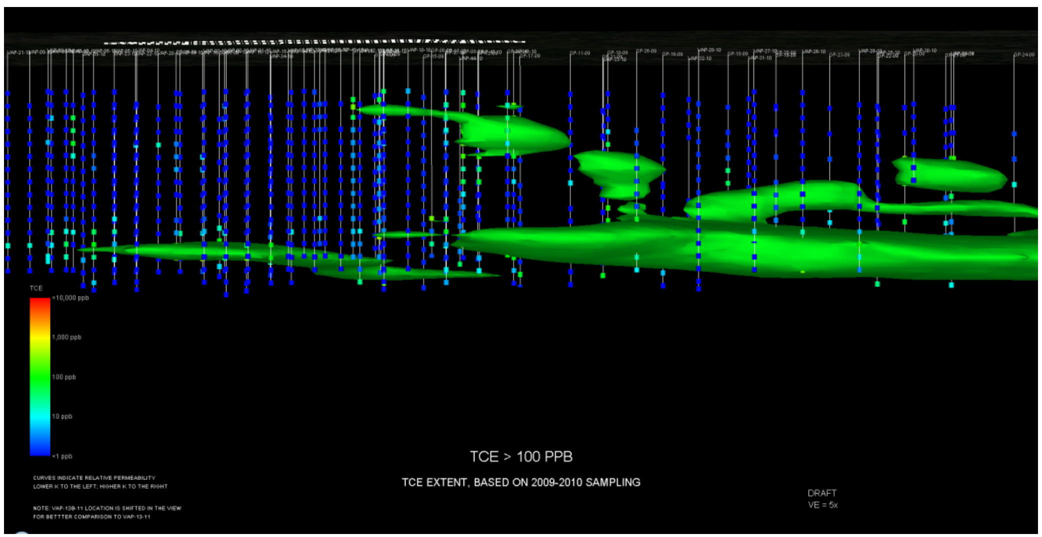
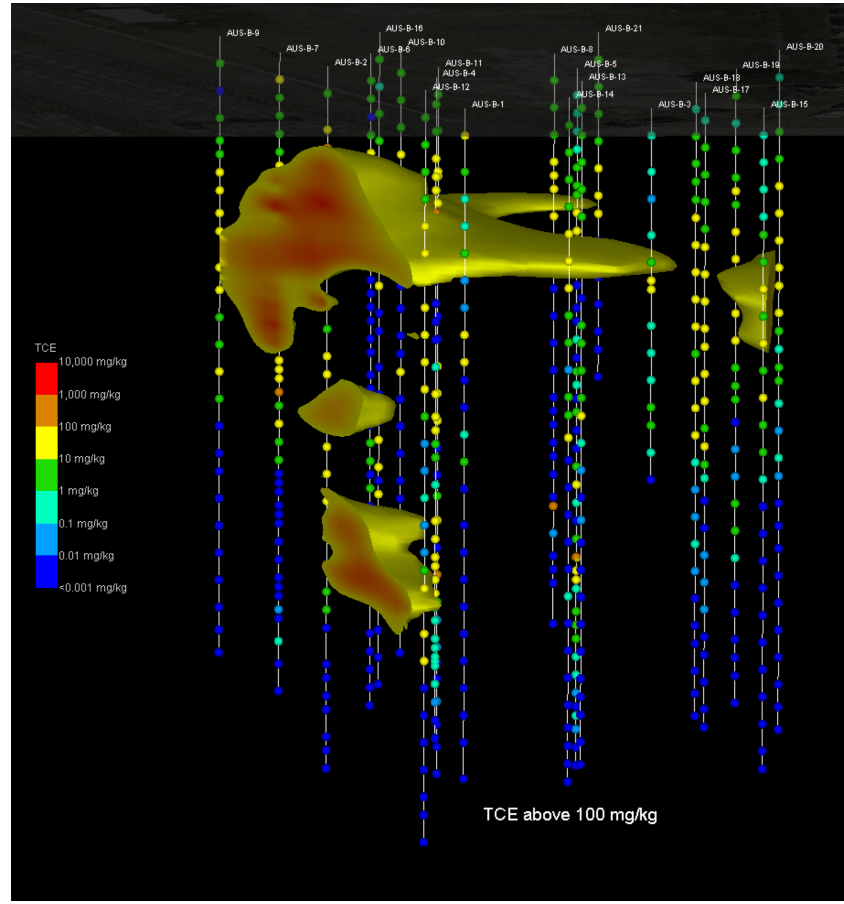
Detailed Structure in Large, Dilute Plumes

Developing Actionable Intel From the Sub-Surface





Fred C. Payne, Ph.D. FRTR – June 20, 2012

Imagine the result

ARCADIS

Next Generation Site Characterization - Two Principle Components

- Fundamental Hydrogeology Framework Shift
  - Transition from water supply hydraulics to a more complete picture of hydrogeologic structure
  - Recognize transport and storage zones in the subsurface

- High-Resolution Toolkit
  - Map Hydrogeology and Contaminant Distribution and Transport
  - Separation of site characterization and monitoring processes

Significant gains can be achieved through a shift in hydrogeology framework, independent of high-resolution analysis

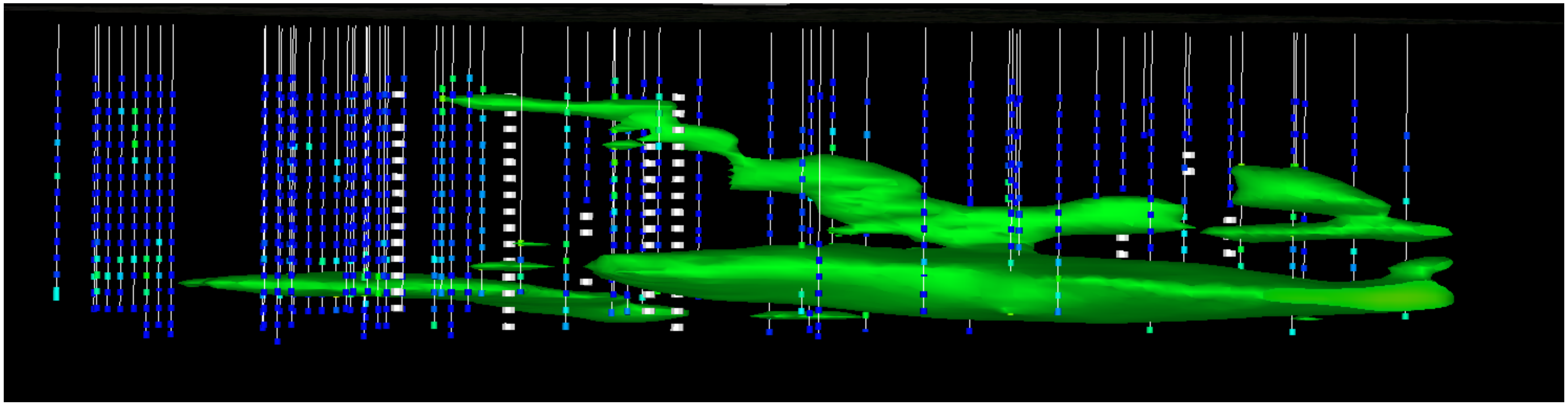
Outline

- Higher Resolution Characterization ⇨ Conceptual Model Adjustments
  - Assimilative Capacities of Lower-Permeability Zones
  - Diffusive Exchanges Occur Between Higher- and Lower-Permeability Zones
  - Bulk K and Mass Transfer Geometry Control Plume Propagation and Treatability
  - Contaminant Transport is Typically Found in a Small Portion of the Aquifer Cross-Section
- Case Studies
  - TCE Washout Conceptual Model at Muskegon Site
  - Finding the Transport at a Glacial Outwash Site
  - Forced Washout of Lower-K at Reese AFB
  - Directed Groundwater Recirculation in an Alluvial Fan Aquifer

A New Conceptual Foundation
That Precedes The Conceptual Site Model Development

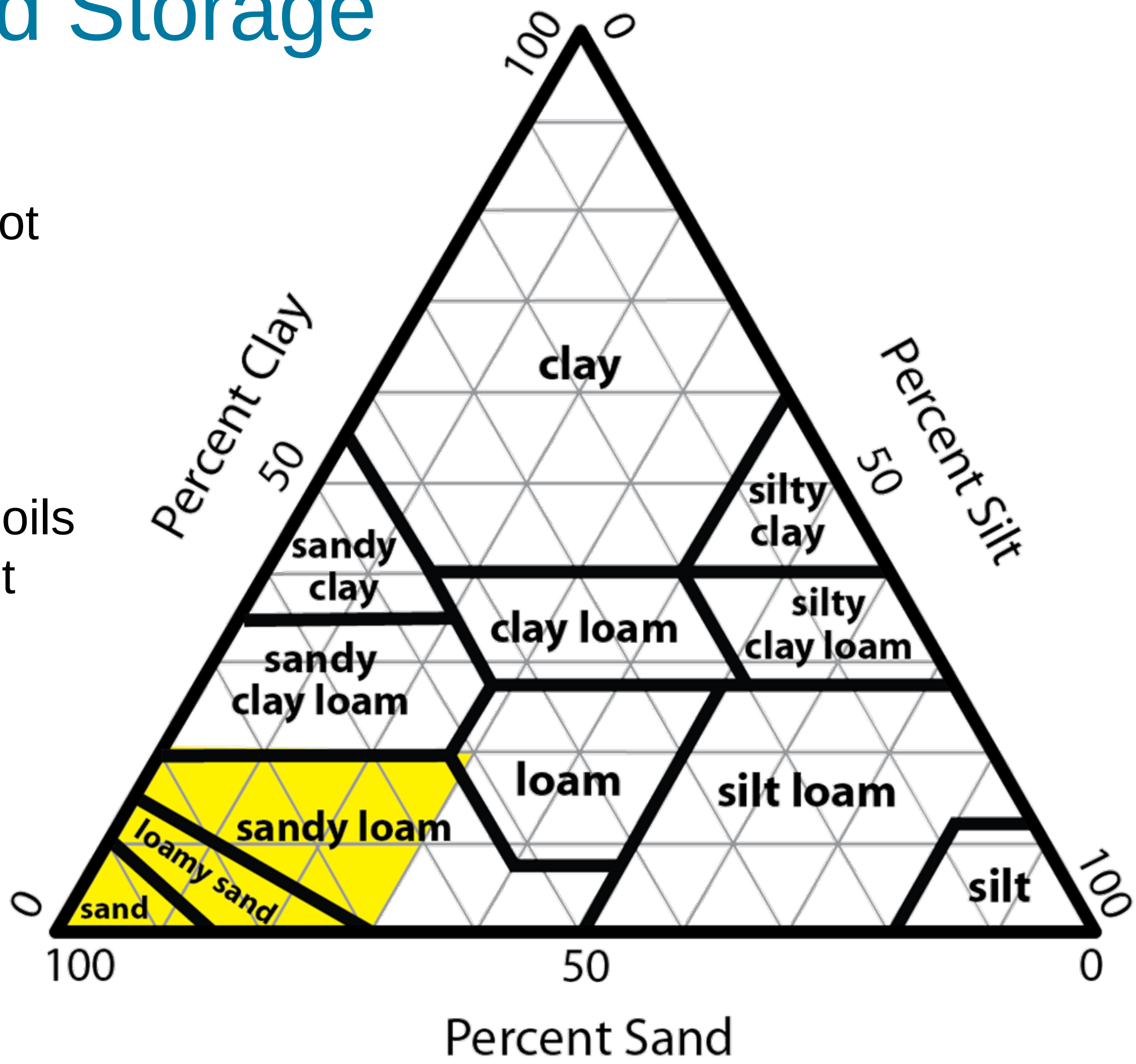
- Homogeneous
- Isotropic
- Gaussian
- Steady-State

- Heterogeneous
- Anisotropic
- LogNormal
- Perpetual Transient State



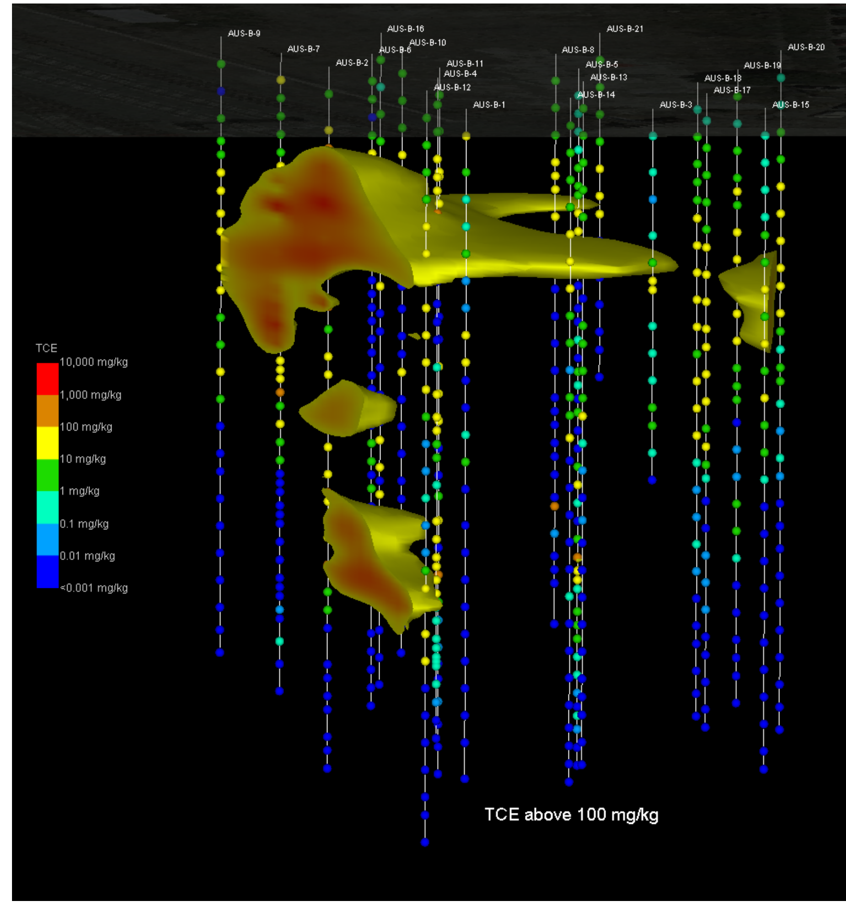
New Working Model – Focused on Transport and Storage

- Most soil types are not conductive
- Transport occurs in conductive zones
- Lower-permeability soils serve as contaminant mass storage sites

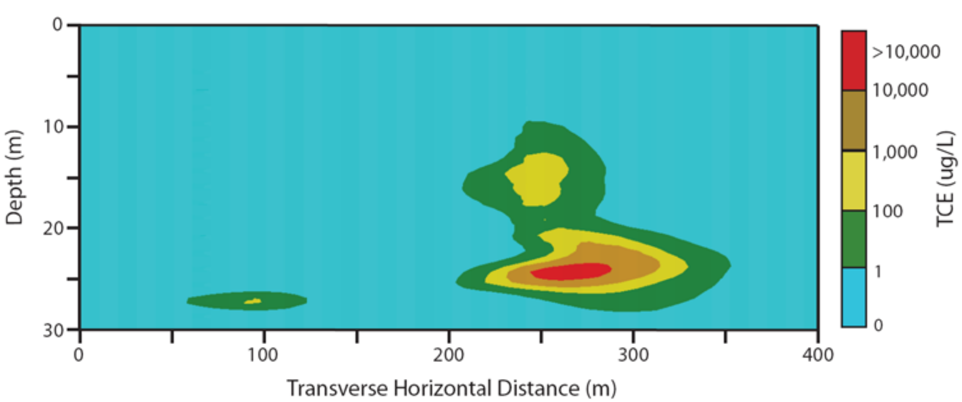


Re-Casting the Site Hydrogeology Framework

- Contaminant mass transport is often concentrated in a small portion of the aquifer cross-section
- Remedies can be designed to take advantage of this distribution pattern



On-going DNAPL source zone characterization



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Factors that Generate Large Plumes

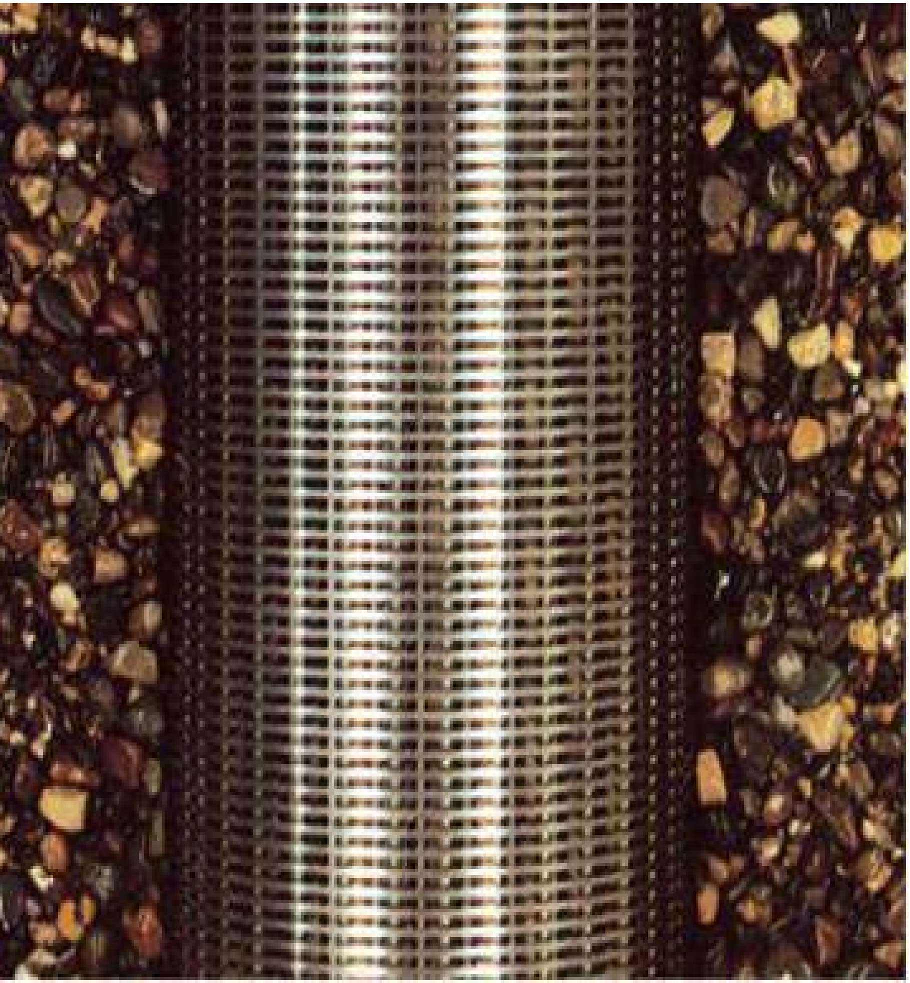
Site Geology

- High-flow aquifers
- Source mass in contact with flow zones
- Long source exposure times

Contaminant

- High aqueous-phase solubility
- Low aerobic biological attenuation rates
- Low matrix sorption potential
- Examples:
  - Chlorination solvents
  - Ethers (MTBE, 1,4-Dioxane)
  - PFOS, nitrates, perchlorate

Re-Thinking Monitoring Wells

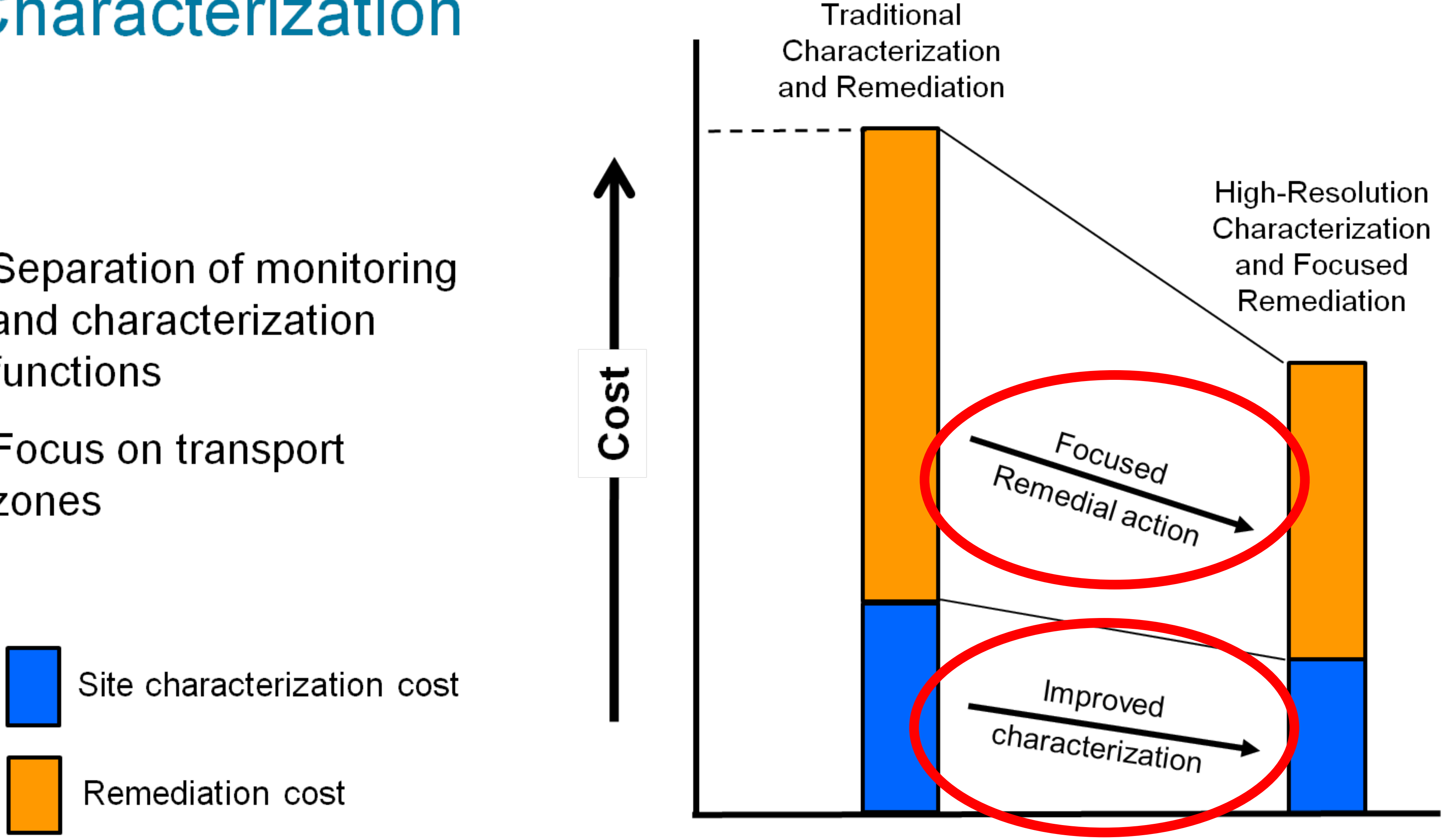


- 10-year life-cycle cost of a single monitoring well ~ $150,000 (construct, develop, monitor and report quarterly, abandon)
- Better approach – ***separate site characterization from monitoring well construction*** – characterize, then determine most effective monitoring well locations.
- Yields a significant reduction in the number of monitoring wells

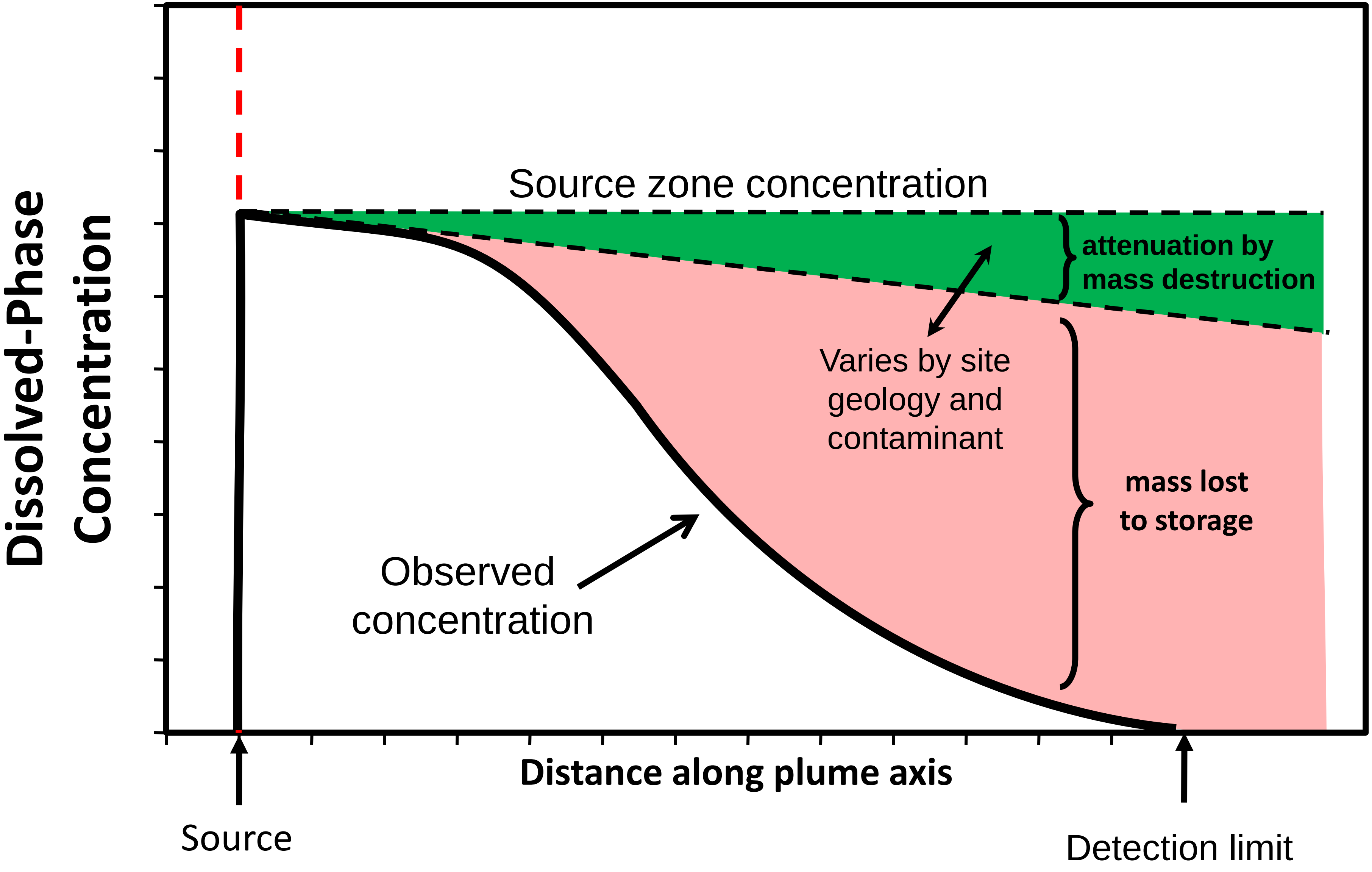
Next Generation Site Characterization

Separation of monitoring and characterization functions

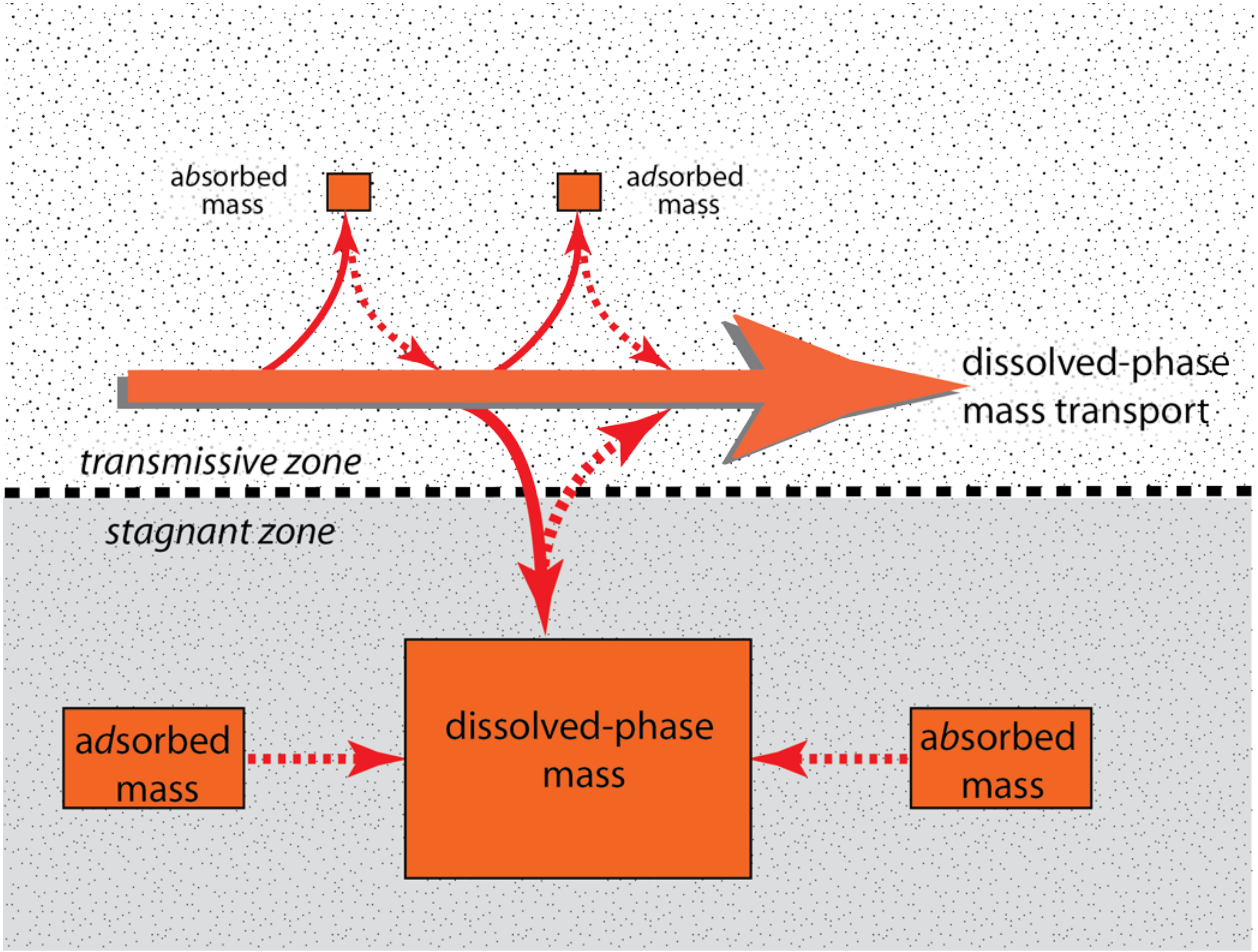
Focus on transport zones



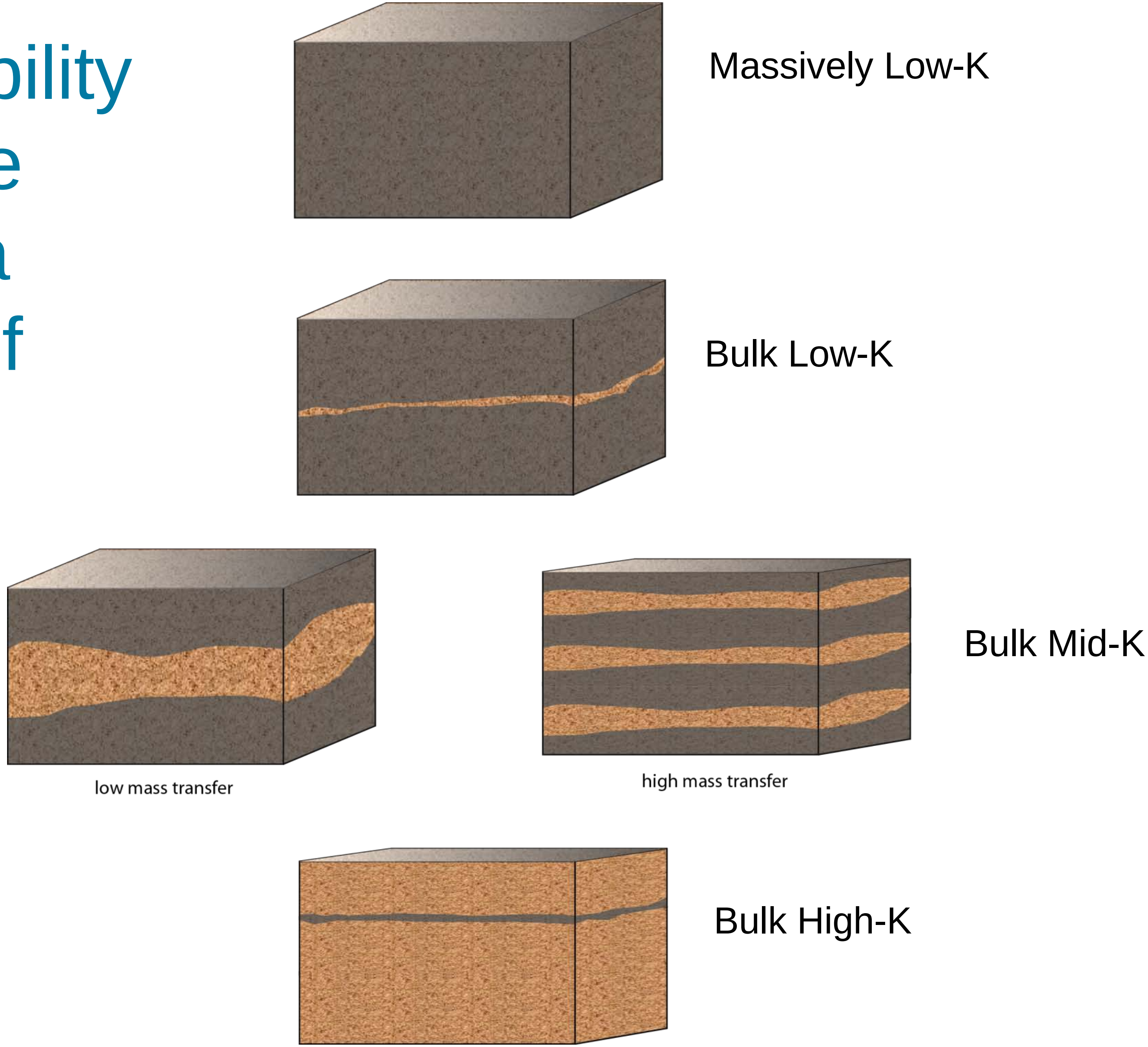
Diffusive Exchange and Plume Attenuation



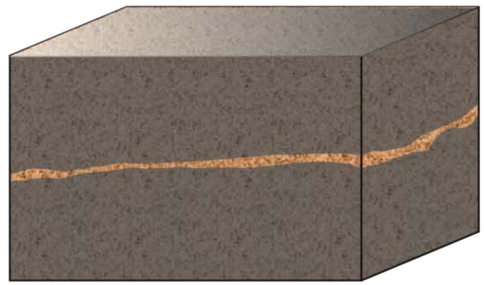
Role of Lower-Permeability Zones



Permeability Structure Across a Range of Settings

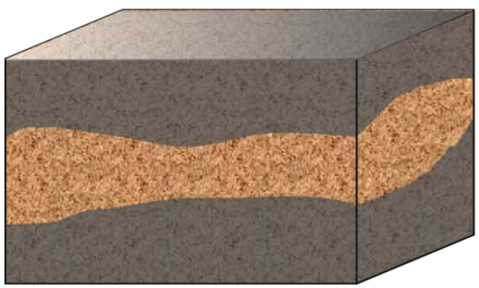


Effective Match-Ups

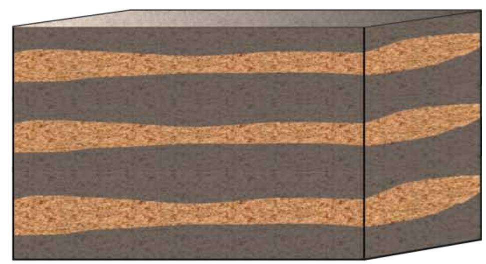


- Clay/ZVI
- Frac Bypass
- Thermal

- Directed GW Recirc



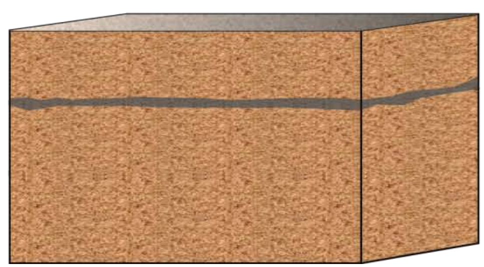
low mass transfer



high mass transfer

- Forced-Gradient
- Clay/ZVI
- Bio and ChemOx

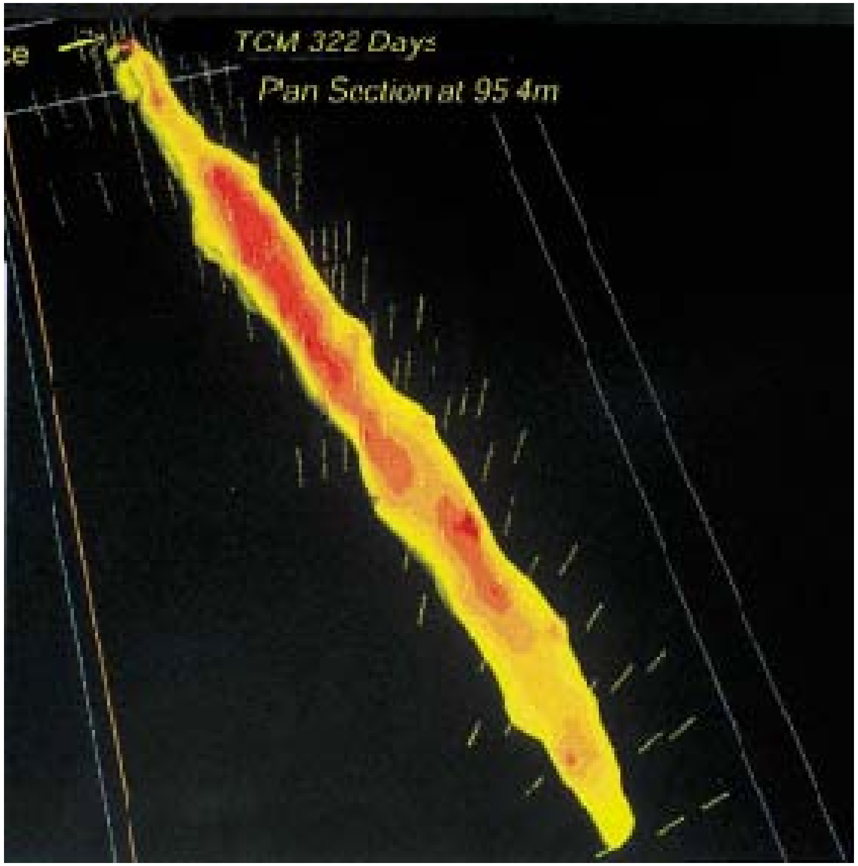
- Directed GW Recirc
- Forced vertical mix



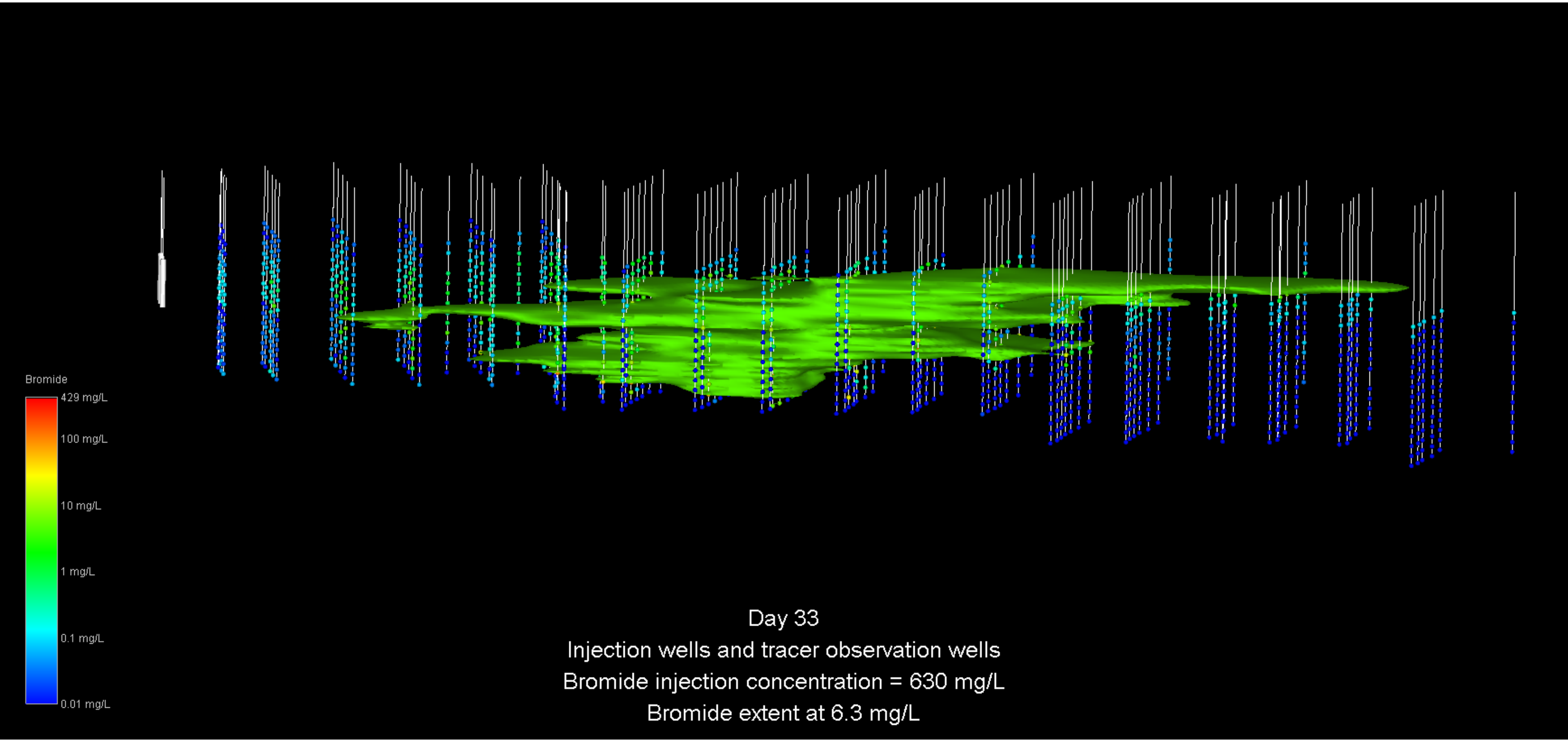
Field research repeatedly confirms that transverse dispersivity is near-zero

Borden aquifer studies – Rivett, Feenstra and Cherry

Natural aquifers show near-zero transverse dispersivity



Cape Cod Tracer Studies – A broad spectrum of transport velocities



Near-zero transverse dispersivity

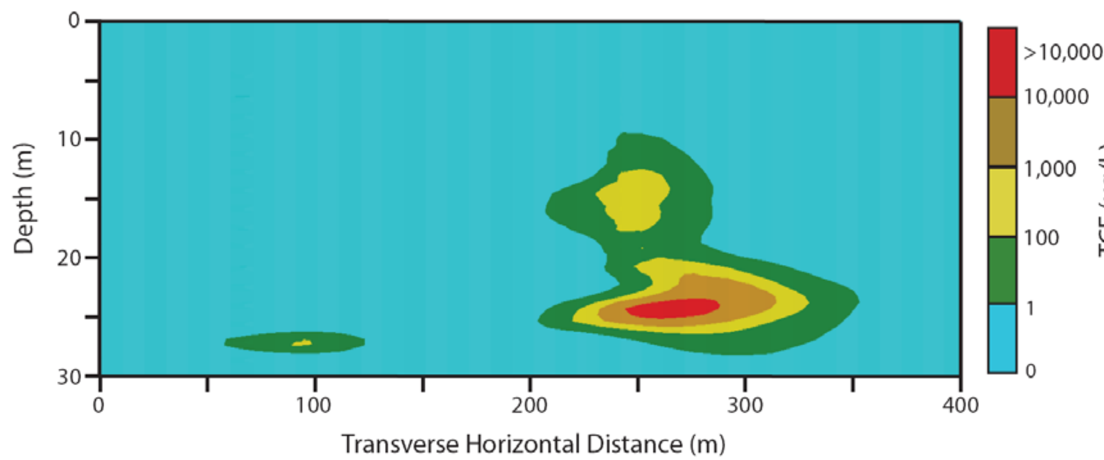
A Synopsis of the 'Take-aways'

- Patterns Emerging from Intensified Site Characterization
  - Heterogeneous, anisotropic structure
  - Extreme low dispersivities
- Large-Plume Conceptual Model
  - Transport in transmissive zones
  - Storage in less-transmissive zones
  - Mass exchange rates are a critical factor
- New Opportunities Arise
  - Remedial strategies (e.g., directed groundwater recirculation)
  - Compliance (e.g., dynamic groundwater monitoring)

Beaver Island, Michigan

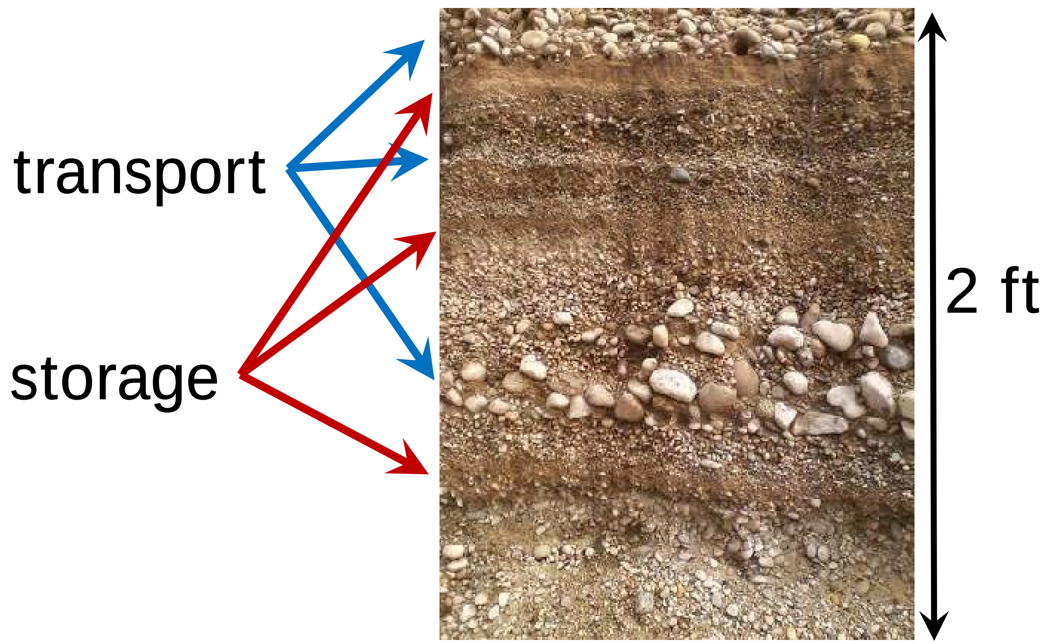
Impacts and Opportunities

- Contaminant mass transport is often concentrated in a small portion of the aquifer cross-section
- Remedies can be designed to take advantage of this distribution pattern

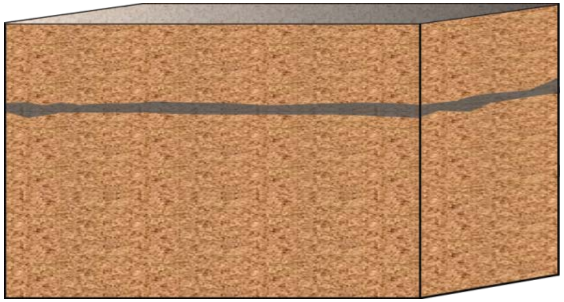


__However,__

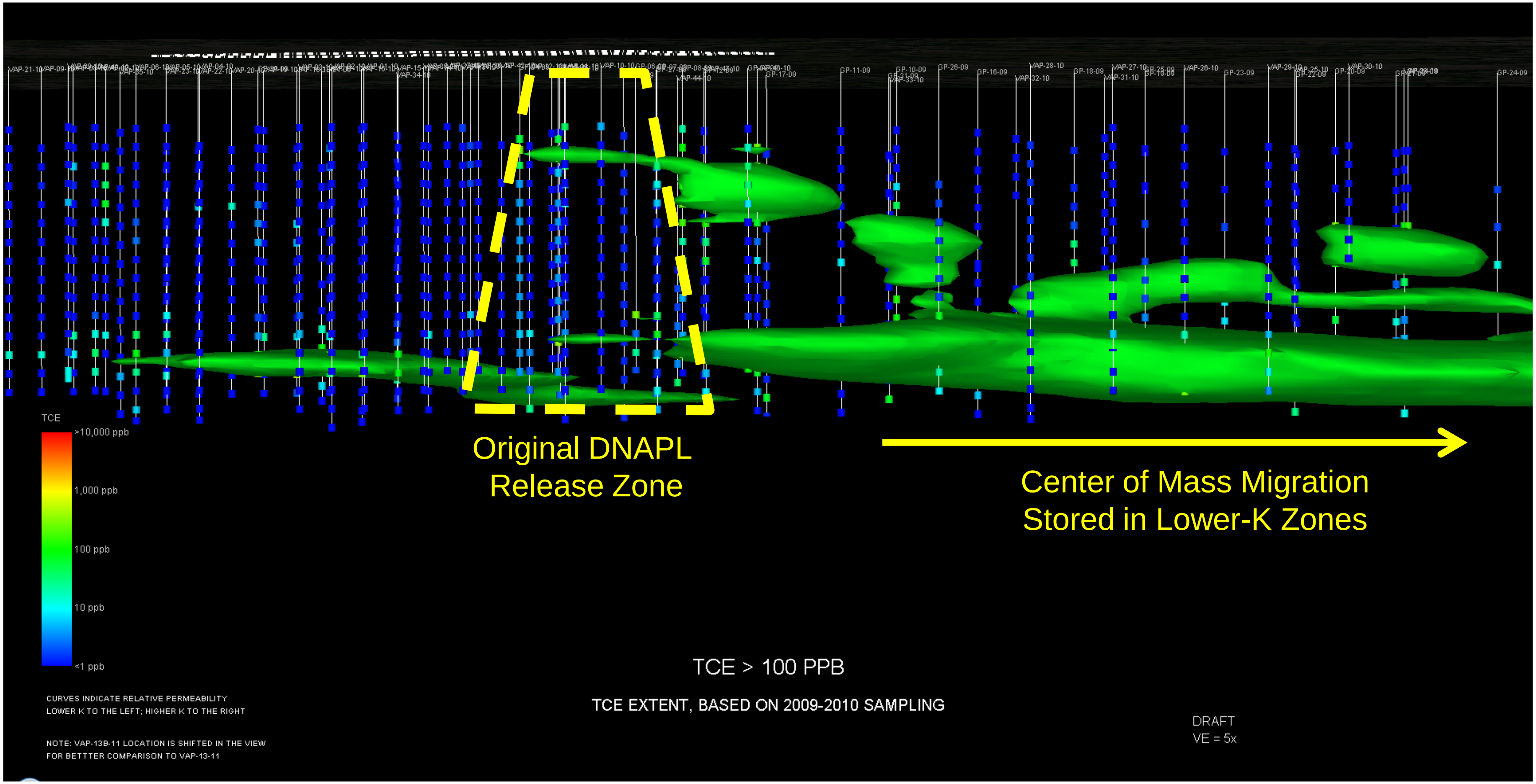
- High-resolution sampling is also unmasking contaminant mass storage – High-C, Low-K zones
    - Mass transfer behavior controls remedy design and success
    - ***Now we can identify and target the critical zones***



Muskegon Site – TCE Washout Model



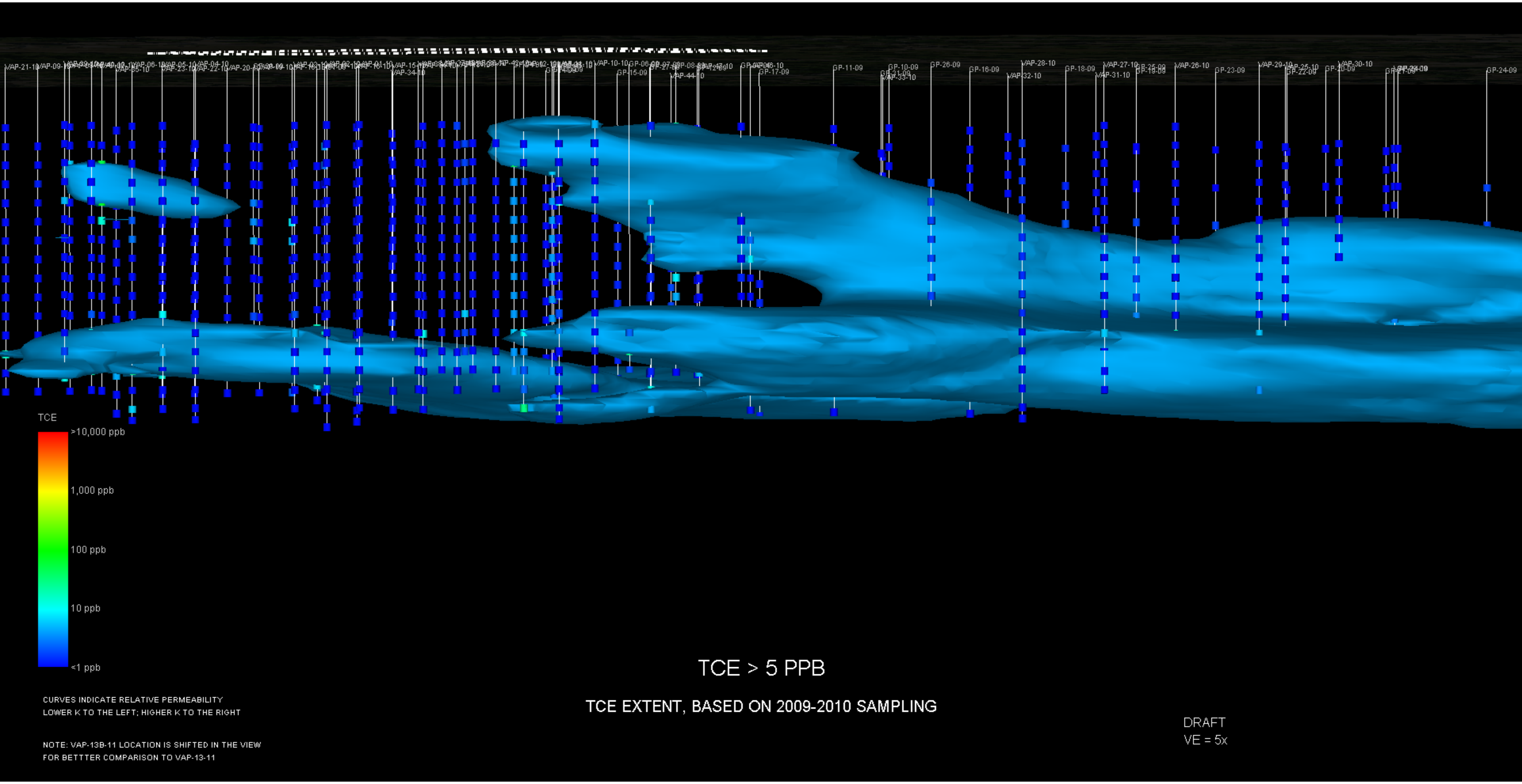
Bulk High-K



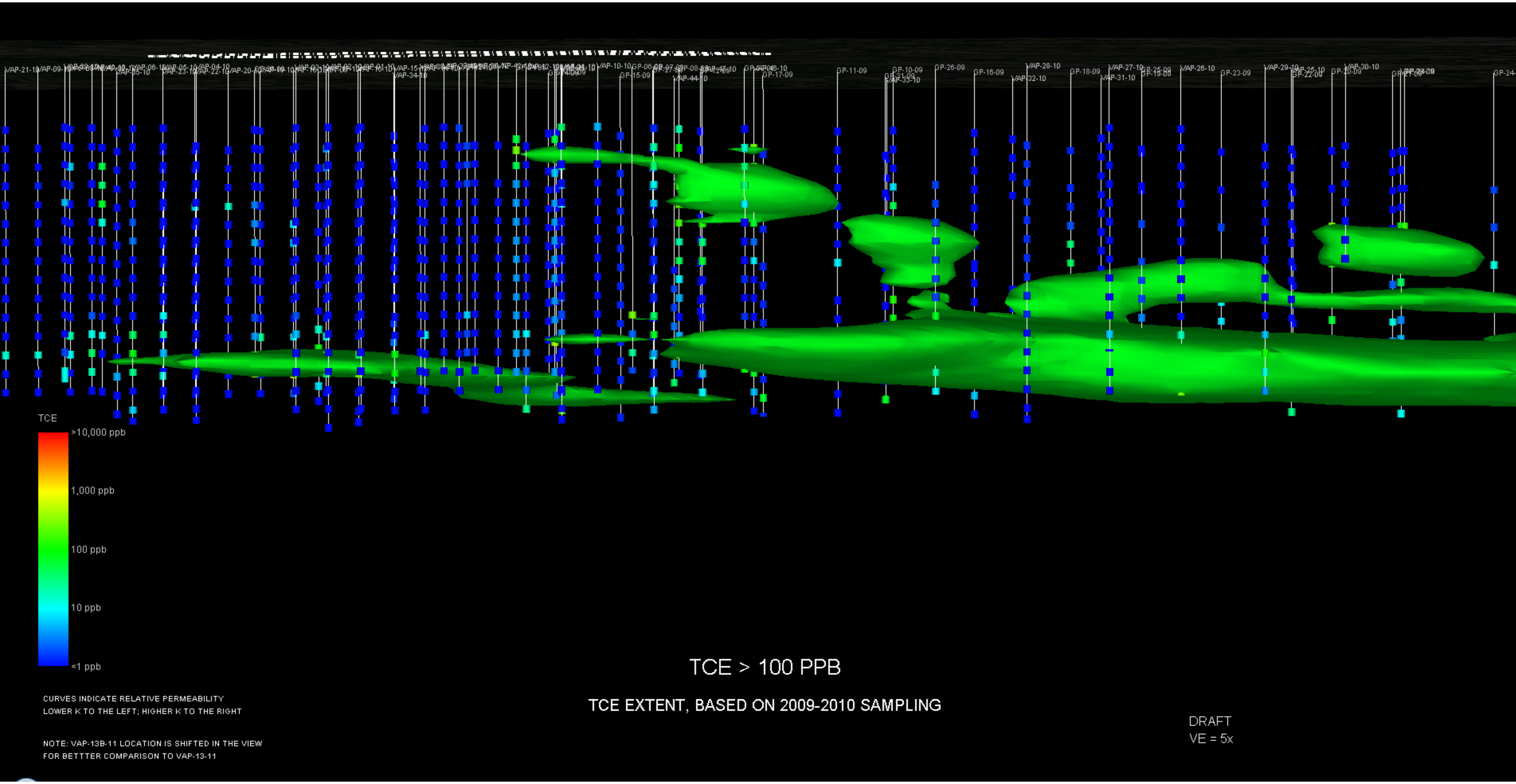
Muskegon Site - Conceptual Site Model

- High-K sandy aquifer
- 100 ft thickness
- Multiple known sources in the area
- TCE used and disposed via seepage lagoon
- Seepage lagoon excavated in 1975
- Conventional monitoring wells indicated 100 ug/L TCE in groundwater, heading off-site

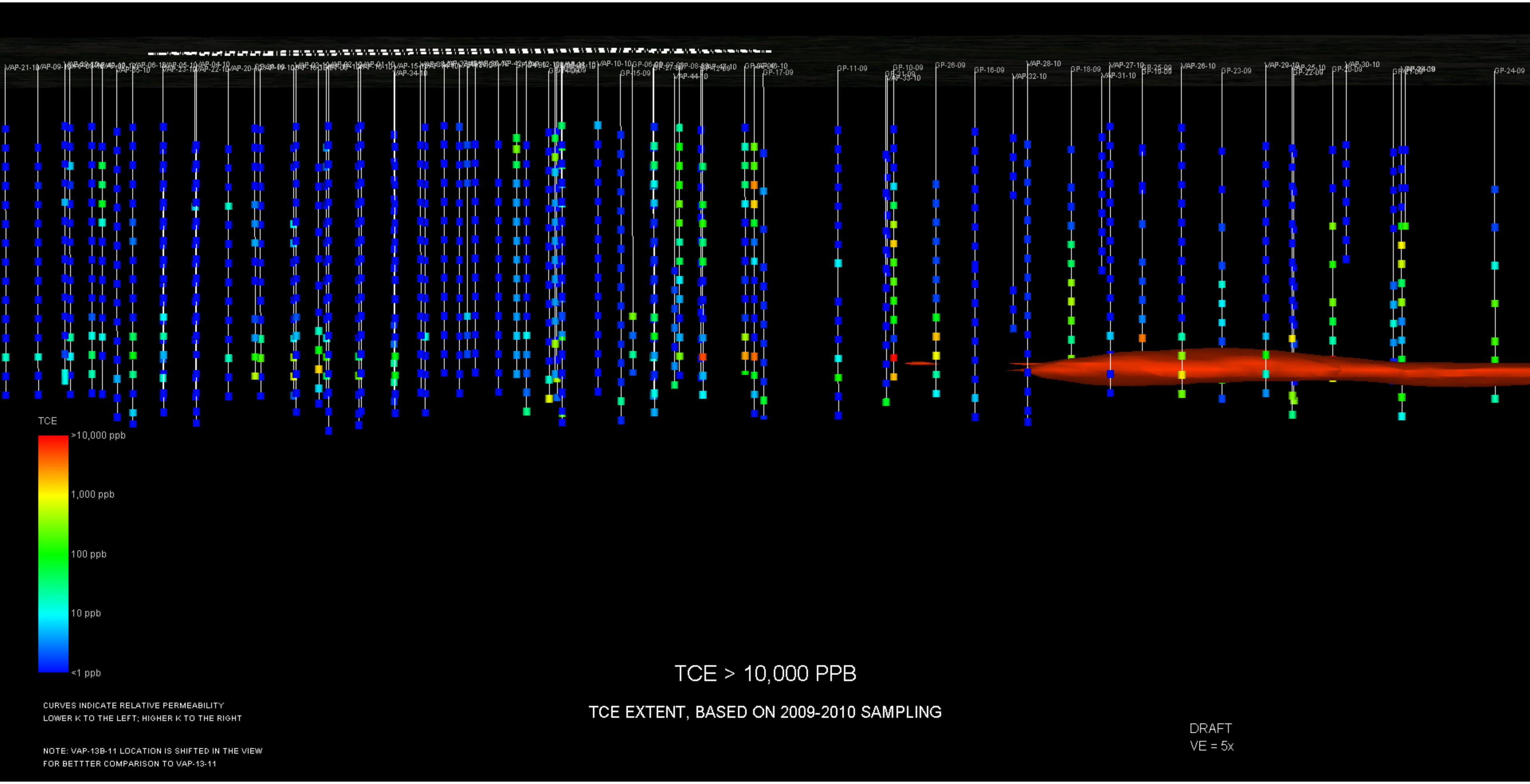
Muskegon Site – 5 ug/L envelope



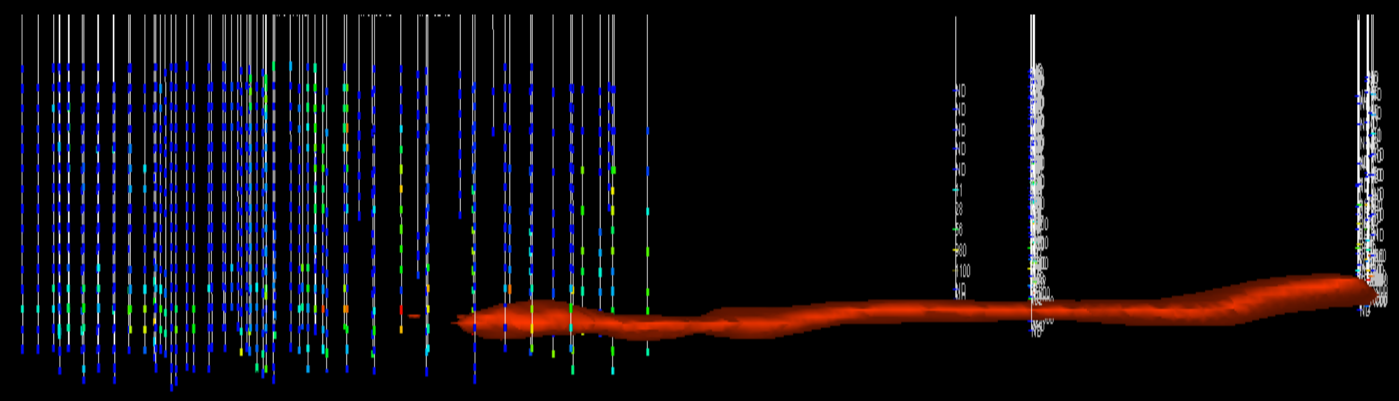
Muskegon Site – 100 ug/L envelope



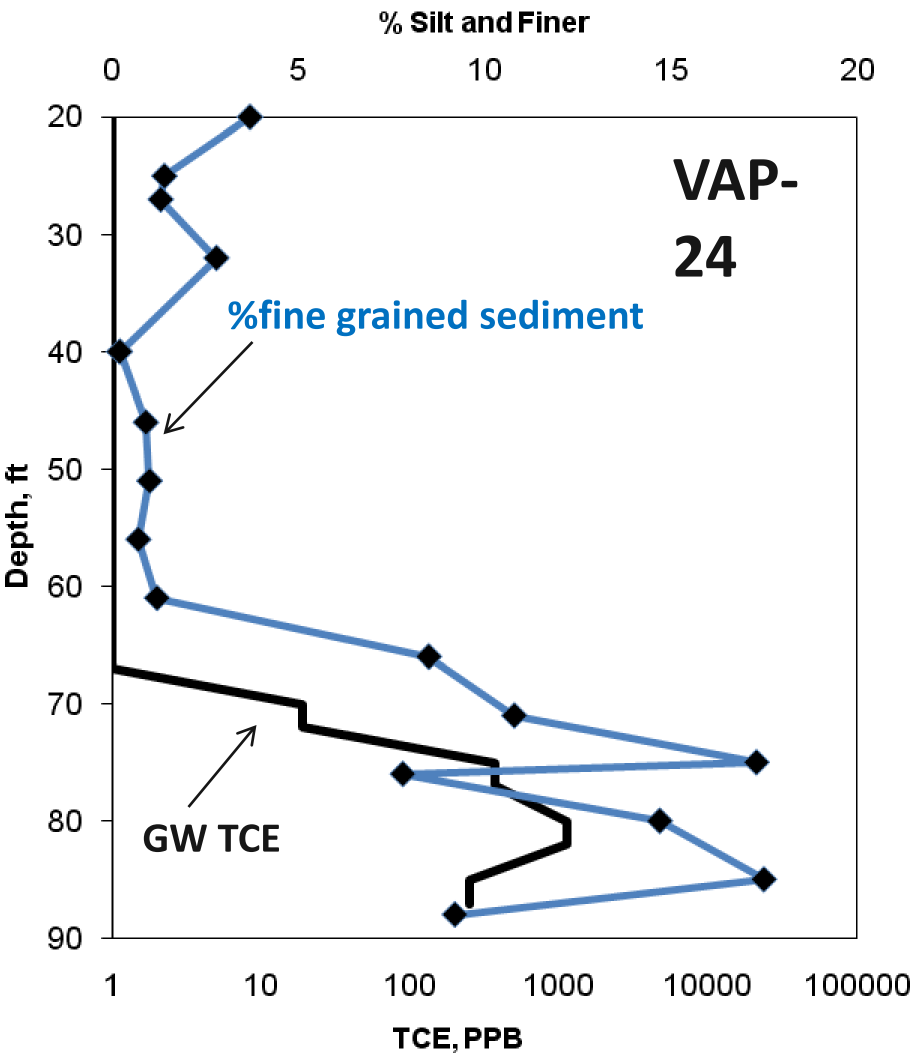
Muskegon Site – 10,000 ug/L envelope



2,600 ft →



Longitudinal cross-section



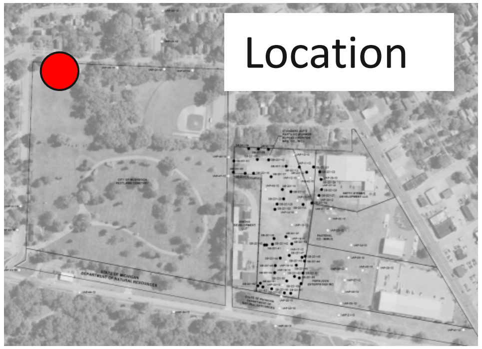
Highest TCE concentrations are in lower permeability sediments

3-5% silt and clay
95-97% sand

<1 ppb TCE

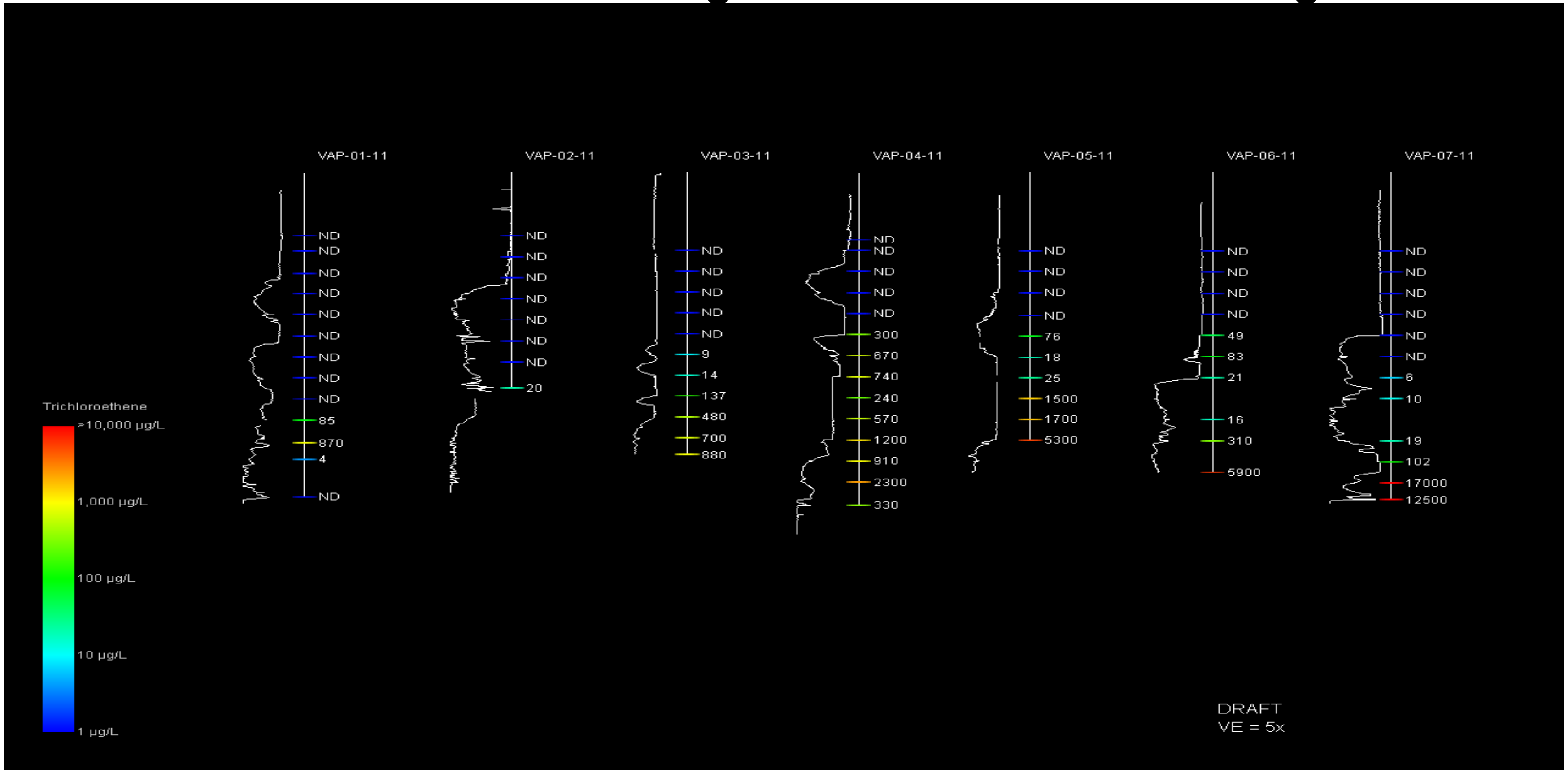
10-20% silt and clay
80-90% sand

10-10,000 ppb TCE



Muskegon Site – Downgradient Transects

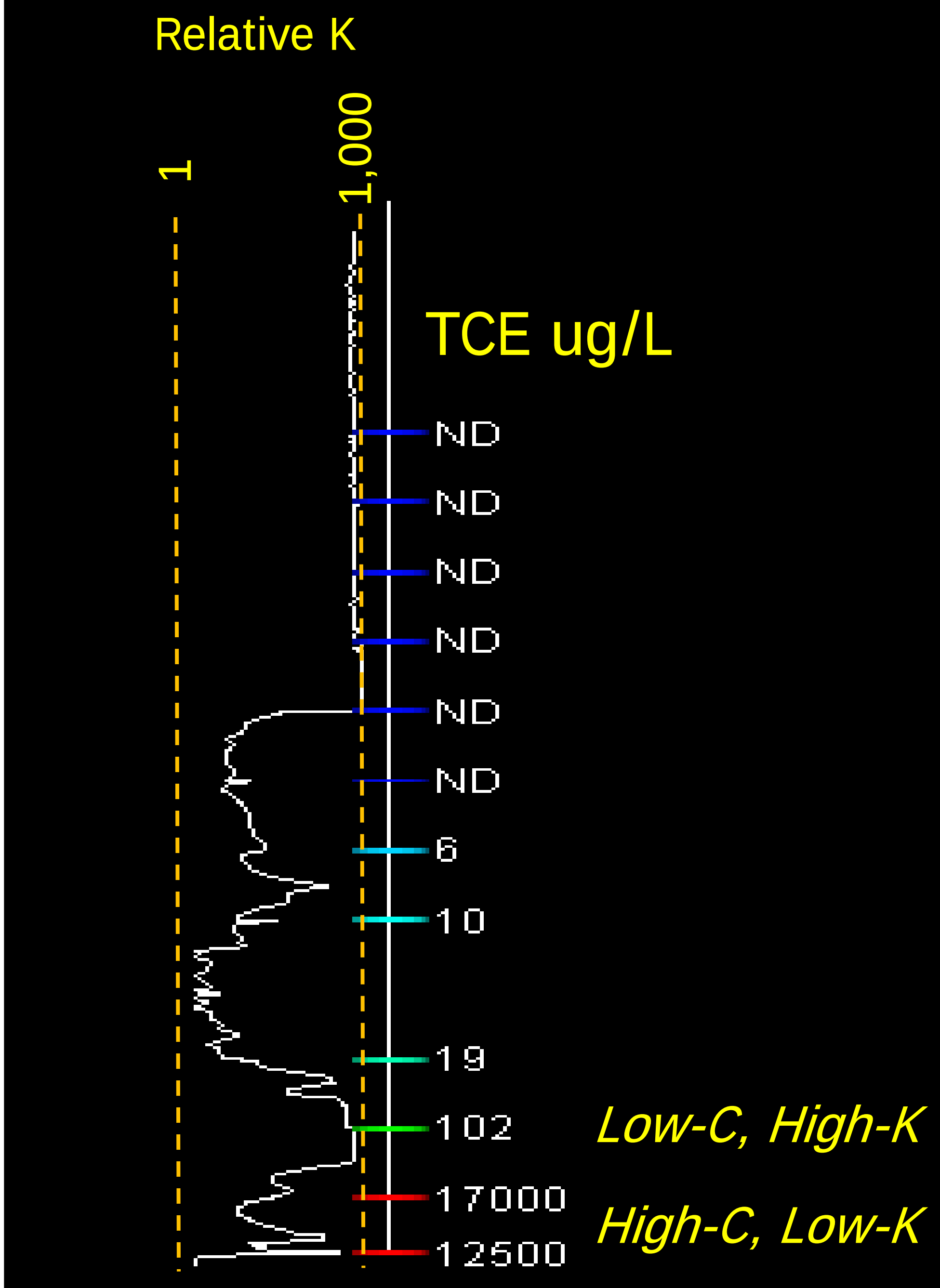
Transect 1 – 2,600 ft downgradient from source lagoon



Waterloo Profiler output

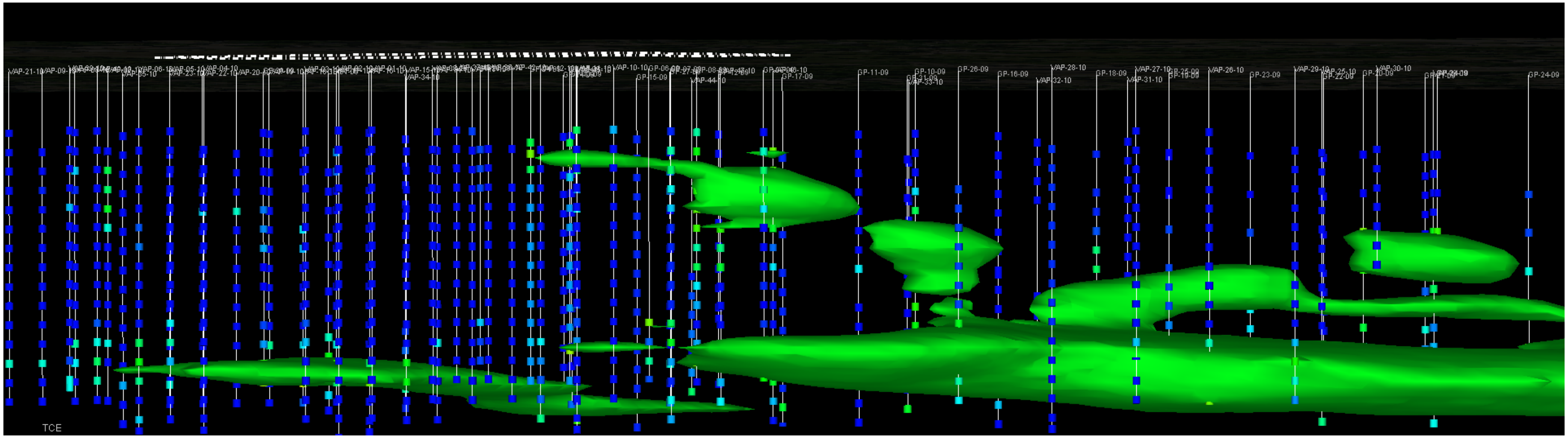
2,600 ft Downgradient

- Maximum hydraulic response on the Waterloo Profiler over a large portion of the cross-section
- More than ½-mile and 35 years from the source zone.
- TCE concentrated in lower-K zones
- A large plume passed by here



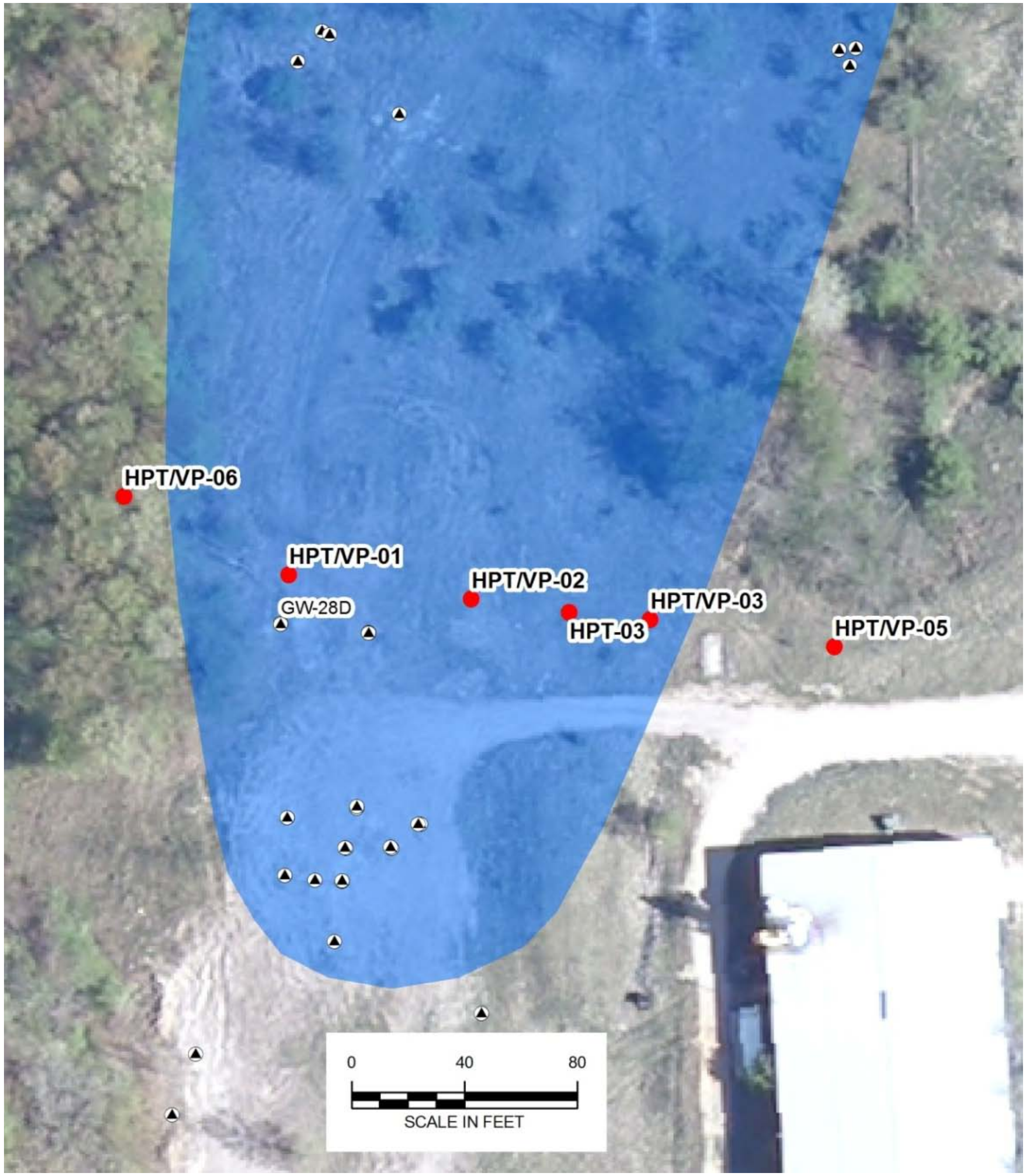
Muskegon Site – On-Going Next Steps

- Extend transect coverage to 1 mile off-site
- Testing MCL-relevant monitoring concept
    - 4-inch, wire-wound stainless wells
    - Pumped at water supply rates for TCE measurement
    - Comparing to vertical aquifer profile results



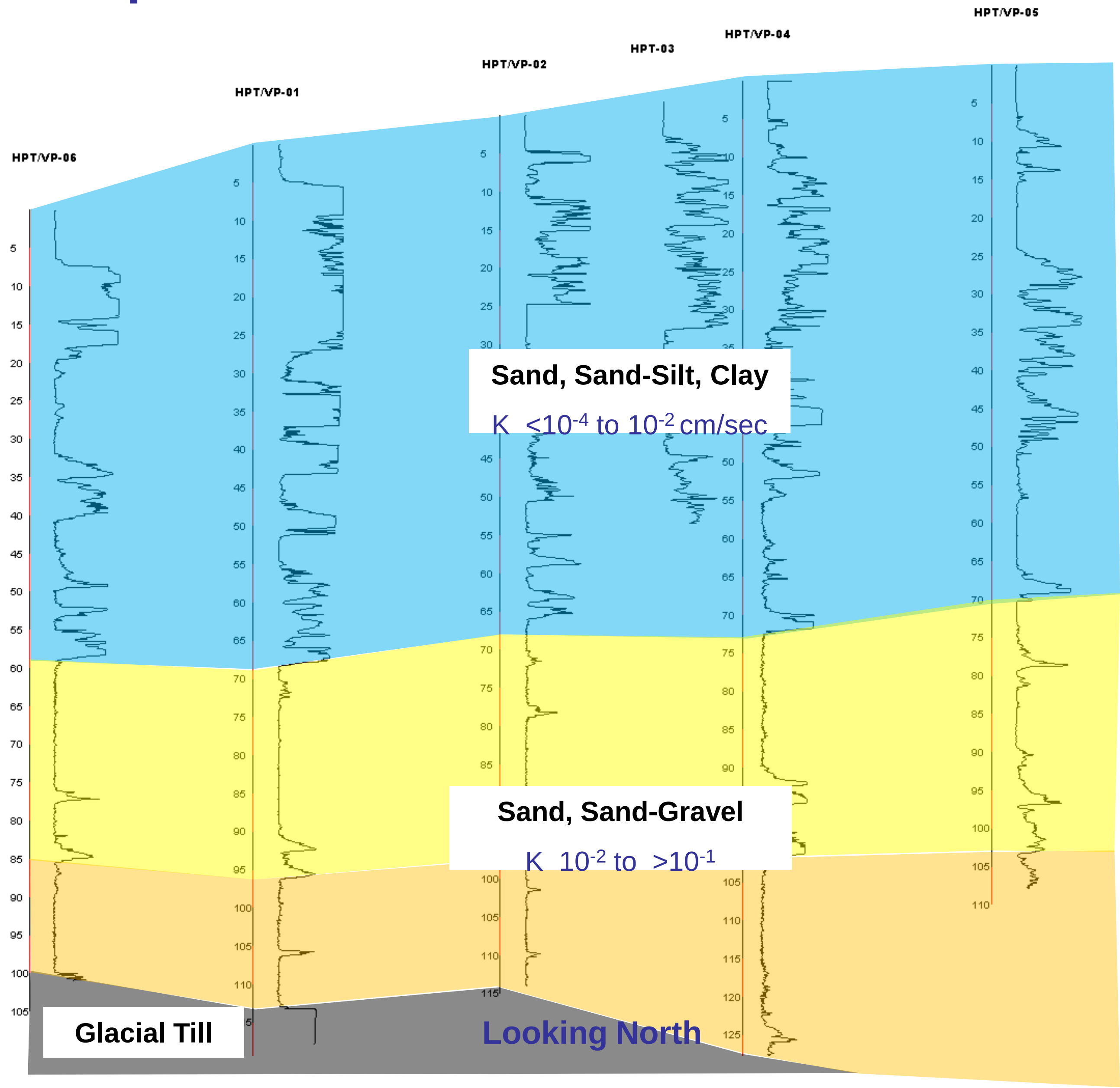
Case Study: Finding Transport Pathways

- Site located atop a glacial esker – high energy, permeable outwash
- Interbedded high-K sediments with little differentiation.
- Mass flux transect completed immediately downgradient of primary source area.

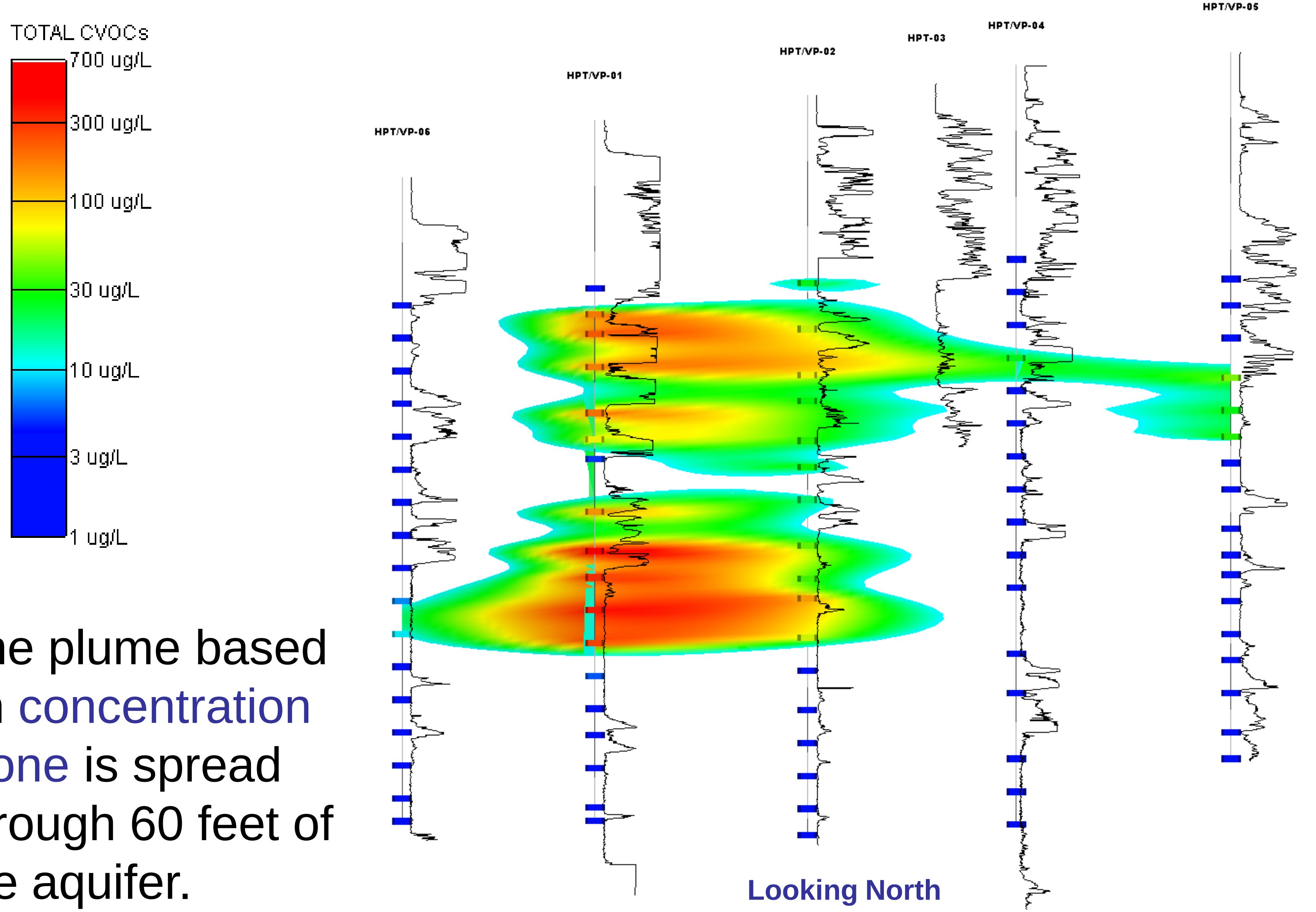


Hydrofacies Interpretation

- HPT response indicated the shallow lithology is complex with a significant fine grained component.
- Results allowed for VAP sampling bias toward permeable zones.



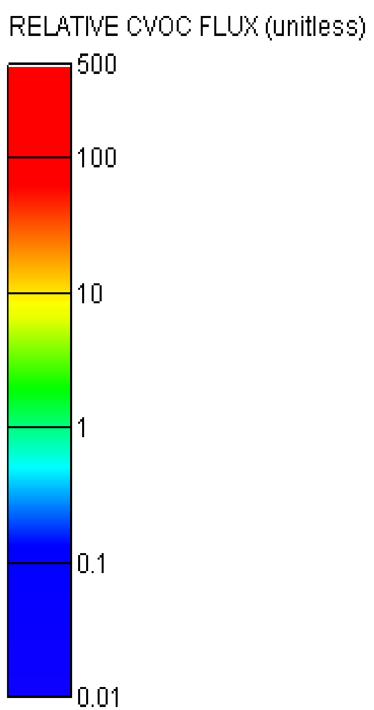
Groundwater Analytical – Total CVOCs

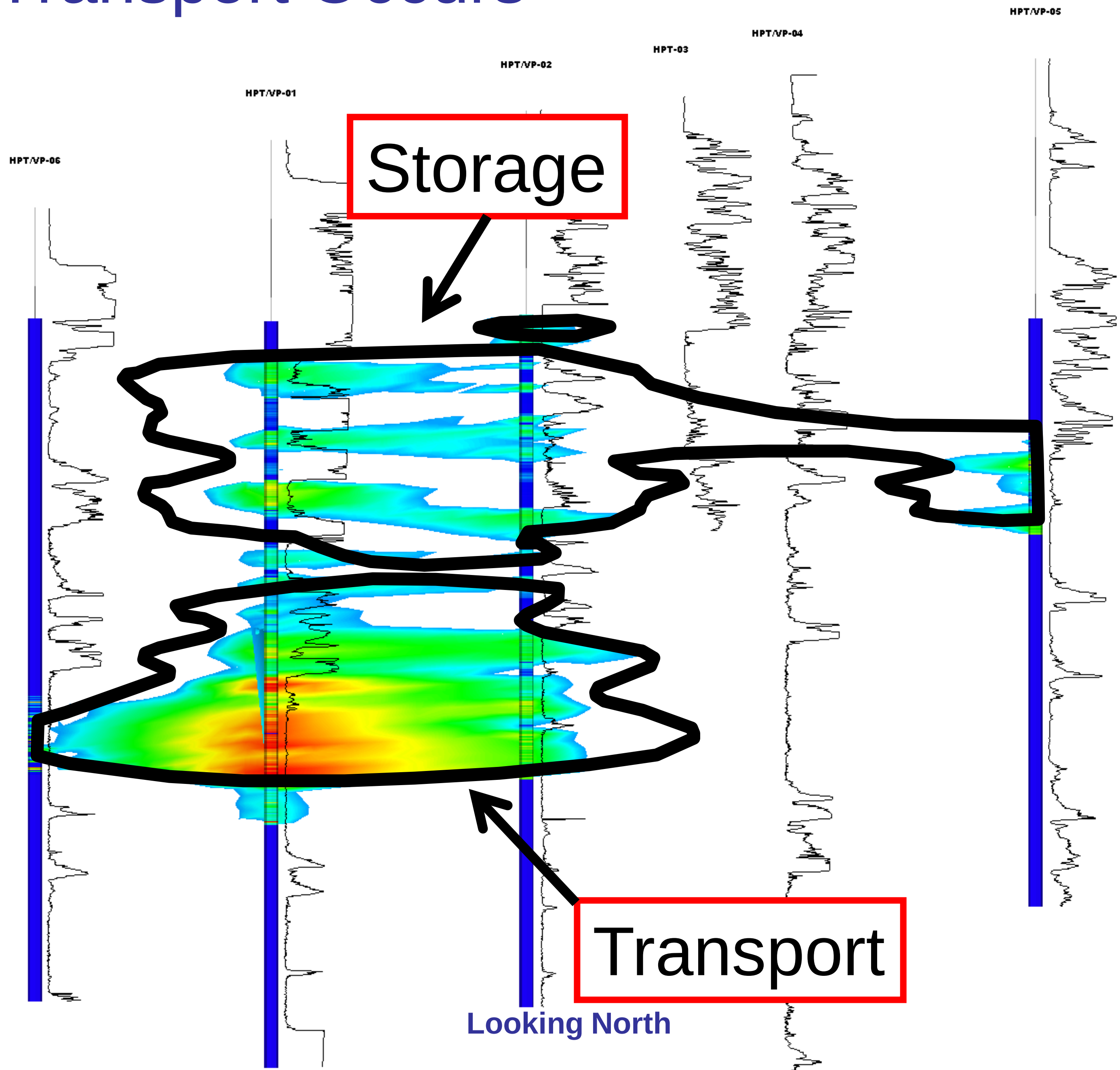


- The plume based on concentration alone is spread through 60 feet of the aquifer.

Where the Transport Occurs

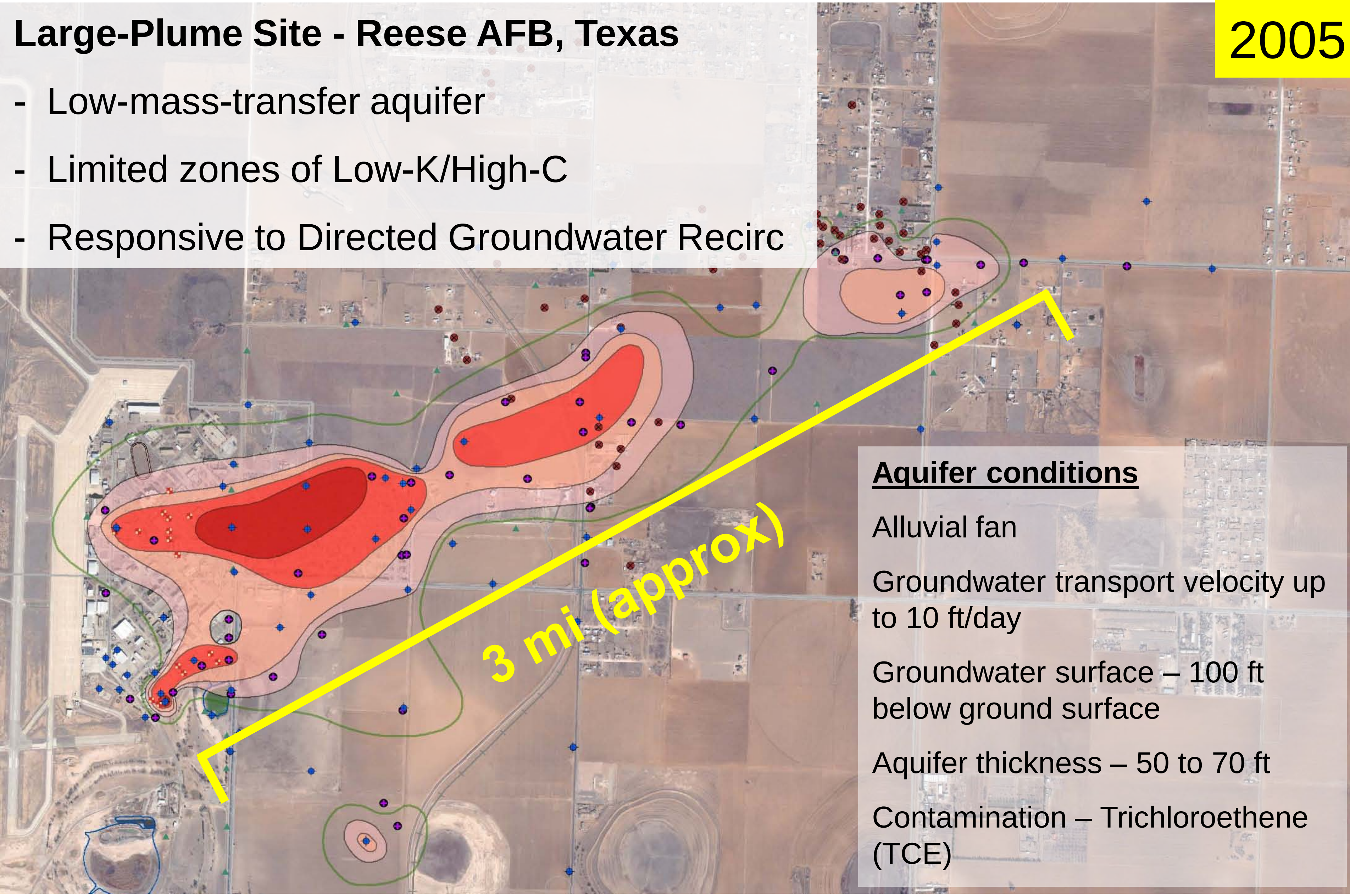
- Mass in shallow interbeds is several hundred fold less mobile than deep zone





Large-Plume Site - Reese AFB, Texas

- Low-mass-transfer aquifer
- Limited zones of Low-K/High-C
- Responsive to Directed Groundwater Recirc



Aquifer conditions

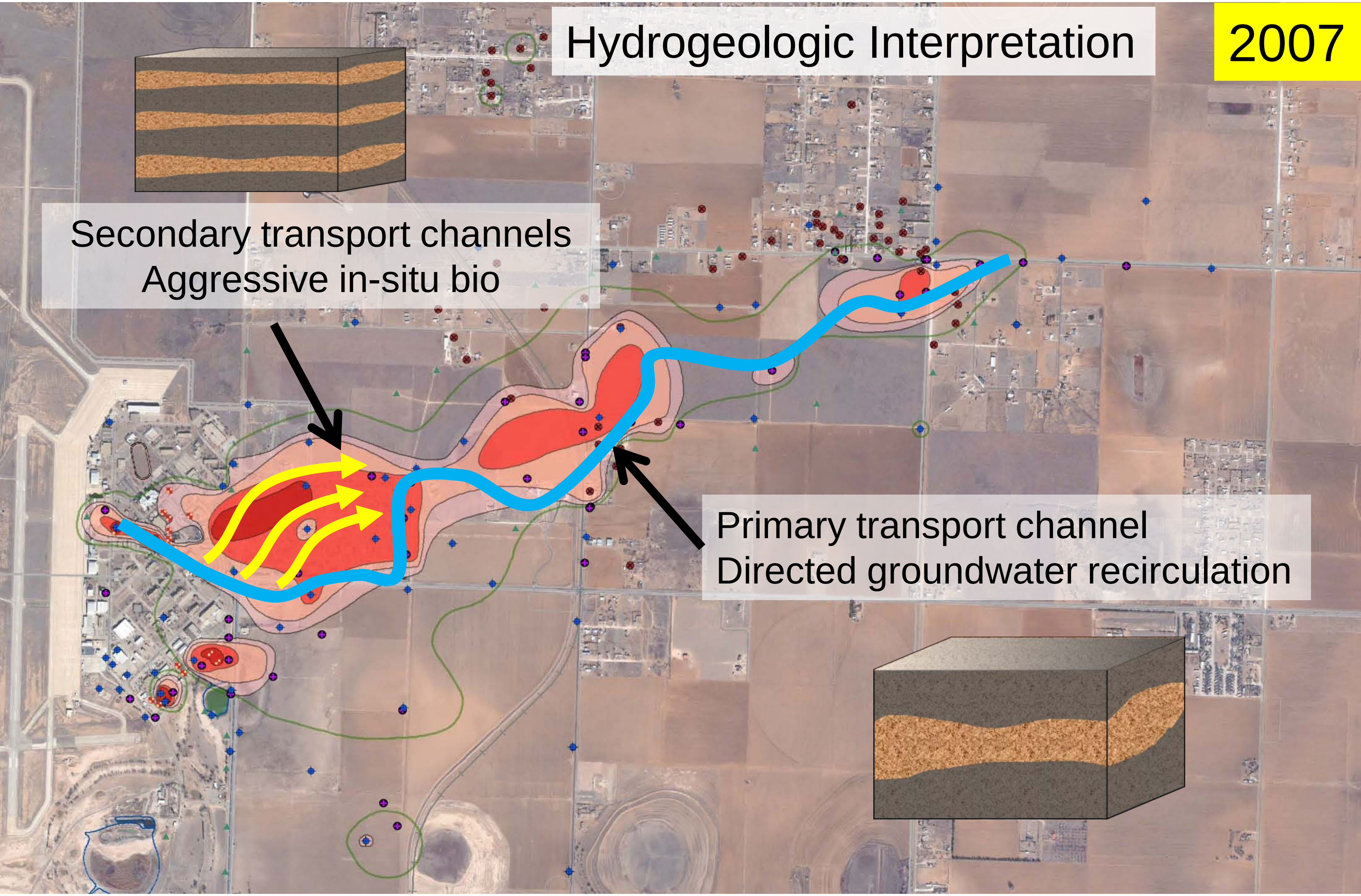
Alluvial fan

Groundwater transport velocity up to 10 ft/day

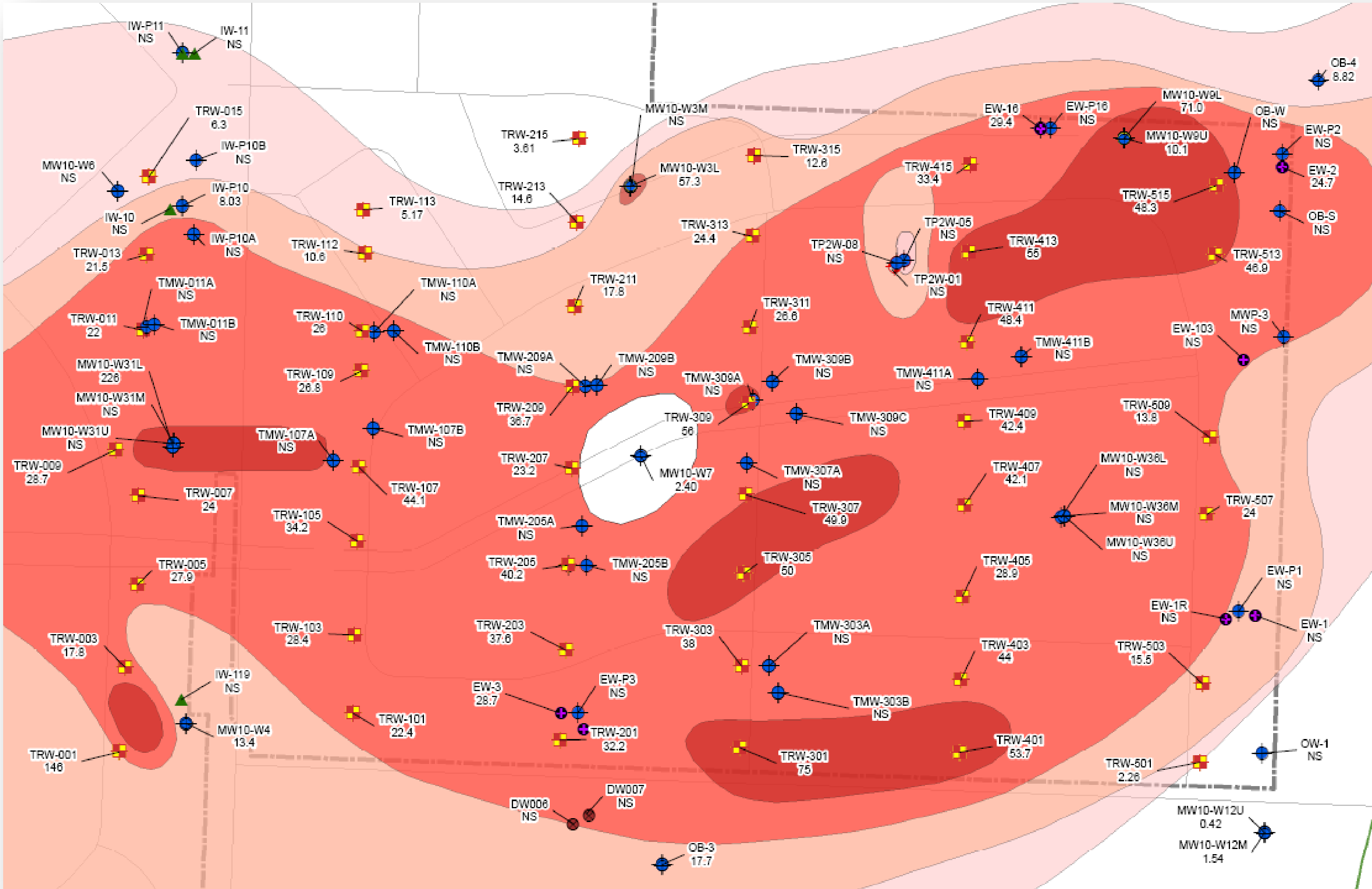
Groundwater surface – 100 ft below ground surface

Aquifer thickness – 50 to 70 ft

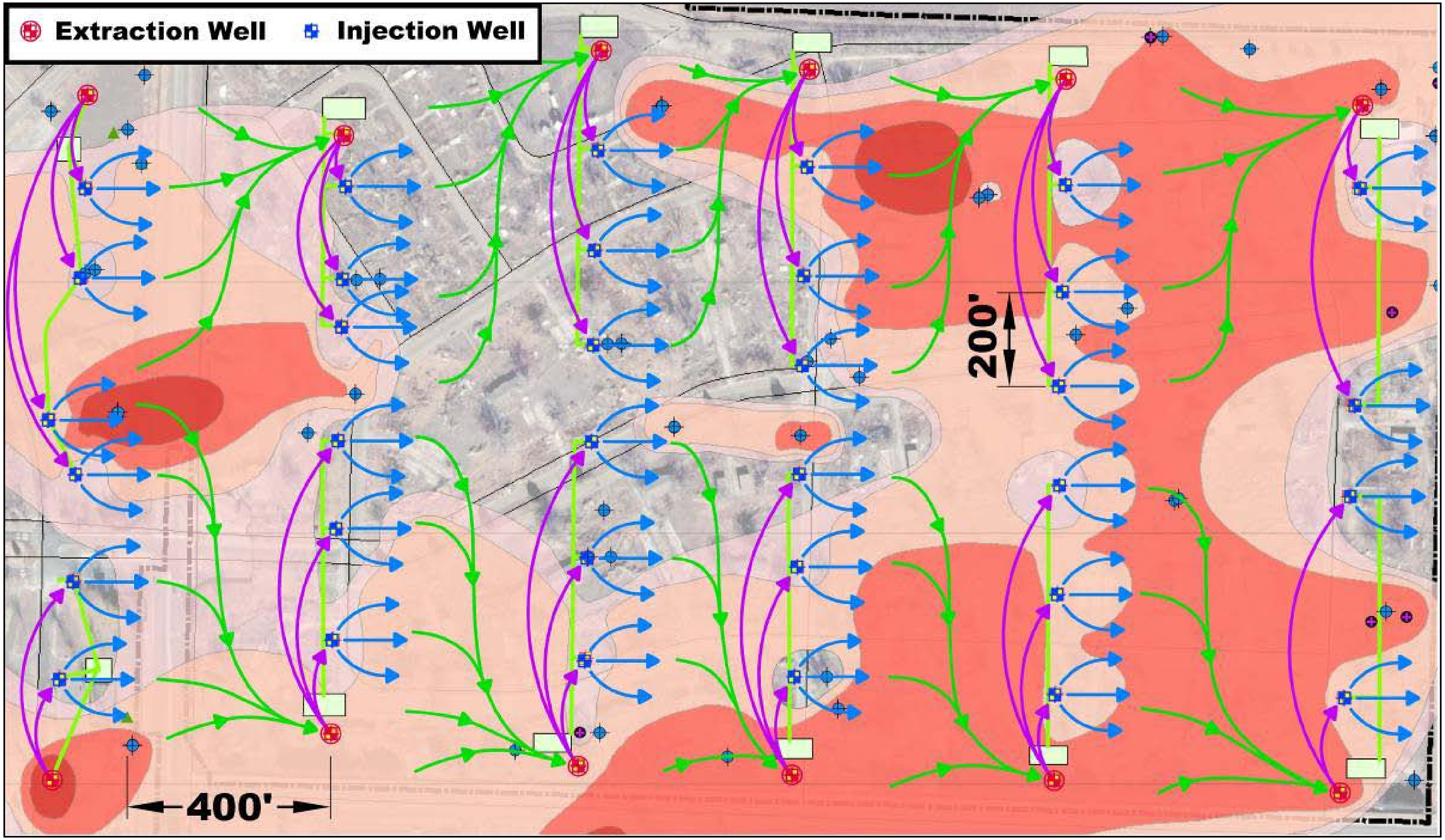
Contamination – Trichloroethene (TCE)

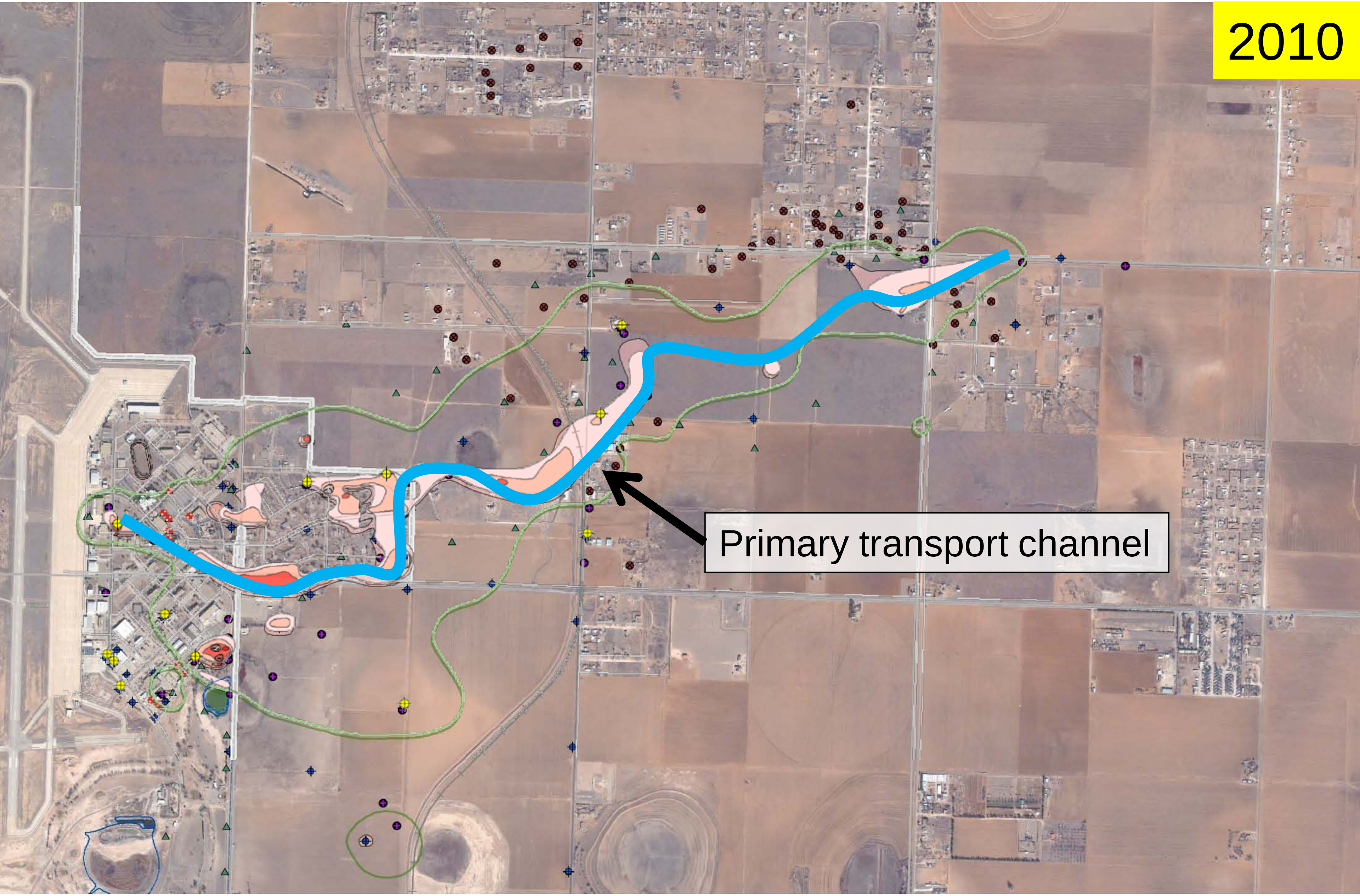

Hydrogeologic Interpretation
2007
Secondary transport channels
Aggressive in-situ bio
Primary transport channel
Directed groundwater recirculation

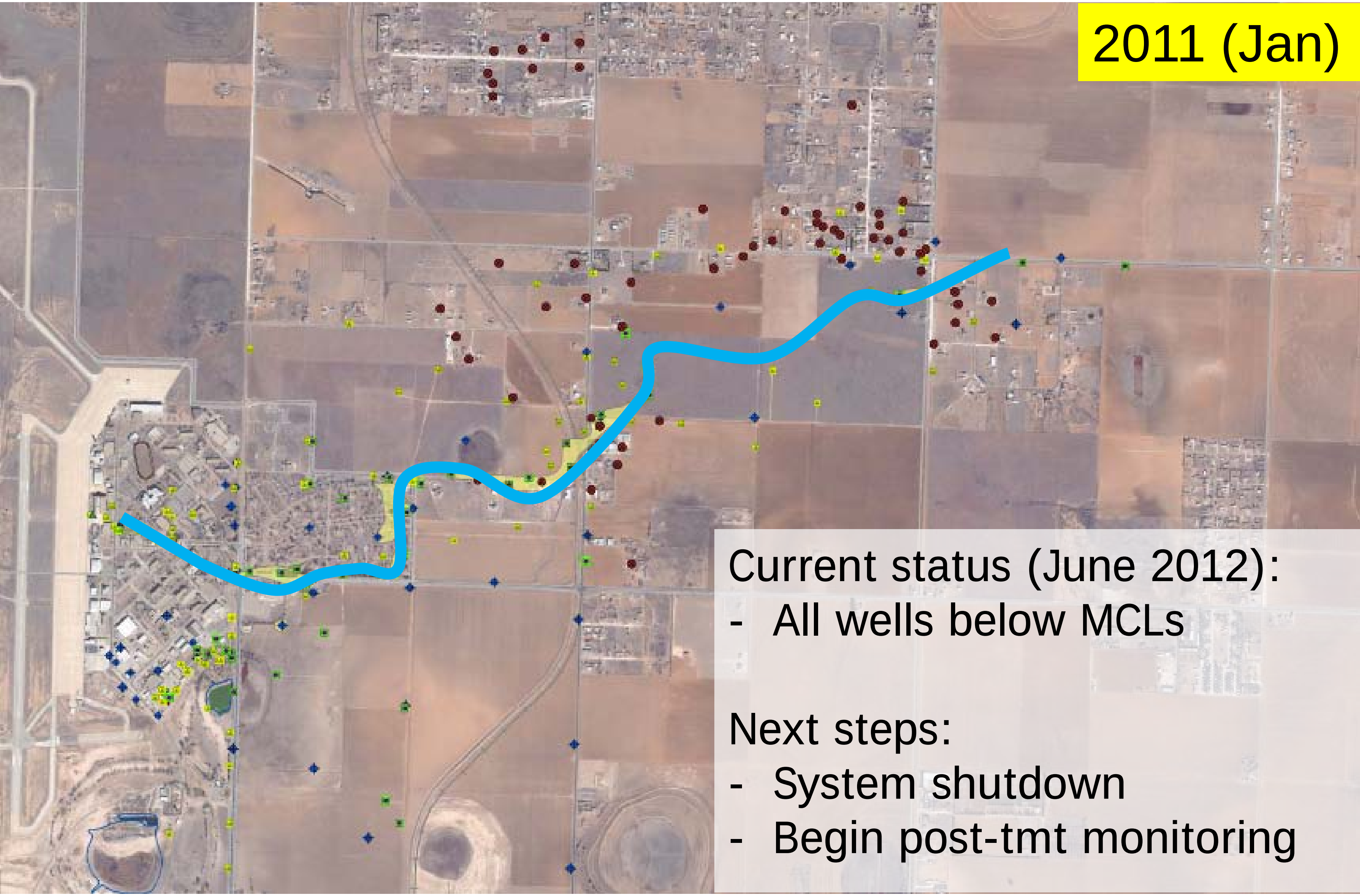
Forced-Gradient Distribution



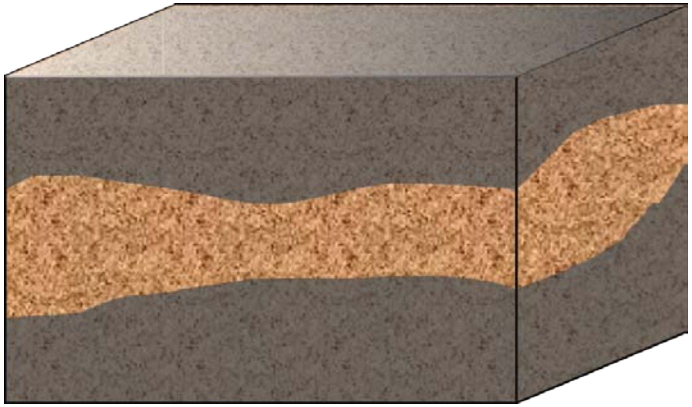
Forced-Gradient ERD Zone



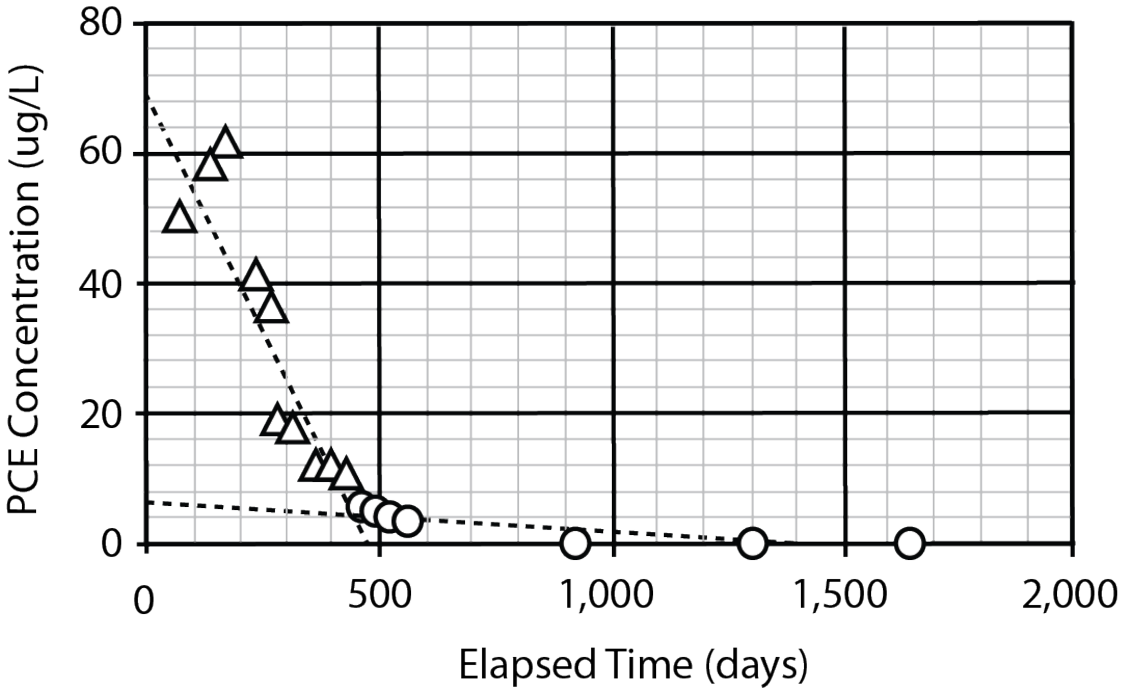

2010
Primary transport channel


2011 (Jan)
Current status (June 2012):
- All wells below MCLs
Next steps:
- System shutdown
- Begin post-tmt monitoring

Bi-Modal Washout in an Alluvial Fan

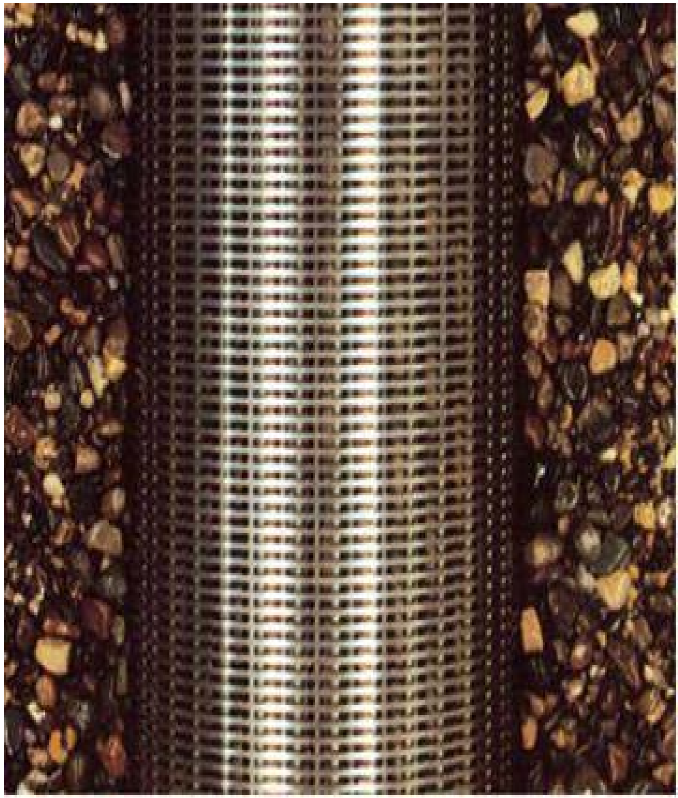

High-K, low-mass-transfer

- Source zone cutoff established
- Clean water insertion
- Washout completed (1 mi) to GSI



A Basis for MCL-Relevant Monitoring

- Higher-resolution mappings are unmasking complex contaminant distribution patterns
- High-K (transport) zones can meet standards, while adjacent low-K (storage) zones significantly exceed standards
- Remedy designs need the higher-resolution mappings to be successful, *however:*
- Low-K zones cannot be treated to MCL-level compliance.
- ***MCL-Relevant Groundwater Monitoring*** is a potential solution:
  - Separate site characterization from compliance monitoring
  - Build and sample monitoring wells to reflect protected use (i.e. drinking water protection)
  - Avoids inevitable application of TI arguments in low-K zones



Questions and Discussion

For more information, contact:

Fred.Payne@arcadis-us.com

Site Closure Focused, Safety a Priority

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