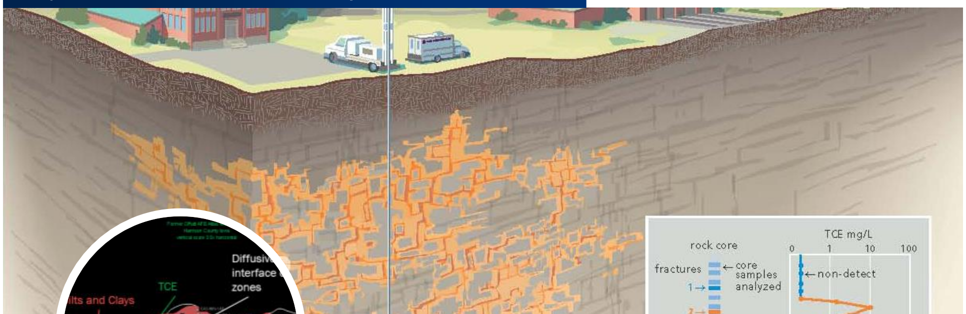
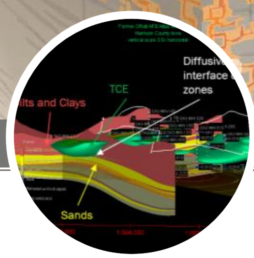
TETRA TECH

Accessing the Subsurface

(it's dark down there…)





Data Collection & Interpretation: State of Practice & Lessons Learned

Seth Pitkin, Principal Hydrogeologist

complex world | CLEAR SOLUTIONS™

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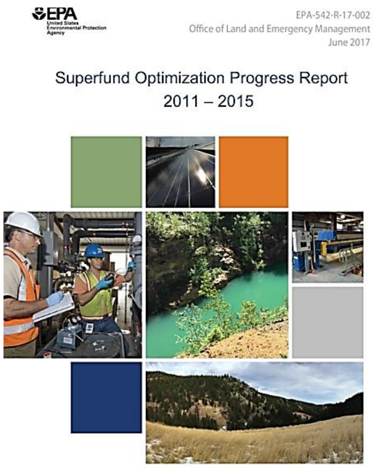
The Problem

- One cannot effectively solve a problem which one has not adequately and accurately defined (CSM)
- Many remedies underperform or fail due to a lack of understanding of site conditions and processes (heterogeneity)
- The cost of these failed/ underperforming remedies is large
- The costs of inefficient long term monitoring programs related to investigating sites with monitoring wells is large
- The costs of High Resolution Site Characterization, which allows one to avoid failed remedies, is small in comparison, but requires an up front investment to result in lower life cycle costs.

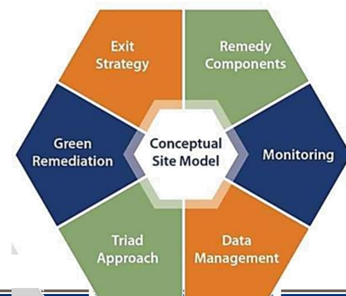
Takeaways from the Superfund Optimization Program



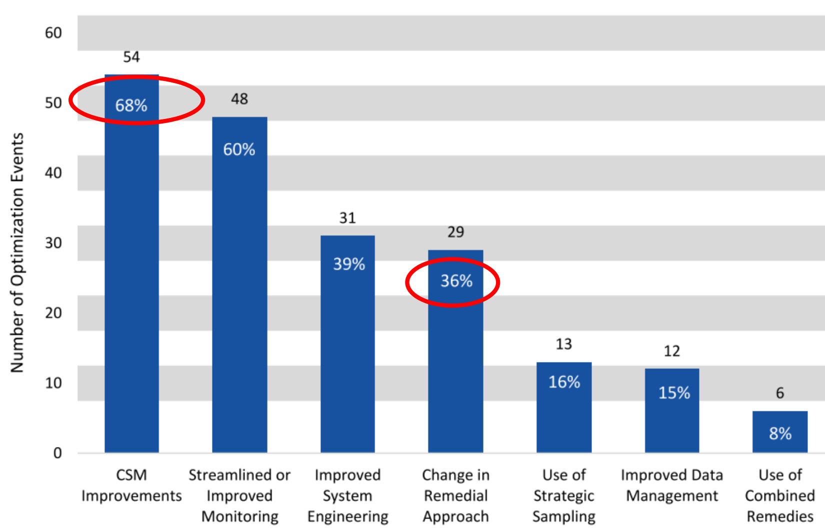
Recommended Tools and Techniques

1. Use of strategic sampling approaches
2. Improvements to CSM
3. Improved data management
4. Improved system engineering
5. Change in remedial approach
6. Use of combined remedies
7. Streamlined or improved monitoring

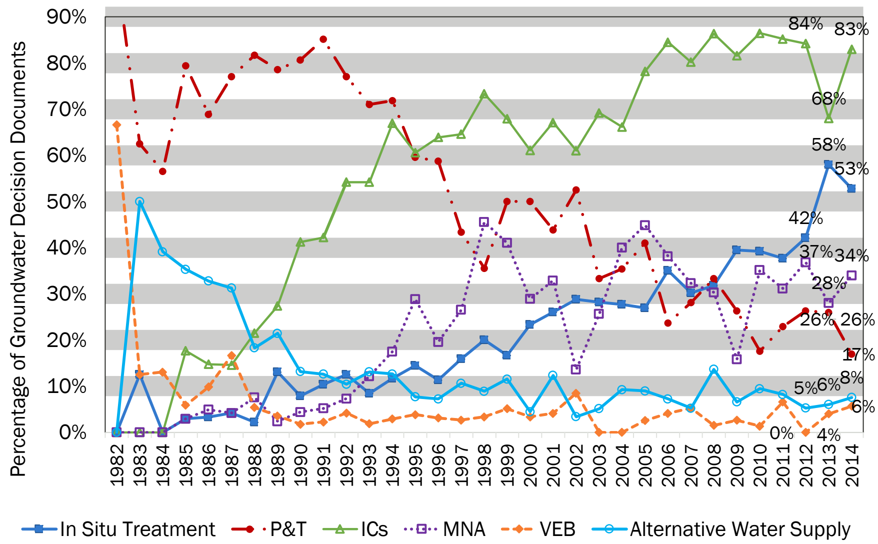
KEY OPTIMIZATION COMPONENTS



What Are We Getting Wrong?



HRSC is a response to in situ remedies



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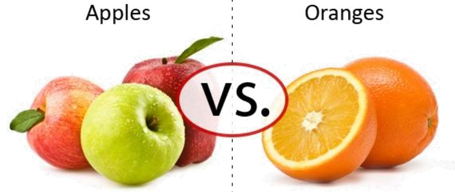
Groundwater Monitoring vs Characterization

Apples | Oranges

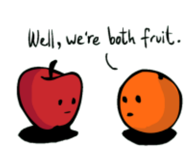


Site Characterization

- Objectives
- Tools
- Approaches

Site Monitoring

- Objectives
- Tools
- Approaches

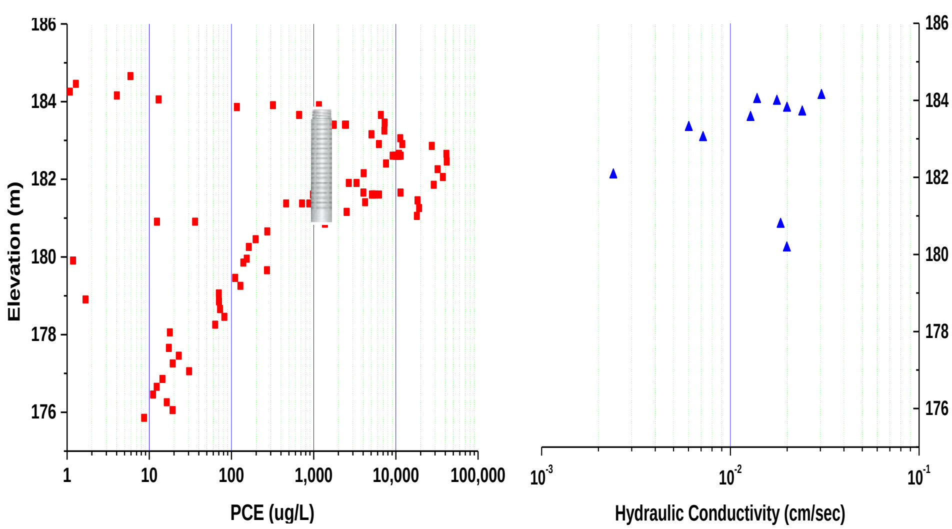


Key Point Monitoring tools are not ideal for characterization.

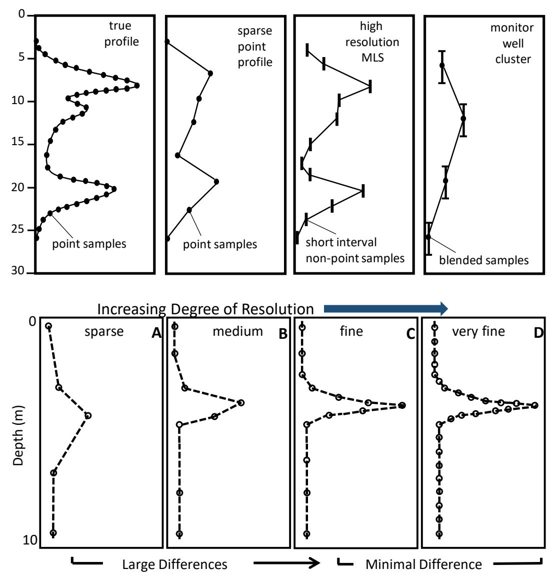
How “Well” Do You Understand Site Conditions

- Technology used influences the understanding you develop
- The scale of measurement must be appropriate for the scale of the heterogeneity
  - Variability of hydraulic conductivity and other parameters
  - Weak transverse hydrodynamic dispersion
  - Heterogeneous distribution of DNAPL sources
- Conventional monitoring wells are not optimal investigation tools
  - Wells yield depth-integrated, flow-weighted average data
  - Cannot discern small scale heterogeneities controlling contaminant transport in groundwater
- Monitoring wells have high life cycle costs

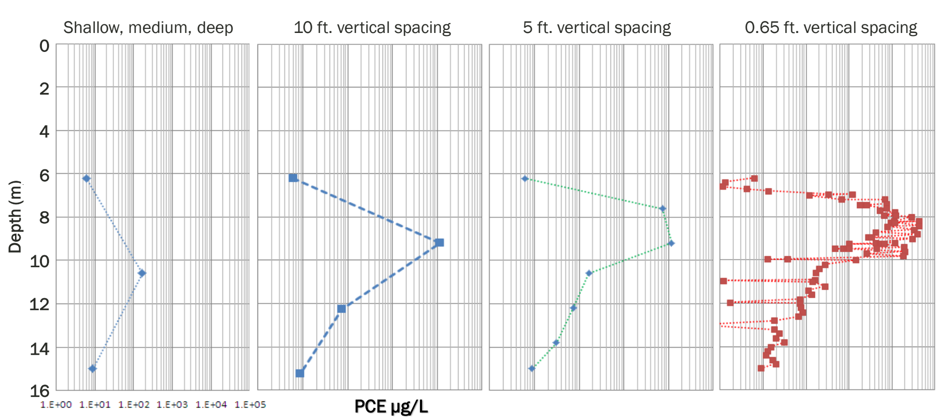
Depth-Integrated, Flow Weighted Averaging



Vertical Resolution: Interval and Spacing

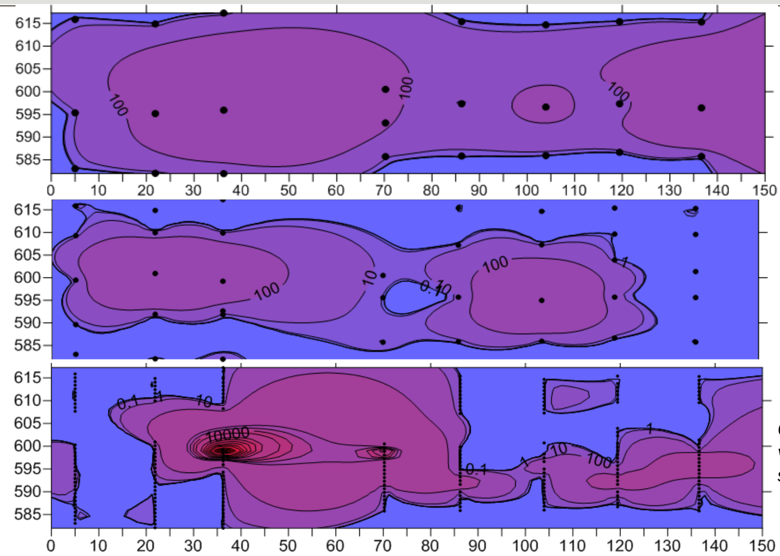


A Profile Through a PCE Plume in Sandy Aquifer



Key Point The vertical spacing you use determines whether you understand the nature of the plume or not.

Multi-Level Sampling Transect
PCE in a Sandy Aquifer



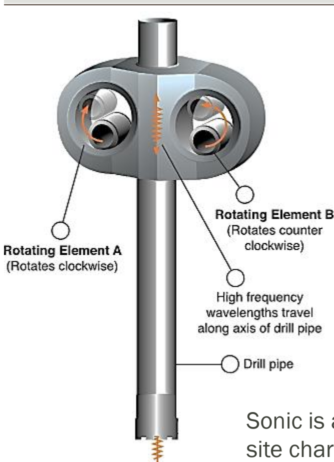
Where We Are

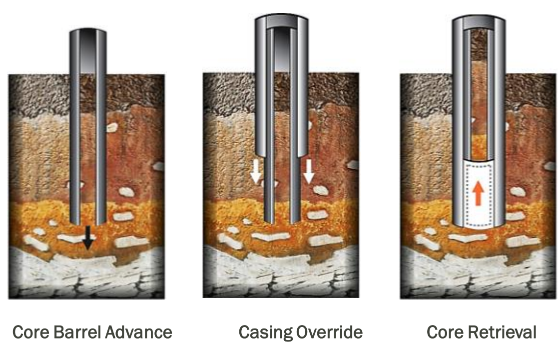
- High Resolution Site Characterization Gaining Traction
- Diffusive Flux/Back Diffusion Largely Understood/Accepted
- New Tools and Methods
  - Direct Sensing – LIF, MIP, Dye-LIF etc.
- Non-permanent Groundwater Sampling
- Coring of Unconsolidated Porous Media Underutilized (especially below the water table)
- Multi-Level Monitoring Approaches

Drilling/Direct Push Platforms

- Sonic methods
  - Very high frequency vibration - Liquifaction
- Direct Push methods
  - Variable Percussion and downpressure
  - Geoprobe and similar
  - Cone Penetrometer Technology
- Auger/Rotary Methods
  - Low frequency percussion
  - Mud Rotary, Air Rotary
- Cable tool rig (rare in the Northeastern US)

Rotosonic Drilling Process





Sonic is a fast and versatile drilling method but has limitations for site characterization:

1) Disrupts the structure of soils through liquefaction
2) Generates lots of heat that volatilizes analytes
3) Uses large volumes of water which dilutes/flushes analytes

Some Characterization Approaches

High Resolution Site Characterization

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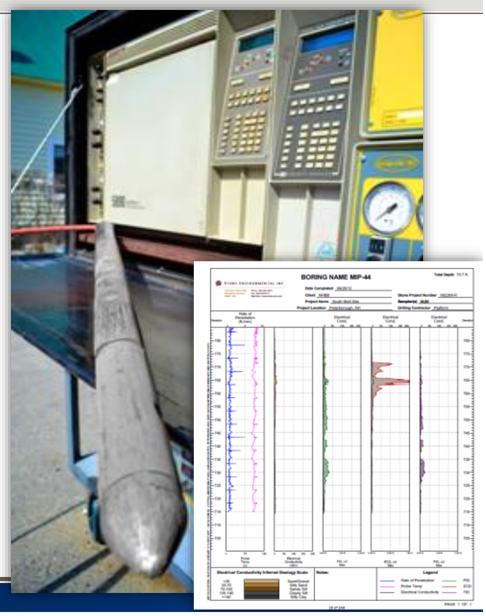
Deployment of HRSC Tools

- Vadose zone
  - Soil gas sampling (passive, active, profile, temporal)
  - Screening tools (*e.g.*, MIP)
  - Soil coring and profile sampling
- Saturated zone
  - Direct Sensing Screening tools for rapid reconnaissance of source zones, plume cores, hot spots (*e.g.*, MIP, Laser Induced Fluoresence (LIF)). These tools coupled with EC and/or injection logging
  - Groundwater sample profiling of permeable zones (mobile porosity) coupled with injection logging
  - Soil coring and profile sampling for low-K zones (immobile porosity

Membrane Interface Probe: Rapid Direct Push VOC Screening Tool

Rapid screening of volatile organic compound (VOC) distributions for a more focused, higher resolution investigation

- MIP can very quickly generate a large data set
- MIP is capable of completing 150 to 250 + linear feet of exploration per day
- MIP is effective in both saturated and unsaturated zones
- MIP data are immediately available



MIP and Groundwater Concentration Correlations (Not Good)

Range of R^2 on individual holes = 0.06 to 0.92

Transect D

Hole ID	1	2	3	4	5	6	7
Visual Correlation	1	1	1	2	1	1	3
ECD R^2	0.32	0.38	0.07	0.4	0.64	0.06	0.22
TVOC Range, ppm	0-3	0-12	0-40	0-16	0-20	0-15	0-.005

Average R^2 for Transect B = 0.37

Transect E

Hole ID	10	11	12	13	14	15	16	17
Visual Correlation	3	1	1	1	1	1	1	3
ECD R^2	0.09	0.62	0.72	0.64	0.92	0.53	0.66	0.01
TVOC Range, ppm	0-3	0-8	0-50	0-15	0-12	0-20	0-6	0-.005

Average R^2 for Transect E = 0.72

Transect F

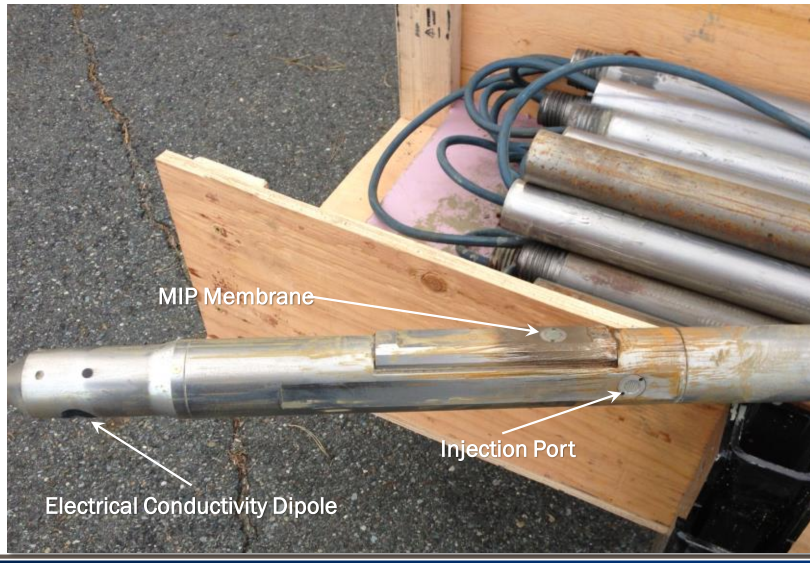
Hole ID	19	20	21	22	23	24	25
Visual Correlation	1	2	1	2	1	2	1
ECD R^2	0.13	0.58	0.58	0.01	0.38	0.77	0.92
TVOC Range, ppm	0-6	0-10	0-.4	0-4	0-16	0-16	0-.1

Average R^2 for Transect F = 0.37

Average R^2 for All Transects = 0.49

Visual correlation Rankings; 1 = good, 2 = fair, 3 = poor.

MiHPT – Combined MIP and Hydraulic Profiling Tool



Laser Induced Fluorescence (LIF) Tools

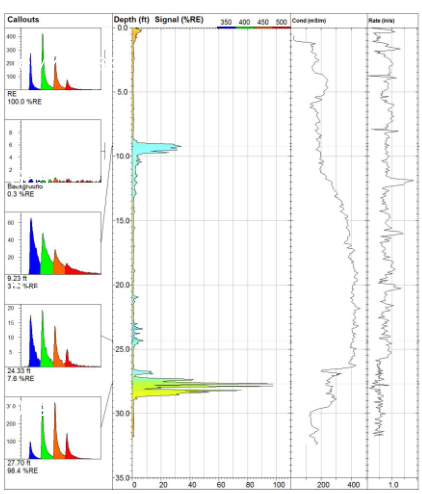
- UVOST
  - Ultraviolet Optical Screening Tool – Fuels and Oils
- TarGOST
  - Green Optical Screening Tool – Coal Tar and Cresosote
- Dye-LIF
  - Hydrophobic dye injection LIF tool – Chlorinated Solvents
- Geoprobe Optical Image Profiler
  - Fluoresence (but not laser induced) probe

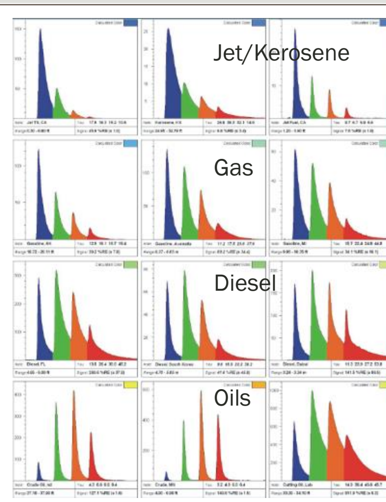
UltraViolet Optical Screening Tool (UVOST)

Ultra Violet Optical Screening Tool (UVOST)

- Fuel NAPL
- Best for use where presence of NAPL is driver for investigation
- Detects 1 and 2-ring PAH
- Provides identification of fuel type
- **Cannot see dissolved phase PAHs**

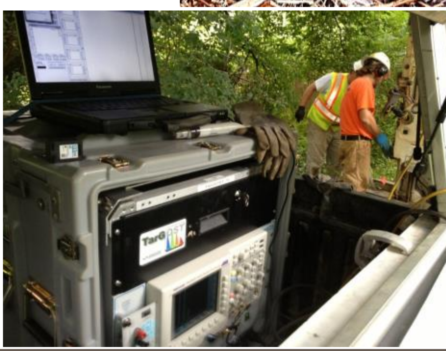
UVOST Field Log: ID of Targets





Tar-specific Green Optical Screening Tool (TarGOST)

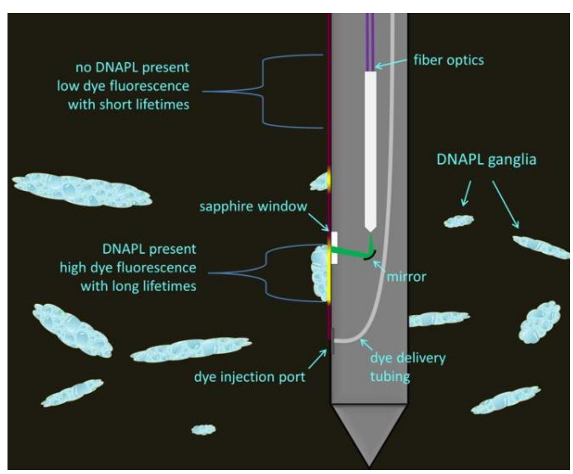
Green wavelength laser light causes fluorescence of multi-ring PAH in coal tar and creosote NAPLs



Dye LIF from Dakota Technologies

Direct Detection of Cl Solvent DNAPLs

Dye enhanced direct push LIF method for detection of chlorinated solvent DNAPLs

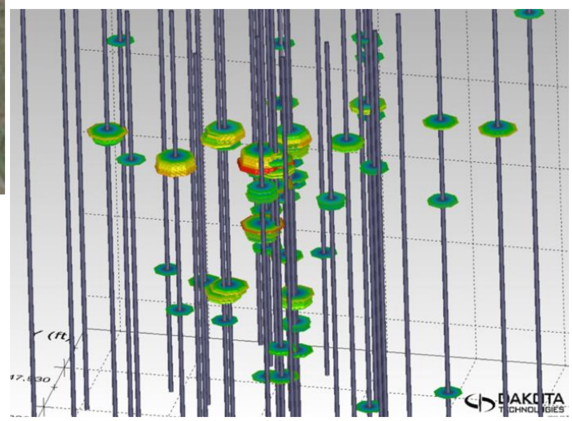


Courtesy of Dakota Technologies

Dye LIF Field Trials Successful

Dense Push Array at Highly Characterized DNAPL Source Zone

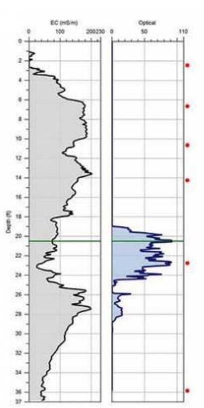
Post Processed 3D rendering of DNAPL Distribution from Dye-LIF Data

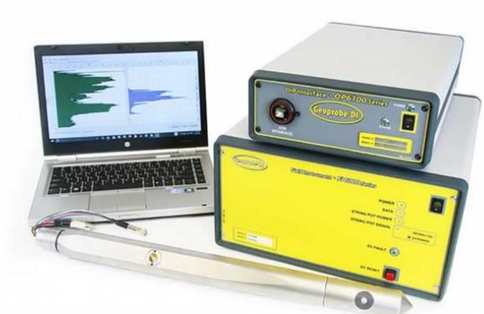


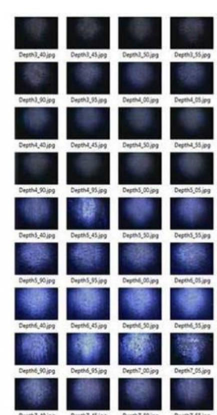
Courtesy of Dakota Technologies

Optical Image Profiler By Geoprobe

Downhole camera
Two light sources: natural light and UV light
Detector response and photos
No ID of target through waveforms





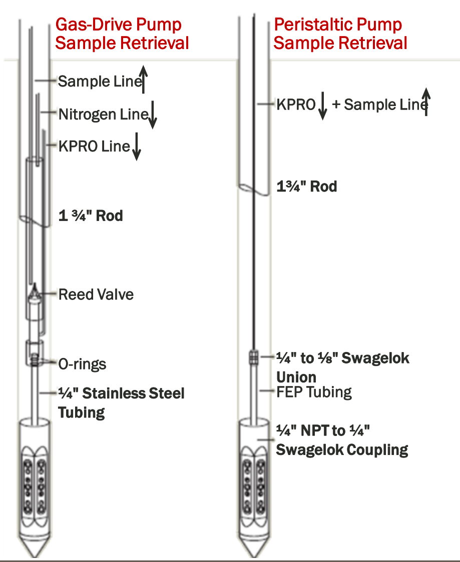


Waterloo^APS™ Integrated Direct Push Data Acquisition

Direct Push Groundwater Profling and injection logging

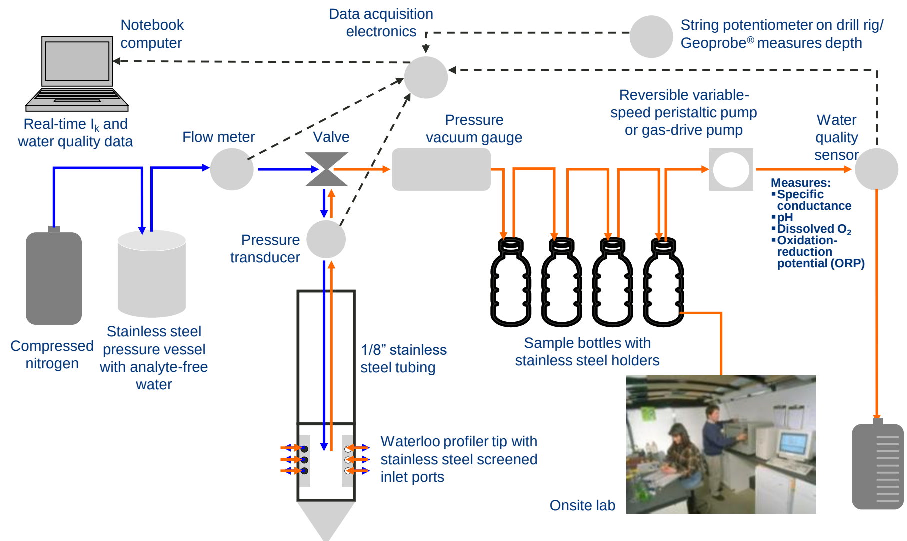
- Physical Chemical Data
- Concentration Data
- Hydraulic Head Data
- Index of Hydraulic Conductivity Data

Waterloo^APS™ Configurations

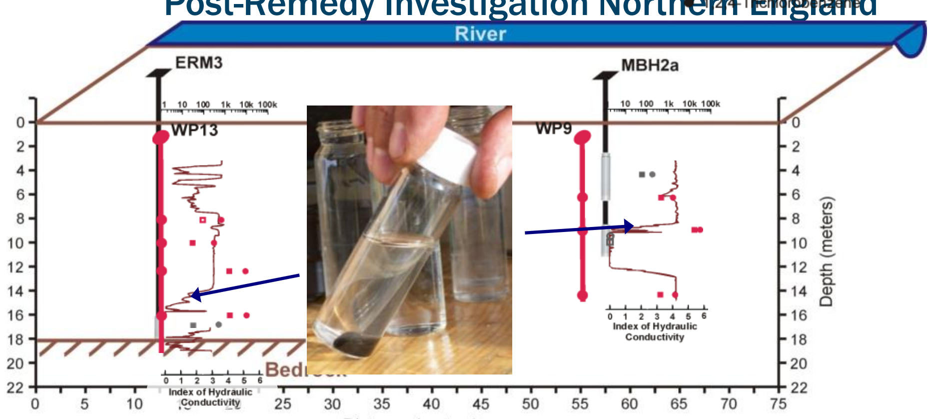


APS 225 APS 175 APS 150

Waterloo$^{APS™}$ Data Acquisition Configuration and Process



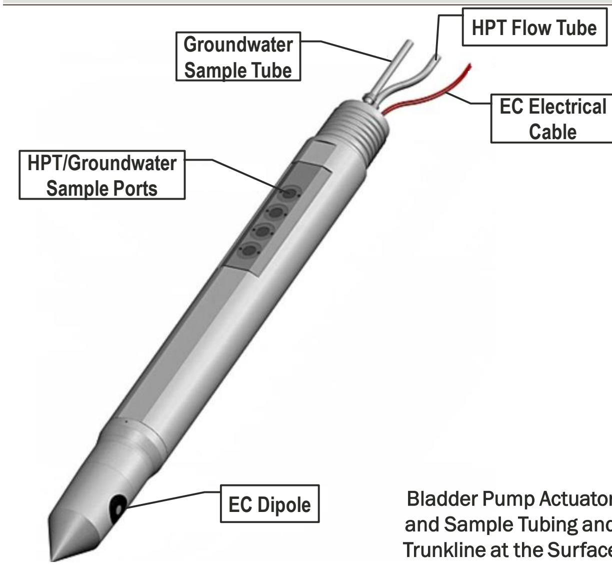
Post-Remedy Investigation Northern England



Key Point

Use of low resolution (conventional) techniques resulted in remedy failure and need for second remedy.

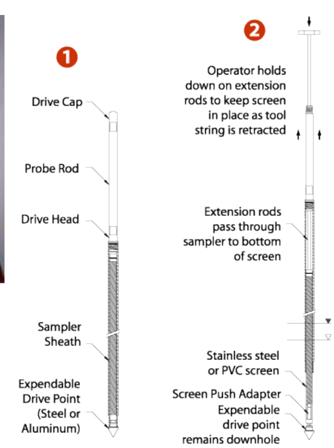
Geoprobe® HPT-GWS



Bladder Pump Actuator and Sample Tubing and Trunkline at the Surface

Direct Push Groundwater Sampling Tools

- Geoprobe® SP16/SP21
  - Small diameter
  - Variable screen length
- Removed (tripped) following collection of each sample

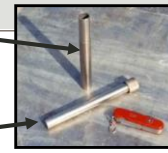


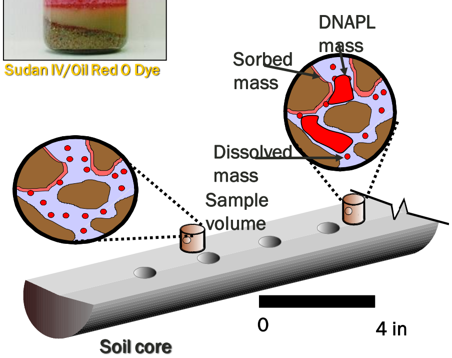
- Solinst® Drive Point Piezometers
  - Left in Place
  - Fast, low material cost

Essential Information from Cores

- Geologic/hydrogeologic features
- Physical, chemical & microbial properties
- Contaminant mass distributions (high- & low-K zones)
- Contaminant phase distributions (detection of DNAPL)
- Concentration gradients/diffusive fluxes
- Effectiveness of remedial technologies

Sudan IV/Oil Red O Dye

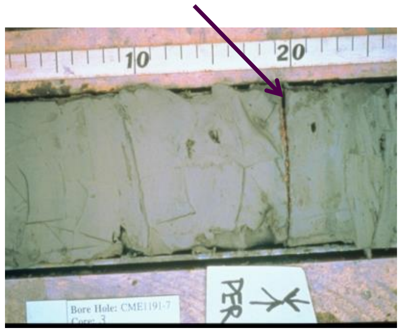




Coring Aquitards/Low K Zones

Small Scale Features are of Great Importance

Sand microbed



Courtesy of Beth Parker

DNAPL (red) migration in sand microbed

Boring Logs

CH2MHILL

PROJECT NUMBER	BORING NUMBER: WAG-MW07S
143433.FI.MW	

SOIL BORING LOG

PROJECT :WNY Well Installations LOCATION : Washington Navy Yard, Washington DC
GROUND SURFACE ELEVATION (ft. MSL): 23.6 DRILLING CONTRACTOR : Parrat-Wolff
DRILLING METHOD AND EQUIPMENT USED : 4 & 1/4" inner dia. Hollow Stem Auger & 3" inner dia. (acetate lined) split spoon powered by Geoprobe
DEPTH TO WATER (ft. Bgs): 12.35 START : 8/31/99 END : 8/31/99 LOGGER : Robert M. Pierpont

DEPTH BELOW SURFACE (FT)	INTERVAL (FT)	RECOVERY (IN)	#/TYPE	STANDARD PENETRATION TEST RESULTS 6"-6"-6"-6" (N)	SOIL DESCRIPTION SOIL NAME, USCS GROUP SYMBOL, COLOR, MOISTURE CONTENT, RELATIVE DENSITY, OR CONSISTENCY, SOIL STRUCTURE, MINERALOGY.	USCS	COMMENTS DEPTH OF CASING, DRILLING RATE, DRILLING FLUID LOSS, TESTS, AND INSTRUMENTATION. OVM (ppm): Breathing Zone Above Hole
2	0 - 2'				4" of Asphalt 20" of concrete.	(FILL)	
4	2' - 4'	2'			6"- Gravel w/ Sand. D. Brown 5YR 2/2 v. moist. Gravel is well graded. Sand is moderately graded. 8"- Sandy CLAY, light brown, 5YR 6/4, Clay is soft, dense, elastic, Moist 8"- Clayish SAND, Pale Brown 5YR 5/2, v. moist CLAY is soft, dense, w/ moderate elasticity	GW (FILL) CH (FILL) SC (FILL)	0.2ppm WAG - SB07 - 02 and WAG - SB22- 02 (DUP) collected for Lab.
6	4' - 6'	1.5'			4"-CLAY, w/some Sand, and little Gravel, Pale Brown, 5YR 5/2, moderately moist. CLAY is soft, dense, and elastic. 12"-CLAY, w/sand and wood, Mainly light brown, 5YR 6/4, but Grey brown, 5YR 3/2, where discolored. CLAY is soft, dense, and eleastic. Discoloration of soil is around wood, but no apparent odor present.	CH (FILL) CH (FILL)	0ppm Moist

Criteria for a Successful Coring Tool

- 100% recovery and retention
  - allow the core to enter the core barrel (diameter, cutting shoe)
  - core must not expand in volume (clays) or fall out (sand)
  - Known depth of origin
- Minimal disruption of the structure of the strata
- Retention of pore fluids
- Does not heat the core sample.

The core one sees at the surface should be as accurate a representation of the subsurface conditions as possible.

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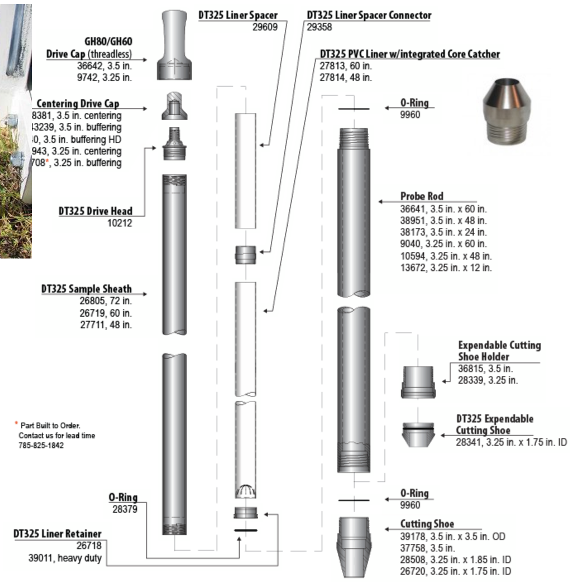
Geoprobe DT325 Dual Tube Sampler

3.25-inch OD
1.85-inch core



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DT325 Cutting Shoes

Cutting shoes are designed for different conditions in the same way different drill bits are designed for different materials.
If recoveries are poor consider different cutting shoes and core sizes

3.5 x 1.85-inch ID

3.25 x 1.85-inch ID

3.25 x 1.75-inch ID

Geoprobe MC5
General Purpose Coring Tool

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- 2.25-inch OD x 1.5-inch liner ID
- Can be used as:
  - A single rod tool
  - A piston tool
- Multiple cutting shoes
  - Affect recovery and deformation

1.25" ID

1.35" ID

1.5" ID

Recovery: Diameter
Coring Tool Trials at Chambers Works Site

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Rock stuck in MC5 cutting shoe.

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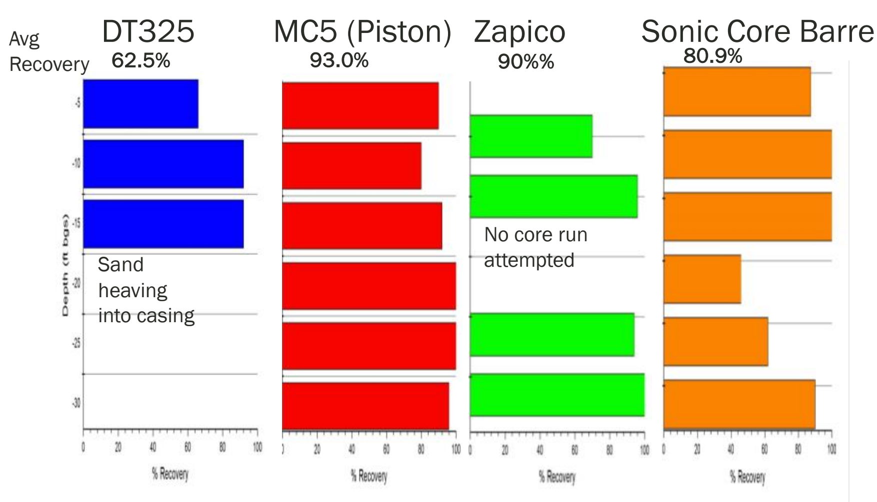
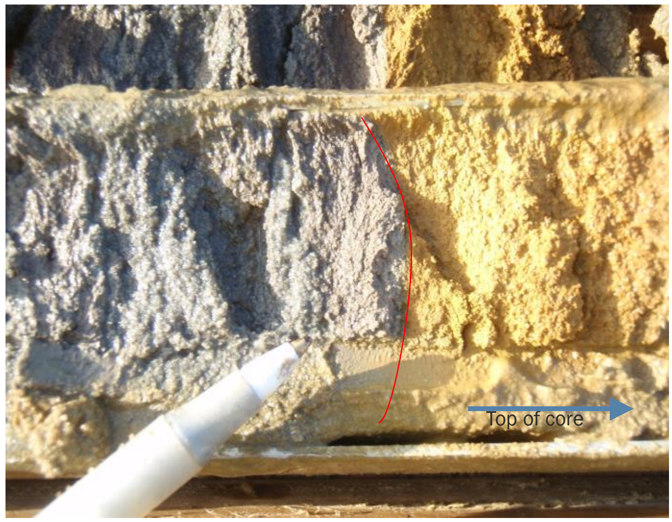
Recovery: MC5 100% in Course Sand & Gravel
Coring Tool Trials at Chambers Works Site

Recovery at B003
Coring Tool Trials at Chambers Works Site



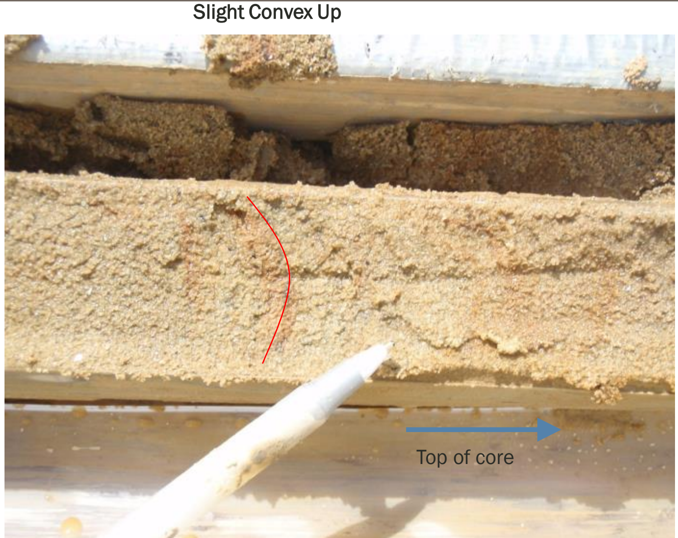
Deformation: Zapico at B003
Coring Tool Trials at Chambers Works Site

Minimal convex up



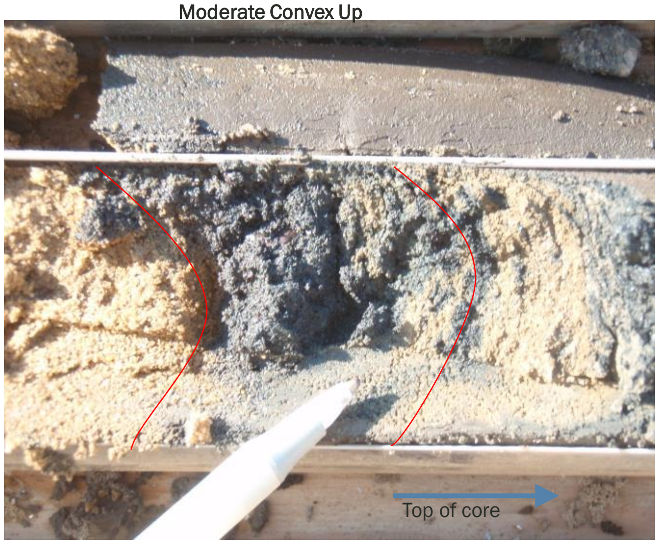
Deformation: MC5 at B003
Coring Tool Trials at Chambers Works Site

Slight Convex Up



Deformation: DT325 at B049
Coring Tool Trials at Chambers Works Site

Moderate Convex Up



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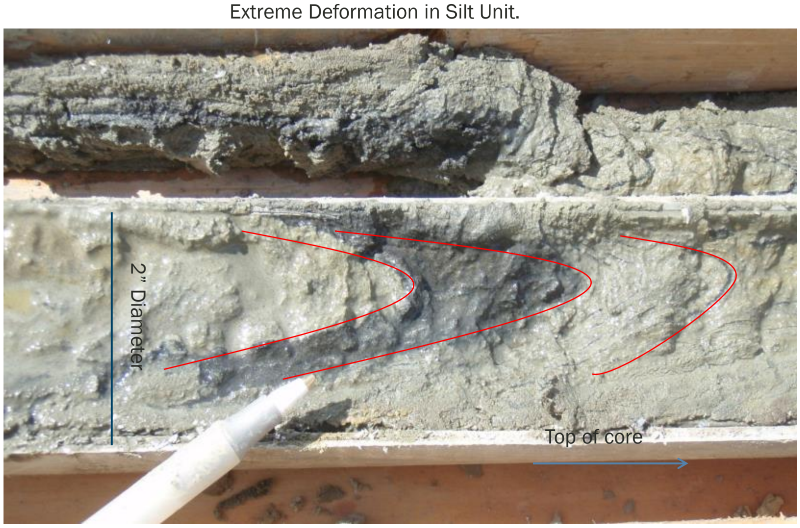
Deformation: Zapico at B006
Coring Tool Trials at Chambers Works Site

Extreme Deformation in Silt Unit.



Summary of Ranking by Criteria

Coring Tool	Overall % Recovery	Deformation of Structure	Speed	Heat	Use of Drilling Fluid	Heave	Pore Fluid Retention	TOTAL SCORE
MC5	4	4	2	4	4	4		**22**
Zapico	2	2	1	4	4	4		**17**
DT325	1	3	3	4	4	1		**16**
Sonic	3	3	4	3	1	4		**18**

Ranking Score of 1 - 4. Score of 1 indicates the tool performed the worst of all the tools; 4 indicates the tool performed the best

Speed of sonic drilling is assumed: DT325 = 26 ft/hr; MC5 = 18 ft/hr; Zapico = 6.6 ft/hr
Heat of sonic cores is assumed all others measured
Lack of heave for sonic is due to use of water

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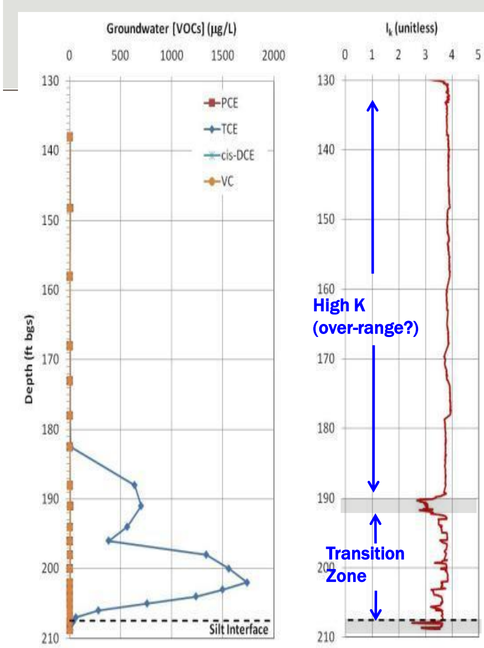
Waterloo APS™ I_k and Groundwater VOCs
at MMR Cape Cod



Observations:

- little change in I_k to 188 ft bgs
  - over sensitivity range?
- plume resides in lower K "transition" zone
  - sluggish flow zone?
- no TCE degradation products
- low [TCE] near inferred silt interface

Refusal @ 208 ft
(inferred silt interface)

Sonic Rig Coring (12/2009 ~ 4 days)
at MMR Cape Cod

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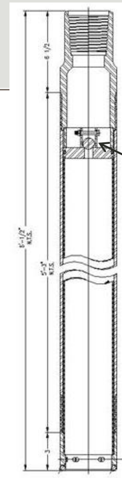

Split core barrel w/ lexan liner (5 ft cores)

check valve (not used)

Continuous cores
water table to bedrock
70 – 315 ft bgs

Sonic Coring Issues
at MMR Cape Cod

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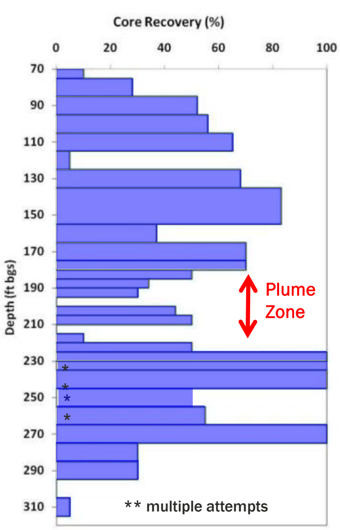
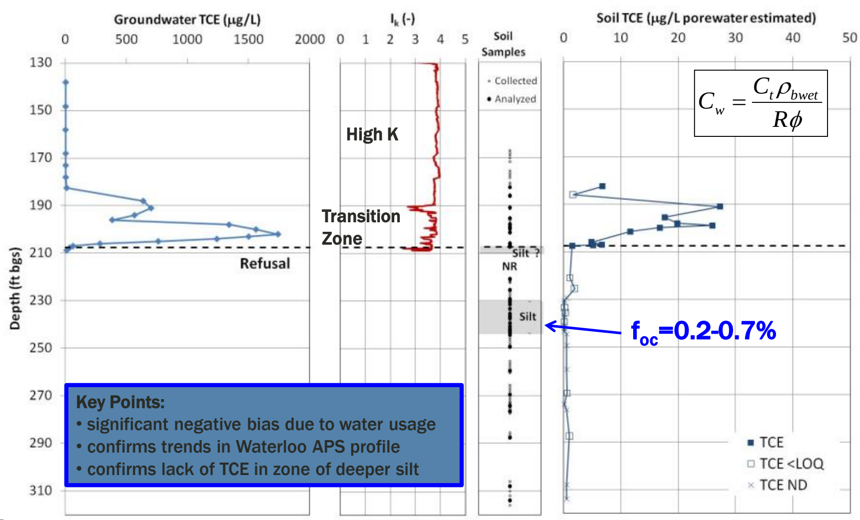


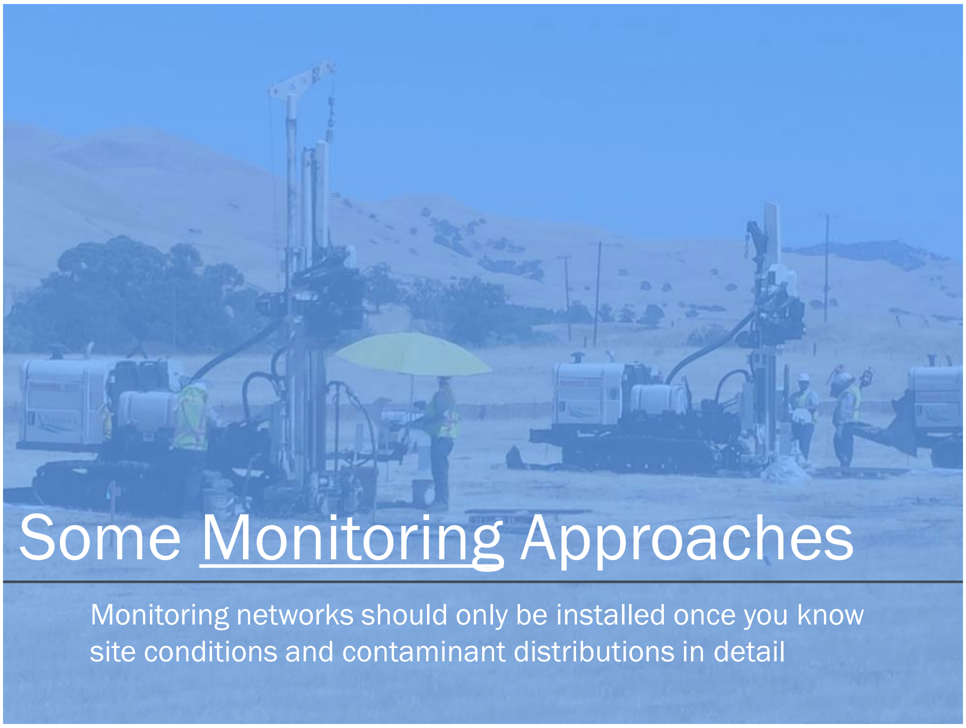
- poor recovery
  - flowing sands
  - lower friction w/ lexan liners?
- heaving conditions
  - water used to minimize effects
    - approx. 4000 gal total (~20 gal/ft)
  - water flushes through cores
    - no check valve
    - significant negative bias for VOCs
- core samples highly disturbed
  - limited insight on detailed lithology
  - inadequate for VOC sampling

Mass Distribution Via Core Subsampling
at MMR Cape Cod



Conclusions

- Collection of high quality cores is an essential component of site characterization
- Sonic is fast and can penetrate in nearly all conditions but quality of cores is not always good (heat, water use, deformation)
- Geoprobe tools getting better and with more options.
- Tool performance varies across different strata – use a variety of tools/don't rely on just one
- Details matter: cutting shoe diameter and ratio of tool OD to core OD affect recovery
- If pore fluids are important keep cores vertical and capped
- Provide incentives for drillers to focus on quality cores rather than footage



Some Monitoring Approaches

Monitoring networks should only be installed once you know site conditions and contaminant distributions in detail

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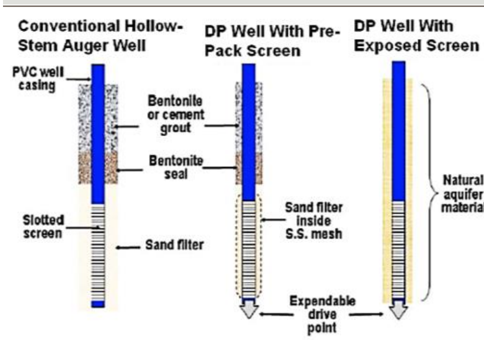
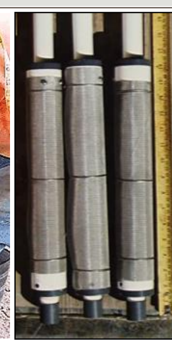
Groundwater Monitoring Wells

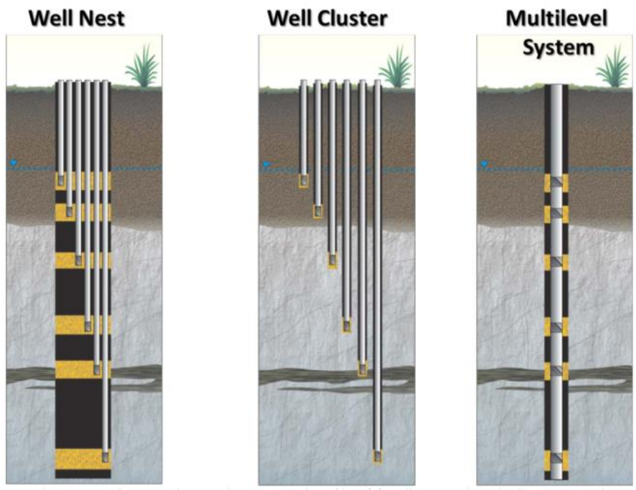


Building a well inside a HSA



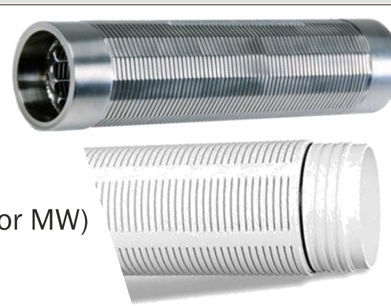
Pre-packed well screens wrapped w/ ss mesh

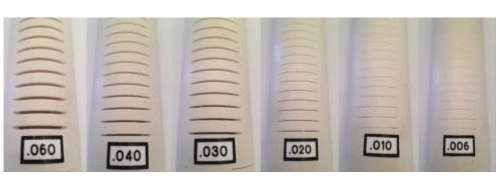
Multi-Level Groundwater Monitoring Approaches



Key Point — Short open intervals and close spacings

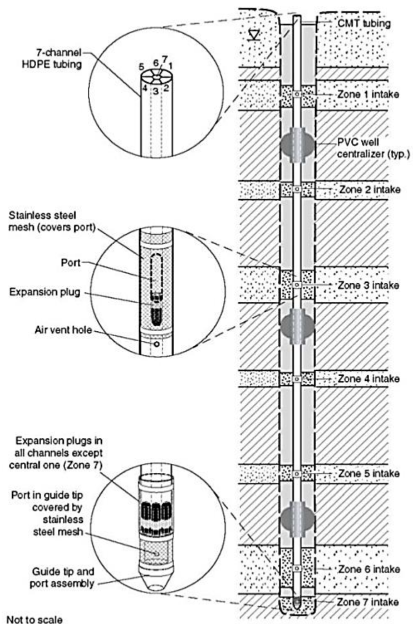
- Screen material
  - PVC (sched 40, sched 80 etc)
  - Stainless steel, wire wound
  - Other
- Well inner diameter (typically 2-inch for MW)
- Screen length
- Screen slot size (based on formation particle size distribution
- Sand pack size (based on formation particle size distribution)

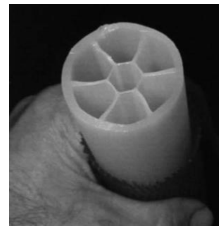


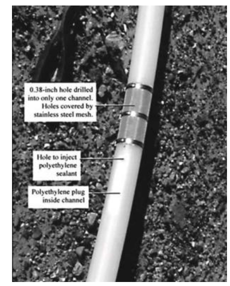


ASTM standard D5092, *Design and Installation of Ground Water Monitoring Wells in Aquifers*

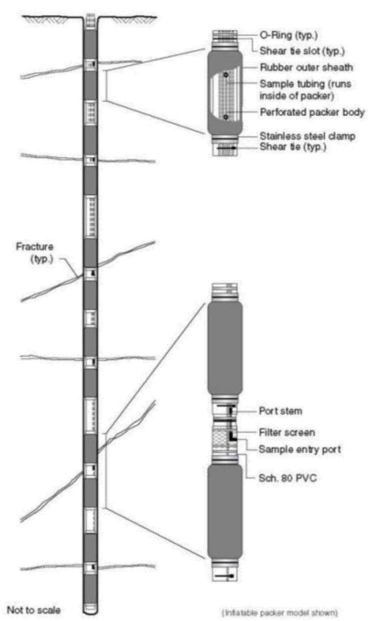
Continuous Multichannel Tubing (CMT)

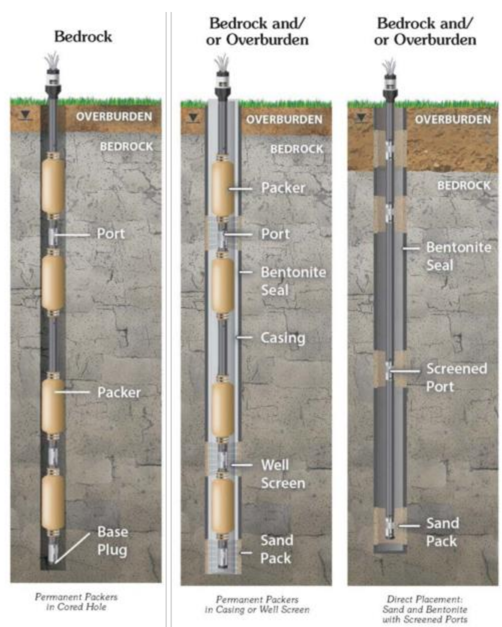






Waterloo System (Solinst)





Westbay System