Stone Environmental
100% Employee-Owned

Introduction to Site Characterization & Real-time Data Collection

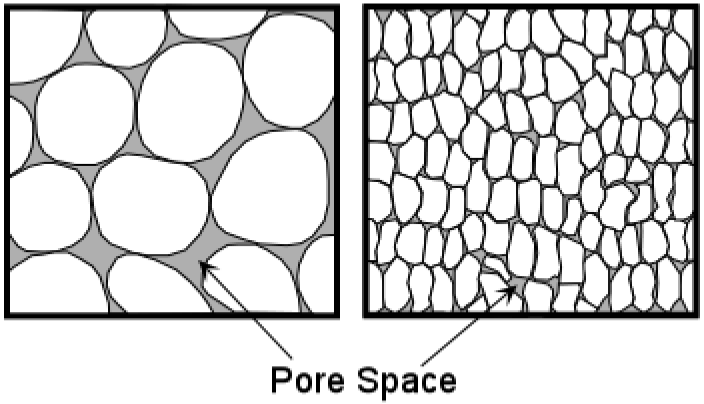
May 2025

Presented by Jacob Vincent

Review of Hydrogeological Concepts

Porosity (Φ)

The measure of pore space between grains



Permeability (k)

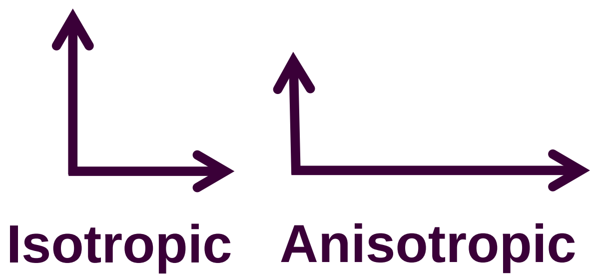
The ease at which fluid can move through a media

Hydraulic Conductivity (K)

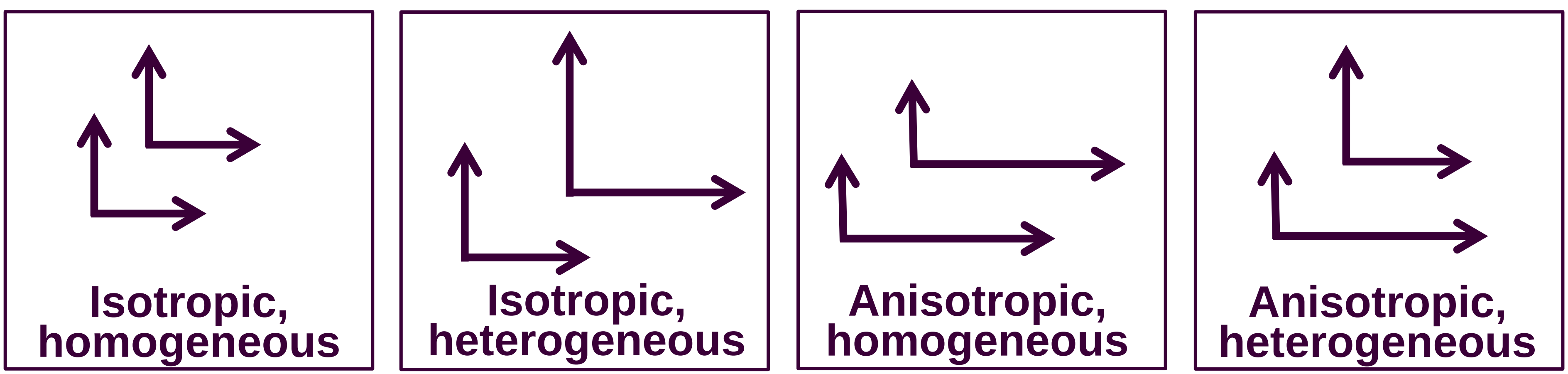
The ease at which a certain fluid (water) moves through

$$K = \frac{k\rho g}{\mu}$$

Homogeneity and Isotropy



- Isotropic: aquifer properties (*e.g.*, hydraulic conductivity) are the same regardless of the direction of measurement (*e.g.*, horizontal vs. vertical)
- Anisotropic: aquifer properties vary with direction
- Homogeneous: aquifer properties are constant everywhere
- Heterogeneous: aquifer properties vary spatially



From Freeze and Cherry, 1979

Homogeneity of Real Soils

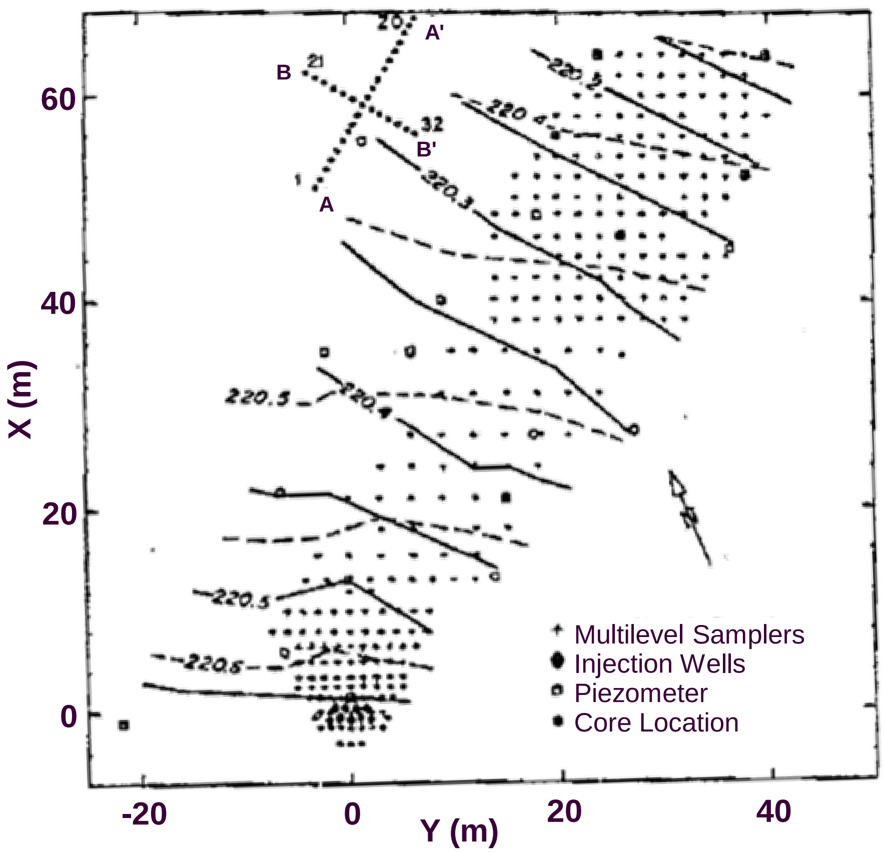
Homogeneity Studies of Sandy Soils

Location	Horizontal K Correlation Length (m)	Vertical K Correlation Length (m)	Investigator
Borden, Ontario	2.8	0.12	Sudicky (1986)
Otis, ANGB	2.9 – 8	0.18 – 0.38	Hess et al (1992)
Columbus AFB	12.7	1.6	Rehfeldt et al
Aefligan	15 – 20	0.05	Hess et al (1992)
Chalk River, Ontario	1.5	0.47	Indelman et al (1999)

Current MODLFOW software automatically uses this 10/1 K difference in the vertical to horizontal directions.

Advection and Diffusion/Dispersion

Stanford-Waterloo Natural Gradient Tracer Test Layout, Water Resources Research, 1982



Natural Gradient Tracer Tests

- Sudicky – 1979
- Stanford/Waterloo – 1982
- USGS Cape Cod – 1986
- Rivett *et al*. – 1991

Transverse horizontal dispersion is weak

Transverse vertical dispersion is even weaker

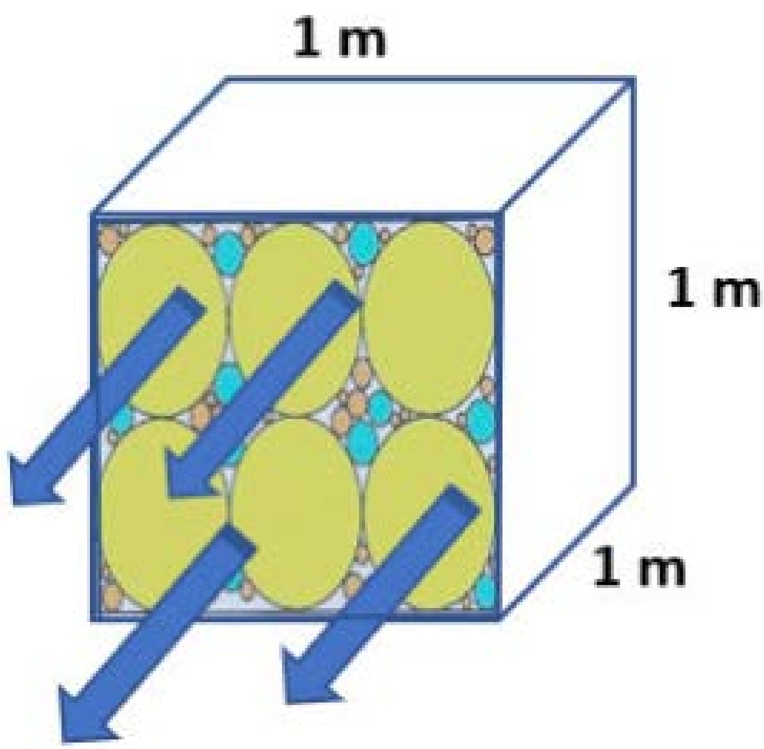
Longitudinal dispersion is significant

Plumes do not spread out. Concentration gradients sharply change perpendicular to flow direction.

Flux and Specific/Mass discharge

a)

$$q = \frac{Q}{A} = -K\,\frac{\Delta h}{\Delta L}$$



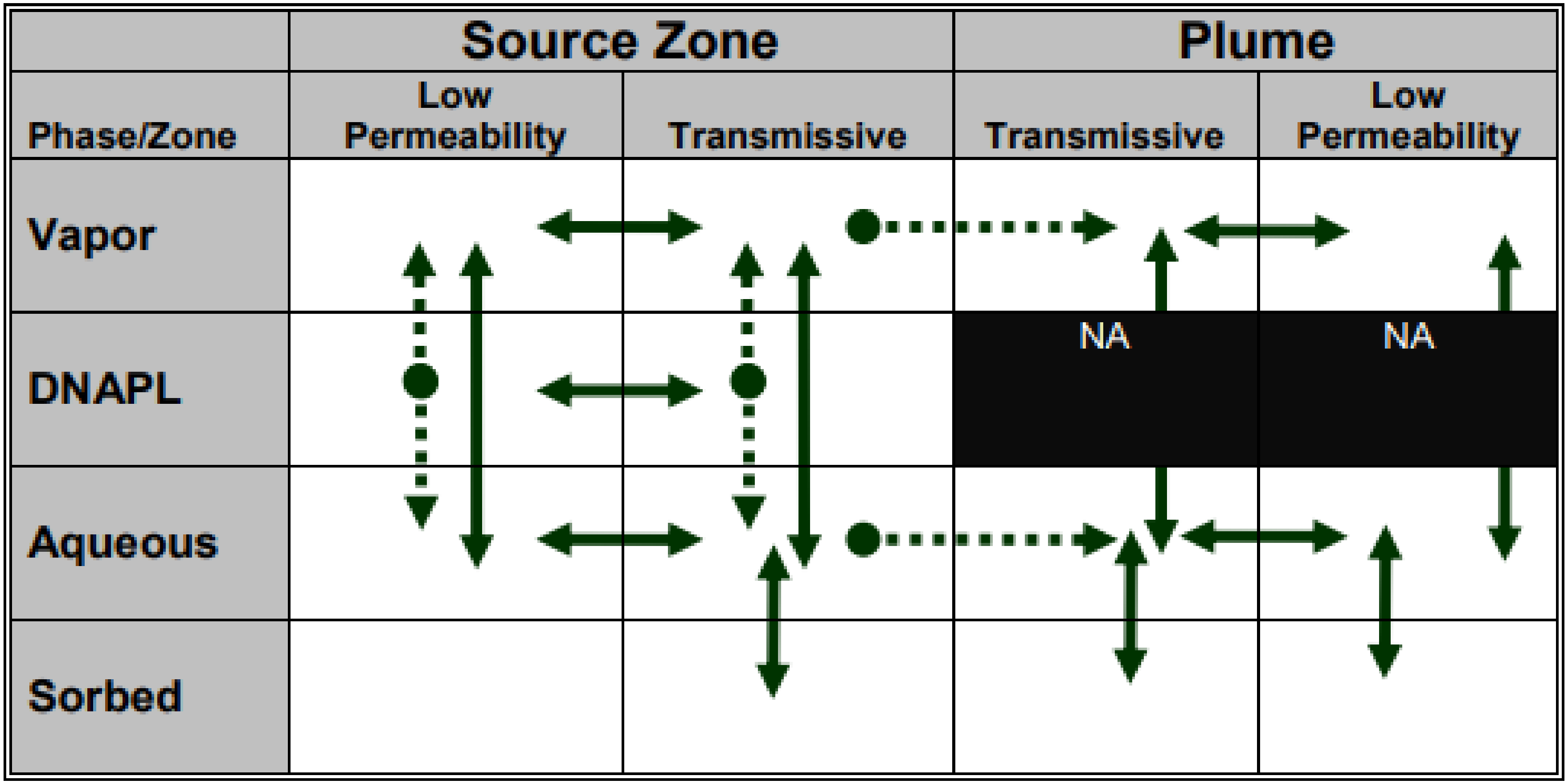
- **Specific discharge:** also referred to as “groundwater flux” represents the volume of water that flows through a cross-sectional area of porous media per unit time

- **Mass Flux:** amount of mass that moves across a unit cross sectional area over a given time (mass/area/time)

What information do you need for a complete conceptual site model?

- What phases are the contaminants in? (NAPL, aqueous, sorbed, gas)
- What is the source? (NAPL, sorbed mass, solute mass in low K zones)
- Where is the source located in 3 dimensions?
- Where is the source located with respect to permeability? (in high K zones or low K zones)
- Where and what are the primary transport pathways?
- Where are the receptors?
- What attenuation mechanisms are active? (sorption/retardation, biodegradation, abiotic degradation, dispersion, diffusion into low K zones)

What phases are the contaminants in?



Sale and Newell., 2011

Matrix of subsurface compartments potentially containing chlorinated solvents.

Arrows show mass potential transfer links between compartments. Dashed arrows indicate irreversible fluxes.

Dual Porosity Systems and Diffusion

- Systems in which there are (relatively) high and low permeability units. Very common in New England.

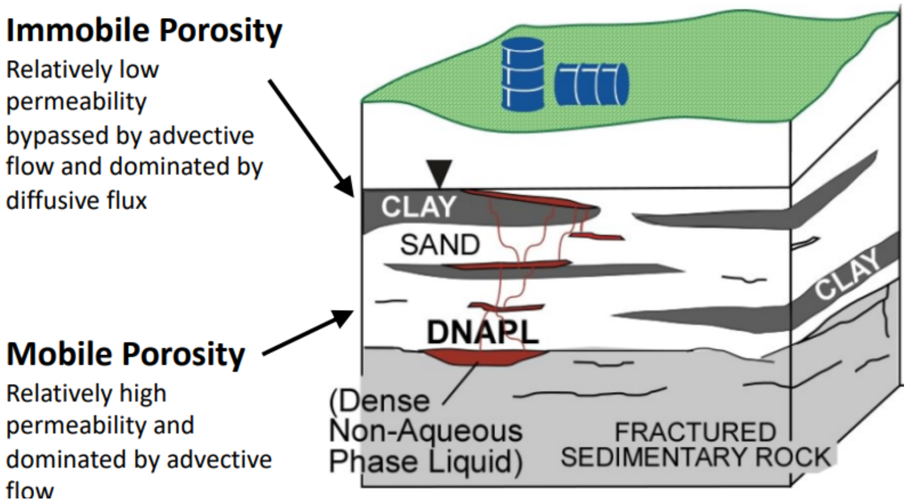
- Nearly all advective flow takes place through the pores in the high permeability materials (mobile porosity)

- Water in the saturated pore spaces in the low permeability materials (immobile porosity) is dominated by diffusive, rather than advective flux

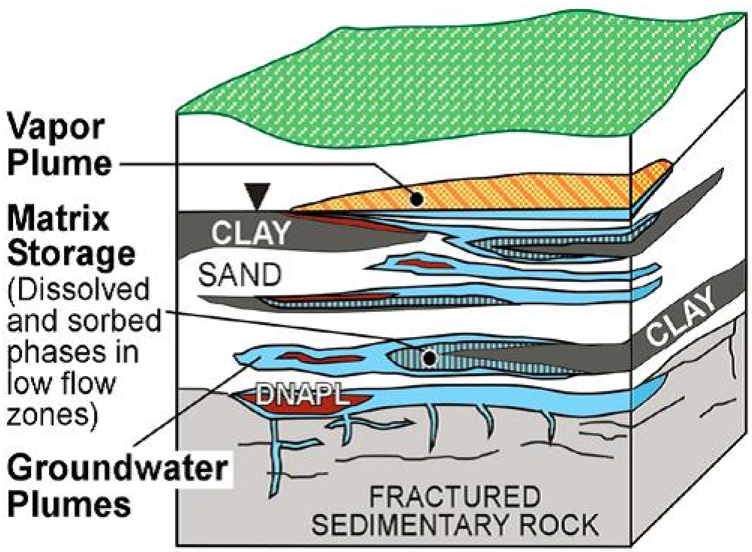
- Pore water in the low permeability materials essentially serves as storage for solutes

What is the Source and Where is it Located?

Stages of a DNAPL Plume

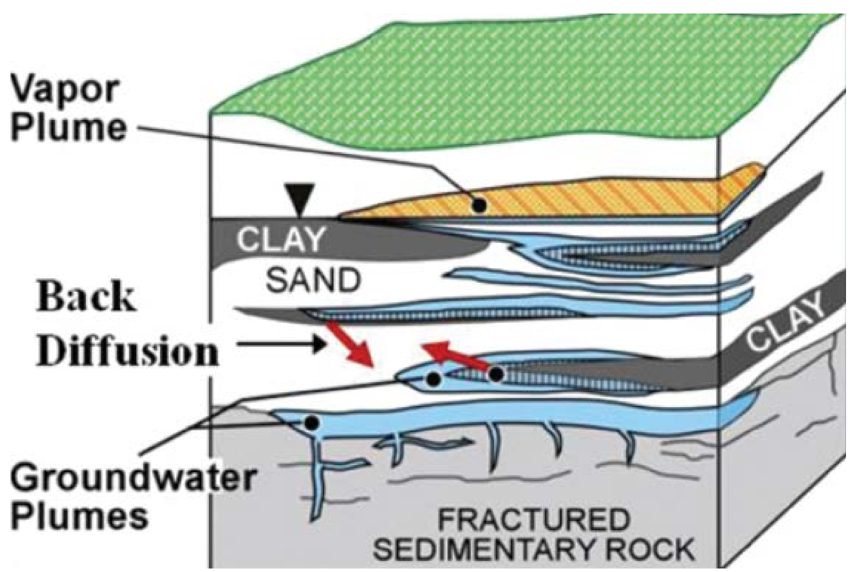


Early Source



Mature Source

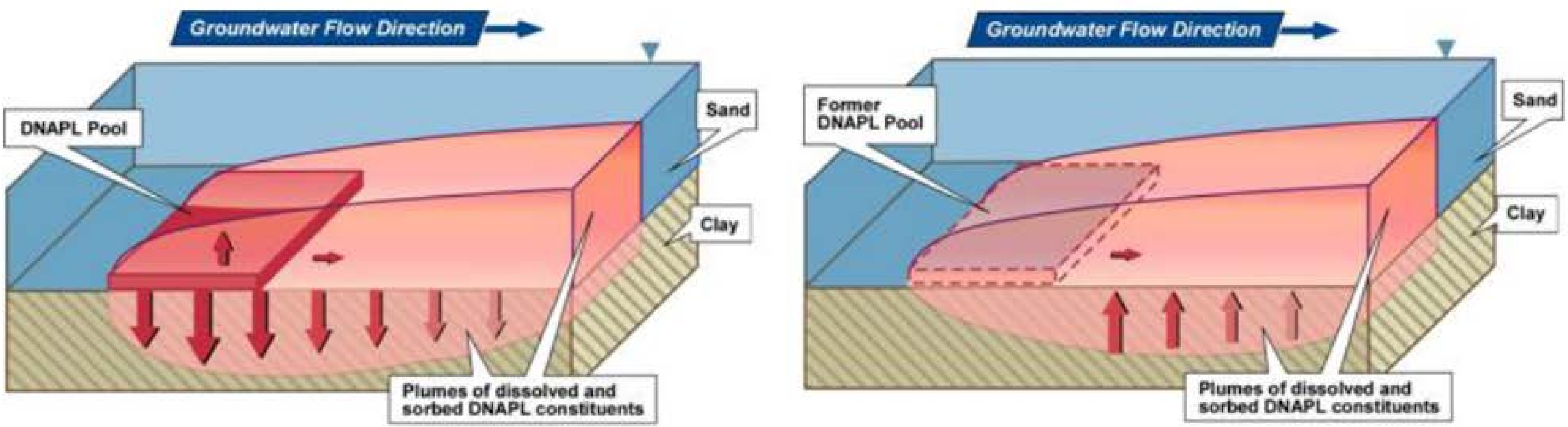
Aged Source



Stroo et al., 2012

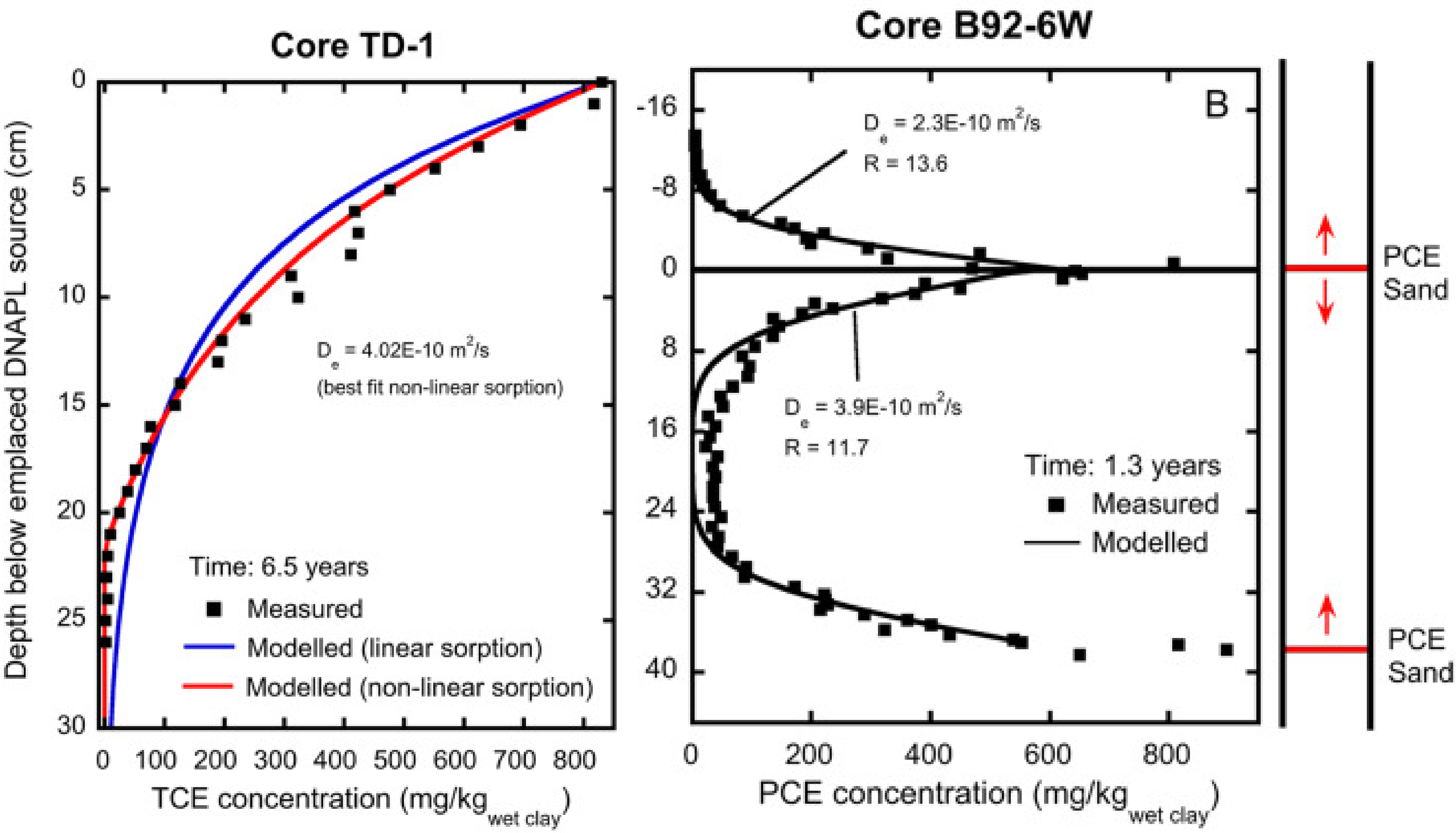
The Challenges with Matrix Diffusion

- Low-K zones serve as ongoing sources of contamination separate from the initial source and throughout the plume footprint
- This source persists for long time periods
- Concentrations in permeable zones rebound following remediation of those zones
- Introduction of remedial agents into the low-K zones is controlled by the rate of diffusion and takes a very long time



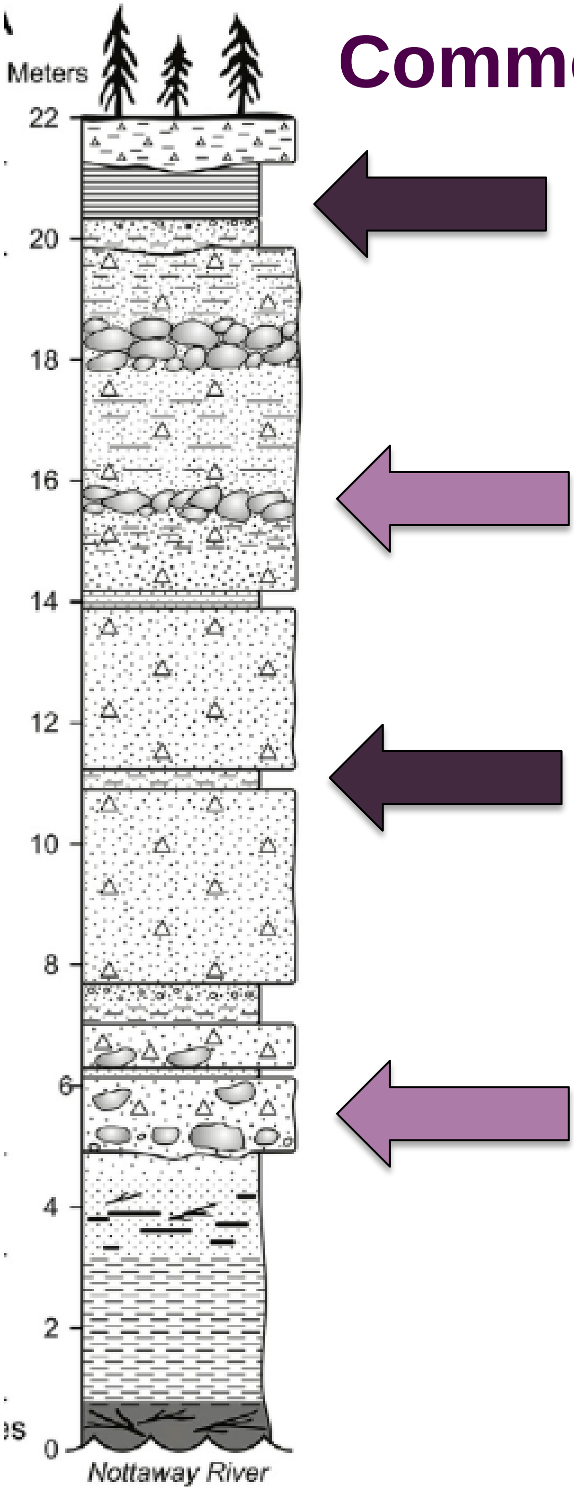
Sale and Newell, 2011

Is There a Source in Low K Units?



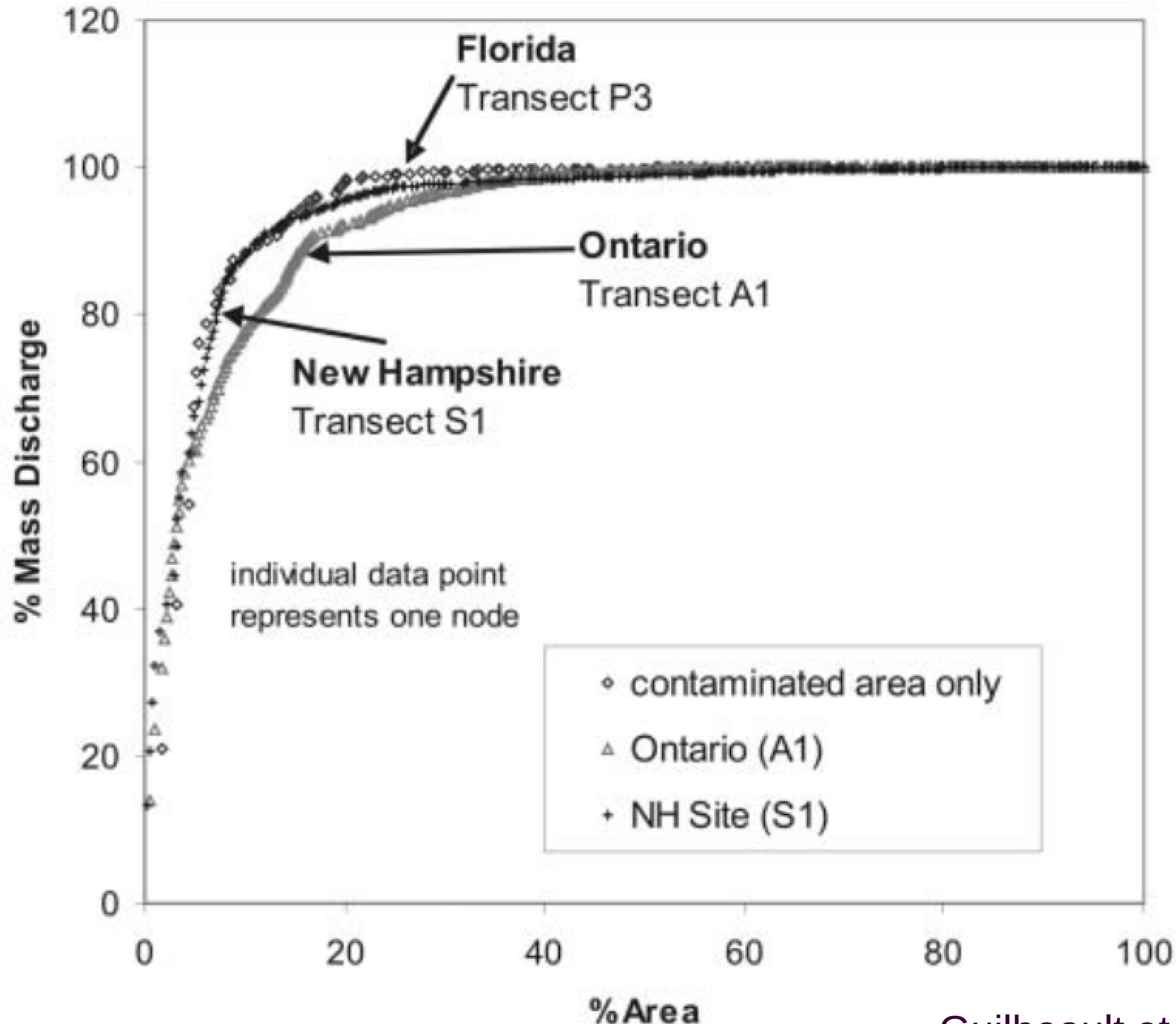
Parker et al., 2022

Common Glacially Influenced Dual Porosity System in New England



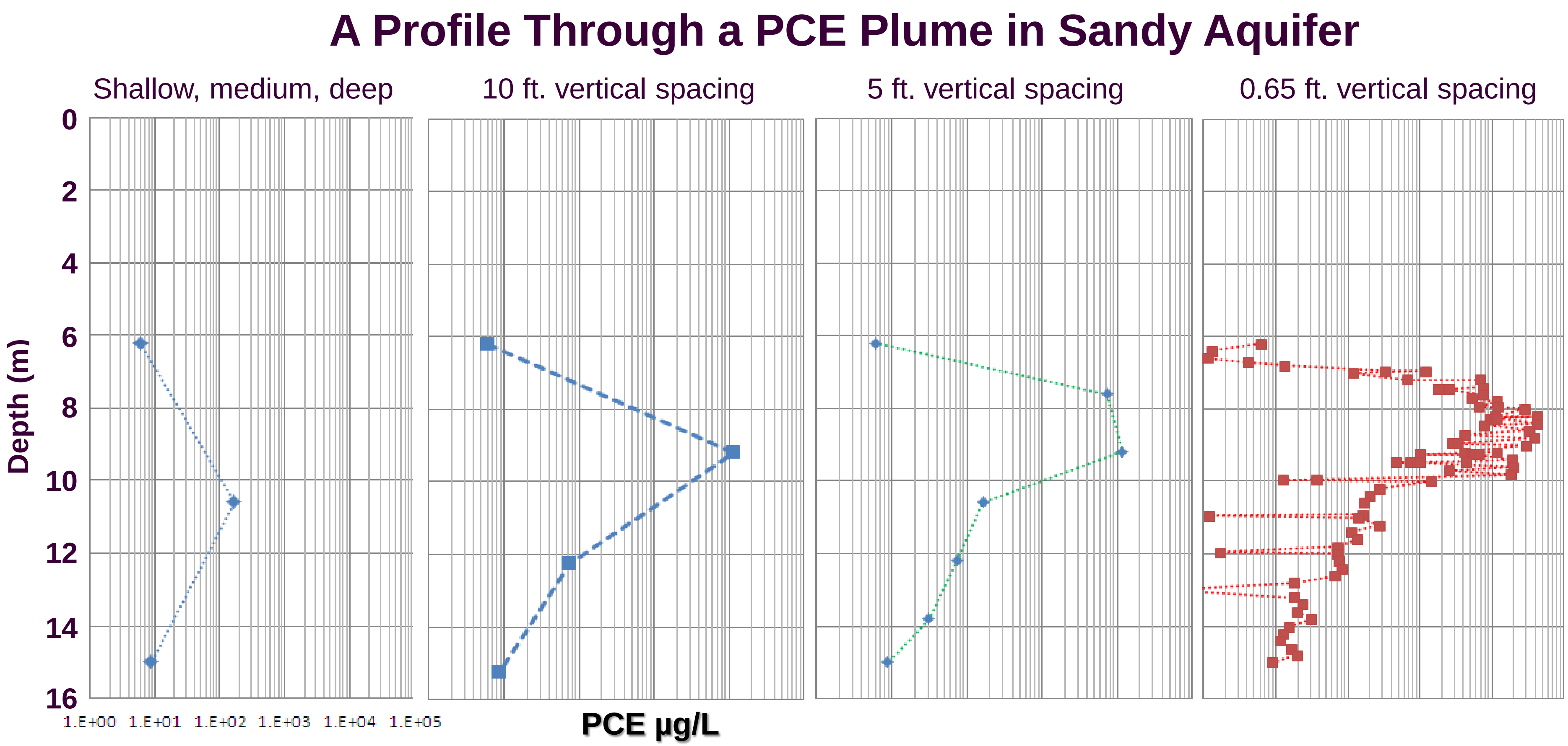
Higher K units (*i.e.*, coarse sand) where most advective flux will take place

Lower K units (*i.e.*, clays) where most diffusive flux will take place



Guilbeault et al, 2005

Where is the Source Located in Three Dimensions? What Resolution is Required?



How much resolution does your monitoring well give you?

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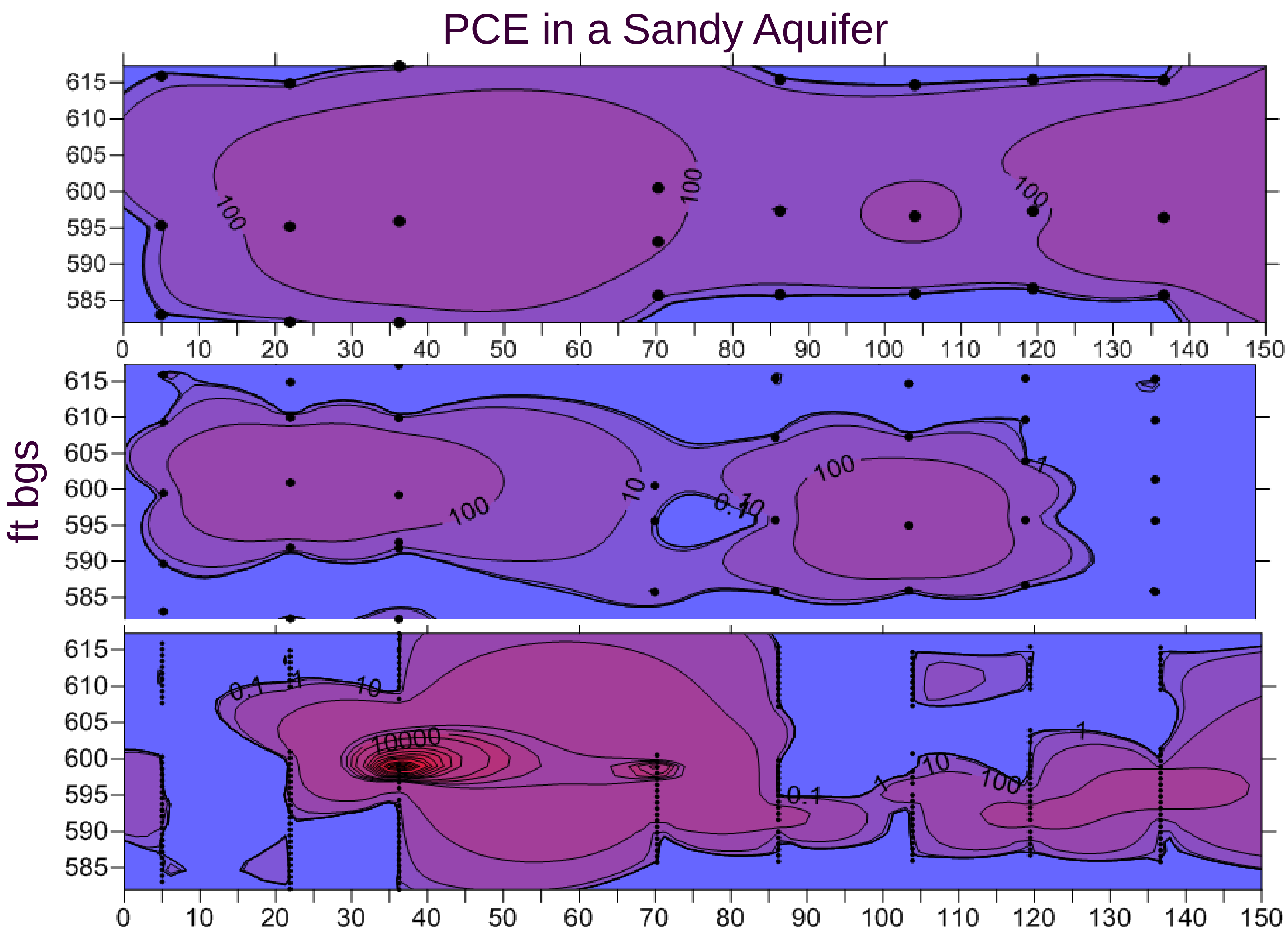
Where is the Source Located in Three Dimensions? What Resolution is Required?



The Main Problem with Environmental Remediation

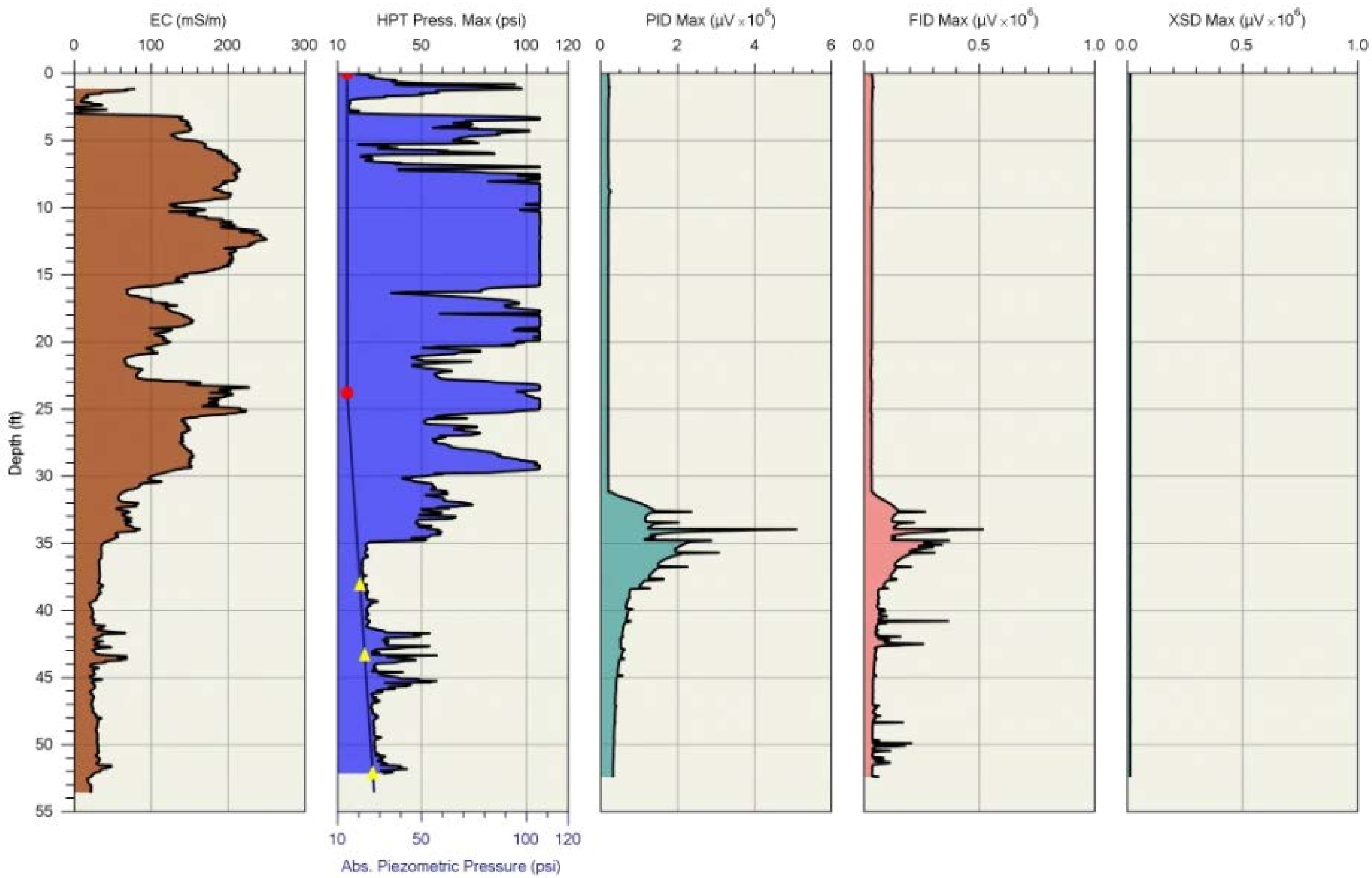
- One cannot effectively solve a problem which one has not adequately and accurately characterized (CSM)
- Many Remedial Investigations continue for years or even decades
- Many remedies underperform or fail due to a lack of understanding of site conditions and processes (heterogeneity)
- The cost of these failed/ underperforming remedies are high.
- The costs of excessive long-term monitoring programs related to investigating sites with monitoring wells are high.
- The costs of High-Resolution Site Characterization, which allows one to avoid failed remedies, are minimal in comparison, but requires an up front investment to result in lower life cycle costs.

Commonly Used Tools
Quantitative vs. Qualitative

- MIP, MiHPT, Low Level MIP (screening)
- Optical Image Profiler
- Nuclear magnetic Resonance
- Waterloo^{APS} with I_K (Definitive)
- LIF/UVOST (LNAPL Detection)
- TarGOST (Coal Tar/ Creosote NAPL Detection)
- Dye-LIF (Cl Solvent NAPL detection by LIF with dye)
- High Res. Soil Core Profiling in Aquitard Materials (Definitive)
- CORE^{DFN} Approach in fractured rock

Geoprobe

MIP / MiHPT



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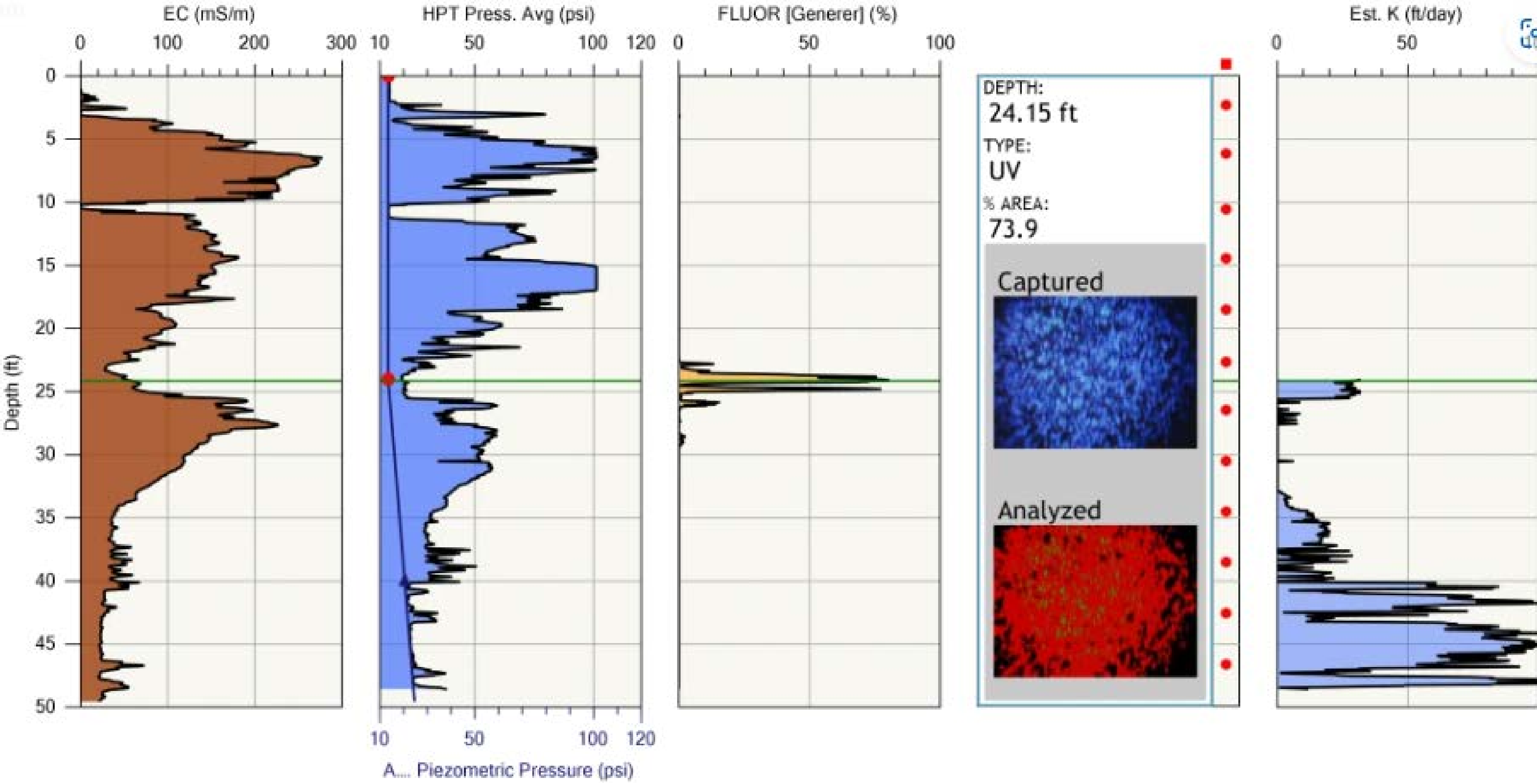
Geoprobe

Optical Image Profiler



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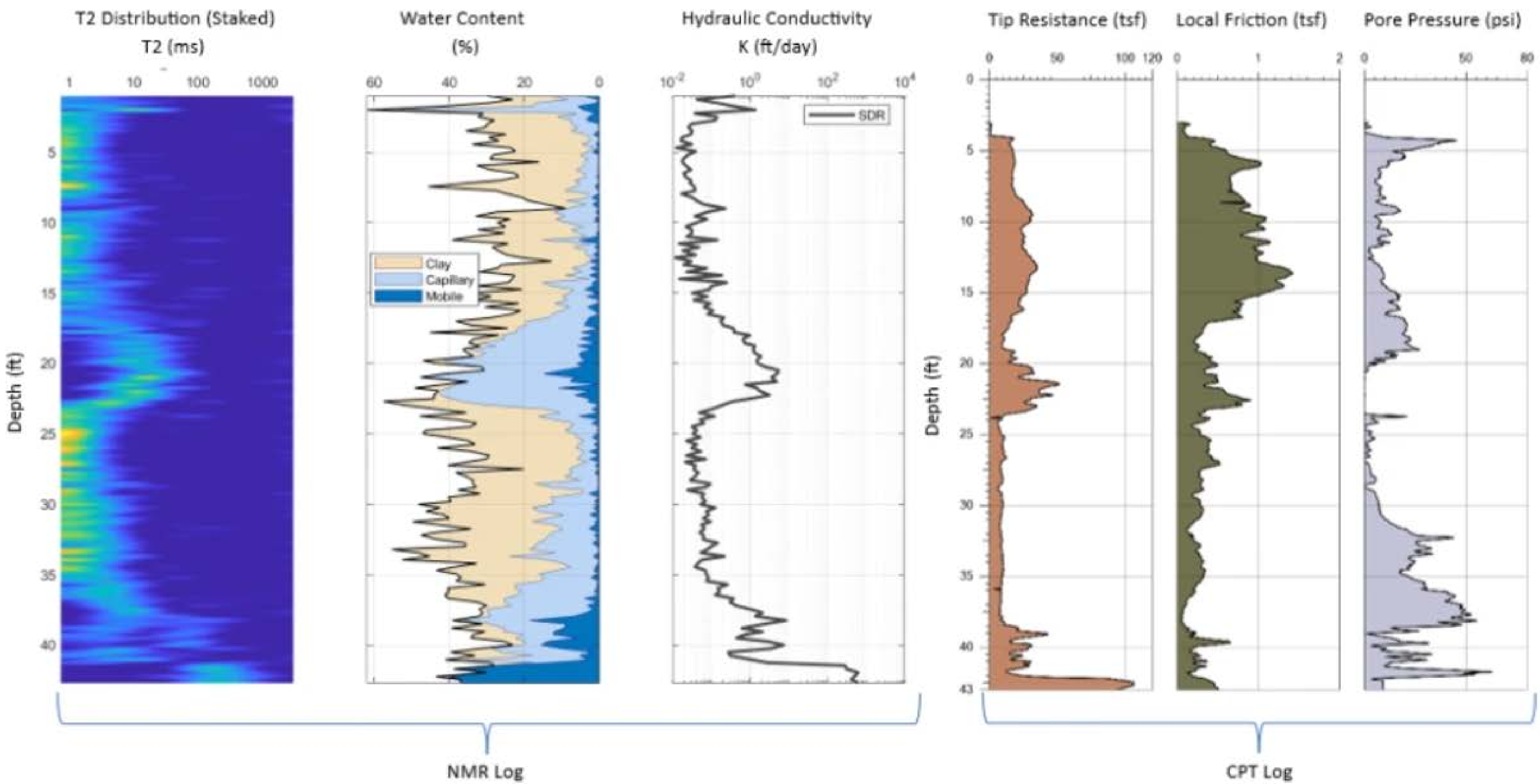
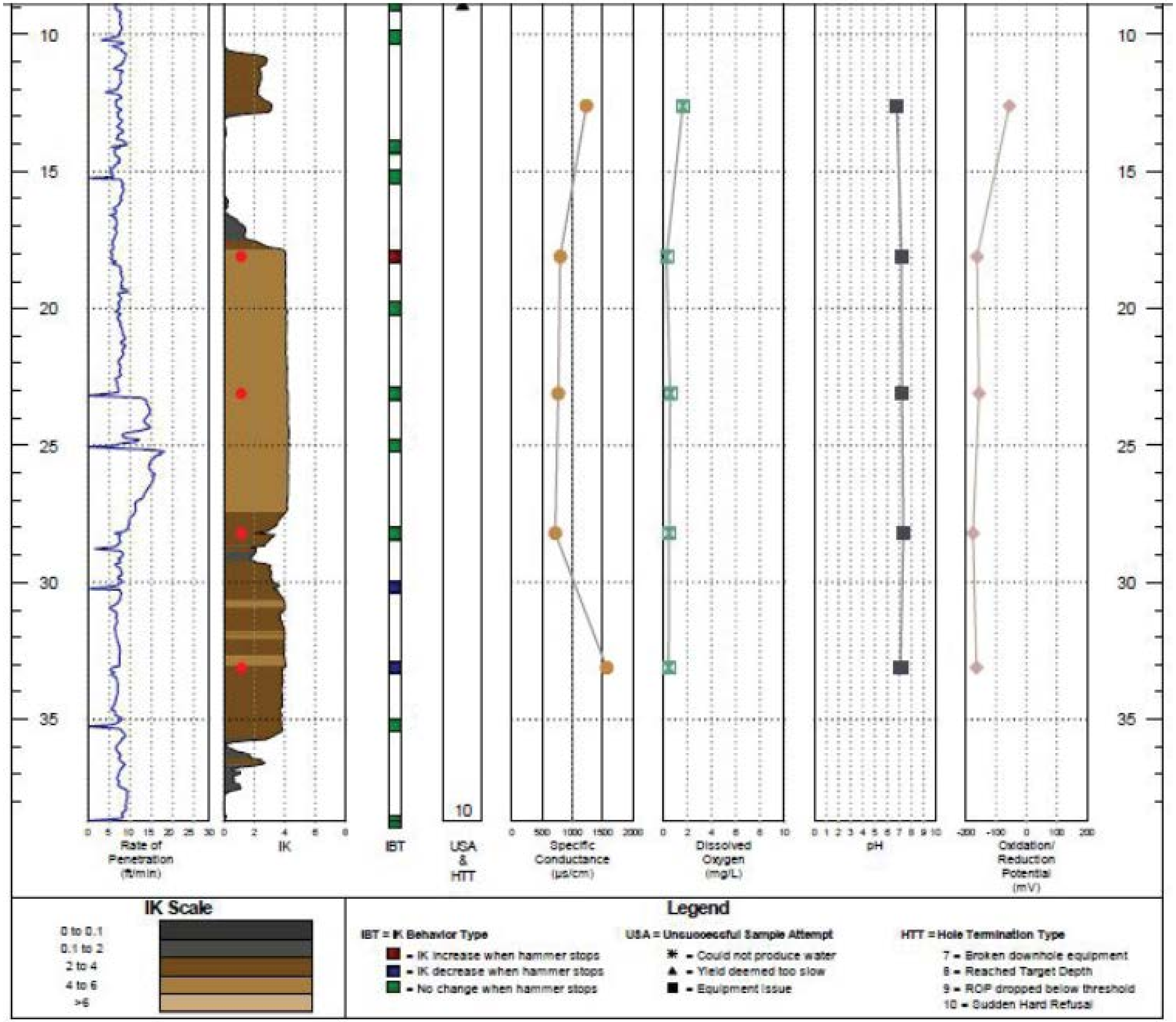
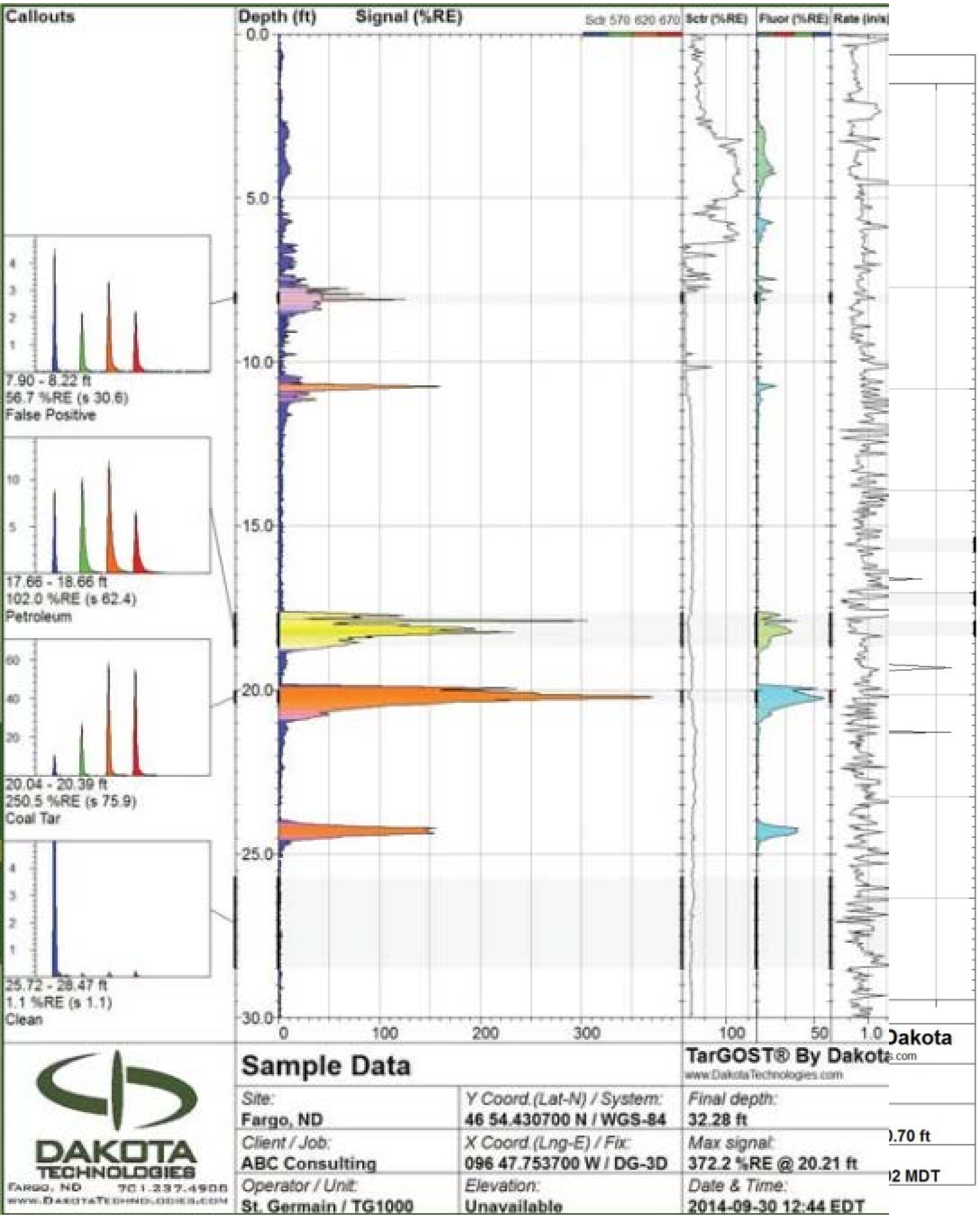
Direct Push
Nuclear Magnetic Resonance

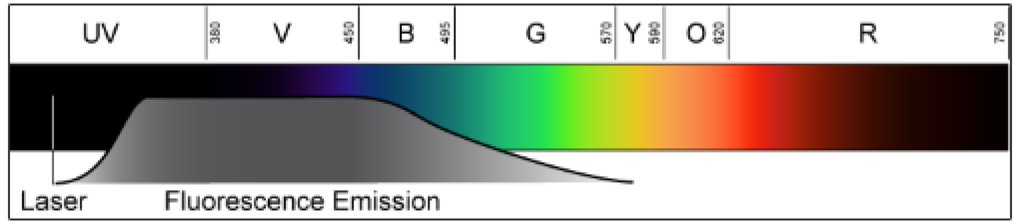


Waterloo^APS

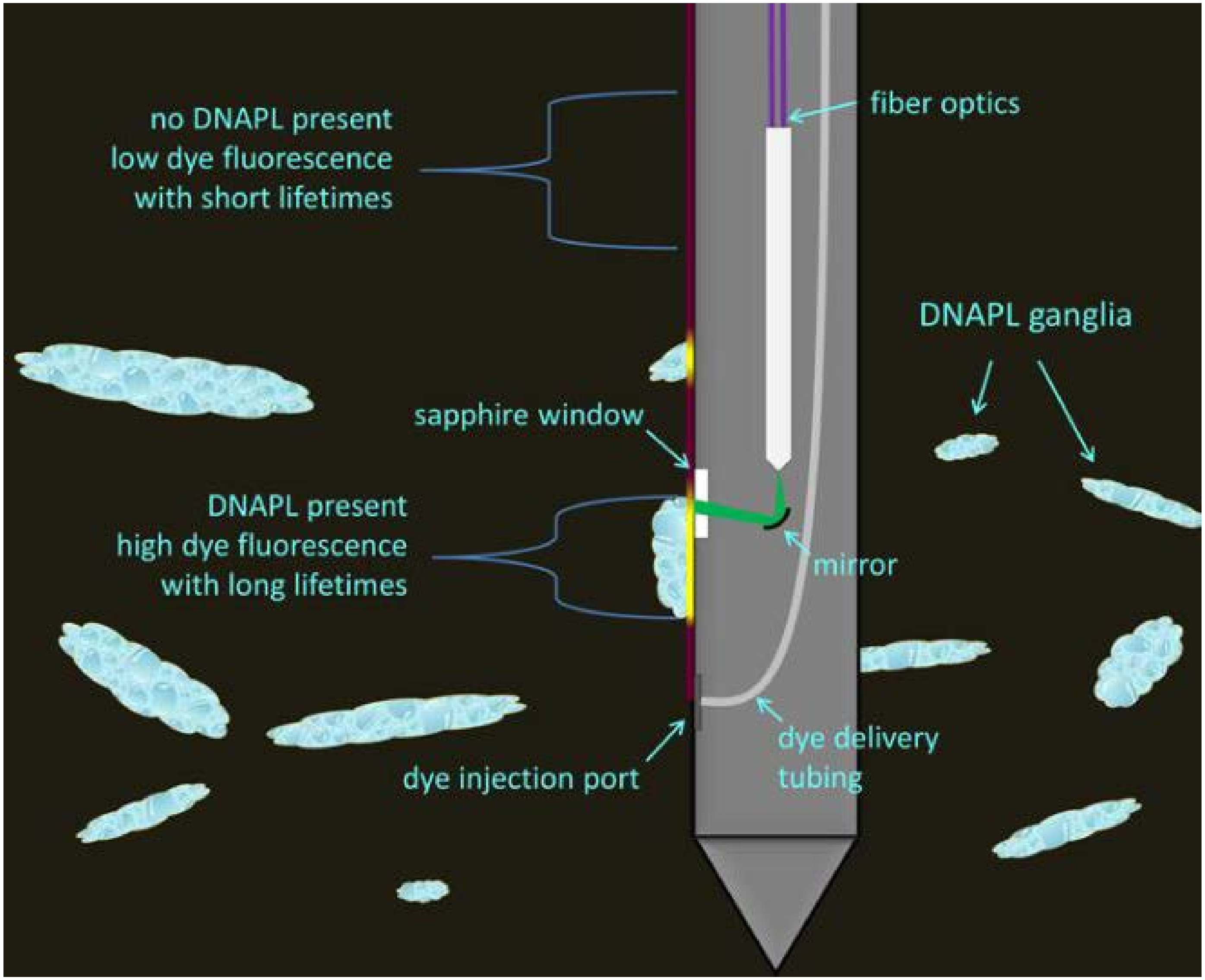


UVOST and TarGOST



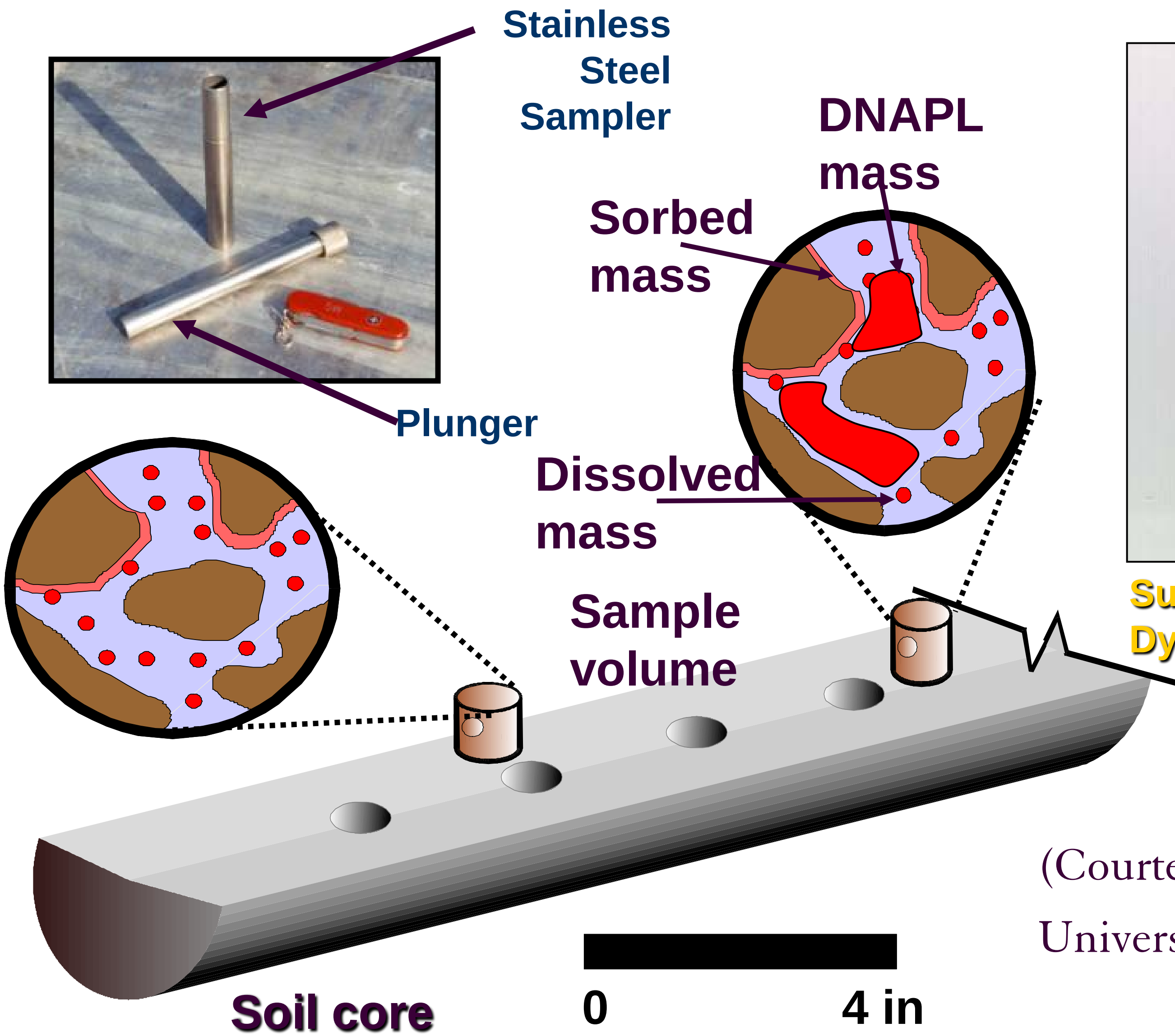


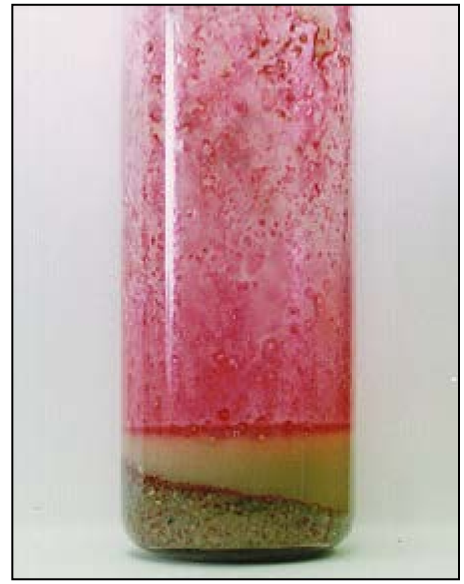
Dye-LIF


no DNAPL present
low dye fluorescence
with short lifetimes
fiber optics
DNAPL ganglia
sapphire window
DNAPL present
high dye fluorescence
with long lifetimes
mirror
dye delivery
tubing
dye injection port

High Resolution Soil Coring

Soil Core Sampling - NAPL Detection

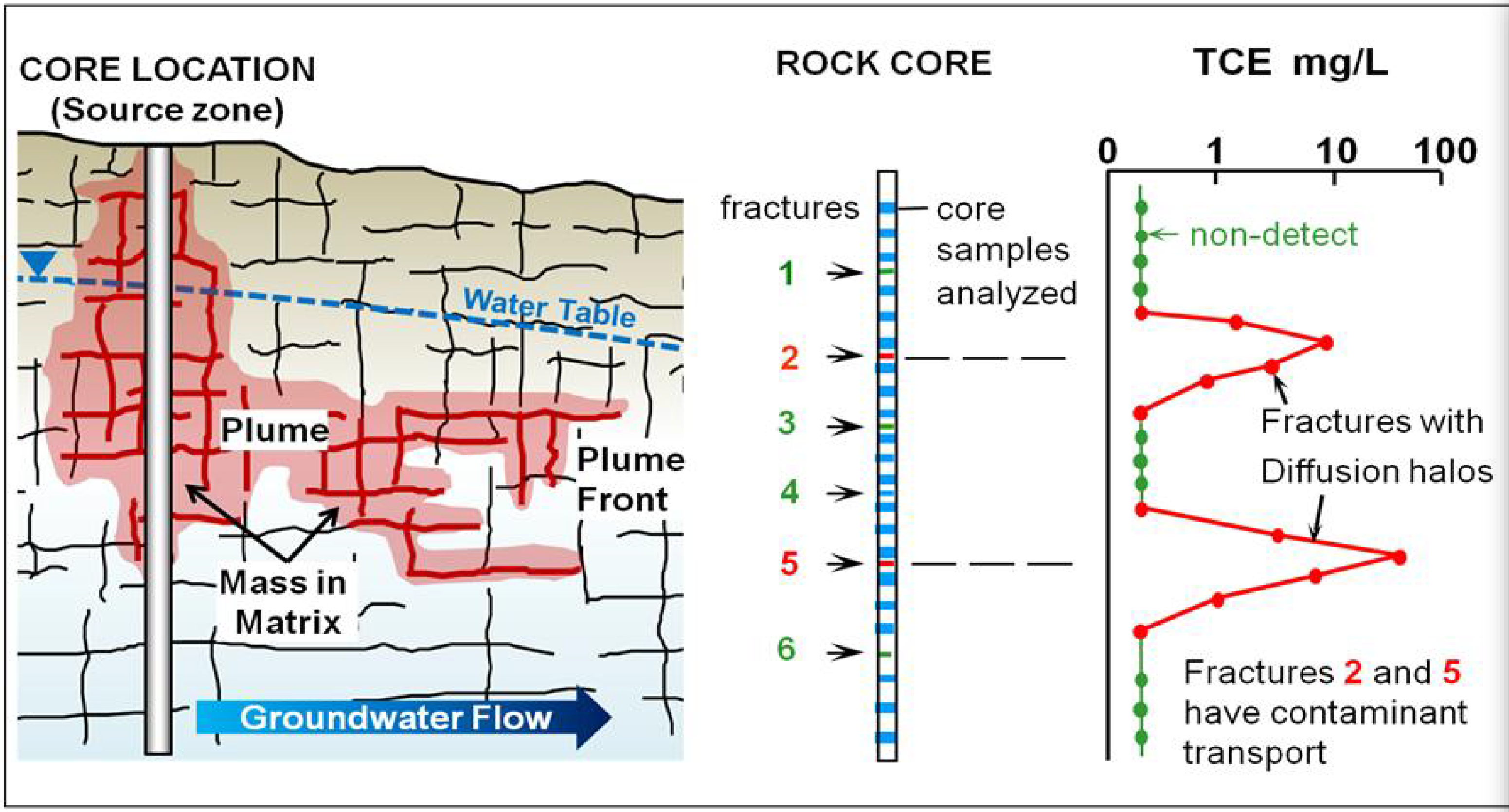




Sudan IV/Oil Red O Dye

(Courtesy of Beth Parker, University of Guelph)

CORE^{DFN} Sampling Approach for Transport Pathways and Mass Distribution



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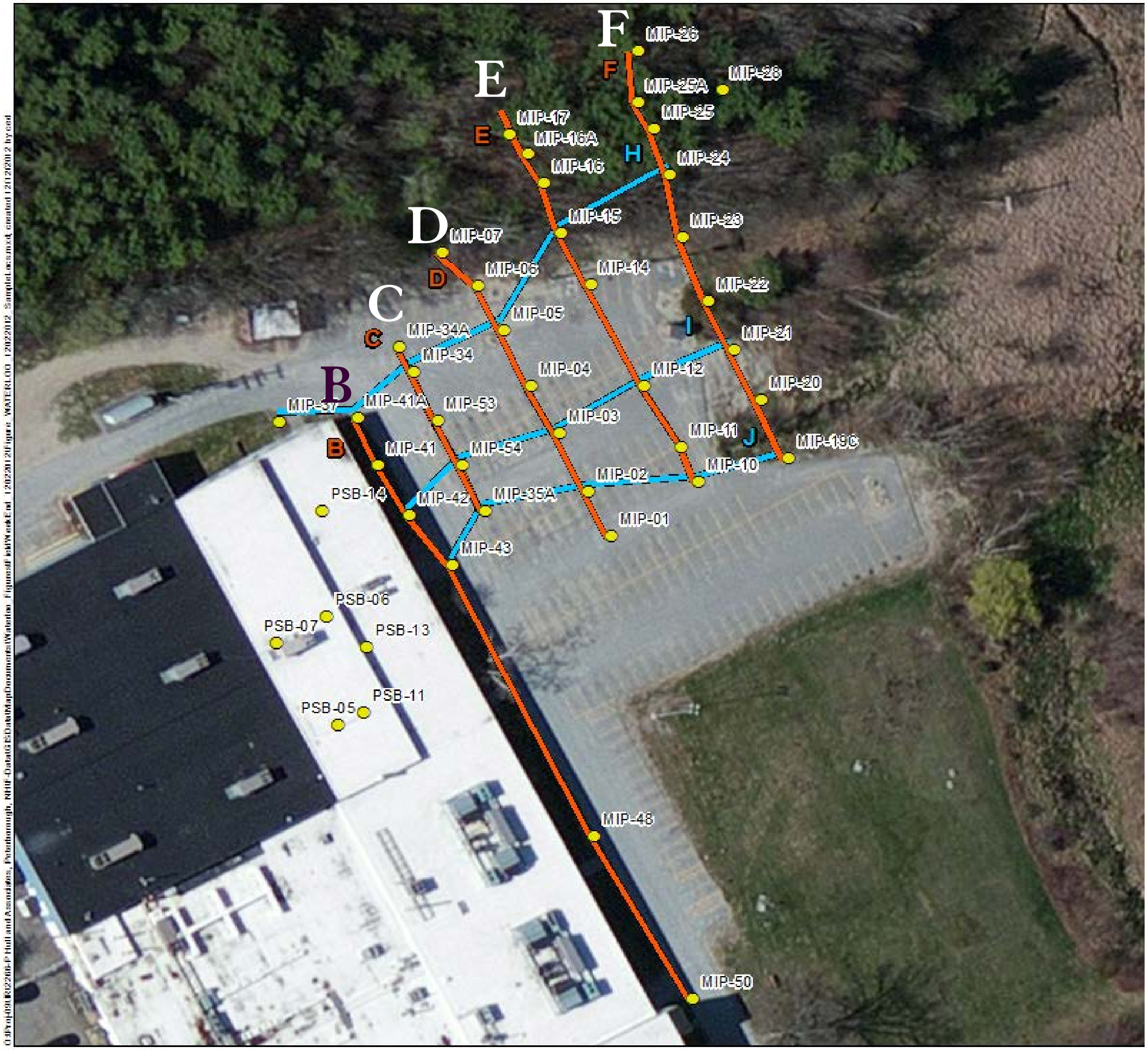
Examples of Persistent Plume after Remediation Due to Back Diffusion



South Municipal Well Superfund Site

DNAPL CVOC Plume

Initial remediation of soil removal and groundwater/ vapor extraction in the early 1990s

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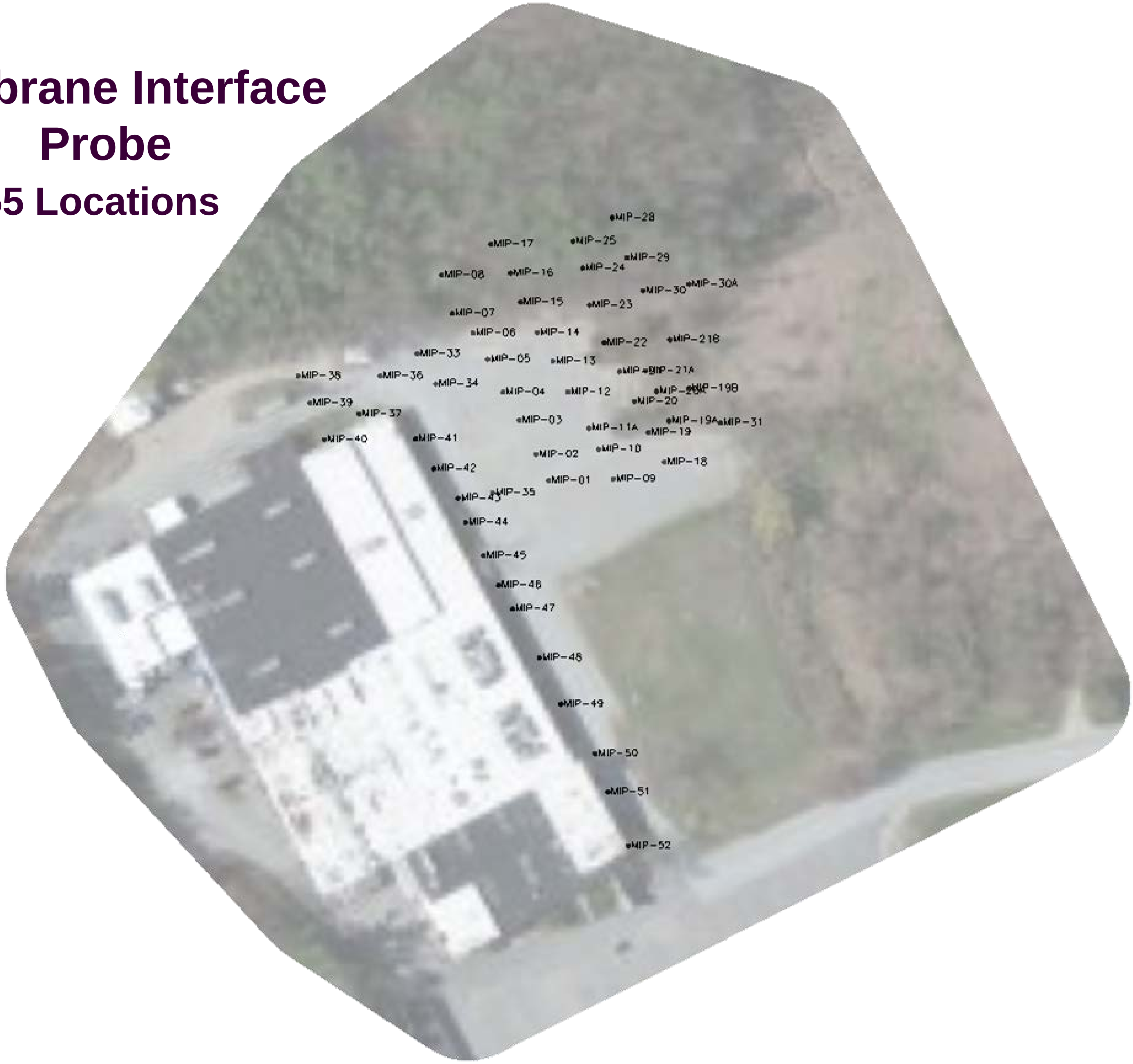
Membrane Interface Probe

55 Locations



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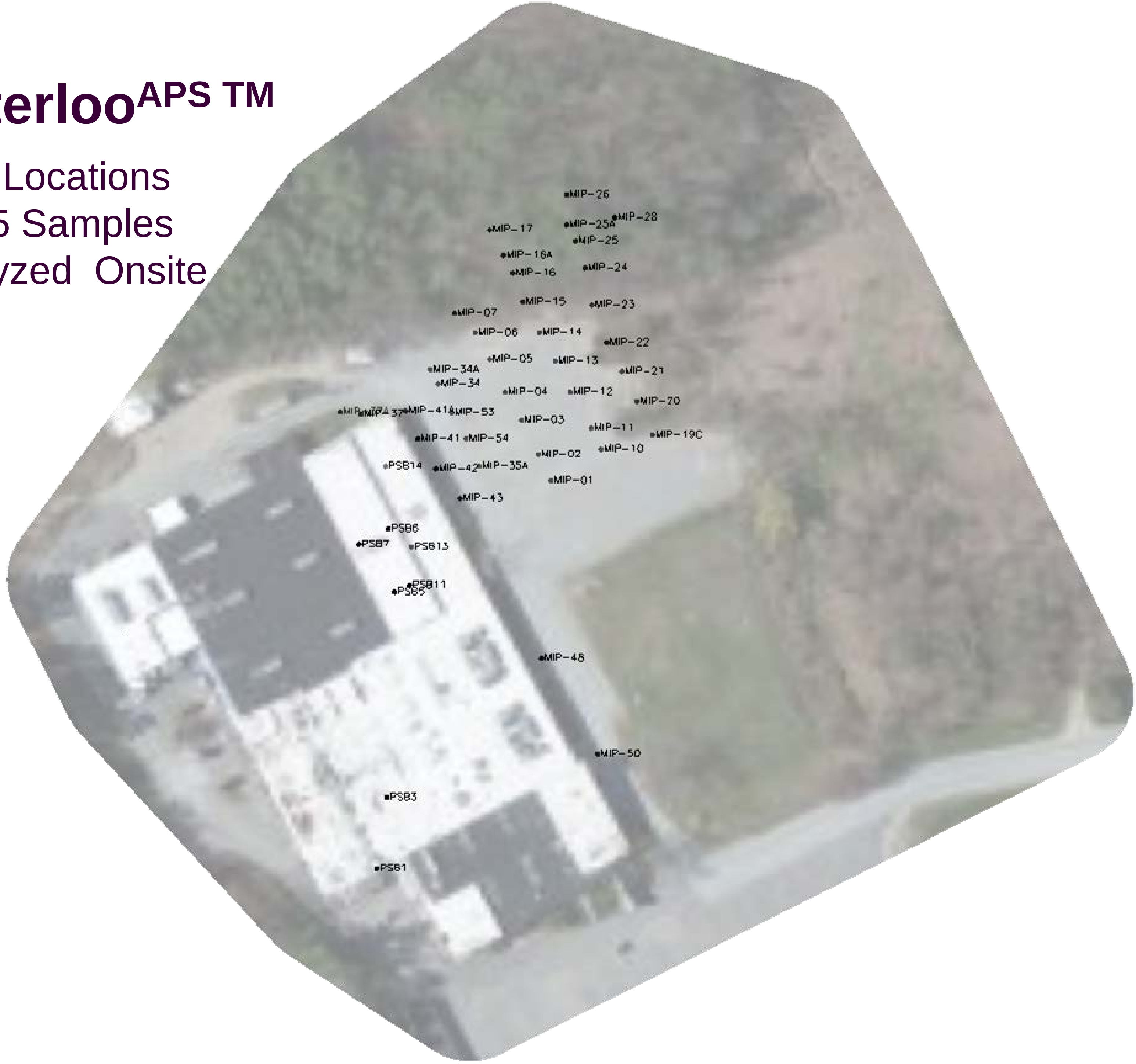
Waterloo^APS TM

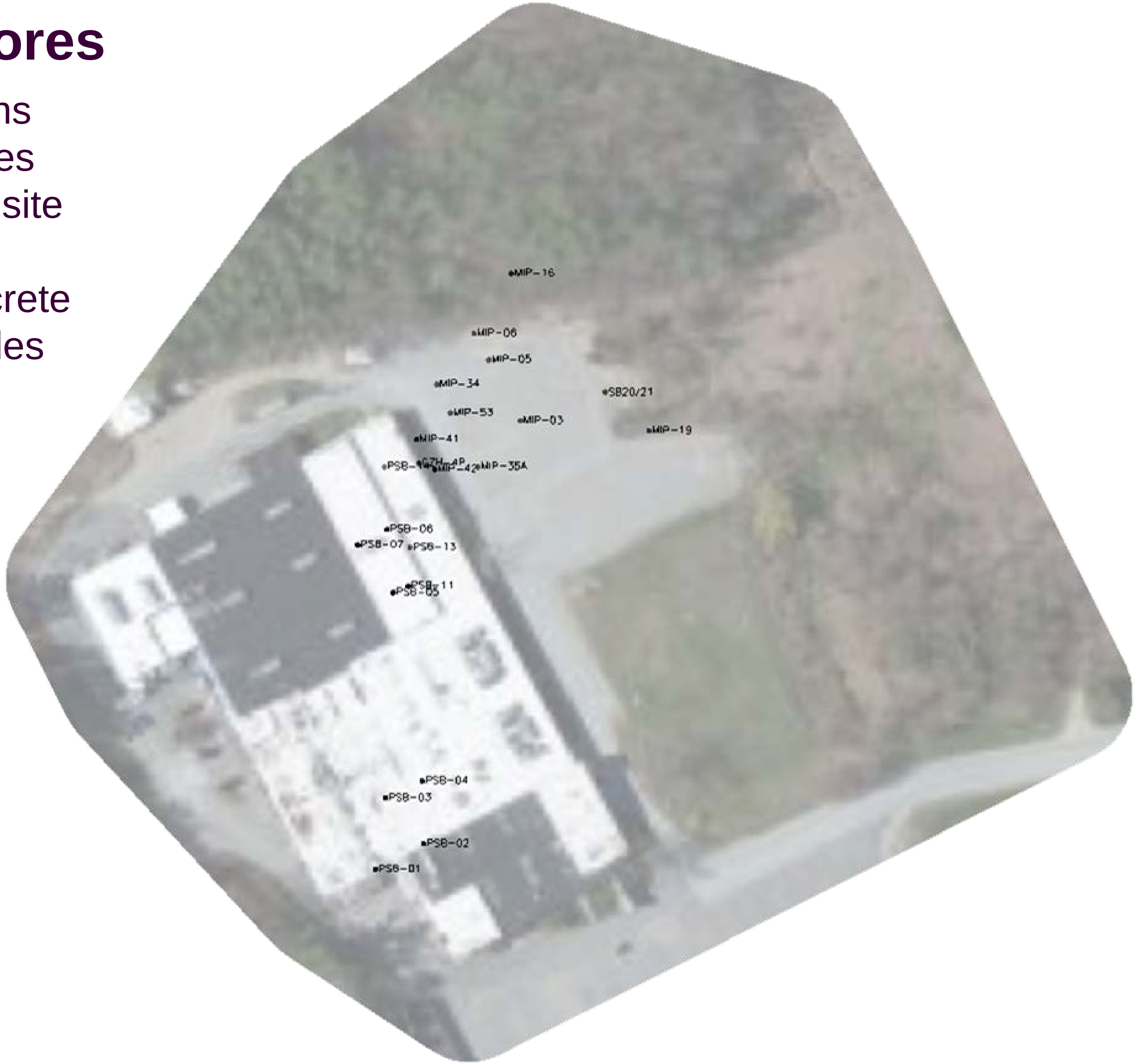
47 Locations
755 Samples
Analyzed Onsite



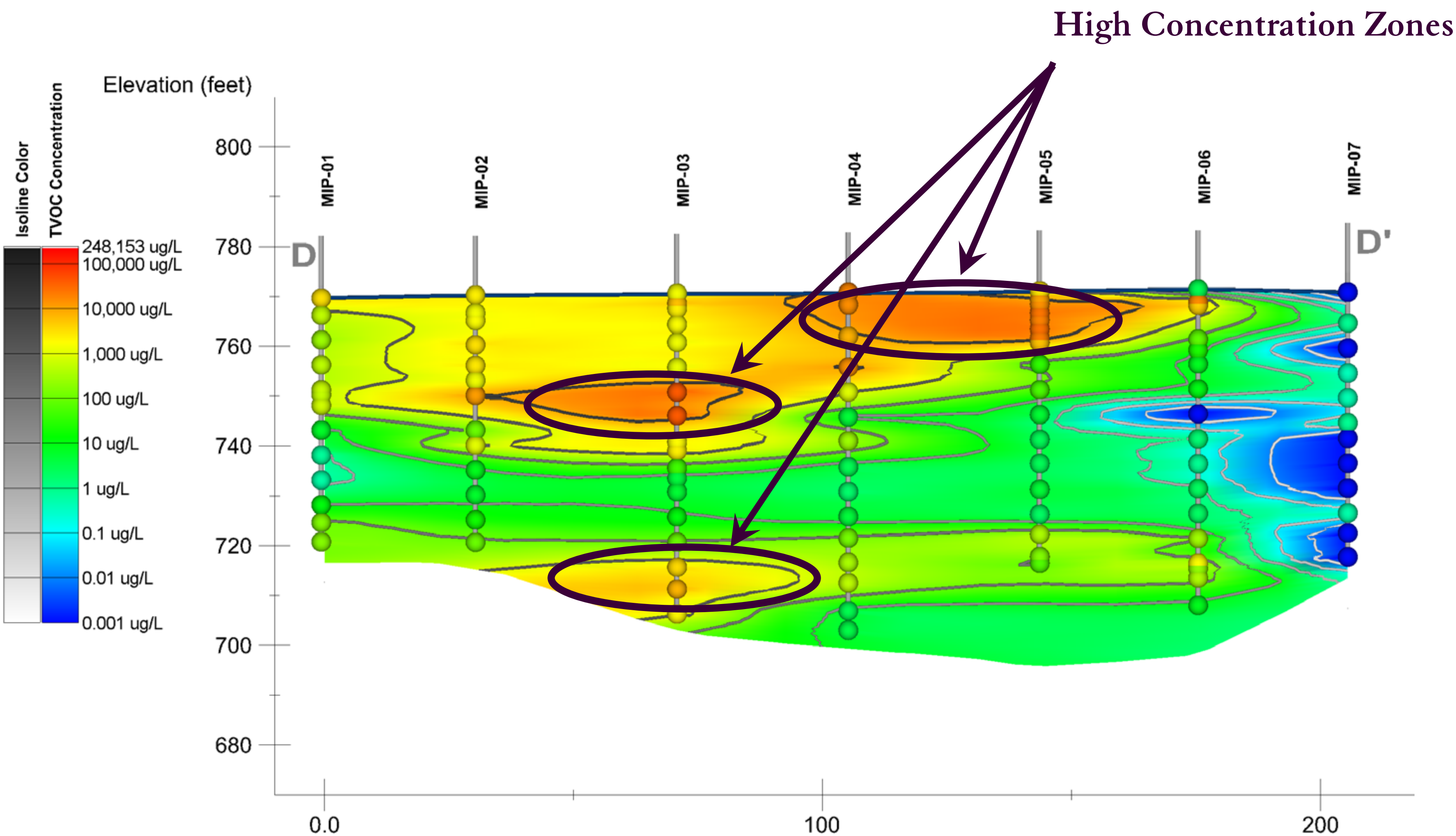
Soil Cores

21 Locations
966 Samples
Analyzed Onsite

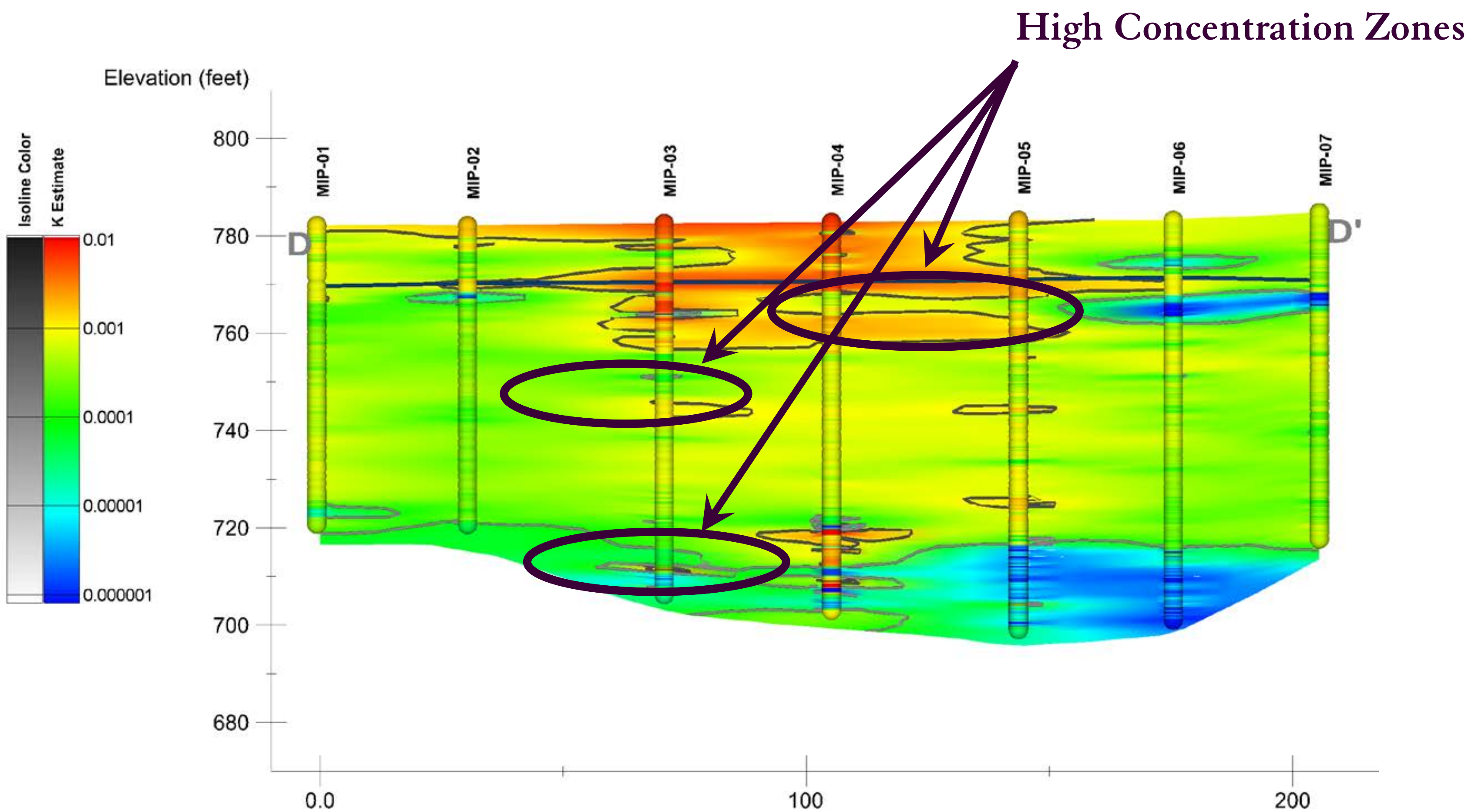
Plus 17 Concrete
Core Samples
Analyzed



Transect D – TVOC Concentration (mg/L) WaterlooAPS Data



Transect D – Estimated Hydraulic Conductivity WaterlooAPS Data



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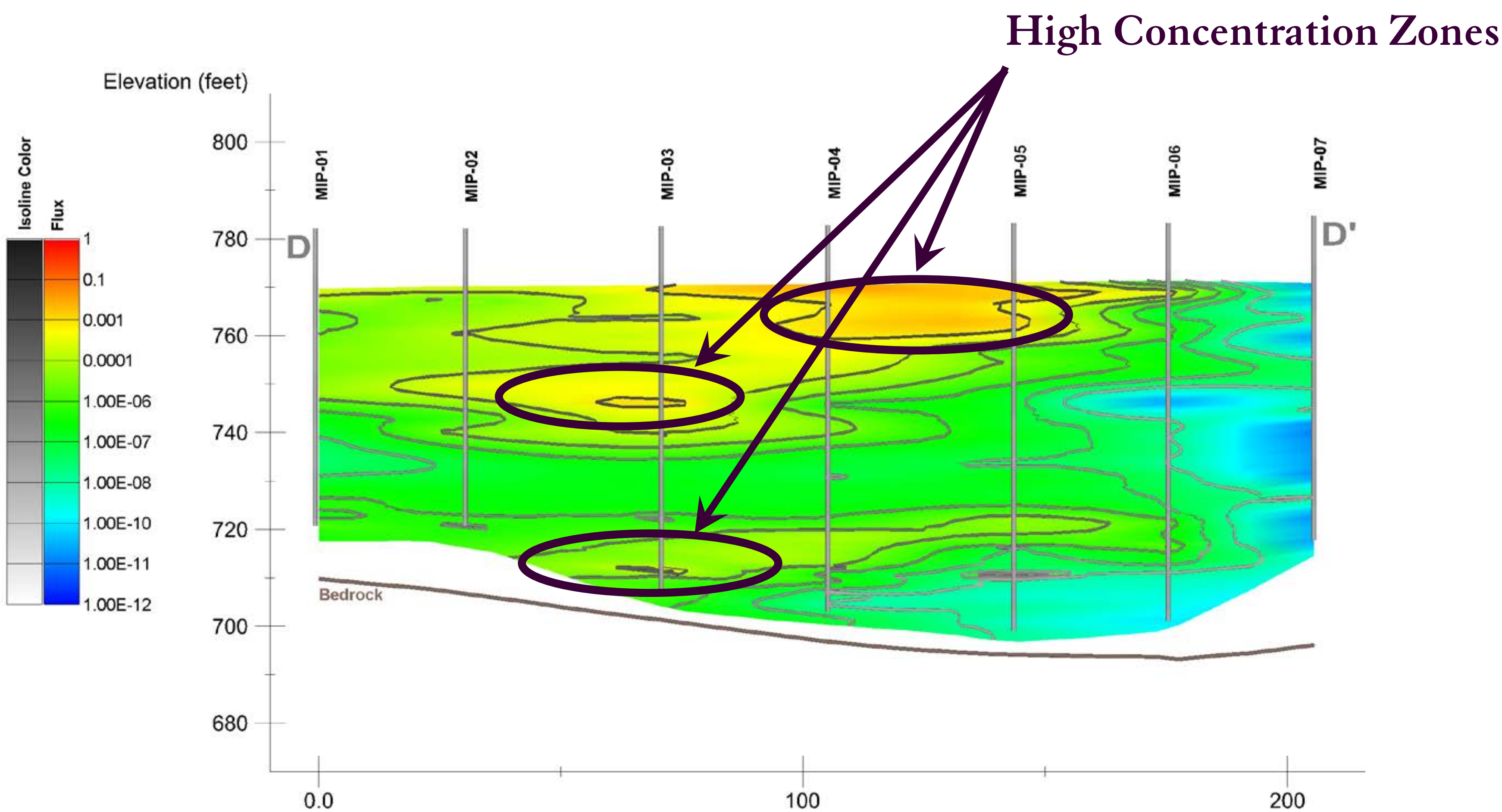
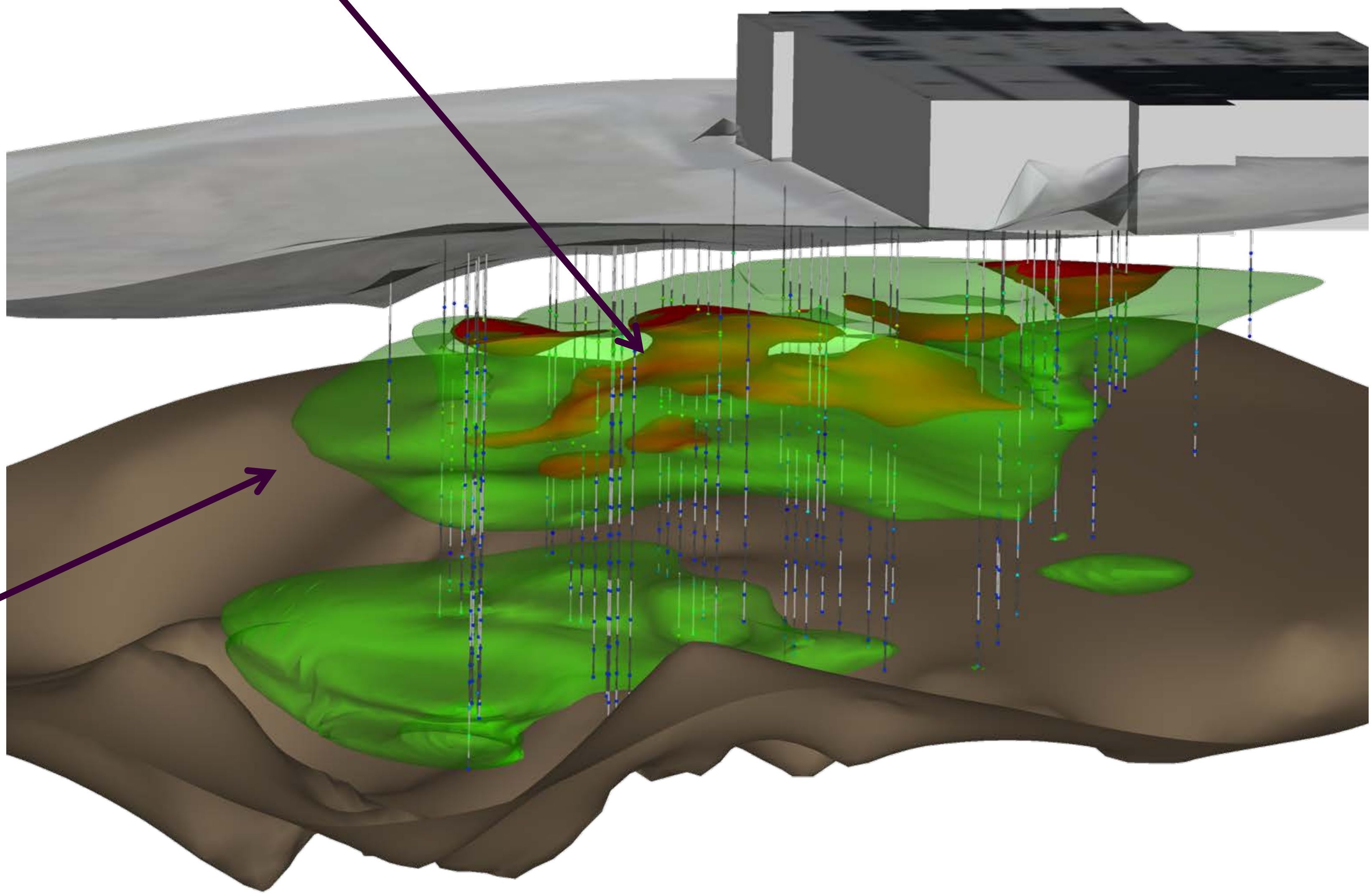
Transect D – Relative Mass Flux Distribution WaterlooAPS Data

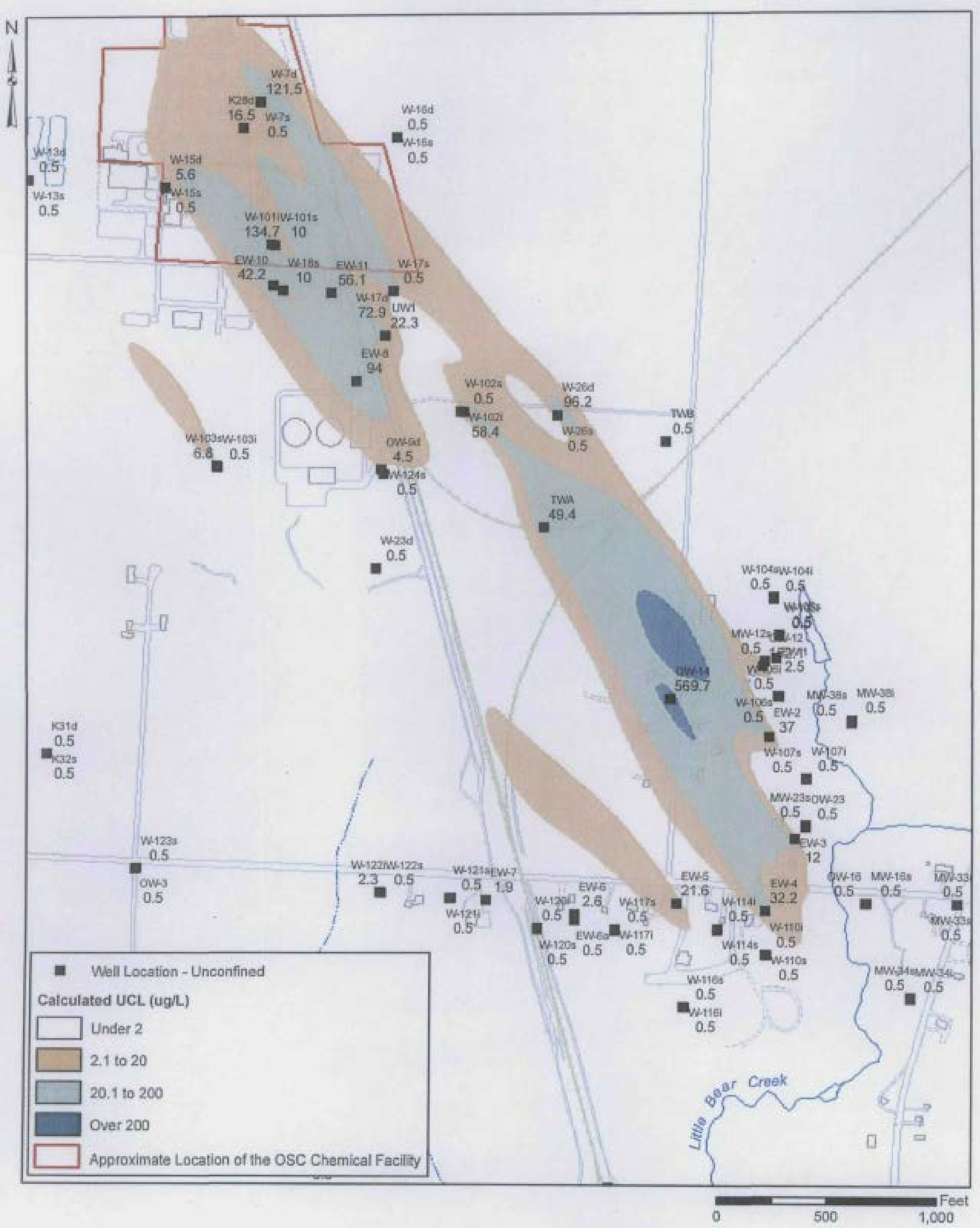


Mass Flux Relative to Plume volume

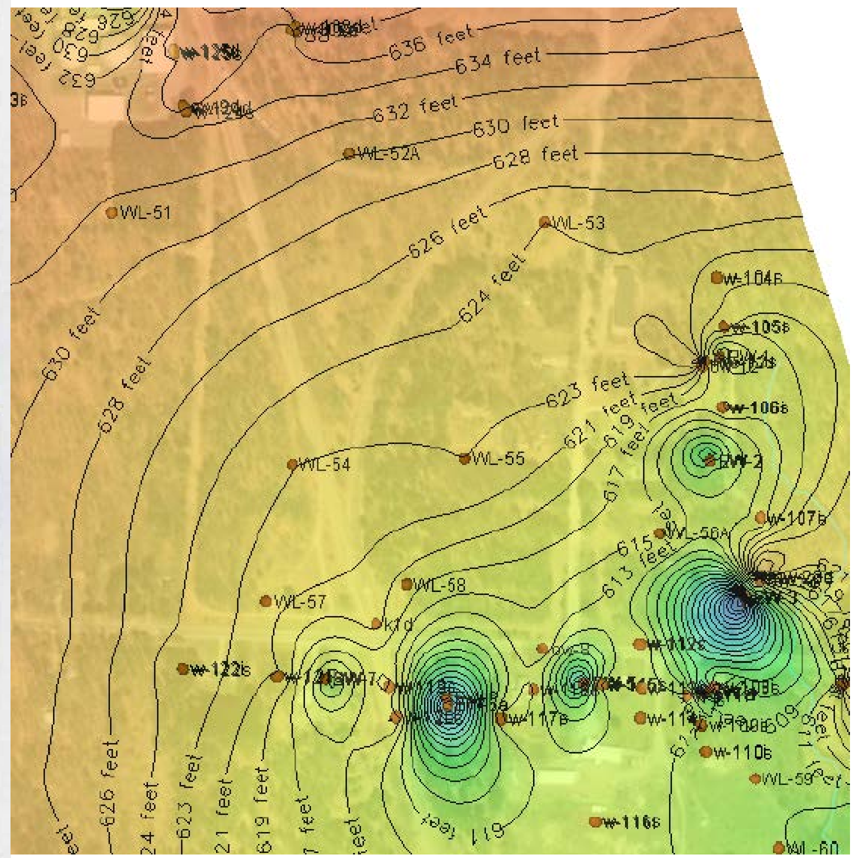


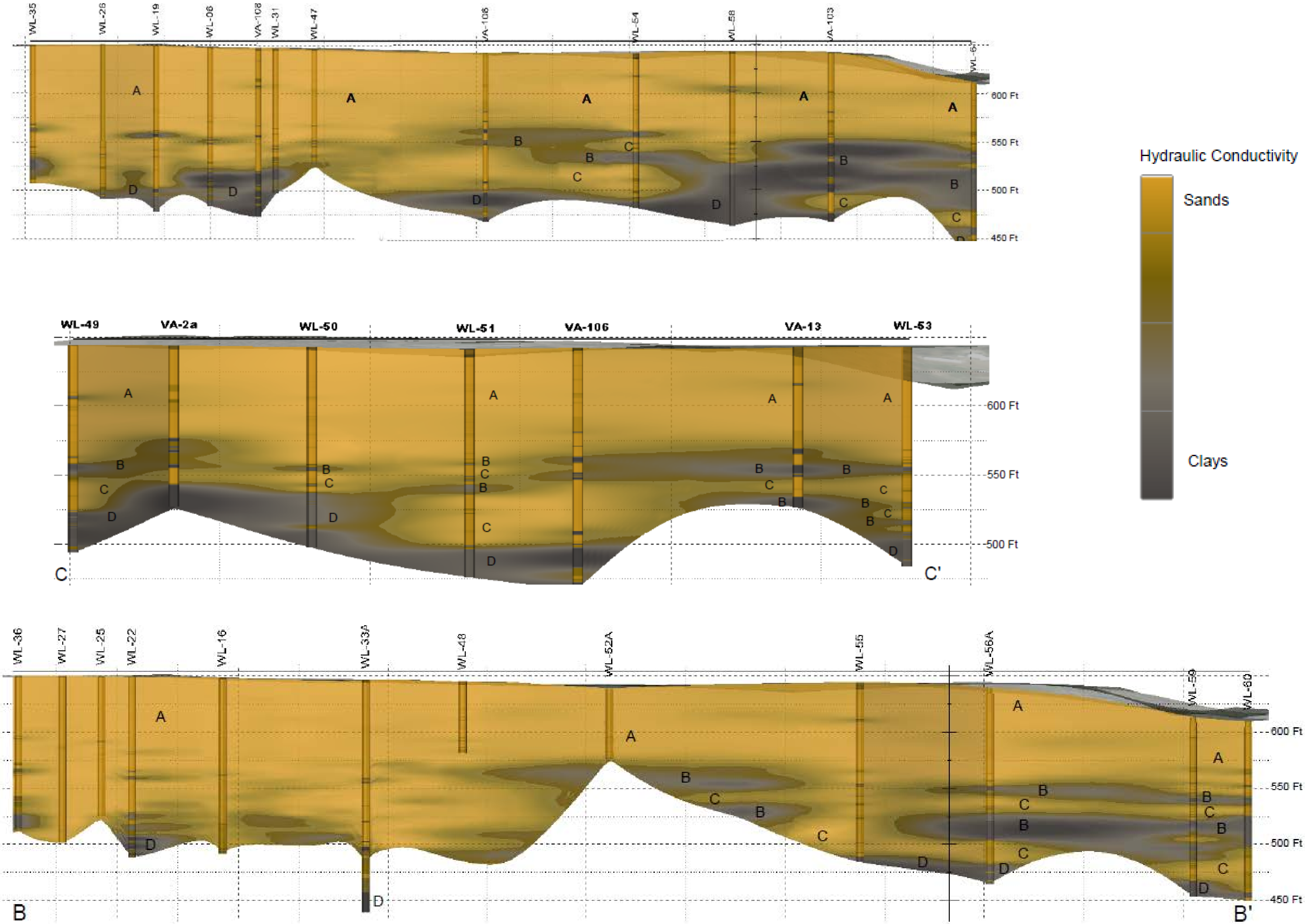
OTT/STORY/CORDOVA Superfund Site

- CVOC contamination
- EPA removed thousands of drums and thousands of cubic yards of sludge in the 1970s
- Groundwater pumping and treatment started in 1996 averaging 25-45 million gallons per month.
- 13,000 pounds of VOCs were extracted and removed from 1996-2007.



After $65 million spent through 2010 and almost half a billion gallons of water treated, HRSC was implemented in 2014





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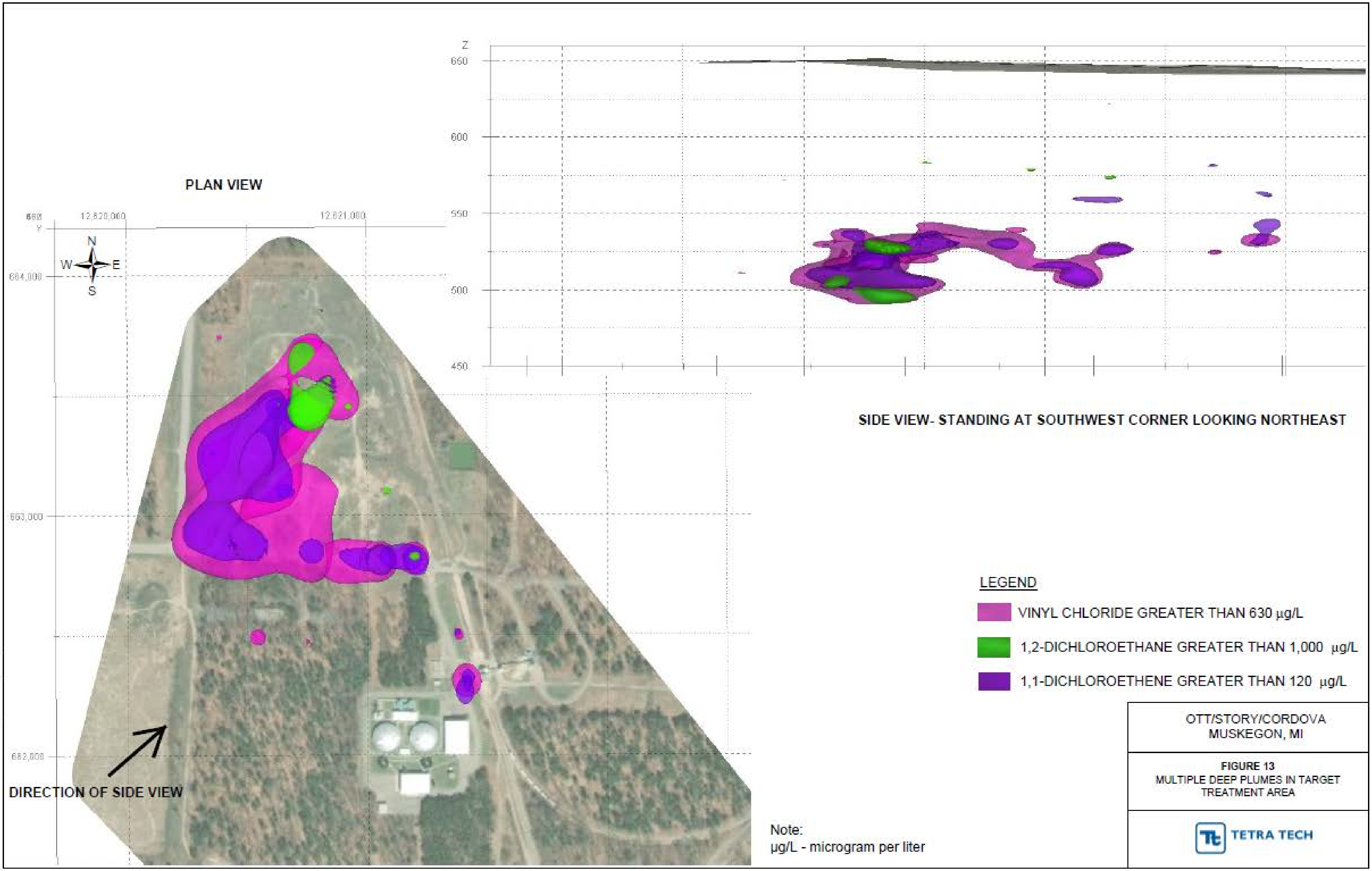
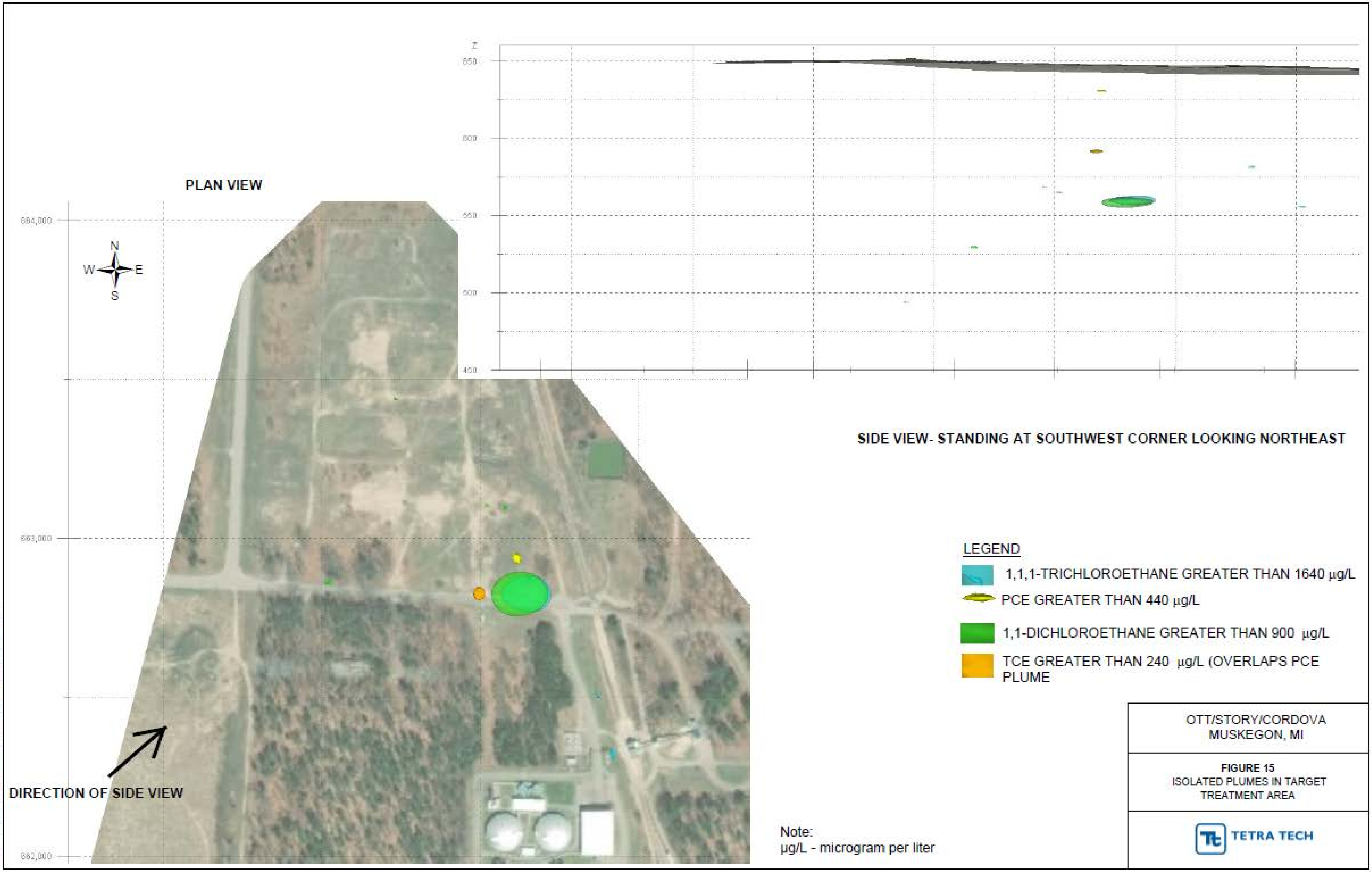
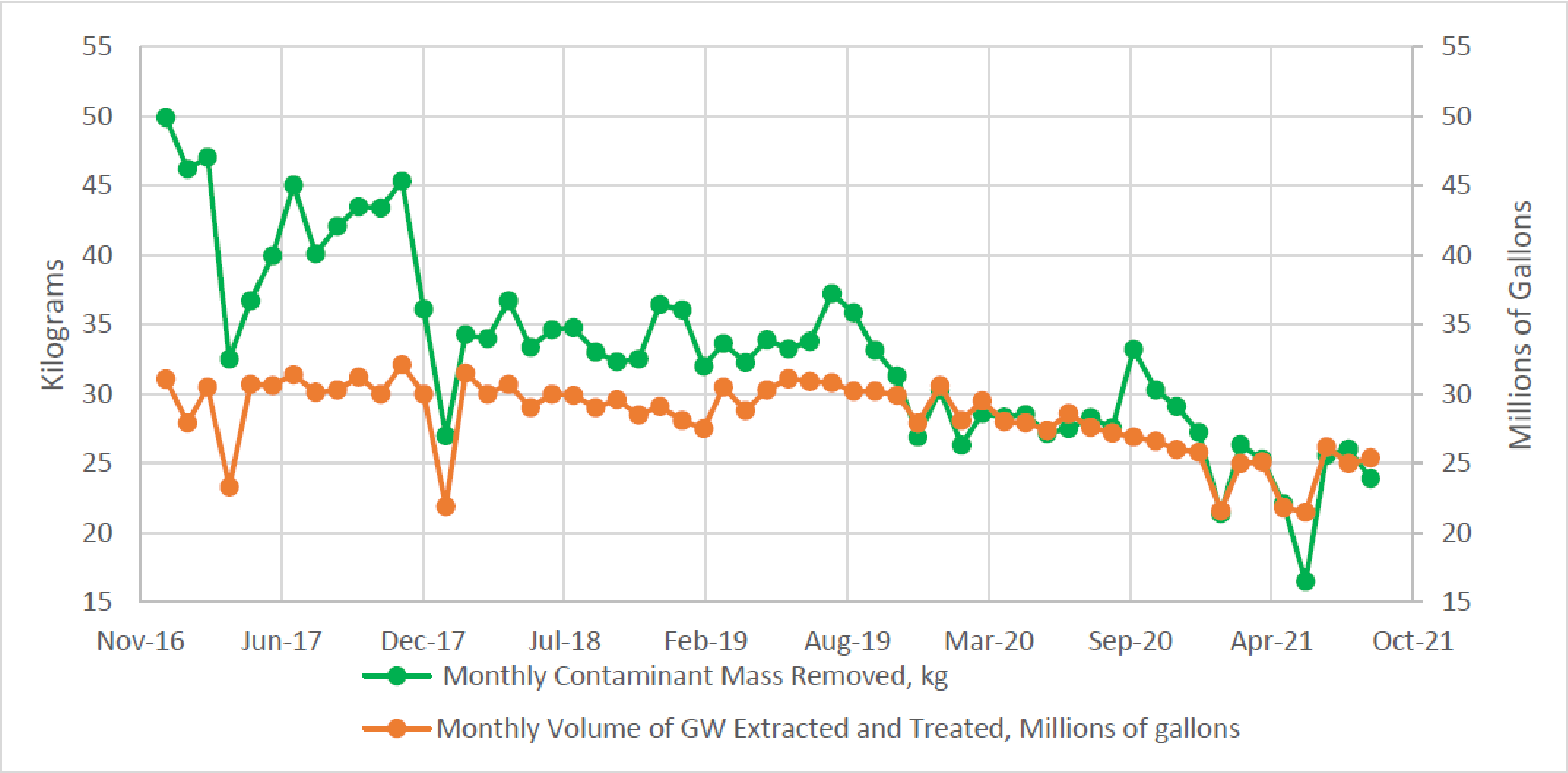


PLAN VIEW
N
W
E
S
DIRECTION OF SIDE VIEW
Z
650
600
550
500
450
SIDE VIEW- STANDING AT SOUTHWEST CORNER LOOKING NORTHEAST
LEGEND
VINYL CHLORIDE GREATER THAN 630 µg/L
1,2-DICHLOROETHANE GREATER THAN 1,000 µg/L
1,1-DICHLOROETHENE GREATER THAN 120 µg/L
OTT/STORY/CORDOVA
MUSKEGON, MI
FIGURE 13
MULTIPLE DEEP PLUMES IN TARGET TREATMENT AREA
TETRA TECH
Note:
µg/L - microgram per liter


PLAN VIEW
N
W
E
S
DIRECTION OF SIDE VIEW
SIDE VIEW- STANDING AT SOUTHWEST CORNER LOOKING NORTHEAST
LEGEND
1,1,1-TRICHLOROETHANE GREATER THAN 1640 µg/L
PCE GREATER THAN 440 µg/L
1,1-DICHLOROETHANE GREATER THAN 900 µg/L
TCE GREATER THAN 240 µg/L (OVERLAPS PCE PLUME
Note:
µg/L - microgram per liter
OTT/STORY/CORDOVA
MUSKEGON, MI
FIGURE 15
ISOLATED PLUMES IN TARGET TREATMENT AREA
TETRA TECH

Monthly Volume of Groundwater Extracted and Mass of Organic Chemicals Removed



Key Points

- Successful remedies require site characterization data collected at a scale consistent with the spatial structure of the controlling variables.

- Hydraulic conductivity often varies at the cm scale vertically and the meter scale horizontally.

- DNAPL distributions are influenced by capillary pressure distributions that can vary at the mm scale.

- Transverse hydrodynamic dispersion is weak (*i.e.*, plumes don't "spread out" much).

- 75% of mass flux occurs through only 5 to 10% of the plume's total cross-sectional area.

Key Points

• Substantial contaminant mass may be present in low permeability zones due to diffusive flux and cause rebound following remediation.

• HRSC is implemented using:

o Very short sampled intervals/small sample volumes

o Closely spaced samples/measurements

o Transects (orthogonal to direction of transport) of profiles

• Monitoring wells provide depth-integrated, flow-weighted average data and may obscure important information.

• Multiple tools and methods are required:

o Screening tools can save time and money

o Groundwater profiling and analysis in the higher permeable zones

o Soil core profiling and analysis in the low permeability zones