PLUME PERSISTENCE FOLLOWING FULL-SCALE SOURCE ZONE REMEDIATION DUE TO AQUITARD BACK DIFFUSION WITH INSIGHTS ON DEGRADATION EFFECTS

Chapman, S.[1], Parker, B.[1], Wanner, P.[1, 2], Aravena, R.[3], Mack, E.[4]

1. G360 Institute for Groundwater Research, University of Guelph, ON, Canada
2. Institute of Geology, University of Bern, Switzerland
3. Dept. of Earth & Environmental Sciences, University of Waterloo, ON Canada
4. DuPont, Wilmington, Delaware, USA

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Session E3: High Resolution Site Characterization

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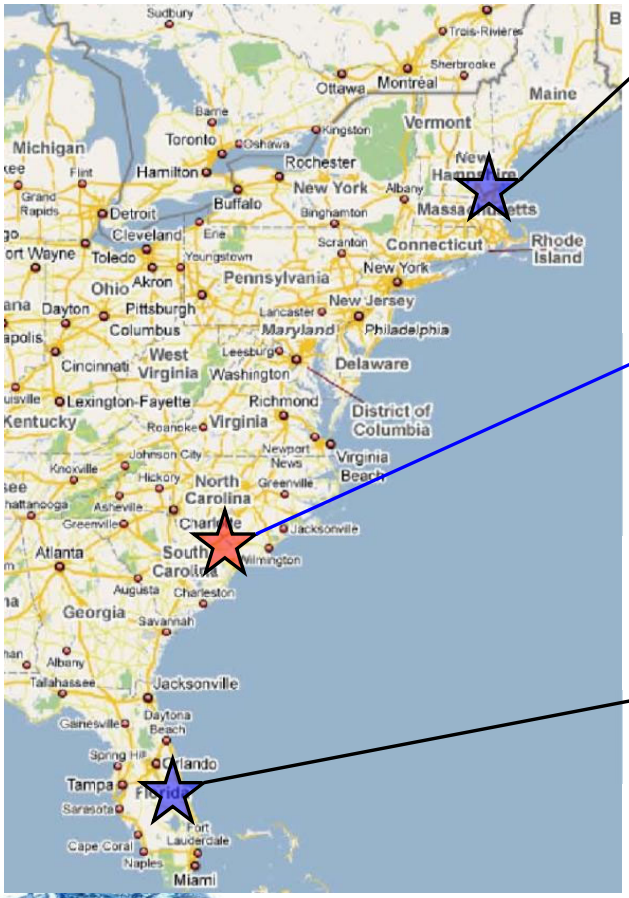
STUDY SITES: PLUME RESPONSE TO SOURCE ZONE ISOLATION / TREATMENT



North Haven, CT
- sand aquifer, underlying thick lacustrine aquitard
- single component (TCE)
- very limited degradation
- source isolation via sheet pile enclosure

Chapman et al. (WRR, 2005)

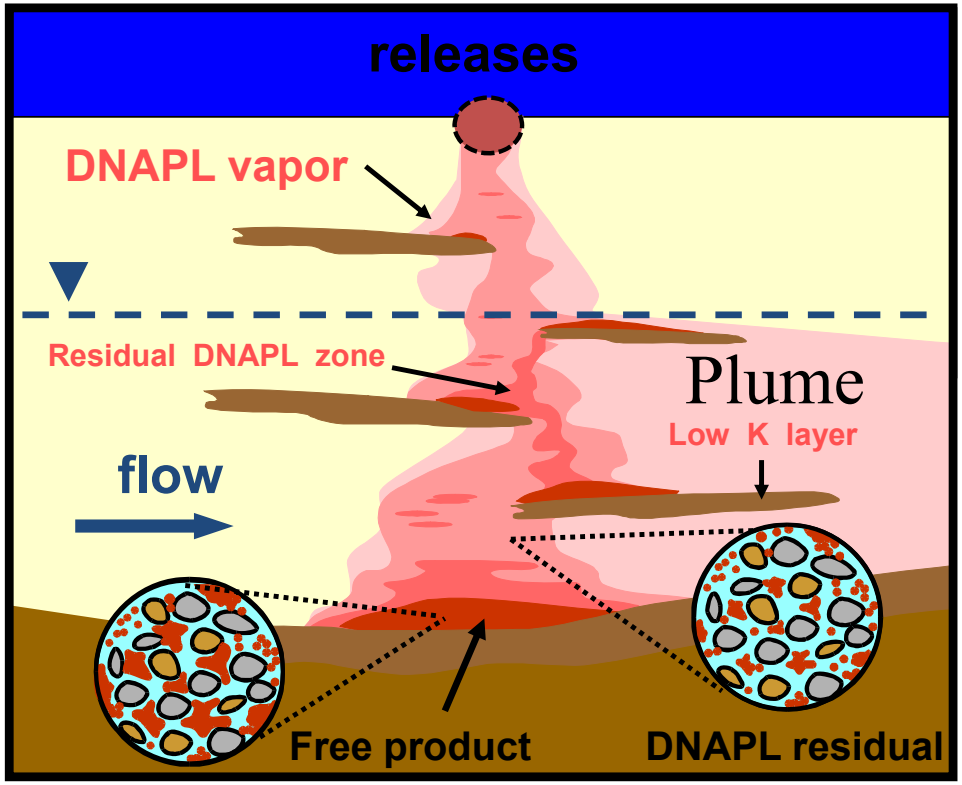
Florence, SC
- **more complex geology**
- **heterogeneous aquifer with underlying aquitard**
- **suspended low K zones (e.g. clayey layers)**
- **multicomponent DNAPL source**
- **Insitu soil mixing (ZVI / bentonite)**

Focus of this talk

Cocoa, FL
- sand aquifer with thin suspended clayey layers
- single component release (TCE)
- degradation TCE → cDCE → VC (limited)
- hydraulic capture w/ downgradient re-injection

Parker et al. (JCH, 2008)

DNAPL Source Zone in a Sandy Aquifer
Interest in diffusion into / out of low K zones



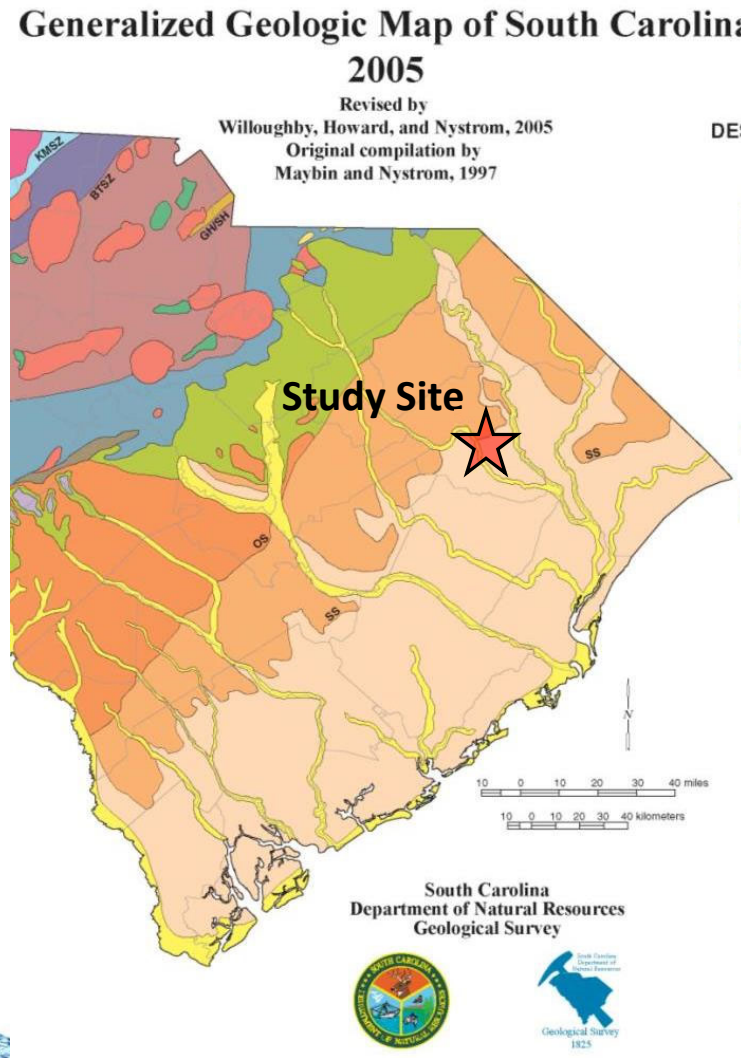
Key Questions:

- Source treatment / effectiveness
- Impacts on downgradient plume
- Diffusion in/out of low Z zones
- Degradation in low K zones

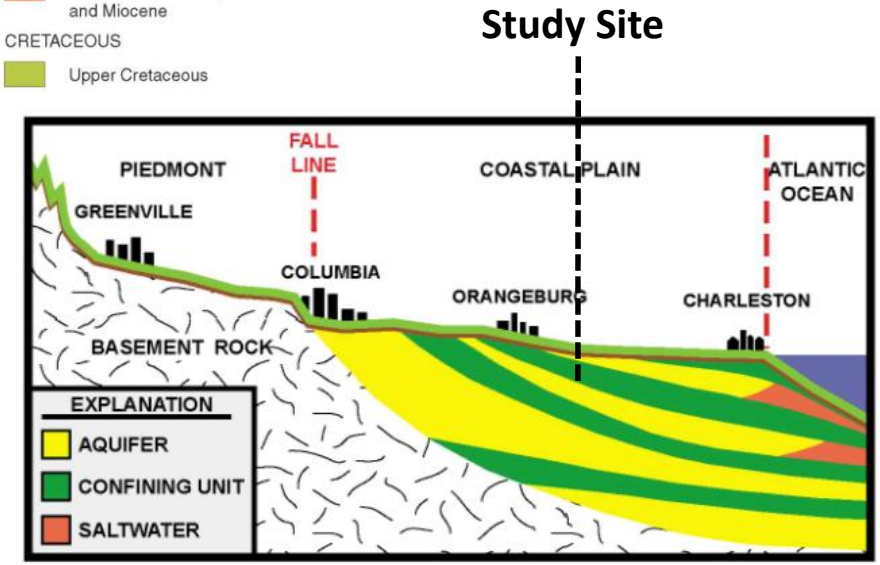
Aquifer

Aquitard

GEOLOGIC SETTING



Coastal plain sediments
~ 100's to >1000 ft thick



Cross-section from "General Hydrology of South Carolina"
SC DNR Geological Survey, 2001

Plume Response Study: Florence, SC

- Small quantities of mixed NAPL wastes disposed in French drain (1960s – early 70s)
  - CT, CF, 1122-PCA, xylenes

DNAPL Source Releases

- Unit consisted of a gravel-filled french drain (7 ft x 4 ft by 8 ft deep)
- Periodic disposal of liquid waste from QC testing over 11 year period (1961 - 1972)
- QC liquid waste consisted of carbon tetrachloride, chloroform, 1,1,2,2-PCA, phenol, and xylenes

Rare scenario where you know exactly where DNAPLs entered the subsurface

MMPE Trial (~2008)

Soil Mixing Implementation (2007)

- 21 field days, mixing ~11 days
- 40 x 60 ft area, max 22 ft depth
- 1155 cubic yards → $228 per yard
- 43 tons ZVI (~1.5–2.5%)
- 82 tons bentonite (~4%)
- 61,000 gal of water

Excavation of overburden

Placement of ZVI / Bentonite in Cells

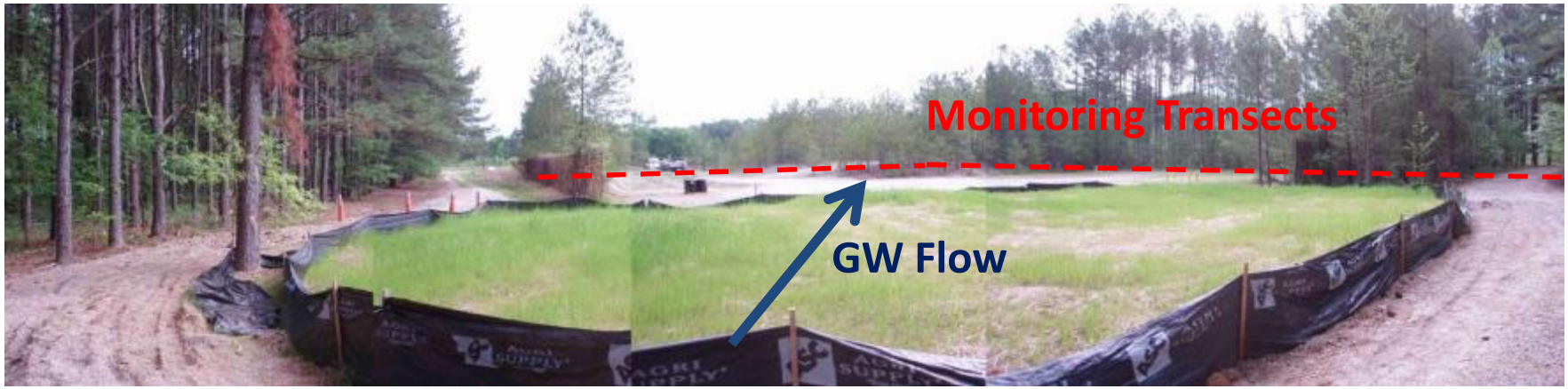
Lang Mixing Tool

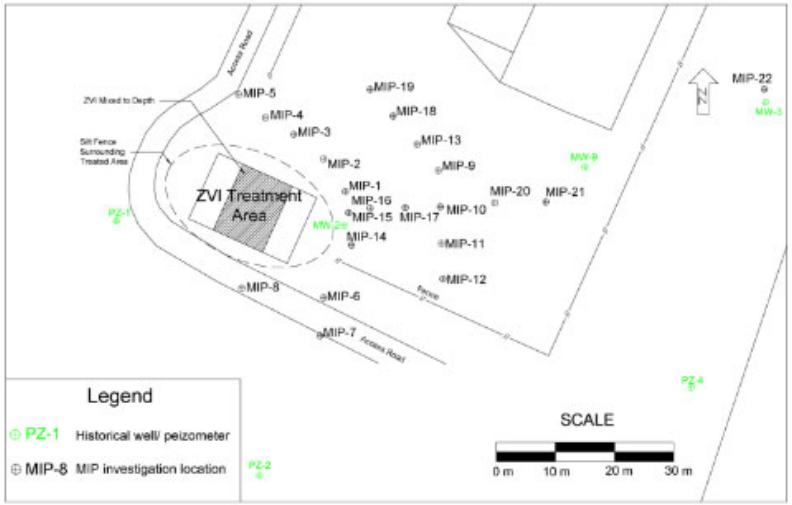
Water addition, gross mixing w/ excavator

Blending with insitu blender

CH2MHILL

UW / UG Plume Response Study (2008 – 2018)



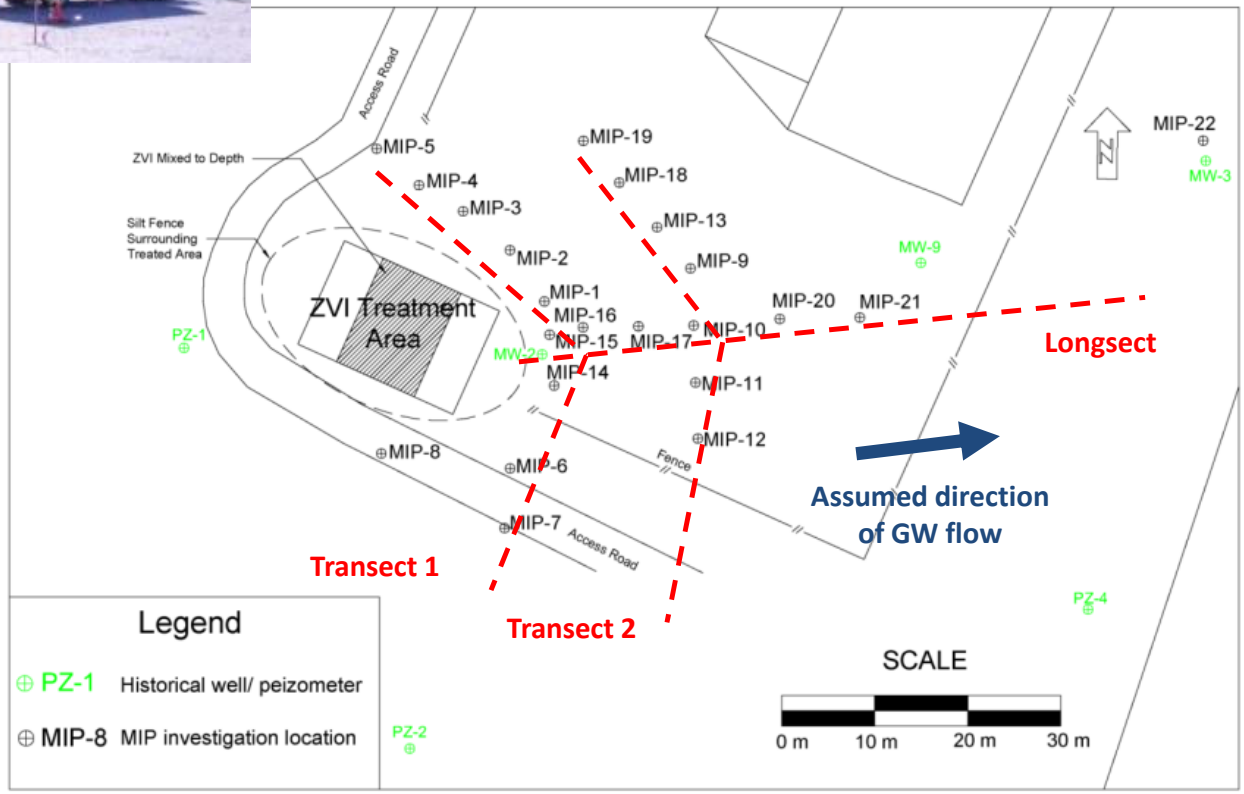


Post-Remedial Investigation / Monitoring

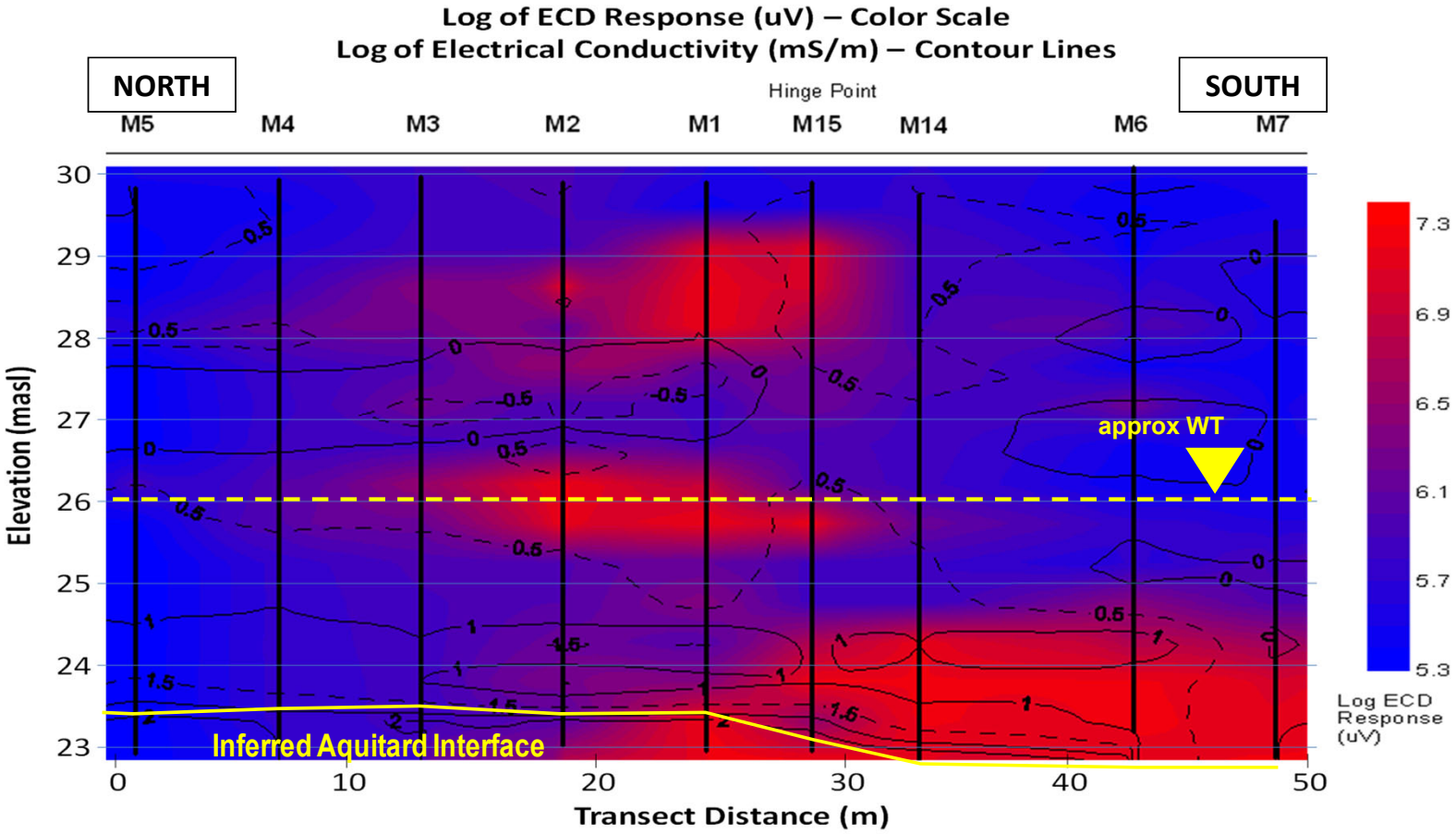
- MIP
- Waterloo APS™
- Continuous cores
  - high resolution VOC sampling (aquifer, aquitard)
  - physical properties
- Multilevel well installations (CMT™)
  - long-term groundwater monitoring
  - VOCs, hydrochemistry, CSIA, flow system

MIP INVESTIGATION (4/2008)

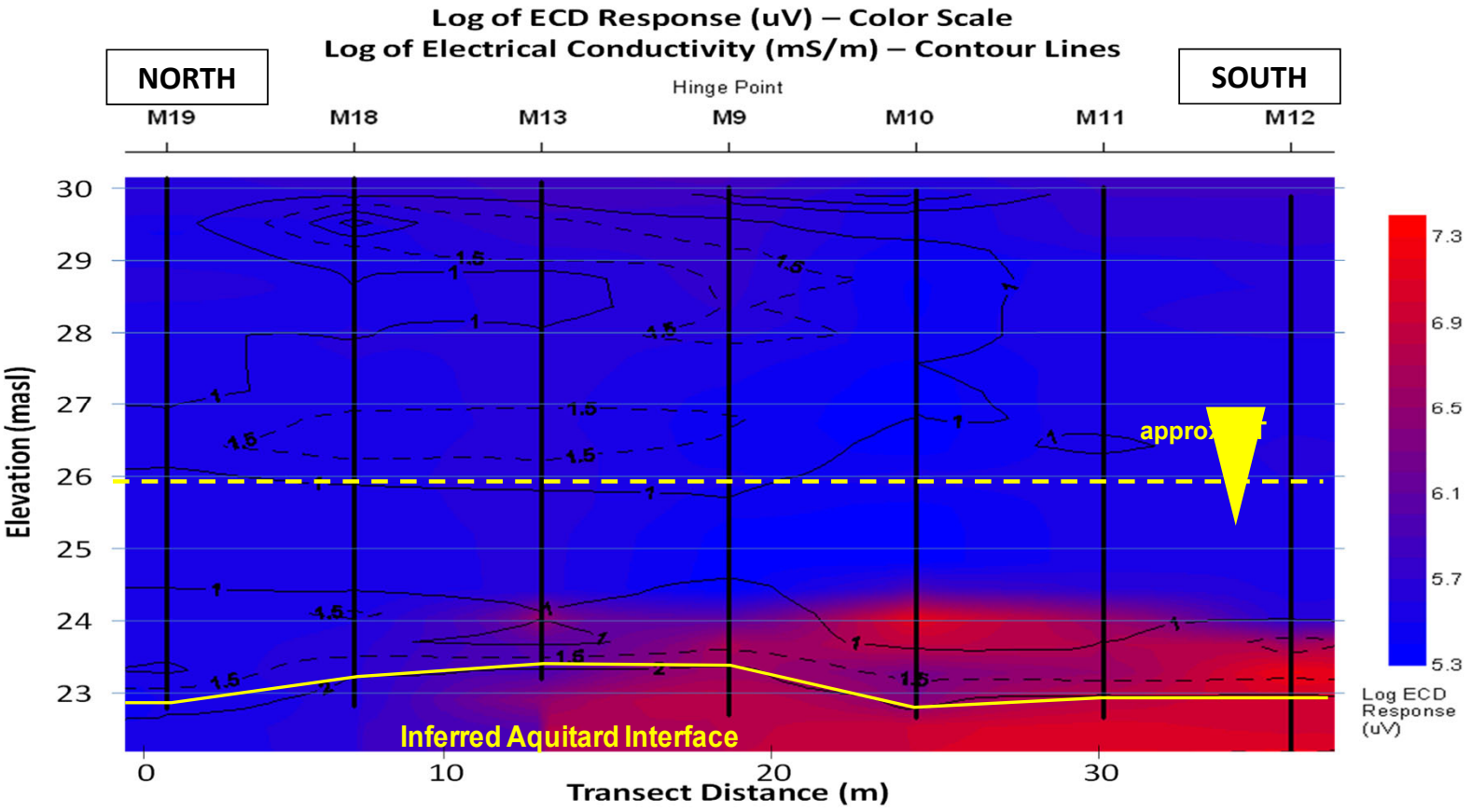
(21 LOCATIONS ~3 DAYS)



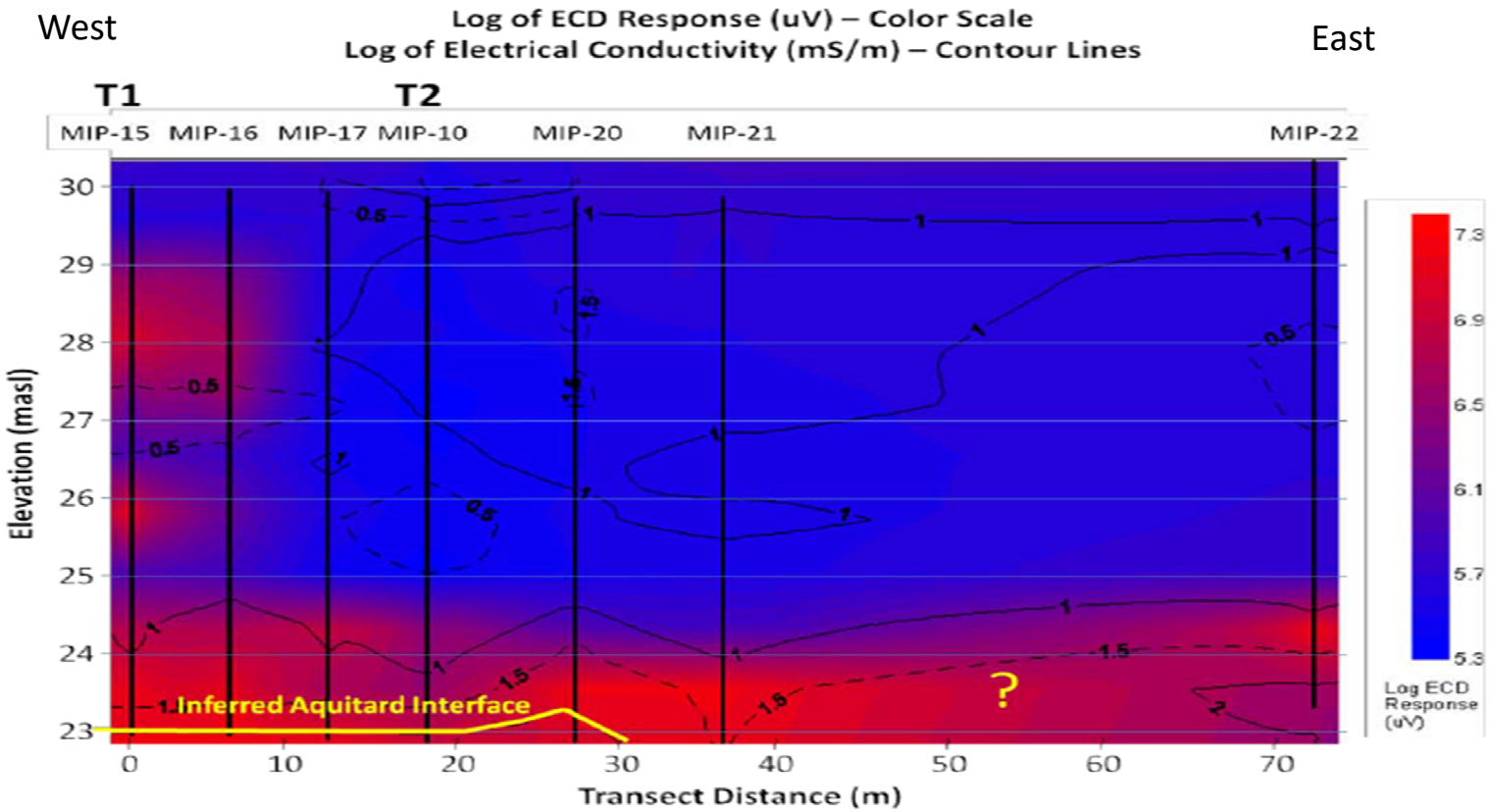
Transect 1: MIP ECD and EC Contours



Transect 2: MIP ECD and EC Contours



Longsect: MIP ECD and EC Contours



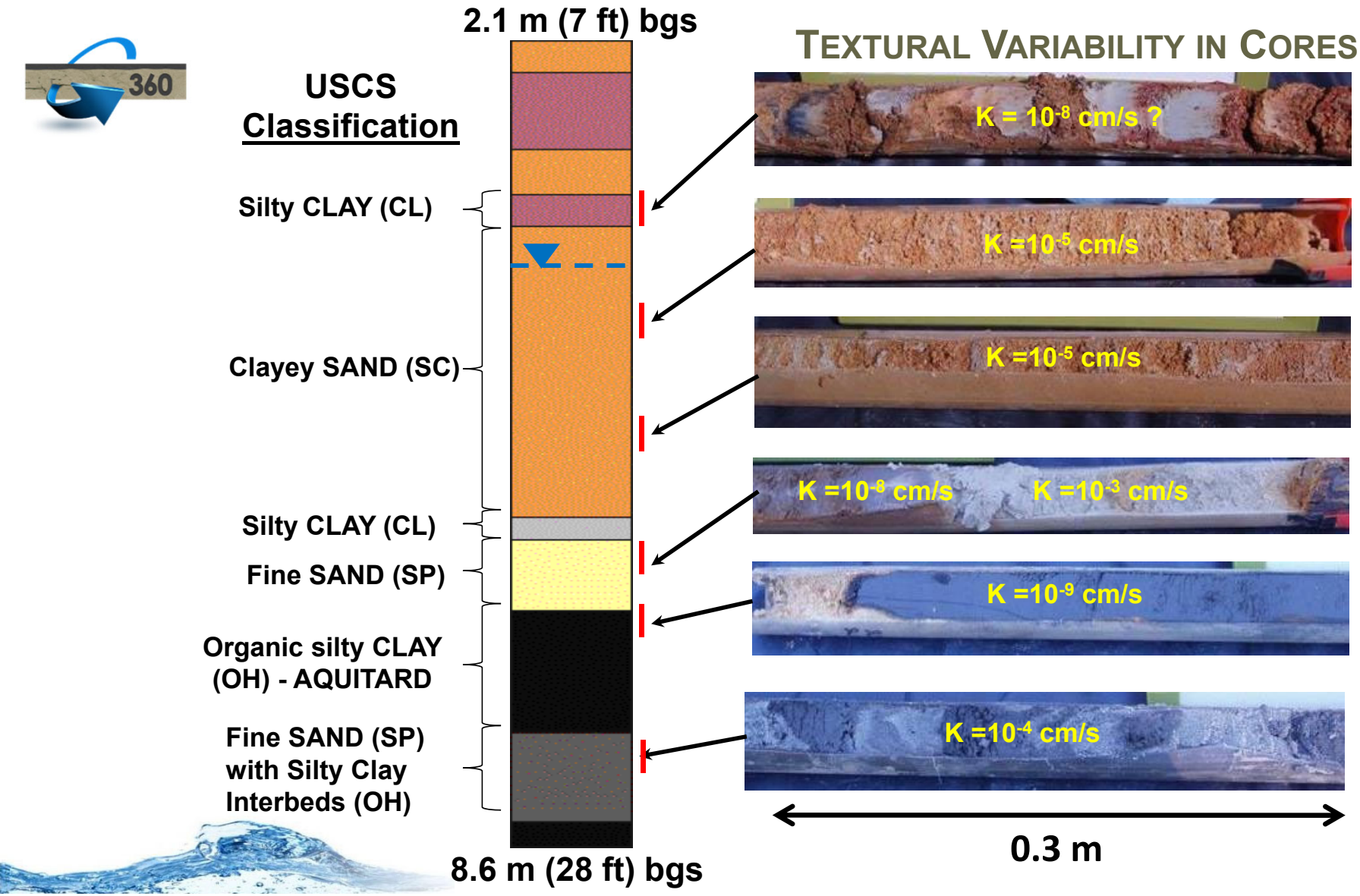
High Resolution Insights

- rapid and cost-effective initial plume characterization via MIP + EC (target cores and MLS)
- plume width >> expected (later hydraulic head monitoring showed >60 deg flow direction shifts)

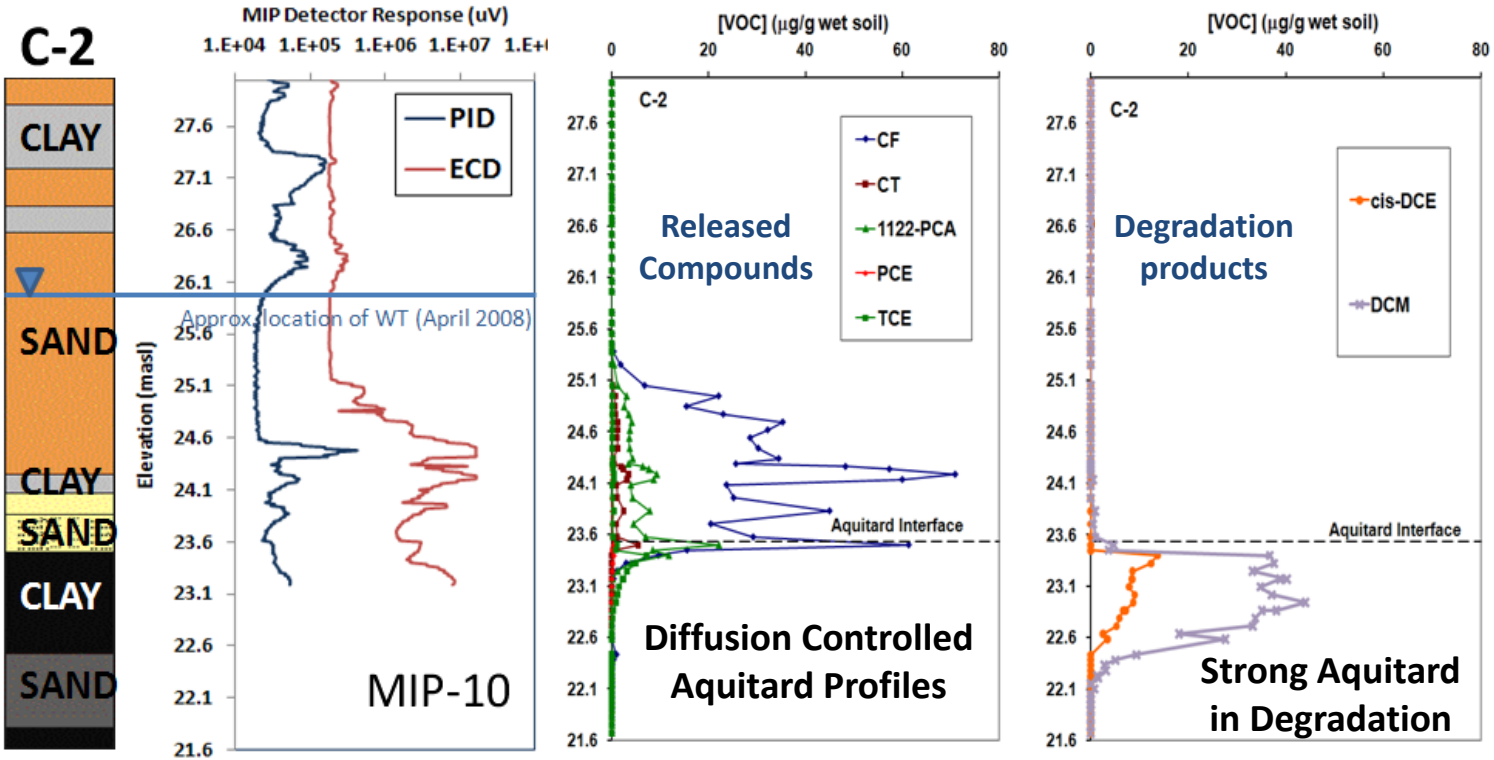
Direct Push Enviro-Core Rig for Collecting Continuous Cores (2008)

Enviro-Core dual casing method:

- high quality cores w/ excellent recovery
- install CMT MLS on same pass in outer casing

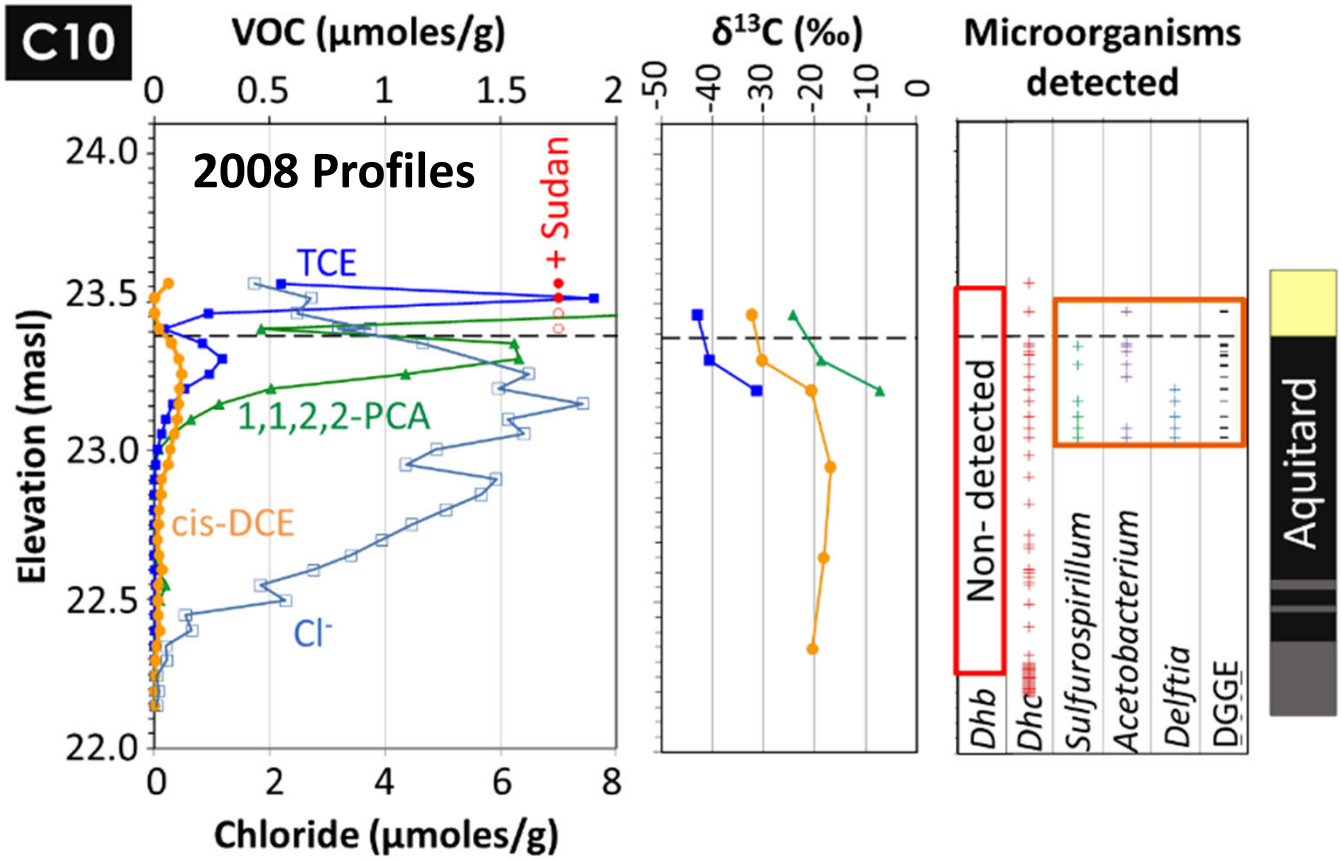

2.1 m (7 ft) bgs
USCS Classification
Silty CLAY (CL)
Clayey SAND (SC)
Silty CLAY (CL)
Fine SAND (SP)
Organic silty CLAY (OH) - AQUITARD
Fine SAND (SP) with Silty Clay Interbeds (OH)
8.6 m (28 ft) bgs
TEXTURAL VARIABILITY IN CORES
K = 10-8 cm/s ?
K =10-5 cm/s
K =10-5 cm/s
K =10-8 cm/s
K =10-3 cm/s
K =10-9 cm/s
K =10-4 cm/s
0.3 m

MIP versus Soil VOCs (Transect 2)

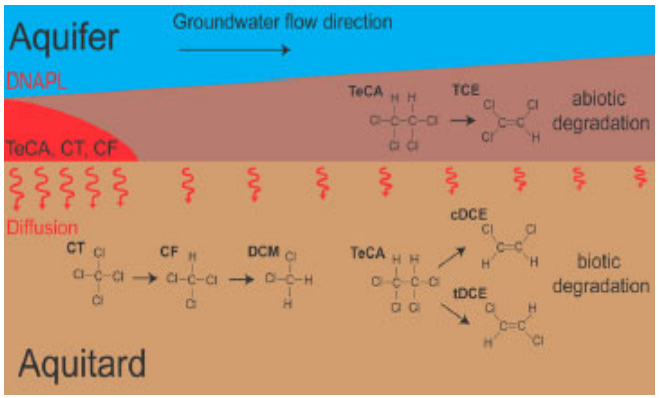


- High concentrations of 1122-PCA, CT, CF in low and high K units at base of aquifer
- Minimal diffusive penetration of primary contaminants in aquitard (~0.3-0.5 m)
- Accumulation of degradation products in aquitard
- MIP ECD / PID response reflects VOC profile qualitatively

DEGRADATION IN THE AQUITARD (VOCS + CSIA + MICROBIOLOGY)



Degradation Pathways



1122-PCA → TCE → cDCe

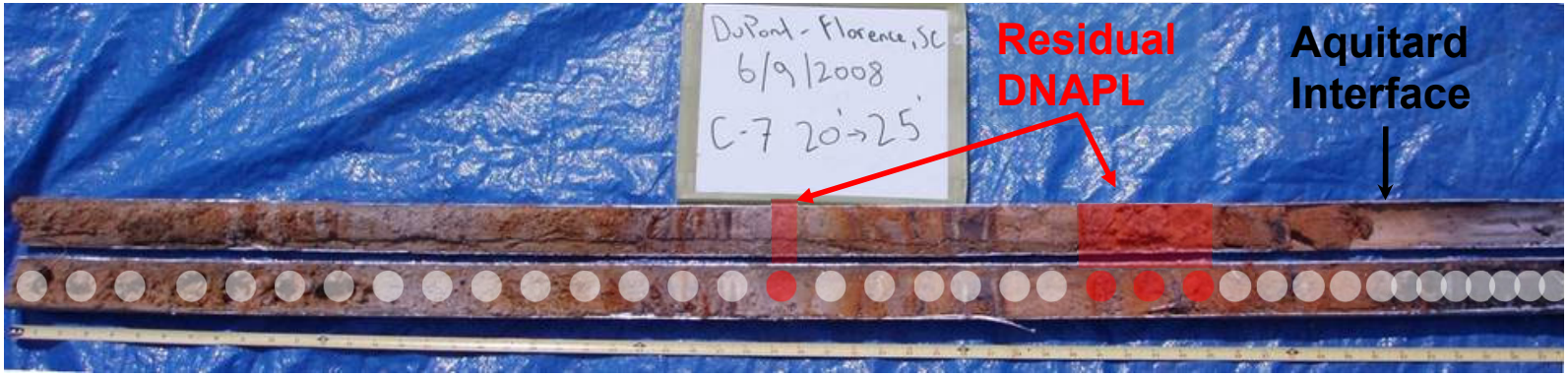
1122-PCA → cDCE / tDCE

CT → CF → DCM

Wanner et al., ES&T (2018)

Residual DNAPL Outside Treated Zone: High Resolution Assessment Required

C-7: 20-25 ft Core Run

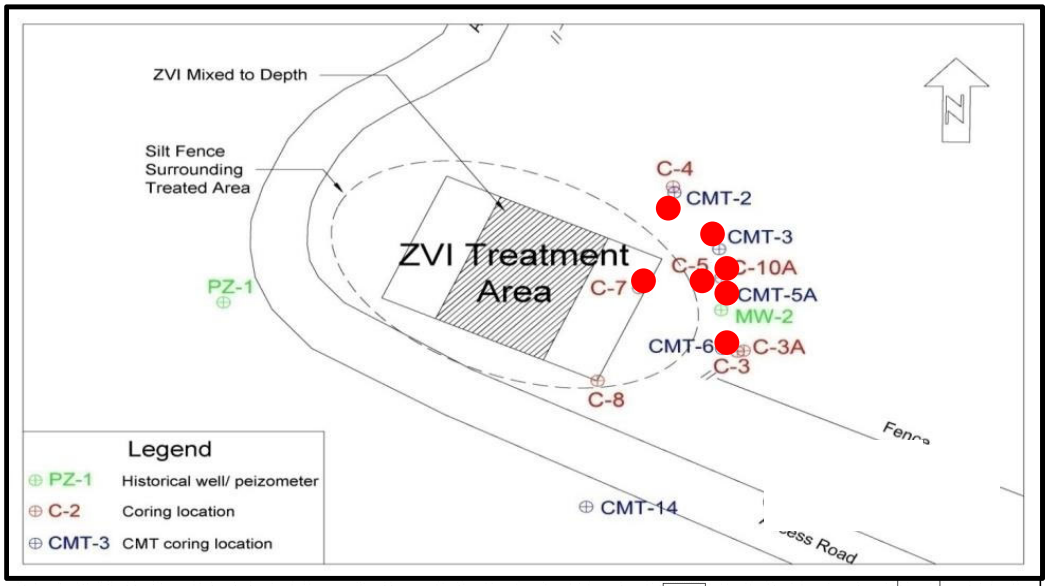


PID Screening

Oil-Red-O Dye Shake Tests

DNAPL Screening

- Absent
- Present

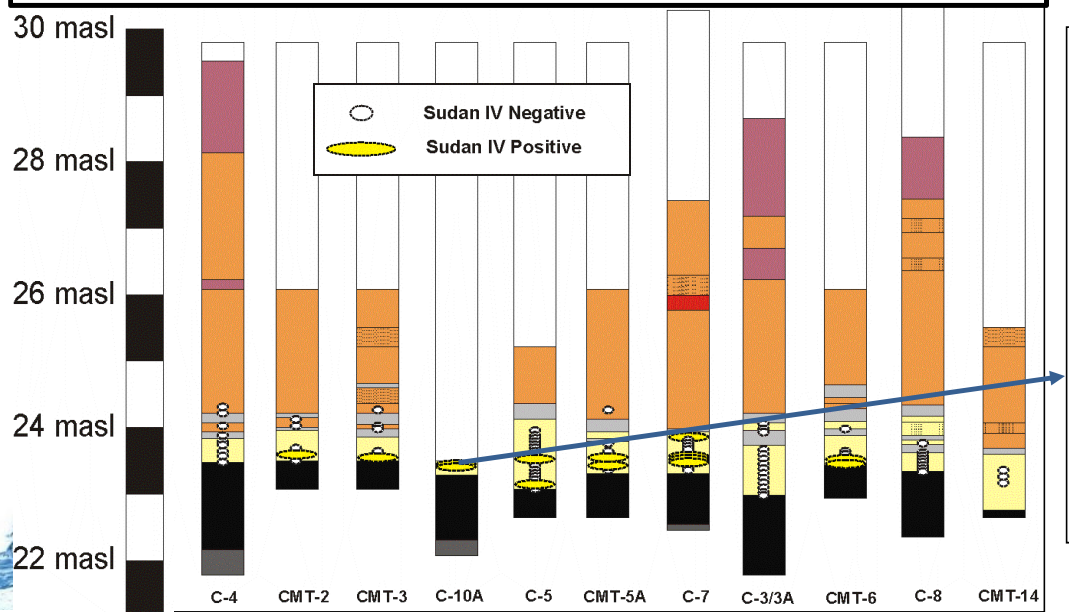


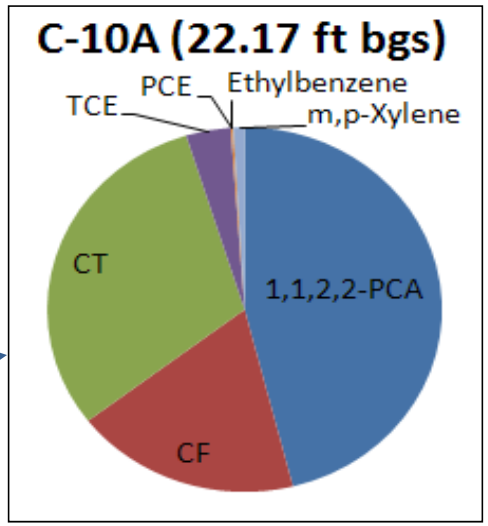
DNAPL Occurrence Outside Treated Zone

NAPLANAL:

"An Algorithm for the Estimation of NAPL Saturation and Composition from Typical Soil Chemical Analyses."

Mariner et al. [1997]





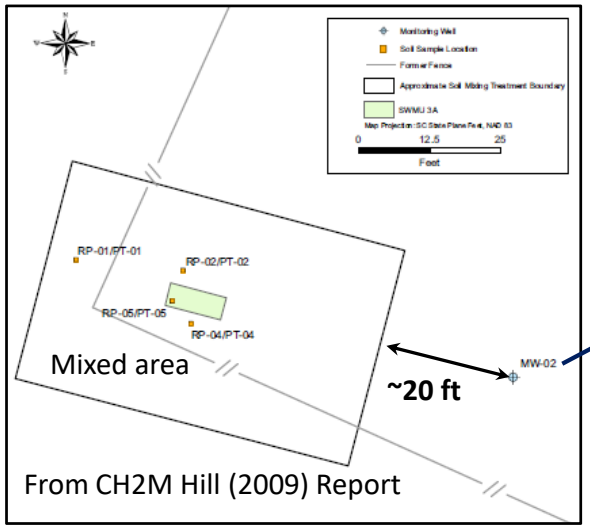
NAPL saturation ~ 1%

Possible Reasons for DNAPL Outside Treated Zone

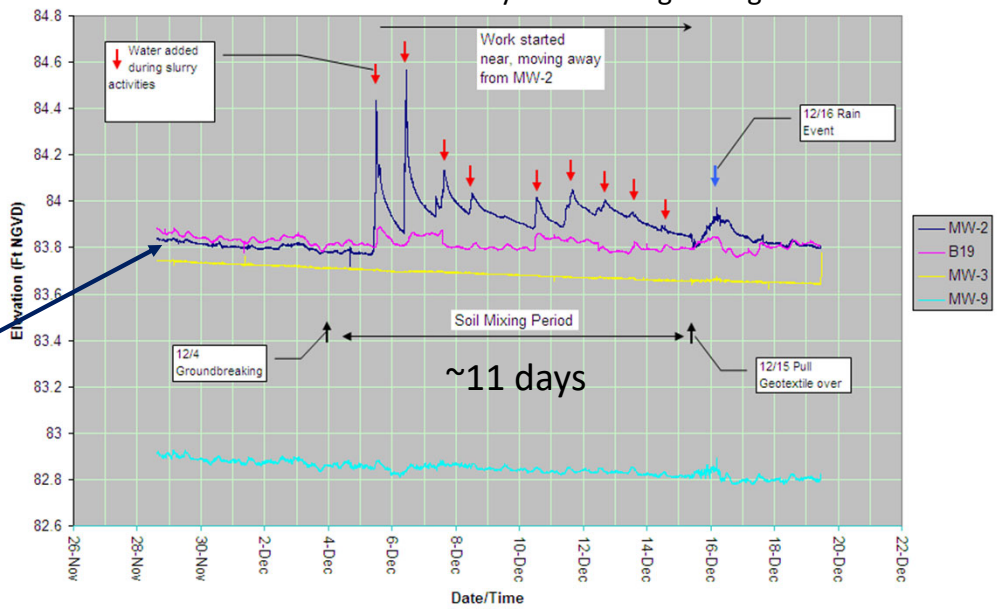
- Missed in initial site characterization
  - Challenges locating cm-scale DNAPL lenses
- Mobilized during soil mixing activities
  - Heavy equipment operations
  - Large water addition during source zone

Mixing quantities:

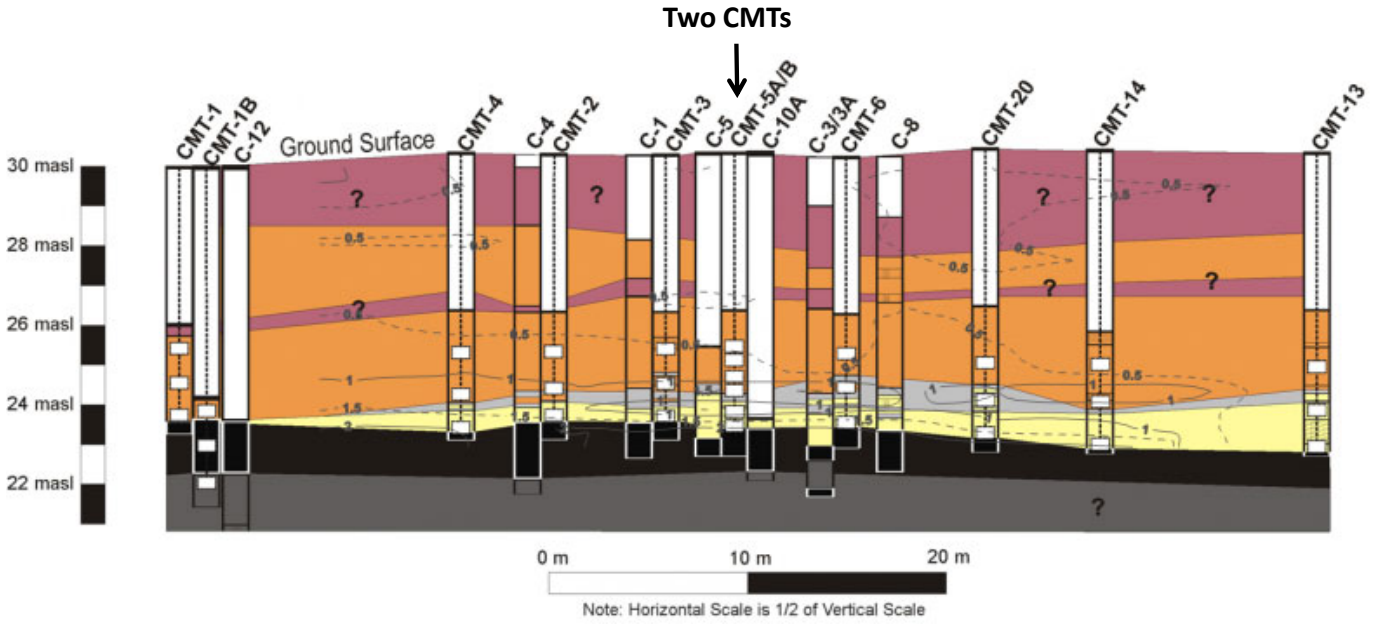
- Bentonite = 82.5 tons (4.0%)
- ZVI = 42.9 tons (1.5 - 2.5%)
- Water added = 61,000 gal
  - 53 gal per cubic yard treated
  - 26% of total treated volume



Water levels in nearby wells during mixing



GROUNDWATER MONITORING NETWORK: TRANSECT #1

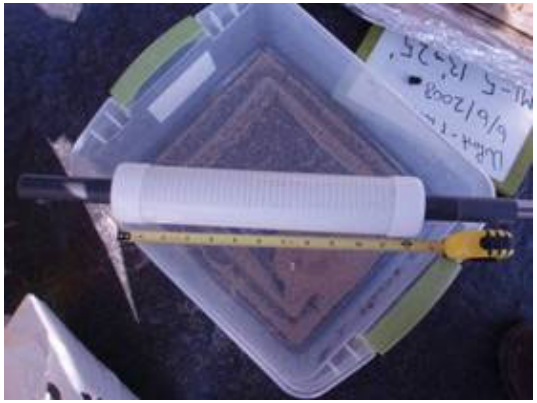


Monitoring Focus

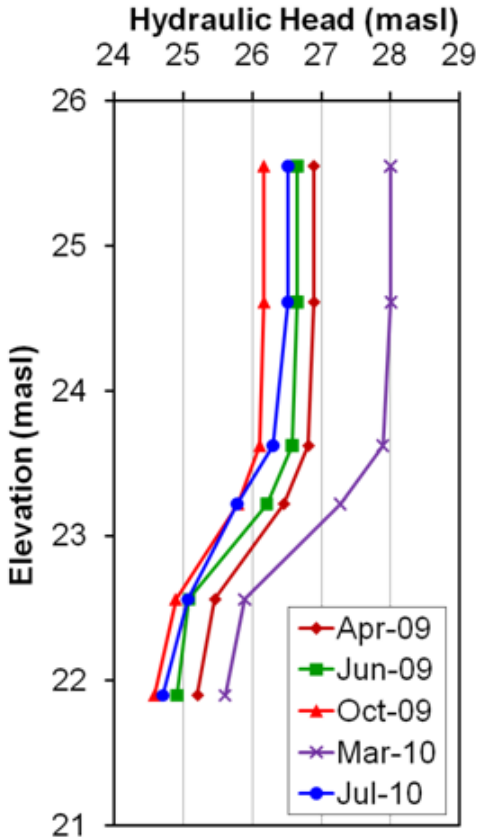
CMT Multilevel Installation – 3 port systems

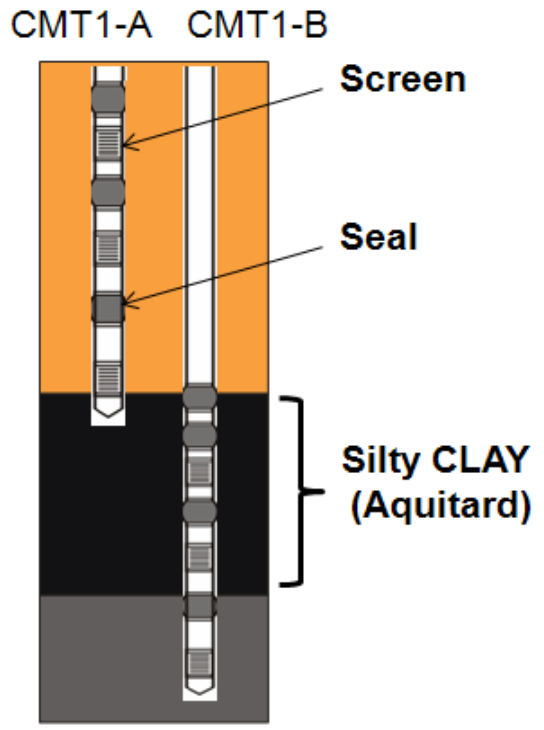
Pre-packed seal

Pre-packed screen



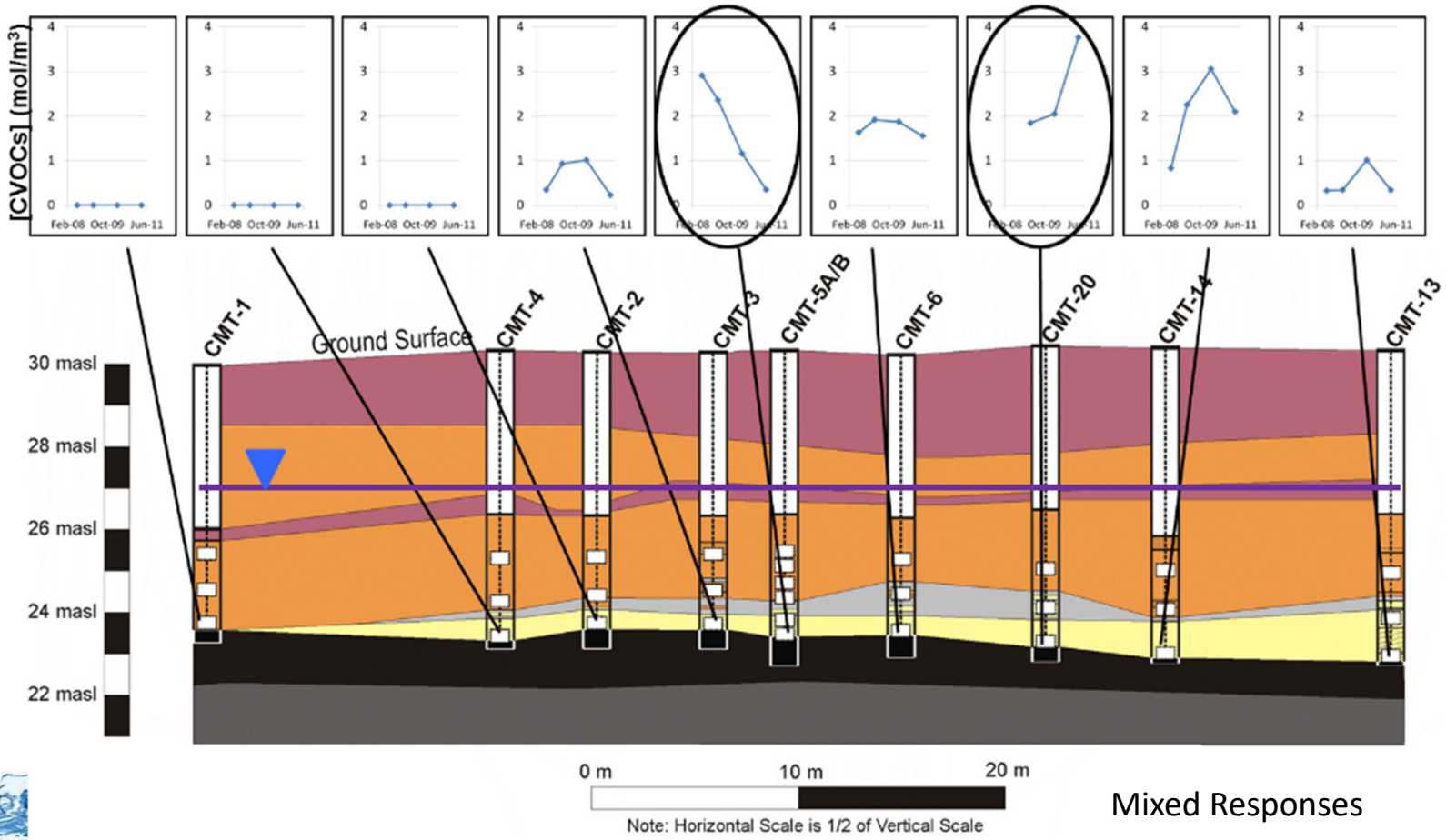
HIGH VERTICAL GRADIENTS IN AQUITARD: INDICATIVE OF GOOD HYDRAULIC INTEGRITY





confirms excellent seal between ports

Intensive Early Monitoring: Transect 1 (July 2008 to Mar 2011 – 4 snapshots)



Mixed Responses

Google Earth Images (Study Period 2008-2018)

Source Zone Treated (12/2007)

Property Clear Cut (~2012-2013)

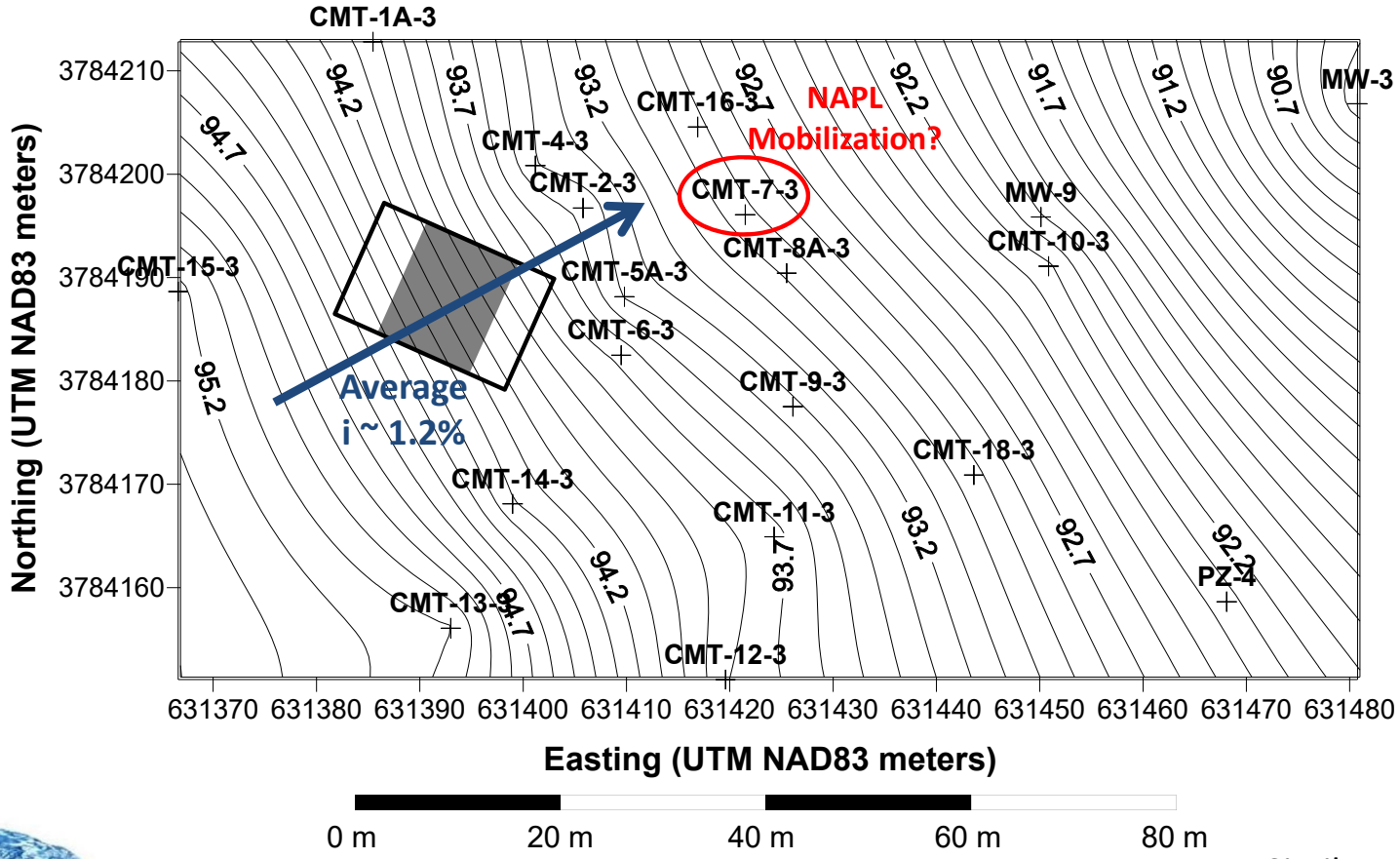
Changing Site Conditions During Monitoring Period

Altered landscape from clear cutting

- increased recharge
- flow system changes
- several MLS / wells destroyed
- source phytoremediation ☺

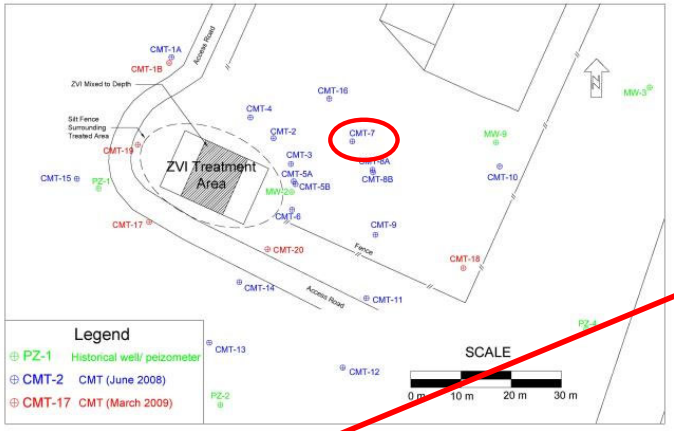
Facing Downgradient from Treated Source

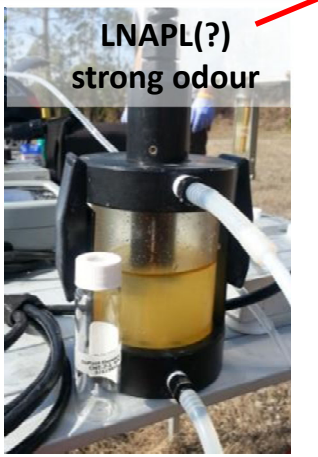
POTENTIOMETRIC SURFACE: FEB 2014 (HIGHEST WLS OBSERVED)

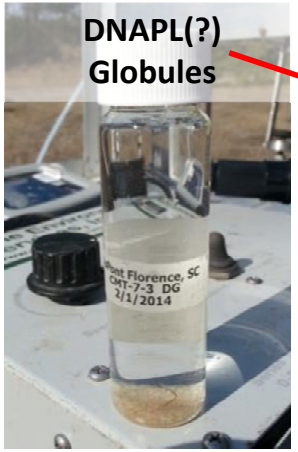


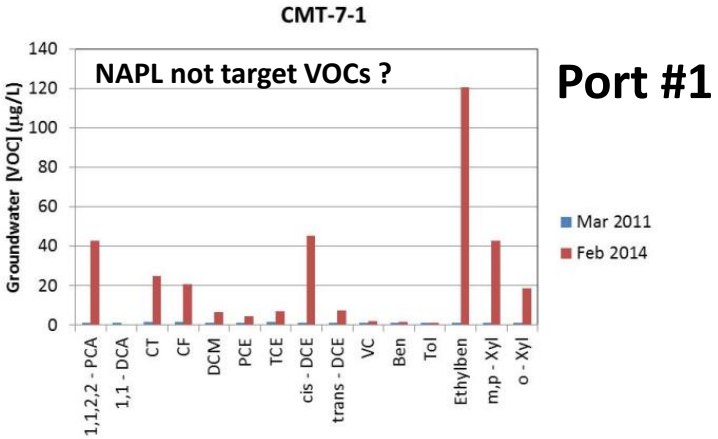
Similar conditions 3/2018

NAPL Encountered along Transect 2 (CMT-7) during February 2014 Groundwater Sampling Episode

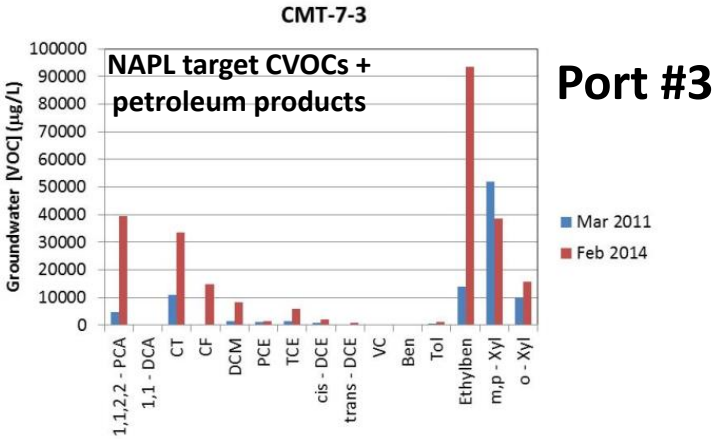






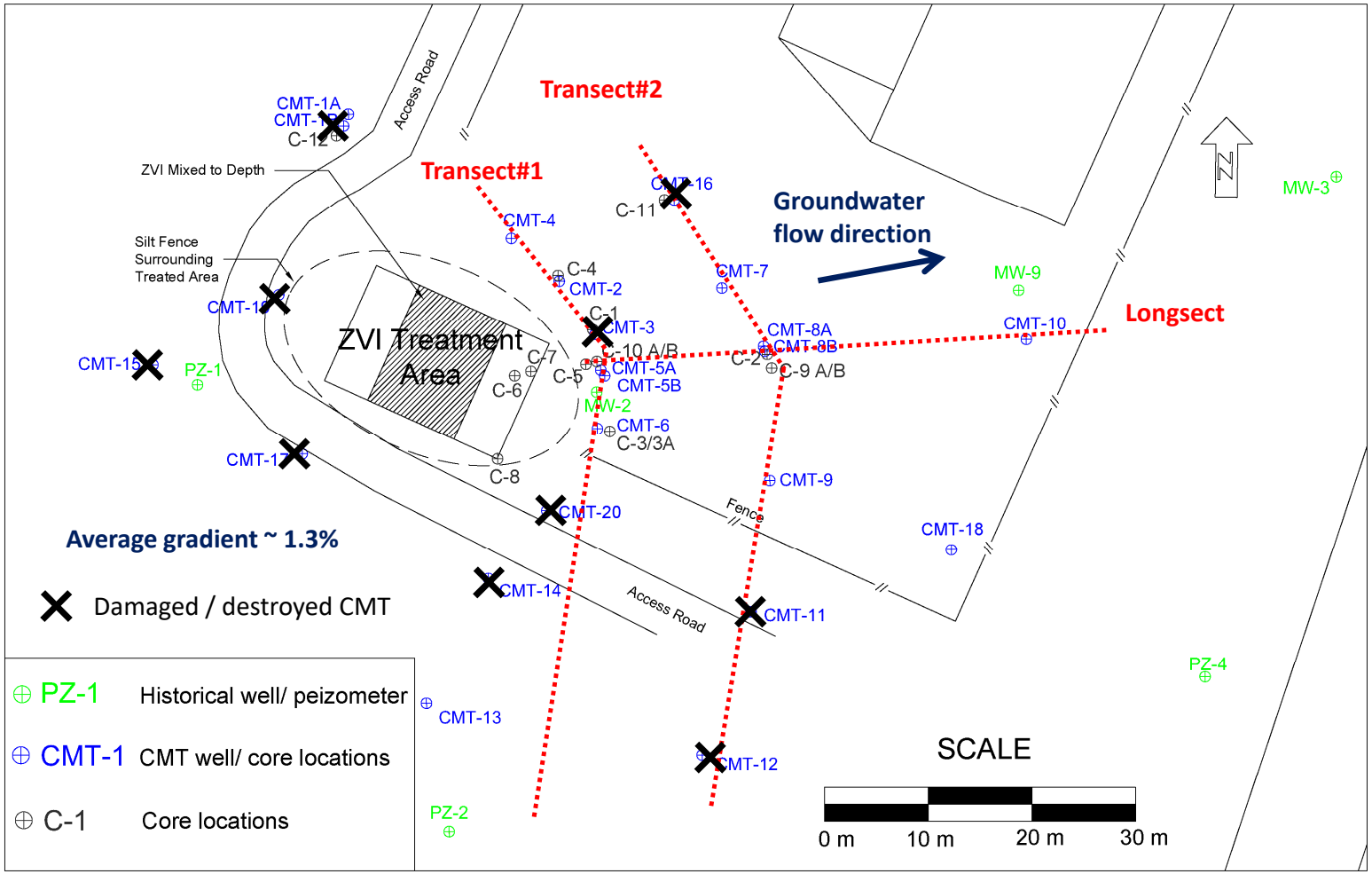


Port #1

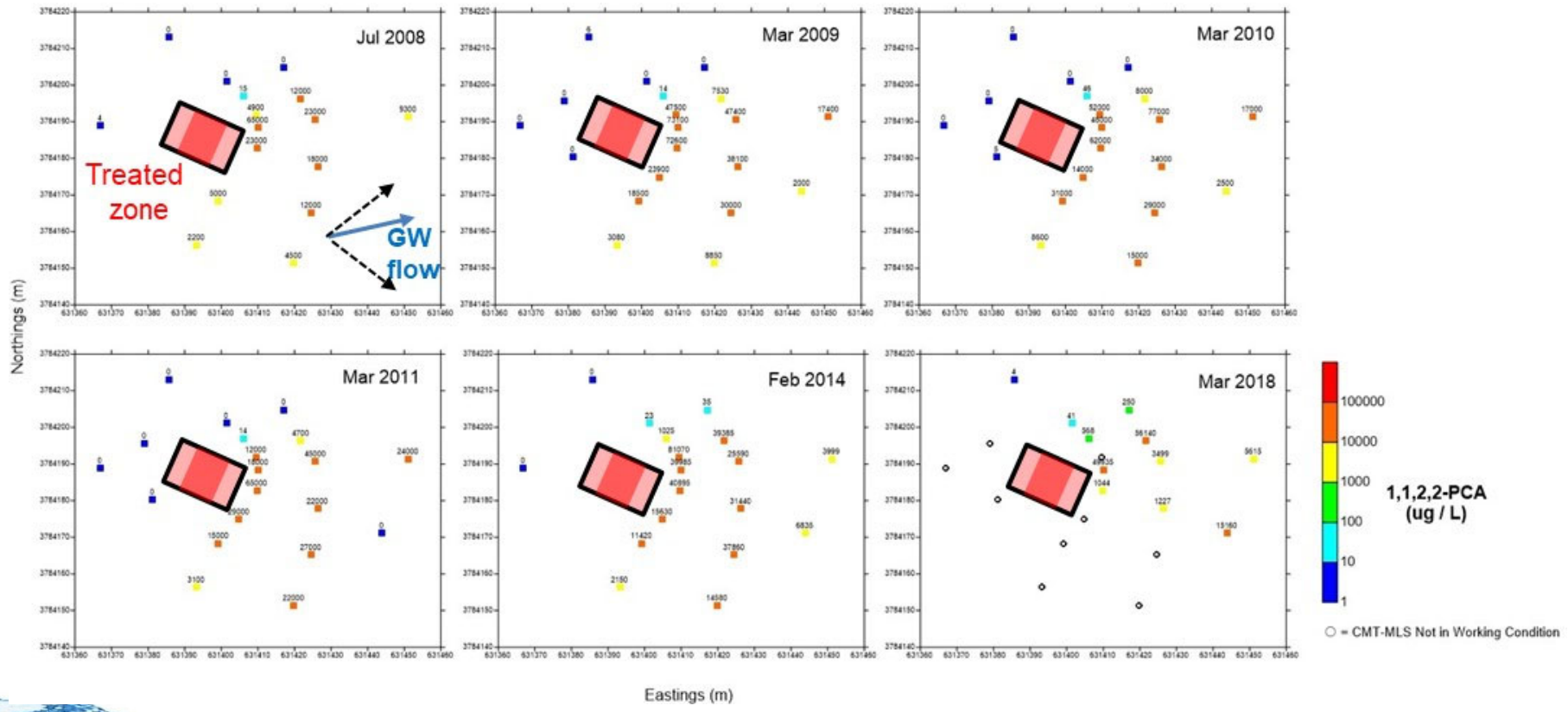


Port #3

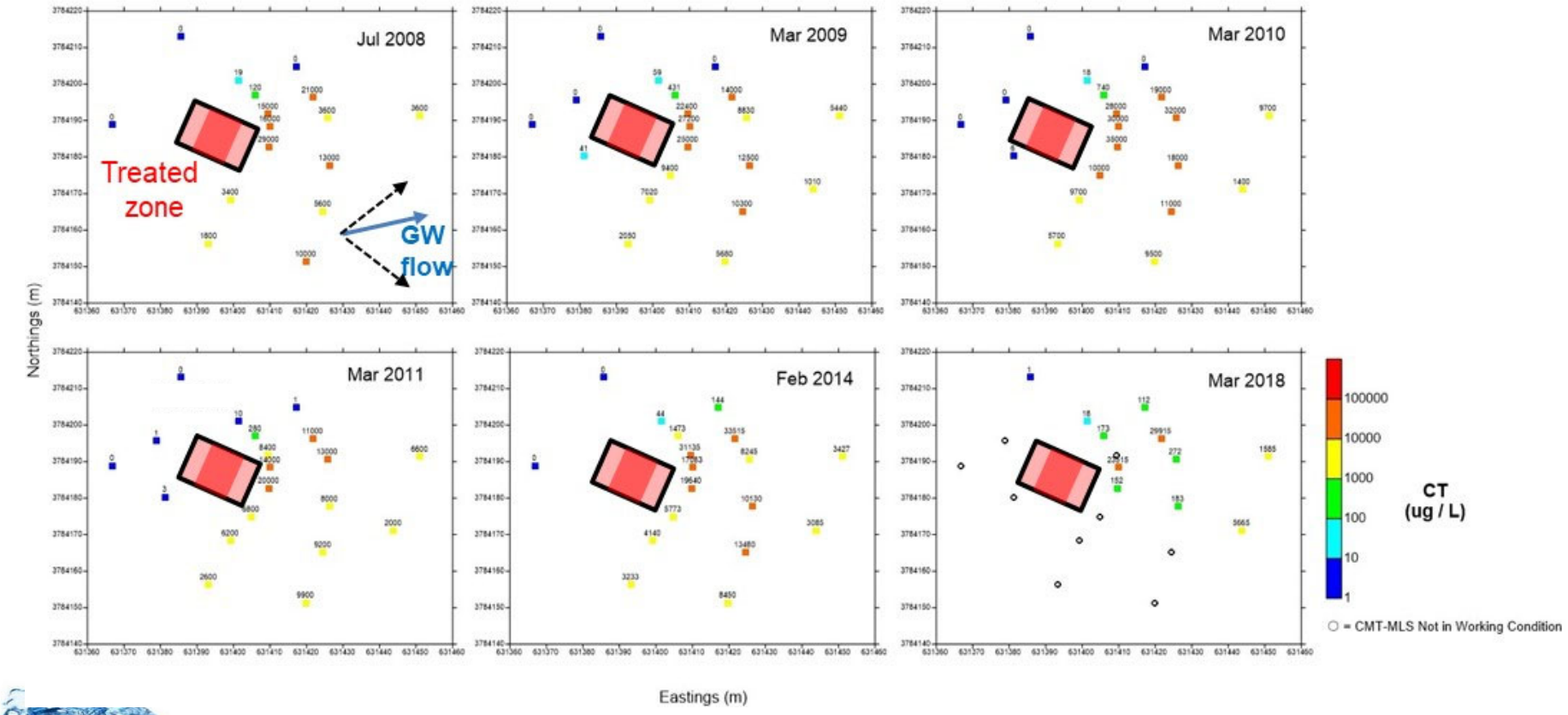
GROUNDWATER SAMPLING LOCATIONS (2008 – 2018)



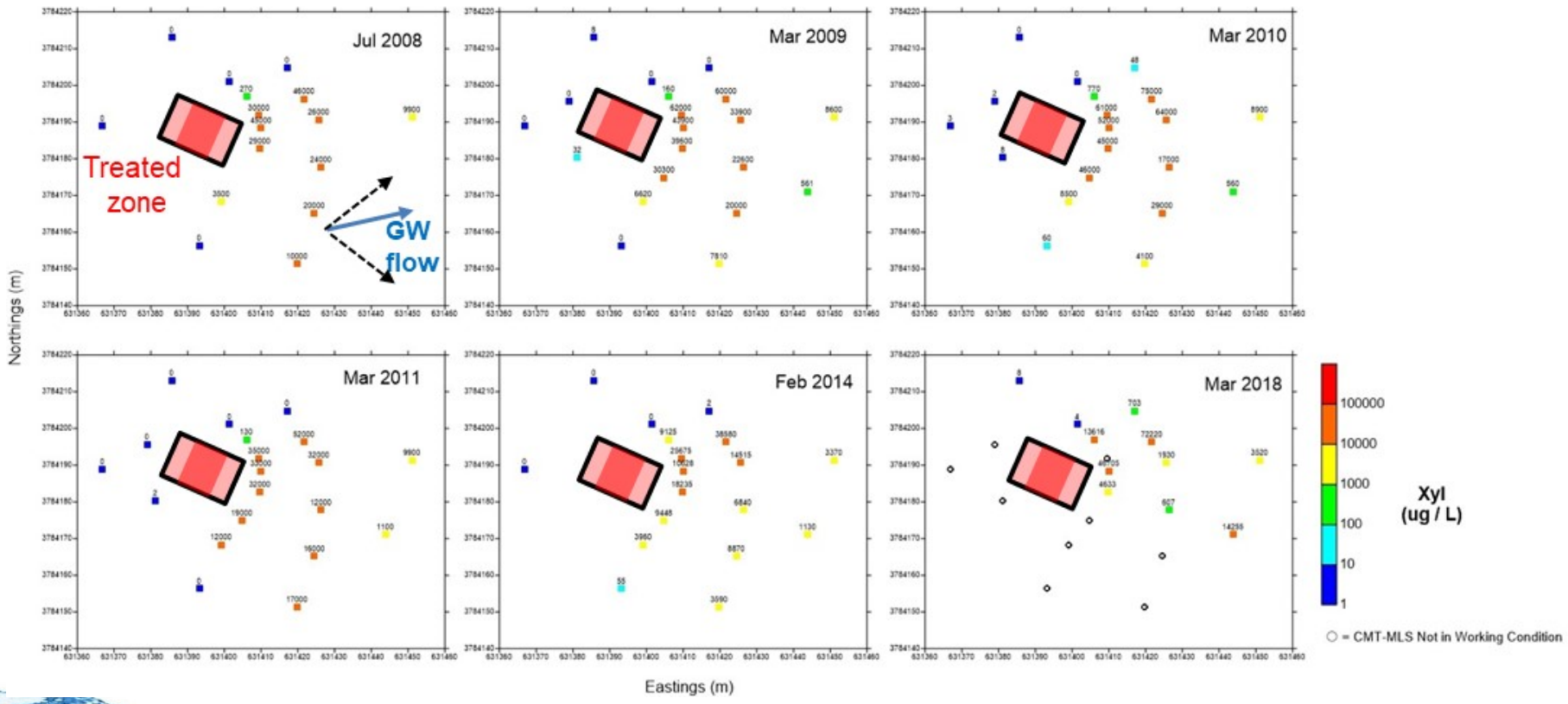
PLUME RESPONSE ASSESSMENT: CMT PORT #3 TRENDS (1122-PCA)



PLUME RESPONSE ASSESSMENT: CMT PORT #3 TRENDS (CT)



PLUME RESPONSE ASSESSMENT: CMT PORT #3 TRENDS (XYLENE)



Possible Factors Affecting Plume Response to Source Treatment

- DNAPL outside of treatment area footprint
  - Missed during pre-treatment site characterization
  - Mobilized during soil mixing / water addition
  - Post-treatment influences (logging, flow system changes)
- Source zone treatment / soil mixing influences
  - Inadequate mixing to aquitard interface depths
    - Intervals with highest mass / DNAPL near interface
  - Residual contamination within mixed zone
    - Treatment media depletion (ZVI)
- Sluggish groundwater flow system
  - Clayey sands in aquifer overlying sandy unit
- Aquitard mass storage / back diffusion effects
  - Strong degradation limits back diffusion

2008 Site Characterization

Assessed in 2018 Field Program

Plume Response Study Goals

Two Geoprobe Rigs (2018 Investigation)

MiHPT Rig: Geoprobe 7820DT

Advance MiHPT Tooling (~1.75” diameter)

- Controlled penetration rate
- Avoid damaging MiHPT tooling

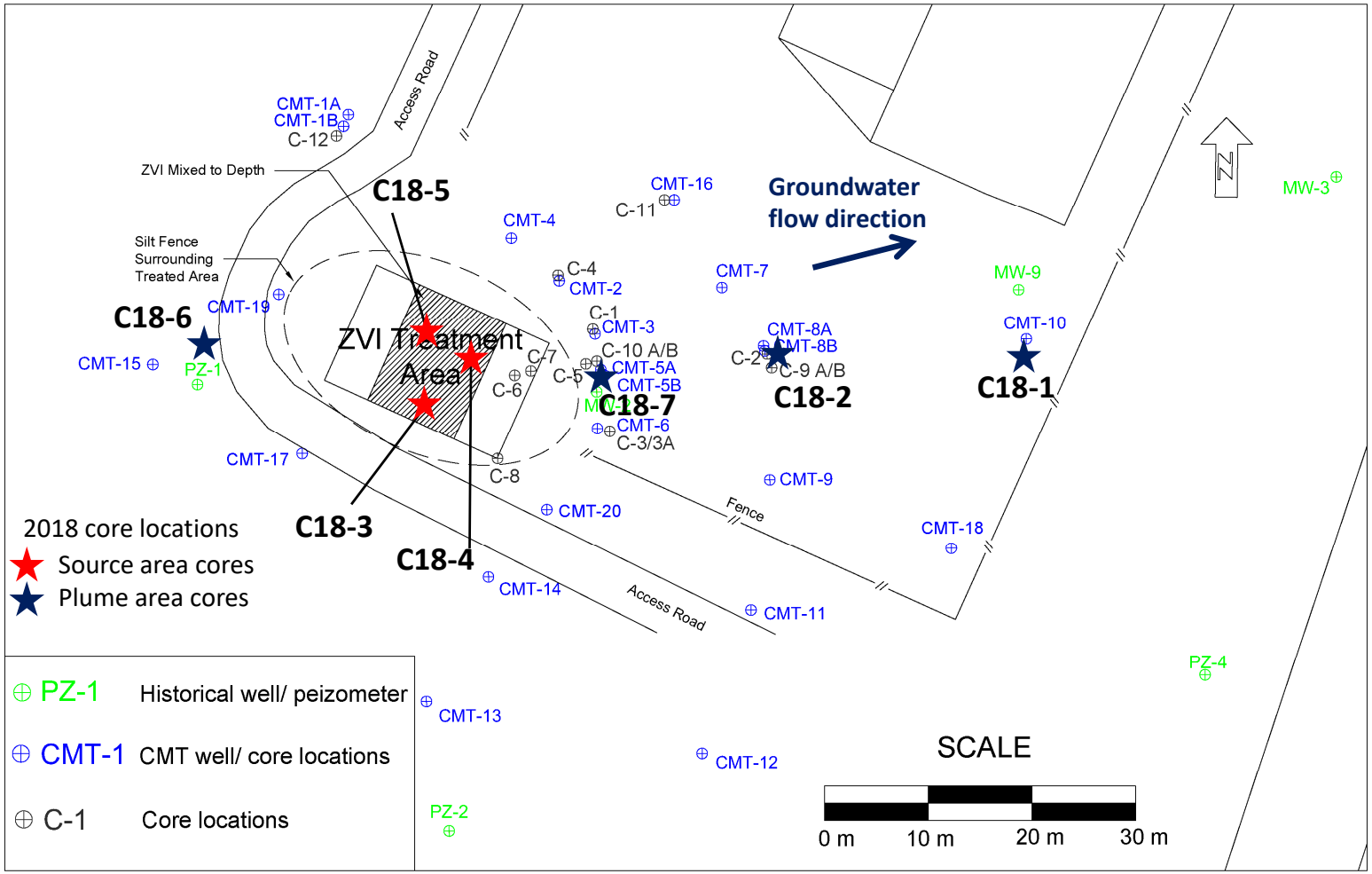
Coring Rig: Geoprobe 3230DT

Large diameter cores required

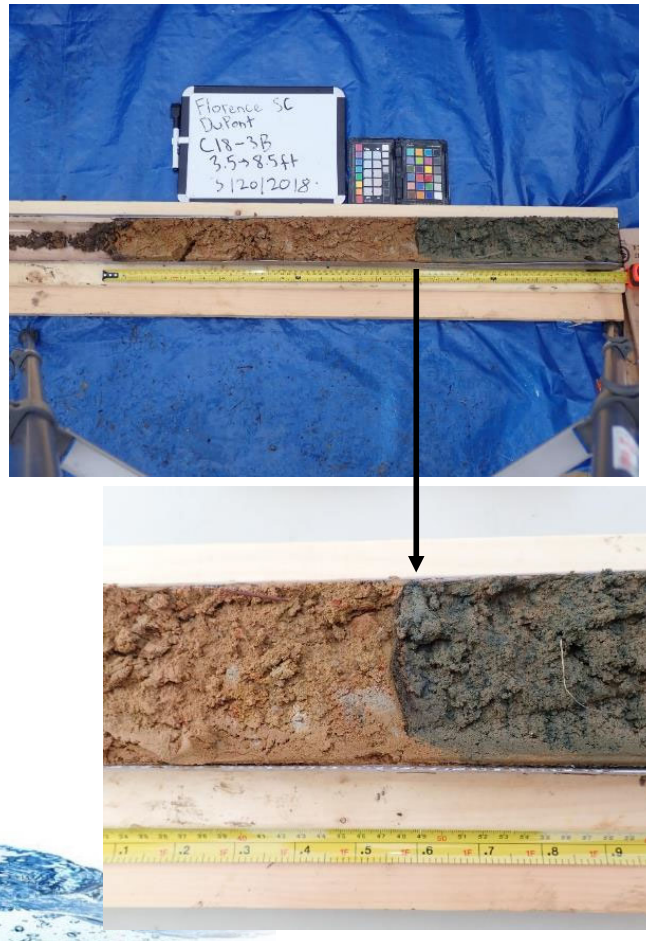
- MC-7 (3.0” cores) – single casing (slower)
  - re-entry grouting
- DT-45 (3.0” cores, 4.5” outer casing)
  - retraction grouting

5 ft runs

2018 Core Locations



Source Zone Mixing Evaluation
Good mixing at shallower depths



Source Zone Core Evaluation
Challenge Mixing to Aquitard Interface Depth

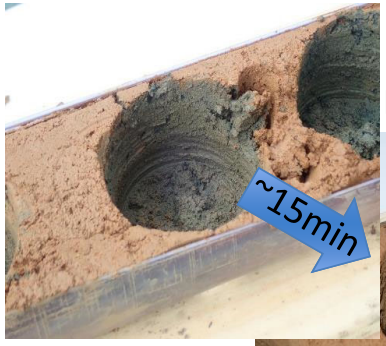
Unmixed interval ~ 1.5 ft

Unmixed interval ~ 7.0 ft (step up zone?)

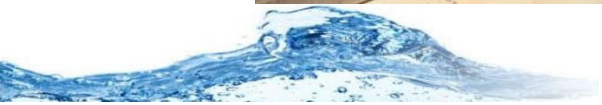
DNAPL in unmixed interval

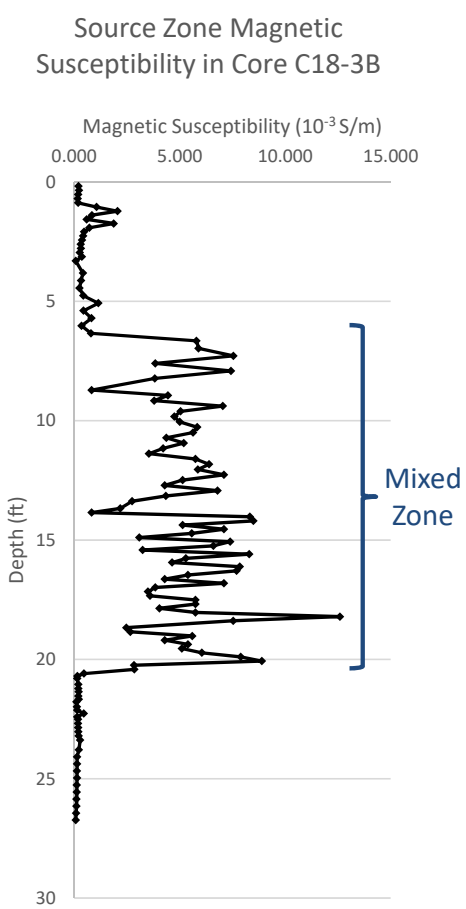
MAGNETIC SUSCEPTIBILITY SCREENING (ZVI DISTRIBUTION)

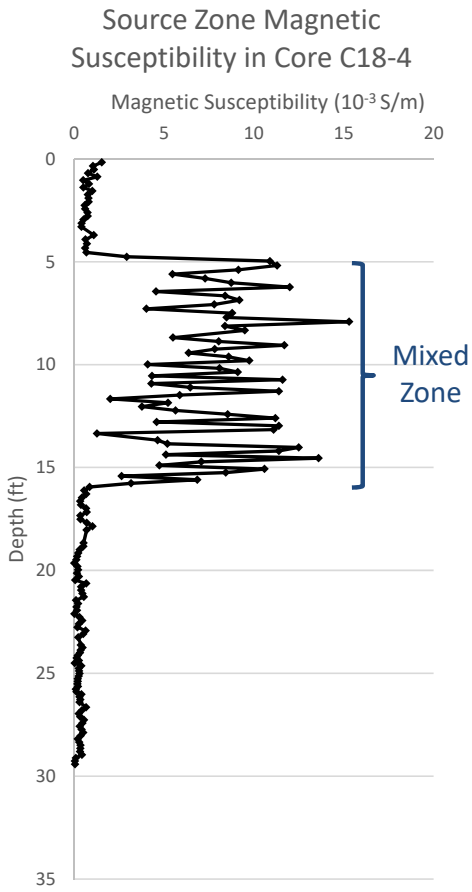
Terraplus KT-20

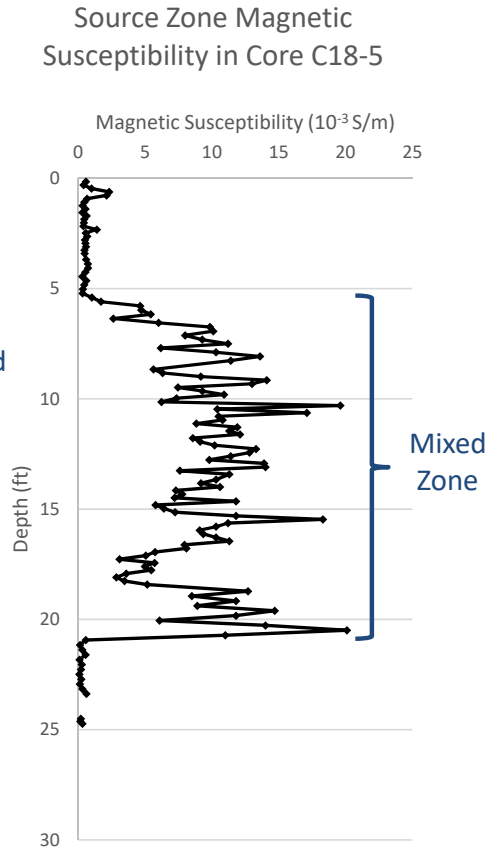


Redox Changes

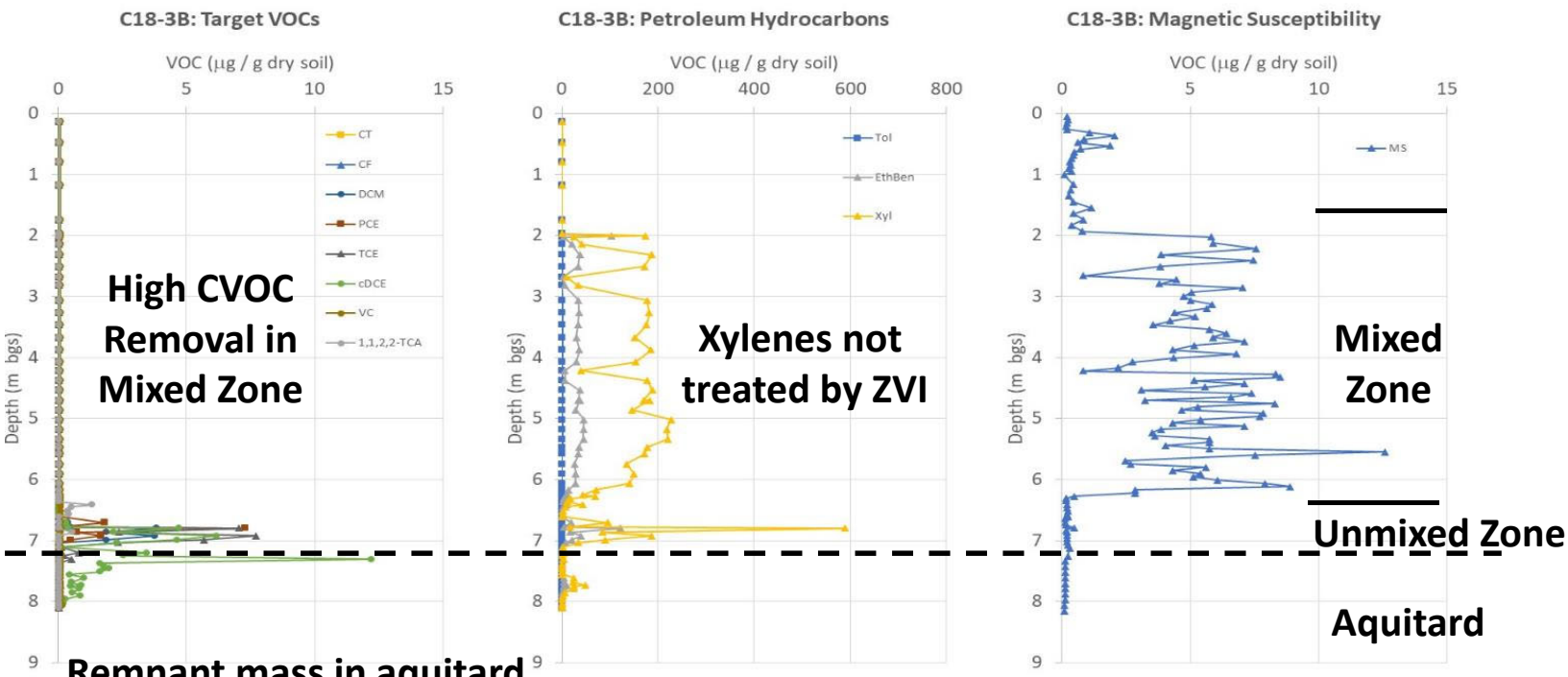




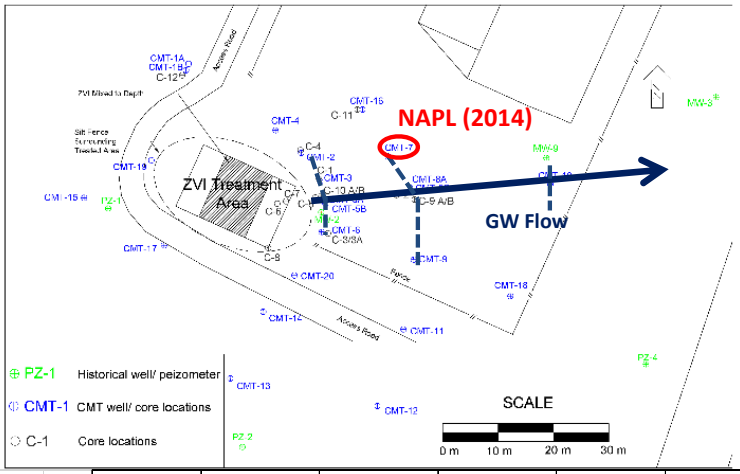




CORES FOR ASSESSMENT OF TREATMENT IN MIXED SOURCE ZONE



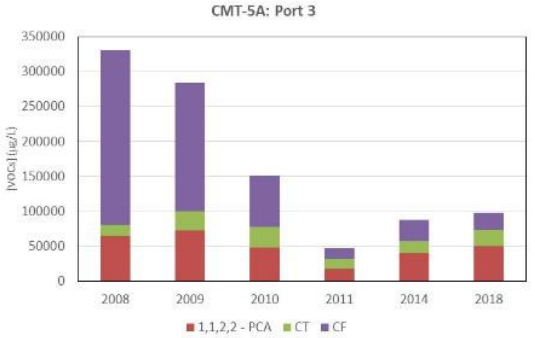
GW Concentration Trends: Plume Longsect (2008-2018)

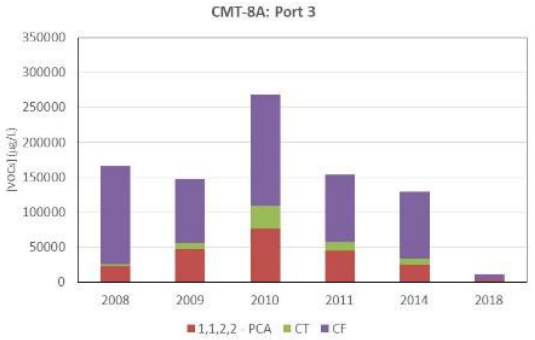


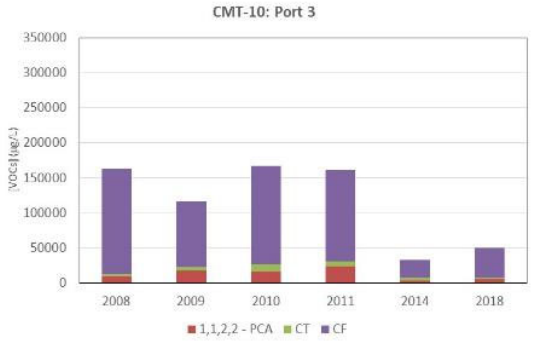
		1,1,2,2 -PCA		CT		CF		DCM		TCE		cDCE		
CMT ID	Transect	% change	absolute [µg/L]	% change	absolute [µg/L]	% change	absolute [µg/L]	% change	absolute [µg/L]	% change	absolute [µg/L]	% change	absolute [µg/L]	Notes
CMT-2	1	3687%	553	44%	53	-38%	-53	-55%	-12	41%	13	426%	196	
CMT-5A	1	-23%	-15,065	47%	7,515	-90%	-225,550	-81%	-22,735	-99%	-4,650	-56%	-1,405	
CMT-6	1	-95%	-71,956	-98%	-28,848	-99%	-147,967	-70%	-2,882	-96%	-2,782	-46%	-338	
CMT-7	2	368%	44,140	42%	8,915	1143%	35,420	-99%	-3,950	-48%	-865	49%	1,025	NAPL observed (2014)
CMT-8A	2	-85%	-19,501	-92%	-3,328	-94%	-132,052	-88%	-35,164	-81%	-2,607	-70%	-4,047	
CMT-9	2	-93%	-16,773	-99%	-12,817	-96%	-144,209	-94%	-6,756	-94%	-2,734	-74%	-1,113	
CMT-10	3	-40%	-3,685	-56%	-2,015	-71%	-107,050	-58%	-3,070	-96%	-1,350	-73%	-1,240	

Parents | Degradation Products

increase | decrease



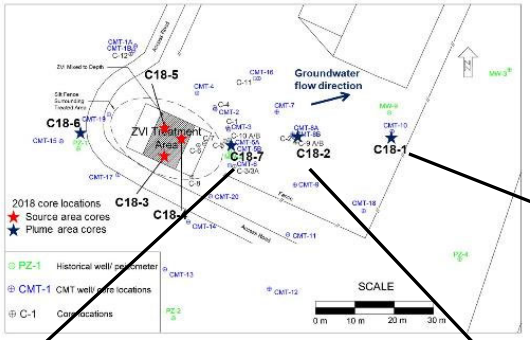


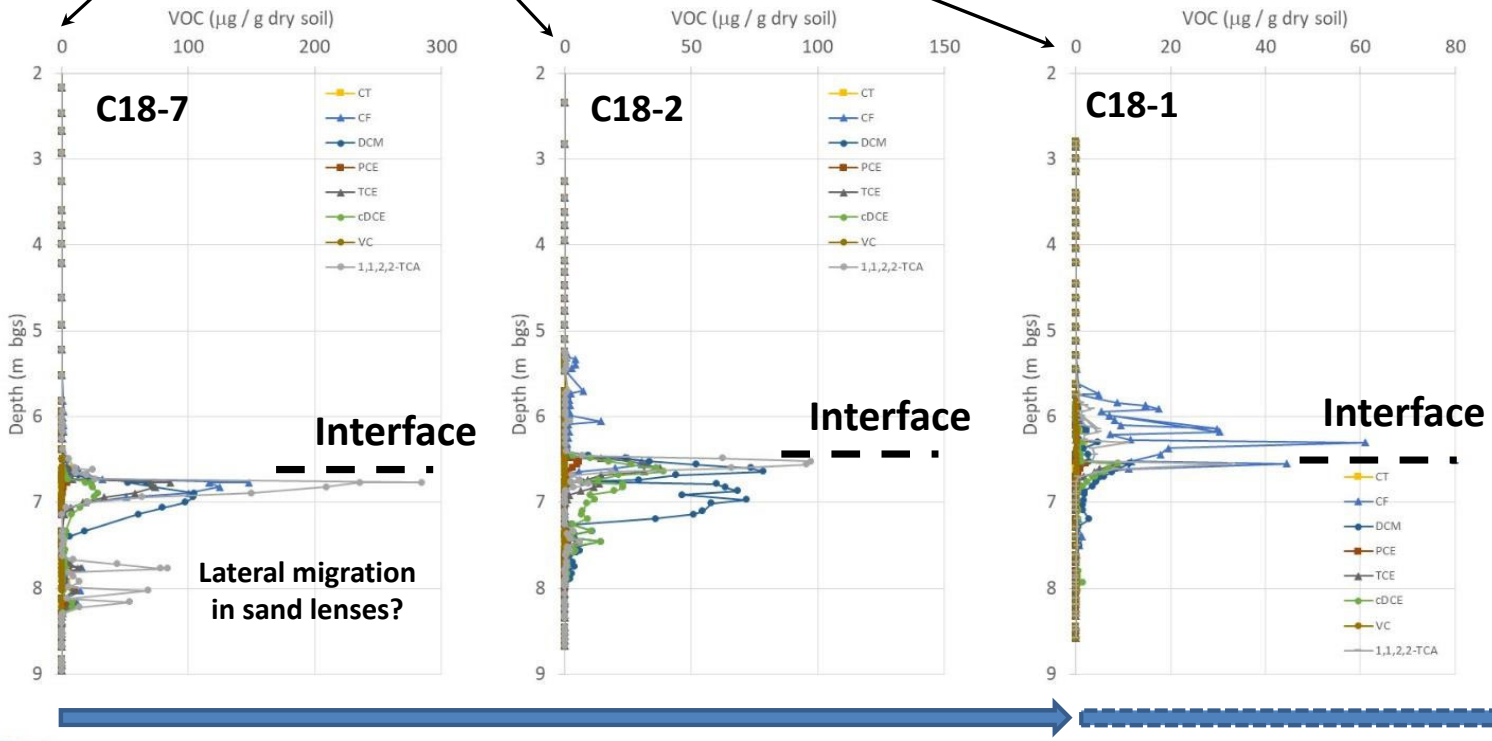


GW Flow

Overall improved conditions 2008 → 2018 (but persistent groundwater VOC plume)

TARGET VOCS: PLUME LONGSECT (CORES)





Expected Plug Flow

- **Improvements / flushing in aquifer beyond Transect #2**
- **Aquitard back diffusion (mostly degradation products)**

INSIGHTS FROM HIGH RESOLUTION CHARACTERIZATION

- Rapid characterization tools (MIP, MiHPT, etc.) and transect approach
  - plume width >> expected (shifting flow direction, low K zone diffusion)
  - target preferred locations for quantitative tools
  - recent tools (e.g. Dye-LIF; Einarson et al. GWMR 2018)

- Good integrity of thin aquitard
  - Diffusion controlled transport
  - Strong degradation – limited back diffusion of parent compounds

- Modest improvements in downgradient plume gw quality after 10 years
  - Residual DNAPL outside treatment zone
  - Incomplete treatment within mixed zone (untreated zones near interface)
  - Sluggish flow / diffusion from low K zones
  - Aquitard back diffusion (**limited due to degradation**)

- Case studies needed to show
  - Complementary tools (cores with high resolution sampling + gw sampling)
  - Sampling scales for controlling processes in low K zones
  - “Manage expectations” for remediation

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- DuPont / Chemours – technical support / funding
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- Parker NSERC Discovery Grant - funding
- UG / G360 Field crews (2008 – 2018)
  - A Gilmore, R. Kroeker, B. Ingleton, P. Johnson (2008-2014)
  - P. Wanner, N. Glas, F. Isenschmid, R. Kroeker (2018)
- UG G360 Lab analyses
  - M. Gorecka, R. Jadeja, G. Lima, K. Dunfield
  - Groundwater and soil VOCs, microbial analyses
- Stone Environmental / Cascade Technical Services
  - Coring, MIP / MiHPT field services
- U. Tennessee (F. Loeffler, F. Kara-Murdoch)
  - Microbial Analyses (2018)
- U. Neuchatel (D. Hunkeler), U. Waterloo (R. Aravena)
  - CSIA on groundwater and soil (2008, 2018)
- University Consortium for Field-Focused Groundwater Contamination Research https://theuniversityconsortium.org/