DNAPL Zone Data Collection for Remedial Design

Duke Engineering and Services

SEAR Workshop

The DNAPL Problem

1989

"....very little success has been achieved in even ***locating*** *the subsurface sources [of DNAPL], let alone* ***removing*** *them."*

Mackay, D.M., and Cherry, J.A. 1989. "Groundwater Contamination: Pump-And-Treat Remediation"; *Environ. Sci. Technol.* 23(6), 630-636.

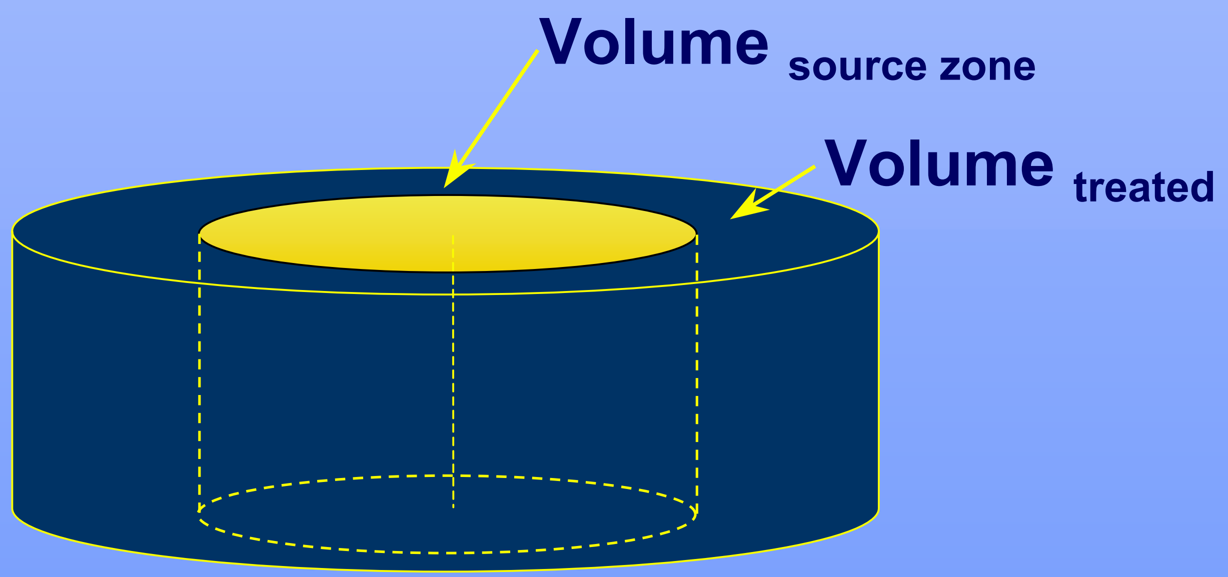
What is the Purpose of Characterizing the DNAPL Source?

- Determine Impact and Risk
- Select Appropriate Remedy
- Measure Baseline Conditions for Remediation Performance Assessment
- **Develop a Remedial Design Basis (Volume and Extent)**

Why is Accurate Source Data So Important?

Cost

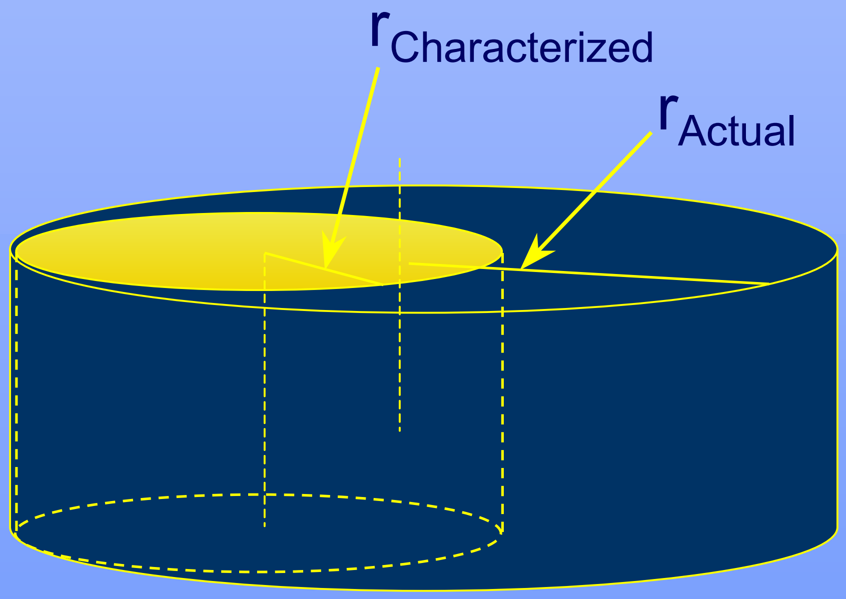
- If Volume $_{\text{source zone}}$ = Volume $_{\text{treated}}$, treatment costs will be minimized.



Why is Accurate Source Data So Important?

Performance

- If NAPL volume is missed, then plume concentrations will rebound.



Presentation Objectives

- Dispel myths about the inability to locate and remediate a DNAPL source zone
- Establish ways to determine the volume and spatial distribution of DNAPL in the subsurface
- Emphasize that NAPL remediation requires an accurate design basis

Presentation Outline

- DNAPL:
  - Review DNAPL terminology, properties and behavior
- Geosystem:
  - Identify important **subsurface** and **DNAPL** properties for remediation
- Characterization:
  - Improve investigative and interpretive methods

Definitions

DNAPL

- Dense nonaqueous-phase liquid
- Not the dissolved or aqueous phase contamination
- Origins for chlorinated DNAPLs (primarily degreasers)
  - Chlorinated hydrocarbon (CHC): the chlorinated compound itself without additives
  - Chlorinated solvent: a mixture of solvent(s) + additive + any solubilized oil & grease

The Key Physical-Chemical Parameters of Chlorinated DNAPLs

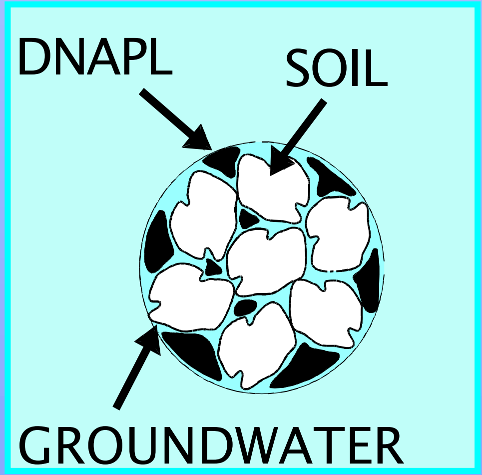
- Liquid density: much heavier than water
- Relative vapor density: very volatile
- Absolute viscosity: low
- Aqueous solubility: “immiscible” but above MCL
- Interfacial tension: relatively low
- Wettability

Recommended Reading

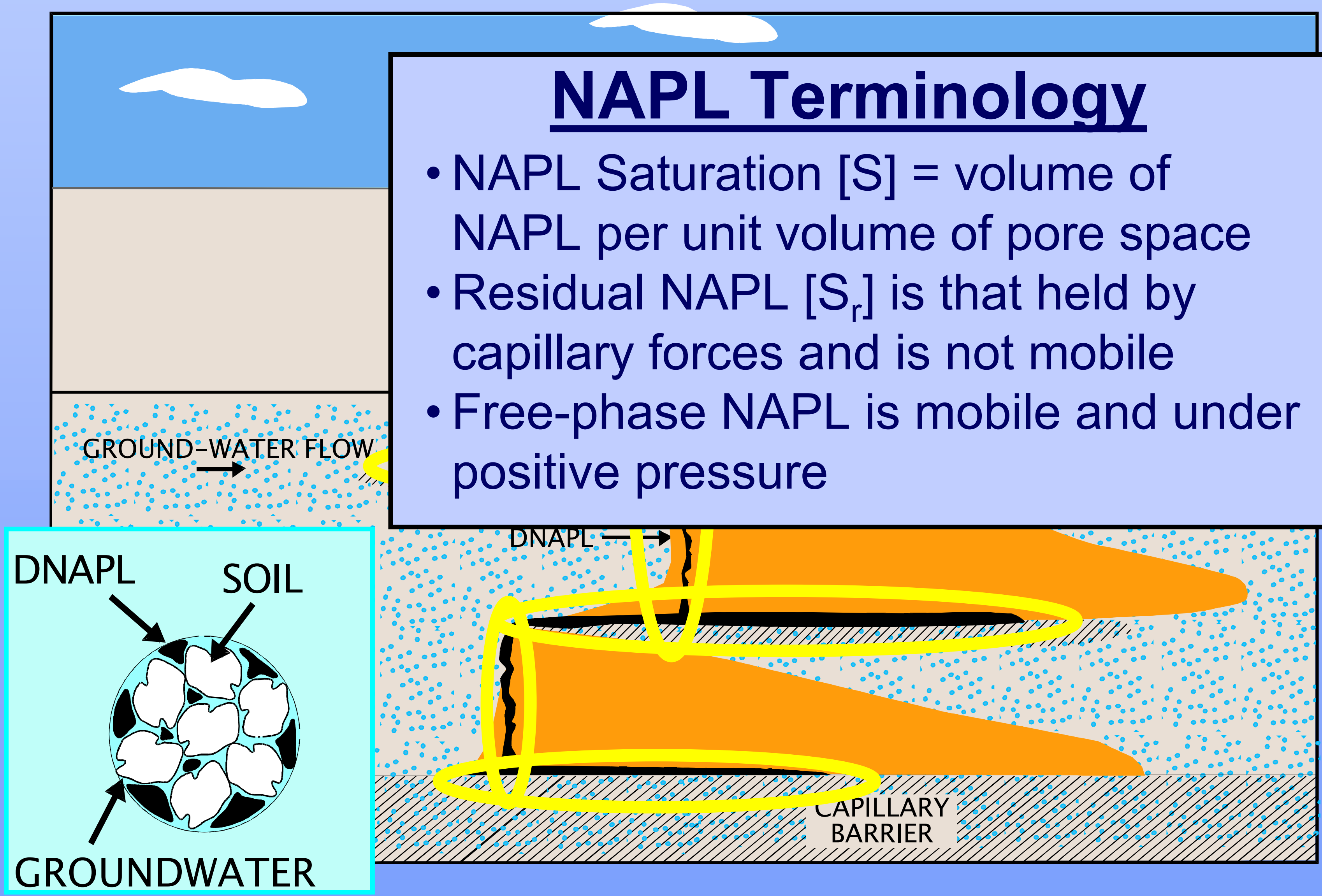
- Handout on the physical-chemical properties of chlorinated degreasing solvents
- Broholm and Feenstra on the solubilities of CHCs
- U.S. EPA 1994 DNAPL site characterization handout
- Pankow & Cherry (Editors), 1996, Dense Chlorinated Solvents and other DNAPLs in Groundwater. Waterloo Press, Portland OR.

NAPL Terminology

- NAPL Saturation [S] = volume of NAPL per unit volume of pore space
- Residual NAPL [Sr] is held by capillary forces and is not mobile
- Free-phase NAPL is mobile and under positive pressure



Conceptual Model



NAPL Terminology

- NAPL Saturation [S] = volume of NAPL per unit volume of pore space
- Residual NAPL [S_r] is that held by capillary forces and is not mobile
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Understanding DNAPL Migration and Behavior

- **NAPL Properties**
  - Interfacial tension (IFT), viscosity, density, solubility
  - Wettability
- **Subsurface Properties**
  - Heterogeneity (grain size)
  - Structure (capillary barriers)
- **Predictive Tools**
  - Partitioning
  - Multi-phase multi-component simulator (3-D)

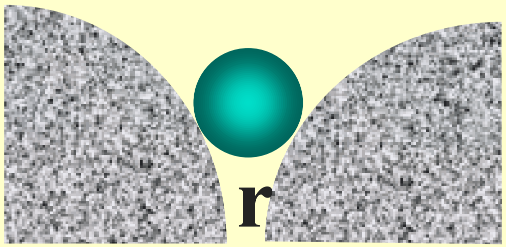
Physics of DNAPL Migration

- Identification of wetting fluid
- Capillary pressure relations
- Relative permeability relations
- Kueper’s sand box experiments

Capillary Pressure Function

Viscous forces exerted by flowing water

Gravity forces due to density of DNAPL



$$P_c = \frac{2\sigma \cos\theta}{r}$$

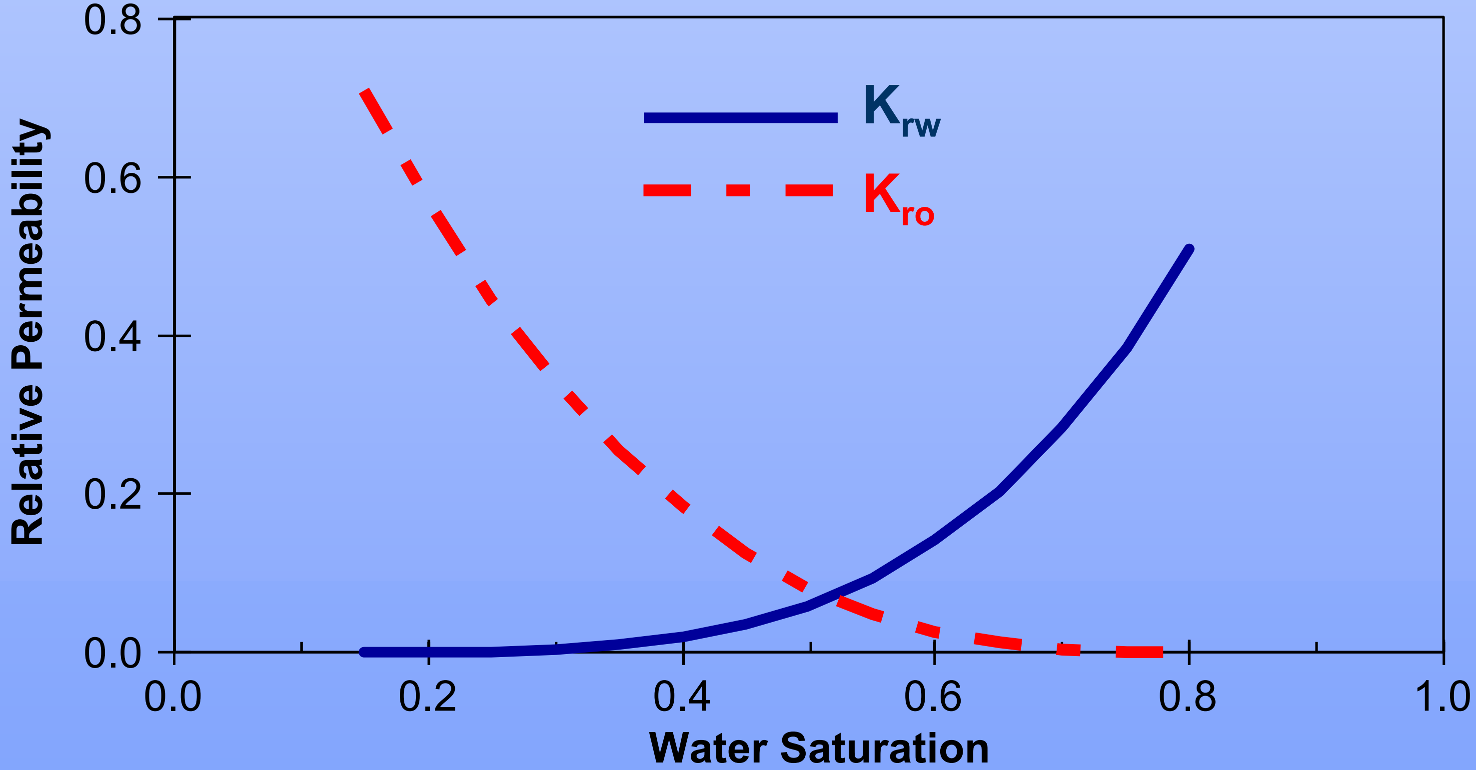
DNAPL ganglion trapped by capillary forces

Source of Data:

1) Drainage capillary pressure data matched to water/PCE data in Borden sand (Kueper, B.H., and E.O.Frind, Water Resources Research, Vol. 27, No. 6, 1991, p1049-1057)

2) Imbibition curves were assigned to be consistent with the drainage data

Relative Permeability Function

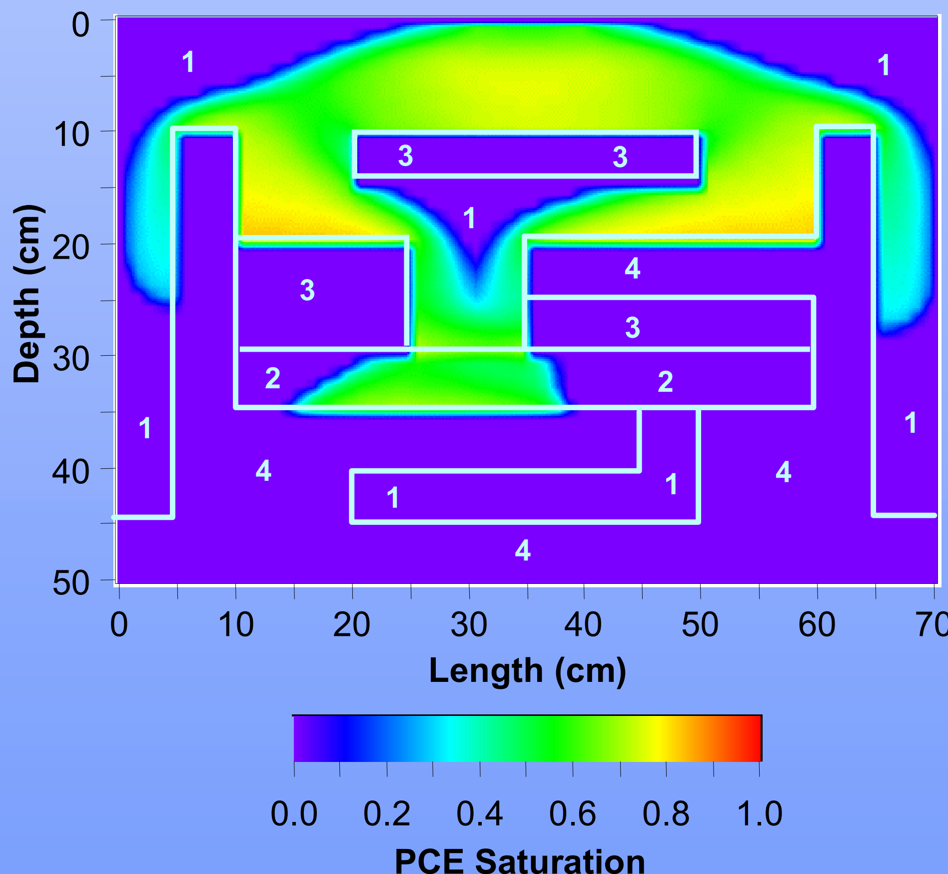


Source of Data:

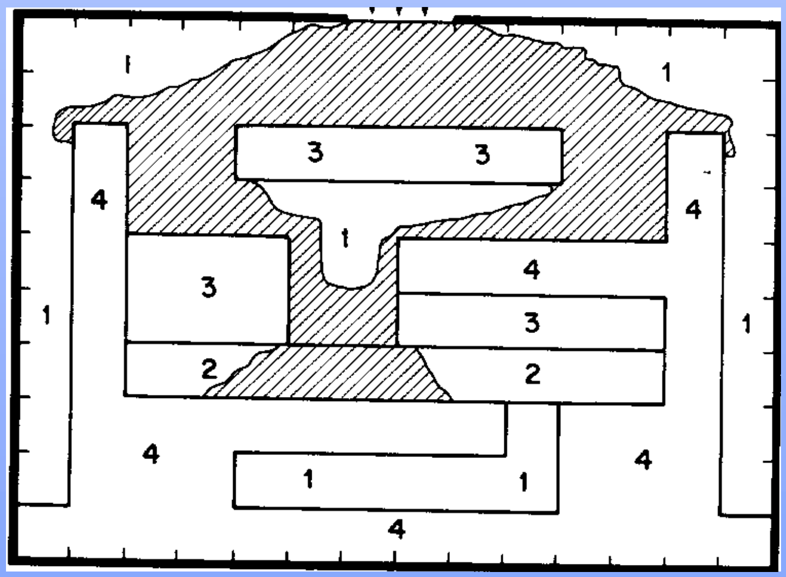
Oolman, T, et al., DNAPL Flow Behavior in a Contaminated Aquifer: Evaluation of Field Data . *Ground Water Monitoring and Remediation, Fall 1995, p125-137*

PCE Migration Through Sand Units

UTCHEM Modeled
Time = 310 seconds



Experiment by Kueper et al., 1989
Time = 313 seconds



Conclusions for Remedial Data Collection

One must understand:

- The DNAPL source
  - DNAPL physical and chemical properties
  - DNAPL release history
- The aquifer soil
  - Grain size
  - Capillary barrier
- The forces acting on the NAPL within the aquifer

Successful NAPL Remediation Requires:

- NAPL expertise
  - NAPL chemistry, migration and behavior
- Good geology/hydrogeology
- Field expertise
- Team management
  - Integration of theoretical, experimental, and field practice
- Rigorous, robust design capability
- Quantitative performance assessment

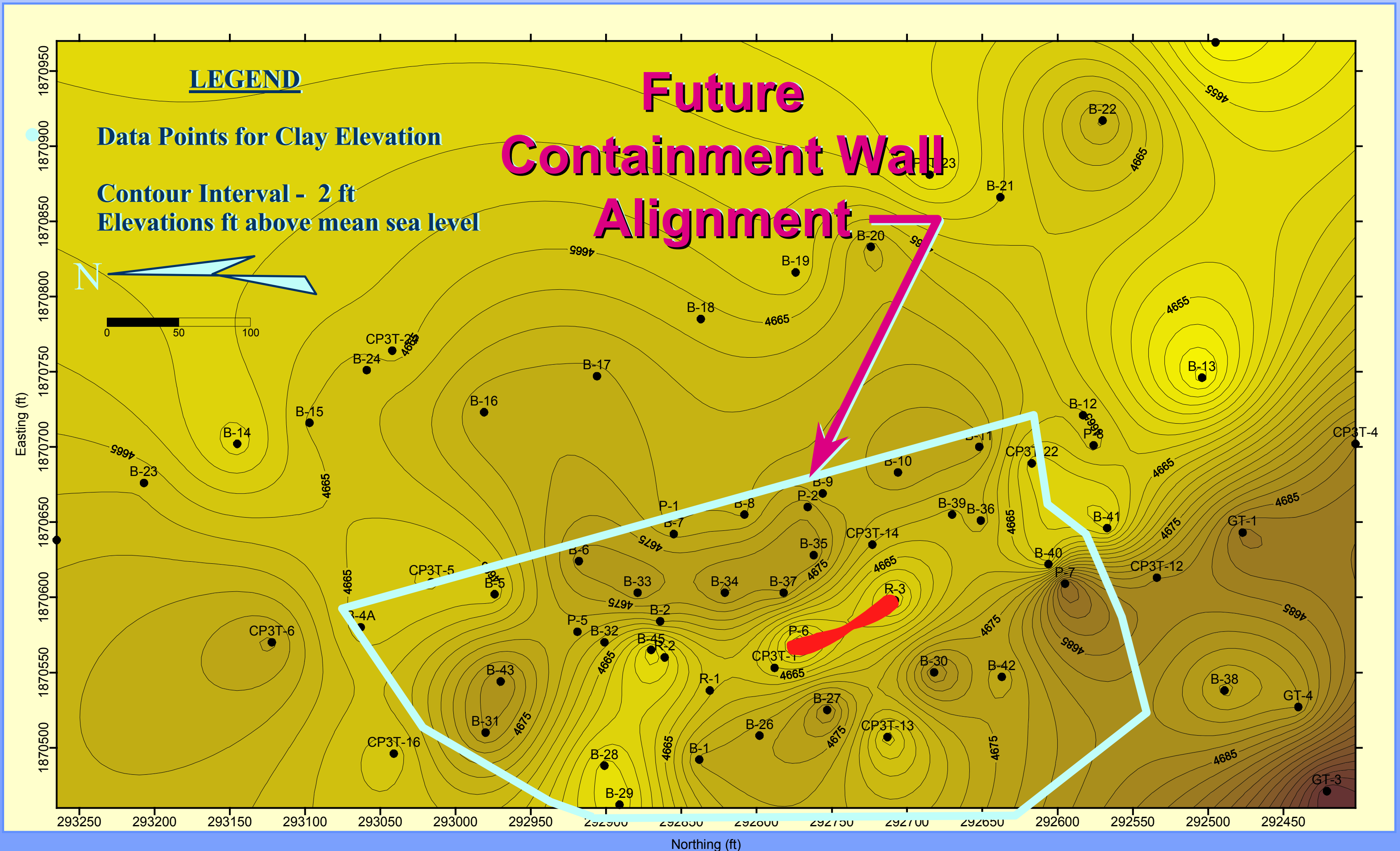
Characterization Team Should Include:

- Hydrogeologists
- Petroleum (Geosystem) engineers
- Geochemists
- Chemical engineers

What is a “Geosystem Model”?

- Comprehensive model of the source zone:
  - Hydrostratigraphy
  - Hydrogeology
  - Geochemistry
  - Physical properties of the NAPL
  - Multi-phase fluid flow parameters
- Progresses from conceptual to quantitative
- Guides characterization and becomes the remediation design basis

Characterization Example: Pre-1996 Map of Aquiclude Surface



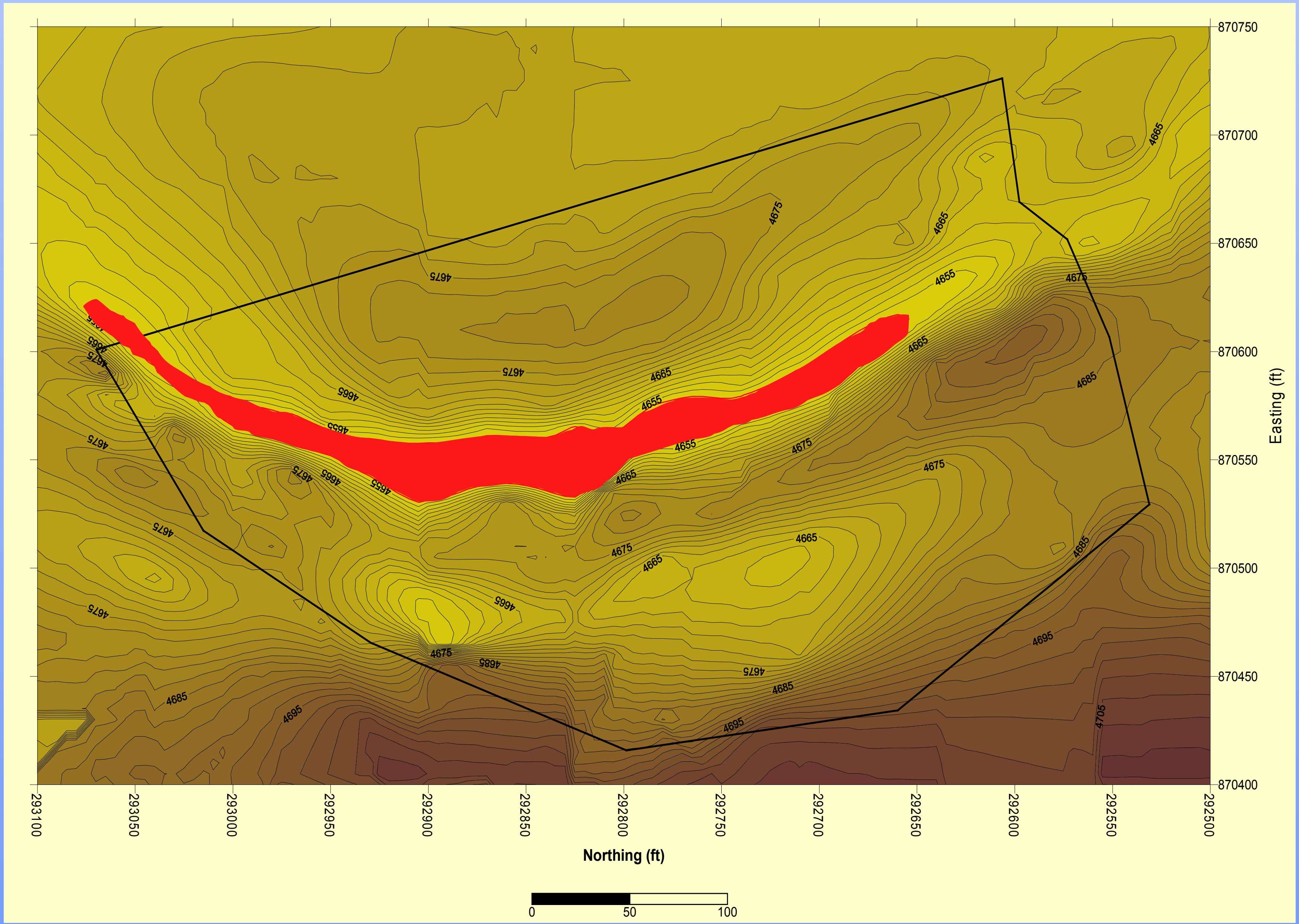
Iterative Characterization Approach

GPR Survey

CPT Survey

Drilling/Sampling

1998 Map of Aquiclude Surface



DNAPL Source Zone Characterization
Phase I

Finding the DNAPL Source

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Conventional Characterization Tools

- Desktop data review
- Remote sensing (geology/hydrogeology)
  - Electromagnetic (EM) surveys
  - Seismic/ground-penetrating radar (GPR)
  - Borehole geophysics
- Direct push methods (CPT, Geoprobe® etc.)
  - Geology/hydrogeology
  - NAPL tools (scale of investigation)
  - Soil-gas surveys

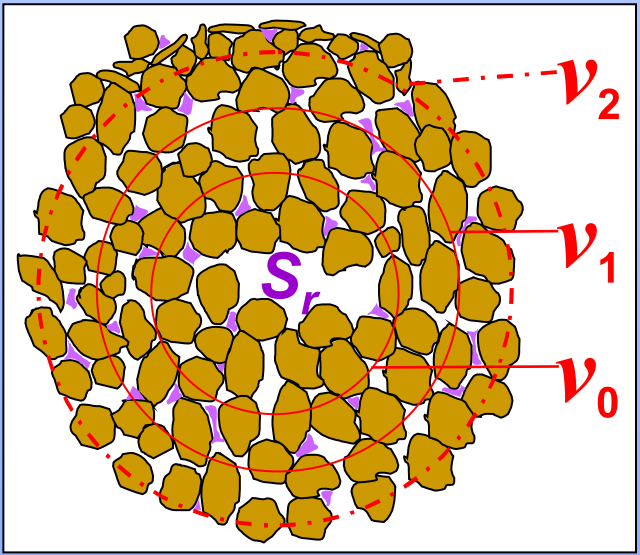
Source-Focused Desk Top Review

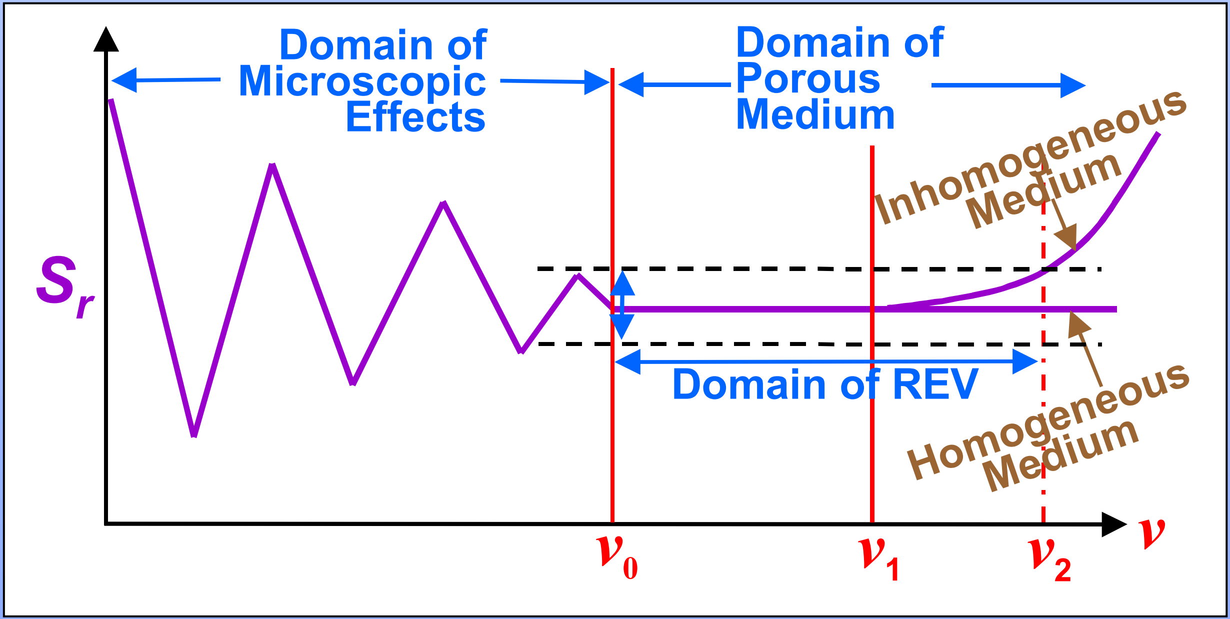
- Look for:
  - Release point
  - Release history and volume (ha!)
  - NAPL properties
  - Hydrostratigraphy (where is the NAPL going to end up?)
  - Plume attributes
- Assimilate data into Geosystem (scoping calculations)
- Identify data gaps and evaluate data needs
- Plan objectives for investigation

Conventional Characterization Tools (cont.)

- Water sampling
  - Solubility limitations
  - The use and abuse of the 1% rule
  - Degradation products
  - Possible NAPL recovery for analysis
- Using a drill rig (the Neanderthal method)

Representative Elementary Volume (REV)



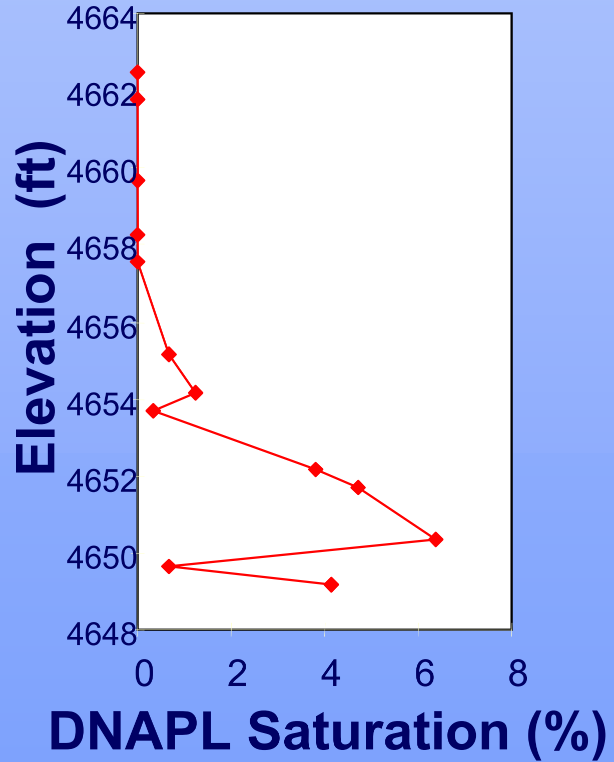


- Est. range of REV for NAPL in soil = $10\text{-}10^4$ cm^3 = 0.0003 to 0.3 ft^3
- Volume of typical soil sample = $30\text{-}10^2$ cm = 0.001 to 0.01 ft^3

Why Collect Soil Samples?

- Screening for source zone, alongside other indicators such as:
  - Soil-gas concentrations
  - Aqueous concentrations
  - Geophysical anomalies
- Once source found:
  - Vertical distribution of DNAPL

Vertical DNAPL distribution at IW-1



DNAPL Source Zone Characterization
Phase II

DNAPL Source Found!

Developing a Remediation Design Basis

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Source Zone Characterization: Task List

- Collect hydrogeologic information
- Obtain accurate soil samples
- Soil and groundwater analyses
- Hydraulic testing
- Measure aquitard properties
- Estimate DNAPL volume and distribution
- Construct a geosystem model

Data Types

- Detailed hydrostratigraphy
  - Grain-size distribution (permeability variations)
  - Heterogeneity
  - Structural traps and capillary barriers
- Hydraulic data
  - Hydraulic conductivity, dispersivity, porosity
  - Gradients
  - Saturated thickness
- DNAPL
  - Physical and chemical properties
  - Mass
  - Distribution (saturation)

Innovative Tools for DNAPL Characterization

- UTCHEM
  - University of Texas Chemical Flooding Simulator
- Partitioning interwell tracer tests (PITTs)
  - Measure the average DNAPL saturation and the spatial distribution of the DNAPL between wells

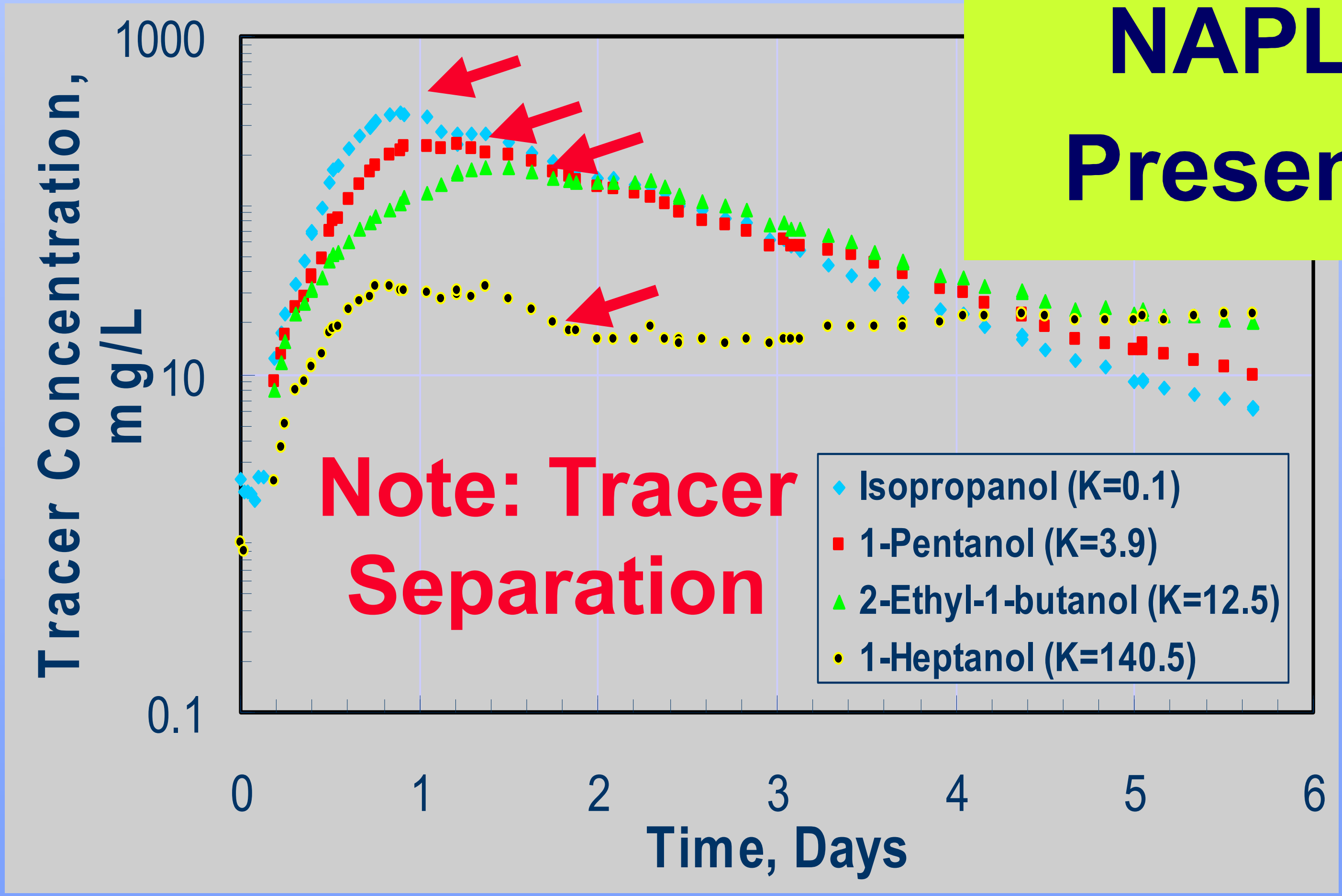
UTCHEM

- Chemical flood simulator from the University of Texas
- Multi-phase, multi-dimensional chemical compositional simulator
- Biodegradation, vadose zone capability
- U.S. EPA (1999) approved numerical simulator

Partitioning Interwell Tracer Tests (PITTs)

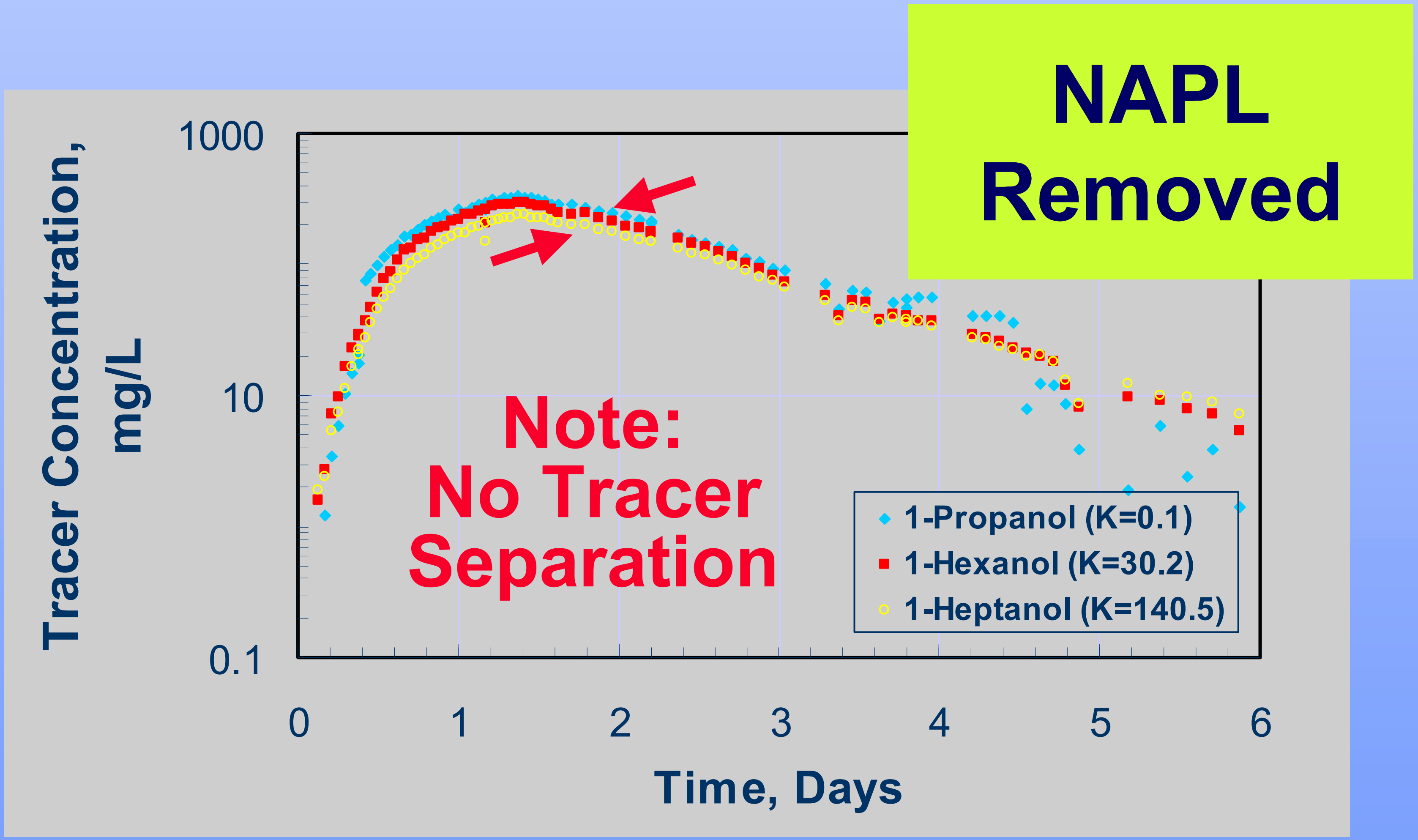
- Developed for NAPL site characterization by DE&S and Dr. Gary Pope at UT-Austin
- Adopted by U.S. EPA & the USAF for technology performance assessment at Hill AFB, UT
- More than 40 conducted since 1994
- U.S. Patent No. 5,905,036

Pre-SEAR Characterization

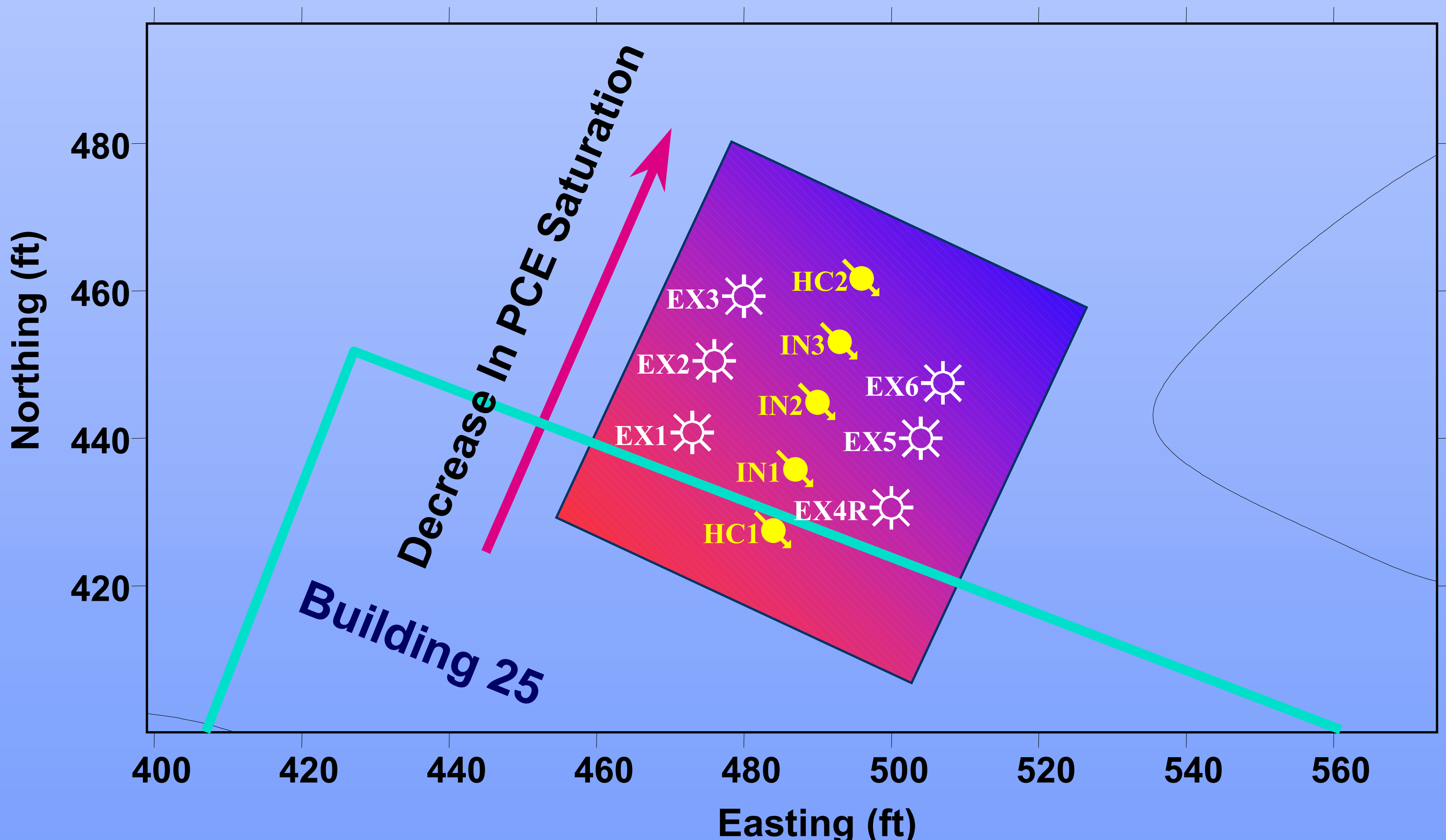


NAPL Present

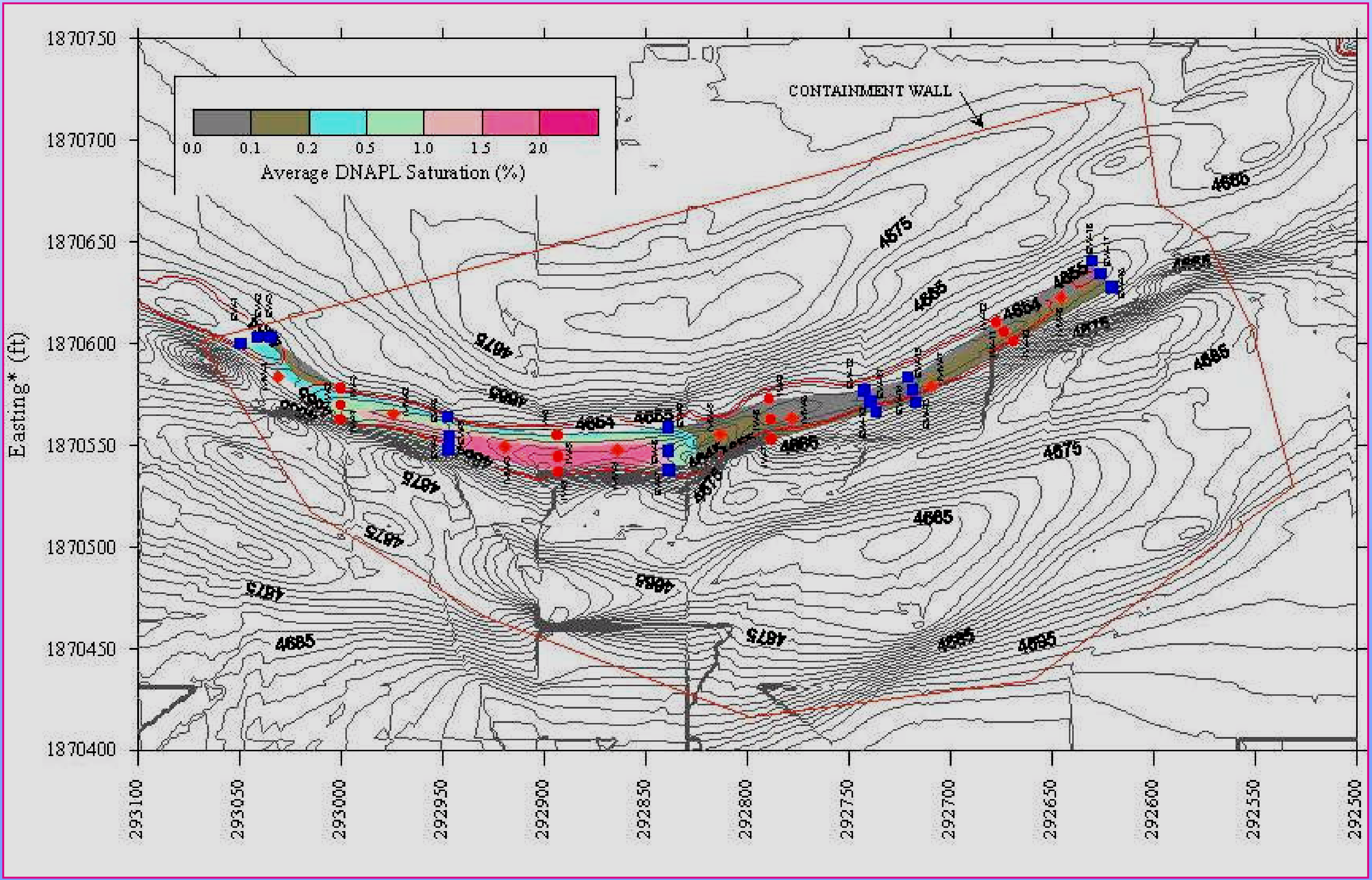
Post-SEAR Characterization



Trend of PCE Saturation Distribution



Remedial Design Basis!



Site Costs