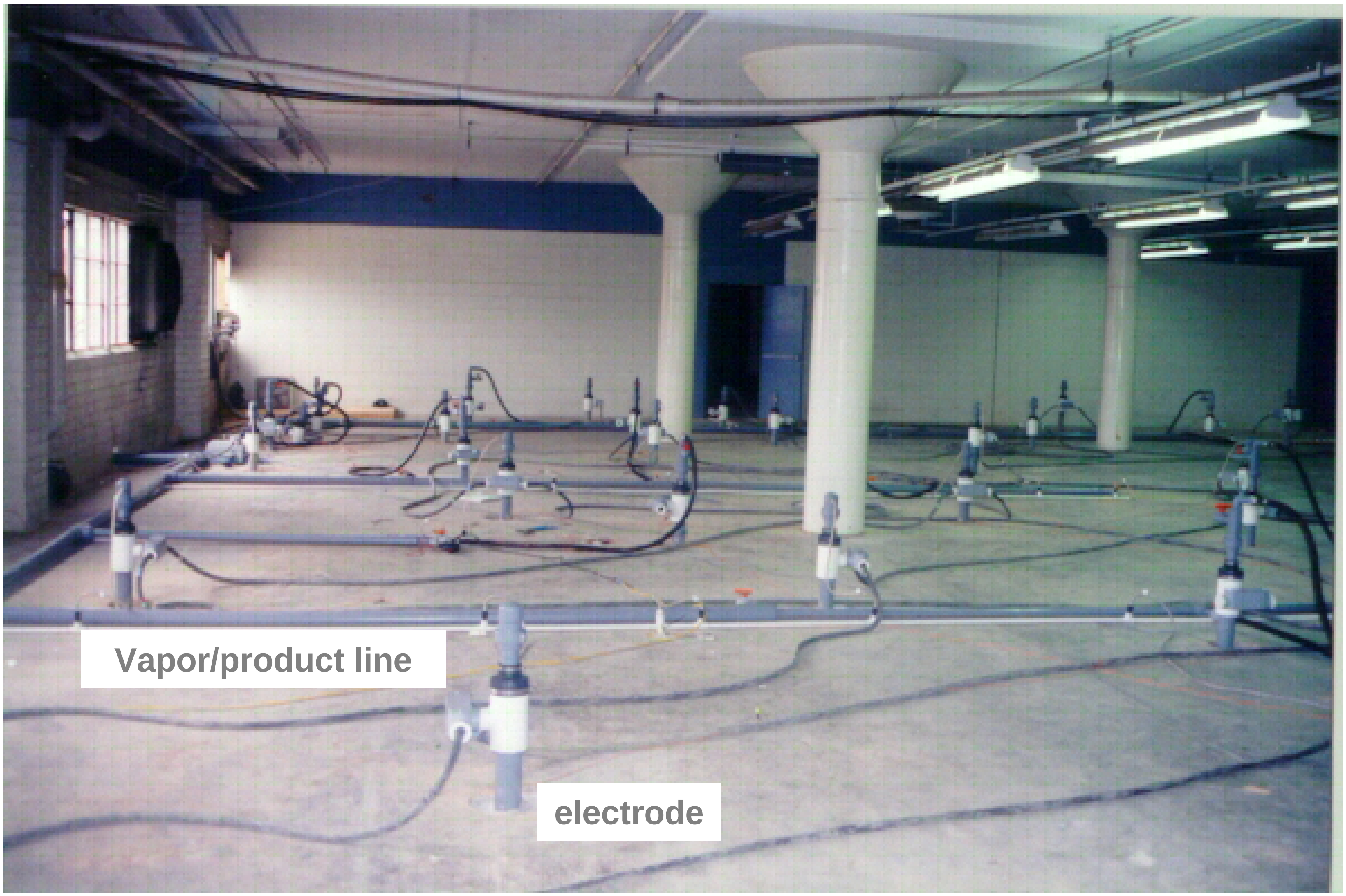
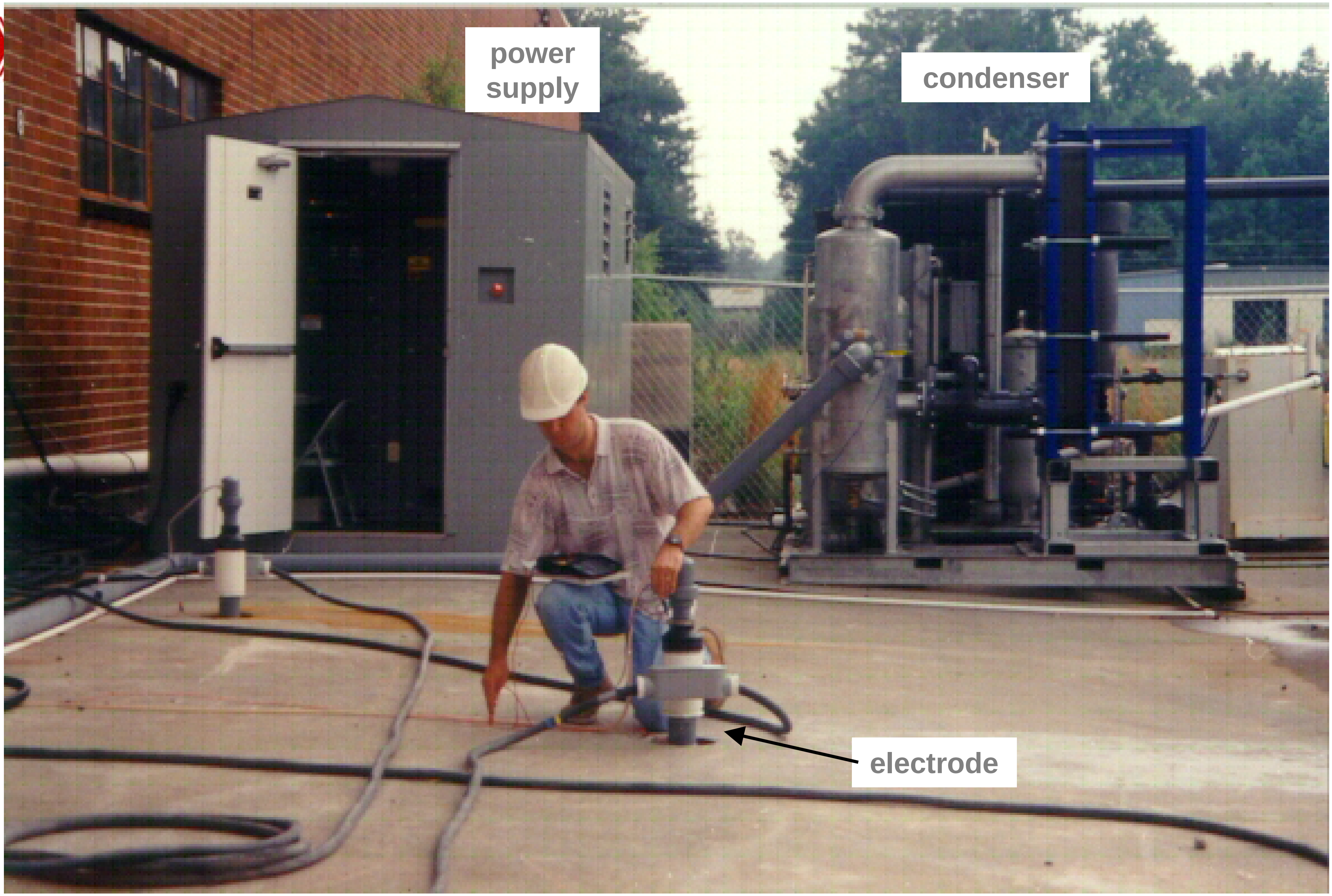


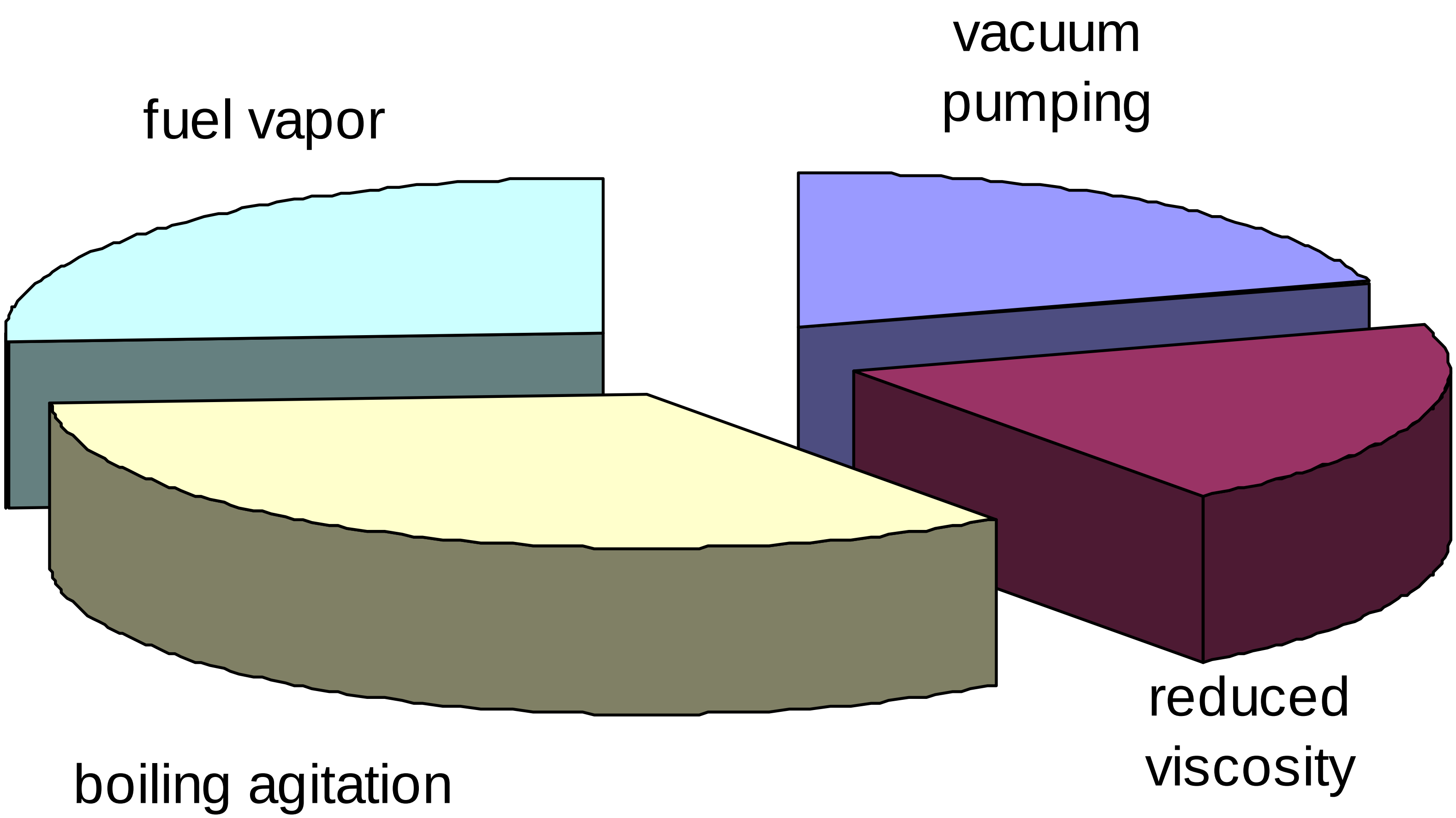

XXXIII

Indoor Installation




power supply
condenser
electrode

LNAPL Removal by Mechanism



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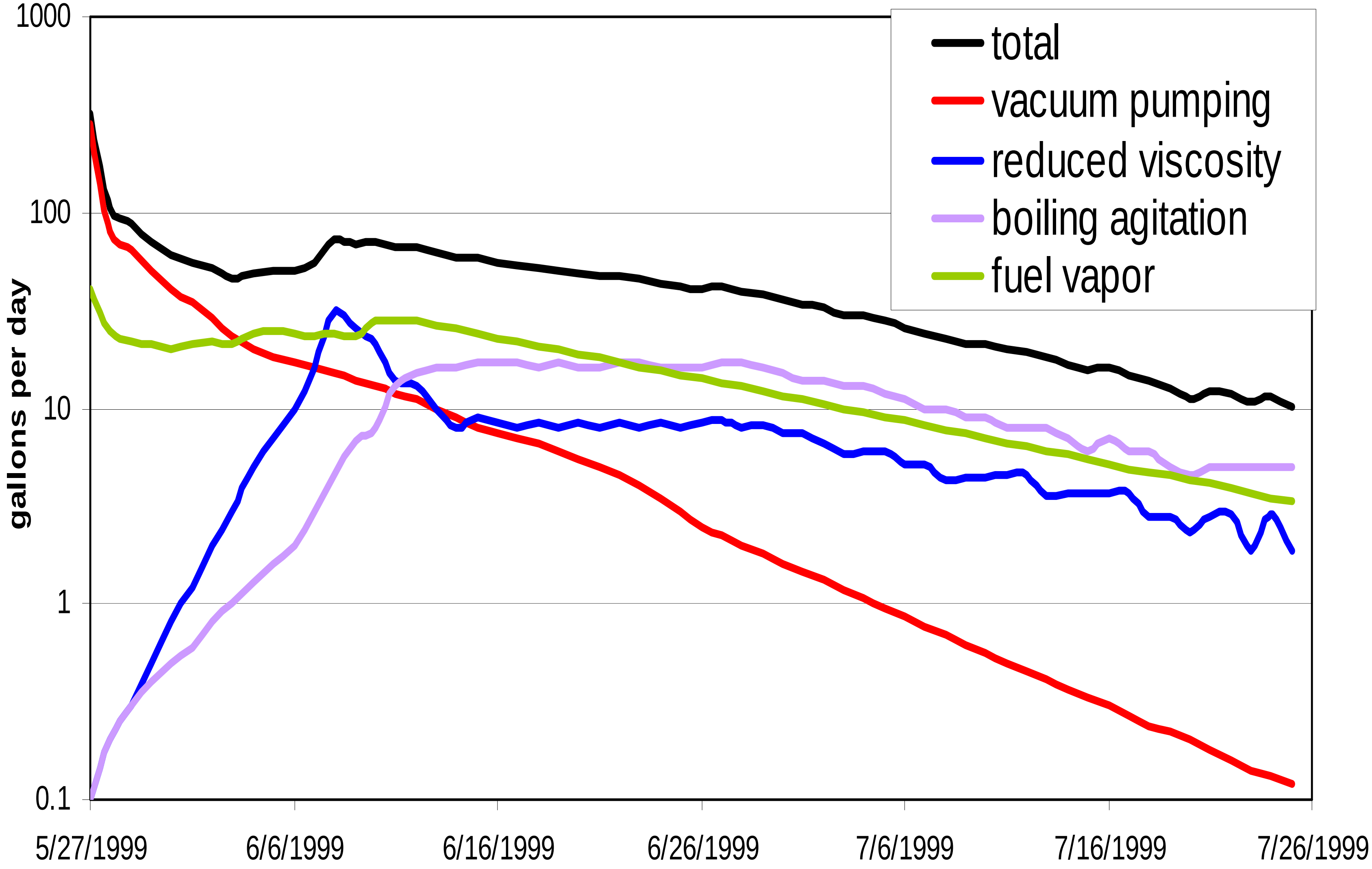
Viscous LNAPL Extraction Rate



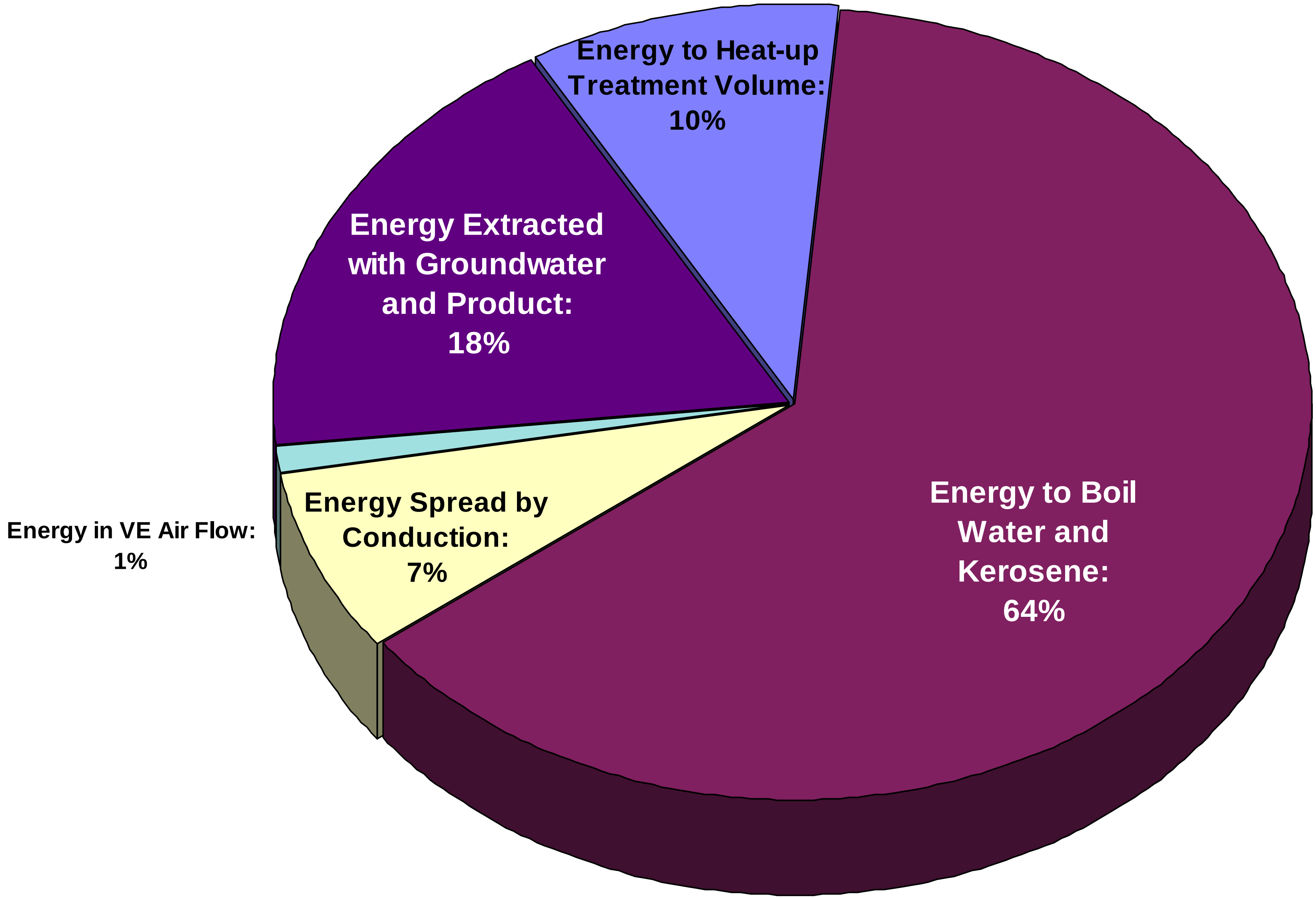
Summary Facts

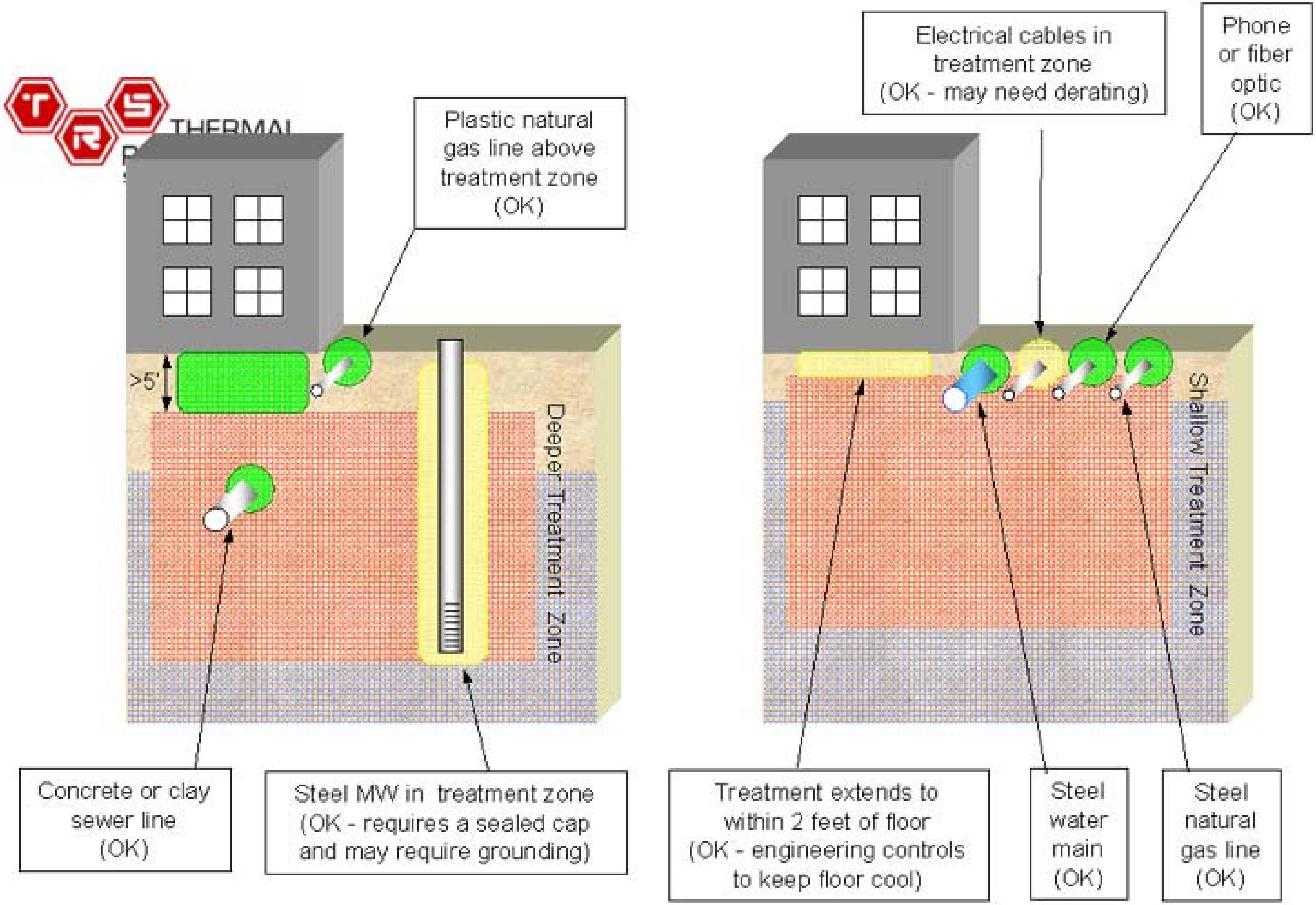
Cost

- Total remediation cost: approx. $770K
- Initially more $$ than conventional MPE, but shorter duration provided cost savings (monthly O&M, alternative use of property).
- Power cost: $79K

Time Required: <7 months

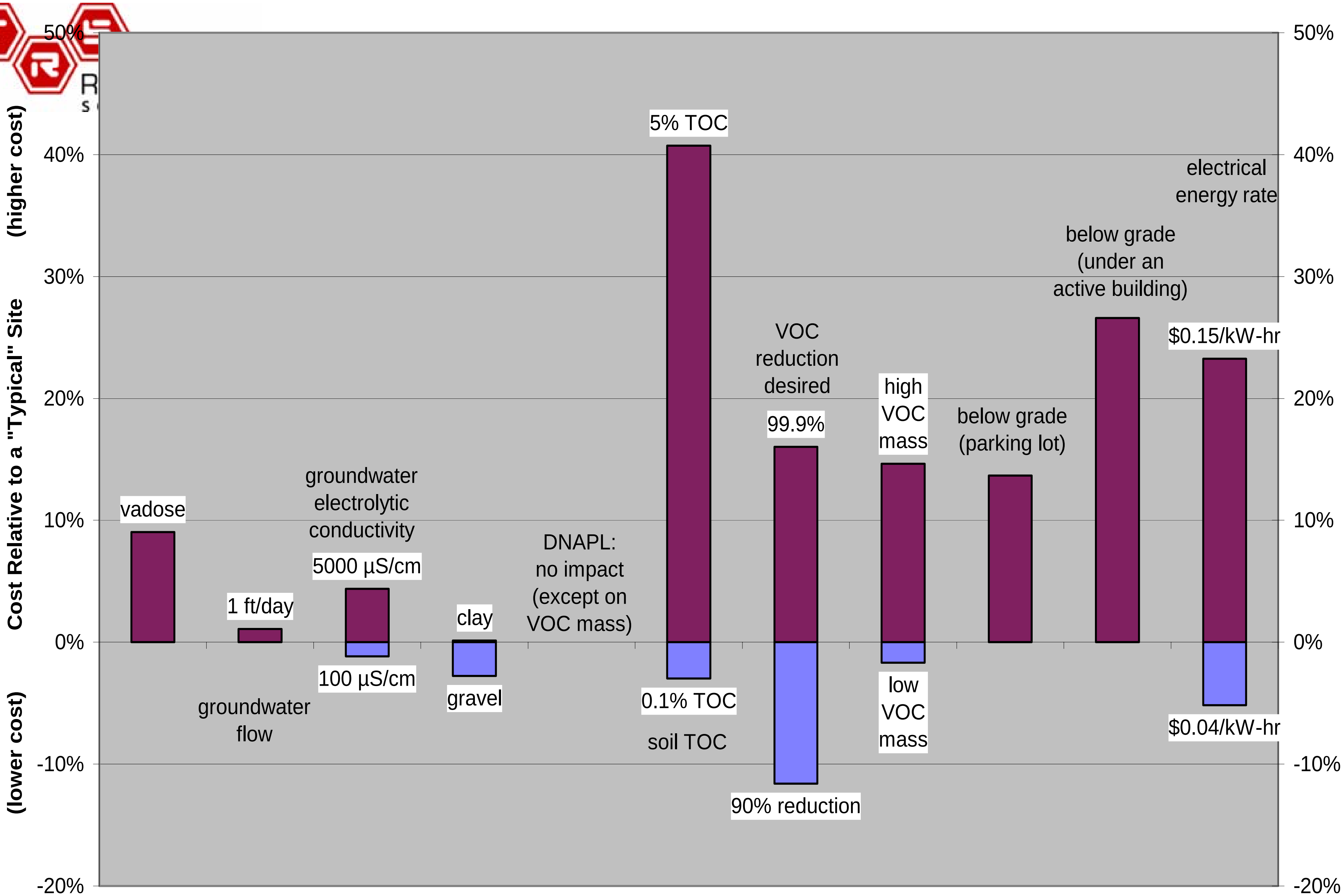
Energy Requirements





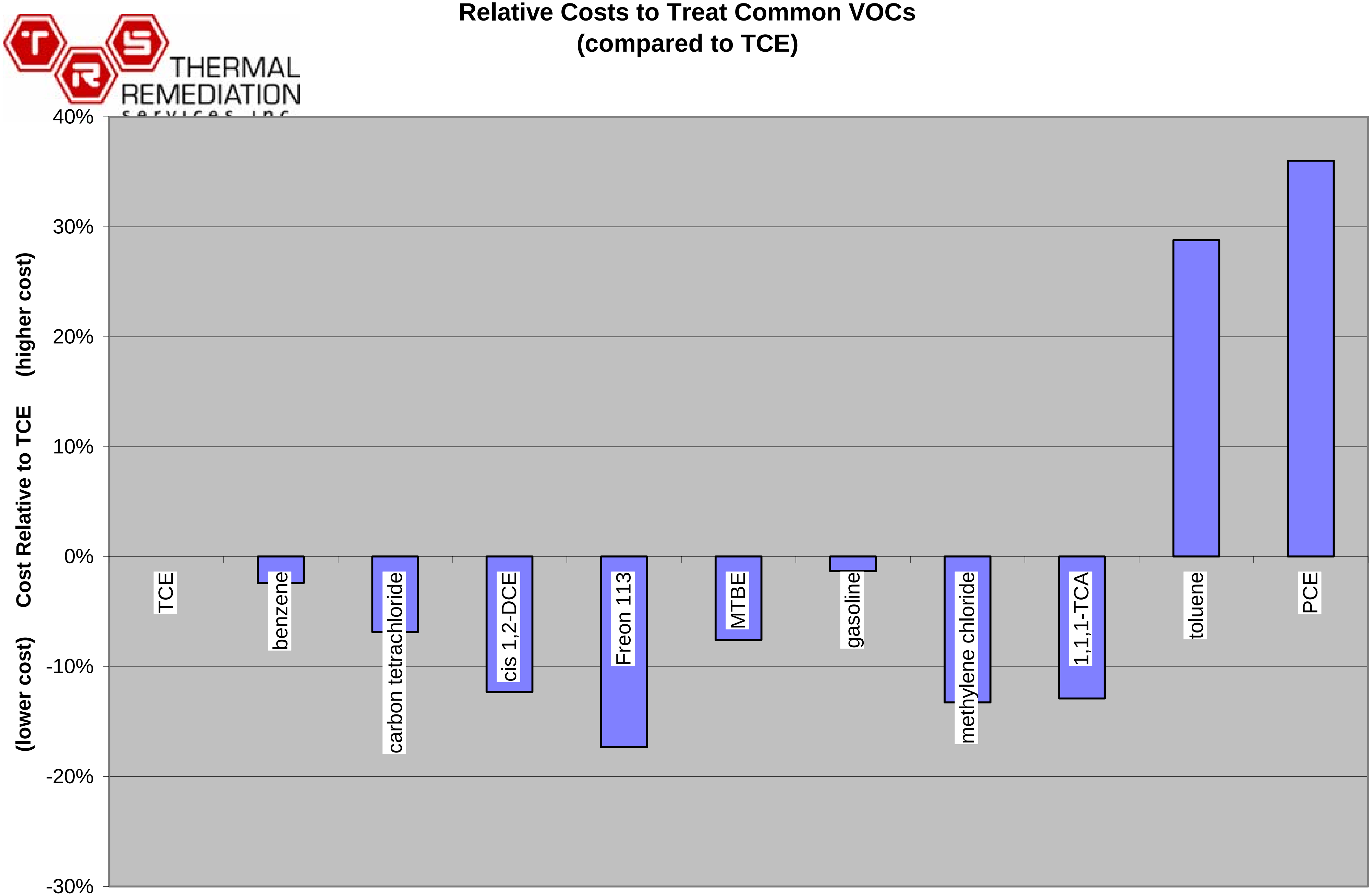
EFFECTS OF ERH ON BURIED UTILITIES AND BUILDING INFRASTRUCTURE

Other Impacts on Relative ERH Cost



Typical Site: 99% reduction of TCE, commercial application
Cost: about $200,000 plus about $45 per cu. yd.

Relative Costs to Treat Common VOCs
(compared to TCE)



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